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### Automated Whiteboard Eraser

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# Washington University in St. Louis

## JAMES MCKELVEY SCHOOL OF ENGINEERING

### FL19 MEMS 411 Mechanical Engineering Design Project

### **Automated Whiteboard Eraser**

Several classrooms located on Washington University in St. Louis' campus have two whiteboards mounted on the walls for lectures. Professors will fill a single whiteboard with lecture notes multiple times throughout the course of one lecture period. Having just two boards to write on requires the professor to spend time erasing the board and thus wasting valuable lecture time. The issue was first presented by Professor Chiamaka Asinugo. She proposed the solution of an semi-autonomous erasing unit.

From our interview with Professor Chiamaka Asinugo, it was made clear that she is looking for a product that is fixable to the boards, efficient, and quiet. Our product meets these design request as it consists of a light frame that mounts to a whiteboard via suction cups and bears an eraser on a coded path. This eraser path will allow for a clean and efficient erasing that leaves the board ready for writing once again.

Our final design is an applicable design to all three designs to the Jolley 110, 100, and basement. It uses suction cups to hold to the board and is very sturdy. It consists of two vertical aluminum rods and two horizontal aluminum rods. We have 3D printed components that slide up and down the rods. These components are moved using DC motors and timing belts that are fixed to the 3D printed components. The eraser is attached to one of these components and has enough pressure applied to easily erase anything written on the desired whiteboard.

Polasek, Tyler  
Houpt, Trent  
Luo, Rocky  
Huang, Kenny

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**FALL 2019 MEMS 411**  
**Mechanical Engineering Design Project**

**Automated Board Eraser**

**Group U**

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Haupt, Trent

# 1 Introduction

The Automated Whiteboard Eraser is a product designed to erase whiteboards with the touch of a button. With this product students and teachers will be able to save time and energy as they can continue to work without having to stop and erase. From our research others have attempted to construct similar products. We intend to improve these thoughts and designs in order to build a better and more efficient product.

From our interview with Professor Chiamaka Asinugo, she made it clear that she is looking for a product that is portable, efficient, and quiet. Our product meets these design request as it consists of a light frame that mounts to a whiteboard via suction cups and bears an eraser on a coded path. This eraser path will allow for a clean and efficient erasing that leaves the board ready for writing once again.

## 2 Problem Understanding

### 2.1 Existing Devices

The first existing device is Ifreed Window Cleaning Robot which can move around the vertical smooth surface and clean it. The goal of the robot is similar to the white board cleaner. The most common design for window cleaning robot is using magnetic force but it requires the robot able to reach the other side of the surface. However the white board can only provide the front side of the board. The White Board Cleaning Robot is made of tracking racks which make the cleaning process fast and clean but the portability can not satisfy the client's need. The last design is The Autonomous Board Erasing Robot. It uses magnets to hold the position of the robot and move the robot by two wheels. This design has high portability and high autonomous ability. However the efficiency is limited by its design. It would take to long to clean board.

### 2.1.1 Existing Device #1: Ifreed Window Cleaning Robot



Figure 1: Ifreed Window Clean Robot (Source: AliExpress)

Link: [https://www.youtube.com/watch?time\\_continue=50&v=dyLgRyrL9T4](https://www.youtube.com/watch?time_continue=50&v=dyLgRyrL9T4)

Description: The Ifreed Window Clean Robot is window clean robot use suction force and rotating its cleaning pad to move and hold its position on the window. The suction force can provide enough pressure to help the cleaning pad. It is an automated system utilizing sensors to detect the cleanness and edge of the window. It is built with two rotatable cleaning pad. Each cleaning pad can use suction force on the window to rotate itself and move around the window. This two "wheel" design can provide stability and maneuverability on the window and the robot can reach any place on a smooth surface. The emergency battery is used on the robot and it can support the robot move without electric cable for 20 minutes.

## 2.1.2 Existing Device #2: WHITE BOARD CLEANING ROBOT

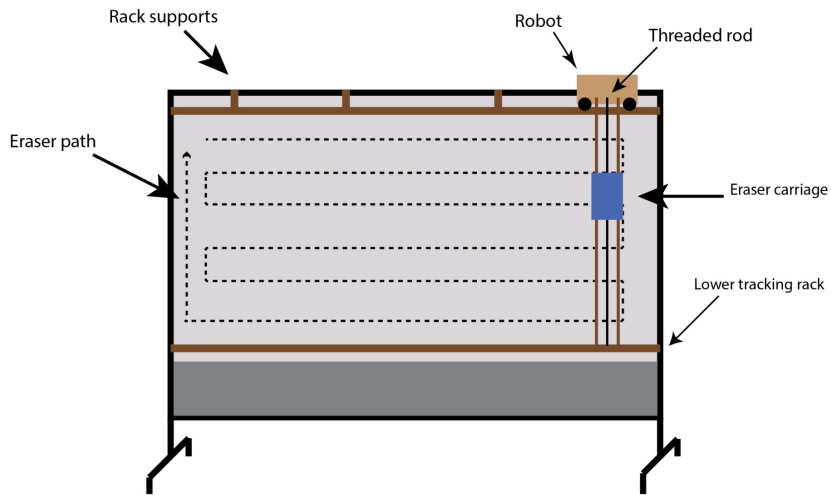


Figure 2: White Board Cleaning Robot (Source: Nunu)

<https://cambridge.nuvustudio.com/studios/cleaning-robots/whiteboard-cleaning-robot#tab-portfolio-url>

The White Board Cleaning Robot is made of two tracking racks and a robot to control the location of the eraser carriage. The device is mounted on the whiteboard and eraser is controlled like 3D painter. The control module is located on the top tracking rack along with the motors. The eraser can move around the whiteboard as programmed and cover the whole area easily and able to clean the board fast.

### 2.1.3 Existing Device #3: Autonomous Board Erasing Robot

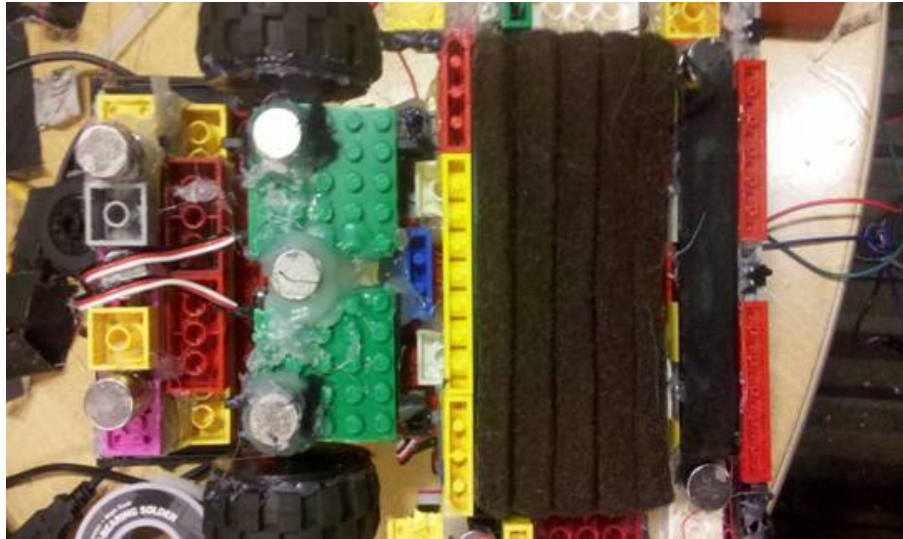


Figure 3: Autonomous Board Erasing Robot (Source: Cornell University Electric and Computer Engineering)

The Autonomous Board Erasing Robot used Lego as main body part of the robot and use the glued magnets to keep the robot on the whiteboard. The robot use wheels to move and the motion of the wheels are recorded to locate its position based on the accelerator's data. The front end of the robot is made of the regular whiteboard wiper and uses the pressure provided by the magnets. The gravity makes the robot not balanced at different orientation which can cause the wiper can not receive enough pressure to clean.

## 2.2 Patents

### 2.2.1 Manually operated magnetic window wiper (USS5515570A)

This patent mainly combines two ceramic rectangular permanent magnets. One side of the magnet is attached with a set of wiper blades. When the two magnets are placed opposite each other across the window surface the magnetic attraction pulls the slave unit wiper blades against the window surface. Then, the master unit can be moved across the window surface so that the slave unit follow the same path on the other side of window and the wiper blades flip-flop wiping the window clear.

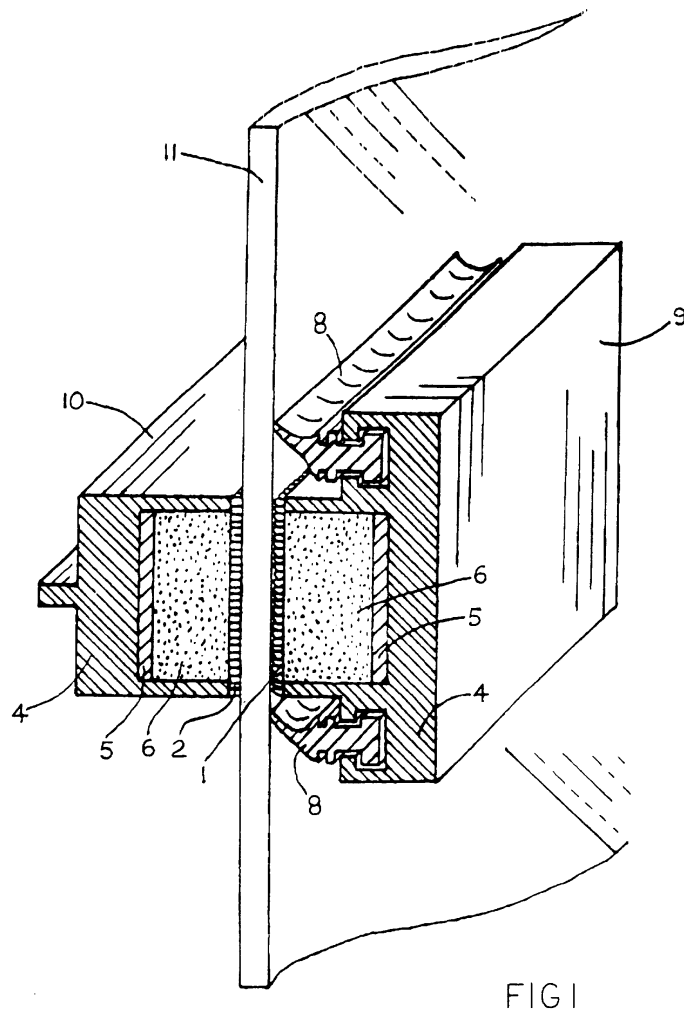


Figure 4: Patent Images for Window Wiper

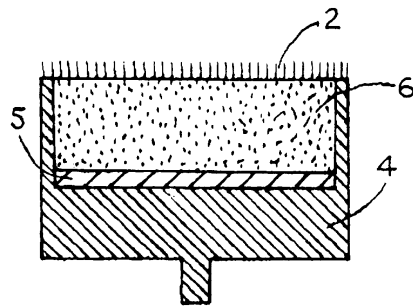
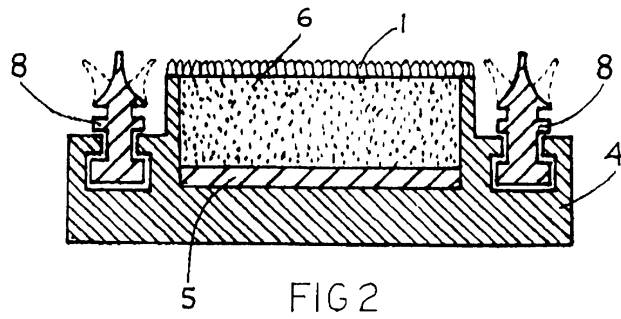


FIG 3



FIG 4

Figure 5: Patent Images for Window Wiper



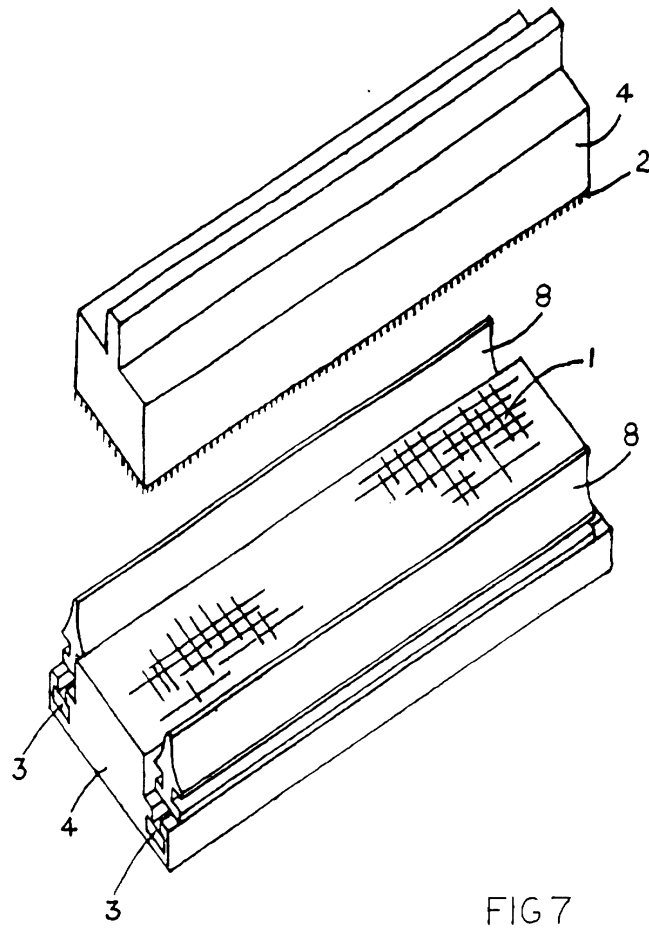


FIG 7

Figure 6: Patent Images for Window Wiper

### 2.2.2 Method and device for obstacle detection and distance measurement by infrared radiation (EP1354220B1)

This method mainly introduces how to use the infrared-ray to measure the distance from two objects. The infrared-ray emitter will be installed on the first object and the infrared-ray will be transmitted towards the second object. Then, the infrared-ray will be reflected back towards the first object after it reaches the second object. The receiver installed on the first object will catch the signal returning to it. Because we know the frequency of infrared-ray and the total time from beginning to end, we are able to find out the exact distance that wave travel through.

