Fall 2023

MEMS 411: Swing Energy Demo

Joshua Yoon
Washington University in St. Louis

Owen Culver
Washington University in St. Louis

Angel Wan
Washington University in St. Louis

Gabriel Myong
Washington University in St. Louis

Washington University in St. Louis

James McKelvey School of Engineering

Mechanical Engineering Design Project
MEMS 411, Fall 2023

Swing Energy Demo

This report is an in-depth description of the engineering design process undergone for the creation of a Swing Energy Demo device. The goal of the device is to demonstrate the physics concepts behind what makes a swing go higher, without someone pushing it, to children. The intended customer of our device is the St. Louis Science Center, or other similar science museums that have a target audience of school children around the age of eight to twelve.

The Swing Energy Demo device is operated by a foot pedal that the user can step on which is connected to a string that pulls a mass up and down. The mass is on the end of a rod, swinging back and forth in a pendulum motion. If the user can properly time when to raise and lower the mass with the foot pedal, the mass will swing higher and higher. The end goal for the user is to have the mass swing a full 360 degrees.

In summary, our project isn't just about building a device; it's about creating an educational experience that is both engaging and informative. We believe that by merging interactive design with fundamental physics concepts, we can inspire the next generation of scientists and engineers.

YOON, Joshua
WAN, Angel
CULVER, Owen
MYONG, Gabriel

Contents

List of Figures

List of Tables

1 Introduction

Swings, a commonly found interactive structure on children's playgrounds, utilizes the work input of its user to sway back and forth across a fixed axis. By pumping their legs, the user transfers the chemical energy of their body to shift their center of mass upwards at the peak of the swinging arc. This effectively adds potential energy to the swing, which translates into the kinetic energy of the swing system during the descent, allowing the user to swing to an increased height. This concept will be employed on a miniaturized scale for a demonstration exhibit at a science museum, where users can interact with the swing by mechanically adding energy to increase the swing height. Energy will be added through an external trigger held by the users that will shift the center of mass of the system, rather than pumping the swing themselves.

2 Problem Understanding

2.1 Existing Devices

Aside from actual swings, the span of existing devices that closely models their specific work-energy mechanisms and relations are minimal. However, numerous devices exist that demonstrate the transfer of energy from one source to another to achieve a specific goal.

2.1.1 Existing Device #1: Rock 'Em Sock 'Em

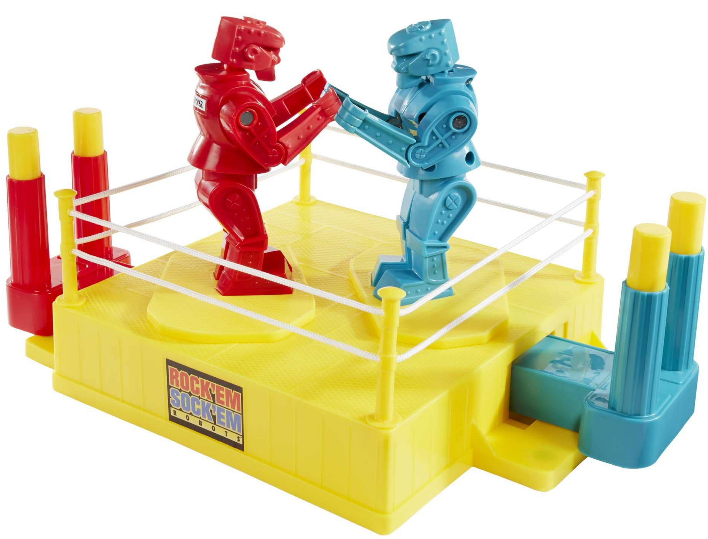


Figure 1: Rock 'Em Sock 'Em Toy (Source: Amazon)

Link: https://www.amazon.com/Rock-Em-Sock-Robots-Control/dp/B00LJ2WF6A

Description: Rock 'Em Sock 'Em is a popular toy where users control a figure with the aim of punching the opponent's figure. The user inputs work into the system by pressing down a button. This work is then transferred into the extension of the figure's arms, effectively causing it to punch.

2.1.2 Existing Device #2: Pendulum Clock

Figure 2: A Pendulum Clock (Source: Amazon)

Link: https://www.amazon.com/Pendulum-Wall-Clock-Grandfather-Wooden/dp/B074CKQ6C8
Description: Similar to a swing, the pendulum exhibits oscillatory motion across a fixed pivot. Rather than increasing the oscillation height, however, pendulum clocks maintain the same oscillation period, which keeps the clock's timing accurate. Work is added to the pendulum to maintain oscillatory motion via mechanical gearing systems that transfer stored potential energy, or chemical energy in some modernized versions.

2.1.3 Existing Device #3: Bicycle Breaks

Figure 3: Bicycle break being used(Source: Enduro)

Link: https://enduro-mtb.com/en/how-to-set-up-your-brake-levers-perfectly/
Description: The user does work to squeeze the break's handle, which is a lever. This motion pulls a piece of metal wire rope connected to the break disks, squeezing them and activating breaking. The work added to pulling the wire rope is transferred to the squeezing motion of the breaks, and the user can squeeze the break handles tighter to pull the wire rope tighter, which in turn squeezes the breaks harder as well.

2.2 Patents

2.2.1 Pendulum Box for Clock (US7229209B2)

This patent consists of a simple pendulum, except that a portion of the oscillating pendulum rod is secured within a smaller space referred to as the "pendulum mover" to prevent motion outside of a singular plane, thus allowing the pendulum to retain a more consistent motion and to be used within a clock, which is an object with a sole purpose of being consistent and keeping the time. Maintaining this level of accuracy and consistency in our project would allow for a more effective demonstration of the physical concept of a simple pendulum.

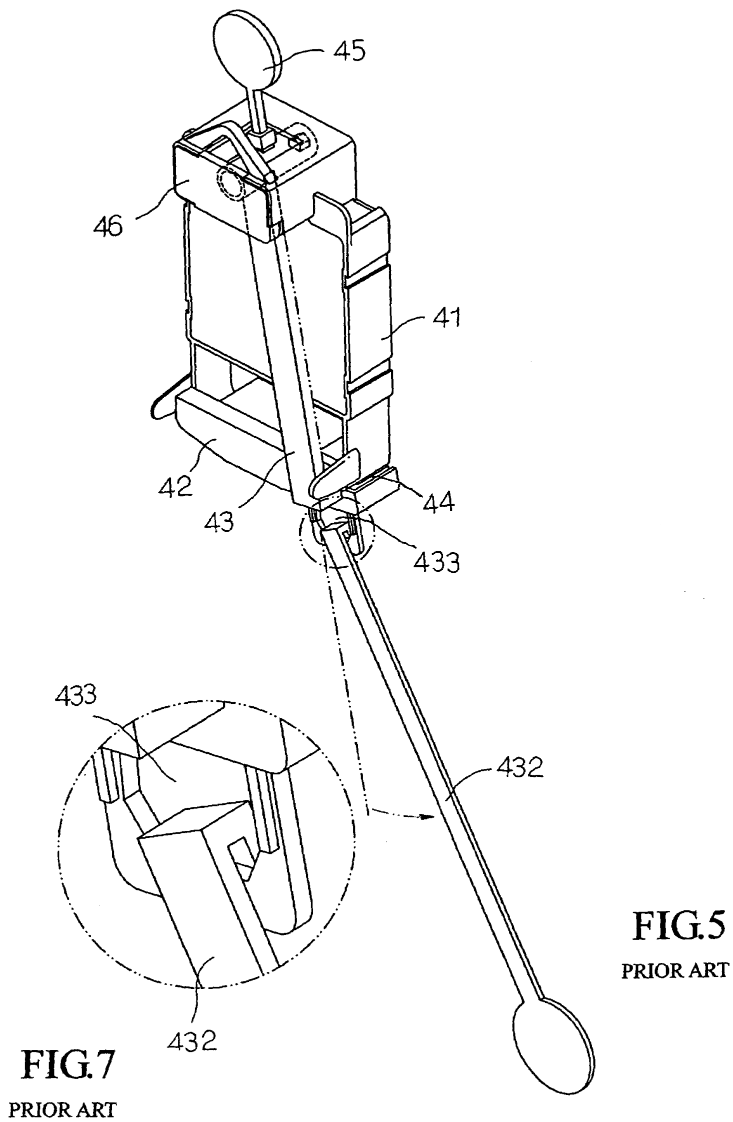


Figure 4: Patent Image for Pendulum Box for Clock

2.2.2 Torsion Pendulum (US1904169A)

This patent is a certain type of pendulum that, similar to the previous patent mentioned above, also addresses the issue of the pendulum swinging out of its original plane or at irregular and inconsistent speeds due to even the slightest touch or shock. The solution in this invention is to rigidly attach the oscillating rod to a device called a "flywheel" which is a wheel that creates the pendulum swinging motion. In this sense, the amplitude of the swinging motion is equivalent to that of the flywheel, ensuring a sort of rigid oscillation that cannot be impacted by the slightest touch or shock, but rather consistently swings on the same plane or path as intended. Though it is the same idea as the patent previously mentioned, it proposes a different method of ensuring a consistent swing path.

