[Mechanical Engineering Design Project Class](#)   [Mechanical Engineering & Materials Science](#)

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The Design of a Paper Launching Device

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MEMS 411 ASME Design Group II

Paper Crusher/Launcher

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The American Society of Mechanical Engineers (ASME) 2016 Design Competition has challenged students to design and build a device that takes in a shoots out 3 pieces of paper. The objective for the competition is to maximize the distance that the paper is launched, while minimizing the volume in which the device can be packaged.

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1   Introduction

1.1   Project problem statement

The American Society of Mechanical Engineers has challenged us to create a machine that forms a projectile from a single sheet of paper, and then launches that projectile. The success of the device will be measured by how far the projectile is effectively propelled, how straight the projectile is propelled, and how much volume the device takes up when packaged.

For the ASME competition, the device must be able to successfully repeat the above task 3 times, meaning that after it shoots out the first piece of paper, the device must reset and prepare to intake the second piece of paper. This process must be fully automated.

1.2   List of team members

Jake Emmerick

Nick Cooley

Matt Ludwig

2   Background Information Study

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

The American Society of Mechanical Engineers has challenged us with designing a compact device that manufactures and launches projectiles from a single sheet of paper. The device will be judged on two performance metrics: the distance the projectile is launched and the packaging volume of the device. ASME assigns each device a score, which is calculated by summing the distance of three projectiles and dividing that by the volume of the device while it is packaged.

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

Because this is a unique problem designed by the ASME for a competition, there are very few patented devices that were built to accomplish the same task. The only relevant technology that we were able to find is device that intakes paper, folds it into a paper airplane, and then shoots out the paper airplane. The device is formally named the "Paper Airplane Machine Gun", and is not yet patented, but may be viewed on YouTube at https://www.youtube.com/watch?v=J7K91g8yG_w. Seeing the complexity and difficulty of fabrication for this device turned our group away from the idea of forming a paper airplane for a projectile, but rather to form a crushed paper ball.

The paper intake and paper crushing system developed by our team were from unique thought, where no aspects of their designs were inspired from research. The paper launching

system, however, was inspired by a pitching machine- a device that launches baseballs for batting practice. Background information on pitching machines was found, primarily from patent US 7806788 B1, and this patent inspired our team's design, which consists of two adjacent wheels spinning at high speeds.

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

Project/Product Name: ASME Design Competition Paper Launcher			
Customer: Dr. Jakiela		Inteviewer(s): Jake Emmerick, Matt Ludwig, Nick Cooley	
Address: Washington University		Date: 9/14/2015	
Question	Customer Statement	Interpreted Need	Importance
What specifications are required?	Any requirements outlined in the design competition packet	Zero Emissions	5
		Shoots Paper	5
		Shoots Paper Straight	4
		Able to be packaged into a small container	5
Do you have a preference on if	It should have some	none	n/a

the paper is crumpled or folded into an aerodynamic design?	aerodynamic advantages, but it really doesn't matter how its shaped.		
What other considerations would you like to see?	Minimize total number of parts in general	Minimize number of parts	3
	Minimize linear bearings		
	Minimize number of sensed inputs		
	Minimize signal level forces		
	Minimize welds and soldered joints		
	Minimize Length of shafts		
	Minimize number of		

	milled parts		

3.1.2   List of identified metrics

Needs Table for AMSE Paper Launching Device

Need Number	Need	Importance
1	Device shoots paper	5
2	Device can be packaged in a small container	5
3	Device shoots the paper as far as possible	5
4	Device produces 0 emissions	5
5	Device shoots the paper in a straight line	4
6	Device resets itself to its initial position after use	5
7	Device uses as few parts as possible	2
8	Device applies concepts of aerodynamics	1
9	Device minimizes signal forces	1

Metrics Table for ASME Paper Launching Device

Metric Number	Associated Needs	Metric	Units	Min Value	Max Value
1	7	Number of Milled Parts	Integer	0	10
2	3,5,8	Air Resistance Force	Newton	0	10
3	4	Emissions	lbs	0	10
4	7	Number of Linear Bearings	Integer	0	5
5	2	Length	Meter	0.1	0.5
6	2	Width	Meter	0.1	0.5
7	2	Height	Meter	0.1	0.5
8	7	Number of Sensors	Integer	0	5
9	7	Number of Welds	Integer	0	10
10	9	Signal Forces	Newton	1	100
11	3	Distance Traveled	Meter	0	20
12	5	Shooting Angle	Degree	0	180
13	6	Parts returning to original position	Percentage	0	100

3.1.3   Table/list of quantified needs equations

Concept		Metric															
		Number of Milled Parts	Air Resistance	Number of Linear Bearings	Emissions	Length	Width	Height	Number of Sensors	Number of welds	Signal Forces	Distance Traveled	Shooting Angle	Parts in original position after use	Need Happiness	Importance Weight (all	Total Happiness Value
Need #	Need	1	2	3	4	5	6	7	8	9	10	11	12	13			
1	Takes up small space when packaged														0	0.2	0
2	Aerodynamic Ability														0	0.05	0
3	Uses as few parts as possible														0	0.05	0
4	Low Emissions														0	0.05	0
5	Low Number of Linear Bearings														0	0.025	0
6	Minimize Sensors														0	0.025	0
7	Minimize Signal Level Forces														0	0.025	0
8	Minimize Welded Joints														0	0.025	0
9	Minimize Length of Shafts														0	0.05	0
10	Minimize number of Milled Parts														0	0.05	0

#														Percentage	Total Happiness	
11	Shoots a Long Distance													0	0.2	0
12	Shoots Straight													0	0.15	0
13	Resets to original position after use													0	0.1	0
Units		Number	Newton	Number	lbs	meter	meter	meter	Number	Number	newton	meter	degrees	Percentage	**Total Happiness**	
Best Value		0	0	0	0	0.1	0.1	0.1	0	0	1	20	0	100		
Worst Value		10	10	5	10	0.5	0.5	0.5	5	5	100	0	180	0		
Actual Value																
Normalized Metric Happiness																

3.2   Concept drawings

Concept 1: Catapult
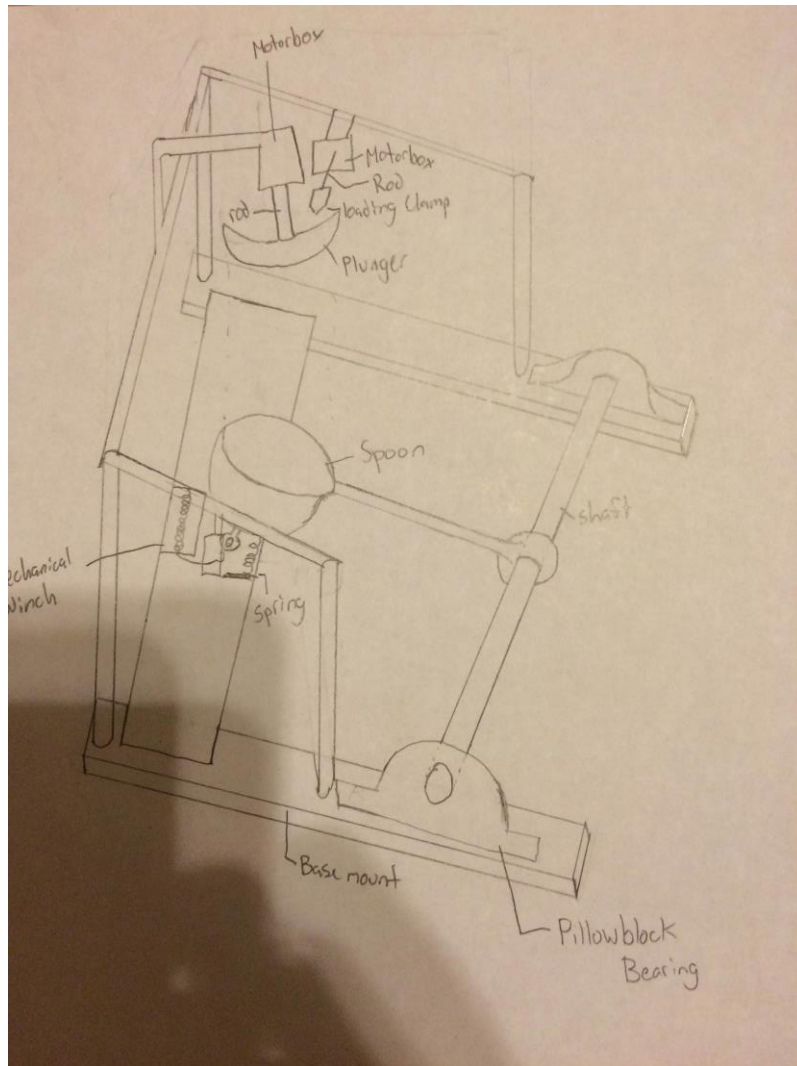
Figure 1 Concept Drawing 1

Concept 2: Ram Rod/Cannon
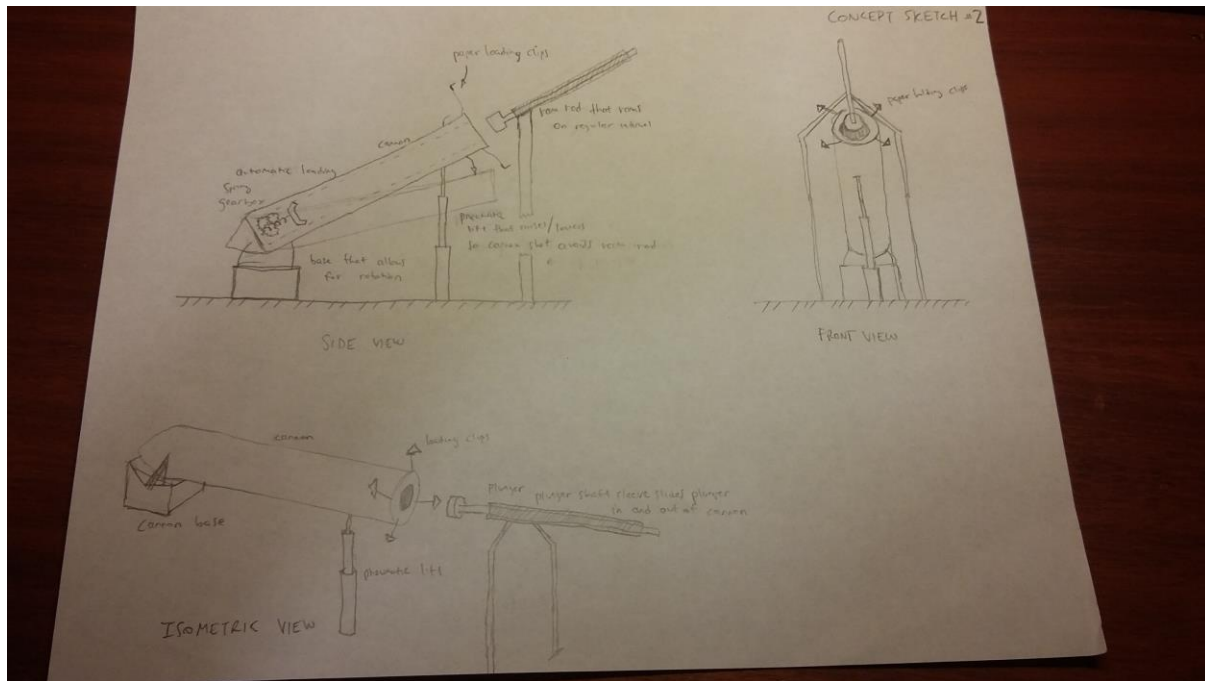
Figure 2 Concept Drawing 2

Concept 3: Paper Airplane Folder & Launcher
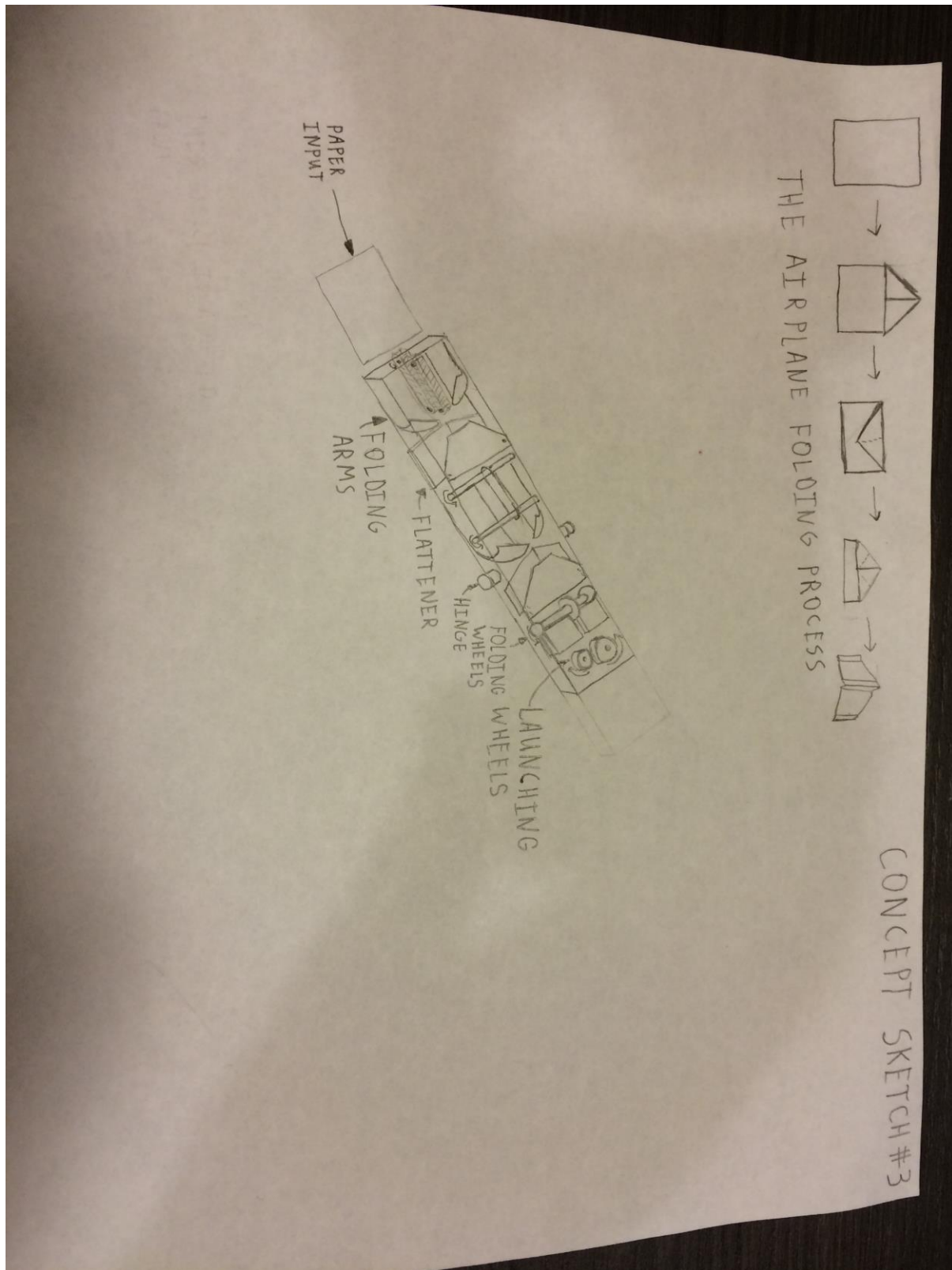
Figure 3 Concept Drawing 3

Concept 4: Claw/Conveyor/Catapult
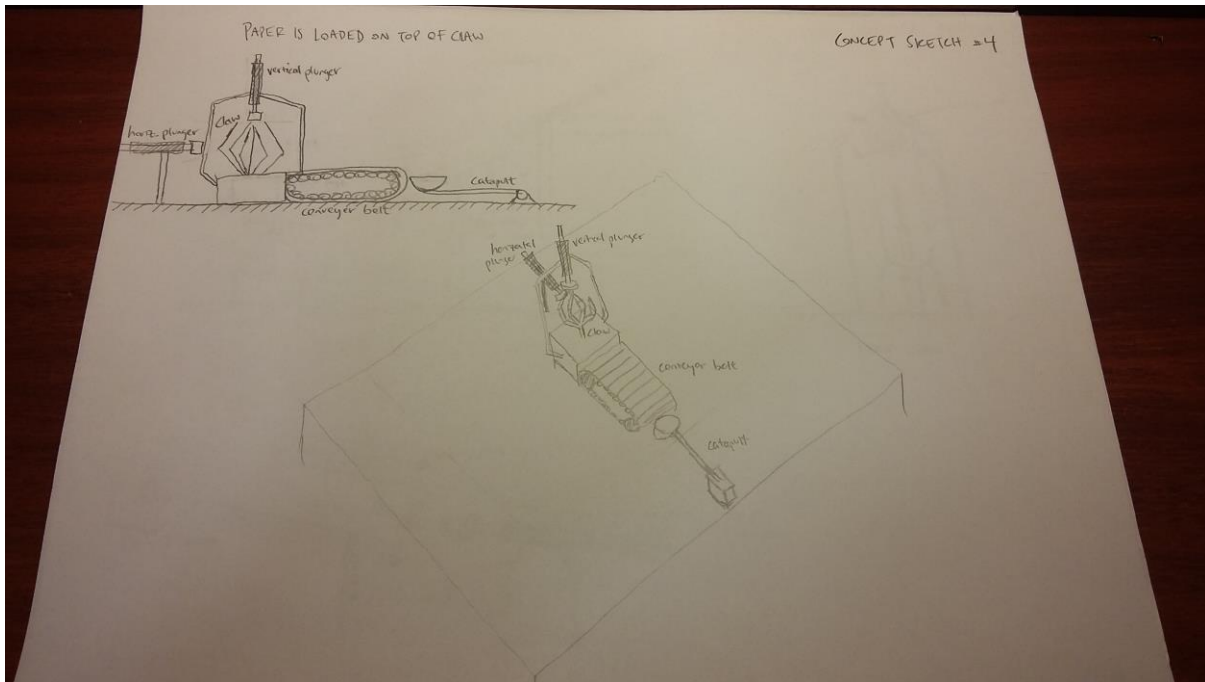
Figure 4 Concept Drawing 4

3.3   Concept selection process

3.3.1   Concept scoring (not screening)

Concept 1 Happiness Equation Scoring

Concept 1	Metric															
		Number of Milled Parts	Air Resistance	Number of Linear Bearings	Emissions	Length	Width	Height	Number of Sensors	Number of welds	Signal Forces	Distance Traveled	Shooting Angle	Parts in original position after use	Need Happiness	Importance Weight (all	Total Happiness Value
Need #	Need	1	2	3	4	5	6	7	8	9	10	11	12	13			
1	Takes up small space when packaged					0.33	0.33	0.33							0.726	0.2	0.1452

#	Requirement	Number	Newton	Number	lbs	meter	meter	meter	Number	Number	newton	meter	degrees	Percentage	Value	Weight	Weighted
2	Aerodynamic Ability		1												0	0.05	0
3	Uses as few parts as possible	0.33		0.33					0.33						0.627	0.05	0.03135
4	Low Emissions				1										1	0.05	0.05
5	Low Number of Linear Bearings			1											0.4	0.025	0.01
6	Minimize Sensors								1						0.8	0.025	0.02
7	Minimize Signal Level Forces										1				0.5	0.025	0.0125
8	Minimize Welded Joints									1					0.8	0.025	0.02
9	Minimize Length of Shafts				1										0.8	0.05	0.04
10	Minimize number of Milled Parts	1													0.7	0.05	0.035
11	Shoots a Long Distance											1			0.5	0.2	0.1
12	Shoots Straight												1		1	0.15	0.15
13	Resets to original position after use													1	0.9	0.1	0.09
Units		Number	Newton	Number	lbs	meter	meter	meter	Number	Number	newton	meter	degrees	Percentage	**Total Happiness**		**0.70405**
Best Value		0	0	0	0	0.1	0.1	0.1	0	0	1	20	0	100			
Worst Value		10	10	5	10	0.5	0.5	0.5	5	5	100	0	180	0			
Actual Value		3	10	3	0	0.2	0.2	0.3	1	1	50	10	0	90			
Normalized Metric Happiness		0.7	0	0.4	1	0.8	0.8	0.6	0.8	0.8	0.5	0.5	1	0.9			

Concept 2 Happiness Equation Scoring

Concept #2 Ram Rod/Cannon	Metric															
Need # / Need	Number of Milled Parts	Air Resistance	Number of Linear Bearings	Emissions	Length	Width	Height	Number of Sensors	Number of welds	Signal Forces	Distance Traveled	Shooting Angle	Parts in original position after use	Need Happiness	Importance Weight (all	Total Happiness Value
	1	2	3	4	5	6	7	8	9	10	11	12	13			
1 Takes up small space when packaged					0.333	0.333	0.333							0.4125	0.2	0.0825
2 Aerodynamic Ability		1												0.2	0.05	0.01
3 Uses as few parts as possible	0.25		0.25					0.5						0.725	0.05	0.03625
4 Low Emissions				1										1	0.05	0.05
5 Low Number of Linear Bearings			1											0.8	0.025	0.02
6 Minimize Sensors								1						0.6	0.025	0.015
7 Minimize Signal Level Forces										1				0.5	0.025	0.0125
8 Minimize Welded Joints									1					0.4	0.025	0.01
9 Minimize Length of Shafts					1									0	0.05	0

Need #	Need	1 (Number)	2 (Newton)	3 (Number)	4 (lbs)	5 (meter)	6 (meter)	7 (meter)	8 (Number)	9 (Number)	10 (newton)	11 (meter)	12 (degrees)	13 (Percentage)	Total Happiness	Importance Weight	Total Happiness Value
10	Minimize number of Milled Parts	1													0.9	0.05	0.045
11	Shoots a Long Distance											1			0.75	0.2	0.15
12	Shoots Straight												1		1	0.15	0.15
13	Resets to original position after use													1	1	0.1	0.1
Units		Number	Newton	Number	lbs	meter	meter	meter	Number	Number	newton	meter	degrees	Percentage	**Total Happiness**		0.68125
Best Value		0	0	0	0	0.1	0.1	0.1	0	0	1	20	0	100			
Worst Value		10	10	5	10	0.5	0.5	0.5	5	5	100	0	180	0			
Actual Value		1	8	1	0	0.5	0.2	0.3	2	2	50	15	0	100			
Normalized Metric Happiness		0.9	0.2	0.8	1	0	0.75	0.5	0.6	0.4	0.5	0.75	1	1			

Concept 3 Happiness Equation Scoring

Concept 3	Metric	Number of Milled Parts	Air Resistance	Number of Linear Bearings	Emissions	Length	Width	Height	Number of Sensors	Number of welds	Signal Forces	Distance Traveled	Shooting Angle	Parts in original position after use	Need Happiness	Importance Weight (all)	Total Happiness Value
Need #	Need	1	2	3	4	5	6	7	8	9	10	11	12	13			
1	Takes up small space when packaged					0.33	0.33	0.33							0.61875	0.2	0.12375

#	Requirement	Number	Newton	Number	lbs	meter	meter	meter	Number	Number	newton	meter	degrees	Percentage			
2	Aerodynamic Ability		1												0.7	0.05	0.035
3	Uses as few parts as possible	0.33		0.33				0.33							0.363	0.05	0.01815
4	Low Emissions				1										1	0.05	0.05
5	Low Number of Linear Bearings			1											0	0.025	0
6	Minimize Sensors							1							1	0.025	0.025
7	Minimize Signal Level Forces								1						0.808080808	0.025	0.020202022
8	Minimize Welded Joints								1						0.6	0.025	0.015
9	Minimize Length of Shafts					1									0.25	0.05	0.0125
10	Minimize number of Milled Parts	1													0.1	0.05	0.005
11	Shoots a Long Distance										1				0.25	0.2	0.05
12	Shoots Straight											1			0.805555556	0.15	0.120833333
13	Resets to original position after use													1	1	0.1	0.1
Units		Number	Newton	Number	lbs	meter	meter	meter	Number	Number	newton	meter	degrees	Percentage	Total Happiness		0.575435354
Best Value		0	0	0	0	0.1	0.1	0.1	0	0	1	20	0	100			

	Number of Milled Parts	Air Resistance	Number of Linear Bearings	Emissions	Length	Width	Height	Number of Sensors	Number of welds	Signal Forces	Distance Traveled	Shooting Angle	Parts in original position after use			
Worst Value	10	10	5	10	0.5	0.5	0.5	5	5	100	0	180	0			
Actual Value	9	3	5	0	0.4	0.25	0.1	0	2	20	5	35	100			
Normalized Metric Happiness	0.1	0.7	0	1	0.25	0.625	1	1	0.6	0.808080808	0.25	0.805555556	1			

Concept 4 Happiness Equation Scoring

Concept #4 Claw/Conveyor/Catapult	**Metric**															
		Number of Milled Parts	Air Resistance	Number of Linear Bearings	Emissions	Length	Width	Height	Number of Sensors	Number of welds	Signal Forces	Distance Traveled	Shooting Angle	Parts in original position after use	Need Happiness	Importance Weight (all	Total Happiness Value
Need #	**Need**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**			
1	Takes up small space when packaged					0.333	0.333	0.333							0.61875	0.2	0.12375
2	Aerodynamic Ability		1												0.5	0.05	0.025
3	Uses as few parts as possible	0.2		0.3					0.5						0.54	0.05	0.027
4	Low Emissions				1										1	0.05	0.05
5	Low Number of Linear Bearings			1											0.6	0.025	0.015

#	Requirement	Number	Newton	Number	lbs	meter	meter	meter	Number	Number	newton	meter	degrees	Percentage			
6	Minimize Sensors								1						0.4	0.025	0.01
7	Minimize Signal Level Forces										1				0.80808 08 08	0.025	0.0 20 20 20 2
8	Minimize Welded Joints									1					0.5	0.025	0.0125
9	Minimize Length of Shafts					1									0.25	0.05	0.0125
10	Minimize number of Milled Parts	1													0.8	0.05	0.04
11	Shoots a Long Distance											1			0.65	0.2	0.13
12	Shoots Straight												1		1	0.15	0.15
13	Resets to original position after use													1	0.95	0.1	0.095
	Units	Number	Newton	Number	lbs	meter	meter	meter	Number	Number	newton	meter	degrees	Percentage	**Total Happiness**		**0.7 10 95 20 2**
	Best Value	0	0	0	0	0.1	0.1	0.1	0	0	1	20	0	100			
	Worst Value	10	10	5	10	0.5	0.5	0.5	5	10	100	0	180	0			
	Actual Value	2	5	2	0	0.4	0.1	0.25	3	5	20	13	0	95			
	Normalized Metric Happiness	0.8	0.5	0.6	1	0.25	1	0.625	0.4	0.5	0.808080808	0.65	1	0.95			

3.3.2 Preliminary analysis of each concept's physical feasibility

Concept 1: Catapult

This concept is a catapult design. The thought behind this is that by crushing the paper with a certain method, the device can consistently make the same paper ball. In order to crush the paper, the device would twist the paper, push it together, and then have a high-powered plunger apparatus

crush the paper into the spoon of the catapult. This design requires multiple extendable arms that would each require motors, as well as another motor to draw back the catapult arm. After the paper is crushed into the catapult spoon, a pin would release on a winch in order to release the catapult and shoot the paper wad into the air. The issue with this concept is that the catapult will not return to its original position after launching the paper, which is a requirement considering that the catapult needs to fire 3 projectiles without being manually reset.

Concept 2: Ram Rod/Cannon

This design is essentially a cannon. It consists of a barrel, a spring launcher inside the barrel, a support structure for the cannon, a paper loading station, and a ram rod. The piece paper is loaded into the station, which will just be little ledges that will keep the paper in place. The ram rod, inside the ram rod sheath, will be used to stuff the paper into the cannon barrel. The ram rod sheath will have automatic rollers that insert and remove the ram rod from the cannon. Afterwards, the cannon support structure will pneumatically lower the cannon, so that the ram rod does not interfere with the launch path. Then, the spring gearbox (similar to inside an airsoft pistol) will launch the paper ball out of the cannon.

Concept 3: Paper Airplane Folder & Launcher

This concept is focused on minimizing the volume of the launching device. There are hinges in the middle of the device to allow for the frame to fold in on itself to minimize the footprint. Additionally, the linear characteristic of this device will allow for operation from a single drive train. This will minimize the complexity of the device and reduce the amount of motors/power needed to run this machine. This design concept should be possible, but it will require extensive aligning and tuning to get the folding devices working accurately. Luckily 3D prototyping can be utilized to quickly generate successive iterations of the folding arms and flattening devices pictured in the sketch. The paper advancing rollers will be simple and easy to implement, although they will require bearings on either side to allow for friction free motion. The launching wheels will need to also be extensively tested to shoot the paper airplane with enough speed to fly, but not too much to cause instability. Once a speed/material has been determined, the wheels can be geared up using the existing drivetrain or even powered by another motor if absolutely necessary.

Overall, this concept should be feasible and easily tested. The real question is whether consistent paper airplane flight can be achieved that will outperform a crumpled paper ball. We await further testing to answer this question.

Concept 4: Claw/Conveyor/Catapult

This design is a crumpling method that launches the paper ball from a catapult. It consists of a claw, vertical and horizontal plungers, a conveyor belt, and a catapult. The piece of paper is loaded so that it rests on top of the open claw. The vertical plunger slides down on top of the paper, pushing it into the grasp of the claw. The claw will then close very tightly, crumpling the paper into a tight ball. Next, the claw will open fully, and the horizontal plunger will extend to push the ball from inside the claw onto the conveyor belt. Both plungers are inside sheaths that roll the plunger in and out of the claw. The conveyor belt will carry the paper ball a short distance and into the loading chamber of

the catapult. Finally, the catapult (loaded by an automatic spring) will send the paper ball sailing into the air.

3.3.3   Final summary

Winner: A completely new concept!