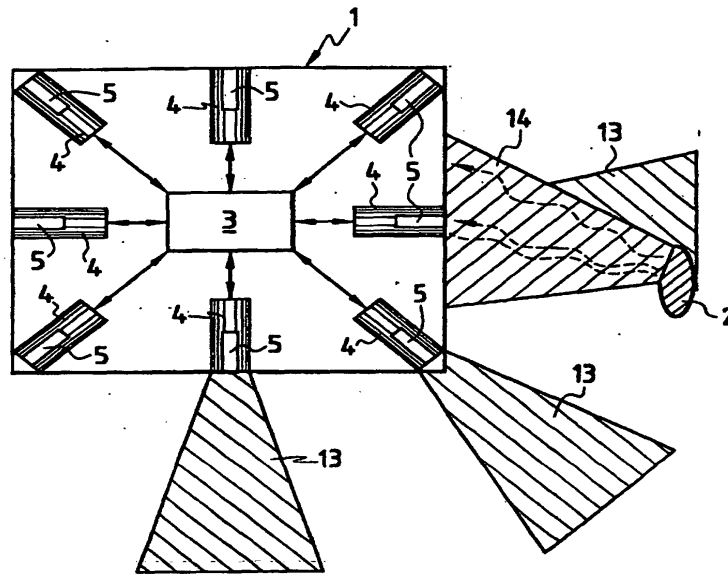


FIG.1

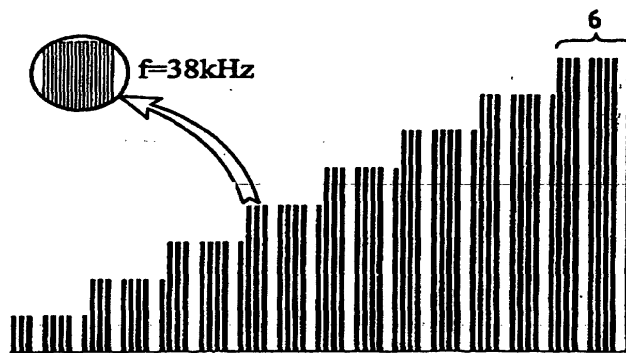


FIG.2

Figure 7: Patent Images for method of distance measurement

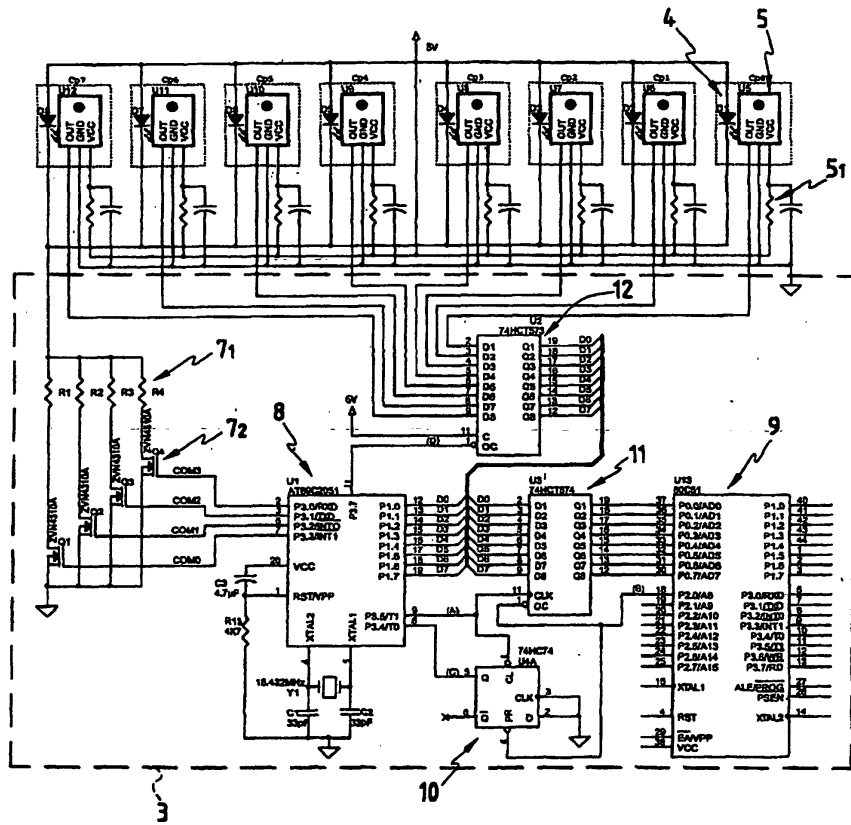


FIG.3

Figure 8: Patent Images for method of distance measurement

## 2.3 Codes & Standards

### 2.3.1 Control Motors - Stepping Motors (CLS/TS 60034-20-1)

The standard set requirements for rotating motors and provides a specific standard for the motors. When using the stepping motors, it moves the wipers and able to record the amount degrees turned to locate the robot. It will be important that the stepping motor is accurately provide location of the robot.

### 2.3.2 Standard Test Methods for Rubber Deterioration-Dynamic Fatigue (ASTM D430-06(2018))

This standard can be used to simulate the continually repeated distortions received in service by the rubber material. These distortion can be produced by extension, compression and bending force. The effect of the distortions is to weaken the rubber until surface cracking or rupture occurs. In our design, the rubber will be placed between the wiper and magnet and it will be mainly affected by the compression.

## 2.4 User Needs

The user needs are critical to take into account when designing a new product. This section consists of the customer interview details, interview notes, and the interpreted user needs.

### 2.4.1 Customer Interview

Interviewee: Prof. Chiamaka Asinugo

Location: Jolley 110, Washington University in St. Louis, Danforth Campus

Date: September 6<sup>th</sup>, 2019

Setting: We interviewed the customer about their basic needs for the product as well as their thoughts on ideas we had for the design. The interview was conducted in a classroom and took roughly 30 minutes.

Interview Notes:

*What is the biggest problem with how you currently clean a white board?*

- Takes up lecture time when it should not have to. Should not be an interruption to the flow of the lecture.

*How portable does the product need to be?*

- It should be compact enough to fit in a small bag and carry around campus.

*Do you want it to erase the board in a way that will make the cleaned parts accessible before it has completely finished erasing?*

- Efficiency is a bigger priority, but I wouldn't mind if it could erase in a fun way.

*What would be an acceptable setup time?*

- Something that can just hook onto the top would be ideal.

*Do you want it to be easily repaired by yourself?*

- Would be nice if it was easy to change out the eraser.

### 2.4.2 Interpreted User Needs

Listed below in Table 1 are the interpreted needs from the costumer interview.

Table 1: Interpreted Customer Needs

Need Number	Need	Importance
1	The ABE is easy to transport	5
2	The ABE is aesthetically pleasing	1
3	The ABE is not disruptive to the class	5
4	The ABE can be set up efficiently	5
5	The ABE is efficient	4
6	The ABE has multiple functions	2
7	The ABE is wireless	4
8	The ABE operates several times before recharging	4

A rating of 1 to 5 was determined for the level of importance of each interpreted need listed above.

## 2.5 Design Metrics

In the following table, Table 2, are the design metrics for our Automatic Whiteboard Eraser.

Table 2: Target Specifications

Metric Number	Associated Needs	Metric	Units	Acceptable	Ideal
1	1	Total weight	kg	4.5	6.8
2	1	Total volume	$in^3$	$< 40$	$< 20$
3	2	Battery life	Cycles	15	20
4	3	Maximum part movement when shaken firmly by hand	mm	$> 2$	$> 5$
5	5	Number of drops from hip height onto hard surface before malfunction	integer	$> 3$	$> 5$
6	6	Set up time	minutes	3	5
7	7	Time required to erase board	minutes	$> 7$	$> 10$