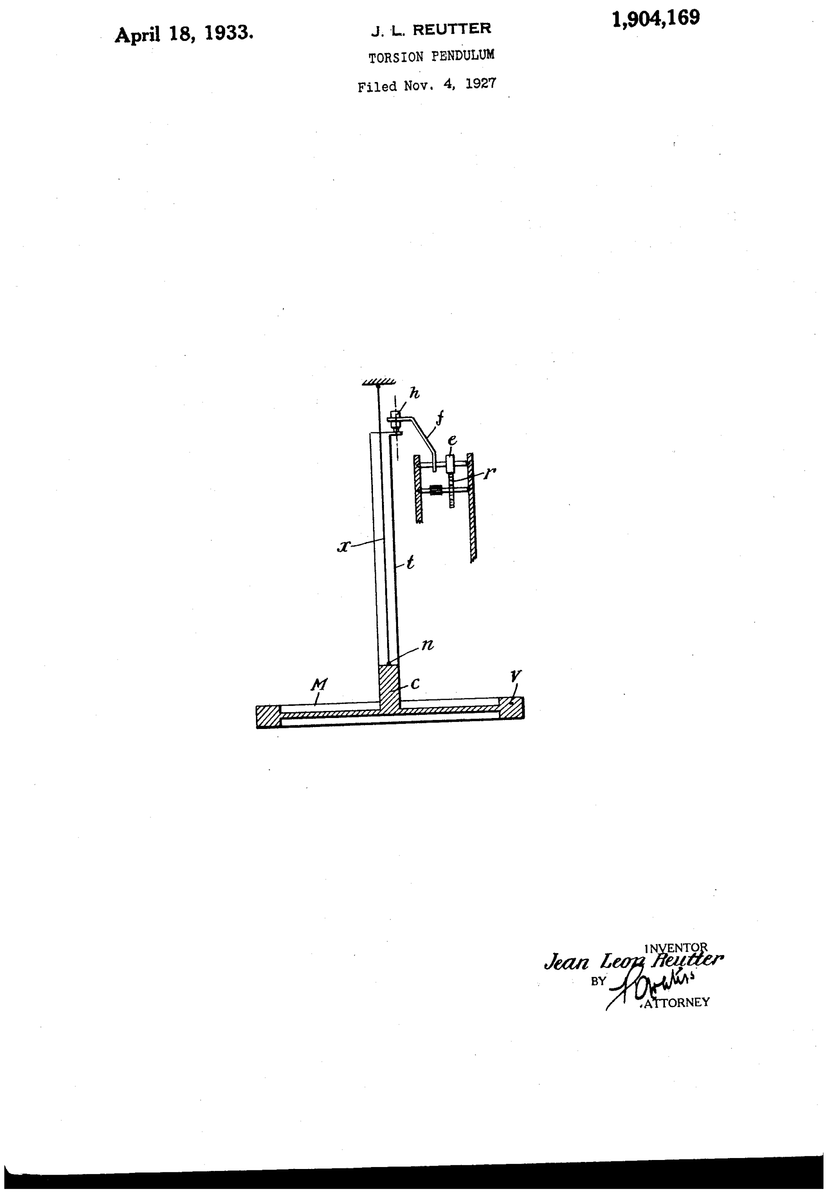


Figure 5: Patent Image for Torsion Pendulum

2.3 Codes & Standards

2.3.1 Safety Requirements for Hydraulic Systems (ISO 4414 Section 6)

This standard covers general safety guidelines and requirements for hydraulic fluid power systems. It discusses all significant hazards that could arise in these systems, and illustrates specific steps to avoid encounters with these hazards. This standard is applicable to our project because the mass attached to the end of the swing rod will be powered by a handheld hydraulic pump which moves the mass vertically upward and downward to create the swinging motion.

2.3.2 Home Playground Equipment Safety Standard (F1148-22)

This standard covers specific safety standards for home playground equipment, including weight limits and tolerances required to meet these standards. Home playground equipment is mostly targeted toward children, which implies that the safety requirements are probably stricter with a higher factor of safety than other systems. Not only will our system be more precise should we follow this particular standard, but the safety of the user will be further emphasized.

2.4 User Needs

The museum needs a miniaturized model of a playground swing set that demonstrates the physics concepts that cause a swing to go higher. The main concept that is being demonstrated here is that the timing that the energy is introduced to the system affects whether the energy is adding or taking away from the total energy of the system. In other words, the user needs to clearly see that when they add energy through the external trigger, that this energy is either making the swing go higher or slowing it down based on the timing of the trigger interaction.

2.4.1 Customer Interview

Interviewee: Dr. James Jackson Potter
Location: Jolley 110, Washington University in St. Louis, Danforth Campus
Date: September 8^{th}, 2023
Setting: We showed a mock-up drawing of the swing set up to the customer, gave him a box similar in size to the intended size of the model, and had him imagine using it. We ran through some potential ideas of how the energy will be introduced to the system along with ideas for the trigger that controls this introduction of energy. The whole interview was conducted in the lab room and took ∼35 min.

Interview Notes:
What is the ideal size for the entire model?

- Intend for it to take up a good portion of a lab table, and the trigger to be low enough a kid can operate it.

How much would you like for the model to weigh?

- ∼15 lb.

Do you want the rods connecting the structure and where the person swinging sits to be fixed or free to move (like a chain link swing)?

- Fixed.

How do you want the user to be able to operate the trigger that introduces the energy to the system?

- Some sort of hand force operating system.

Does the model have to be weather resistant?

- No, but we would like it to be rugged since kids are going to be operating it and we don't want them to be able to break it.

Do you want the amount of energy that is introduced to be adjustable? Something where it is dependent on how much force the user introduces?

- Yes. For example, If you used a weight moving up and down to introduce the energy to the system, we want the height the weight moves to be dependent on the amount of force introduced by the user.

How do you envision safety precautions being introduced?

- A plexiglass shield that surrounds the model to prevent the weight from flying out if it somehow comes off the swing.

2.4.2 Interpreted User Needs

In this section, the user needs are listed and given a numerical value representing its importance to the customer. In this table 1 is the least important and 5 is the most important.

Table 1: Interpreted Customer Needs

Need Number	Need	Importance
1	The swing model stays together while in different positions	5
2	The swing model is safe for children	5
3	The swing model allows for the introduction of energy to the system every time the user operates the trigger	5
4	The swing model allows for the amount of energy introduced that is dependent on the force applied to the trigger by the user	5
5	The swing model trigger is easy to operate	5
6	The swing model allows a full 360-degree rotation of the swing so it can go all the way around the axle	4
7	The swing model motion is appealing	4
8	The swing model is under 15 lb.	3
9	The swing model is robust to use and does not break easily	3
10	The swing model is easy to transport	3
11	The swing model is inexpensive	1
12	The swing model is robust to weather conditions	1

2.5 Design Metrics

In this section the design metrics are listed with the target specifications. These target specifications are based on the user needs and information given in the interview.

Table 2: Target Specifications

Metric Number	Associated Needs	Metric	Units	Acceptable	Ideal
1	8,10	Total weight	lb	15	10
2	1	Total volume	ft^3	< 12	< 10
3	2	Rating of "entertainment" by class focus group	avg. score	$> 3/5$	$> 4/5$
4	1,7,9,12	Maximum part movement when shaken firmly by hand	mm	< 10	< 2
5	6	Degrees of rotation of the swing about the axle	degrees	> 300	360
6	2	Sharp edge test in 16 CFR 1500.49 Code of Federal Regulations (CFR) Consumer Product Safety Commission	binary	Pass	Pass
7	3,4,7	Height removed/added to the max height of the swing by user trigger operation	in	0-2	0-3
8	5	Force required by the user on the trigger to achieve the max height added per swing	lb	$\sim$15	$\sim$12

2.6 Project Management

The Gantt chart in Figure ?? gives an overview of the project schedule.

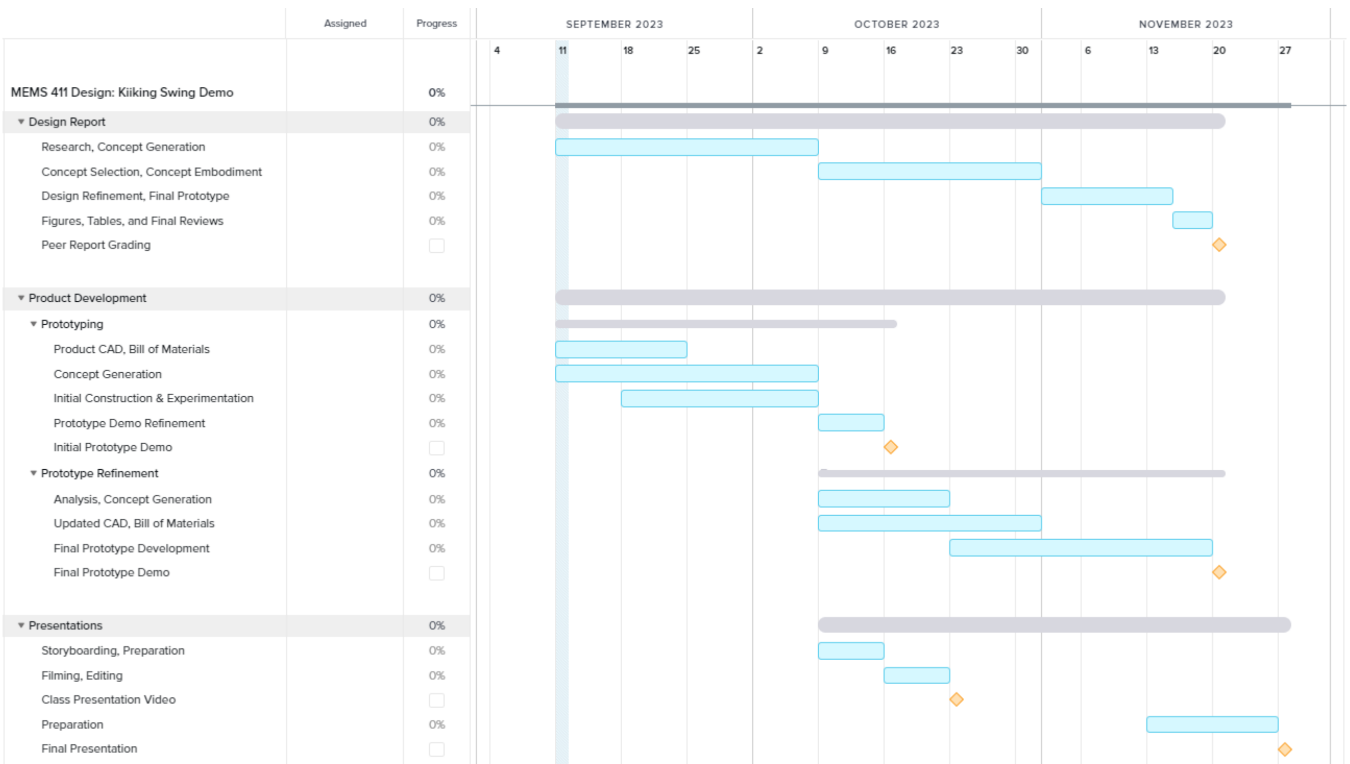


Figure 6: Plan for Product Development

3 Concept Generation

3.1 Mockup Prototype

The figures below depict a mockup prototype that was built out of wooden dowels, thin rope, small plastic tubing, and hot glue.