Each of these concepts has its own unique strengths and weaknesses, but the feasibility of manufacturing each seemed unreasonable. Therefore, the group went back to the drawing board and came up with a completely new concept, one that allowed consistent crushing of the paper and a strong launching mechanism. The new concept is pictured below, and allows for greater consistency in meeting the user's needs.
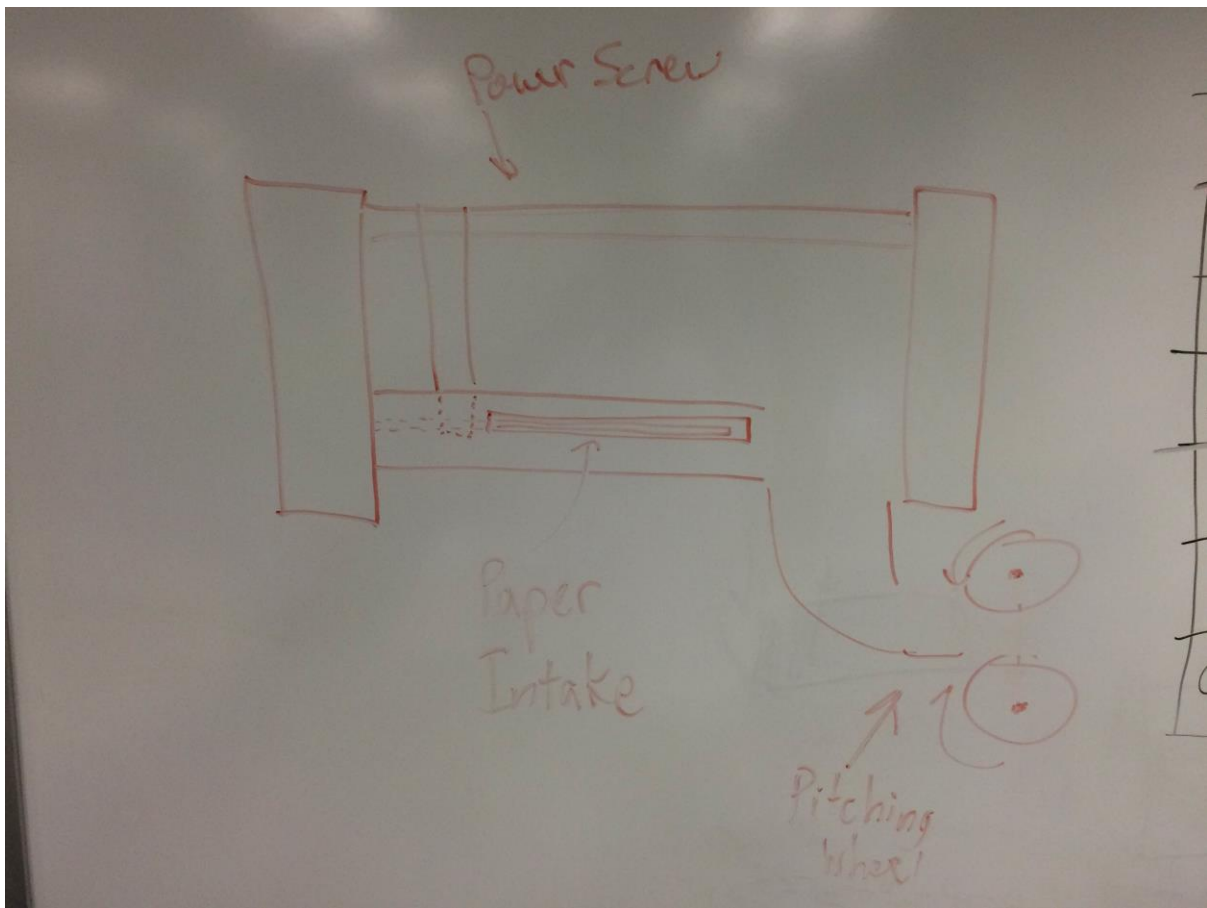
Figure 5 Final Concept Drawing

3.4   Proposed performance measures for the design

The only performance metrics for this design are the distance that the paper is projected, how straight of a line the paper flies in, and how much volume the device takes up when packaged. It is desirable to minimize the packaging volume of the device.

3.5   Design constraints

3.5.1   Functional

The overall geometry of the device must fit into a box of minimal volume. In order to accomplish this, the intake/crushing assembly and launching mechanisms are not attached to each

other, allowing them to shifted and rotated to fit inside of a smaller volume. In the future, we plan to add hinges to the bottom of the launching mechanism to allow it to fold downward, allowing for even less volume to be used during packaging.

3.5.2   Safety

This device is safe to the environment. Running purely on electricity, this device does not produce any potentially harmful emissions. Also, this device is safe for the user. The device is completely automated through the use of an Arduino, so once the paper is loaded, the user may steer clear of all moving parts of the device.

3.5.3   Quality

This device is very reliable. All components of the paper intake/crushing system that have a force acting on them have been made out of steel or aluminum, ensuring that the device will not see failure in its critical components. The launching assembly is made out of less reliable material, where the wheels are 3D printed. This issue is resolved by the floating mount design, which attaches the wheels to their base. This allows for the distance between the wheels to adjust accordingly with the size of the projectile that they launch.

3.5.4   Manufacturing

All components required to assemble this device can be purchased or fabricated with amateur level skill in a machine shop. Also, one of our performance metrics was to minimize the packaging volume needed to transport the device, which we have taken into consideration.

3.5.5   Timing

This design and construction of this device adhered to the timelines set by the Washington University in St. Louis Mechanical Engineering Department faculty.

3.5.6   Economic

The fabrication of this device was well below the budget set by the Washington University in St. Louis Mechanical Engineering Department faculty.

3.5.7   Ergonomic

The design allows for the user to easily insert a piece of paper, and allow the machine to do the rest of the work to accomplish the given task. It is comfortable for the user to use, and incredibly easy with the fully automated process.

3.5.8   Ecological

The design is only powered by electricity. This prevents the device from giving off any emissions, which could potentially harm the environment.

3.5.9   Aesthetic

Aesthetic appeal was prioritized very lowly for this device. The device was designed to complete a certain task, and while aesthetic appeal was taken into consideration, it was decided that it was not as important as other factors, and therefore not considered very heavily in the final design.

3.5.10 Life cycle

The only issue we have seen that causes the device to not function is a paper jam. This occurs when the crushed paper gets stuck in the chute at the end of the crushing mechanism and does not make it to the launching mechanism. In order to prevent this issue from occurring in the future, we plan to add a small servo motor with an attached rod to push paper coming out of the crushing mechanism into the launching mechanism.

3.5.11 Legal

We have done extensive research and our design does not infringe upon any patents, copyrighted material, or other intellectual property.

4   Embodiment and fabrication plan

4.1   Embodiment drawing

The initial Embodiment drawings are below. These rough drawings were followed before running into many iterations of fabrication complications that resulted in the final drawings (see Section 7.1 Final Drawings and Documentation). Below are the front, side, and top views of the initial assembly. These drawings do not include many parts required to hold the machine together, such as bases and fasteners, but do include the mechanical equipment needed to carry out the processes.
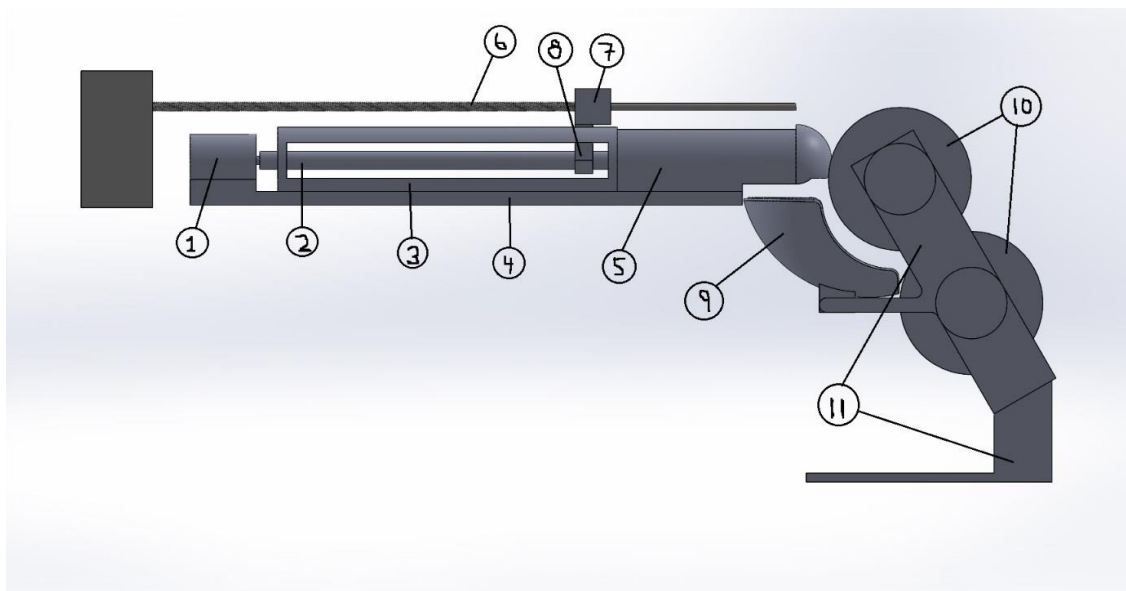
Figure 6: Front view of the initial embodiment drawings, with balloon callouts for each part. These callouts refer to the list in Section 4.2 Parts List.
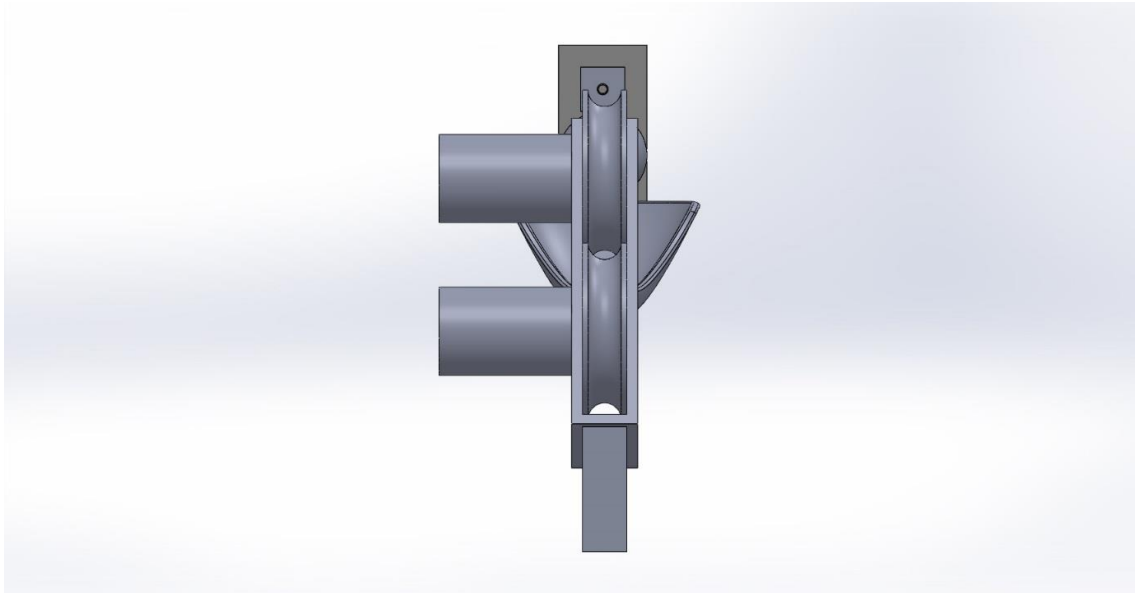
Figure 7: Side view of the initial embodiment drawings.
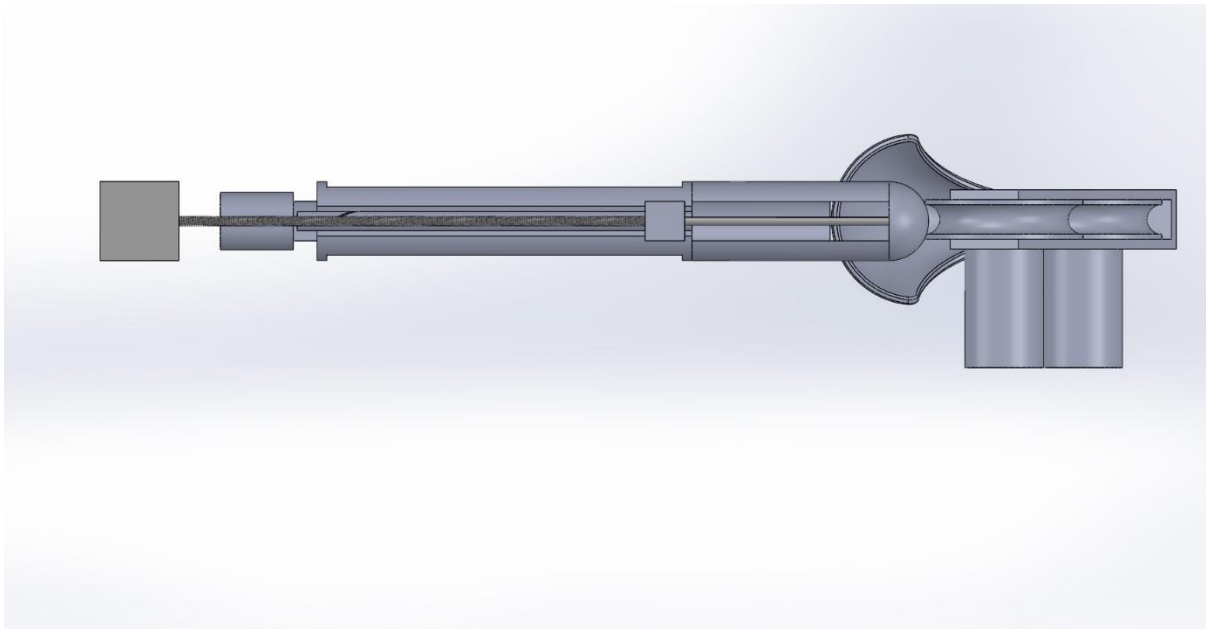
Figure 8: Top view of the initial embodiment drawings.

4.2   Parts List

The initial Parts list, based on the above embodiment drawings, is inserted below. Most of the parts were already scrounged from either the machine shop scraps or the Jolley Basement. Again, this is not a comprehensive list of needed parts, only what was envisioned at this stage in the process.

1. Motor – from Amazon.com (or basement) – **$12.98** (or free)
2. Shaft with Slit – already have from basement – **free**
3. Shaft Casing – from onlinemetals.com (or Pat) – **$19.09** (or free)

4. Base – from onlinemetals.com (or Pat) **– $9.17** (or free)
5. Tube (PVC Pipe) – 5 Inches of 1.5 I.D + Cap – In Jolley Basement - **$0.00**
6. Threaded Shaft – from Mcmaster Carr 98957A111 - **$2.52**
7. Motor for thread rod – Jolley Basement - **$0.00**
8. Plunger – 3D Print - **$?**
9. Guided Slide – 3D Print – **$?**
10. Launching Wheels – 3D Print - **$?**
11. Mounting Bracket – from onlinemetals.com (or Pat) – **~$30.00** (or free)
12. Screws – from McMaster Carr or basement – Price **TBD** (will be nominal)

Forecasted Cost = **$73.76 plus costs of 3D printing and screws**

4.3   Draft detail drawings for each manufactured part

Below are the part drawings for the fabricated parts listed in Section 4.2. These drawings were used to produce the initial prototype.
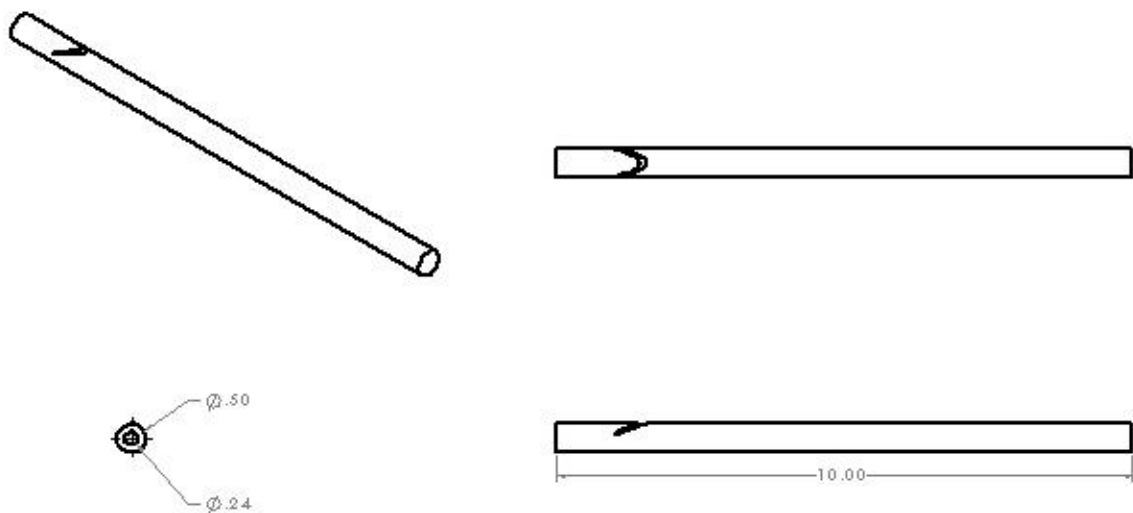
Figure 9: Detail drawing of the Shaft with Slit component.

Part 3: Shaft Casing

0.75

9.00

1.00

R1.00   R0.75

9.50
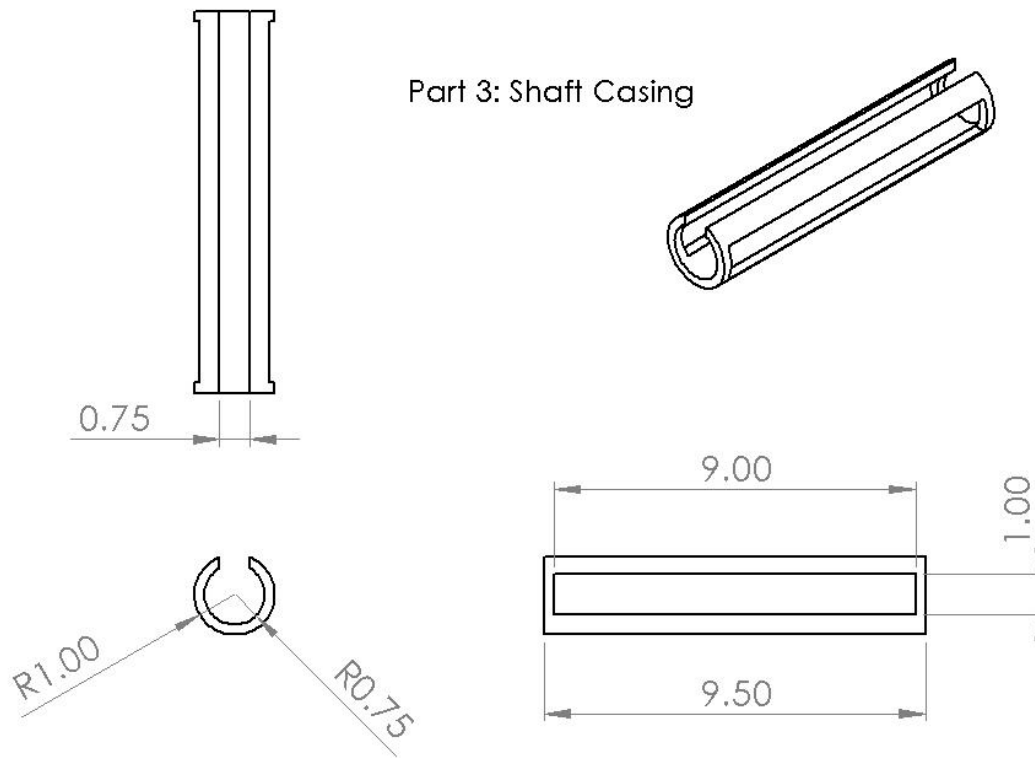
Figure 10: Detail drawing of the Shaft Casing component.

Part 4: Base

1.00

R0.73

R1.00

0.38

0.72

1.85

15.45
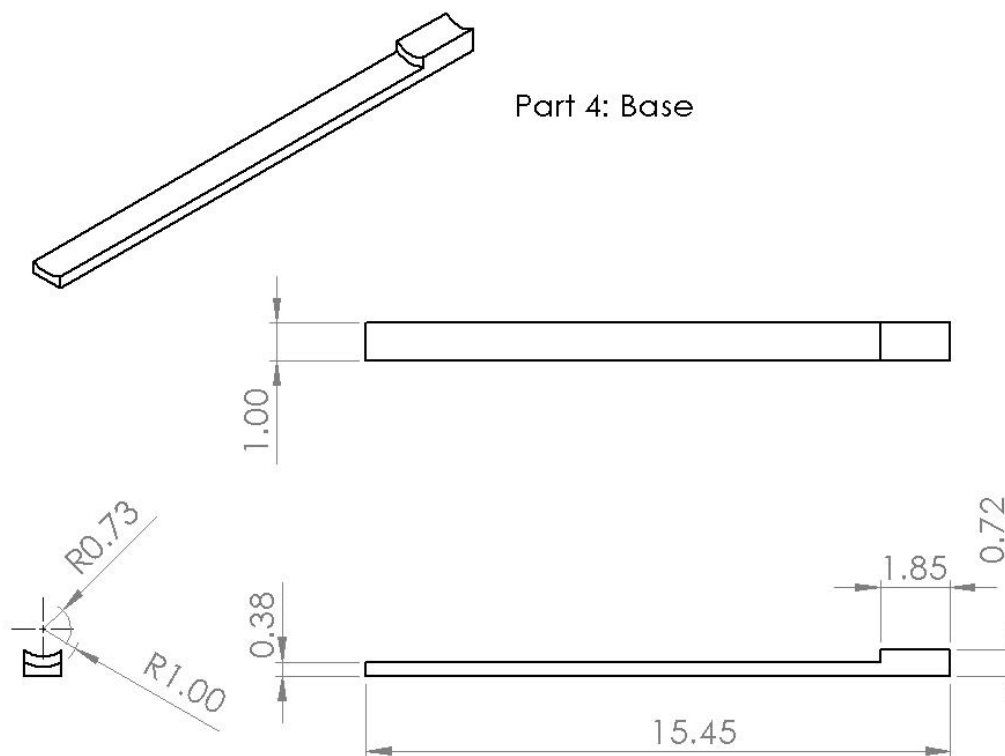
Figure 11: Detail drawing of the Base component.
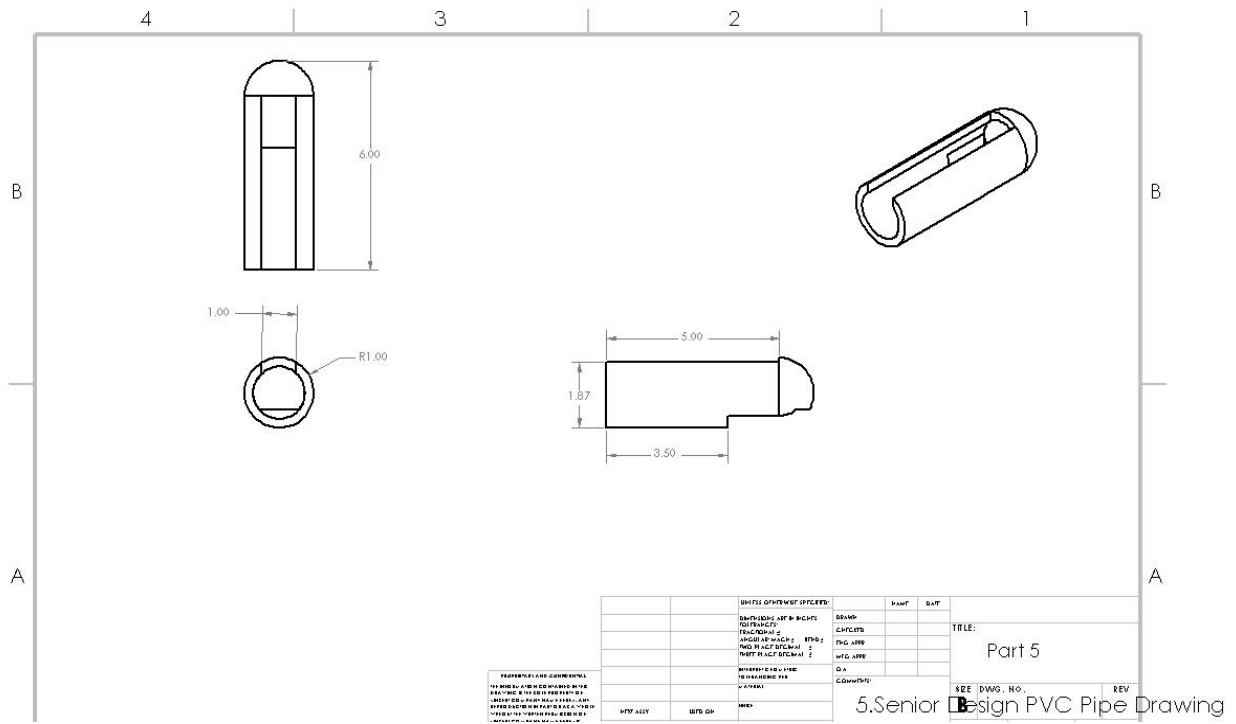
Figure 12: Detail drawing of the PVC Pipe (Part 5) component.
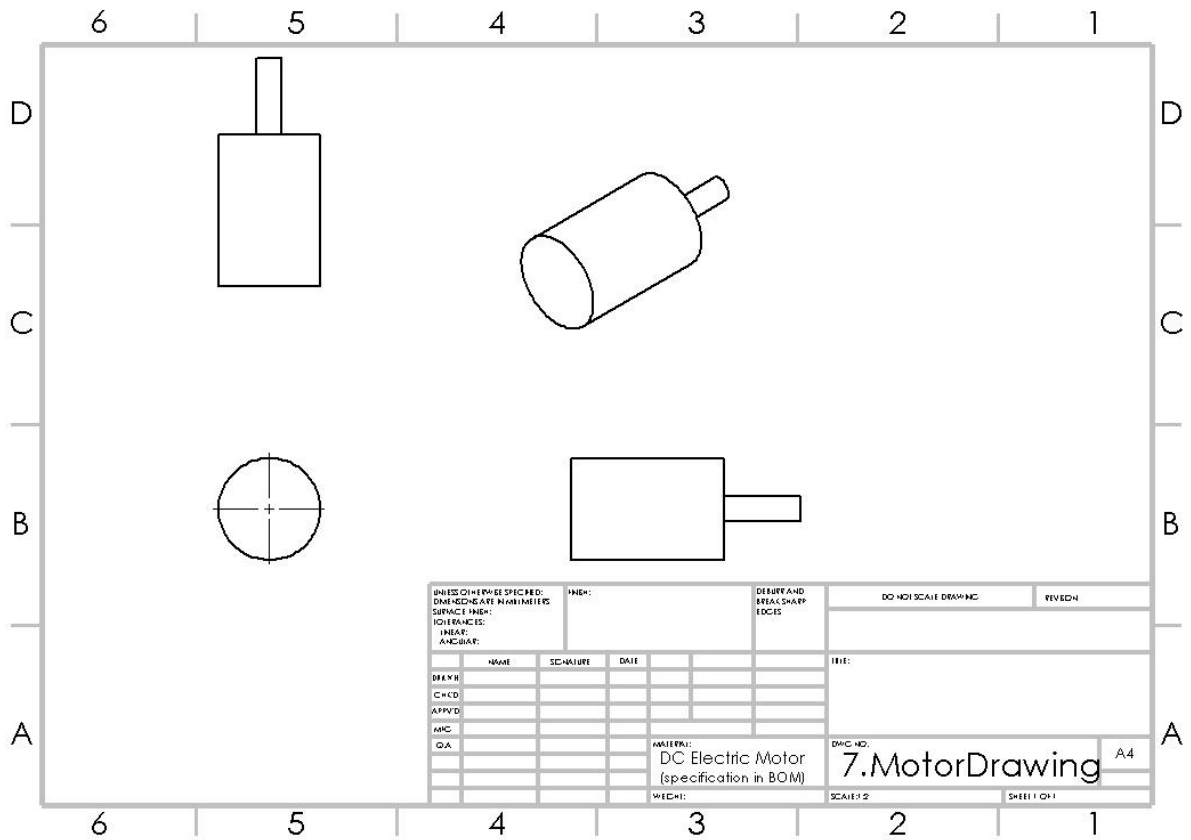
Figure 13: Detail drawing of the Motor (Part 7) component, needed in 2 locations.
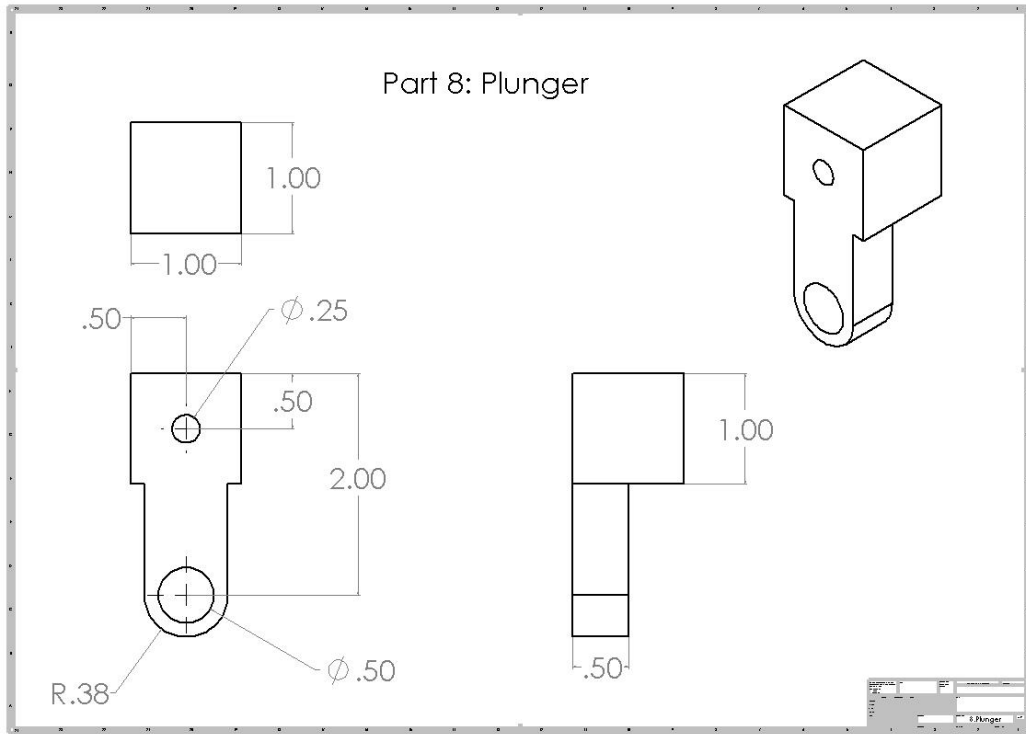
Part 8: Plunger