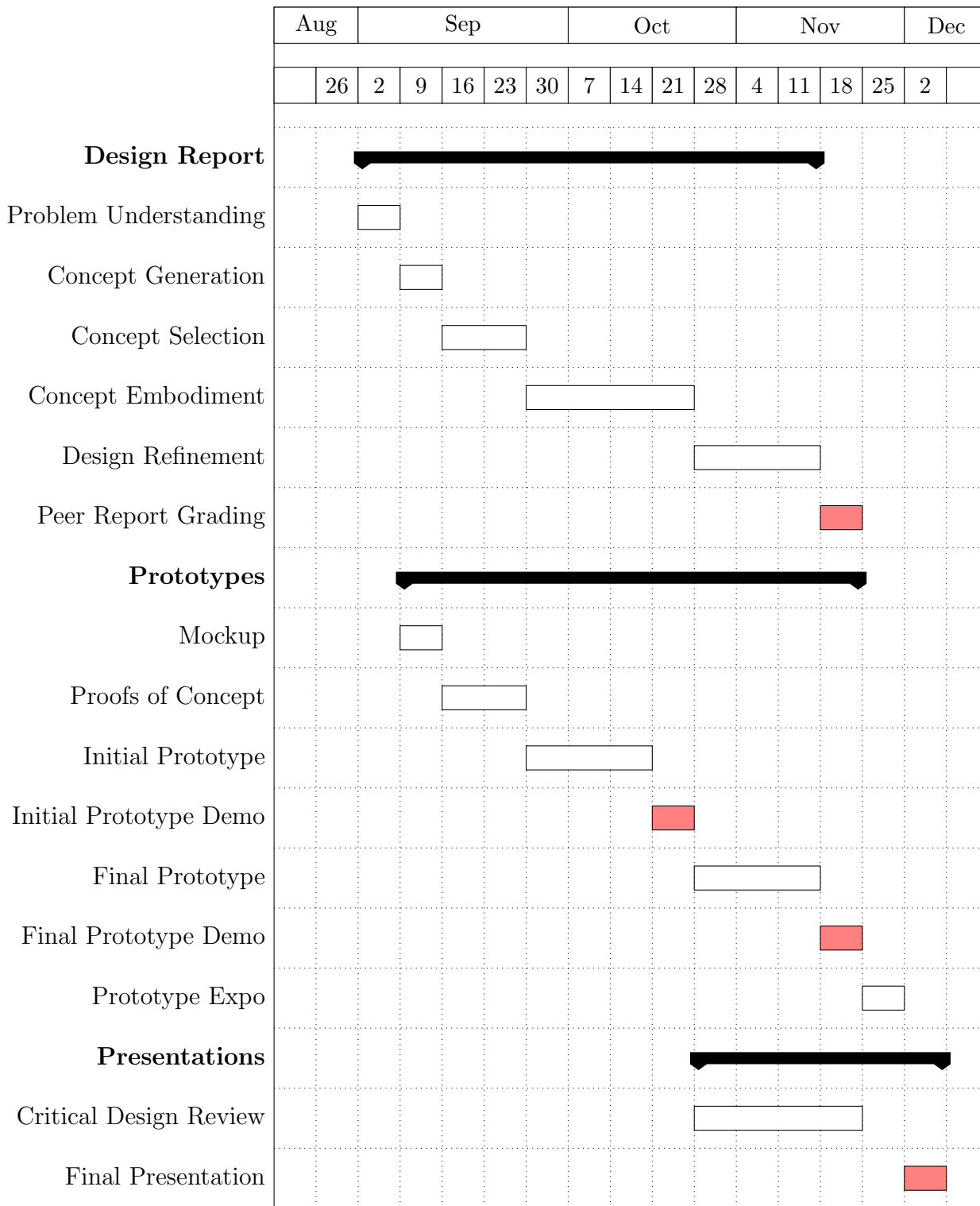


Figure 9: Gantt chart for design project

### 3 Concept Generation

#### 3.1 Mockup Prototype

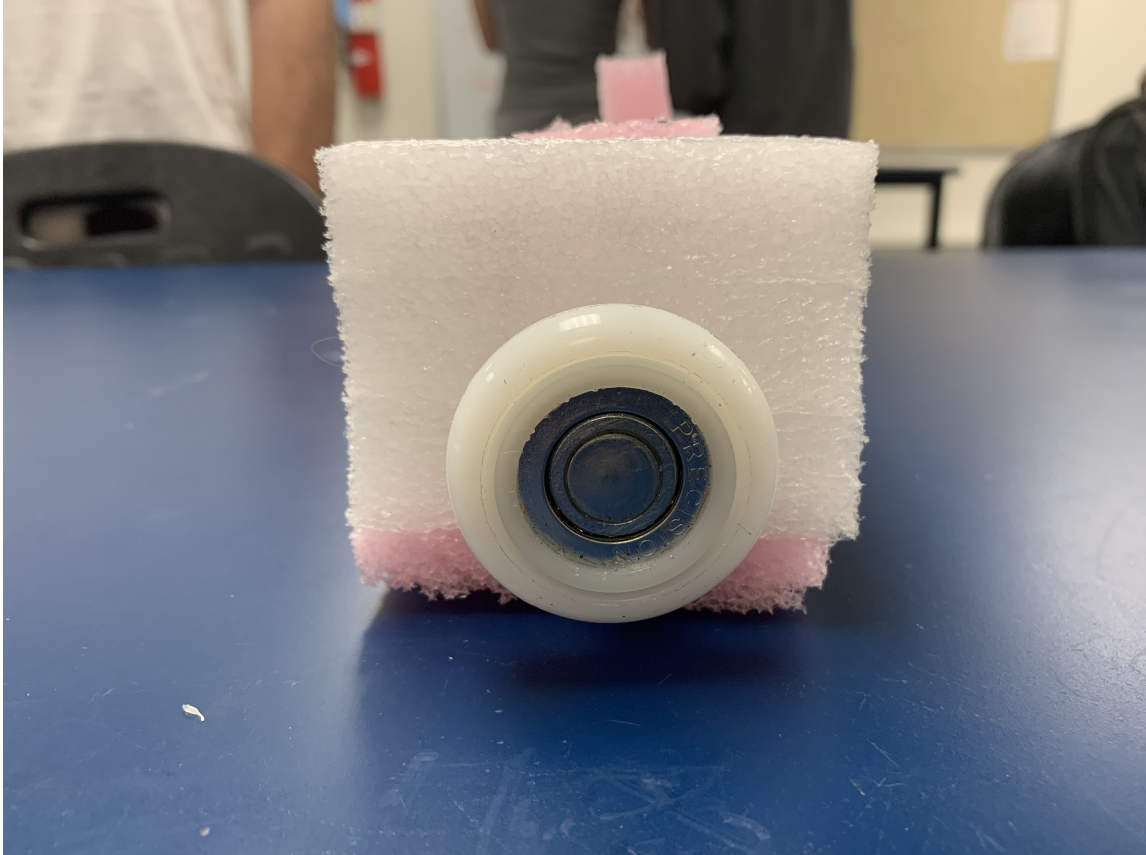


Figure 10: Side view of prototype

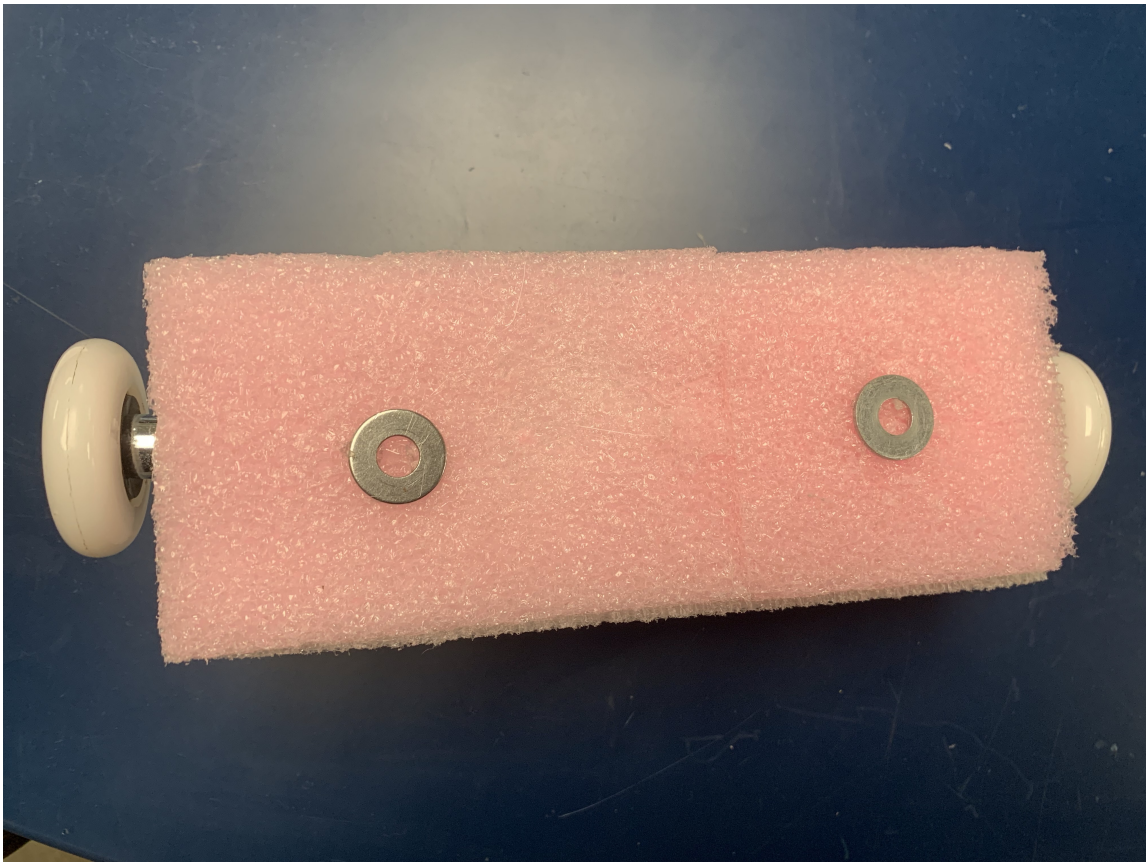


Figure 11: Bottom view of prototype



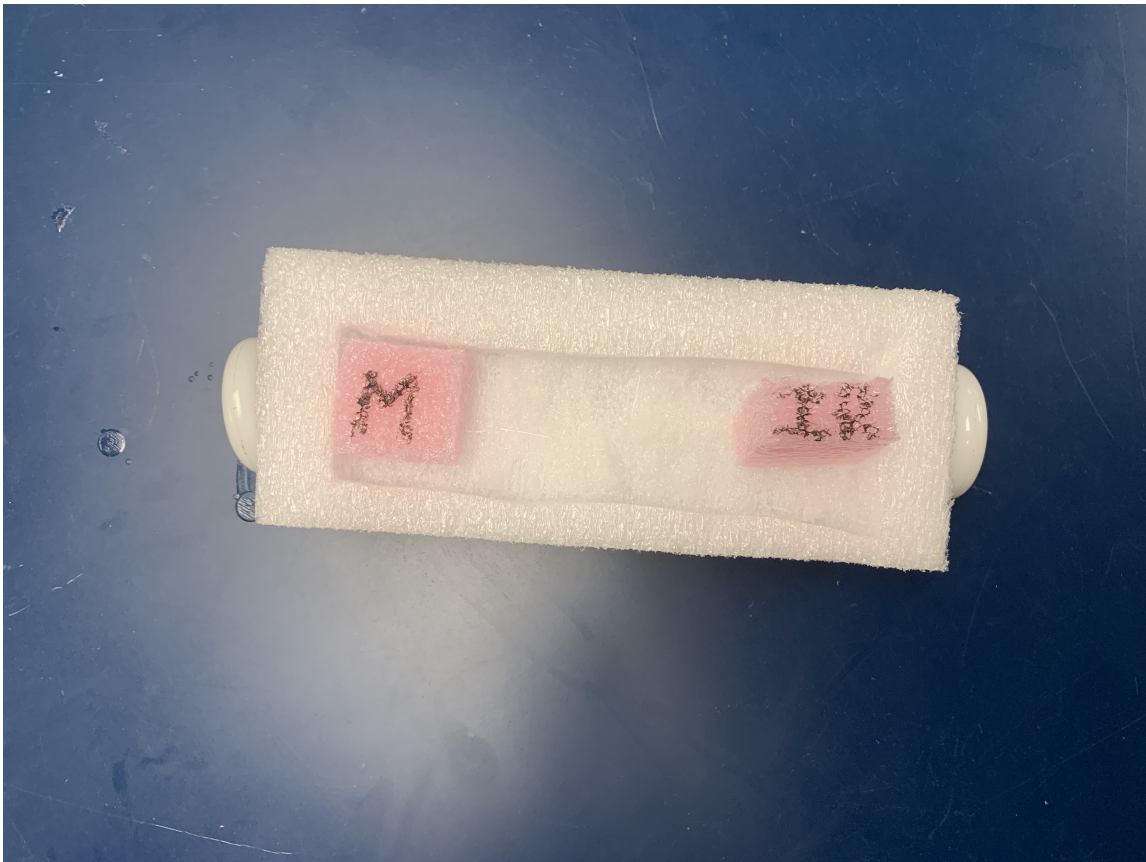


Figure 12: Top view of prototype

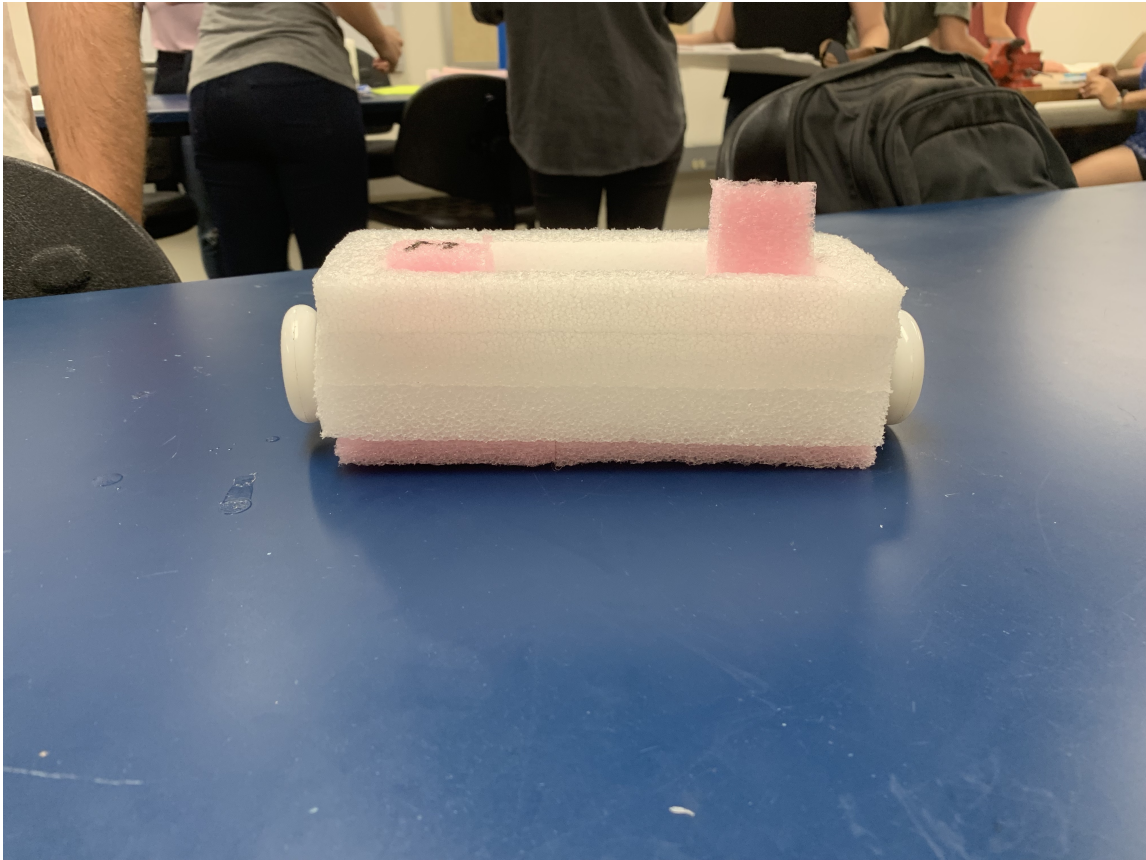


Figure 13: Front view of prototype

This prototype is based on the idea of using a two-wheel robot, which can be programmed to follow the certain path in order to clean up the white board. According to this prototype, we started to think about the number of passes we want the robot to cover the whole board. Also, the size of the robot has to be considered. Because if it's too large, the magnet may not provide enough magnetic force to tightly attach the robot on the board. In addition, this prototype enables us to specify the dominant components in the robot such as motor, transmission system and infrared distance measurement system. Another important thing is that due to the smoothness of the white board, we need to choose some material for wheel with high roughness. Otherwise, it won't provide sufficient friction for robot to move.