Figure 7: Mass Displacement Mechanism

Figure 8: Displaced Mass

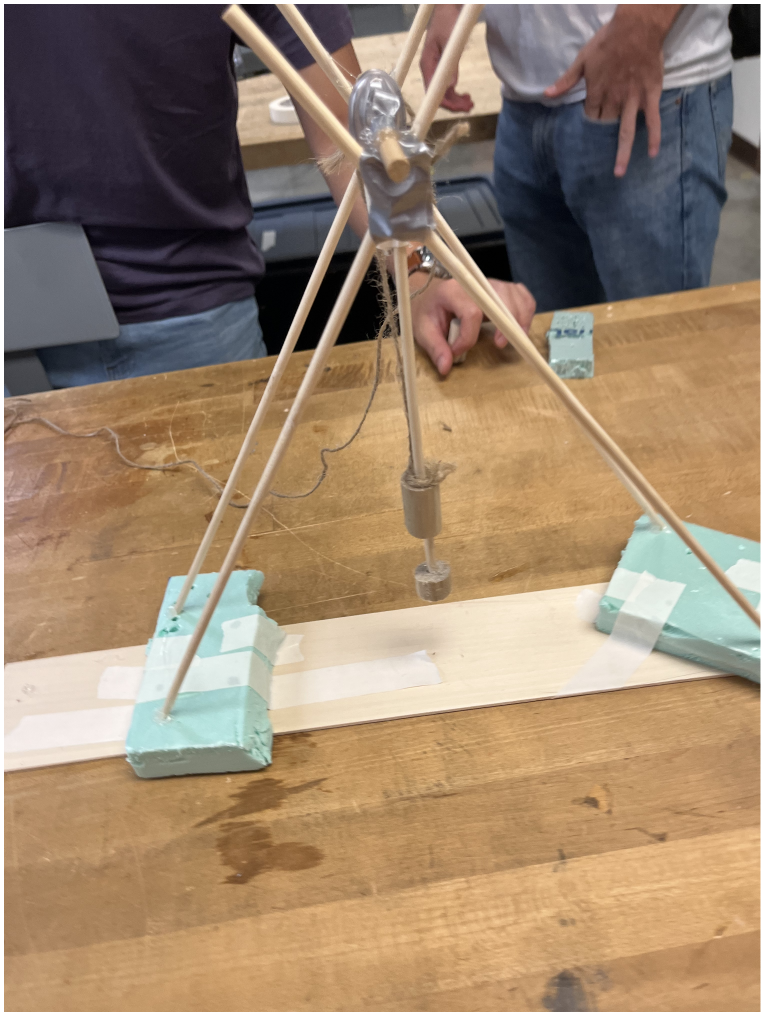


Figure 9: Side view

The mockup was modeled to closely resemble the design of swings. By arranging wooden dowels into a triangle, a stable frame was constructed. Shown in 7, a thin rope is used to pull the mass shown in Fig. 8. This was a simple method of allowing oscillatory motion of the swing while having a mechanism that could displace mass. However, in designing this, a key design requirement was identified. As the pulley system used to displace the mass was part of the rotating swing, the strings would get tangled if the swing were to make a full rotation. To ensure the optimal user experience of the science demo, the mass displacement mechanism will have to be able to swing in a full rotation without requiring the user to reset its position or untangle loose rope. This will be necessary so that the demo can be continually used without the need of staff to fix or adjust the system.

3.2 Functional Decomposition

Figure 10 illustrates a function tree detailing the required functions of the swing energy demo.

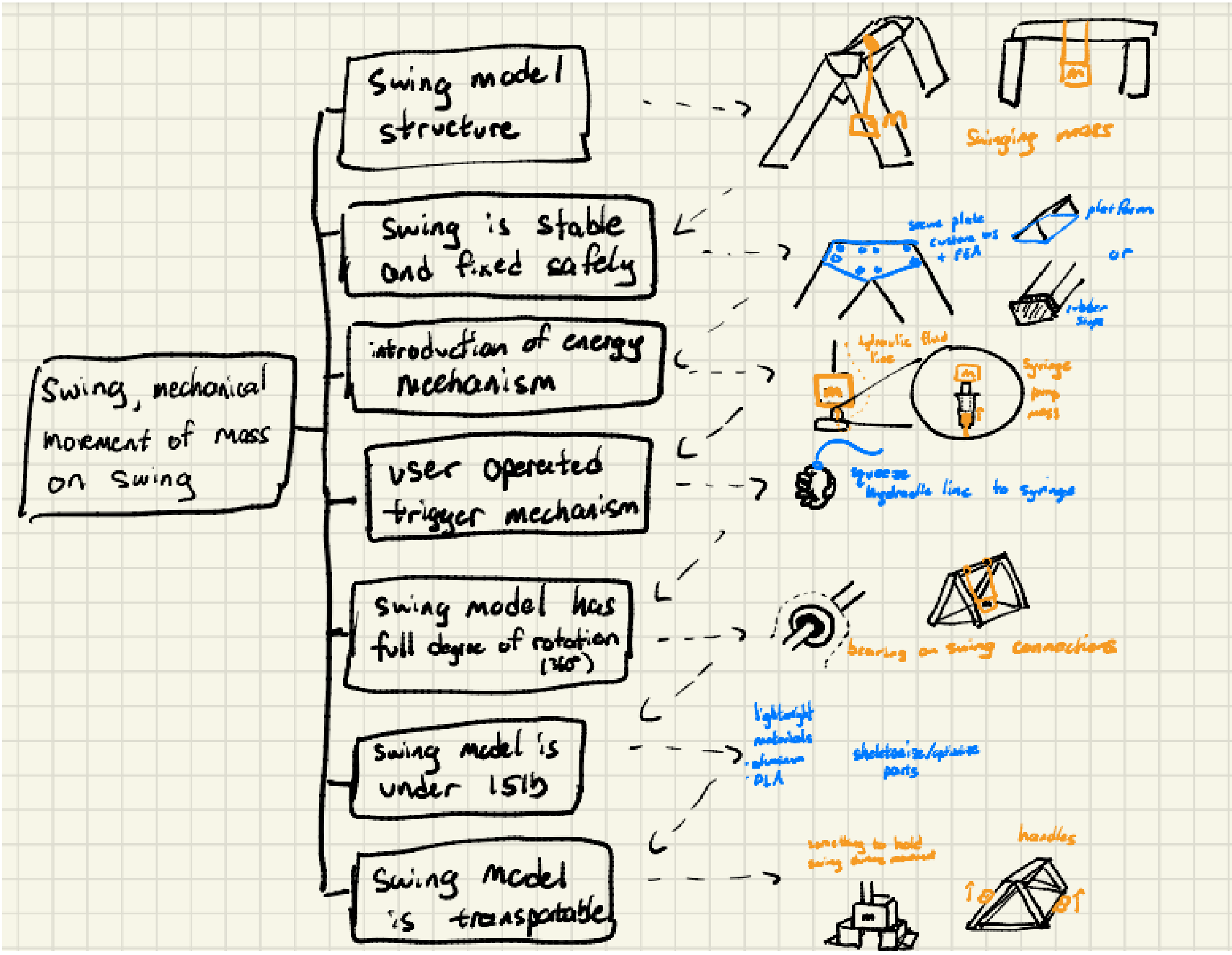


Figure 10: Function tree for Kiiking Swing Demo, hand-drawn

3.3 Morphological Chart

In order to guide the design of the concept swing, a morphological chart was created with several key functions in mind that the concept must demonstrate. These key functions are based off of the customer's preferences towards the project. Then, ideas were collected to serve each of these functions.