Figure 14: Detail drawing of the Plunger (Part 8) component.
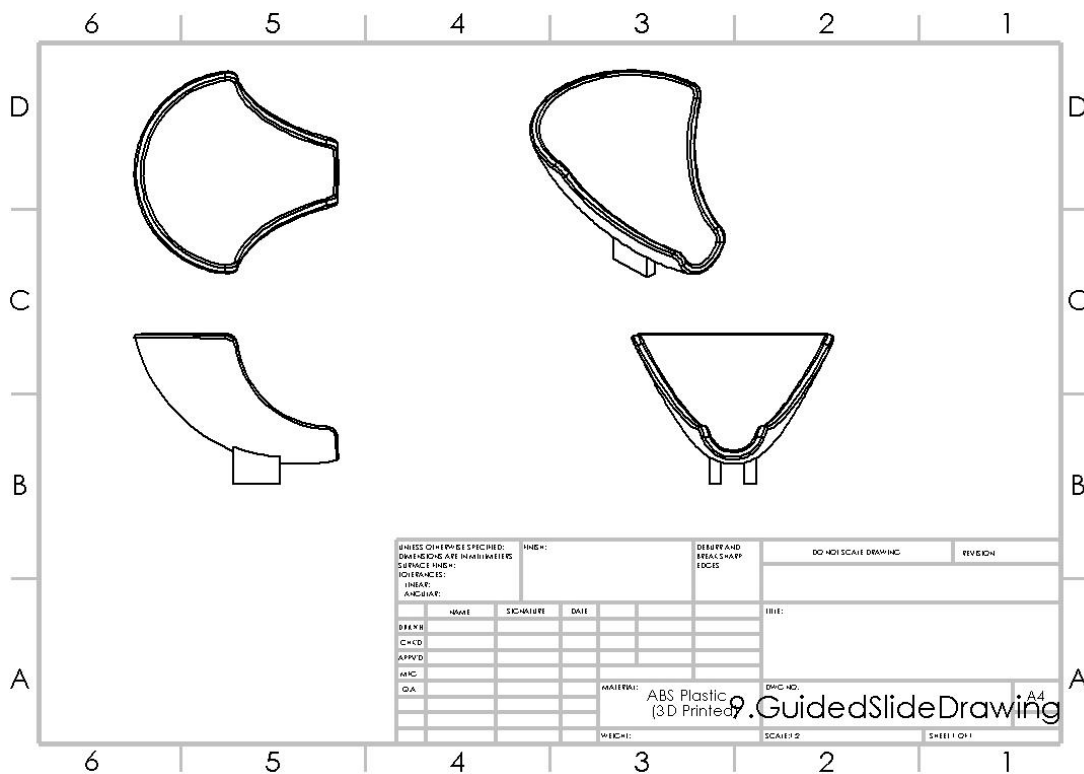
Figure 15: Detail drawing of the Guided Slide (Part 9) component. Dimensions are not included since these are dependent on the size ball the crumpling sub-assembly produces.
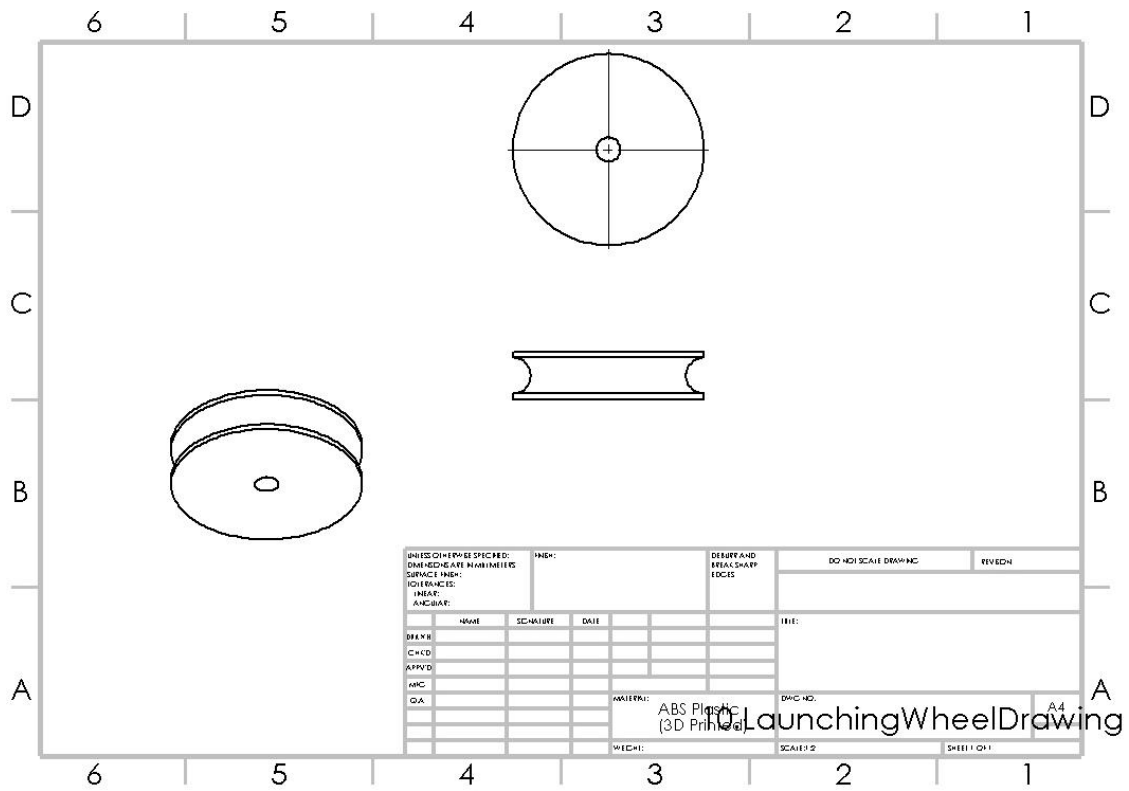
Figure 16: Detail drawing of the Launching Wheel (Part 10) component, 2 necessary. Dimensions are not included since these are dependent on the size ball the crumpling sub-assembly produces.
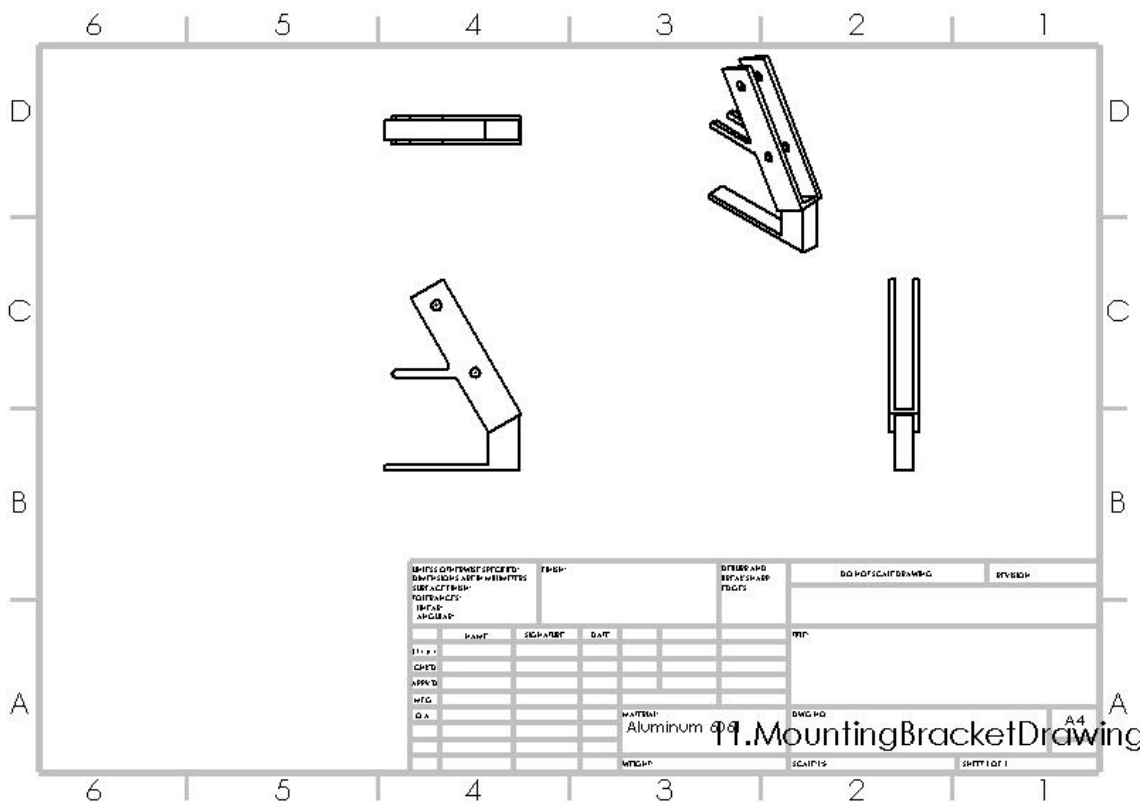
Figure 17: Detail drawing of the Launching sub-assembly Mounting Bracket (Part 11). Dimensions are not included since these are dependent on the size ball the crumpling sub-assembly produces.

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

1. Motor to spin shaft loaded with paper:

http://www.amazon.com/HOSSEN%C2%AE-Mini-Torque-Electric-Motor/dp/B00BX54O8A/ref=sr_1_3/188-8759486-3331446?ie=UTF8&qid=1443319472&sr=8-3&keywords=Low+Rpm+Electric+Motors

$12.98, free shipping with Amazon Prime, Quantity: 1

Specifications:
Torque: 30 N*cm
12V DC
60RPM
Diameter: 37mm
Length [excluding shaft]: 47mm
Shaft length: 21mm
Total length: 68mm
Shaft diameter: 6mm
Weight: 138g
Brand new and unused
Package includes:
1 x Mini 12V DC 60 RPM High Torque Gear Box Electric Motor

This motor will spin fast enough to roll the paper in a good amount of time, is cheap, and is small. A couple motors were found in the basement, and will probably be tested for use, so as to save money and avoid the hassle of ordering a new part.

2. Shaft with Slit:

Made of wood, a wooden rod that fits the specifications was found in the basement, all needs to be modified to fit the design. The slit is there to load the piece of paper into. There is also a hole in one side of the shaft, which can easily be drilled, so the motor shaft can be inserted. The shaft is made of wood because wood is much lighter than most other materials we could use, and the 6mm diameter of the above motor probably wouldn't be able to support the weight of a full metal shaft, but would easily support the weight of a wooden one.

3. Shaft Casing:

Made of aluminum, the below 10"x2"x2" block of aluminum is a perfect candidate. To fabricate, lathe the hole through the middle, then use the mill to adjust the length and create the holes on the sides; these machines can be found in the machine shop. The aluminum will either be obtained from Pat in the machine shop, or from the following site:

http://www.onlinemetals.com/merchant.cfm?pid=1120&step=4&showunits=inches&id=999&top_cat=60

12"x2"x2" bar for $25.45, with 25% discount for new customers = **$19.09**

I decided to use aluminum because it is easy to work with and heavy/smooth enough that the paper will be able to roll inside of it.

4. Base:

Made of aluminum, requires a 16"x1"x1" block of aluminum, milled to size and to create the concave surfaces. Since such a long piece will not fit into the mills we have in the shop, the aluminum will be cut into 3 parts, then attach the individual parts to the parts that rest on the base. All these parts, and the base, will need to have small holes drilled into them so they can be attached by screws. These screws will be obtained through the McMaster-Carr database or found in the basement. The sizes have not yet been determined, but in any case the hardware will not be very expensive. The aluminum for the base will either be obtained from Pat in the machine shop, or from the following site:

http://www.onlinemetals.com/merchant.cfm?pid=1116&step=4&showunits=inches&id=999&top_cat=60

24"x1"x1" bar for $12.22, with a 25% discount for new customers = **$9.17**

Aluminum was chosen as the material because it is easy to work with and sturdy enough to support all the necessary components.

5. Tube:

The tube is necessary for the paper to be crumpled into a rounded ball shape. As the plunger slides down the shaft, it will press the paper into the tube, and the paper will then by default form to its volumetric constraints, which will force it into a ball based on the surrounding geometry.   The tube will be made out of standard PVC pipe and will have an inner diameter of 1.5 inches. This diameter is subject to change as testing of various ball sizes will be required to determine the optimal ball size for the competition. An appropriate cap will be fitted onto the end of the tube, allowing for the paper to form into a ball.

A section will be cut out of the end of the tube to allow the ball to fall into the shooting mechanism. The size of this gap is subject to change based upon what the final ball size will be. All cuts will be made in the machine shop.

6/7. Motor/Shaft:

The purpose of the motor is to spin the threaded shaft, which will in turn propel the plunger down the shaft. The selected motor will be based on cost, and the current selection was found in the Jolley Basement. The shaft attached to the motor will be 18 inches long in order to ensure the plunger can push the paper all the way to the end of the tube.

8. Plunger:

The purpose of the plunger is to push the paper off of the initial loading shaft and into the tube, thus compressing it into a ball. The plunger will be made by a 3D Printer. At the top of the plunger, there will be a tapped hole to match the threaded shaft. When the shaft rotates, the threads will carry the plunger down the shaft, allowing it to push the paper. The lower portion of the plunger will be more slender as to allow it to fit into the tube. It will also have a circular cut out that allows it to fit over the loading shaft. There will be a tight tolerance here, as the plunger must pull the paper off of the loading shaft.

9. Guided Slide:

This part was designed to accept the paper outputted from the tube. Its purpose is to transfer the paper from the tube to the launching wheels. One key aspect of this part is the reduction of radius as the paper is transferred from the initial section to the final section. The paper will be forced against the guided slide by the launching wheel directly to the right of the slide. This will force the paper ball to reduce its radius and begin to take the shape of a tight aerodynamic ball that will be ideal for distance launching. Notice also the two mounting brackets on the bottom of the part that will be used in combination with the mounting bracket to position the guided slide in optimum position for loading the launching wheels. Due to the complex free form shape of this part, it will be 3D printed to save the laborious task of trying to machine the part. It will be made from ABS plastic, as it is cheap and should provide the strength needed to compress the paper ball. Further testing is needed to determine whether the shape can be optimized further.

10. Launching Wheels:

There are two of this part that are identical in size and shape, and these will be used to develop the final compression of the paper ball, as well as launching the projectile. They are shaped with a concave profile to facilitate to the paper being transformed into a tight circular projectile. The top wheel will run at a slightly lower speed to impart backspin to the projectile, which will increase the distance of each throw. These wheels will likely undergo at least a few minor changes, as the speed and final radius desired of the paper ball is still open to change. The exterior of these wheels will need to be covered in a rubber material to allow the wheels to grip the paper and pull the paper ball into the launching zone, in combination with the guided slide. These wheels will also be 3D printed, as finding the correct wheels online with the correct concavity proved to be impossible. They will also be made from ABS plastic, as it is cheap and strong enough to reliable compress the paper ball. The rubber material that will coat the exterior is currently not determined, but it should be simple enough to wrap bands about the wheel radius, or apply an adhesive rubber material.

11. Mounting Bracket:

This part will be fabricated from aluminum and will provide the structural backbone for our launching sub-assembly. Aluminum will provide the best machinability and will easily be strong enough to support our motors, wheels, and guided slide. The final shape of this mounting device will

likely undergo several iterative design changes, as the goal of this part is to have a foldable stand that can fit in a small box volume. The location of the mounting holes and arms to hold the guided slide are pretty finalized, as we desire a launching angle of 30°. There are also screw holes to mount the motors in the correct position to drive the launching wheels.

Wheel Motors:

The motors were represented here simplistically, as the final determination of what motor to buy is dependent on the engineering analysis. This analysis will need to determine the torque, rpm, and price of the final motor used. The motors here were designed as a worst case scenario, as the actual motors used will likely be much smaller than what is currently shown. This was a conscious decision to illustrate the largest the launching assembly is likely to be. They will be DC powered electric motors, with a relatively high rpm, as we desire a high launching speed for the paper ball projectile.

12. Screws:

This is a representative screw that will be used on the launching sub-assembly to hold everything in place. The motors will be mounted to the mounting bracket with 4 screws each, and the guided slide will be mounted to the bracket with two screws on each side. The screws will likely be #10-32 size, but this may need to be adjusted for the motor to accommodate whatever size the mounting holes on the final motor will be.

4.5   Gantt chart

Please see the following page for the Gantt Chart.

MEMS 411 Senior Project

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
1 Elevator Pitch	1	5	1	4	100%
2 Brain Storming	1	6	1	6	100%
3 Project Selection	2	4	2	5	100%
4 Research	4	8	4	8	100%
5 Concept Design and Specification	4	2	4	8	100%
6 Update Concept	12	3	12	3	100%
7 Embodiment and Fabrication Plan	15	4	15	5	100%
8 Ordering Parts	20	16	20	23	100%
9 Engineering Analysis Proposal	20	2	20	2	100%
11 Engineering Analysis Analysis	22	2	24	14	100%
12 Initial Prototype	30	6	30	7	100%
13 Working Prototype	37	6	37	7	100%
15 Final Drawings	43	7	43	8	100%
16 Final Presentation	51	2	51	2	100%
17 Final Report	51	4	51	4	100%
19 Final Teardown	53	1	53	2	100%

Figure 18 Gantt Chart

Period Highlight: 1

Plan

Actual

% Complete

Actual (beyond plan)

% Complete (beyond plan)

PERIODS

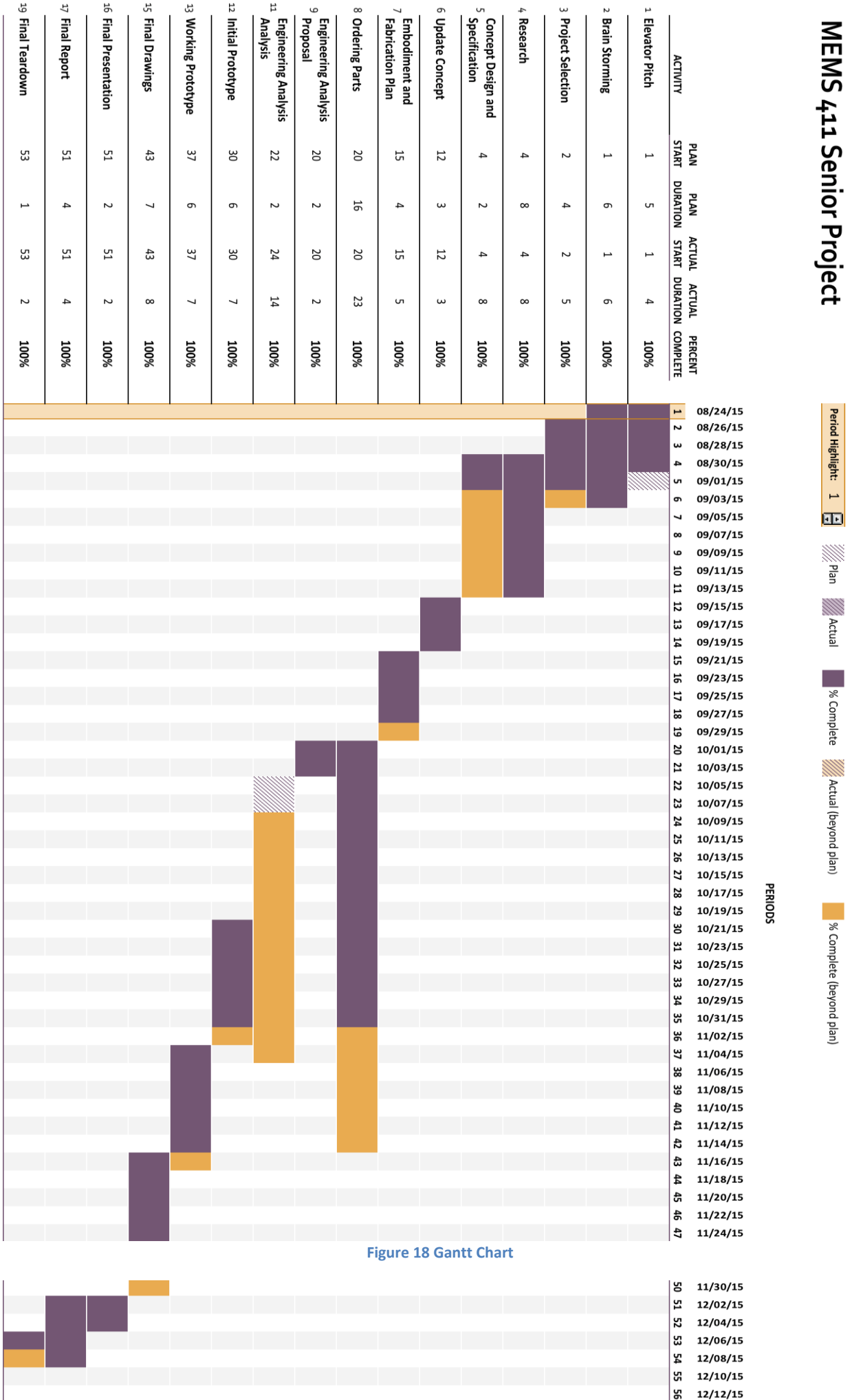|	
1	08/24/15
2	08/26/15
3	08/28/15
4	08/30/15
5	09/01/15
6	09/03/15
7	09/05/15
8	09/07/15
9	09/09/15
10	09/11/15
11	09/13/15
12	09/15/15
13	09/17/15
14	09/19/15
15	09/21/15
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19	09/29/15
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23	10/07/15
24	10/09/15
25	10/11/15
26	10/13/15
27	10/15/15
28	10/17/15
29	10/19/15
30	10/21/15
31	10/23/15
32	10/25/15
33	10/27/15
34	10/29/15
35	10/31/15
36	11/02/15
37	11/04/15
38	11/06/15
39	11/08/15
40	11/10/15
41	11/12/15
42	11/14/15
43	11/16/15
44	11/18/15
45	11/20/15
46	11/22/15
47	11/24/15
50	11/30/15
51	12/02/15
52	12/04/15
53	12/06/15
54	12/08/15
55	12/10/15
56	12/12/15

5   Engineering analysis

5.1   Engineering analysis proposal

ANALYSIS TASKS AGREEMENT

PROJECT: ASME Design Competition NAMES: Nick Cooley   INSTRUCTOR: Mark Jakiela

Jake Emmerick

Matt Ludwig

The following engineering analysis tasks will be performed:

Paper Launching Sub-assembly:

- Analysis to determine of motor torque and max rpm
- Analysis to determine optimal wheel radius
- Analysis to determine optimal launching speed
- Analysis to determine optimal paper ball radius (and hence the radius of the semicircle profile on the wheels)
- Analysis to determine optimal launch angle for the paper ball
- Analysis to determine relative speeds of top and bottom launching wheel (to impart spin on paper ball)

Motor/Shaft/Shaft Casing/Base:

- Analysis on moment shaft exerts on motor shaft
- Analysis of optimal shaft diameter
- Analysis to determine motor rpm
- Analysis to determine minimum thickness and size of base
- Analysis on difference between shaft diameter and shaft casing inner diameter for optimization of paper ball dimensions

Plunger/Tube/Motor Drive:

- Analysis on clearance between plunger and casing and clearance between plunger and shaft
- Analysis on force required to crush paper/motor power required to crush paper
- Analysis on optimal tube length
- Analysis on motor rpm
- Analysis on optimal motor shaft thickness

The work will be divided among the group members in the following way:

 Nick Cooley-**Paper Launching Sub-Assembly**

Matthew Ludwig- **Motor/Shaft/Shaft Casing/Base**

Jake Emmerick- **Plunger/Tube/Motor Drive**

Instructor signature: _____; Print instructor name: _____

(Group members should initial near their name above.)

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?

The preliminary engineering analysis is incredible important to determine the necessary elements of the engineering design. For our project in particular, much of the design cannot be finalized until certain basic components are established. As an example, the entire motor mounting sub-assemblies cannot be designed until the correct motor has been picked. The picking of this motor is critical so that the device is able to meet the various requirements laid out by the ASME design completion.

Once these decisions have been made, the design process is much easier and the designer can be more assured that it will work as intended. The engineering analysis allows for the transformation of various user needs into specific mechanical requirements which can be used to eliminate unfeasible concepts generated in earlier stages of the design process.

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

The analysis completed was almost entirely concerned with the dimensions and launching of the paper ball. The analysis was broken into three sections corresponding to the rolling sub-assembly, crushing sub-assembly and the launching sub-assembly. The rolling sub-assembly analysis found that the initial prototype had sufficient strength and dimensions to roll a satisfactory paper cylinder. The crushing sub-assembly analysis found that the optimal tube length was 14 inches and that the motor torque and rpm was satisfactory with the scrounged motor that was used. The launching sub-assembly analysis led to the selection of a suitable motor, as well as the optimal launching angle. There were also some significant design changes as a result of the launching analysis, such as the addition of a floating mounting system for the top launching wheel and motor. The engineering analysis results are summarized below in Table 5.1.

Sub-Assembly	Analysis	Equations Used	Result
Rolling	Moment shaft exerts on motor shaft	$$\sum M = F * d$$	Motor shaft is capable of supporting the shaft
Rolling	Optimal shaft diameter	-	Testing proved an inner diameter of 1.5" is perfect
Rolling	Motor rpm	$$c = \pi d$$ $$t = \frac{60\ sec.}{RPM} * \#\ of\ revs$$	11 RPM was found to be a perfect speed for the motor
Rolling	Minimum Thickness and size of base	-	Found that aluminum supports the base better than needed
Rolling	Difference between shaft diameter and shaft casing inner diameter	-	Found to be insignificant, shaft diameter is ½"
Crushing	Clearance between plunger and casing	-	Observation showed a 1/8" clearance to be optimal
Crushing	Force required to crush paper	-	-
Crushing	Optimal tube length	-	Observation showed that the optimal tube length is the length of the paper
Crushing	Motor rpm	-	Found to be insignificant
Crushing	Optimal motor shaft thickness	-	Found to be insignificant
Lauching	Motor torque and max rpm	$$w = \frac{v_{max}}{r}$$	Motor selected with 1000kV for a max rpm of 12000
Lauching	Optimal wheel radius	-	2 inches
Lauching	Optimal launching speed	-	50 miles per hour
Lauching	Optimal paper ball radius	r = d/2	0.75 inches, redesign top wheel mount to be floating
Lauching	Optimal lauching angle	$$\theta = \tan^{-1}\left(\frac{8\ ft}{16.4\ ft/2}\right) = 44.3°$$	30°
Lauching	Relative speed of top and bottom wheels	-	Further testing needed.

Table 5.1 Engineering Analysis Summary

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 was completed through a combination of testing and theoretical calculation. Essentially all of the work regarding paper ball crushing force and motor torque needed to do so was done experimentally with prototype rigs. Motors were scrounged from the basement and tested to see if they would provide enough torque and speed to roll and crush the paper. It was fortunate that both motors for the rolling and crushing sub-assemblies provide ample amounts of power and speed for our application.

For the launching sub-assembly, there was more theoretical work completed. Established physics relations were used to calculate the desired rpm of the motors to be used. Other metrics, such as required launching speed were found through experimentation. These experiments were as simple as balling paper by hand and throwing it at various speeds, but they allowed our group to get approximate numbers that could be used for early calculations. The optimal paper ball radius was determined experimentally as well. This was done by experimenting with different crushing configurations until one that consistently produced the desired product was found. The launching angle was determined theoretically, as it would be close to the end of the project before this angle could be tested experimentally. A conservative angle was chosen to allow for the possibility of variation from the theoretical treatment of the situation.

The test rigs that were built to test our design were simply the initial prototypes of our design. This allowed the team to iteratively change various aspects of the test rig to find what worked without then having to build another prototype after. This system worked quite well for the rolling and crushing sub-assemblies. The launching sub-assembly was treated in a more theoretical manner, but this also produced great results. There was no need for computation other than what was used in simple equations. It was determined that the physics behind material manipulation of paper was too complex and time-consuming for our team to undertake. That is why there was a heavy emphasis on experimentation as the main method for determining paper ball radius and crushing force.

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

Paper Launching Sub-assembly Analysis Results

Analysis to determine motor torque and maximum rpm

The analysis for this section was primarily used to pick a suitable motor for the launching of the paper ball. Due to the lack of consistent torque specification for brushless quadcopter motors, the motor decision was based on the rpm requirements. The plan was to test the first motors to see if the required torque was provided and buy new ones if necessary. As hypothesized, the motor provided an ample amount of torque to reliably launch the paper ball to distances of 15 feet or more, which was deemed acceptable for the first working prototype. In order to explain the analysis for this aspect of the design we will assume a maximum target paper ball velocity of 50 mph leaving the launching wheels. We will call this v_{max}

$$v_{max} = 50\ \frac{mi}{hr} * \frac{1\ hr}{60\ min} * \frac{1\ min}{60\ s} * \frac{5280\ ft}{1\ mi} * \frac{1\ m}{3.28\ ft} = 22.36\frac{m}{s}$$

Now that the max velocity is known in SI units, the calculation to determine motor rpm can be completed. Angular velocity, denoted as $w\ \left(\frac{rad}{s}\right)$, is defined by the following formula:

$$w = \frac{v_{max}}{r} \hspace{4cm} \textbf{[1]}$$

In Equation 1, r stands for the wheel radius. This value has not been determined at this point, but it can be estimated as something between 1 and 2 inches. The reasoning for this is that the volume of the device must be minimized while also keeping the radius of the wheel larger than the radius of the paper. We can let $r_{min} = 1\ in * \frac{1\ m}{39.37\ in} = 0.025\ m\ and\ r_{max} = 2\ in * \frac{1\ m}{39.37\ in} = 0.051\ m.$

$$w_{max} = \frac{22.36}{0.025} = 894.4\frac{rad}{s} \hspace{3cm} w_{min} = \frac{22.36}{0.051} = 438.4\frac{rad}{s}$$

Now we simply need to covert w to revolutions per minute to determine the range for our motor rpm. The calculation is shown below.

$$w_{max} = 894.4\frac{rad}{s}\ \frac{60\ s}{1\ min}\frac{1\ rev}{2\pi\ rad} = 8540.89\ \frac{rev}{min}\ and\ w_{min} = 4186.4\ \frac{rev}{min}$$

We now know that a brushless motor with an rpm range of 4186.4 rpm-8540.89 rpm will be suitable for the design. Brushless motors are classified by kV value, which stands for the amount of rpm a motor will output for a given voltage (ie a 1000 kV motor will spin at 1000 rpm when supplied with 1 V). A motor with 1000 kV was settled on, as the voltage needed for the other motors was around 12 V and this would yield a w of 12,000 rpm if supplied with 12 V. The slightly higher rpm than calculated was chosen so as to provide our motors with a healthy factor of safety if they were less powerful than specified.

Analysis to determine optimal wheel radius

This portion of the analysis was based on the results gained from the analysis of max rpm performed in the previous section. After an appropriate motor had been chosen and ordered, it was simple to take the approximation previously used for wheel size and assign that to an actual size. It was decided that to provide the maximum tangential speed from the wheels, the largest radius would be used from the 1"-2" estimate used earlier. This was due to the fact that the tangential speed of the wheel touching the paper is actually less than that of the most outer part. To explain this visually, Figure 5.1, which shows the launching wheel, is shown below.
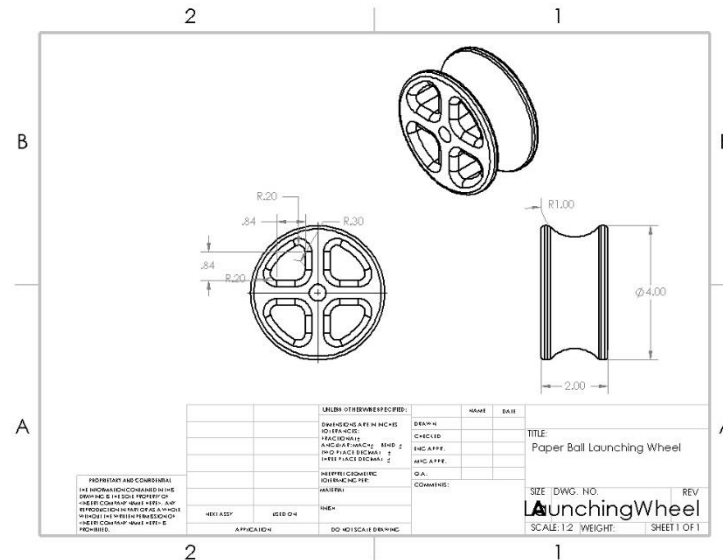
Figure 19 Launching Wheel

As you can see from Figure 5.1, the profile of the wheel is a section of a circle to allow for the paper ball to be formed into a more circular shape by the stacked wheels. For this reason, the speed of the paper ball will actually be less than what would be predicted from a wheel with 2 inch radius. For this reason, and to keep the size requirement specified in the previous analysis, a wheel radius of 2 inches was chosen. This wheel size has allowed launching distances of 20 feet, a result that indicates the success of this wheel size and motor choice.