## 3.2 Functional Decomposition

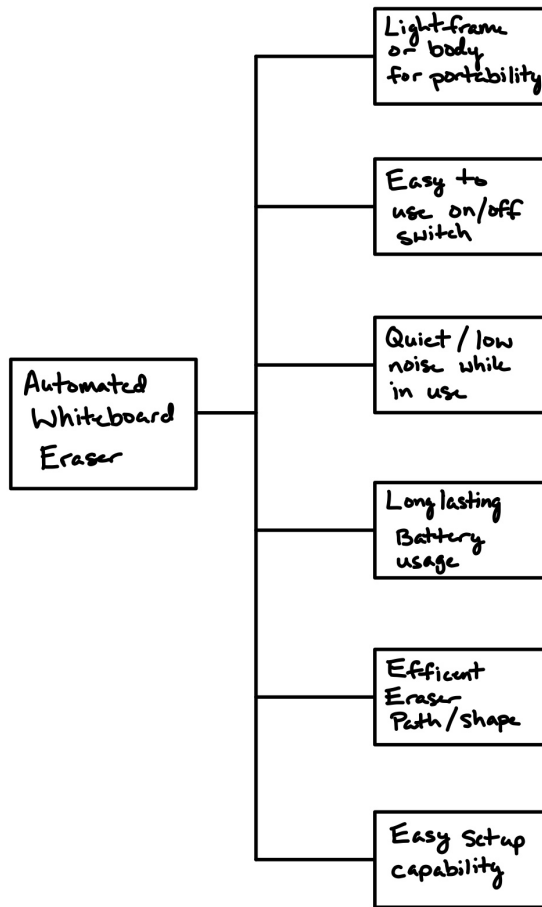


Figure 14: Function tree for Automatic White Board Wiper

### 3.3 Morphological Chart

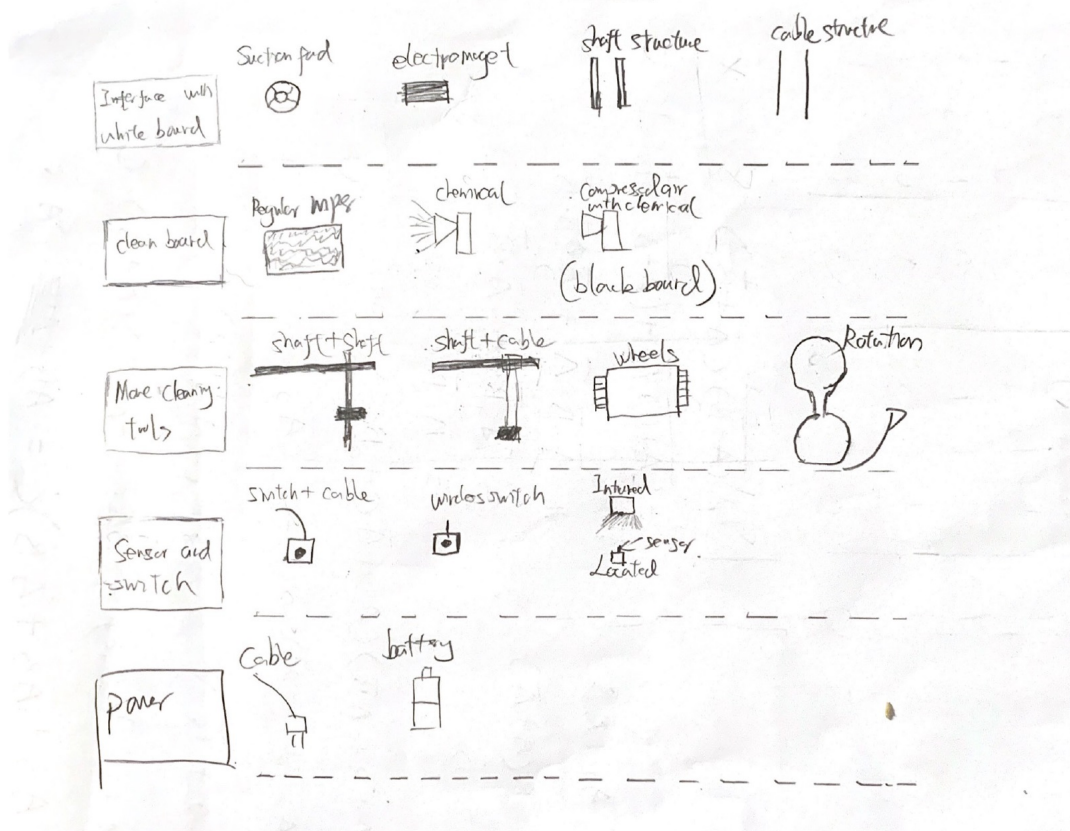


Figure 15: Morphological Chart for Automatic Whiteboard Wiper

### 3.4 Alternative Design Concepts

#### 3.4.1 Shaft-Cable System

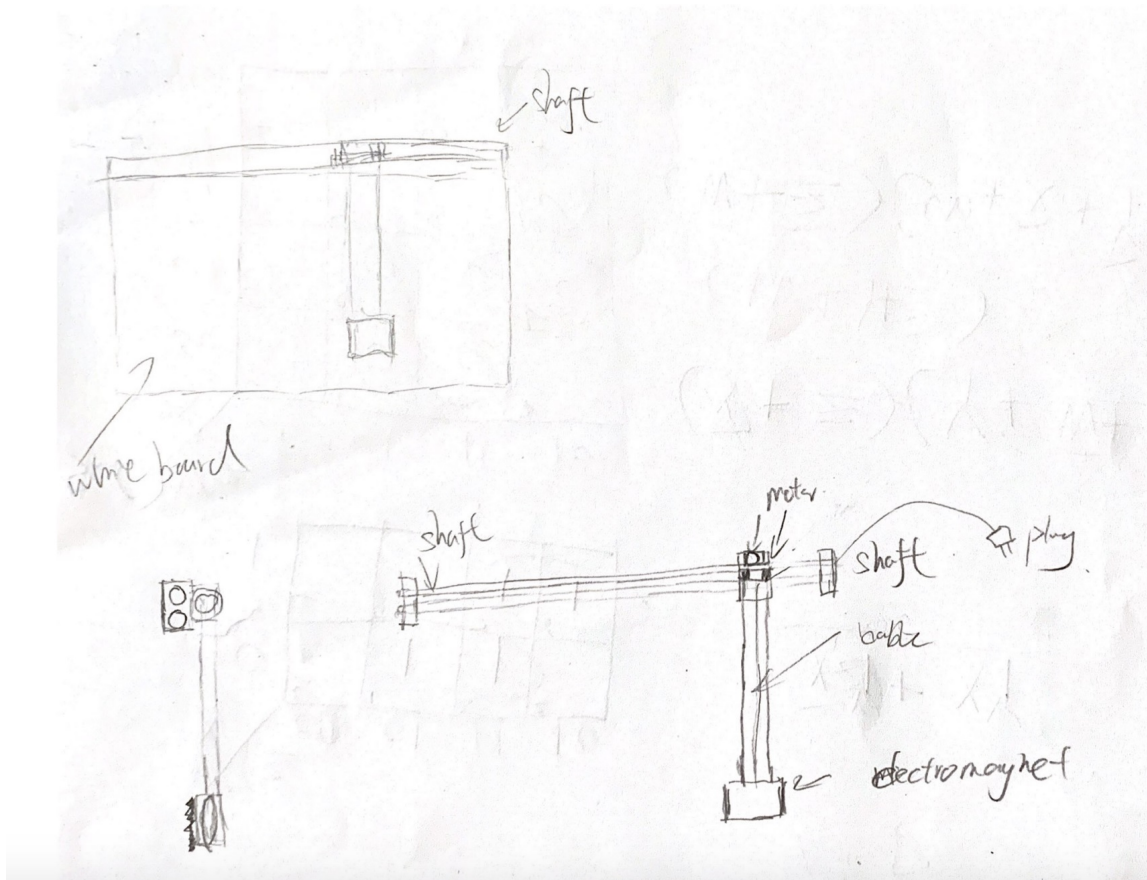


Figure 16: Preliminary sketches of Shaft-Cable System



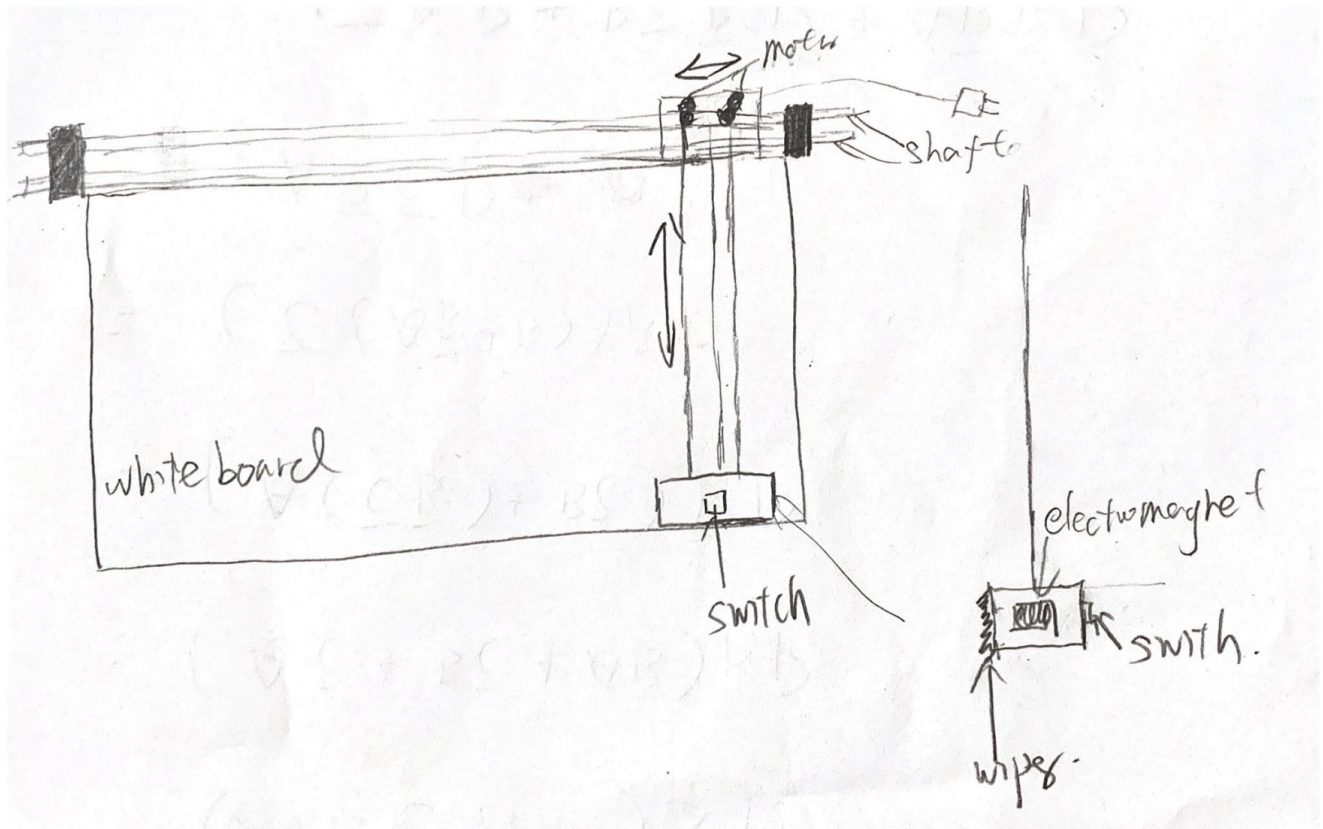


Figure 17: Final sketches of Shaft-Cable System concept

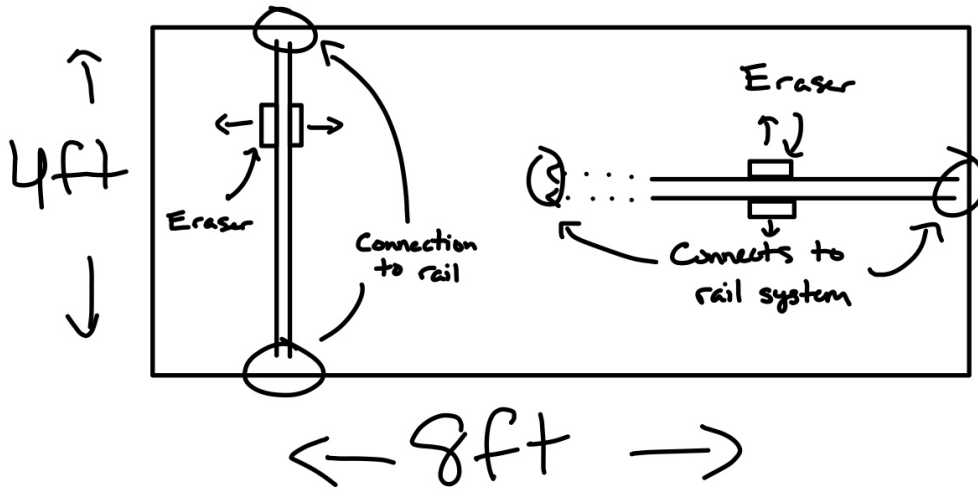
Solutions from morph chart:

1. Electromagnet
2. Regular Wiper
3. Shaft-Cable
4. Wireless Switch
5. Cable

Description: The Shaft and Cable system uses the shaft to move the wiper horizontally and uses the cables to move the wiper vertically. The idea came from the crane. The complicated shaft system would take too much space for the board and does not look good for a classroom. In order to provide enough pressure to wipe the board, the electromagnet is introduced to the wiper. Once the wiper is lowered to the bottom of the whiteboard, current start to generate magnetic force from the electromagnet and provide a force against the whiteboard. The motor on the shaft would start to pull the wiper upward to clean the board. Each line is finished, the wiper would be lowered again and move to the next line by the shaft.

### 3.4.2 Rail Erase System

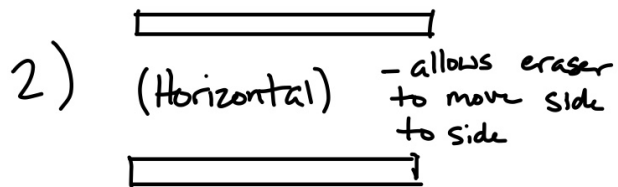
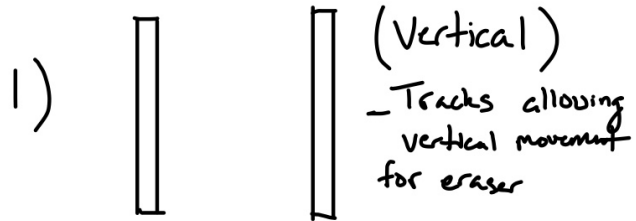
#### Rail Erase System:



#### Thickness:

3/8 in.