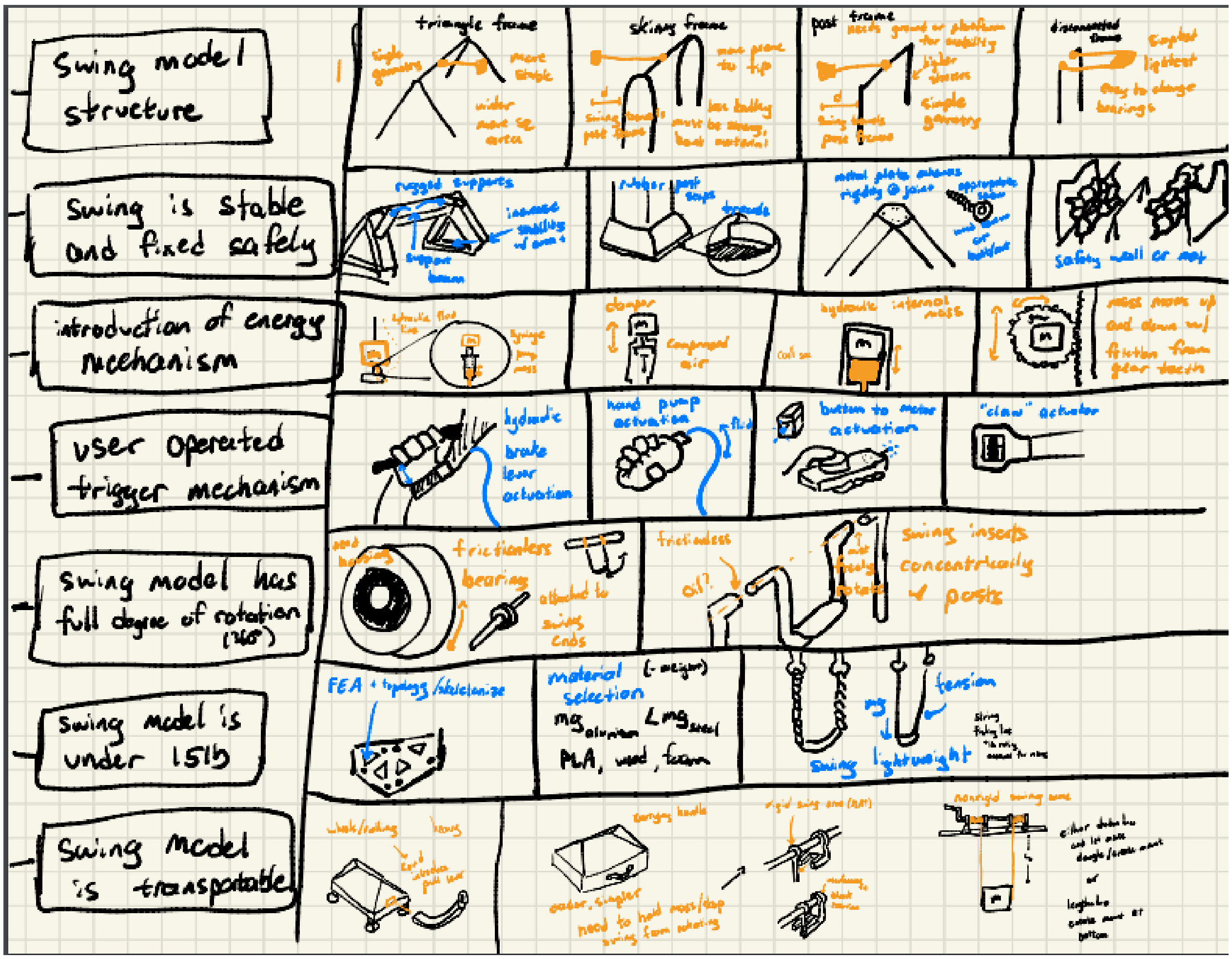


Figure 11: Morphological Chart for Kiiking Swing

3.4 Alternative Design Concepts

3.4.1 Concept #1:

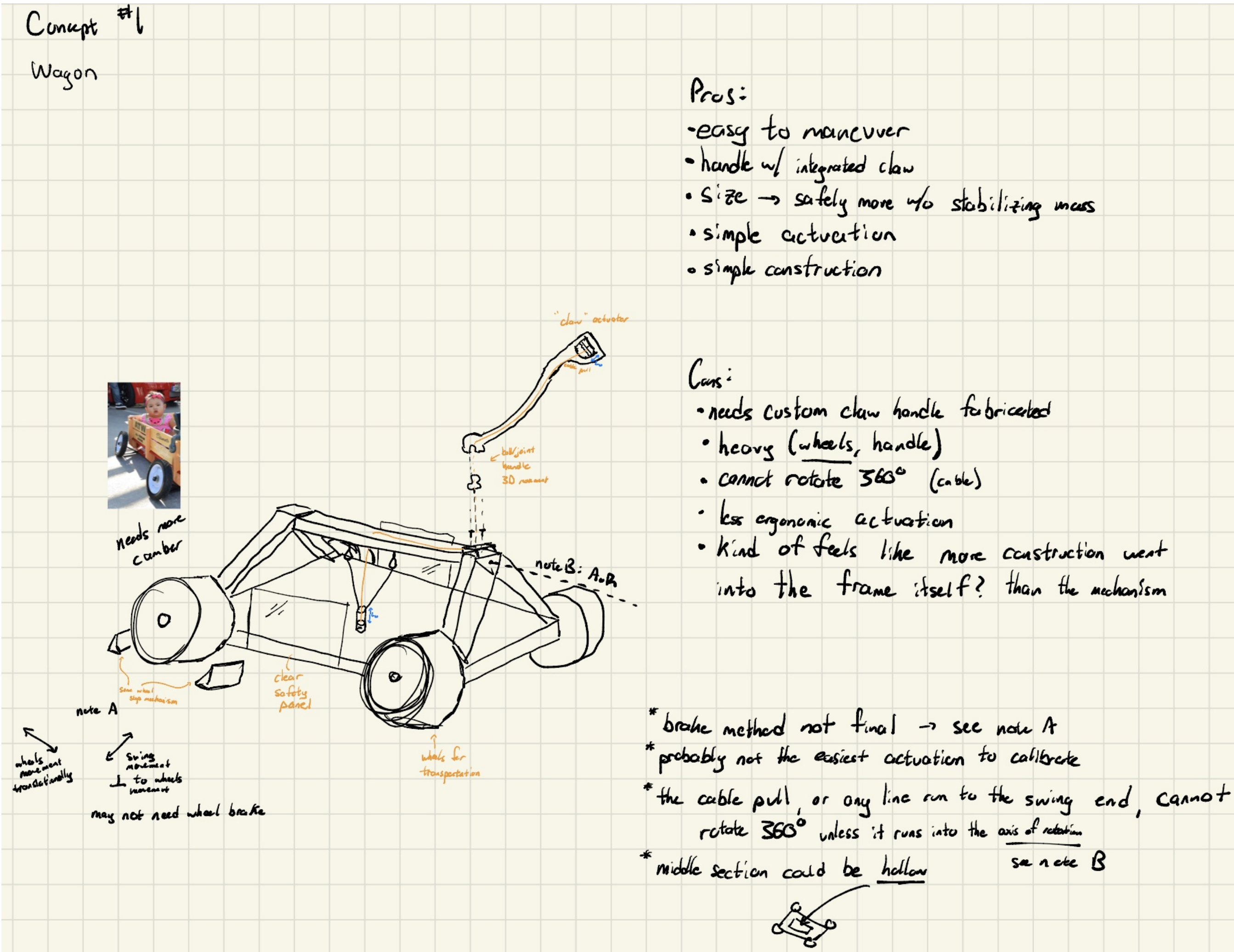


Figure 12: Sketches of Wagon Concept

Description: A wagon is built with a rectangular base and two triangular supports that are connected by a single beam. A string is tied to two hoops that are on the underside of the beam. On this string hangs a clear hollow cylinder that a mass rests inside. The mass is able to move freely up and down inside this cylinder. The mass is tied to a string that can be pulled up and down by squeezing a hand claw actuator. The sketch includes a joint option that would allow for the disassembly of this hand claw, making the device more compact and portable.

3.4.2 Concept #2: Mr. Briefcase

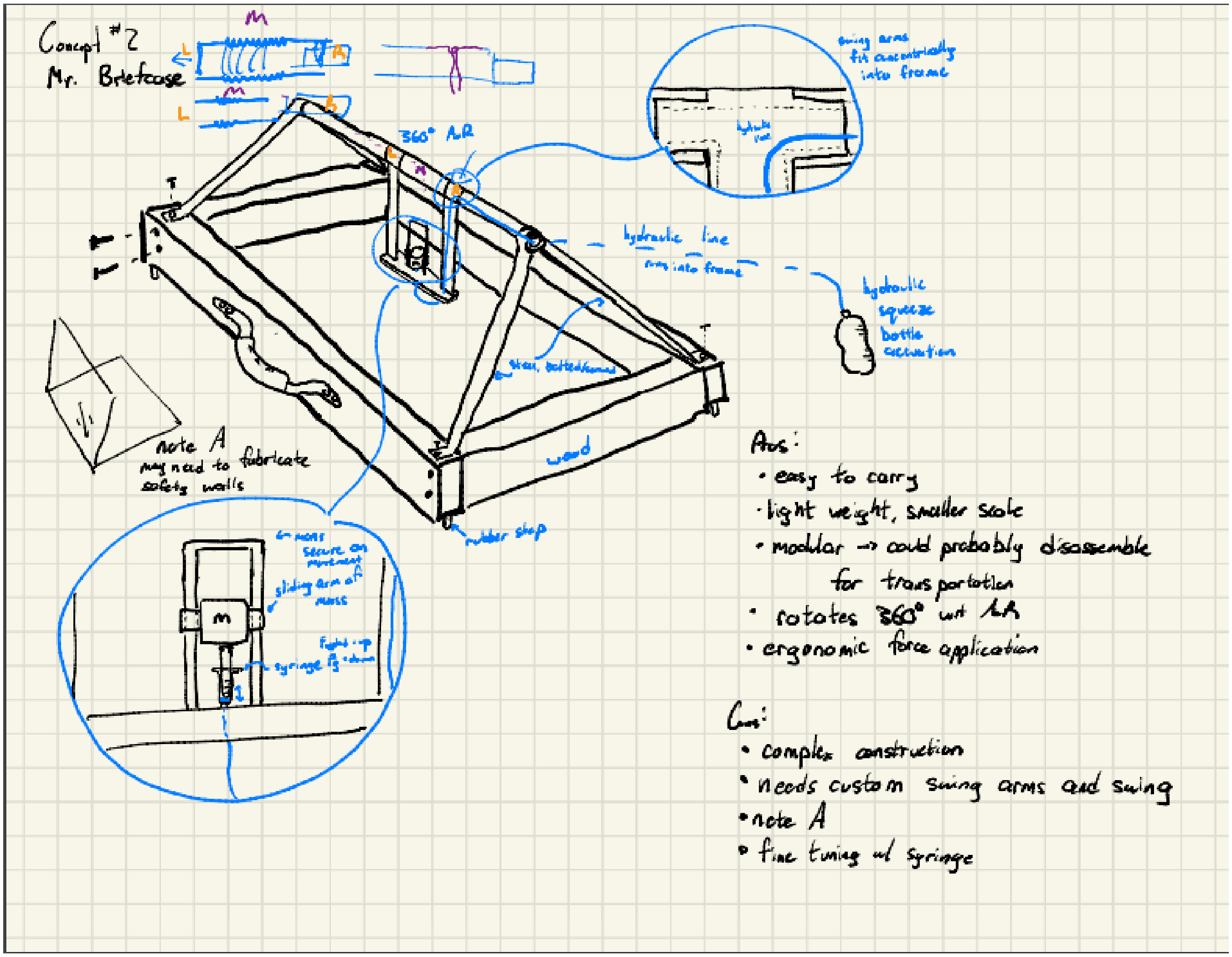


Figure 13: Sketches of Briefcase Swing

Description: A swing is built with a rectangular frame with a handle, in the size of a large briefcase. A hydraulic bottle feeds into the hollow swing axis and swing arm, which is a separate component that rotates 360 degrees on the swing axis. The hydraulic line feeds into a syringe, which is used to raise the mass. The weight of the mass is the acting force that pushes the syringe back down. A concept sketched in the top left explains potential mechanisms to make the swing able to be disassembled, and to be more modular in the case of swing arm replacement.