Analysis to determine optimal launching speed

An optimal launching speed of 50 mph was determined by the extremely scientific process of balling up paper and throwing it at various speeds. With a throwing velocity of about 50 mph, our team was able to achieve throws of 5 m, which was considered a great result. For this reason, we elected to aim for a target velocity of 50 mph. The nature of brushless motors is that they are extremely adjustable, so it was known that if a launching speed of 50 mph was achieved, the system would be able to shoot faster and slower than that target.

Analysis to determine optimal paper ball radius

The optimal paper ball radius was a number that was determined through hands on testing. Theoretically, this number was very hard to determine, as an equation to find the crumpling force as a function of radius was found to be too difficult to be worth the effort. Ultimately, the radius of the paper ball would be dependent on the radius of the cylinder used in the initial phase of the machine operation. In the analysis to determine shaft diameter of this cylinder, it was found that the paper re-expanded to a height of approximately 1.5 inches when crushed by our device. Thus, the paper ball radius of 0.75 inches was decided on as an ideal situation. The wheels were then designed to accommodate this size of paper ball.

An important note is that there was a large amount of variability in radius between successive crushes. As a result, the more important question to answer was not "optimal radius" but optimal spacing of the wheels. The spacing would determine how tightly the paper ball was gripped when being shot. However, due to the previously mentioned variability, this spacing was somewhat difficult to determine. To remedy this situation, the top wheel and shaft were mounted on a floating sub assembly that was kept in tension by rubber bands. This allowed the wheel to conform and move to better grip any size or shape paper ball that came in contact with the machine. This important design change will be shown further in the significance section.

Analysis to determine optimal launch angle for the paper ball

The optimal launch angle would simply be 45° if not for the note in the ASME guidelines that the ceiling height could be as low as 8 feet. With this stipulation, the launching angle then becomes important to avoid having the projectile hit the ceiling and lose possible distance. With this in mind, it is simple to perform a basic geometric analysis to determine a suitable angle. An acceptable overall distance was picked at 5 m and then used to calculate the remainder of the unknowns. An image of this situation can be seen below in Figure 5.2.
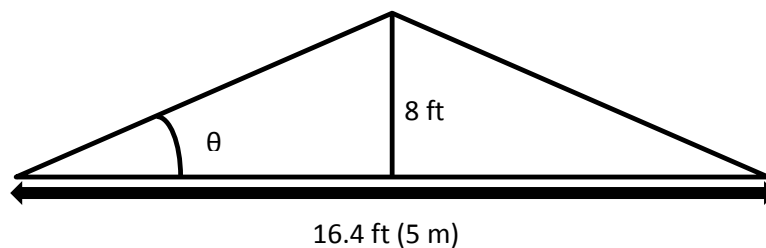

8 ft

16.4 ft (5 m)

Figure 20 Geometric analysis of launching angle

Θ can be solved for based on the numbers that are known. The calculation for this is shown below.

$$\theta = \tan^{-1}\left(\frac{8\ ft}{16.4\ ft/2}\right) = 44.3°$$

Based on this result, it looks like a launching angle of 44.3° would be sufficient to avoid the ceiling. However, after further testing, it was determined that the flight of the paper ball is significantly affected by the spin of the ball. So if the ball was imparted with a heavy backspin it would tend to rise above where it was predicted to move. Due to this fact, it was elected to use a launching angle of 30°. This is a good middle ground between the possible hitting of the ceiling with a 45° angle and the reduced flight distance that would be likely with an angle of 20° or lower.

Analysis to determine relative speeds of top and bottom launching wheel

This analysis was ultimately deemed unnecessary due to the motors that were purchased. It was found that they had different rpms for a given applied voltage, which made it impossible to try to accurately control the relative speed of the wheels. Luckily, the bottom motor was the one with this excess speed, meaning that by applying a given voltage, a sufficient backspin was achieved to

control the flight of the paper ball in a satisfactory manner. Due to the difficulty of performing any sort of accurate aerodynamic analysis of a flying irregular shaped paper ball, future analysis on this topic before the competition will be done experimentally. By recording the results of various voltage application on the two brushless motors controlling launching, we will be able to determine the optimal configuration for our system. Sadly, this result will not be applicable to other applications as it is very specific to our machine.

Engineering Analysis: *Paper rolling sub-assembly*

1. **Analysis on moment shaft exerts on motor shaft:**
   The shaft of the motor is 3/8" diameter, and made of metal. This is a relatively large, sturdy motor shaft, so it is clear that it can support a relatively heavy shaft. Even with this knowledge, the shaft is very minimalistic, with a small aluminum stub attaching to the motor shaft, and 2 skinny pieces of aluminum sheet metal attached to the stub. The entire shaft is about 1 foot long. This whole assembly weighs no more than 0.5 pounds. Assuming the shaft is a point mass, 1/3 of the way down its length (since the stub weighs significantly more than the sheet metal pieces), the moment on the shaft would be 0.5 lbs * 1/3 feet = 1/6 lbs*ft which is easily supported by the motor shaft.

2. **Analysis of optimal shaft diameter:**
   The inner diameter of the PVC pipe was essential to the formation of the paper. After using different scrap tubes with varying inner diameters, the 1.5 inch was decided upon because after the paper re-expanded, it formed into a cylinder that had a height of approximately 1.5 inches. It was important to create a uniformly-sized ball so the wheels could be sized appropriately such that they worked every time.

3. **Analysis to determine motor rpm:**
   Since the shaft motor was working inside of a PVC pipe, which isn't a very structurally sound material, it was decided a motor with a slower RPM would work best. Also, the motor only needed to spin a little over 1 revolution, but it was decided for the motor to spin 2 revolutions to be safe. With an 11 RPM motor, the rolling process will take a mere 10.91 seconds.

   > Amount of 8.5"x11" paper sticking out on each side of the PVC = (11-1.5)/2 = 4.75"

   > Circumference of 1.5" diameter = πd = 4.71"

   > Number of revolutions needed: 4.75/4.71 = 1.01

   > Time per 2 revolutions = (60 seconds/11 RPM)*2 = 10.91 seconds

4. **Analysis to determine minimum thickness and size of base:**
   No calculations were performed to determine specifications for the base, but multiple design iterations were completed to ensure the base was sturdy enough. Initially, the analysis to be completed on the base was so it could withstand the weight of the system, but it was found the weight wasn't an issue. The entire base was originally constructed from wood, since wood is an easy material to work with and was very inexpensive. After testing,

it was determined the wood was able to support the system, but not sturdy enough to counter the forces the plunger exerts due to the paper's resistance to crushing, so the base was reconstructed using aluminum. After testing, and adding multiple structural support measures (angle brackets, extra screws), the base is able to withstand the necessary forces.

5. **Analysis on difference between shaft diameter and shaft casing inner diameter for optimization of paper ball dimensions:**
   After experimentation, it was determined the difference between the shaft diameter and the PVC inner diameter did not matter much at all. The paper does not form around the shaft, but inside the PVC, so that dimension was meaningless. Analysis was performed, however, on clearance between the plunger and shaft diameter, so that was the main design constraint for the shaft diameter, which was initially set to ½", and was determined to be an appropriate size.

Plunger/Tube/Motor Drive:

⬚ Analysis on clearance between plunger and casing and clearance between plunger and

shaft

⬚ Analysis on force required to crush paper/motor power required to crush paper

⬚ Analysis on optimal tube length

⬚ Analysis on motor rpm

⬚ Analysis on optimal motor shaft thickness

1) After designing and testing the rolling shaft, a 1/8 in. clearance will be used between the plunger and shaft. This is because the shaft shows flexibility of 1/8 in. in any direction. With a 1/8 in. clearance, the plunger will be able to consistently move back onto the shaft after it pushes the paper to the end of the tube.

2) After much research and testing, we were unable to find out the exact force required to crush the paper. We considered equations of deformation for a thin walled tube, but we were unable to find anything which was at a level of mathematics which we could understand and apply to our design.

 A low RPM, high torque motor was found in the Jolley basement. After testing, it was found that this motor met all paper crushing requirements, and was used in the final design. It runs at 30 RPM, and has a high enough torque to crush the paper.

3) From testing, optimal tube length is 14 inches. This allows for the paper to have a 4 in. hole to drop down, as once crushed the paper expands again, to an average length of 4 in. After a design iteration, we removed the capped end from the pipe, resulting in a pipe length of 11.25 inches.

4) Motor RPM does not matter because the amount of time required to crush the paper is not a performance metric. However, the motor must be high torque, as the paper requires more crushing force as it gets farther down the tube. High RPM and torque are often tradeoffs, where high RPM is associated with low torque, and vice versa. Therefore, in order to ensure the paper is successfully crushed, a low rpm, high torque motor will be used.

5) The thickness of the motor shaft does not matter, as it is supported on both of its ends, preventing significant deflection. A shaft was found in the Jolley basement that is a three quarters inch thick and has a low thread count, meaning that the plunger moves down the shaft faster. This shaft was tested and found to work exceptionally well; therefore it will be used in the final design.

5.2.5   Significance

The engineering analysis results had a much larger effect on the launching sub assembly versus the crushing and rolling sub-assemblies. This was a result of the iterative design of the crushing and rolling parts of the machine. Theoretical treatment of paper crushing proved to be beyond the scope of our team's expertise, so hands on testing was used to determine the effectiveness of various materials and designs.

The launching assembly differed as the paper was already crushed by the time it was fed into the launching wheels. As a result, the only uncertainty about the paper coming into this sub-assembly was the exact radius and shape of the ball. Once it was determined that the mean radius was about 1.5 inches and there was a large amount of variability in this value, there were important changes made to the design of this aspect of the device. To illustrate this, Figure 21 and Figure 22 are shown below. They are front and right side views of the initial embodiment of the launching device. Note the fixed wheel mounts and lack of clearance between the wheels and the supports on either side.
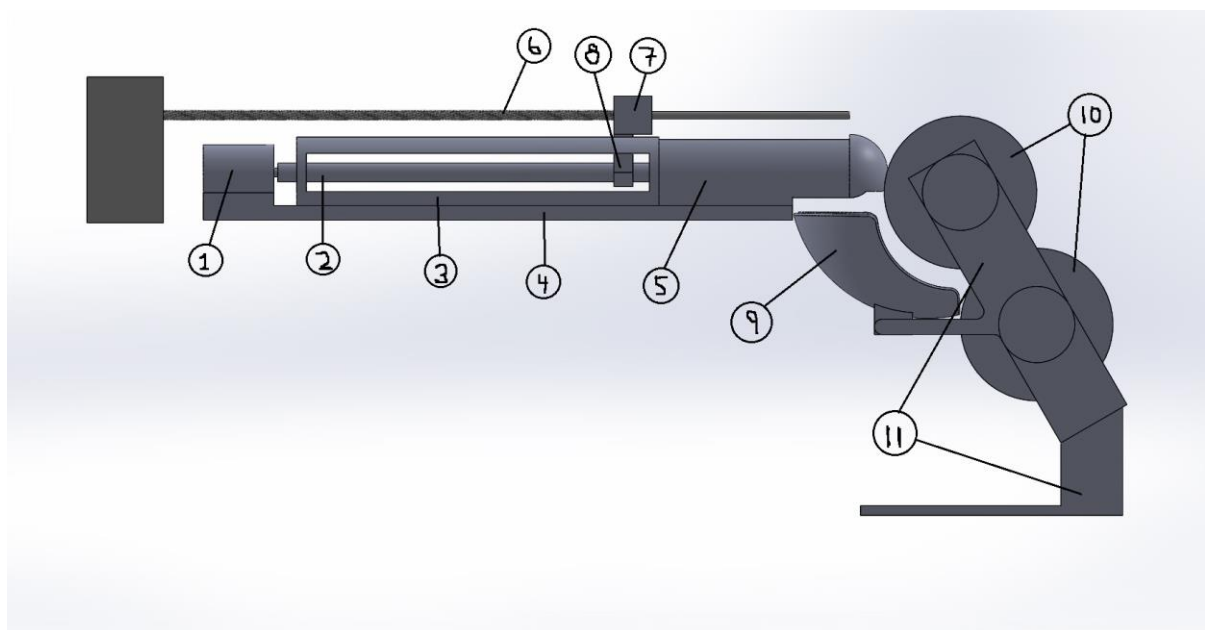

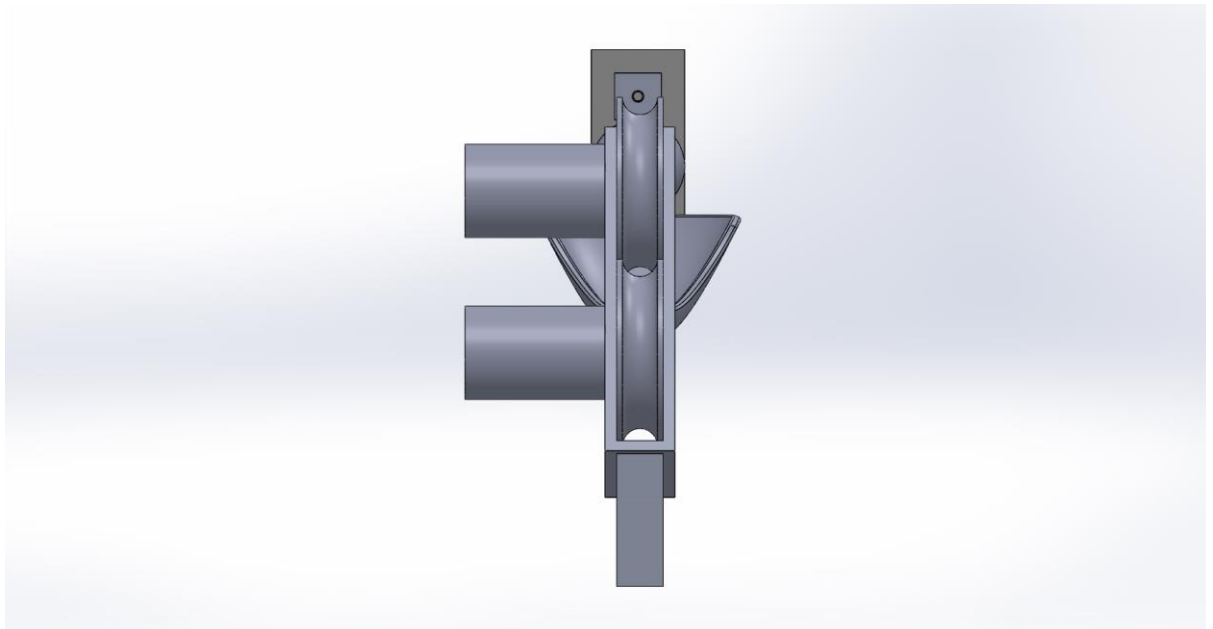**Figure 21 Front view of the initial embodiment**

Figure 22 Right view of the initial embodiment

It is apparent that if the paper ball is slightly too wide, it could easily get caught on either side of the supports or between the wheels if the motor did not have enough torque. As previously mentioned in the analysis results from the motor rpm section, data was not readily available for motor torque. This meant that the motor torque would be unknown. As a result of this, there was a large concern that if the paper was too large it would simply stall one or both of the motors. To alleviate this problem, the launching assembly was changed to accommodate variable paper ball sizes. The changes can be seen below in Figure 23, which is the final assembly drawing of the launching component.
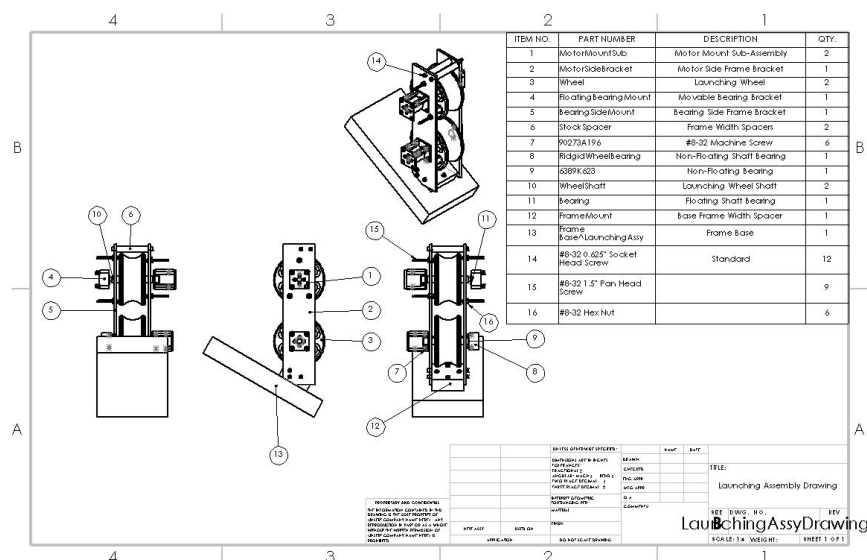

Figure 23 Final Launching Assembly Drawing

Note the top wheel part of this assembly. There as screws protruding from the vertical supports on either side of the assembly that hold rubber band that connect to the motor

mount and bearing mount. The hole in either support for the wheel shaft has 0.5 inches of clearance to allow for the shaft to move in any direction. This allows this launching assembly to adapt to any shape or size of paper ball (within reason). Ultimately, the amount of success that our final prototype has had is directly related to the engineering analysis that was performed and the results that were obtained.

5.2.6   Summary of code and standards and their influence

There were no codes or standards that influenced the design of this machine, as it is would not be used by consumers or commercially. However, there were guidelines set out by ASME that served a similar purpose.

The first guideline that influenced our design was the stipulation that "at the start of the competition, your system must be packed in a rectangular box provided by your team." This requirement meant that as long as your device would fit in this box at the beginning of the competition, it would be acceptable to use. This led to the modular design of our device. With a device in multiple parts, it is easy to rearrange them to interlock with each other and occupy less volume than they would if they were rigidly attached to each other. This means that, although our set up machine is quite long, it can be stored in a box with the parts overlapping to occupy a relatively small volume.

Another key design restraint was that "other stored energy sources (spring or other potential energy for example) are only allowed if these energy sources finish the competition at the same energy as they started the competition." The main takeaway from this stipulation is that if a catapult launching method were to be used, it would a complicated system to reset the catapult multiple times to satisfy this rule. This is why it was chosen to use wheels that were connected to motors. This meant that there was no need to reset anything and there would be no need for sensors or a timing system to detect when the paper ball was ready to launch. The wheels would simply run continuously and the paper would be fed in when it was ready.

5.3   Risk Assessment (Systems Engineering program is your project. You are the project manager)

5.3.1   Risk Identification

The risks that were identified fall broadly into two categories: Technical and Project. These sections are expanded on below.

Technical Risks

Component damage from testing-it was a distinct possibility that by testing some of the team's ideas one or more of the components might be damaged. In fact, early in the design process, some of the motors involved with our initial prototype broke right before our in class demonstration. This was a devastating setback that illustrated the importance of proper risk management.

Motors stalling from paper ball-this was identified as a risk early in the design process. Due to the difficulty of obtaining motor torque specifications, there was not any basis for a theoretical treatment of motor stalling. There would have to be design considerations for the possibility of this happening.

Reliability-this is a primary concern with this machine. Due to the nature of the competition, any sort of paper jam would eliminate our team from the competition.

Project Risks

Shipping time-this was another risk that came about after something went wrong. Some of the critical components did not arrive when they were supposed to. This led to measures being taken to reduce the risk of transportation problems affecting our deadlines.

Missing deadlines-this was a risk that was compounded by the busy schedule of each group member. This was a risk that was identified early on in the design process but not fully solved until later in the semester.

5.3.2   Risk Analysis

Technical Risks

Component damage from testing

As previously mentioned, some of our components were damaged in the testing stages of our initial prototype. This necessitated a system for minimizing risk to our components. Luckily, component damage from testing is a problem that is quite easy to mitigate when taking the proper precautions. The following system was used following the initial incident.

1. Inspect and assess problems that could occur
2. Brief test then re-assess
3. Fully test with constant focus on problems identified earlier

Through this system, risks were able to be avoided. By testing briefly, any sort of thing that could go wrong will be spotted and stopped before any serious damage occurs. By diligently applying this system in all further testing, our team was able to avoid any further damage from testing components.

Motor Stalling from Paper Ball

This risk was determined from the initial prototype. It was discovered that there was a high likelihood of motor stall in the initial design if the paper ball was out of shape. Because the initial motor mounts were fixed in place, a paper ball of abnormal shape being fed into the motors would likely cause a stall, leading to disqualification from the competition and possible motor destruction. As a result of this, the design was changed to mitigate the risks of this occurring. The changed design can be seen below in Figure 24.
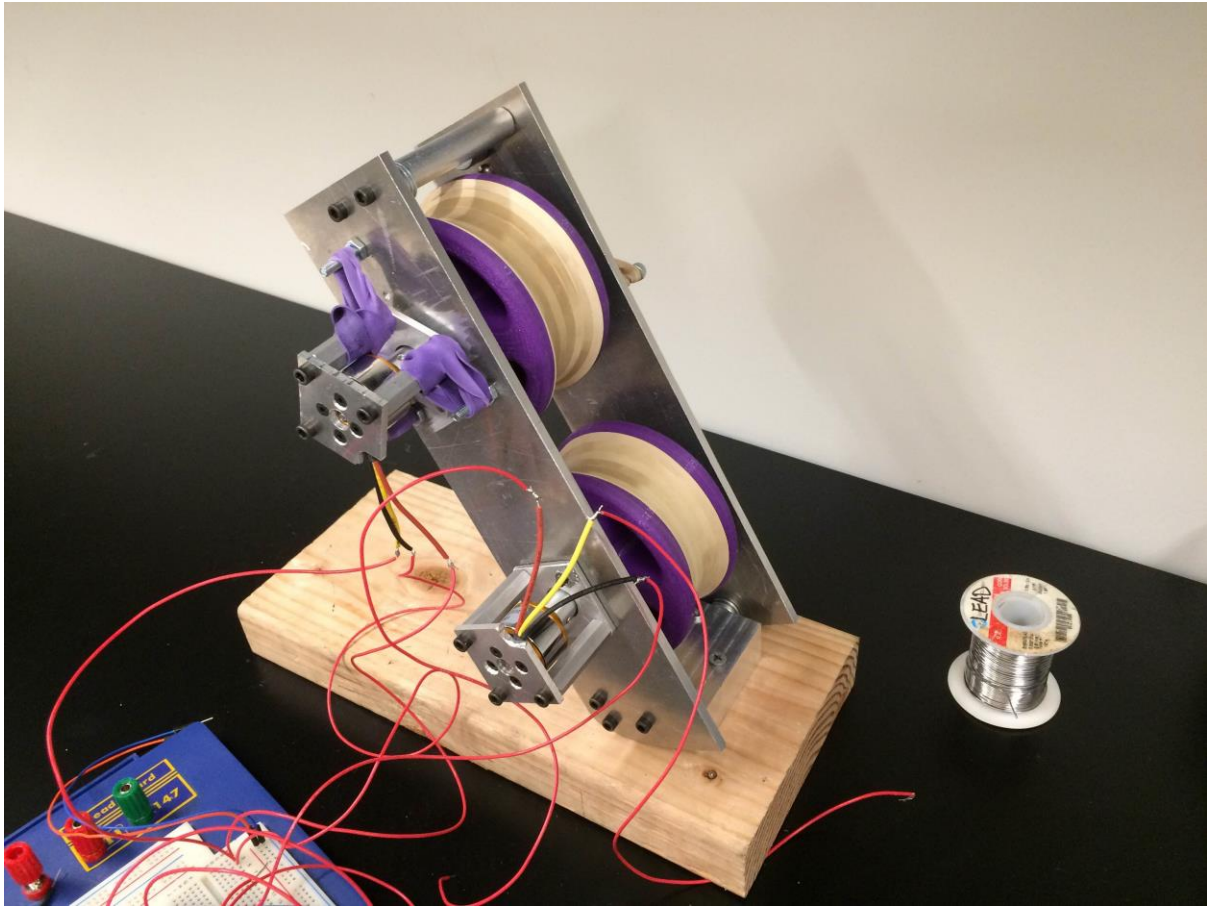
Figure 24 Launching sub-assembly with floating wheel

As you can see from Figure 24, the top wheel is connected to the motor mount, which is connected by rubber bands to the supporting frame. On the other side of the device, the bearing which holds the other end of the axle is also connected in a similar manner. The ability of the top wheel to move in any direction allows for the launching assembly to adapt to a paper ball that is too big for the rigid original assembly. Additionally, the wheels and frame was widened to allow for a wider paper ball to be launched without problem. Numerous testing with various shapes of paper balls, cylinders, etc. has shown this design to be sound. In each occasion, the wheel moved to allow for the passage of whatever irregularity was present. In this way, the risk of motor stall was essentially eliminated in the final prototype.

<u>Reliability</u>

Reliability is an aspect of our machine that is crucially important. In order for our team to succeed in the competition, we must be assured that our machine will work three times in a row without jamming or having problems. Of all the technical aspects of risk, this one is the most theoretical. Our team only recently got our prototype fully working, and it still has some reliability issues. In order for the machine to confidently work in competition, it will be necessary to ensure the reliability of our machine. In order to do that, in the coming weeks before the competition, it is planned to continue testing. In order for the reliability requirement to be satisfied, it will be imperative that our machine is able to perform 10 competition simulations in a row without failing. If this metric is met, we can be confident that our machine will succeed in competition.

Project Risks

<u>Shipping time</u>

This risk was only brought to the team's attention after some parts failed to be delivered on time for the initial prototype. After that experience, a more rigorous analysis of shipping was completed. It was determined that parts should be set to arrive at least a week before they were needed. This necessitated ordering parts at least a week + the estimated shipping time in advance. After this system was implemented, there were no more issues moving forward with parts not arriving on time. In the coming weeks if additional parts are ordered, they will be put onto an excel spreadsheet with the ASME design competition timeline to ensure timely delivery.

<u>Missing deadlines</u>

The risk of missing deadline was a problem of time management. After struggling initially to meet key deadlines, my team created a timeline for the event of the last couple weeks of the class. This timeline is seen below in Table 1.

<div align="center">Table 1 Timeline of senior design deadlines</div>

Friday	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Monday
11/20/2015	11/21/2015	11/22/2015	11/23/2015	11/24/2015	11/25/2015	11/26/2015	11/27/2015	11/28/2015	11/29/2015	11/30/2015	12/1/2015	12/2/2015	12/3/2015	12/4/2015	12/5/2015	12/6/2015	12/7/2015
Prototype must be working														Final Presentation			
	Final Drawings are due																
			Final Presentation (includes powerpoint, working video)														
			Final Report is due (includes all aspects of senior design ie analysis, embodiment, etc.)														

A designated team member was in charge of handling this timeline and converting it into small deliverables spaced evenly over the time until each piece was due. By breaking up large assignments into smaller ones, more things were completed and the sense of satisfaction with the team's progress was increased. The risk of missing deadlines was analyzed and solved through the proper use of time management and planning. Our team expects to utilize the same methods moving forward into the competition to ultimately succeed on the battlefield.

5.3.3   Risk Prioritization

The risks mentioned in the previous sections were prioritized by relative importance. Components breaking from testing was priority number one to solve, as another instance of components breaking would put our team over budget having to buy new parts and set us back having to redesign aspects of our assembly. Secondly, we prioritized meeting deadlines. It was at this point that the timeline and position in charge of time management were created. The reasoning is that by putting this risk highly would allow us to minimize risks of other issues as well. Next was shipping time. This risk fits in well with the meeting deadlines risk. In fact, the same spreadsheet that had our timeline was often used to evaluate when parts would need to be ordered.

Our last two risks were reliability and motor stall. Motor stall was placed last due to the design changes effectively eliminating this risk. Reliability was near the bottom due to the fact that a high reliability was only needed by the time of competition. That meant that by effectively using the timeline and time management skills, our team could plan for ways to increase reliability in a carefully controlled manner as the competition date nears. Through this prioritization of risks, our team was able to effectively create a working prototype for the final presentation after a series of failures and setbacks earlier in the semester.

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 (this section may be left blank).