#### Rail system:



#### Erasers:



Rectangular



Circular

#### Power:

- Battery

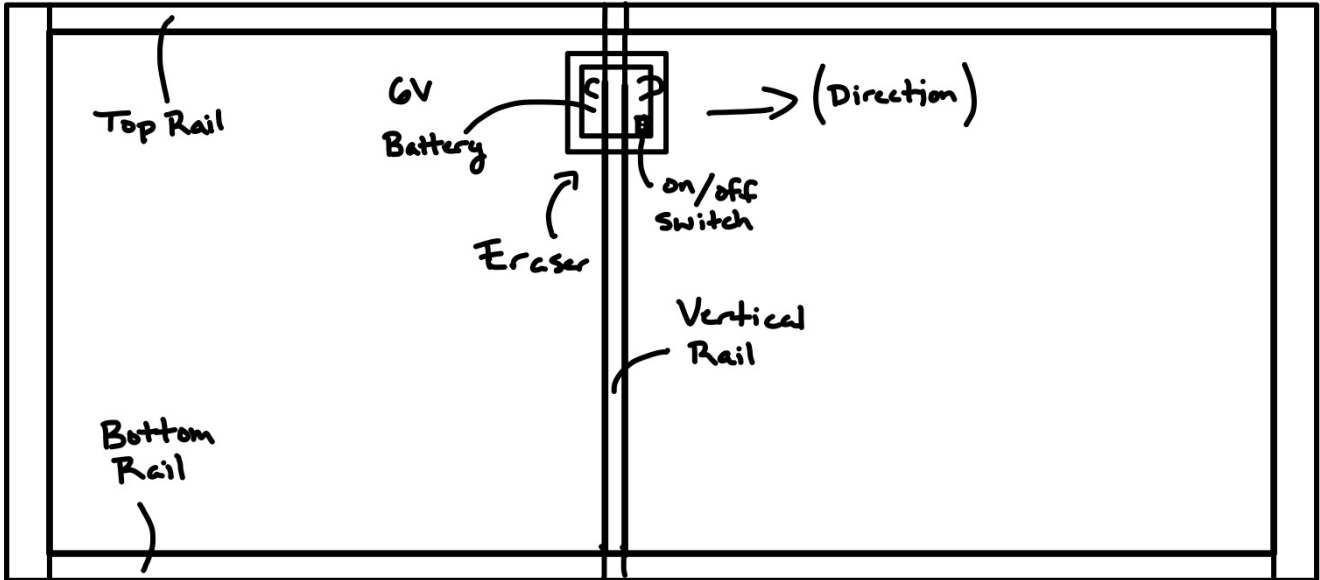


- Wall plug

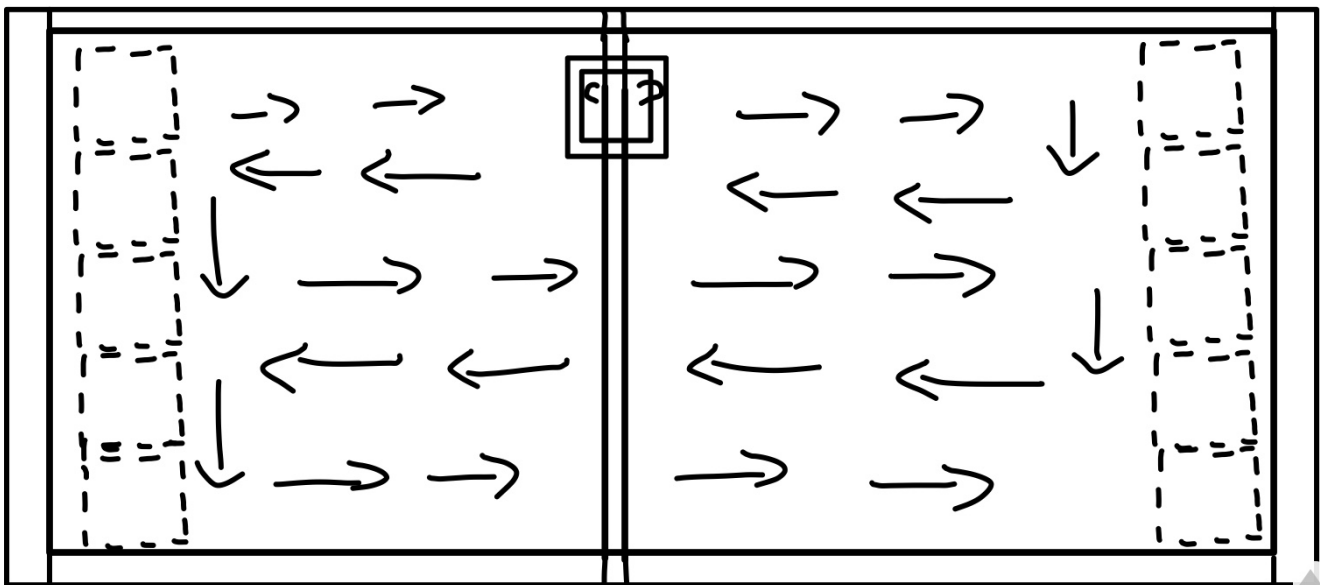


Figure 18: Preliminary sketches of Rail Erase System

# Final Design:



## Path of Eraser:



2  
3



Figure 19: Final sketches of Rail Erase System concept



Solutions from morph chart:

1. On/off switch
2. Power Source
3. Rail System
4. Eraser
5. Circuit board

Description: The Rail Erase System uses a three rails to efficiently wipe and clear a whiteboard. Two of the rails fit on the top and bottom edges of the whiteboard. Once in place a on/off button is used to turn on on the rail system as it begins to move from right to left. Once an end of the board is reached, the third rail system moves to eraser down a desired length. The eraser then continues back to the opposite side as it erases. As the eraser moves across, downward pressure is created allowing the eraser to make a clean swipe across the board until completion.

**3.4.3 Erasing Robot**

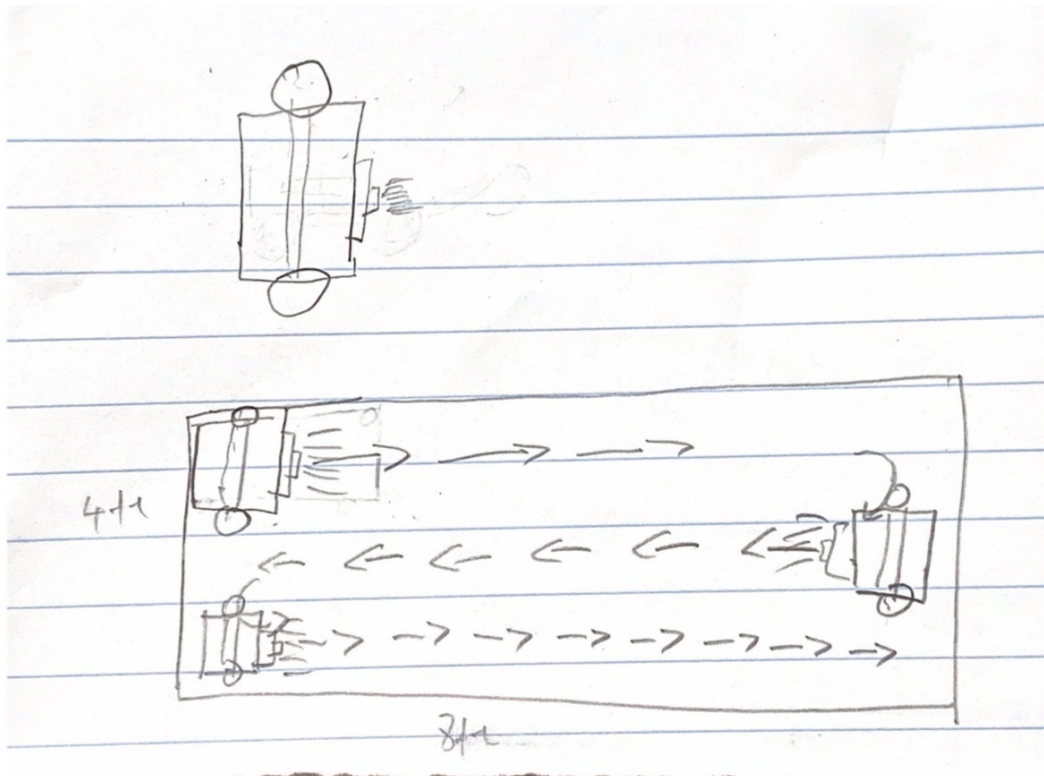


Figure 20: Preliminary sketches of Erasing Robot System

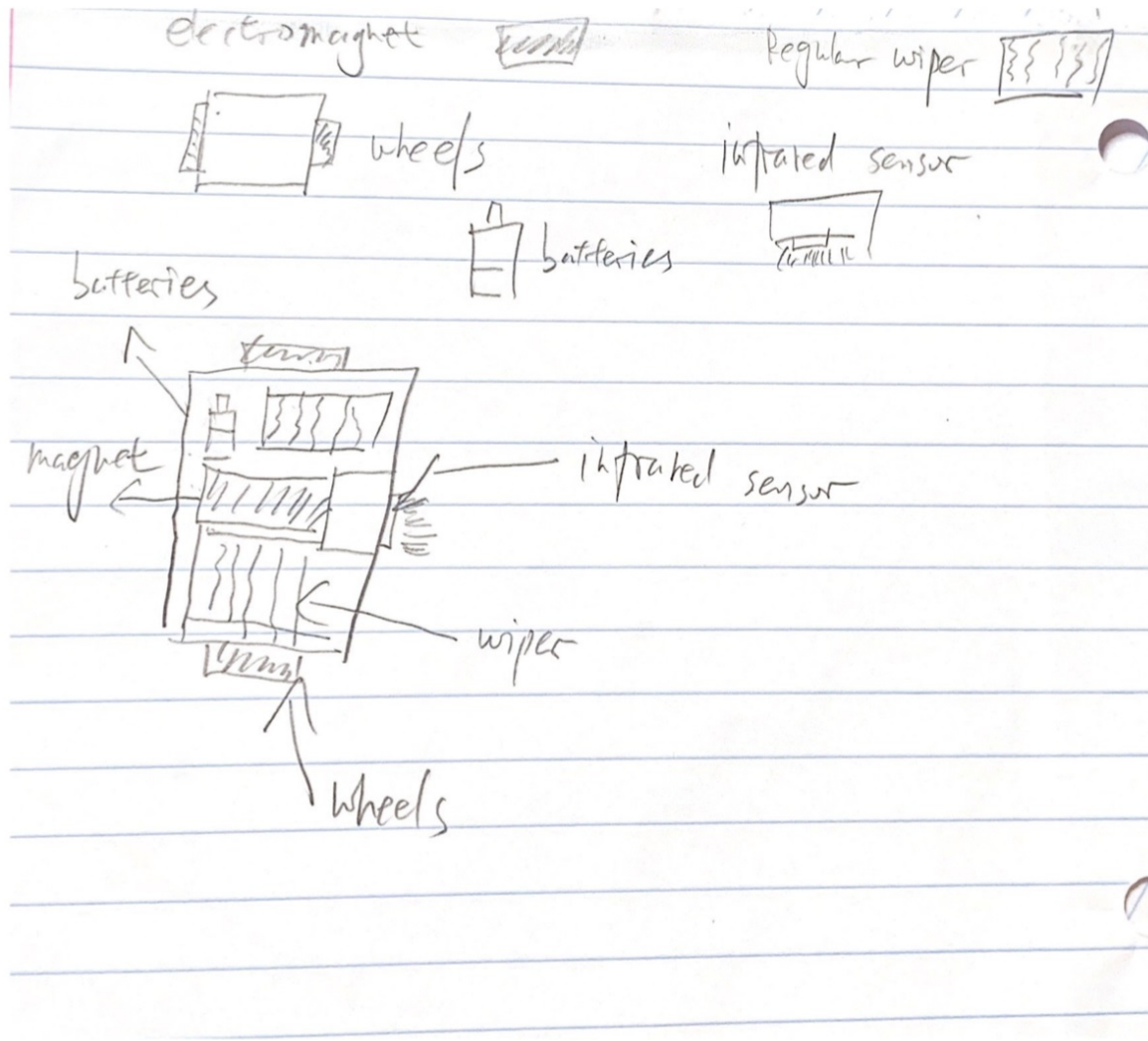


Figure 21: Final sketches of Erasing Robot System concept

Solutions from morph chart:

1. Electromagnet
2. Regular Wiper
3. Wheels
4. Infrared Sensor
5. Battery

Description: This is a two-wheel robot, which can move along the certain path on the white board. The power of the robot is provided by the rechargeable lithium battery and has infrared distance detection system, which enables to turn in the opposite direction when the robot reaching one side of the board frame. The turning of the robot is achieved by self-locked one side of the wheel and the other one slowing moves 180 degrees. The electromagnet will provide sufficient attraction force once the power is on.

### 3.4.4 Windshield Wiper Concept

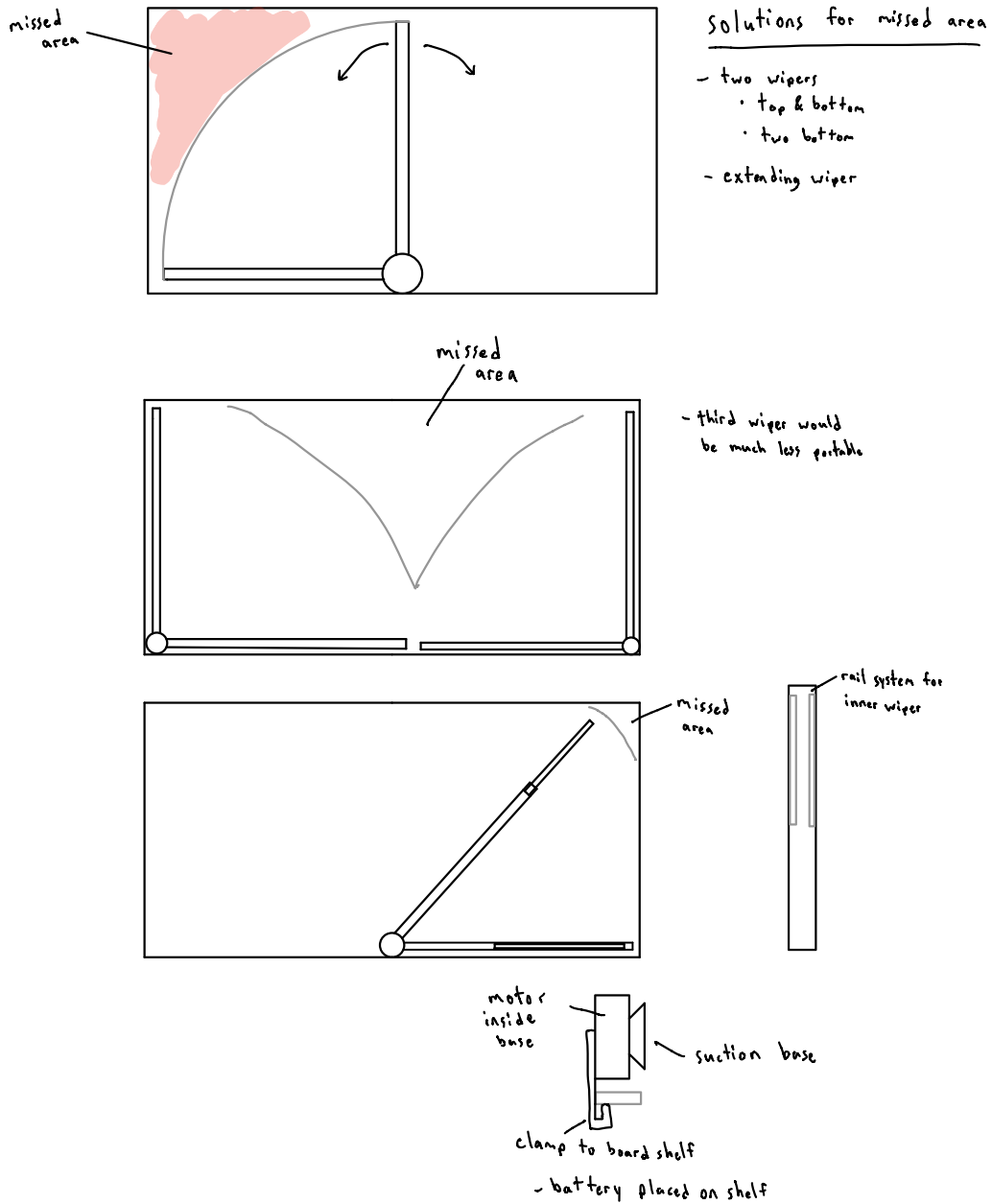


Figure 22: Preliminary and final sketches of Windshield Wiper Concept

Solutions from morph chart:

1. Suction Cup

2. Regular Wiper
3. Rotation
4. Switch
5. Battery

Description: This is a suction-mounted concept that is comparable to the windshield wiper found on cars. It incorporates a secondary wiper within the main wiper that extends to reach the top corners of the whiteboard. The rechargeable battery itself will sit on the shelf of the whiteboard and has a button for startup located on the suction base. The motor is contained within the base to rotate the wiper 180 degrees.