3.4.3 Concept #3: Internal Pulley

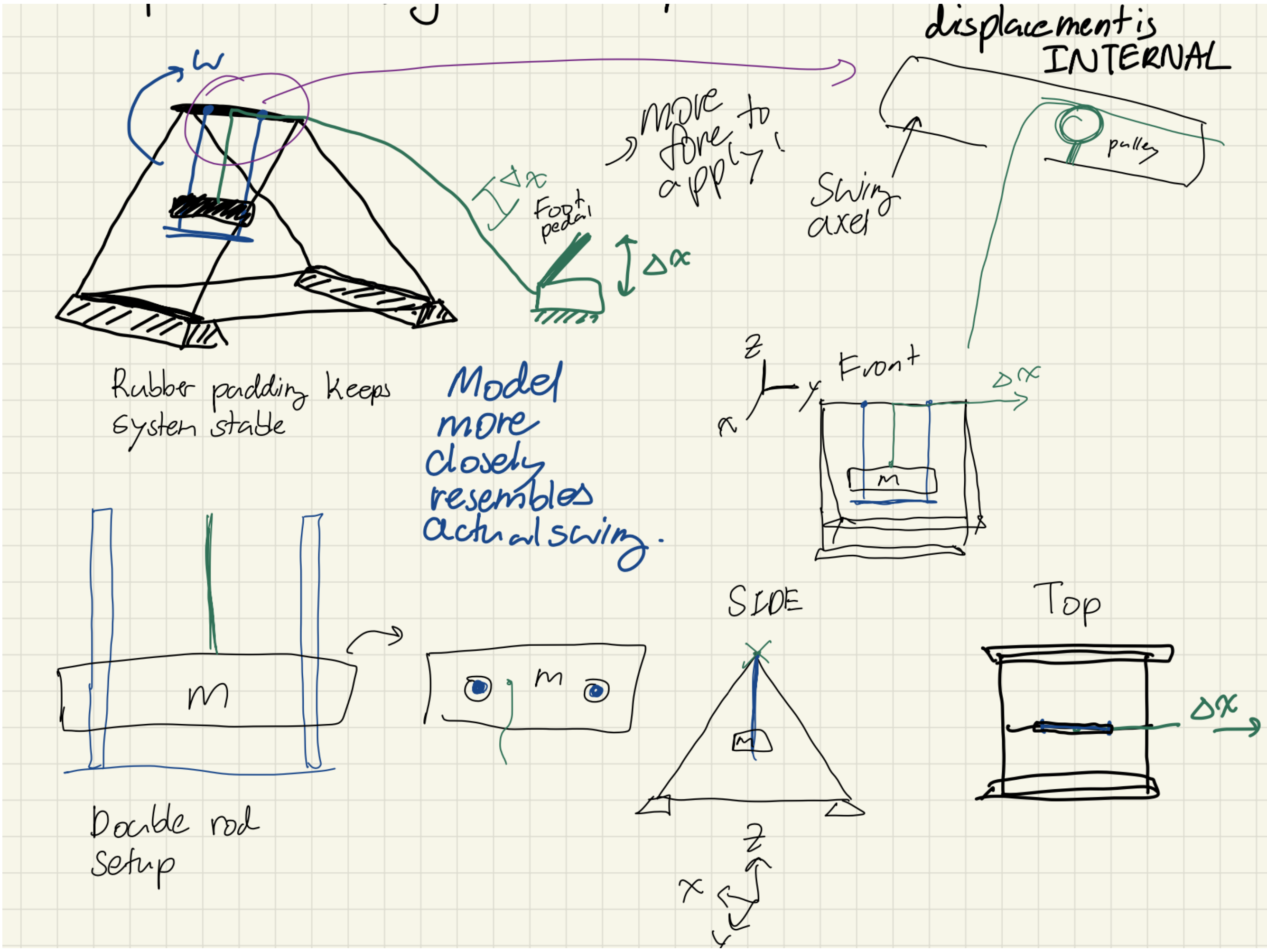


Figure 14: Sketches of Internal Pulley Concept

Description: The swing is made with a double rod setup closely resembling a swing for real children. The mass is attached on either side by these rods for stability. A hydraulic line is connected from a weight activated foot pedal to the mass. When weight is applied to the pedal via somebody's foot, the mass will raise or lower depending on the amount of force applied to it. The hydraulic lines will be mostly internal, as it travels up through the support rods and is completely hidden up until it reaches the hanging mass.

3.4.4 Concept #4: External Pulley

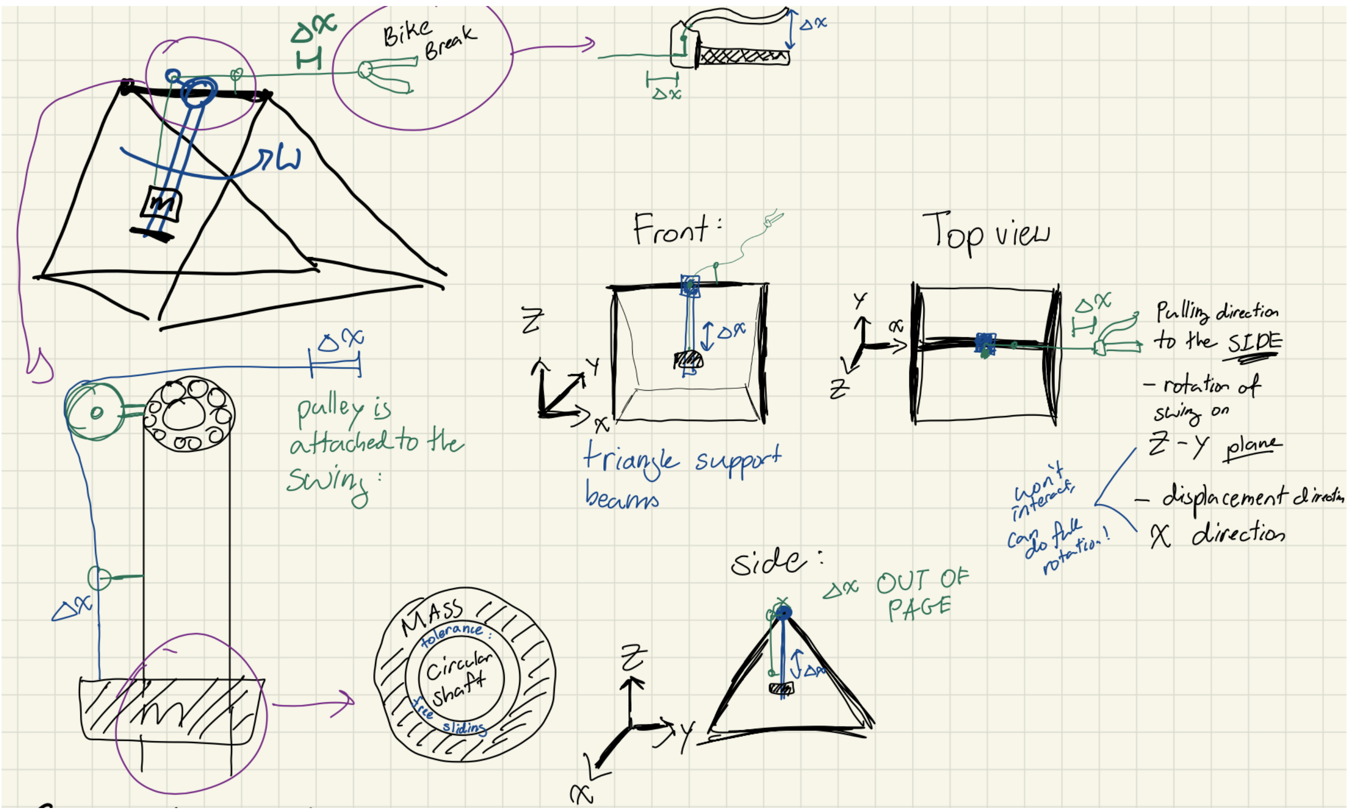


Figure 15: Sketches of External Pulley Concept

Description: The swing is made up of a single rod setup, as opposed to a double rod setup. The mass is attached to the single rod and is able to slide up and down the length of it. A hydraulic line is connected from a bike break type mechanism to the mass. When the bike break mechanism is pulled through the use of a force by a hand, the mass will raise or lower. The hydraulic lines will be external, and a pulley system allows for the connection between the bike break and the mass.

4 Concept Selection

4.1 Selection Criteria

In figure 16 we have an Analytical Hierarchy Process (AHP). This is used to evaluate the different priorities in the design criterion. Safety and ease of operation came out to be our highest priority criterion since it is intended to be used by kids.

	Portability	Ease of Action	Closeness to Real Swing	Safety	Weight		Row Total	Weight Value	Weight (%)
Portability	1.00	0.33	3.00	0.33	1.00		5.67	0.14	14.38
Ease of Action	3.00	1.00	5.00	1.00	3.00		13.00	0.33	32.99
Closeness to Real Swing	0.33	0.20	1.00	0.20	0.33		2.07	0.05	5.25
Safety	3.00	1.00	5.00	1.00	3.00		13.00	0.33	32.99
Weight	1.00	0.33	3.00	0.33	1.00		5.67	0.14	14.38
						Column Total:	**39.40**	**1.00**	**100.00**

Figure 16: Analytic Hierarchy Process (AHP) to determine scoring matrix weights

4.2 Concept Evaluation

Figure 17 represents a weighted scoring matrix. The weights from the AHP are multiplied by the scores the design receives based off of the selection criterion. The briefcase model for this WSM was the closest design to fulfilling consumer needs.

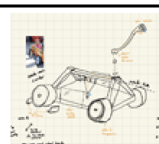
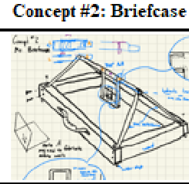
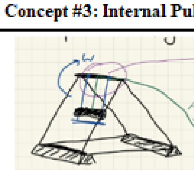
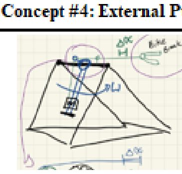
Alternative Design Concepts		**Concept #1: Wagon**		**Concept #2: Briefcase**		**Concept #3: Internal Pulley**		**Concept #4: External Pulley**	
									
Selection Criterion	**Weight (%)**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**
Portability	14.38	5	0.72	4	0.58	2	0.29	2	0.29
Ease of Action	32.99	5	1.65	4	1.32	3	0.99	4	1.32
Closeness to Real Swing	5.25	2	0.11	2	0.11	4	0.21	4	0.21
Safety	32.99	2	0.66	4	1.32	3	0.99	3	0.99
Weight	14.38	1	0.14	3	0.43	5	0.72	5	0.72
	Total score	**3.277**		**3.751**		**3.196**		**3.526**	
	Rank	**3**		**1**		**4**		**2**	

Figure 17: Weighted Scoring Matrix (WSM) for choosing between alternative concepts

4.3 Evaluation Results

Out of the 4 concepts, the briefcase design fulfilled our criteria most effectively. The briefcase design scored highest in portability, ease of action, and safety. The wagon design scored higher in both portability and ease of action, but the briefcase design scored higher in safety and weight, making it the better choice. The external pulley design was placed in second, but it lacked in portability and safety, causing it to fall short of the briefcase. The least likely choice was shown to be the internal pulley design, as it only scored well in the weight and closeness to real swing sections, but didn't score above a 3 in the remaining 3 criteria. For the briefcase design (winning design), scoring a 4 in portability is important because the machine needs to be able to be transported into its place in the museum or demo location. The ease of action is very important as it needs to be able to be set up repeatedly. Scoring a 4 in safety is probably the most important, especially because we do expect children to be using our design, meaning that safety is a very high priority. Closeness to a real swing was the lowest score for the briefcase, but it was also weighted the lowest because the exact degree of accuracy to a real kiiking swing is not as important as displaying the overall concept.

4.4 Engineering Models/Relationships

Figure 18 calculates the new height achieved from the swing from the added energy (added work from displacing mass m). This will help us determine the appropriate displaced mass m, total mass of swing M, and how much to displace the mass dx. These will be important parameters as we expect children to be using the demo: if work doesn't add sufficient height, they wont be motivated to use the demo. However, if too much work needs to be added because of a large M, for each trigger actioning, they will also be discouraged.