6.3   At least two digital photographs showing the prototype

The first picture shows the paper intake/crushing system. As mentioned before, this is not attached to the paper launching mechanism, which is shown in the second picture.
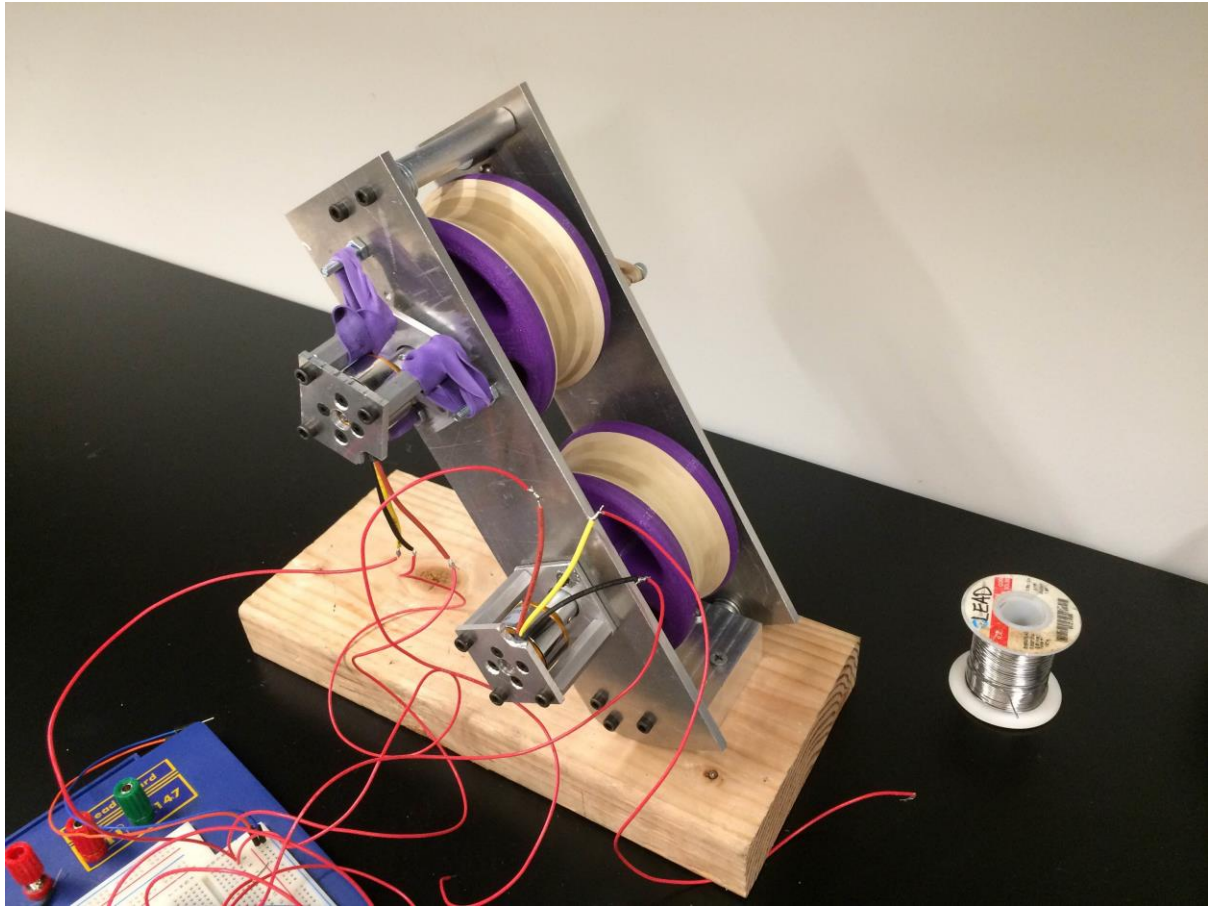

Figure 25

Figure 26

6.4   A short videoclip that shows the final prototype performing

A video may be found at https://youtu.be/rCSs0EjvVuM

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

The following figure shows the area that the paper ball drops through after it has been crushed. The distance from each end is 4 inches. The distance of 4 inches was chosen because after testing the crushing mechanism, it was found that the paper would re-expand to an average length of just less than 4 inches.
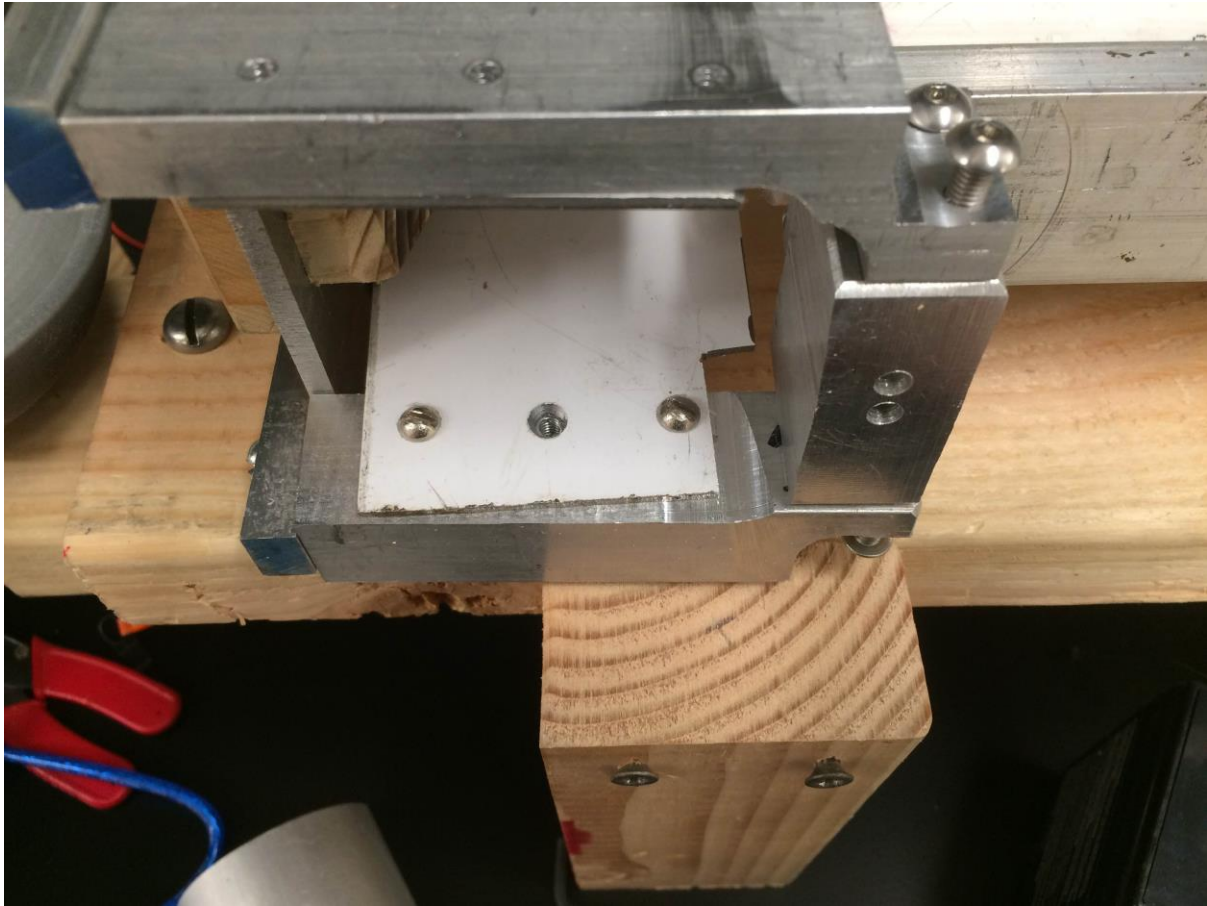
Figure 27

The following figure shows the motors used for the launching mechanism. These motors were specially chosen as a direct result of the optimal RPM analysis for the launching mechanism.
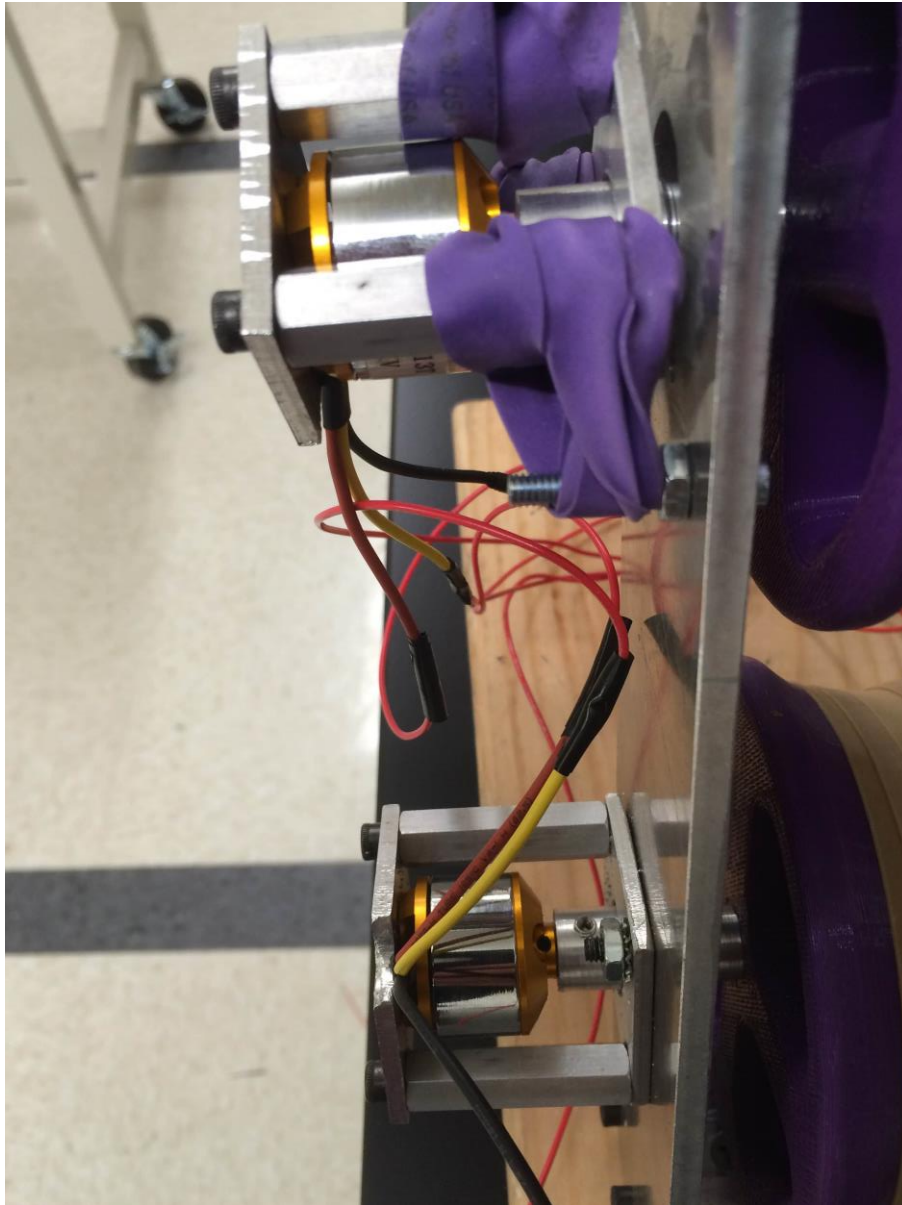
Figure 28

The following figure shows the tilt of the launching mechanism. This again is a direct result of analysis, where the optimal launching angle was found to be 44.3 degrees.
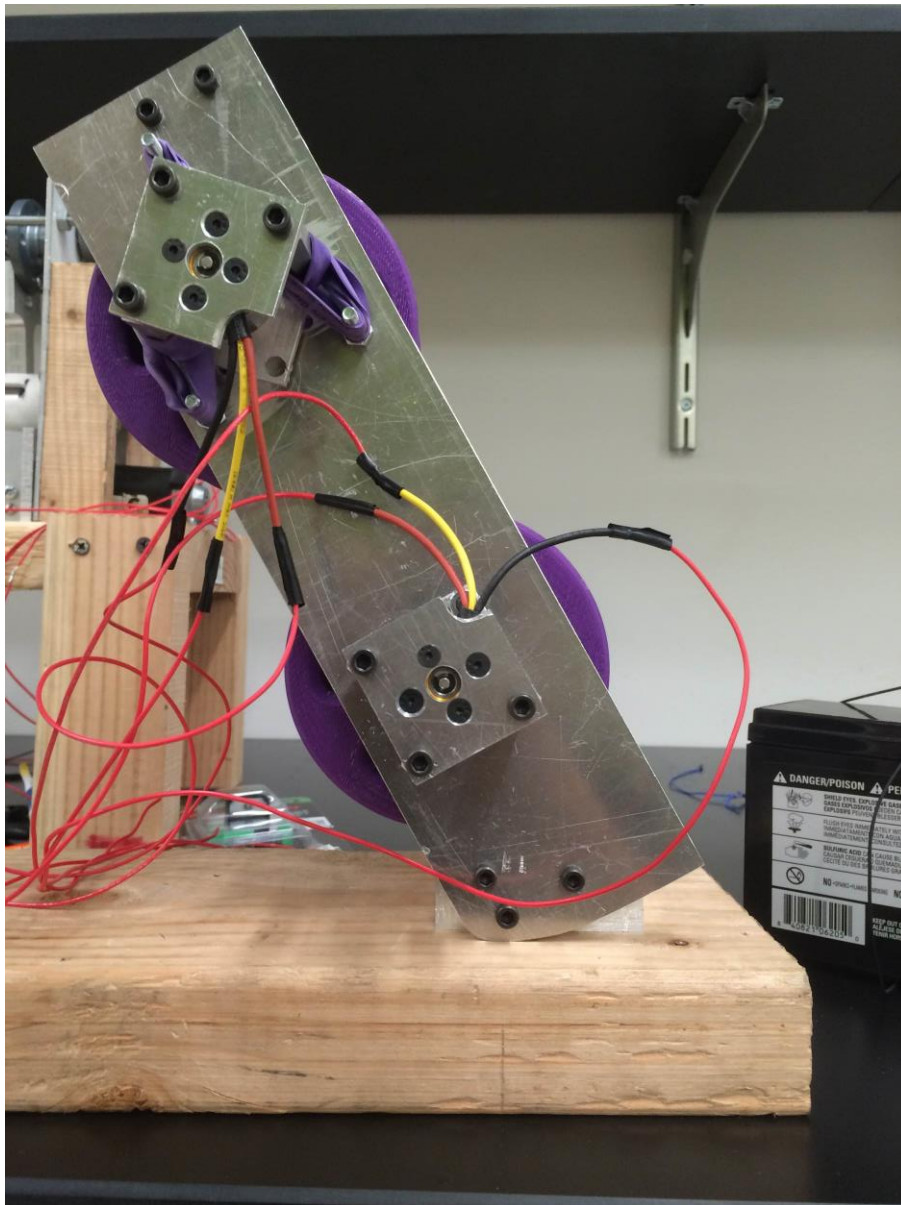

Figure 29

The following figure shows the paper rolling/crushing sub assembly. The inner diameter of the PVC pipe was an important decision to make, as it would decide the diameter of the paper ball. After much testing to find an optimal ball size, a PVC pipe with a 1.5 inch inner diameter was selected due to how the paper acted as a 1.5 inch ball.
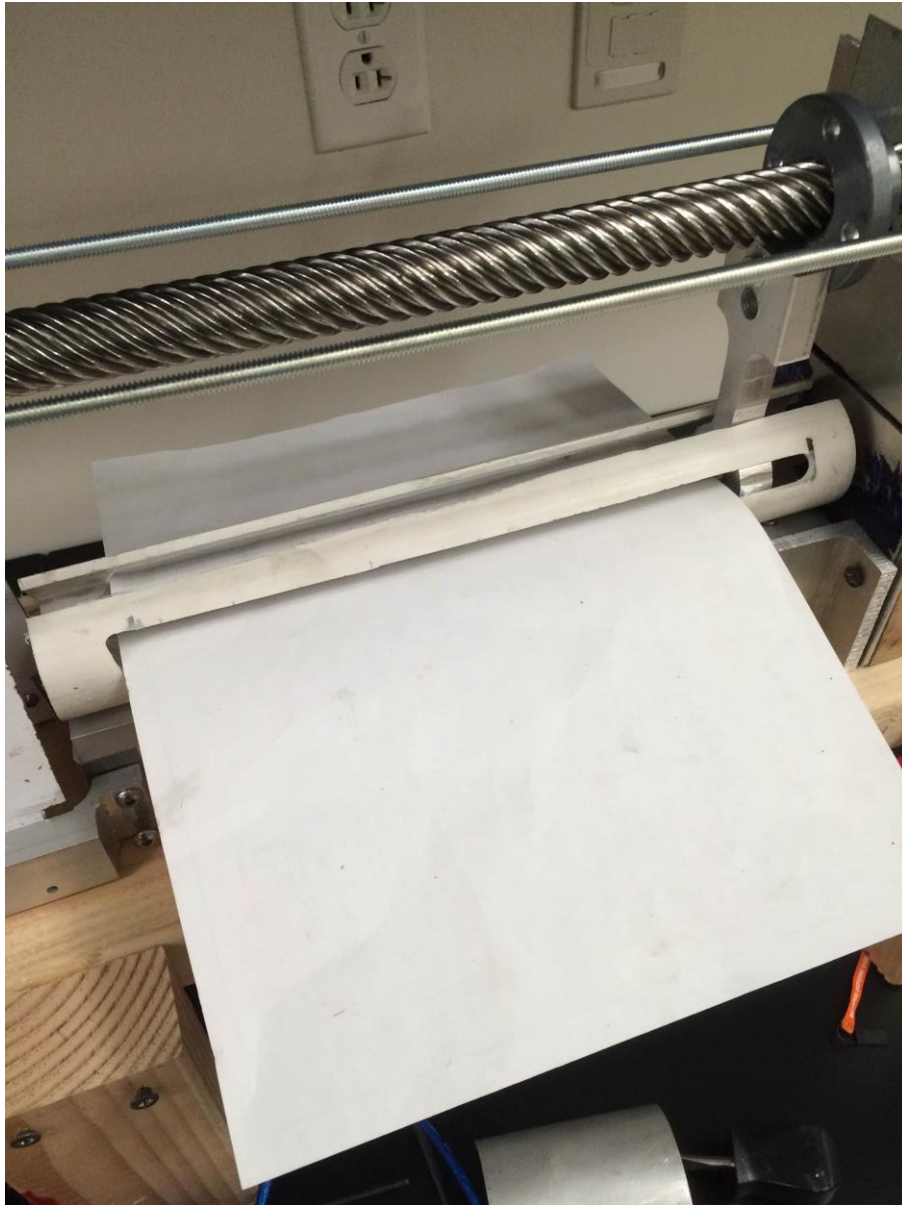

Figure 30

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.

7.1.2   Sourcing instructions
The sourcing information is included in Appendix B – Bill of Materials.

7.2   Final Presentation

7.2.1   A live presentation in front of the entire class and the instructors
The live presentation was given on December 4, 2015

7.2.2   A link to a video clip version of 1
A video clip explaining the requirements and design choices of the machine, as well as a working video, can be accessed at:
https://www.youtube.com/watch?v=44pMqpteZSA

7.3   Teardown
Since the ASME Design Competition is in March/April 2016, the machine will remain intact until after the competition. Therefore, no teardown has been completed as of now. The following pictures, Figures 31 and 32, confirm nothing teardown related needs to be completed.

Figure 31: Front side of Teardown Tasks Agreement form

Figure 32: Back side of Teardown Tasks Agreement form

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.

The 3 most important user needs were to shoot the paper far, shoot the paper straight, and to minimize the device's packaging volume. The final prototype shot the paper an average distance of 13 feet, in an almost perfectly straight line, and the device could be packaged in what we consider to be a small volume. Needless to say, all user needs were met exceedingly well. In comparison to other ASME design groups that we know of, our projectile has the longest average shooting distance, and the device takes up relatively small volume. Furthermore, our projectile shoots in almost a perfectly straight line, which helps to maximize the distance measured from the shooting point.

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?

We only faced one issue when it came to ordering parts, which was a fault of the delivery company and not the part vendor. The group has been having trouble with UPS for quite some time, as the driver responsible for their apartment's packages rarely actually delivered the packages, but rather put a note on the door saying that the package could be picked up at some location on the next business day. The lazy driver did this on the Friday before the working prototype was scheduled to be due (Monday Nov. 16th), which caused the group to not have parts critical to finishing the assembly. Because of this, a one-day extension was needed for the final working prototype demo, and even with the one-day extension, the prototype was still unable to be completed on time. Had the parts been delivered on time, the group would have had the weekend to build the device, as well as troubleshoot any problems with the computer programming before presenting the prototype demo.

In the future, we would recommend that the group minimize how much they rely on outside companies for delivering their parts. Whenever possible, the group should travel to the store and buy the parts themselves. This will ensure that the group receives their parts by the time that they need them.

8.3   Discuss the overall experience:

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

The project was much more difficult than the group expected. The actual design aspect of the project came relatively easily, but building it proved quite a challenge. Each member of the group had nothing but minimal experience in a machine shop before the project began, and had to learn how to use most machine shop equipment as they went. This caused a lot of problems when group members had to make parts that interlinked with one another, as it required the utmost precision.

Furthermore, time was a huge constraint for our group. Working in a group of 3 (as opposed to 4) meant that each member had to take on a heavier workload in order to complete the project. Also, each member of the group was a senior looking for a post-grad job. Because of this, group members were often out of town for recruitment trips, or spending their time preparing for interviews. This made it difficult to adhere to the deadlines associated with the project, as some weeks just had too much going on.

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

The final results align perfectly with the project description. The device is fully automated, and shoots the paper long and straight. Furthermore, the fact that it is battery powered means that there are zero emissions associated with the operation of the device, which was another concern in its design.

8.3.3   Did your team function well as a group?

The team functioned very well together. When one member of the group was unable to complete their assigned tasks, the other group members had no issue in stepping up and covering for them. Each member of this team has been a member of the Kappa Sigma fraternity for the past three years, so they have known each other very well for the entirety of their college experience. Each team member knew each other's strengths and weaknesses coming into the project.

8.3.4   Were your team member's skills complementary?

Each team member brought something unique to the table. Nick is the only team member with a robotics background, so his knowledge and skills were absolutely necessary for using the Arduino to automate the device. Matt has had a few internships that dealt with mechanical design, so his background helped greatly when it came time to design the prototype and draft models in Solidworks. Jake's skill set was not necessarily engineering oriented, but as the prior president of the group's fraternity, he has had ample experience with setting goals and objectives for this group, as well as creating timelines and making sure that the group would adhere to them.

8.3.5   Did your team share the workload equally?

The workload was distributed equally, as each team member was responsible for making sure one part of the system worked. Matt was in charge of making sure the paper intake system worked, as well as making sure that the device was sturdy. Jake dealt with the paper crushing system, and Nick was in charge of the paper launching system. Because Nick's portion required more time to design, Jake and Matt helped him build a good portion of his part. In return, Nick then had more time to complete his launching design, as well as program the Arduino.

8.3.6   Was any needed skill missing from the group?

It would have been a much easier project if one of the group members had previously worked with an Arduino or motor controller. While Nick has had previous experience in robotics, his skill set did not completely align with the tasks we needed to accomplish. Because of this, the group spent much longer than they anticipated on playing with circuitry and programming to get the device working.

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

We did not have to consult with the customer during the process. The ASME Design Competition guidelines were very strict and well defined, clearly outlining what could and couldn't be included. The user needs interview was a good exercise in simplifying the conditions explained in the ASME guidelines. All of the user needs either reiterated the rules of the competition or were focused on minimizing the complexity and size of the machine. These were already guidelines we envisioned, so no further consultation was necessary.

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

The design brief did not change during the process. Since the guidelines were set for a competition, they were not subject to change.

8.3.3   Has the project enhanced your design skills?

Throughout the project, we were constantly running into fabrication errors and design flaws which necessitated design changes. For example, the initial design for the paper intake system included a shaft with a slit instead of the final shaft nub with extending prongs. The slit was unable to hold the paper throughout the rolling process, so the next idea was to cut a slit down the length of a rod. Fabrication was impossible since a small enough end mill was not available, and it was difficult to keep the rod from rotating while cutting it with a band saw. At this point, we took a step back, examined what was working, what wasn't working, and redesigned a system that works. This was one of many instances in which the initial design did not function as planned. All these design blunders allowed us to see what doesn't work, and forced us to take steps for improvement.

The main way this has enhanced our design skills is through trial and error. We have a much broader knowledge base of what designs will work after completing this project. This doesn't mean in the future we will think of the perfect design for the first iteration, but I am confident it will take us significantly fewer iterations to find that perfect design.

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

Absolutely. It is impossible to feel familiar with design before seeing a project from design through fabrication and the completion of this project is the first real design project any of us have completed. By no means would any of us feel completely comfortable with accepting a design project as a job, but we feel significantly more comfortable with the idea now.

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

Two of the group members said yes: the Arduino board and electrical components were very intriguing. Therefore, we would be more cavalier in pursuing projects that involve semi-complex electrical components. We were slightly hesitant towards choosing this project since none of us have any extensive electrical background, and it took a surprisingly long time to figure out the circuitry and Arduino code required. This interest was inspired by reading about the seemingly endless list of what the Arduino is capable of, and the many different methods of completing each action.

The third group member said this project made him realize how little he enjoys design. He thought the process was tedious and annoying in all the wrong ways and is currently not pursuing a career in design. This project, if anything, made him not want to attempt projects he would have attempted before.

9 Appendix A - Parts List

Below are Tables 2, 3, and 4, the detailed parts lists for the Crumpling Assembly, Launching Assembly, and Electronic Controller Components, respectively. Every part used is included in one of the three tables.

Table 2: Detailed parts list for the Crumpling Assembly.

Part Number	Description	Part Number	Material	Size	Quantity
			Crumpling Assembly Parts List		
1	Front Plate	-	Aluminum	4.25"x8"x0.125"	1
2	Wood Block	-	Wood	4.25"x6"x1.5"	1
3	Shaft Motor	-	Metal	4"x3"x3.5"	1
4	Right Angle	-	Aluminum	Angle 1.5"x1.5"x0.25"	1
5	Left Angle	-	Aluminum	Angle 1.5"x1.5"x0.25"	1
6	Shaft Nub	-	Aluminum	0.5" O.D. x 1.75" LG.	1
7	Shaft Stick	-	Aluminum	9.5"x0.5"x0.06"	2
8	PVC Pipe	-	PVC	1.5" I.D x 11.25" LG.	1
9	Power Screw Rod	-	Metal	0.75" O.D. x 15" LG.	1
10	Shaft Ring	-	Metal	2.25" O.D. x 1"	1
11	Plunger	-	Aluminum	4.5"x1.5"x0.5"	1
12	Shaft Support	-	Aluminum	7.75"x4"x0.5"	1
13	Side Support 1	-	Aluminum	4.15"x1.5"x1"	1
14	Side Support 2	-	Aluminum	4.15"x1.5"x1"	1
15	Bridge Leg 1	-	Aluminum	2"x1.4"x0.85"	1
16	Bridge Leg 2	-	Aluminum	2"x1.4"x0.85"	1
17	Bridge	-	Aluminum	11.25"x1.5"x0.5"	1
18	Power Screw Motor, 12V 30 RPM	-	Metal	2" O.D. x 2.5"	1
19	Bracer Rod	-	Metal	0.25" O.D. x 16" LG.	2
20	Small Screw	-	Metal	0.1" O.D. x 0.6" LG.	2
21	Large Screw	-	Metal	0.15" x 0.325" LG.	17
22	Wood Base 1	-	Wood	21"x4"x2.5"	1
23	Wood Base 2	-	Wood	7"x4"x2.5"	2

Table 3: Detailed parts list for the Launching Assembly.

Part Number	Description	Part Number	Material	Size	Quantity
			Launching Assembly Parts List		
1	Motor Mount Sub-Assy	-	-	-	2
1.1	Brushless Quad Motor	-	-	1" O.D. x 2.5" LG.	2
1.2	M3 Machine Screw	91420A118			8
1.3	Back Motor Plate		Aluminum	1.5"x1.5"x0.125"	2
1.4	Hex Standoff	91780A307		1.5" LG.	6

1.5	Floating Shaft Mount		Aluminum	1.5"x1.5"x0.125"	2
1.6	#8-32 Machine Screw	90273A196			6
2	Motor Side Bracket		Aluminum	11"x2.5"x0.125"	1
3	Launching Wheel		ABS Plastic	4" O.D. x 2" LG.	2
4	Floating Bearing Mount		Aluminum	1.4"x1"x0.75"	1
5	Bearing Side Mount		Aluminum	1.35"x0.75"x0.75"	1
6	Stock Spacer		Aluminum	0.5" O.D. x 2.5" LG.	2
7	#8-32 Machine Screw	90273A196			6
8	Rigid Wheel Bearing				1
9	Non-Floating Bearing	6389K623			1
10	Wheel Shaft		Aluminum	0.55" O.D. x 4.2"	2
11	Bearing	6383K227			1
12	Frame Mount		Aluminum	2.5"x2.5"x1"	1
13	Frame Base		Aluminum	10"x5.5"x1.5"	1
14	#8-32 0.625" Socket Head Screw				12
15	#8-32 1.5" Pan Head Screw				9
16	#8-32 Hex Nut				6
	Guided Slide		ABS Plastic	4.35"x3"x2.68"	1

Table 4: Detailed parts list for the Electrical Controller Components.

Electrical Controller Components Parts List		
Part Number	**Description**	**Quantity**
1	24 Gauge Wire	1
2	Relay Module	1
3	Arduino UNO	1
4	A to B Cable	1
5	MCM Jumper Wire Kit	1
6	Osepp Robotic Motor Driver	1
7	SchmartBOARD Female Wires	1
8	Brushless ESC	2

10 Appendix B - Bill of Materials

Below is Table 5, the Bill of Materials. Included is specific sourcing and pricing information for all purchased parts. All parts included in the Parts List (Appendix A) but not in this table were scavenged from the WUSTL machine shop or Jolley basement.

Table 5: Bill of Materials for all purchased parts and equipment.

	Part	Source	Supplier Part Number	Color, TPI, other part IDs	Unit price	Tax ($0.00 if tax exemption applied)	Shipping	Quantity	Total price
1	24 Gauge Wire	Micro Center	444828	Red	$12.99	$1.25		1	$14.24
2	Relay Module	Micro Center	442970	Black	$7.99	$0.77		1	$8.76
3	Arduino Board	Micro Center	327684	Green	$19.99	$1.92		1	$21.91
4	A to B Cable	Micro Center	2.99	Blue	$2.99	$0.29		1	$3.28
5	MCM Jumper Wire Kit 65 Pc.	Micro Center	571356	Various	$9.99	$0.00		1	$9.99
6	Osepp Robotic Motor Driver	Micro Center	576322	Black	$9.99	$0.00		1	$9.99
7	SchmartBOARD Female Jumper Wires	Micro Center	724252	Black	$7.99	$0.00		1	$7.99
8	1/4" Threaded Shaft	Home Depot	16840	Silver	$3.47	$0.33		2	$7.61
9	12V Battery	Battery Center	-	Black	$49.99	$4.81		1	$54.80
10	Bearing	McMaster	6383K227	Silver	5.75	0.55328225		1	$6.30
11	Guided Slide	TechArtista	-	Grey	75	0		1	$75.00
12	M3 Flat Head Screw	McMaster	91420A118	Silver	2.8	0		1	$2.80
13	Hex Standoff	McMaster	91780A307	Silver	1.66	0	$5.62	8	$18.90
14	Sleeve Bearing	McMaster	6389K623	Silver	0.79	3.16		4	$3.16
15	Brushless Motor	Amazon	A2212	Silver/Orange	13.99	0		2	$27.98
16	Brushless Electronic Speed Controller	Amazon	-	Red	11.81	0		2	$23.62
Total:									$296.33

11 Appendix C - CAD Models

This Appendix includes Figures X-Z, all the part drawings necessary for fabrication of the machine.