## 4 Concept Selection

### 4.1 Selection Criteria

There are six important criteria we think are important for our design. Safety is important for any classroom facility. The comfortability level tells how easy to use the product. The portability is another aspect that customer required. The efficiency is important for classroom. The customer had specific time requirement for the AHP.

	Portability	Safety	Efficiency	Cost	Comfortability	Easy To Manufacture	Row Total	Weight Value	Weight (%)
Portability	1.00	0.33	0.17	0.33	0.33	0.25	2.42	0.05	4.61%
Safety	3.00	1.00	1.00	2.00	3.00	1.00	11.00	0.21	20.99%
Efficiency	6.00	1.00	1.00	2.00	3.00	3.00	16.00	0.31	30.52%
Cost	3.00	0.50	0.50	1.00	2.00	1.00	8.00	0.15	15.26%
Comfortability	3.00	0.33	0.33	0.50	1.00	0.50	5.67	0.11	10.81%
Easy to Manufacture	4.00	1.00	0.33	1.00	2.00	1.00	9.33	0.18	17.81%
	<b>Column Total:</b>						<b>52.42</b>	<b>1.00</b>	<b>100%</b>

Figure 23: Analytic Hierarchy Process (AHP) to determine scoring matrix weights

### 4.2 Concept Evaluation

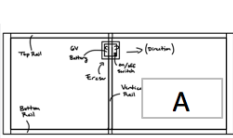
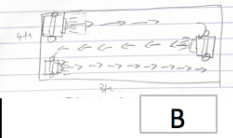
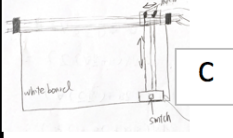
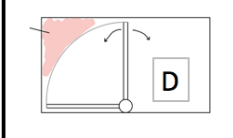
Alternative Design Concepts									
Selection Criterion	Weight (%)	Rating	Weighted	Rating	Weighted	Rating	Weighted	Rating	Weighted
Portability	4.61	1	0.05	5	0.23	3	0.14	4	0.18
Safety	20.99	3	0.63	2	0.42	2	0.42	4	0.84
Efficiency	30.52	4	1.22	1	0.31	4	1.22	5	1.53
Cost	15.26	5	0.76	2	0.31	4	0.61	3	0.46
Comfortability	10.81	3	0.32	3	0.32	3	0.32	3	0.32
Easy To Manufacture	17.81	5	0.89	1	0.18	5	0.89	1	0.18
	<b>Total score</b>	<b>3.874</b>		<b>1.763</b>		<b>3.604</b>		<b>3.510</b>	
	<b>Rank</b>	<b>1</b>		<b>4</b>		<b>2</b>		<b>3</b>	

Figure 24: Weighted Scoring Matrix (WSM) for choosing between alternative concepts

### 4.3 Evaluation Results

As we can generalized from the criteria table, efficiency is the primary factor that we concern the most, because we need whiteboard eraser to finish wiping in the shortest amount of time. Besides the efficiency, three other factors that we are going to concern more are safety, cost and easy to Manufacture. As for portability, in order to achieve all those more important goals we have, It's hard to put more weight on portability.

According to the criteria weight listed above, Concept A scores the highest point overall. Compared with concept C, the biggest difference is that concept A has fixed rack on each side and concept C has wheels attached to the end of beam enabling to move along the edge of the board. Fixed-rack-design will be safer than the moving-rack-design because moving-rack has the potential risk of slipping off. As for concept B, wiping robot can't move too fast and it's lack of stability. In addition, as for concept D, it has advantage of simplicity and high efficiency, but it won't be able to cover through the whole board, which is the fatal defect of this design.

### 4.4 Engineering Models/Relationships

The engineering models/relationships below show the different aspects of our project and how they relate/differ. The first is the relationship between the radius of our motor gear and distance the eraser travels. The second model/relationship is ratio between the eraser and white board area. And the third model/relationship is a diagram comparing the difference in material for our horizontal support bar.

Shown below is the motor gear radius and motor RPM relationship.

<b>Radii for varying RPMs</b>						
<b>RPM (rotations/min)</b>	50	60	70	80	90	100
<b>Radius (in)</b>	0.31	0.25	0.22	0.19	0.17	0.15

Figure 25: Calculated radii for varying motor RPMs

The equation used to find these radii is as follows:

$$L = C * \omega$$

where  $L$  is the length of the board (96 in.),  $C$  is the circumference of the motor gear and  $\omega$  is the rotations per minute. This relationship allows us to design a gear for a motor of specified RPMs that will enable the eraser to cross the whiteboard in one minute. It can be seen in the table that a faster motor requires a smaller gear radius to achieve a traveled distance of 96 in. in one minute. It should be noted that a higher RPM will result in less torque and thus a larger gear radius is optimal.

Shown below is the relationship between the height of the white board compared to different size erasers.

## Ratio between eraser and whiteboard

Heights:

White board : 48in ; Erasers : 1) 5in  
2) 10in

Ratio's: 1)  $\frac{48\text{in}^2}{5\text{in}^2} = \underline{9.6}$  3) 13in

2)  $\frac{48\text{in}^2}{10\text{in}^2} = \underline{4.8}$

3)  $\frac{48\text{in}^2}{13\text{in}^2} = \underline{3.69}$

Figure 26: Relationship between whiteboard height and eraser heights

Here we can compare the ratios of the whiteboard height against the height of different erasers. With these ratios we can determine which eraser will cover the height of the whiteboard in an efficient manner. The less the eraser has to move down and make another pass across the board, the less time to erase the entire board.

Shown below is the engineering model showing the amount of deflection based of the material used.

Material	Mass (g) * 2	Force / 2 (lbs)	Deflection (in)
Steel	4,977.38	0.75	2.4
Aluminum	1,710.04	0.75	6.9
Brass	5,212.22	0.75	4.5
Titanium	2,787.38	0.75	4.5

Figure 27: Deflection of different material

This table shows the amount of deflection the two bars will endure with different materials. The

mass is multiplied by two due to having two bars supporting the eraser and its holder. The force is divided by two due to having two support bars on each side supporting the load.

## **5 Concept Embodiment**

### **5.1 Initial Embodiment**

Shown below the CAD drawings of our Initial Prototype.