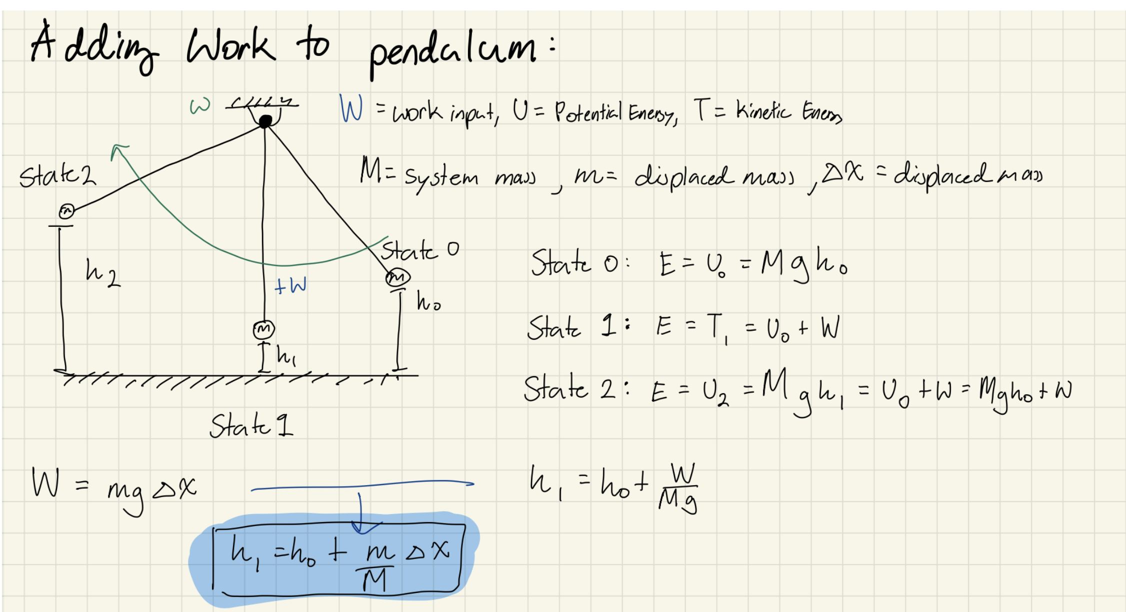


Figure 18: Adding work to pendulum

An adequate base must be constructed to prevent the moment from the swinging pendulum m from causing a rotation in the system (swing tips over). This is illustrated in fig. 19 with variables a and b, the size of the swing supports, will be calculated so that the swing does not tip over.

Further, the appropriate normal force N (weight of swing) can also be determined.

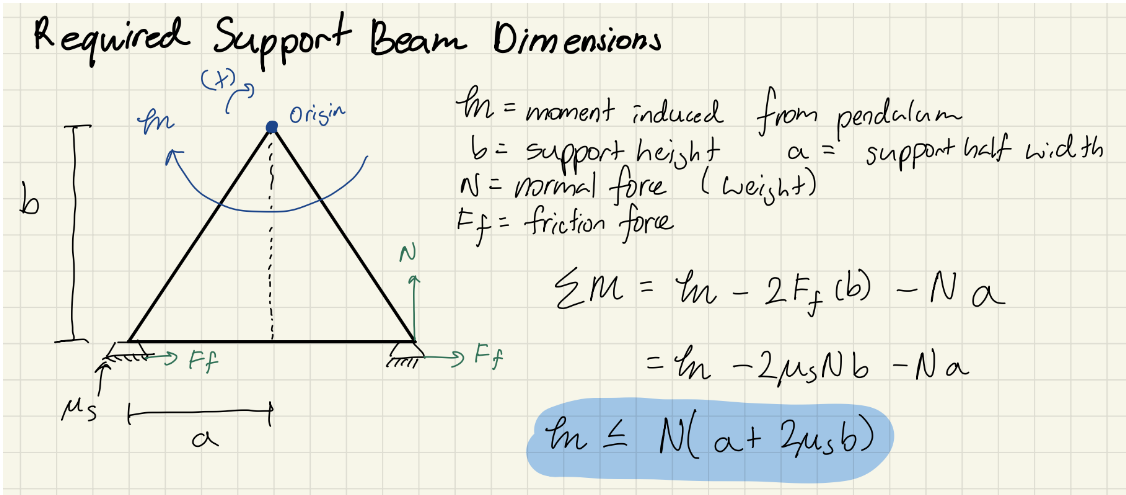


Figure 19: Swing support beam lengths

Figure 20 calculates the work added from user input, where k denotes the spring stiffness and dx denotes displaced length. This model will be employed to choose the appropriate dimensions for the trigger for the user to add work into the system, as well as determining the appropriate spring stiffness. It also demonstrates that for work to be inputted into the swing system, it must be larger than the work needed to extend the spring.

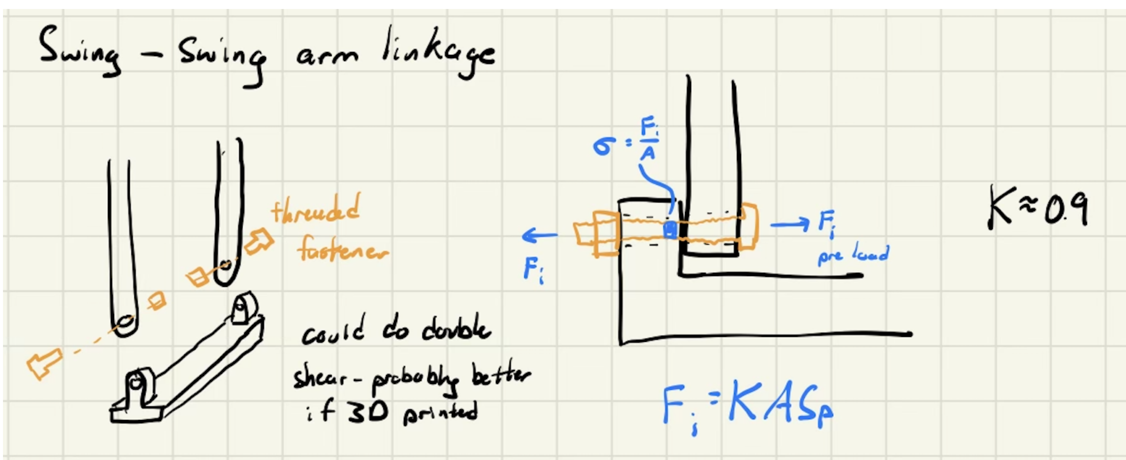


Figure 20: Work added by trigger

5 Concept Embodiment

5.1 Initial Embodiment

Our performance goals sought to evaluate the success of the swing. The swing should be able to **pump from an amplitude of 15 degrees to an amplitude of over 90 degrees in one minute, pump from an amplitude of 15 degrees to ”over the top” in two minutes, and weigh less than 20 lbs.**