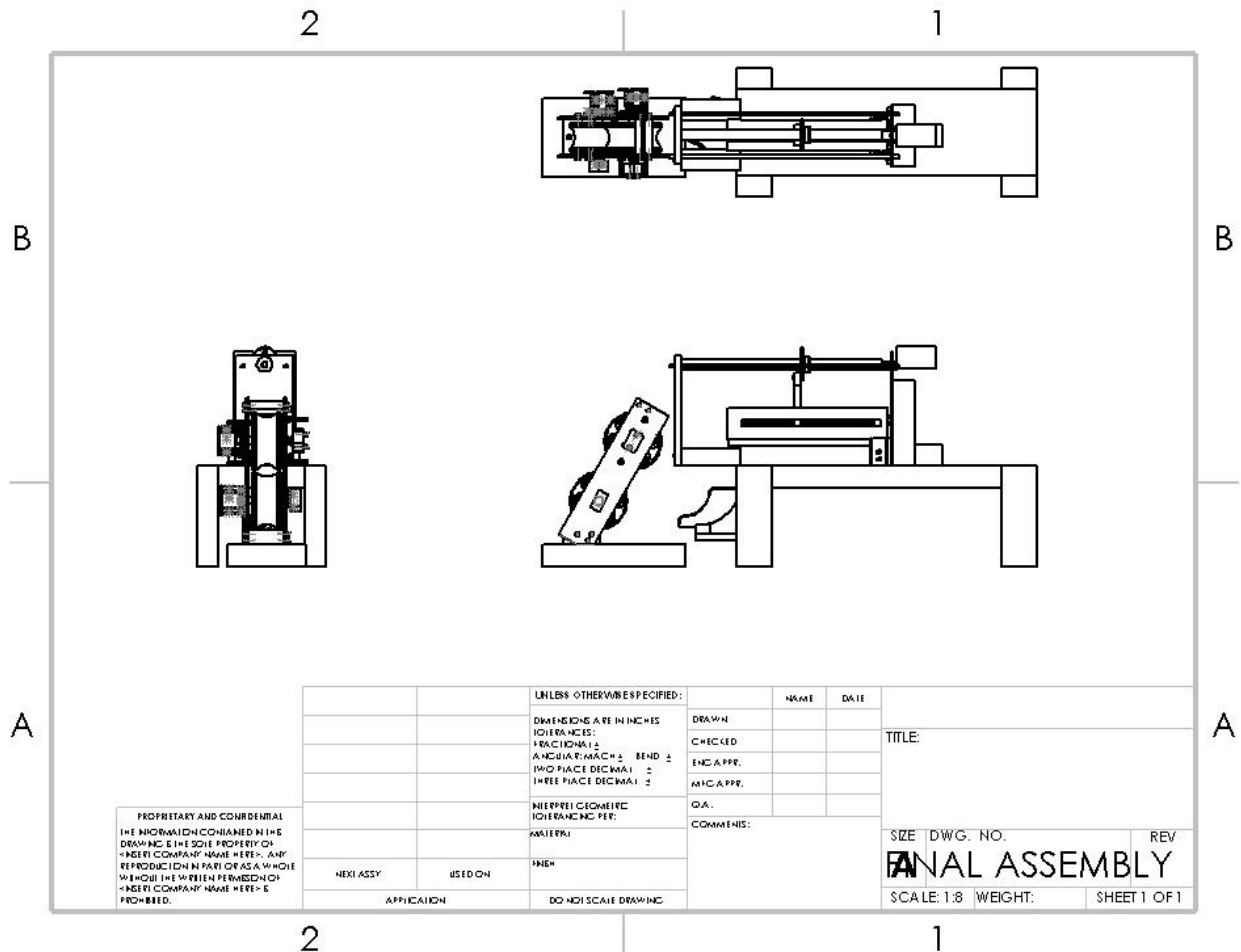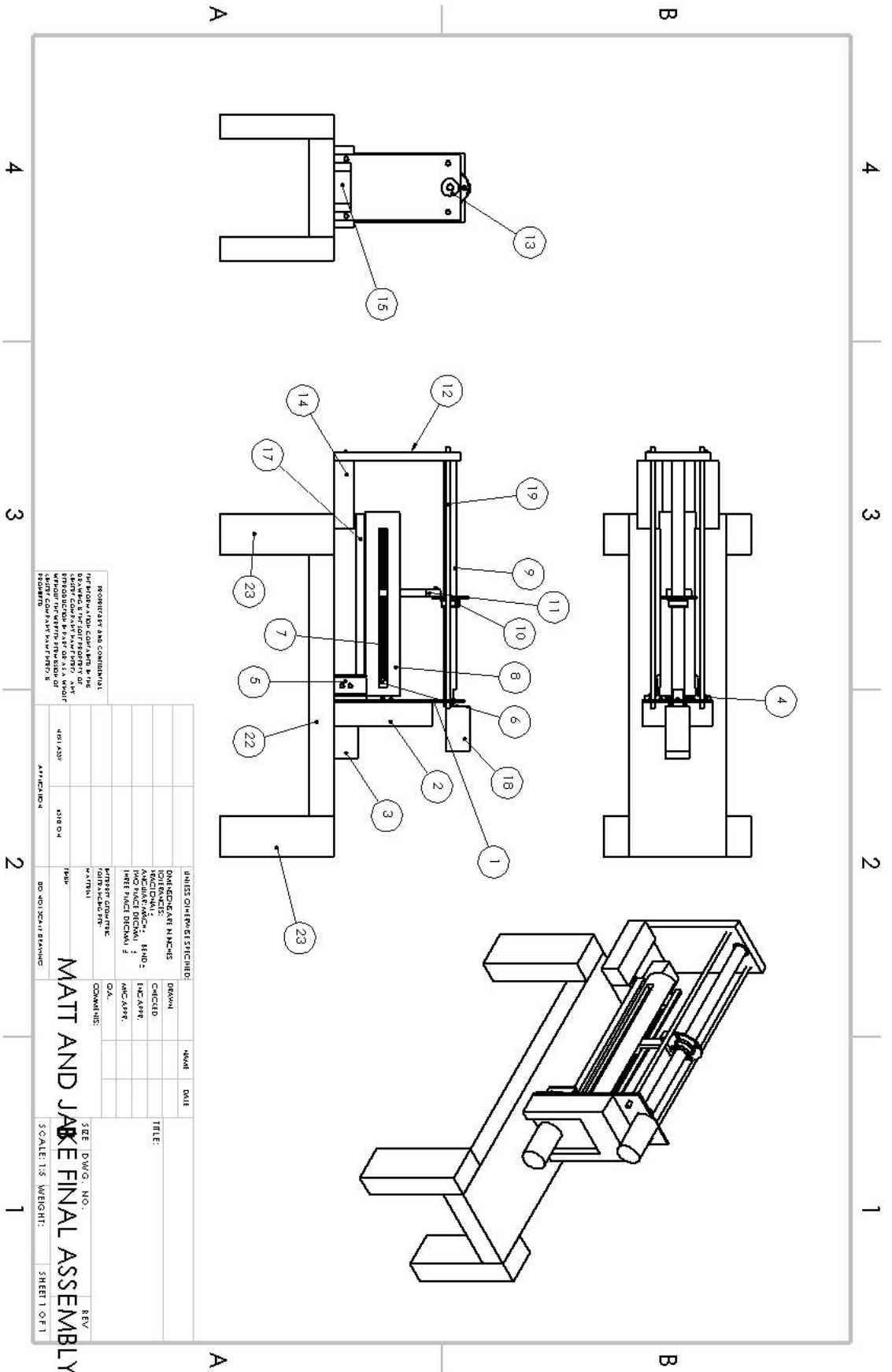Figure 33: Final Assembly

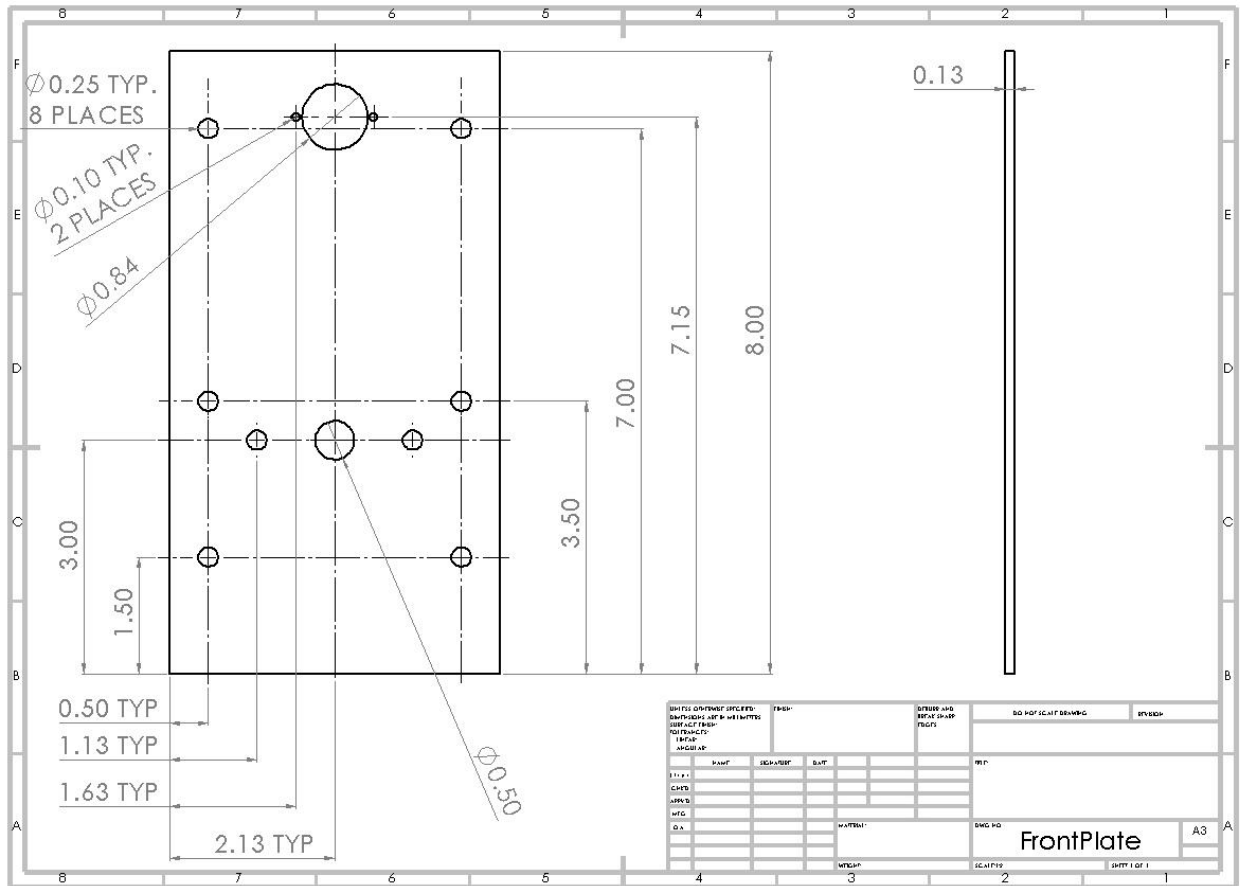**Figure 34: Crushing Assembly**

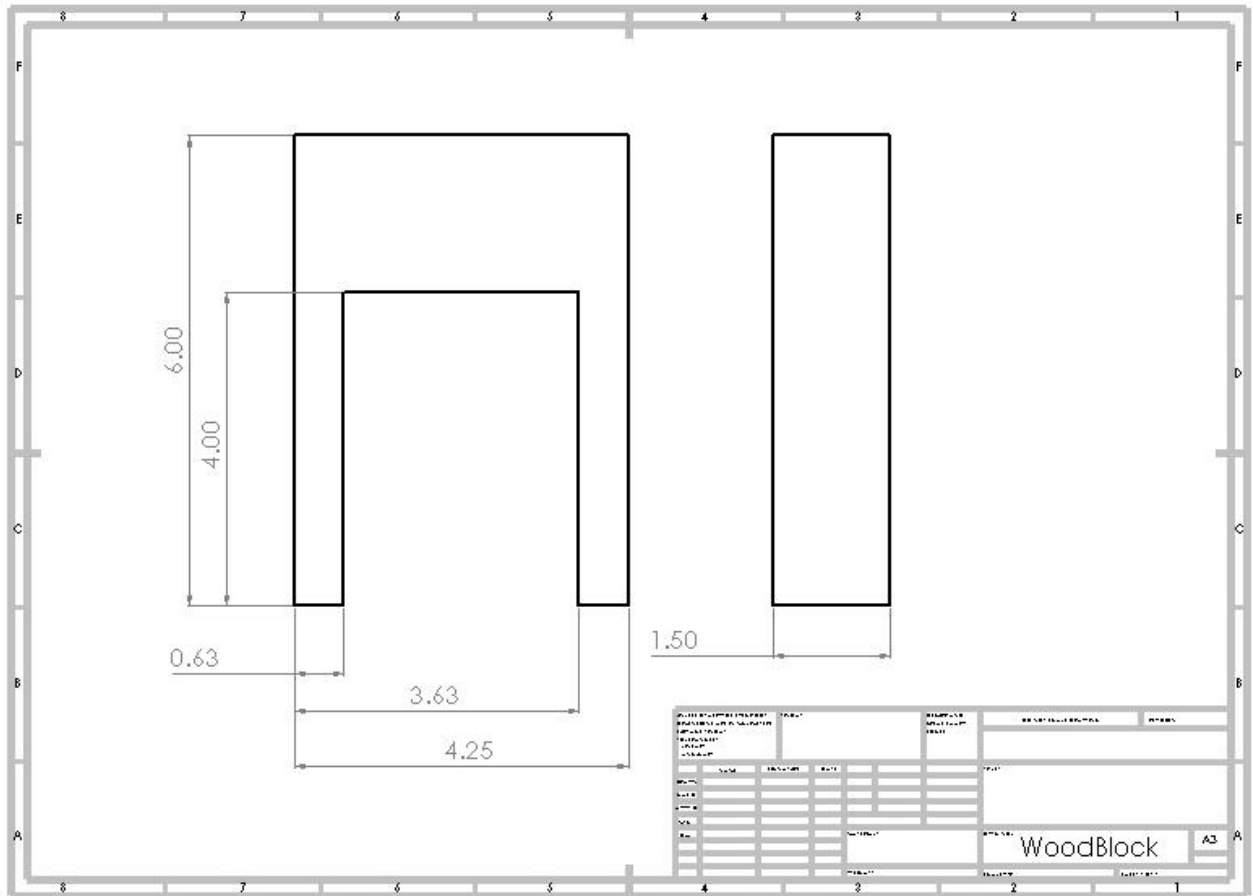**Figure 35**

Figure 36: Part 1, Front Plate
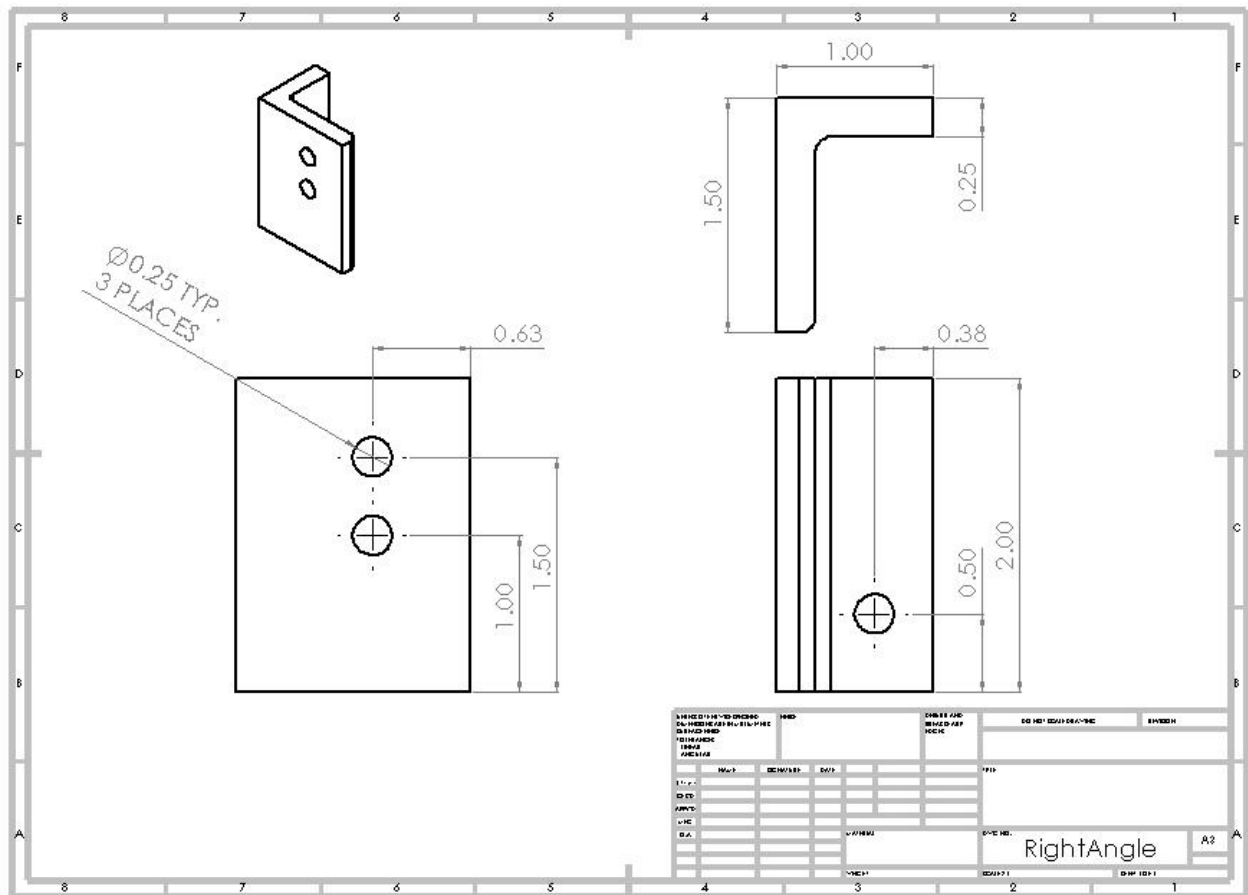
Figure 37: Part 2, Wood Block

Figure 38: Part 4, Right Angle
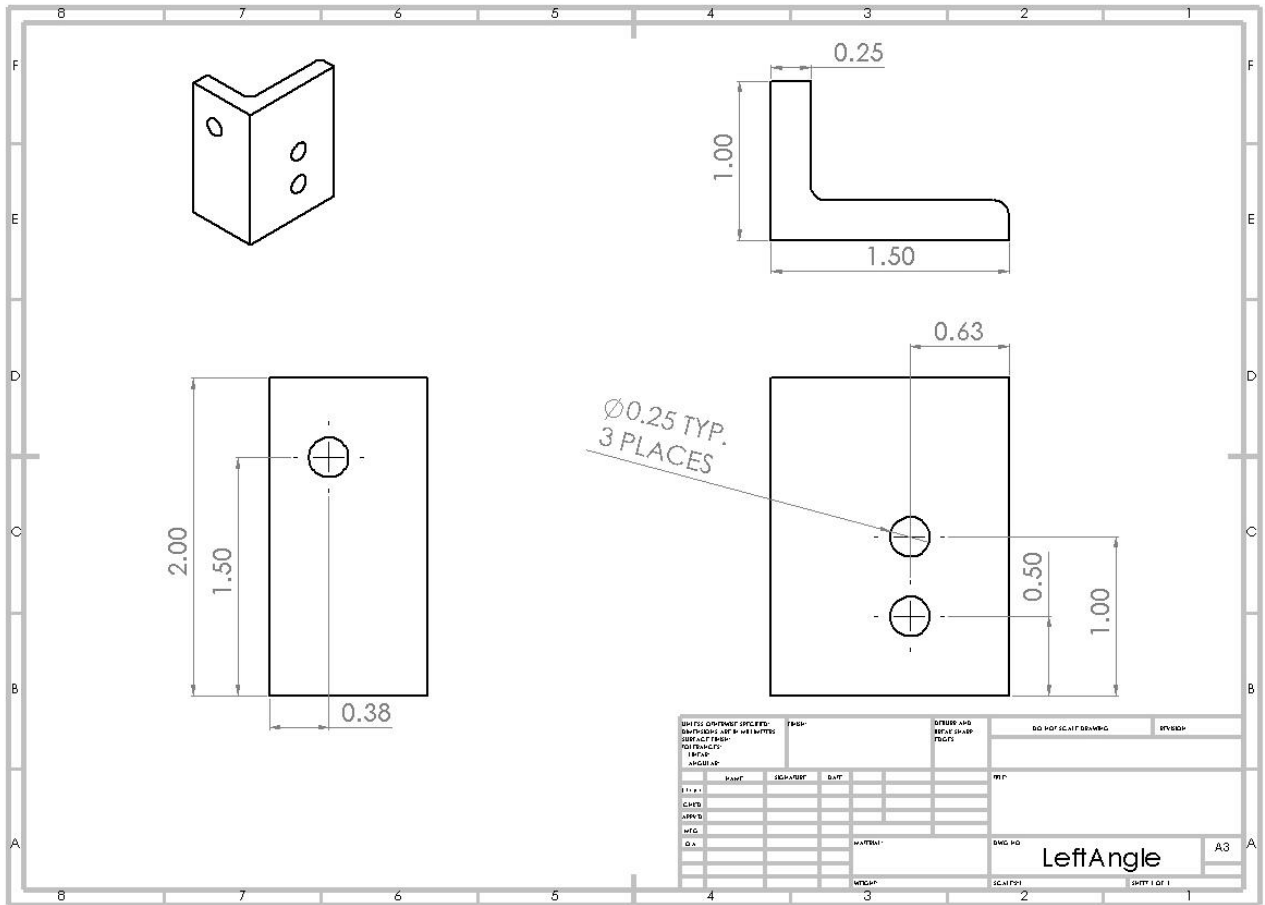
Figure 39: Part 5, Left Angle
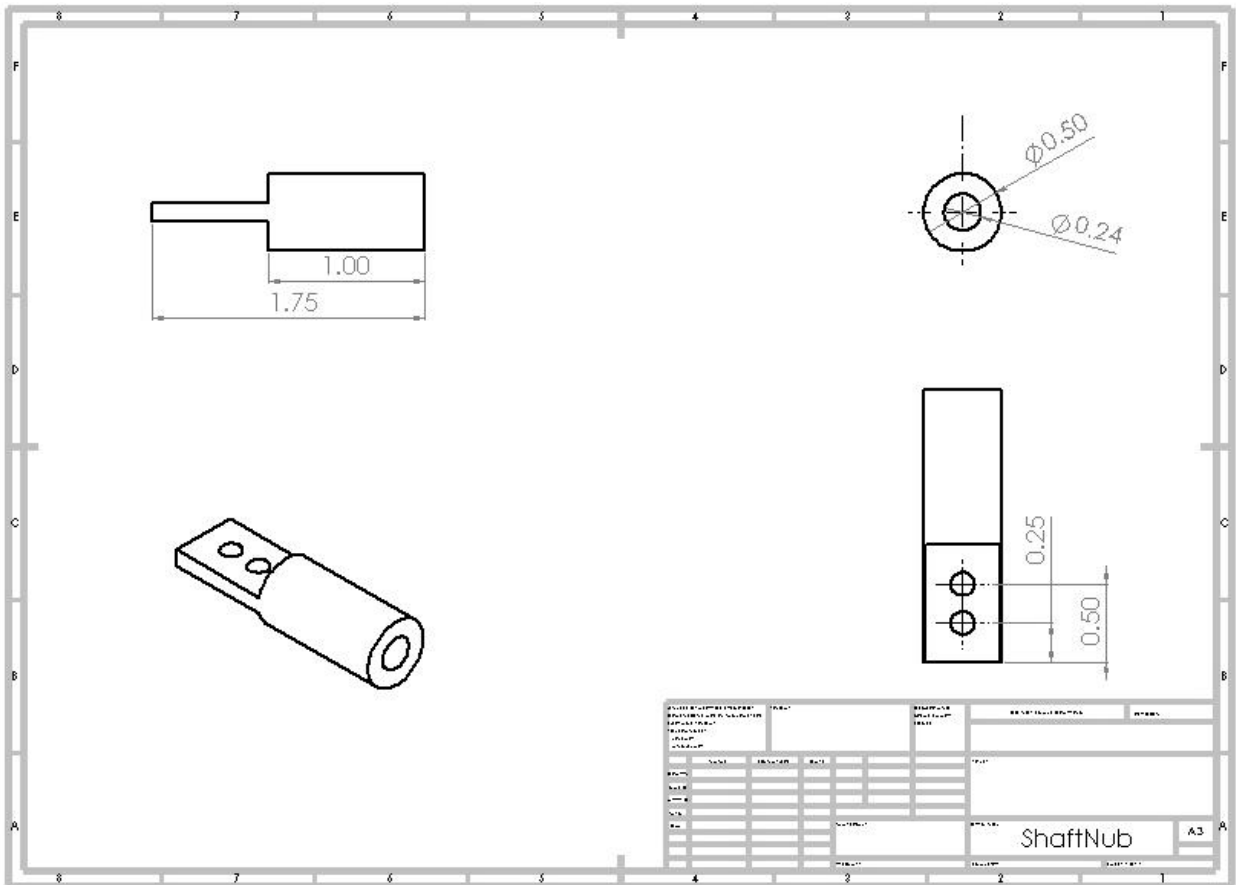
Figure 40: Part 6, Shaft Nub

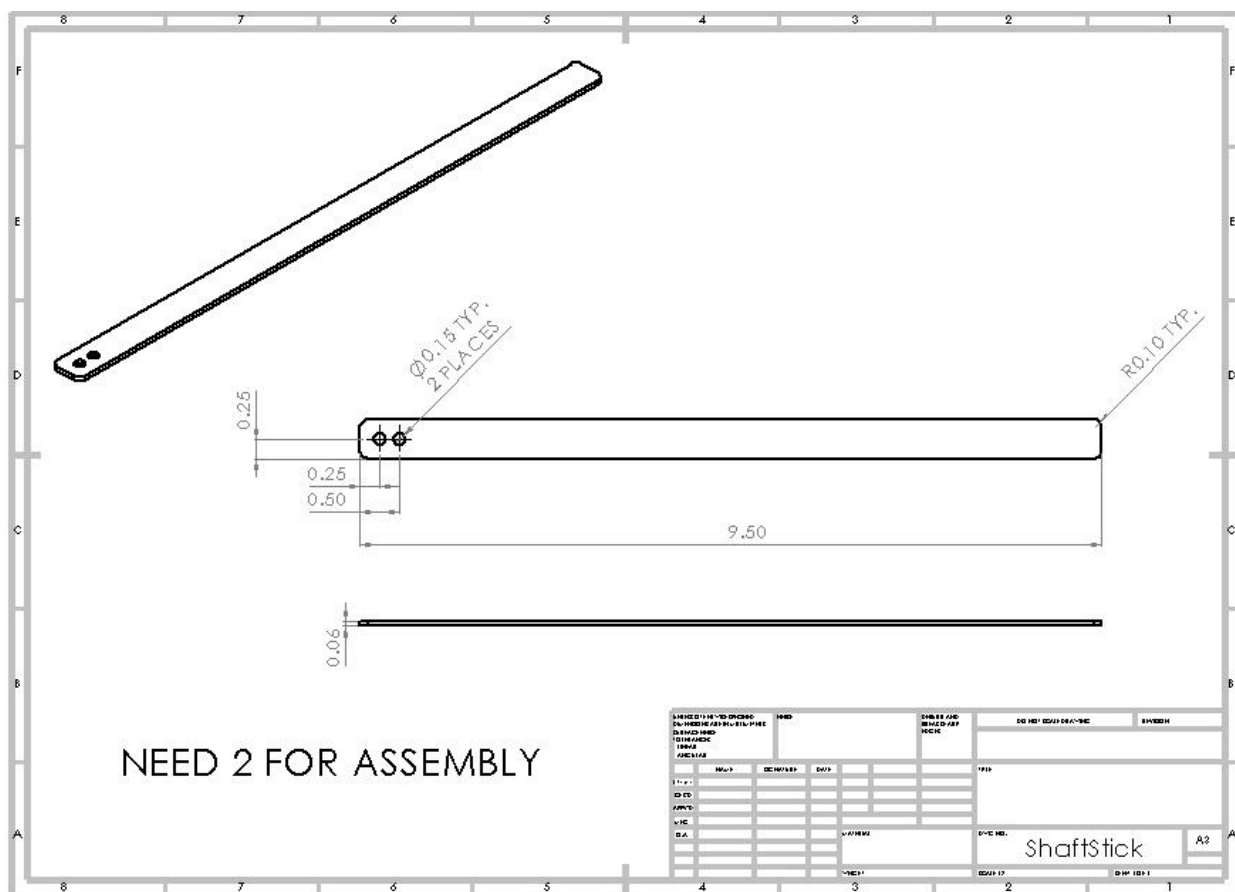NEED 2 FOR ASSEMBLY

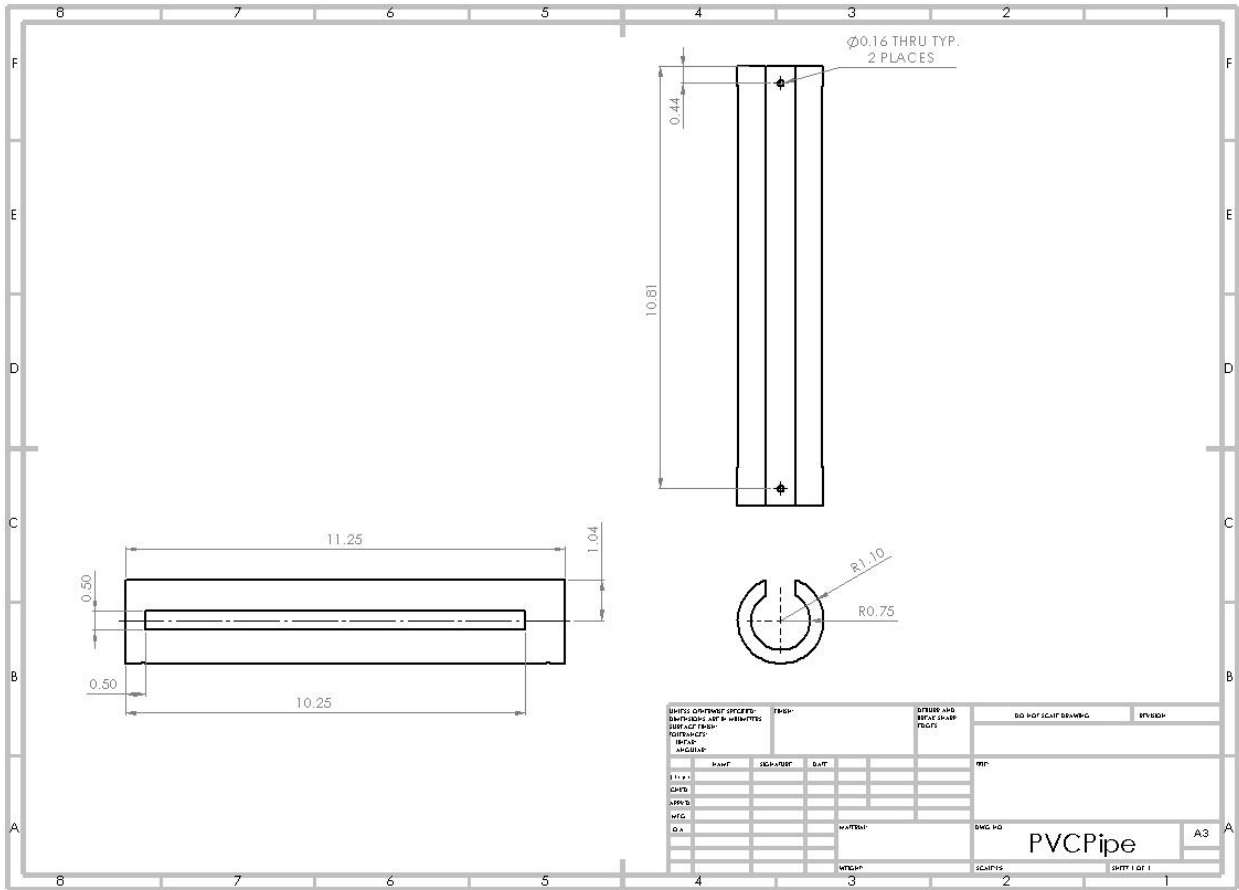Figure 41: Part 7, Shaft Stick, 2 Necessary