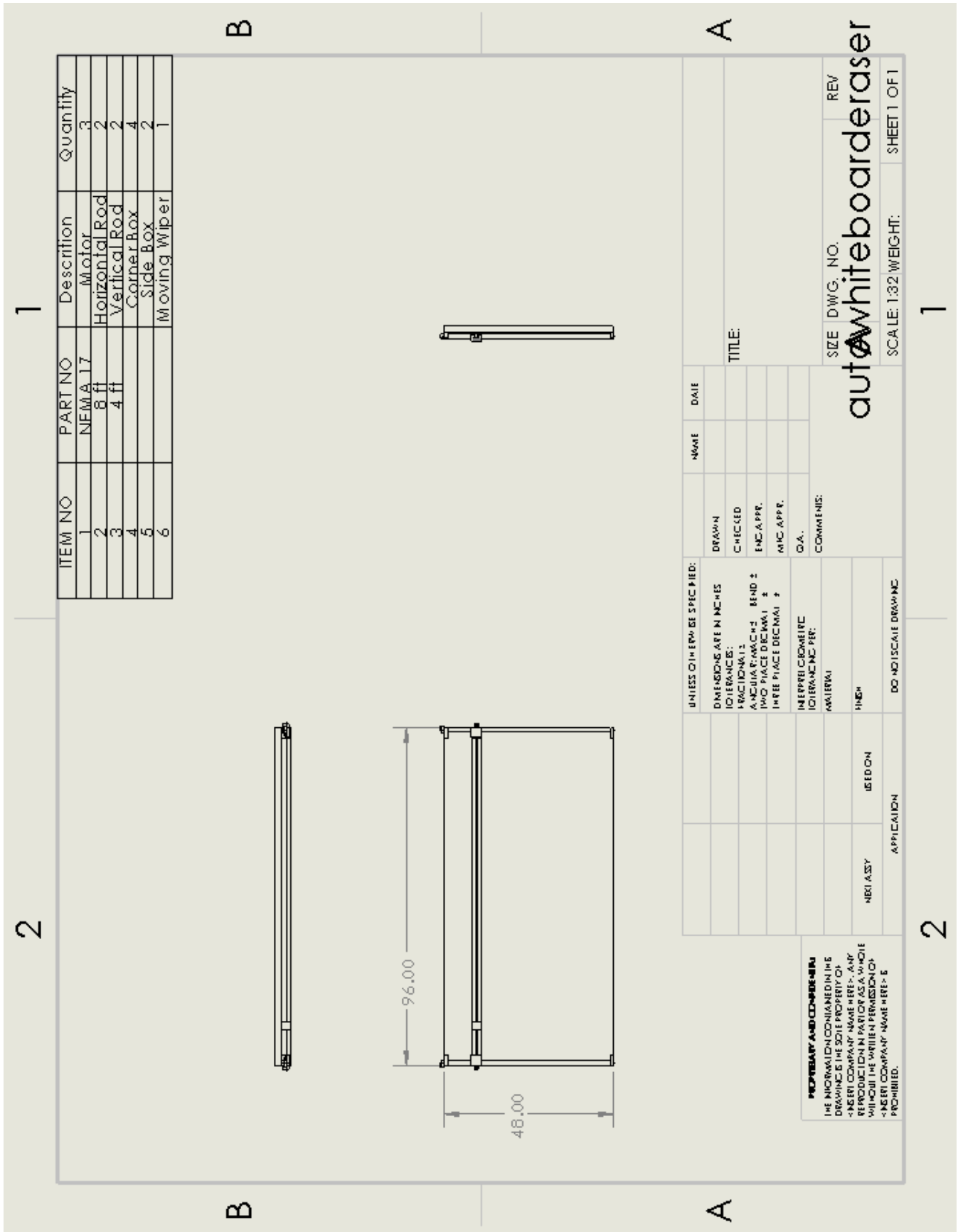


Figure 28: Assembled projected views with overall dimensions

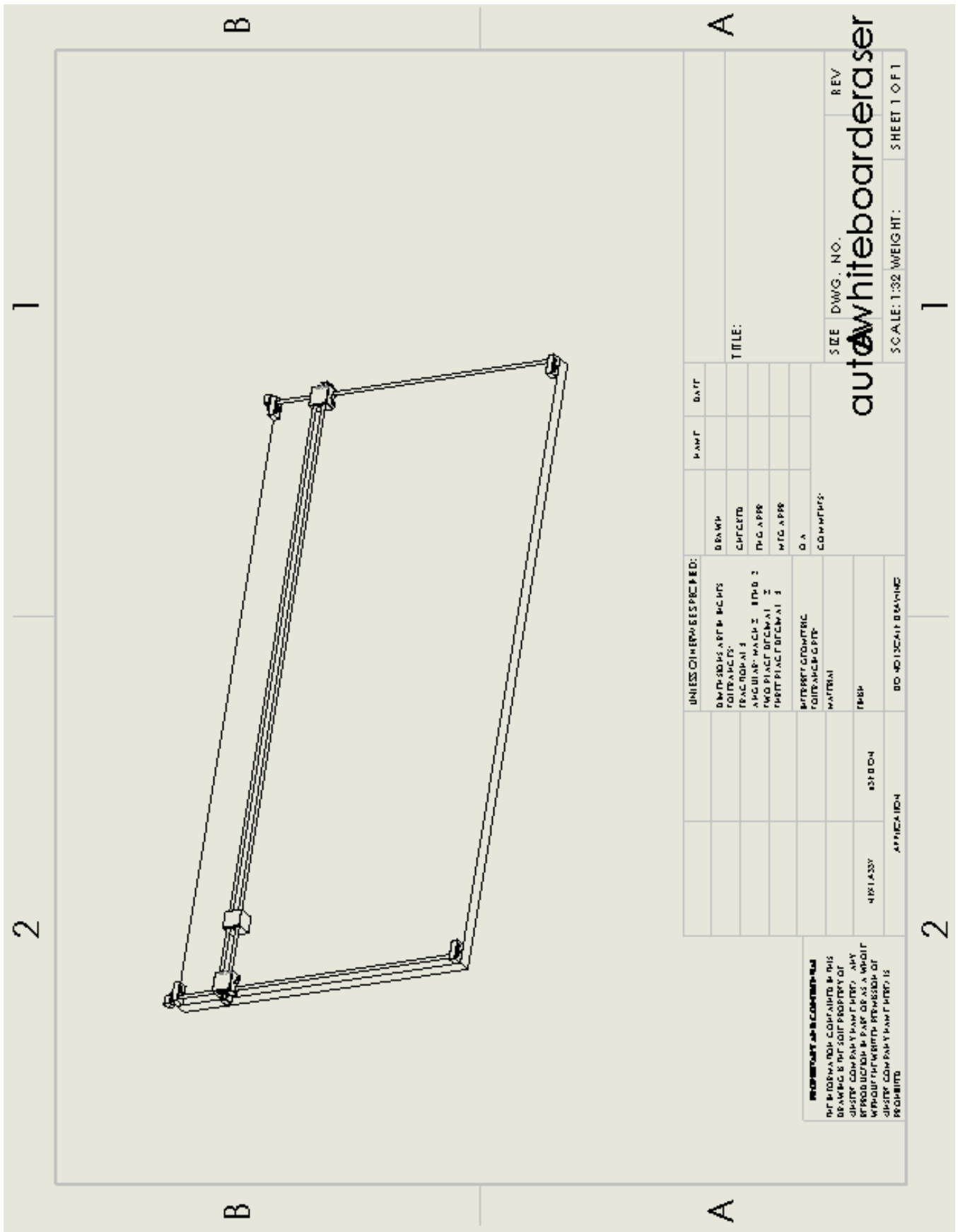
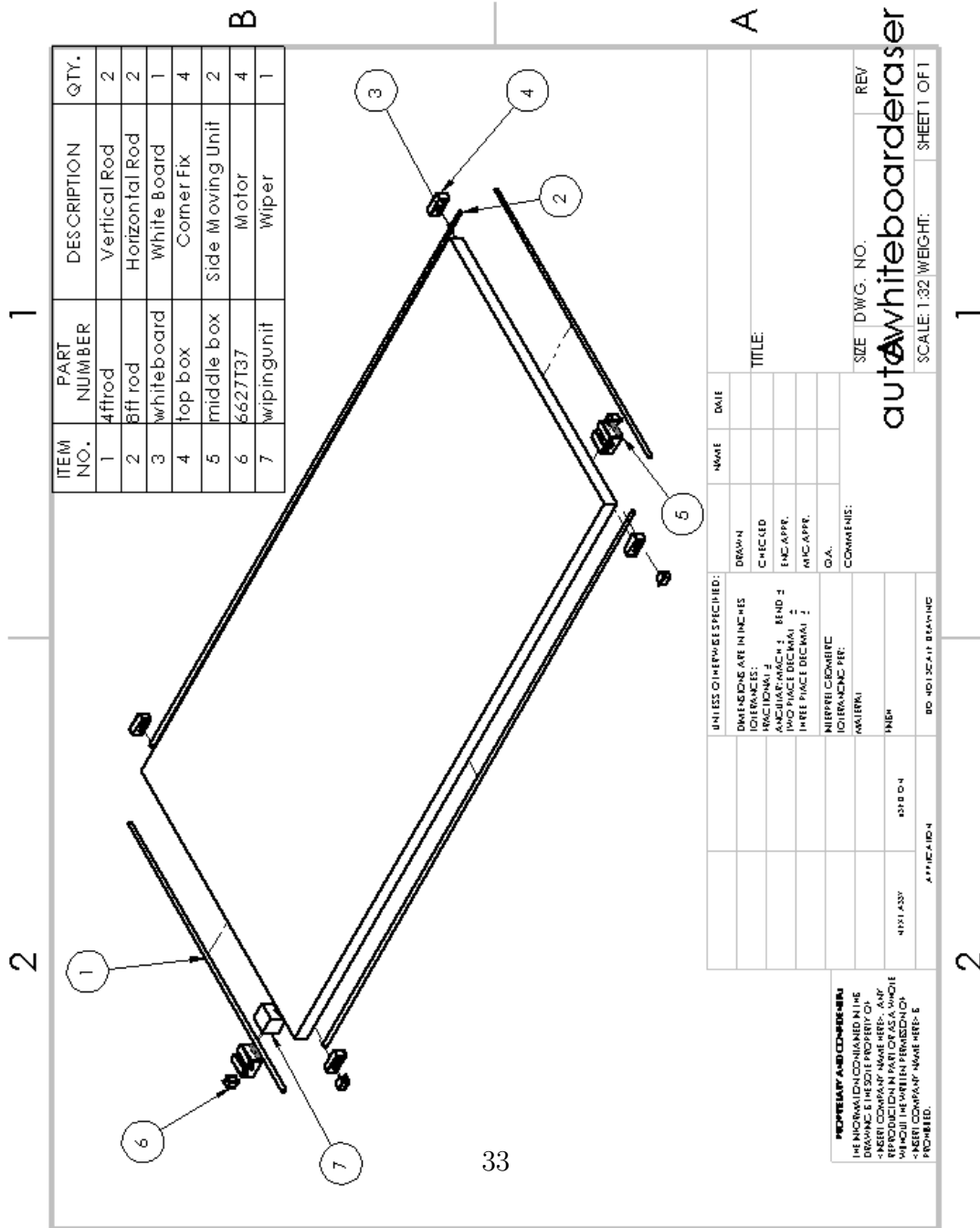


Figure 29: Assembled isometric view

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<p>APPLICATION</p>		<p>DESCRIPTION</p>		<p>DATE</p>		<p>SCALE: 1:32 WEIGHT:</p>		<p>SHEET 1 OF 1</p>		<p>autowhiteboarder</p>		<p>1</p>	



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	4ffrod	Vertical Rod	2
2	8ff rod	Horizontal Rod	2
3	whiteboard	White Board	1
4	top box	Corner Fix	4
5	middle box	Side Moving Unit	2
6	6627137	Motor	4
7	wipingunit	Wiper	1

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONS ± .005 DECIMALS ± .001 ANGLES ± .01 HOLE POSITION ± .010 HOLE DIA. ± .005		NAME	DATE
DRAWN	CHECKED		
DESIGNED	APPROVED		
MANUFACTURED	TESTED		
ASSEMBLED	INSPECTED		
COMMENTS:		SIZE DWG. NO. REV	
AUTOMATICALLY GENERATED DRAWING		AUTOMATICALLY GENERATED DRAWING	
DATE: 02/10/04		SCALE: 1:32 WEIGHT: SHEET 1 OF 1	

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autowhiteboarder

The following table is the list of the initial prototype components

Item Number	Name	Description	Qty.
1	4 ft Vertical Rod	Control the vertical motion	2
2	8 ft Horizontal Rod	Control the horizontal motion	2
3	White Board	White Board	1
4	Corner Box	Fix the 4 sides	4
5	Middle Box	Control the horizontal motion	1
6	Motor	Pull the belt	3
7	Wiper Unit	Wipes the white board	1
8	Spindle	Attached to motor and pull belt	3
9	Timing Belt	Exert force to the body	3



this the 10 inch eraser is the more effective as it takes exactly 4 passes to erase the board and will end up on the left side of the board after its last pass. Ending on the left side of the board allows for an easy transition back the top of the board, ready for the next time of use.

$$\begin{aligned}
 L &= c \omega t & c &= 1 \text{ rotation} \\
 r t &= \frac{L}{2\pi \omega} & 2\pi r &= 1 \text{ rotation} \\
 r t &= \frac{96 \text{ in}}{2\pi (3 \text{ s}^{-1})} & \text{assume } \omega &= 3 \text{ rot/s} \\
 r t &= \frac{16}{\pi} \text{ in}\cdot\text{s} & \omega &= 3 \text{ s}^{-1} \\
 r t &= 5.09 \text{ in}\cdot\text{s} \\
 r &= \frac{5.09 \text{ in}\cdot\text{s}}{t} & t &< 60 \text{ s} \\
 r &= \frac{5.09 \text{ in}\cdot\text{s}}{60 \text{ s}} \\
 r &= 0.084 \text{ in}
 \end{aligned}$$

Figure 33: Minimum Spindle Radius Calculation

The initial equation used above in 33 is the spindle circumference multiplied by the motor's rotational speed and time it takes the eraser to cross the width of the board. This is equivalent to the width of the board. This equation was derived by translating the spindle circumference and rotational speed into a distance. A motor rotational speed of 3 rotations/second was assumed for the motors used in this design. The time was defined to be less than 60 seconds because a maximum total erasing time of 5 minutes is desired. With the eraser doing four total passes on the board results in a time of 4 minutes, but does not account for the time it takes to move the eraser down after completing each pass. With a rotational speed of 3 rotations/second and a time of 60 seconds, the minimum spindle radius was found to be 0.084 inches. A diagram of the components can be seen below in Fig.34.

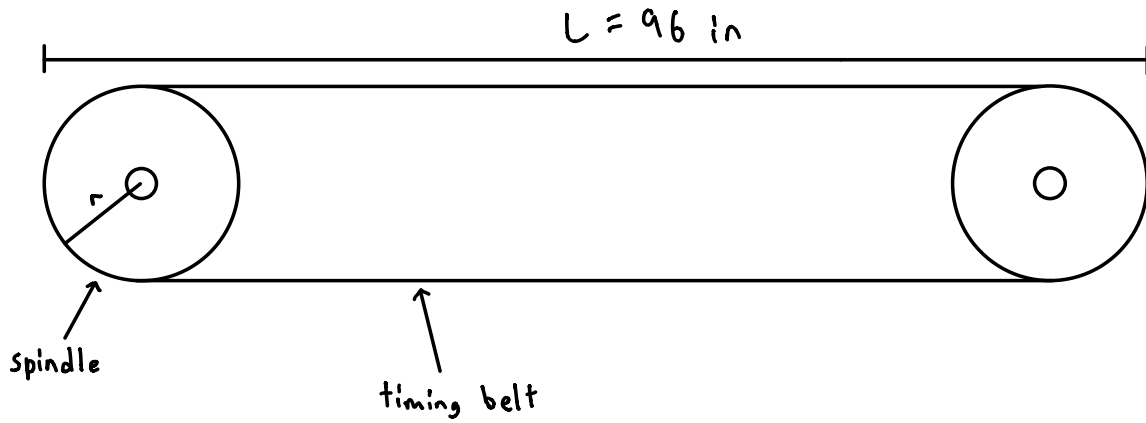


Figure 34: Timing Belt and Motor Spindle Diagram

We had three goals for our initial prototype. The first was to erase a whiteboard (4ft x 8ft) in less than 5 minutes. The second goal was to have the before and after images of a marked and erased board will have an are difference of less than 20 percent with paint.net want magic tool with tolerance of 80 percent. The last goal is that our system can be mounted on at least 3 different board sizes. The whiteboards in Jolley 110, Jolley 111, and the basement.

## 5.2 Proofs-of-Concept

Shown below are three pictures of our Proof-of-Concept prototype. The first picture shows the conceptual idea of a how the frame should be designed and attach to the additional components of the system. The second photo is of the lead screw to help with the vertical movement of the eraser. The thirds photo shows the mounting system.



Figure 35: Proof-of-Concept Prototype Frame



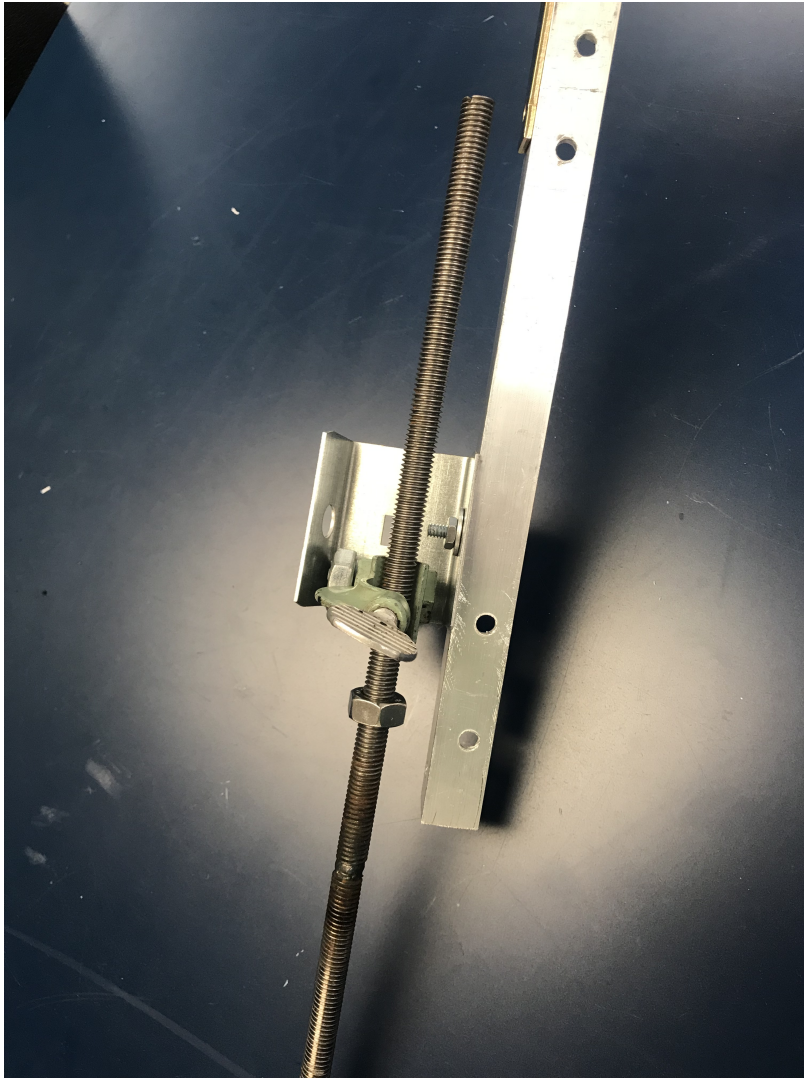


Figure 36: Proof-of-Concept Prototype Lead Screw

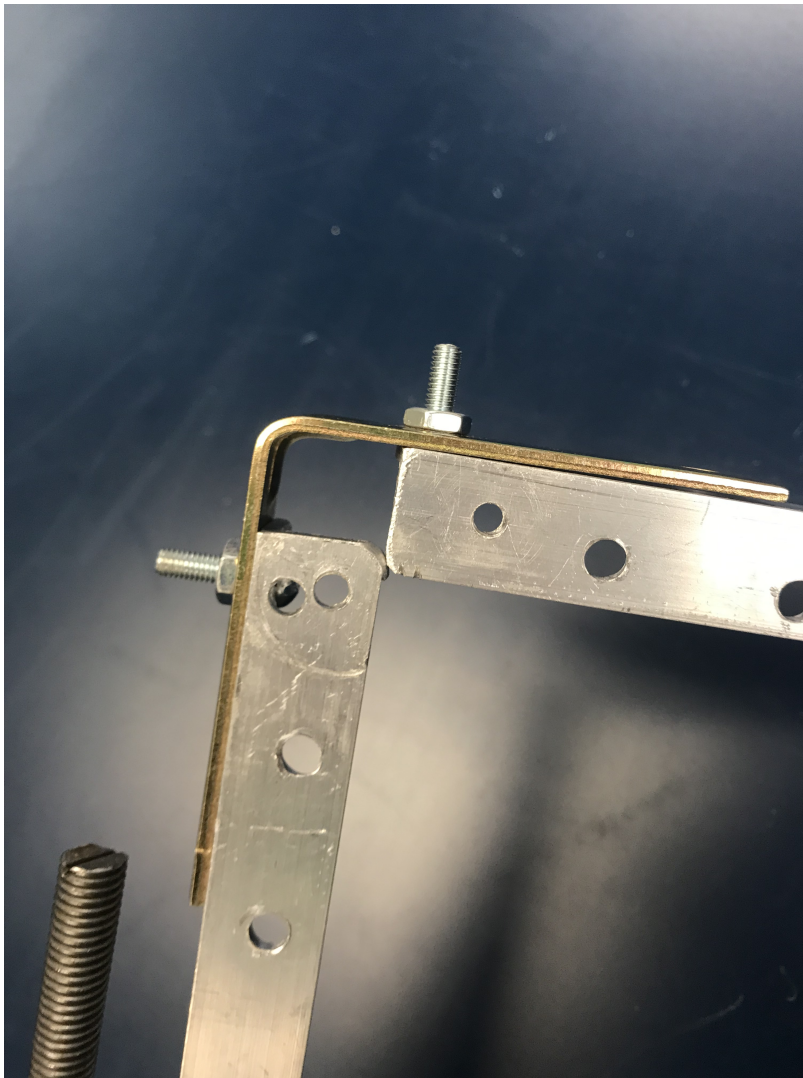


Figure 37: Proof-of-Concept Prototype Board Attachment

The Proof-of-Concept prototype from above influenced our Initial Prototype heavily in regards to how the entire systems setup and how it will be able to move on the board. The idea of using lead screws to move the eraser arm up and down the white board seemed like a good idea at first but we determined that it would take too long. The threading of the lead screw would prevent us from being able to move at our desired speed and not meet our clients goals. By using a DC motor fixed on one end of the board and a spindle on the other, we can use a band fixed to the horizontal eraser arm to move up and down the height of the board faster.