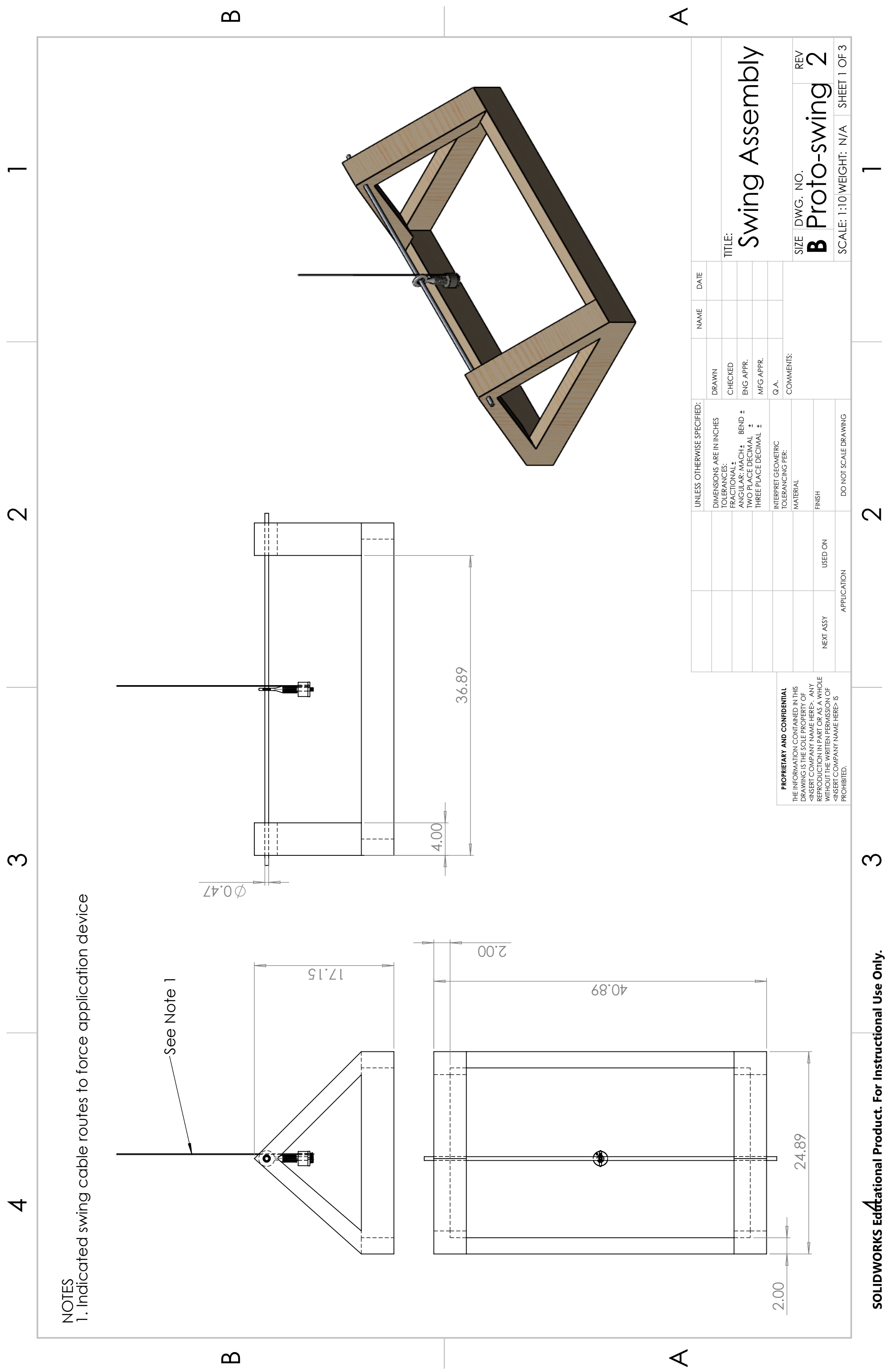


Figure 21: Assembled projected views with overall dimensions

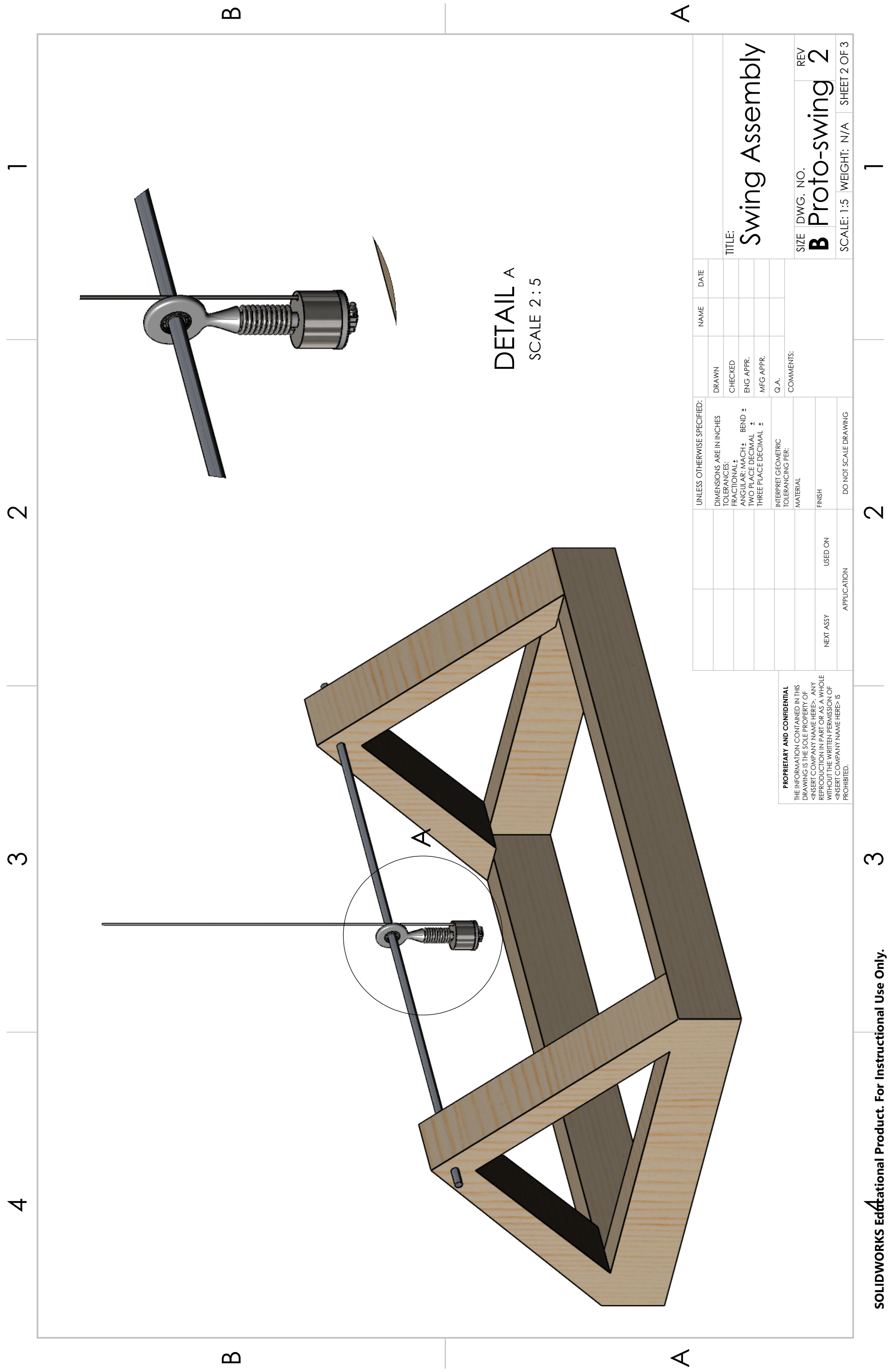


Figure 22: Assembled isometric view with section view of swinging mass

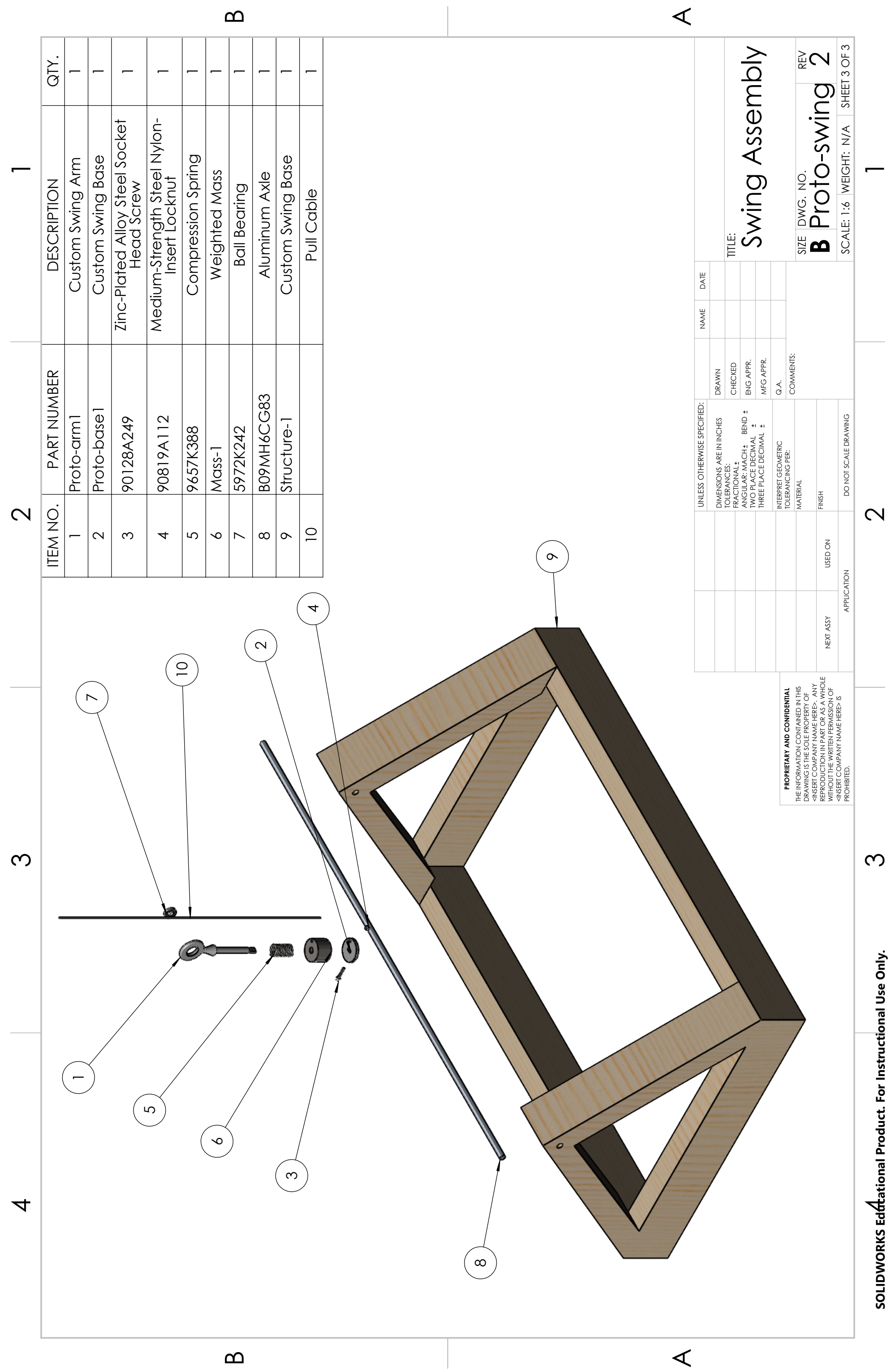


Figure 23: Exploded view with callout to BOM

5.2 Proofs-of-Concept

The proof-of-concept model for our swing energy demo was particularly effective in outlining the design challenges to create the swing energy demo. It was quickly revealed that using rubber tubing for the steel wire caused too much friction during actioning, and prevented the mass from displacing smoothly. Further, an improved approach for housing the mass on the swing and attaching the mass to the actioning mechanism was needed. These challenges were addressed in our initial prototype design.

5.3 Design Changes

In the design selection, one of our focuses was on the portability of the system. The concept we decided to go with was a briefcase model where the swing setup could be folded and fit into a briefcase. This was not done during our prototyping phase as we focused primarily on the swing mechanism and the foot pedal mechanism that are key to the functionality of the model. The portability will be more of a focus in the next round of prototyping. The other design selection we were focused on was deciding whether to route the cable internally through the swing arm or externally along the swing arm. We decided to do it externally and stuck with this decision through the design process. The one other change we made was how we secured the cable and the mass together. In our concept drawings, we planned to attach a hook to the mass that the cable could be tied around. Instead, we drilled a small hole through the mass and routed the cable through it. There is a fastener on the end of the cable that prevents the mass from moving along the cable, so the mass and cable move in unison, without any slack now.

6 Design Refinement

6.1 Model-Based Design Decisions

Throughout the design process we have had two mechanisms that have taken up our primary focus: the weighted pendulum and the foot pedal. The energy model was introduced for the weighted pendulum in section 4.4, see Fig. 18 and is discussed in further detail in this section. The energy model for the foot pedal is introduced in this section as well.

6.1.1 Design Refinement #1: Weighted Pendulum System

The general equations for the energy model of the system can be seen in section 4.4, Fig. 18. This section elaborates on W, the work introduced. The work introduced is dependent on Fm, the force applied to the mass, and δxm, the displacement of the mass. Fm is dependent on the spring force (k*x) and the force of gravity (m*g). The theoretical calculations for the work done on the system at maximum displacement of the spring can be seen in Fig. 24 below.

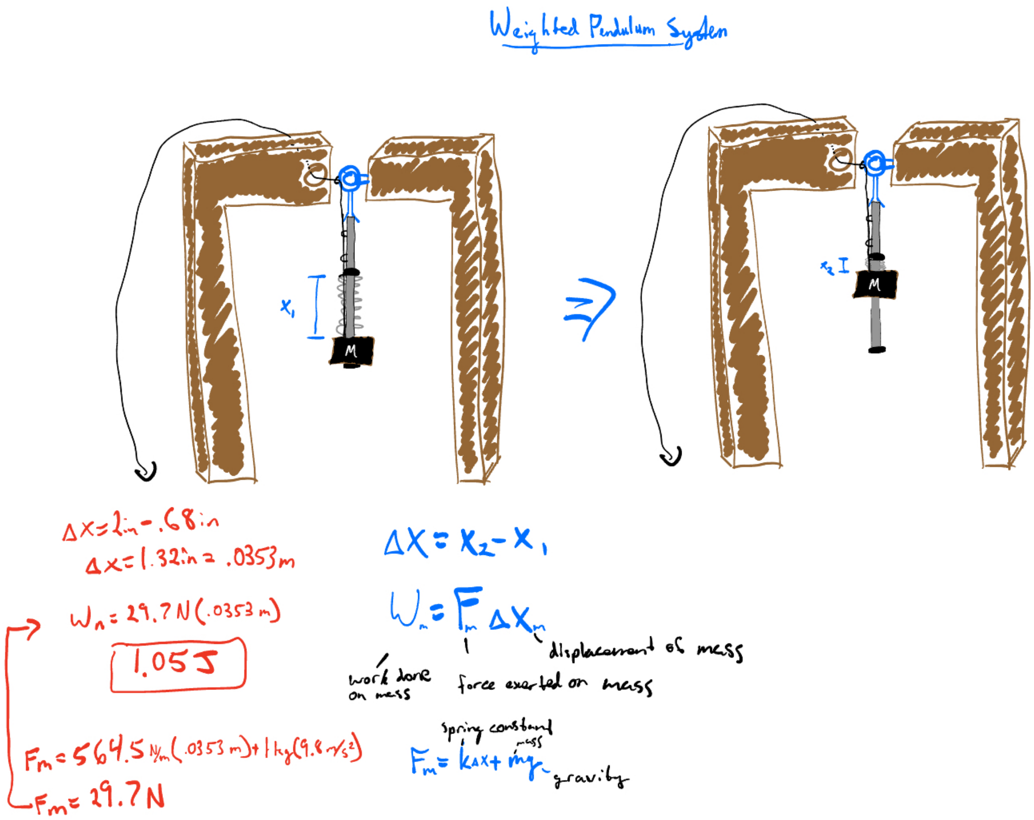


Figure 24: Model Based Design Rationale for Weighted Pendulum System

6.1.2 Design Refinement #2: Foot Pedal System

This section introduces the energy-based model for the foot pedal actuator which introduces energy to the system. The maximum force that the foot pedal can be applied to the system is the Fm at the maximum displacement of the spring. Any additional force to the foot pedal will not increase the work done on the weighted pendulum system since the mass cannot be displaced past this point. Equations relating the work and forces done on the foot pedal system to the weighted pendulum system are seen in Fig. 25 below.