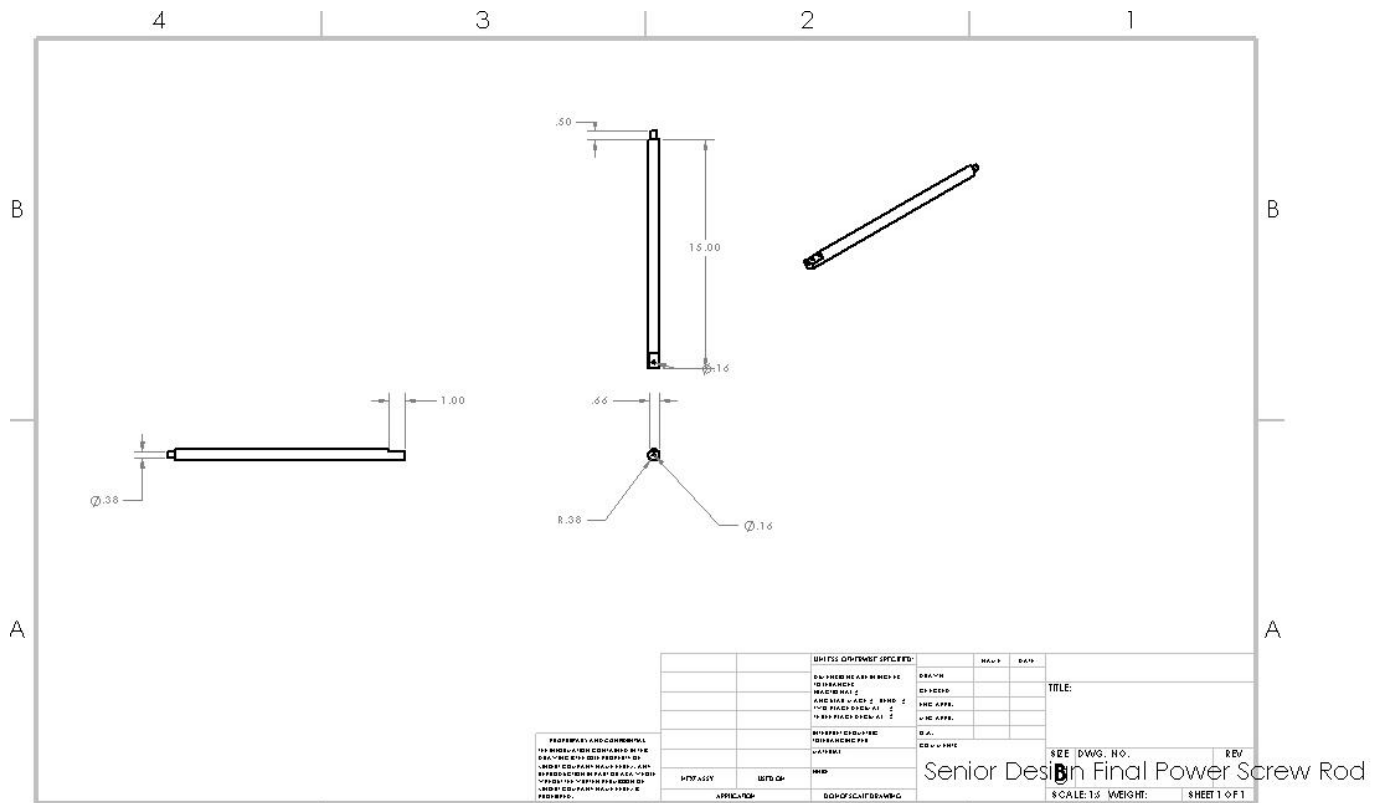Figure 42: Part 8, PVC Pipe

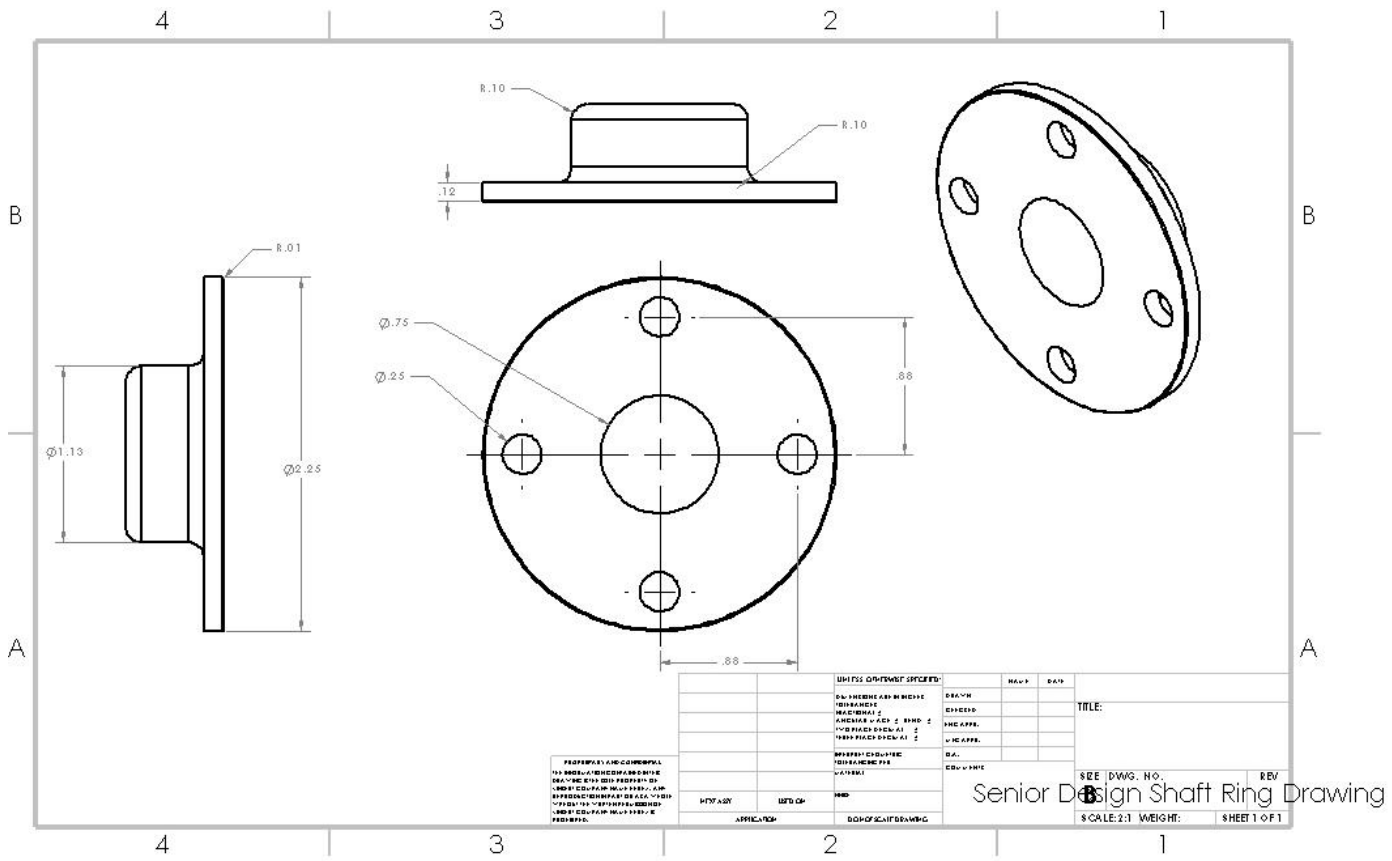**Figure 43: Part 9, Power Screw Rod**
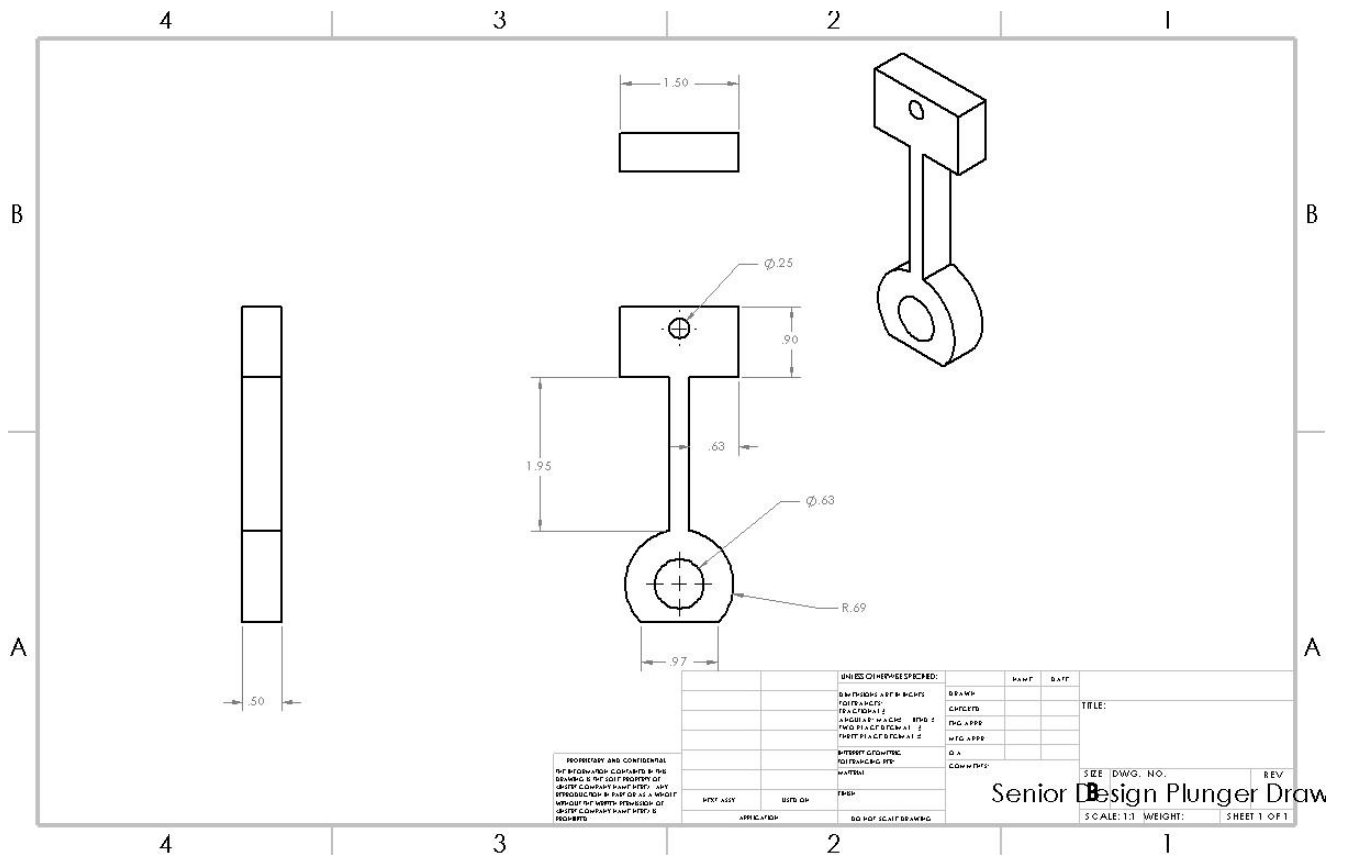
Figure 44: Part 10, Shaft Ring
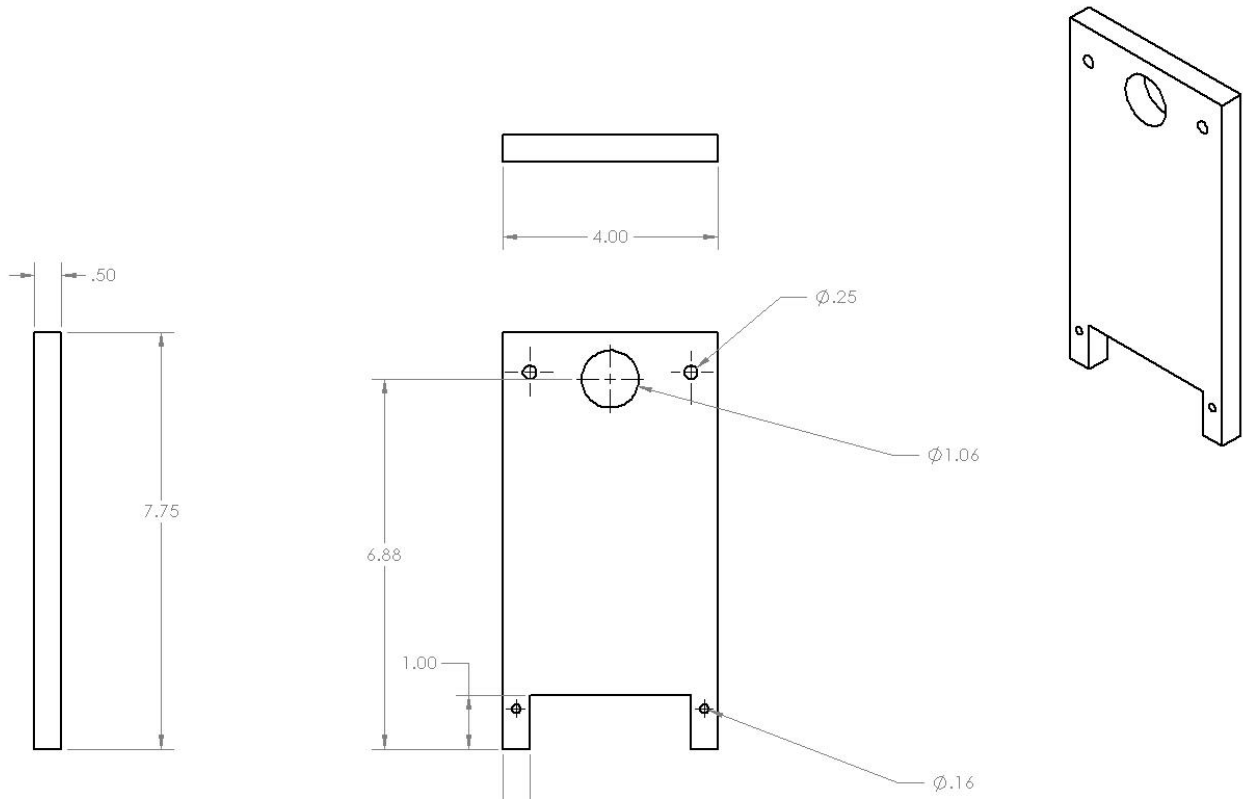
Figure 45: Part 11, Plunger

Figure 46: Part 12, Shaft Support
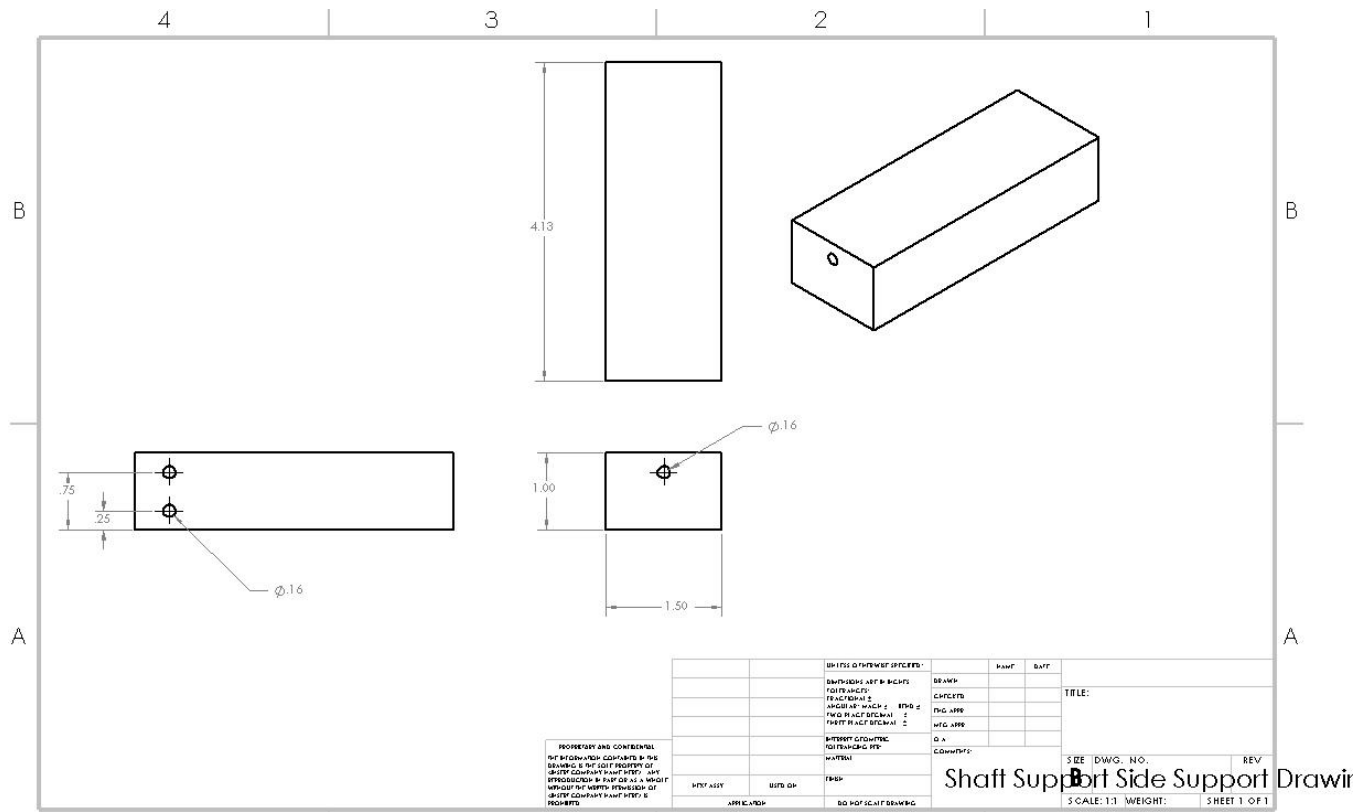
Figure 47: Part 14, Side Support

Figure 48: Part 15, Bridge Legs, 2 Necessary

Figure 49: Part 17, Bridge

Figure 50: Part 22, Wood Base

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	MotorMountSub	Motor Mount Sub-Assembly	2
2	MotorSideBracket	Motor Side Frame Bracket	1
3	Wheel	Launching Wheel	2
4	FloatingBearingMount	Movable Bearing Bracket	1
5	BearingSideMount	Bearing Side Frame Bracket	1
6	StockSpacer	Frame Width Spacers	2
7	90273A196	#8-32 Machine Screw	6
8	RidgidWheelBearing	Non-Floating Shaft Bearing	1
9	6389K623	Non-Floating Bearing	1
10	WheelShaft	Launching Wheel Shaft	2
11	Bearing	Floating Shaft Bearing	1
12	FrameMount	Base Frame Width Spacer	1
13	Frame Base^LaunchingAssy	Frame Base	1
14	#8-32 0.625" Socket Head Screw	Standard	12
15	#8-32 1.5" Pan Head Screw		9
16	#8-32 Hex Nut		6

Figure 51: Launching Assembly

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Motor	Brushless Quad Motor	1
2	91420A118	M3 Machine Screw	4
3	BackMotorPlate	Mounting Motor Plate	1
4	91780A307	1.5" Hex Standoff	3
5	FloatingShaftMount	Front Side Motor Mount	1
6	90273A196	#8-32 Machine Screw	3

				UNLESS OTHERWISE SPECIFIED:		NAME	DATE			
				DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL± ANGULAR: MACH± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN			TITLE:		
					CHECKED					
					ENG APPR.					
					MFG APPR.			Motor Mounting Sub-Assembly		
				INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.					
PROPRIETARY AND CONFIDENTIAL				MATERIAL	COMMENTS:					
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.		NEXT ASSY	USED ON	FINISH				SIZE	DWG. NO. MotorMountSub	REV
		APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:1 WEIGHT:	SHEET 1 OF 1	

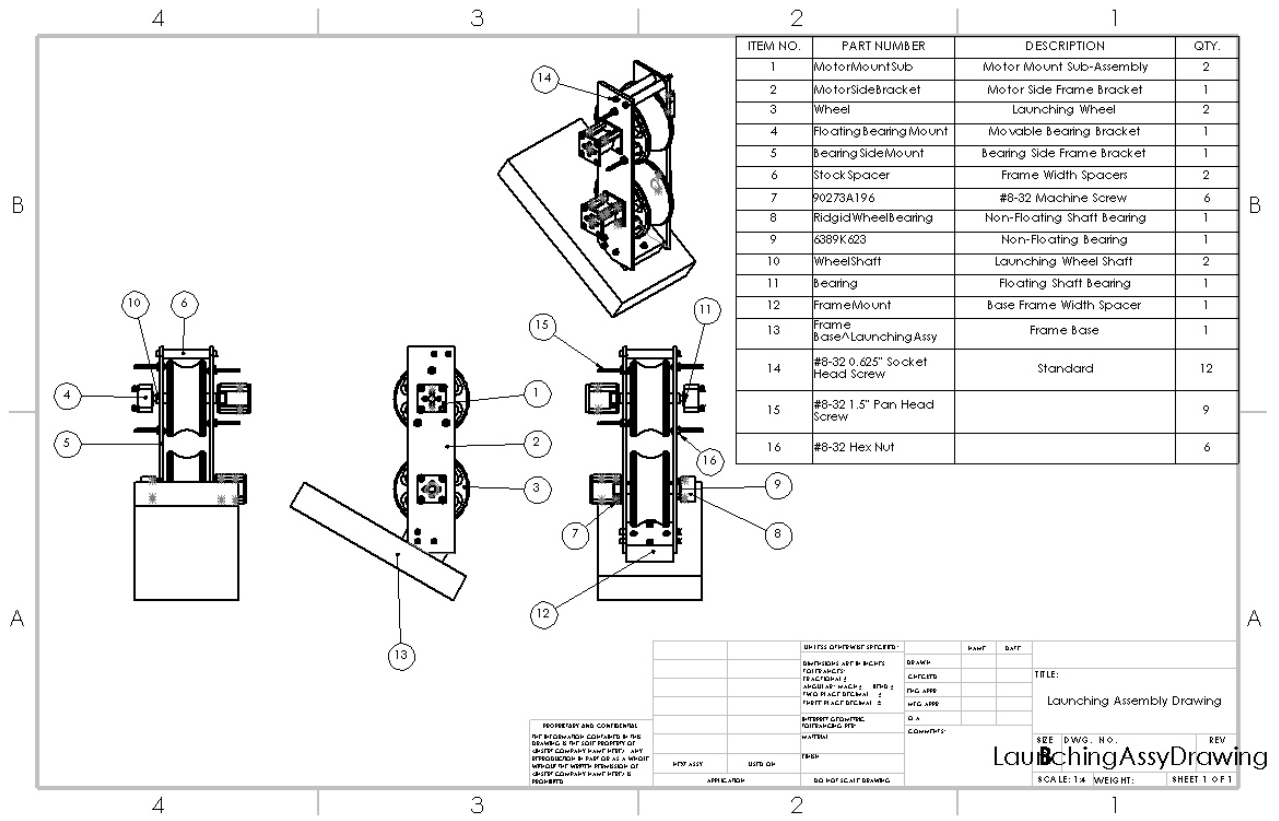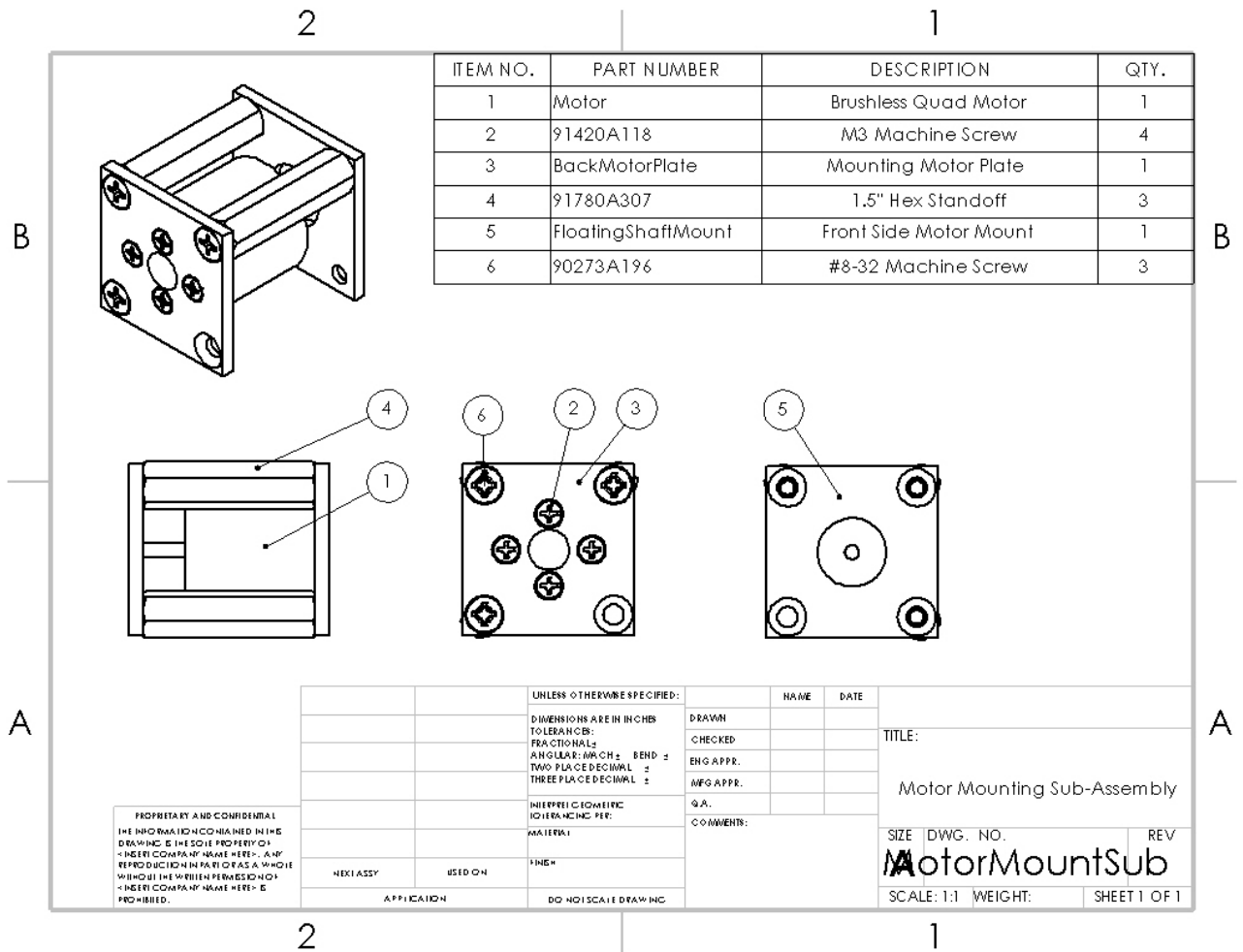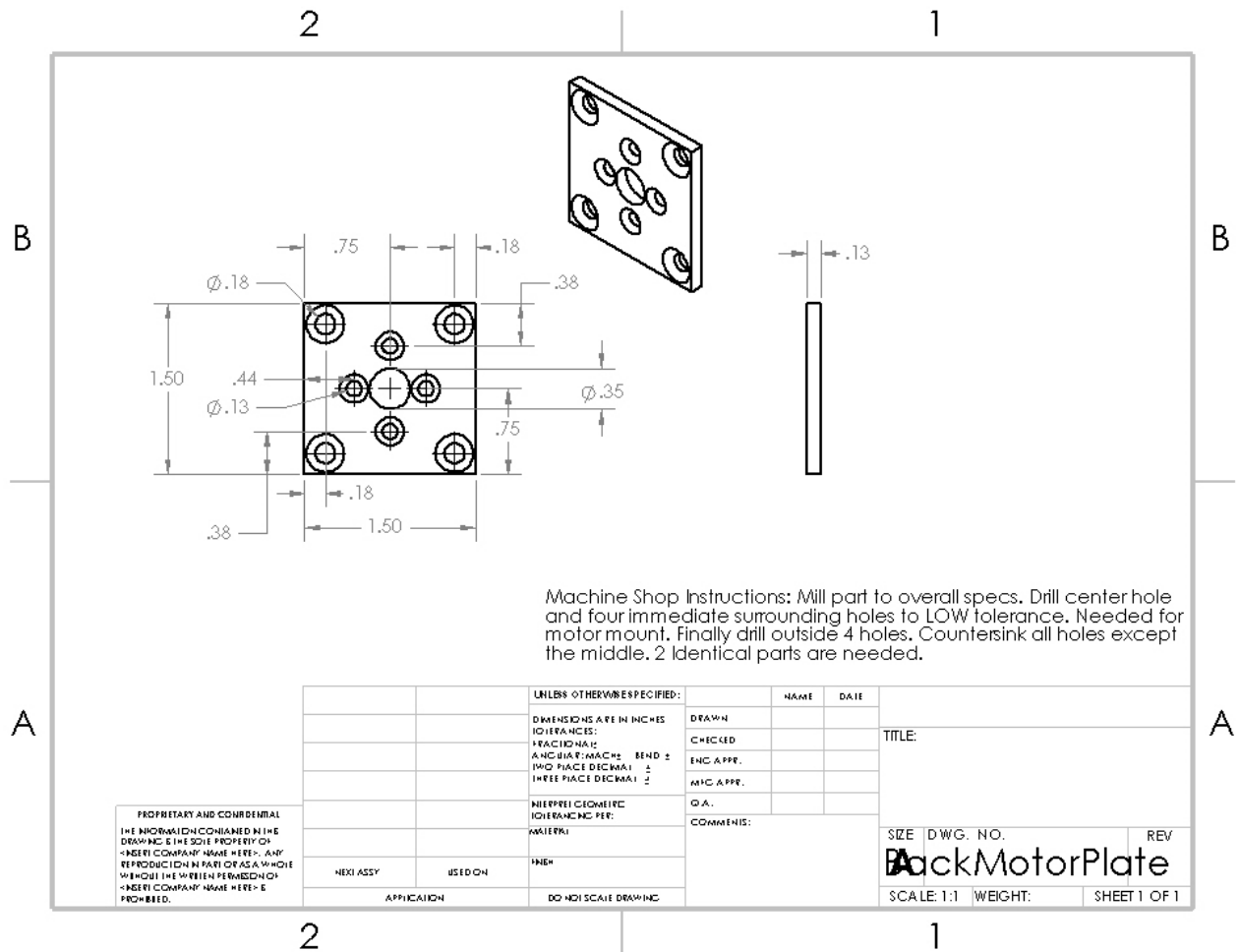**Figure 52: Motor Mount Sub-Assembly**

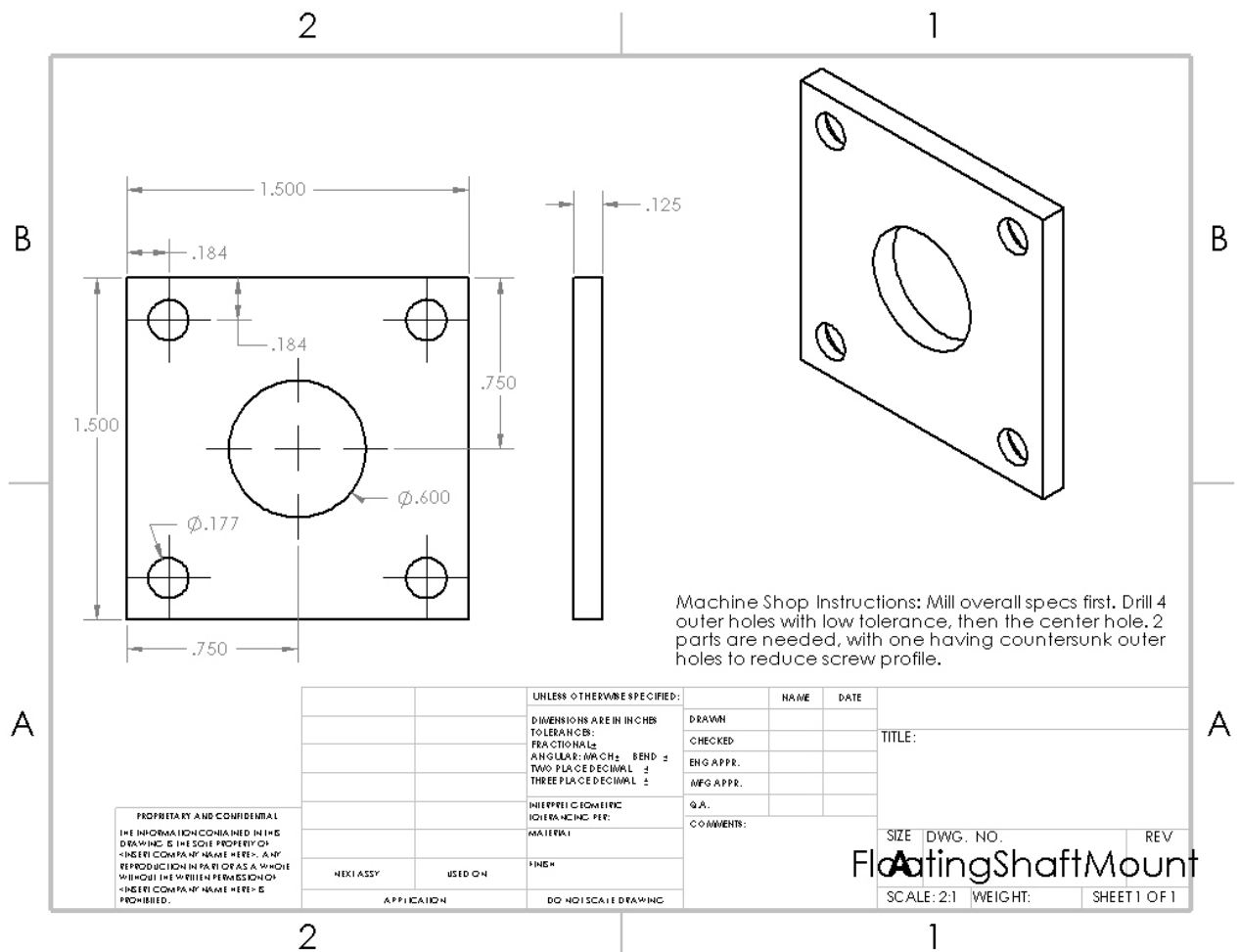**Figure 53: Motor Mount Sub-Assembly Part 3, Back Motor Plate**