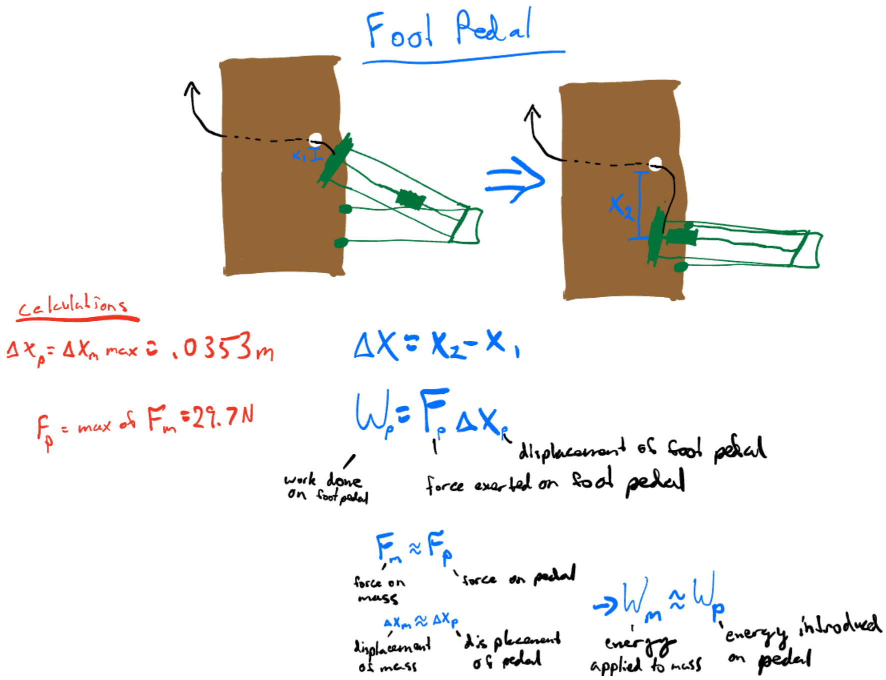


Figure 25: Model Based Design Rationale for Foot Pedal

6.2 Design for Safety

Because this machine involves the use of heavy and metallic objects, safety aspects must be taken under consideration. Additionally, the machine will appeal to an audience primarily under the age of 15 further highlighting the importance of safety in the design.

6.2.1 Risk #1: Airborne Mass

Description: The mass we are using is a solid 304 Stainless Steel cylinder that weighs approximately 1kg. It will be located primarily toward the end of the swinging rod, meaning that if it were to somehow detach itself from the rod, it could be seen as a potential safety hazard.

Severity: Given that the mass is solid stainless steel and weights about a kilogram, the safety risk would be classified as very severe. Especially around children, full oscillation could result in serious injury or even death.

Probability: The probability of this happening is fairly low, though when compared to the other safety risks it is probably the most likely to occur.

Mitigating Steps: Small black clamps were purchased for use in this machine that block the mass from sliding off of the rod on the end away from the bearing. Despite these clamps adding undesirable additional mass to the system, we have decided to include TWO clamps underneath the mass instead of ONE to reduce the risk of this safety hazard.

6.2.2 Risk #2: Structure Collapse

Description: If the structure were to collapse, pieces of it could possibly reach the user and possibly cause minor injury. Additionally, if this collapse were to occur while the mass rod system was swinging, more severe injury could ensue.

Severity: The severity of this safety risk is not as high as the airborne mass, but is still definitely cause for concern as there are some sharp edges that could cause injury.

Probability: The probability of this occurring is the lowest out of the three safety risks, but absolutely cannot be mitigated. This is because the structure will have to hold up constant movement from the rod mass system, meaning that fatigue must be taken into consideration.

Mitigating Steps: Instead of using wooden rods and beams as was done in the initial prototypes, aluminum beams were purchased to increase the rigidity of the structure. Though a collapse with a metallic structure could be more harmful than wood, the risk of it collapsing at all would be much lower. We believed that this tradeoff was worth it. Additionally, the beams should be regularly checked weekly to ensure fatigue has not set in at too extreme of a level.

6.2.3 Risk #3: Swing Reach

Description: With the swing oscillating at decently high speeds during operation, anything or anyone in the way of it could be damaged or injured.

Severity: While not as a severe as the airborne mass, it is probably more severe than a structure collapse as the uninterrupted oscillation of a metallic rod with a metallic 1kg mass on the end of it could seriously injure someone, especially a child.

Probability: The probability of this occurring is probably the highest out of the three, as the safety risk depends on the user rather than the machine failing.

Mitigating Steps: Some steps to prevent this risk from occurring would be to place the machine far enough away from the foot pedal and therefore the user so that putting a head or arm far enough to be in the way of the swing would be impossible. Additionally, a plexiglass box could be placed around the machine to prevent anything from getting inside, but this is probably unrealistic considering the timeframe.

6.3 Design for Manufacturing

Figure 24 above depicts a rough sketch of the physical embodiment of the swing energy demo, where blue indicated the pendulum, and green represents the spring.

Excluding threaded fasteners, there are currently **19** parts and **42** fasteners in the design. There are a total of 5 theoretically necessary components listed below:

- Swing Frame
- Pendulum
- Displaced Mass
- Spring
- Actioning Wire

The swing frame must be an independent part from the pendulum to allow for oscillatory motion. Similarly, the displaced mass must be an independent component as it must displace radially on the pendulum to add work to the system. Although the actioning wire is connected to the displaced mass, it is considered a separate component as is it made of different material. If the actioning wire was made of the same material as the displaced mass, it would be a solid rod, making it difficult for user input for work and impractical for the swing to rotate. The components above are theoretically necessary for the swing energy demo, as it constitutes the spring itself and the mechanism to add work.

Currently, seven T frame bars are fastened to create the swing frame. The design could be minimized by manufacturing the swing frame as one singular piece. Further, the bearing connecting the pendulum to the swing axle could be removed, but this would be counterproductive as it would reduce the swings ability to swing freely. The displaced mass and spring could be combined into a single component, would be difficult to source from a manufacturing standpoint as springs with a mass at one end are seldomly produced.

6.4 Design for Usability

In order to create a universally accessible swing mechanism and actuation system, the physical interface between the user and the device is based off of a radial actuation system connected to a line. This system allows users with a general range of motion and force application to induce a linear force through the cable. To reduce the friction that the line experiences when being pulled within the system, a protective sleeve is threaded around the cable and fixed in place. The sleeve has the alternative function of protective the rugged but easily kink-able cable. These elements allow for a smooth application of force by a wide variety of users because of it's simple design.

Usability for the device is also factored into its modularity, where the entire device can be disassembled in minutes due to simple fixture settings for the frame and swing assembly. The frame utilizes lightweight and reliable aluminum segments with grooves that fit threaded and lockable fixtures, which can be replaced with alternate segments to produce swing frames of various heights and sizes. The swing itself is fixed with fasteners and can be removed after the cable is disconnected. Even the mass can be removed and adjusted as the washers used for the weights can be added for more weight or removed for less accordingly. While no quantitative measurements are logged with the device, the flexibility in its construction sets a sound base for further experimentation in spring-mass and momentum systems.

6.5 Design Considerations

Table 3: Factors considered for design solution

Design Factor	**Applicable**	**Not Applicable**
Public Health		X
Safety	X	
Welfare		X
Global		X
Cultural	X	
Societal		X
Environmental		X
Economic		X

Table 4: Contexts considered for ethical judgments

Situation	Applicable	Not Applicable
Global context		X
Economic context	X	
Environmental context		X
Societal context	X	

7 Final Prototype

7.1 Overview

A Swing Energy demo was successfully developed and manufactured. T-slotted framing brackets were utilized to provide structural rigidity and reduce manufacturing time. A linear bearing was incorporated to reduce the friction of the sliding mass, and fishing wire replaced the use of steel wire. All of the performance goals were achieved: the device is able to complete a full rotation under a minute, and weighs less than 20 lbs. However, the swinging motion induced a significant moment to the device, and stability was an issue. For the final demonstration, the legs of the device had to be taped to the ground. Further improvements to this device can be made by increasing the weight limit, so that a more secure frame can be built that can withstand the moments of rotation during operation. Overall, this project was completed successfully.

7.2 Documentation

The figure below depicts the final swing energy demo during operation.

Figure 26: Final prototype during operation

A Parts List

	Part	McMaster Part #	Description	Unit Price	Quantity	Total price
1	T-Slotted Framing	47065T101	Aluminum	$10.24	5	$51.20
2	T-Slotted Framing Bracket	47065T278	Aluminum	$12.10	2	$24.20
3	T-Slotted Corner Bracket	47065T239	Aluminum	$8.00	2	$16.00
4	T-Slotted Anti-slip cover	47065T362	Rubber	$19.01	1	$19.01
5	Steel compression springs	9434K116	Steel	$1.31	3	$3.39
6	Clampining Two-piece Shaft	6436K12	Carbon Steel	$6.48	2	$12.96
7	Flange-mounted Linear Bearing	6483K51	Stainless Steel	$24.88	1	$24.88
8	1/4"x12" 6061 Aluminum shaft	8974K22	Aluminum	$2.53	1	$2.53
9	Bike pump	NA	Green paint	NA	1	$0.00
10	304 Stainless Steel Mass	NA	Stainless Steel	NA	1	$0.00
11	Fishing wire	NA	Green/translucent	NA	1	$0.00
					Shipping:	$52.43
					Tax:	$15.26

					Total:	$222.39