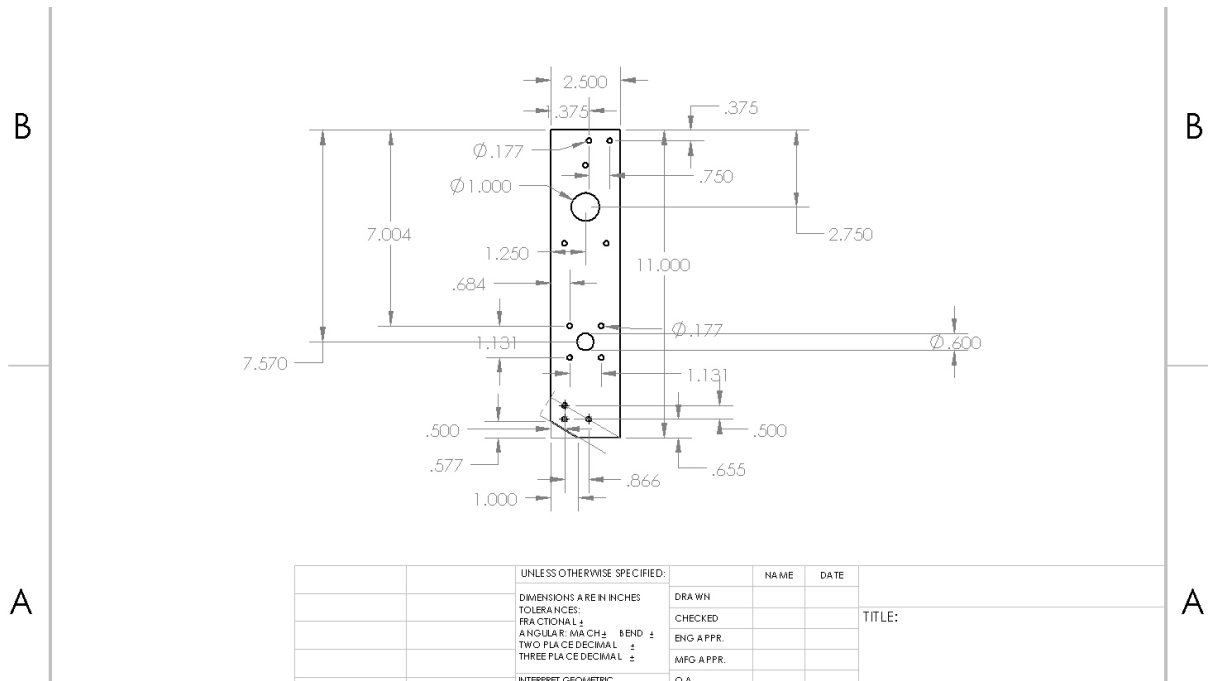**Figure 54: Motor Mount Sub-Assembly Part 5, Floating Shaft Mount**
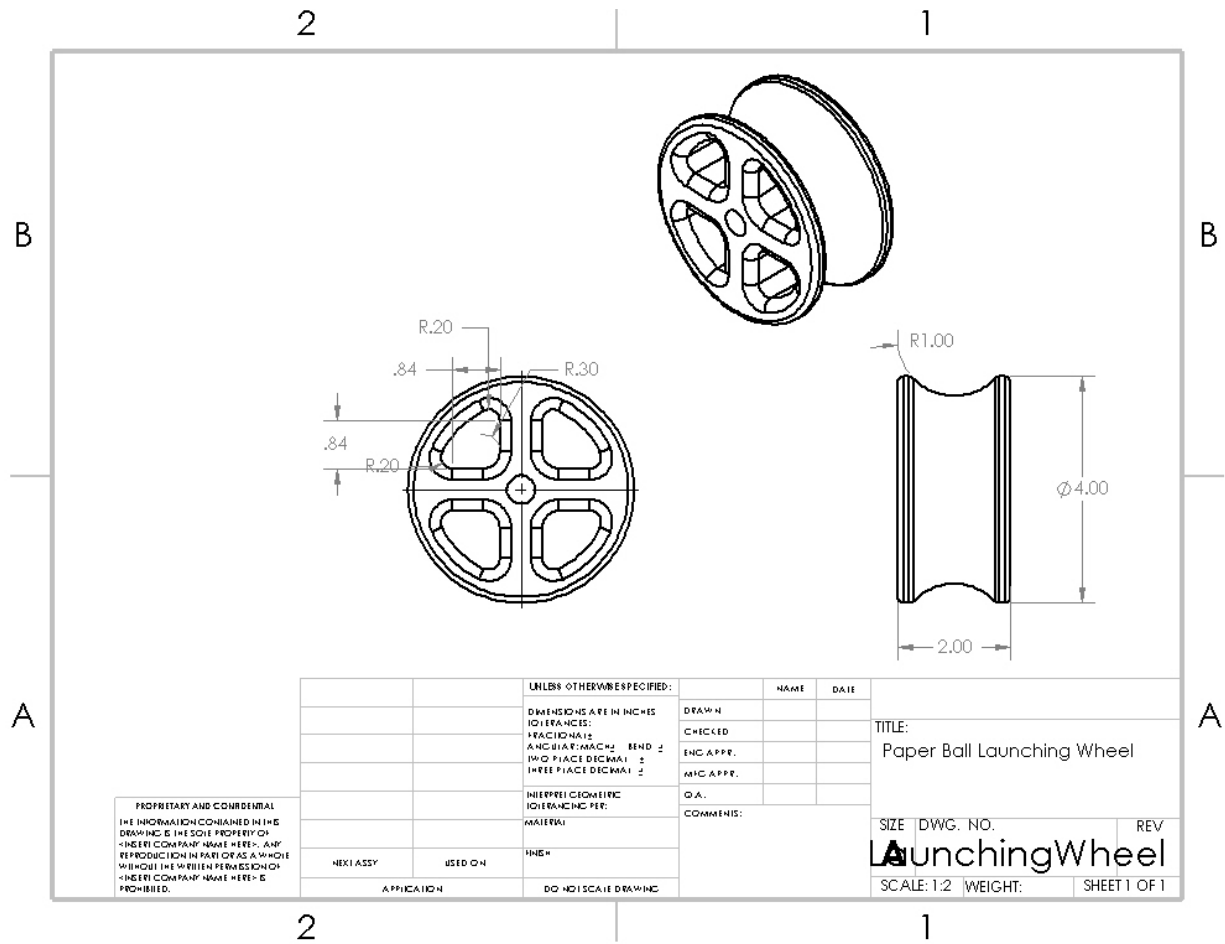
Figure 55: Launching Assembly Part 2, Motor Side Bracket

Figure 56: Launching Assembly Part 3, Launching Wheel, 2 Necessary

Machine shop instructions: Find aluminum block and mill down sides to meet specs. Drill the .61" hole, then the two tap holes. Tap these holes.

.75

.18   .18

.50

#8-32 Tapped Hole

R.20

Ø.61

1.00

1.40

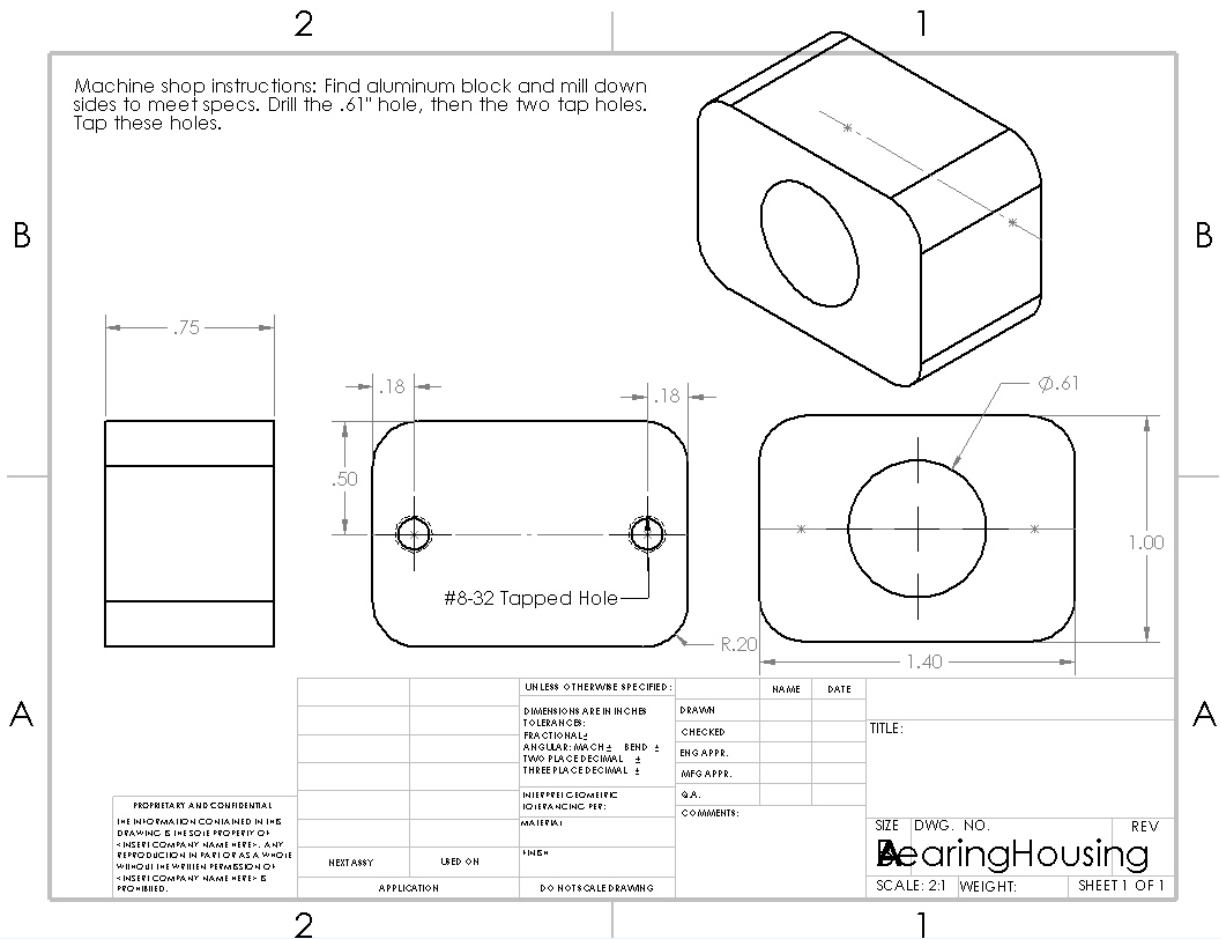|		UNLESS OTHERWISE SPECIFIED:		NAME	DATE		
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			CHECKED				
			ENG APPR.				
			MFG APPR.				
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.				
			COMMENTS:				
PROPRIETARY AND CONFIDENTIAL THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.		MATERIAL			SIZE	DWG. NO.	REV
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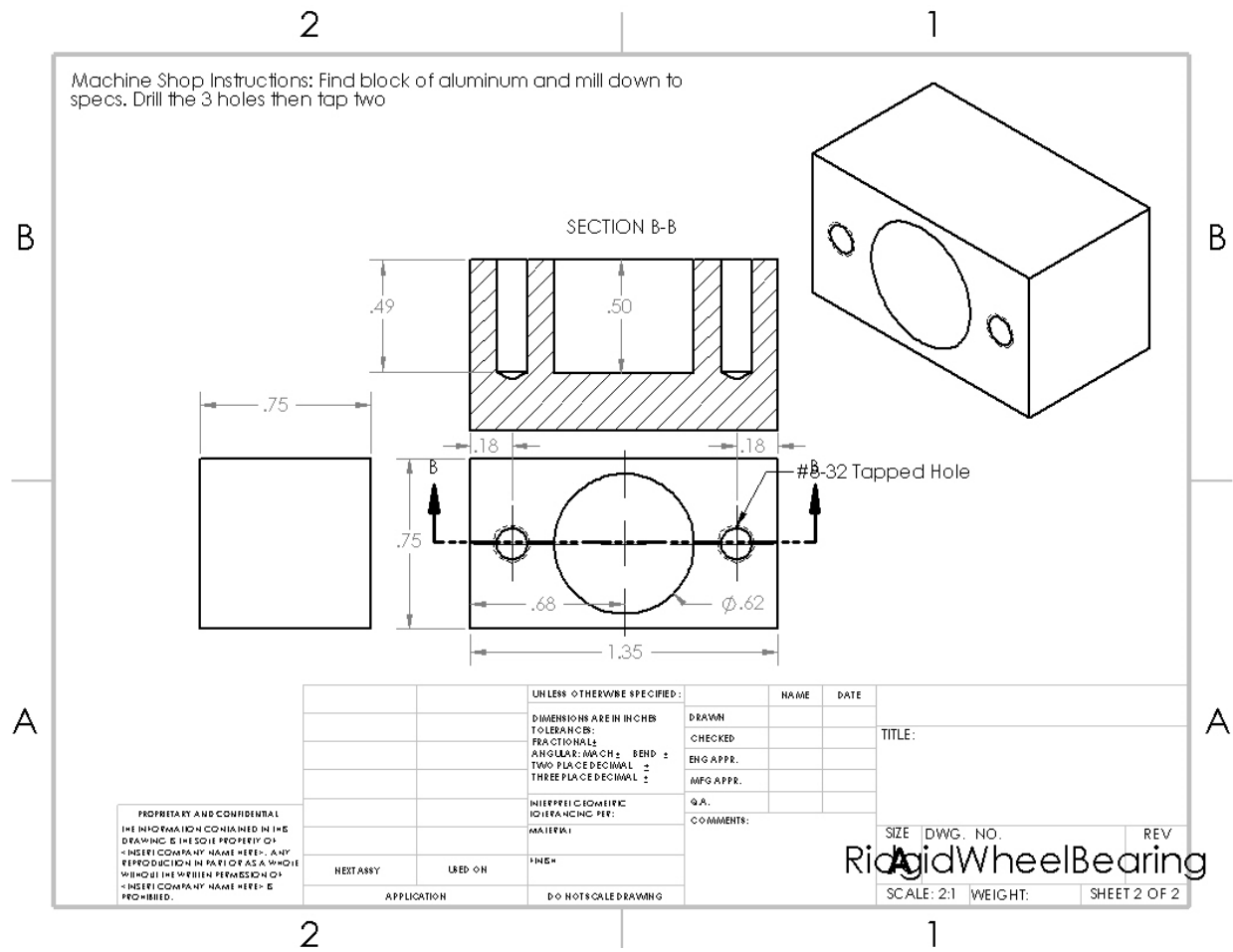**Figure 57: Launching Assembly Part 4, Floating Bearing Housing**

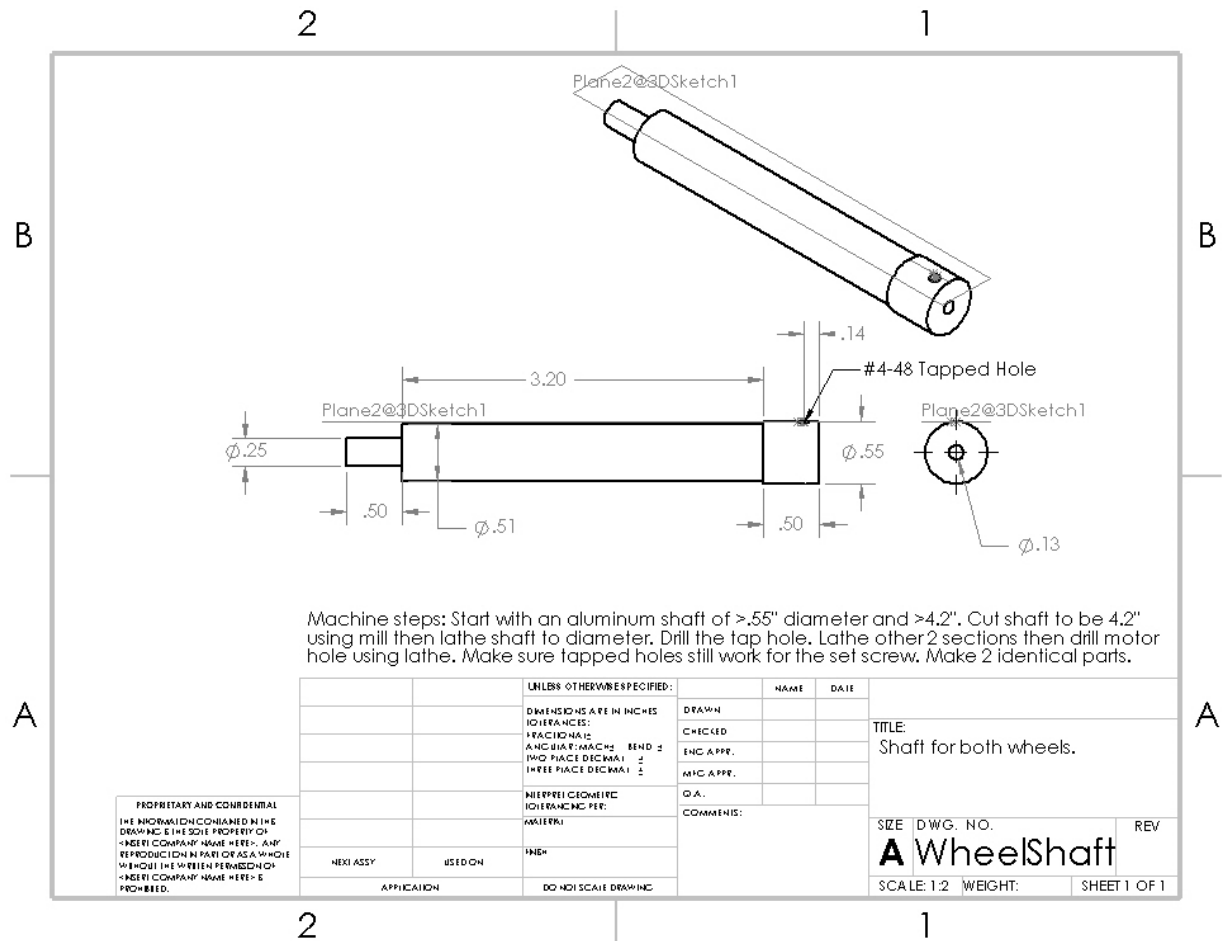**Figure 58: Launching Assembly Part 5, Rigid Wheel Bearing Side Mount**

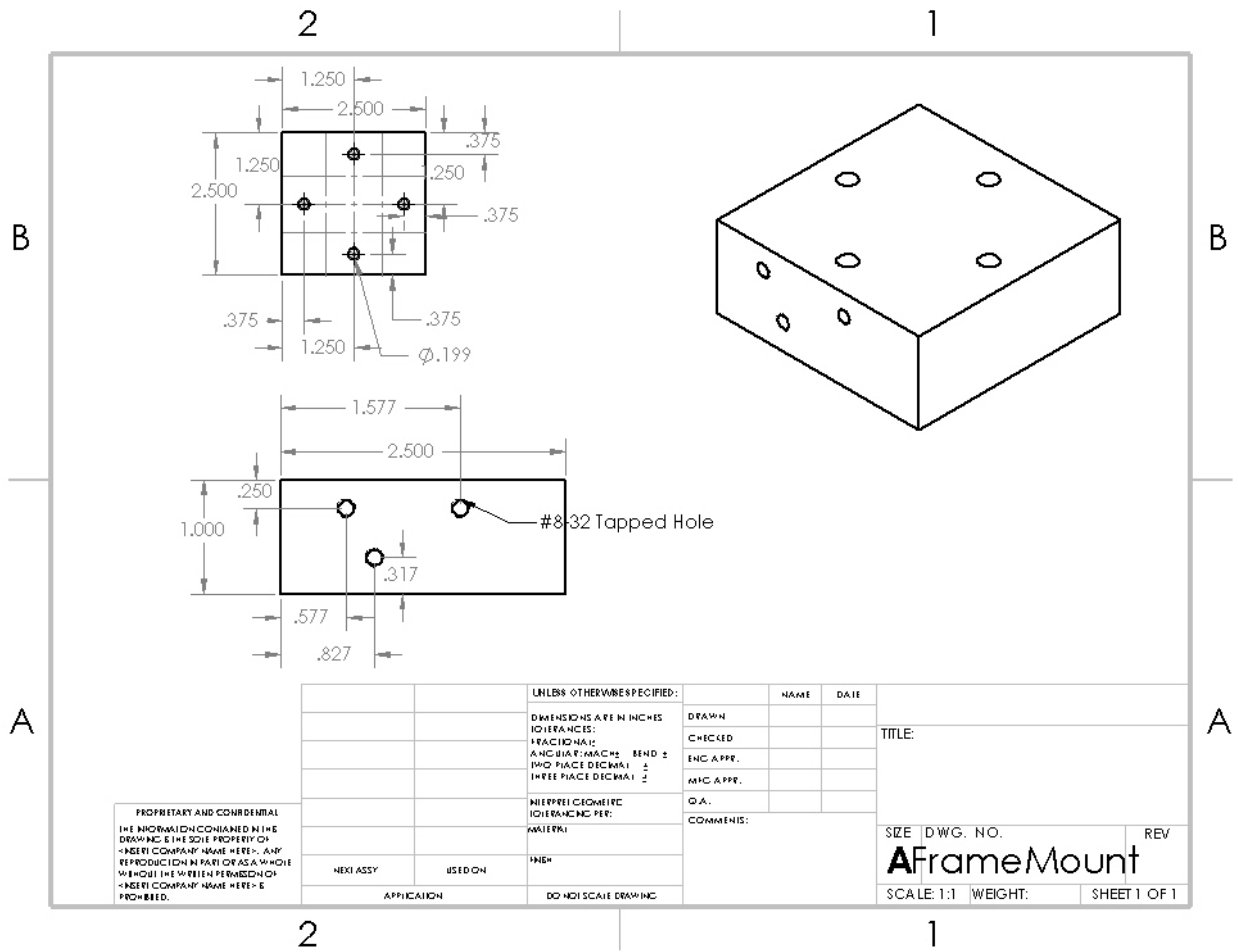**Figure 59: Launching Assembly Part 10, Wheel Shaft**

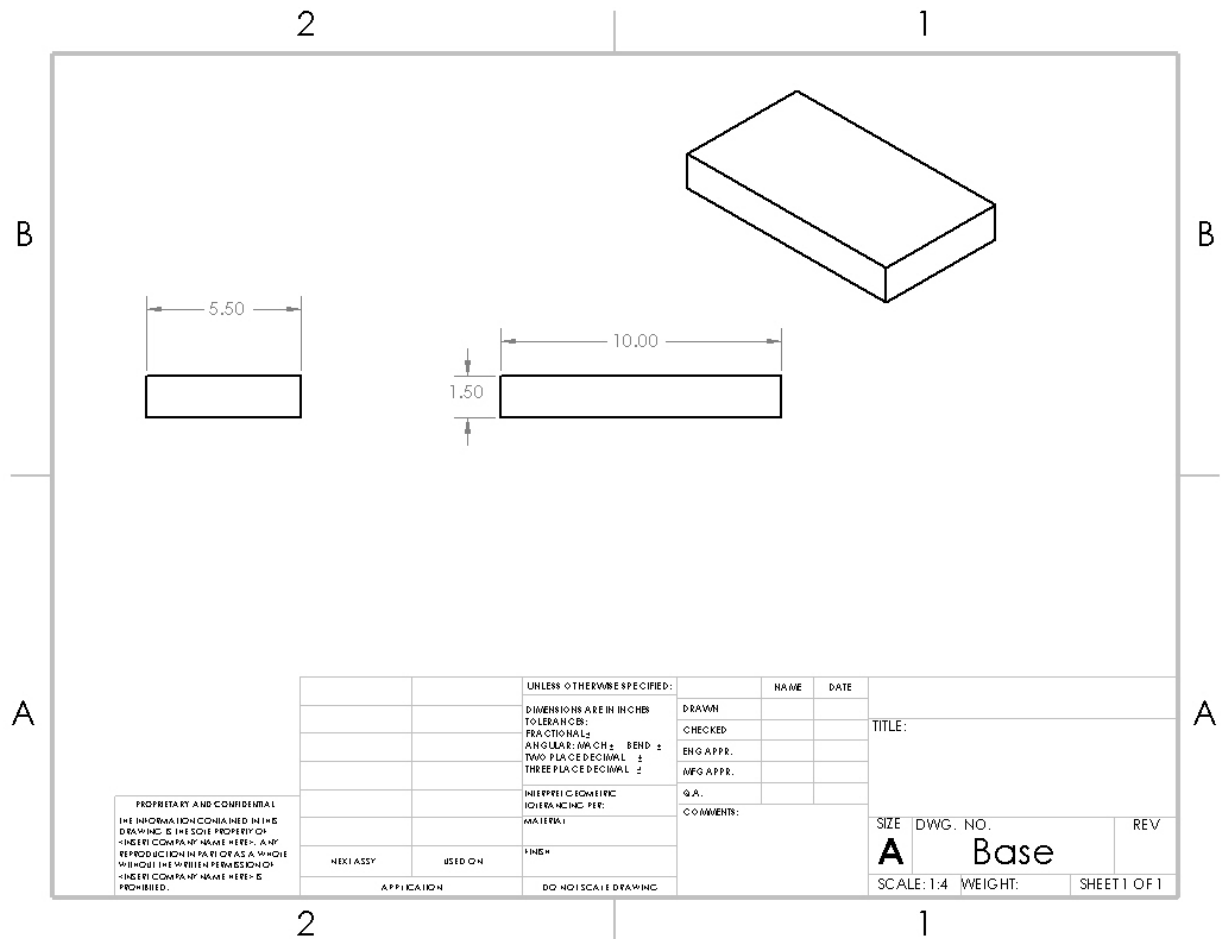**Figure 60: Launching Assembly Part 12, Frame Mount**

Figure 61: Launching Assembly Part 13, Frame Base
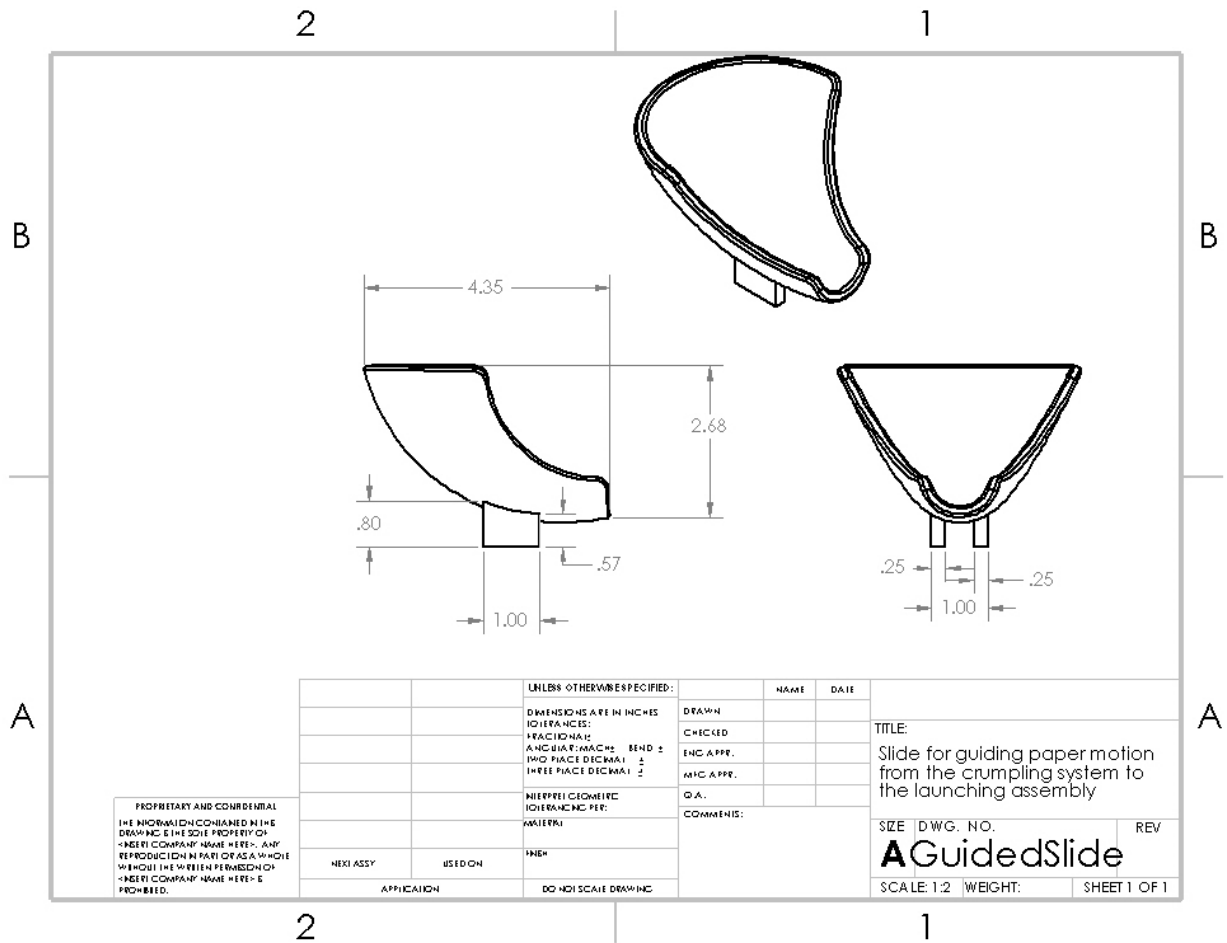
Figure 62: Guided Slide

12 Annotated Bibliography (limited to 150 words per entry)

Neuman, Daniel R. Pitching Machine. Neuman Daniel R, assignee. Patent US 7806788 B1. 6 June 2008. Print.

- Pitching machine patent. Used for design inspiration for the launching mechanism for this device
- http://www.google.com/patents/US7806788