The idea of having a frame around the entire board influenced us to change to use suction cups to mount the system to the board. From discussing within our group as well as very helpful information from Dr. Potter and the classes TA's, we agreed it is a simpler and more effective set up. It also brought our attention that having a frame around the entire board may potentially crack or damage the board as we fix the frame to the board itself.

Shown below are both our Initial Prototype and our Rail Erase System (from Section 4):



Figure 38: Initial Prototype Total Set Up



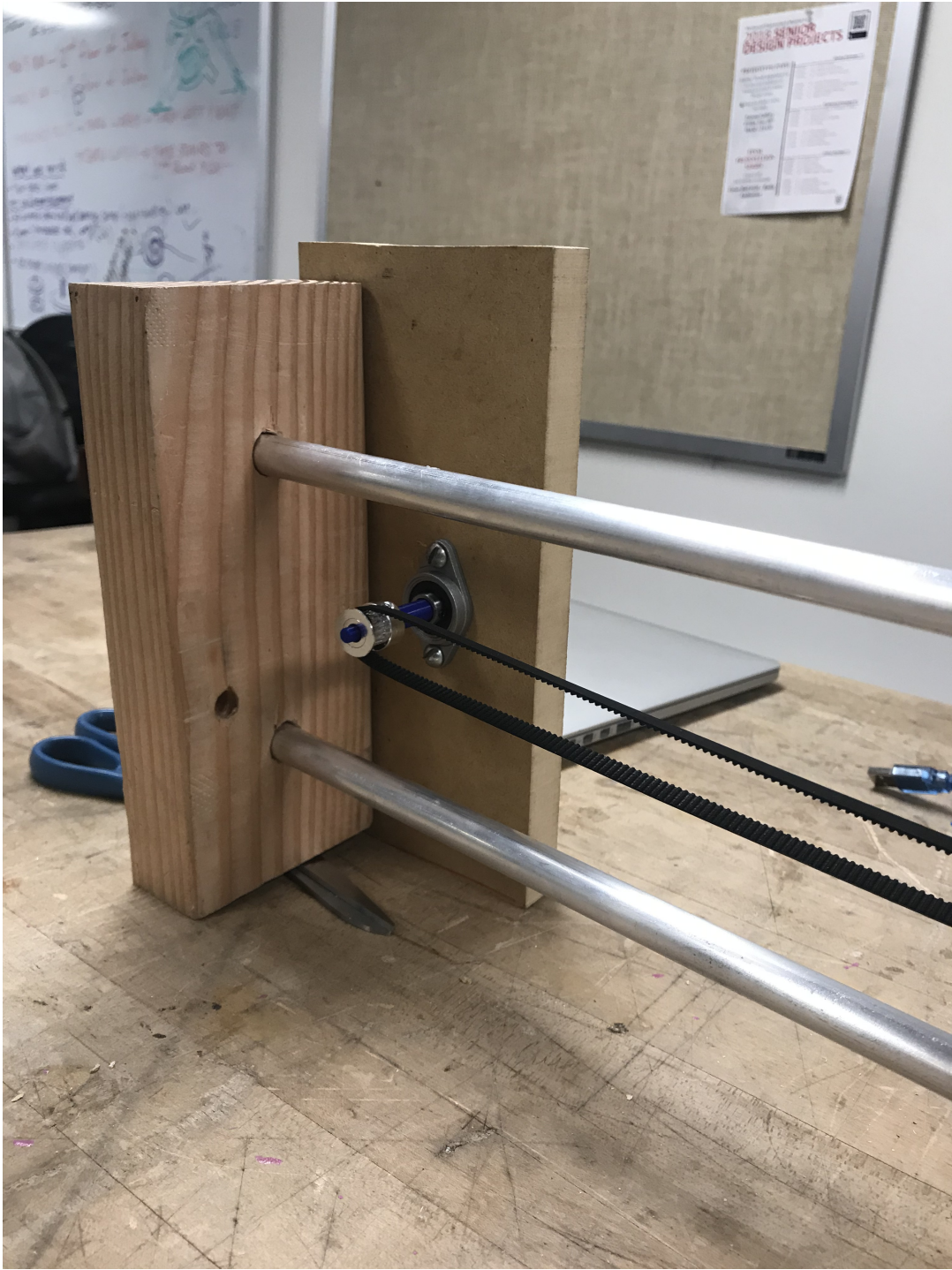
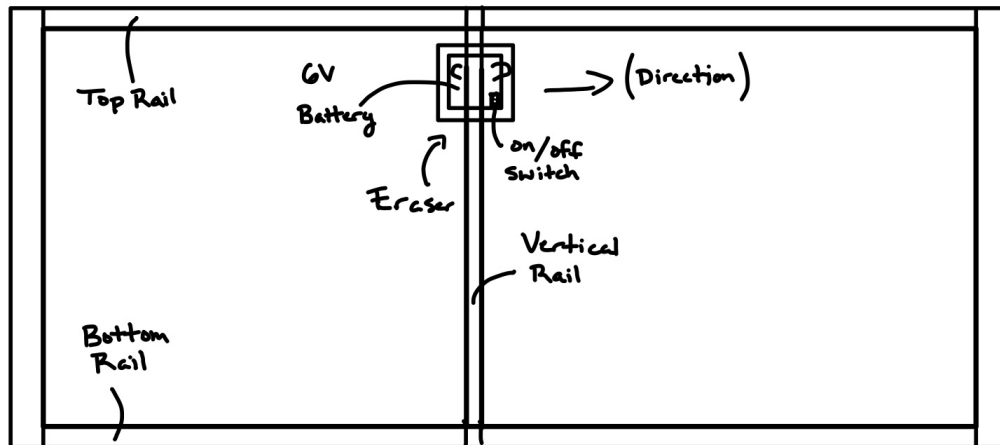


Figure 39: Initial Prototype Small Spindle Set Up



Figure 40: Initial Prototype DC Motor Set Up

## Final Design:



## Path of Eraser:

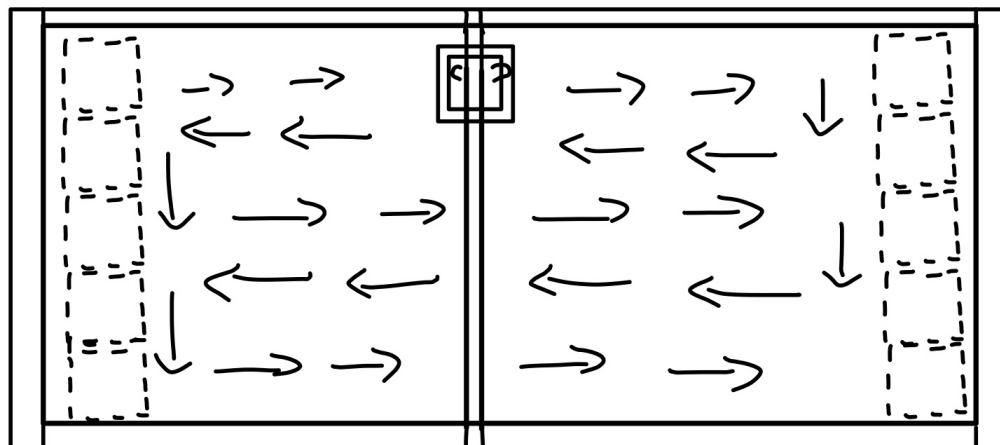


Figure 41: Rail Erase System

Between our Initial Prototype and our selected concept from Section 4, the Rail Erase System, there are a few main differences. The main difference is how the system moves across the white board. In Fig. 10 the idea of a rail system was used in order to provide horizontal movement to our eraser arm which would move the eraser vertically as it erased. Instead of using a rail system to provide horizontal movement across the board we determined it would be easier to vertically use a DC motor and a spindle to move our horizontal eraser arm with the help of gravity. Also the eraser arm changed from moving the eraser vertically to horizontally. The reason for this change was to shorten the distance that needed to be traveled by the eraser arm and have gravity help with the vertical movement up and down the white board.

## 6 Working Prototypes

### 6.1 Overview

Sed ut perspiciatis unde omnis iste natus error sit voluptatem accusantium doloremque laudantium, totam rem aperiam, eaque ipsa quae ab illo inventore veritatis et quasi architecto beatae vitae dicta sunt explicabo.

### 6.2 Initial Prototype

### 6.3 Final Prototype

Sed ut perspiciatis unde omnis iste natus error sit voluptatem accusantium doloremque laudantium, totam rem aperiam, eaque ipsa quae ab illo inventore veritatis et quasi architecto beatae vitae dicta sunt explicabo.

## 7 Design Refinement

### 7.1 FEM Stress/Deflection Analysis

When we were selecting material for the center 8 feet rod, the most important factor was how much deflection it would have after it applied pressure to the wiping unit. Based on our test, the pressure needed for the wiping unit is 8 newton. We neglected the friction force is because it is much less than the pressure force. The analysis also helps our team to find the correct thickness for the wiping unit to able to provide enough pressure while the wiping unit is at the center of the board and still able to provide 8 newton force to the wiping unit. The deflection analysis is simple therefore the mesh setting does not play an important role. The boundary condition is two ends of the 8 feet rod is fixed. This would be very close to the real scenario. The real scenario would be slightly smaller deflection because of the two sides 4 feet rod would deflect as well.



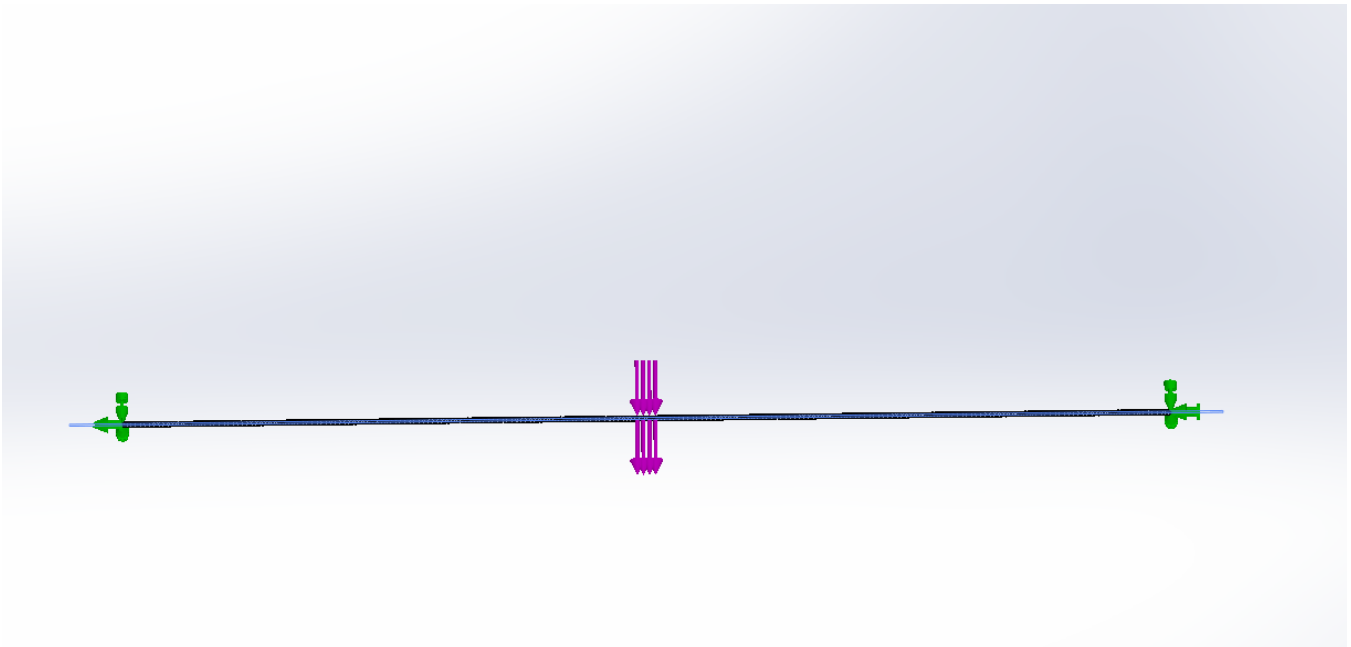


Figure 42: Meshed, boundary condition and applied force due to the wiping unit

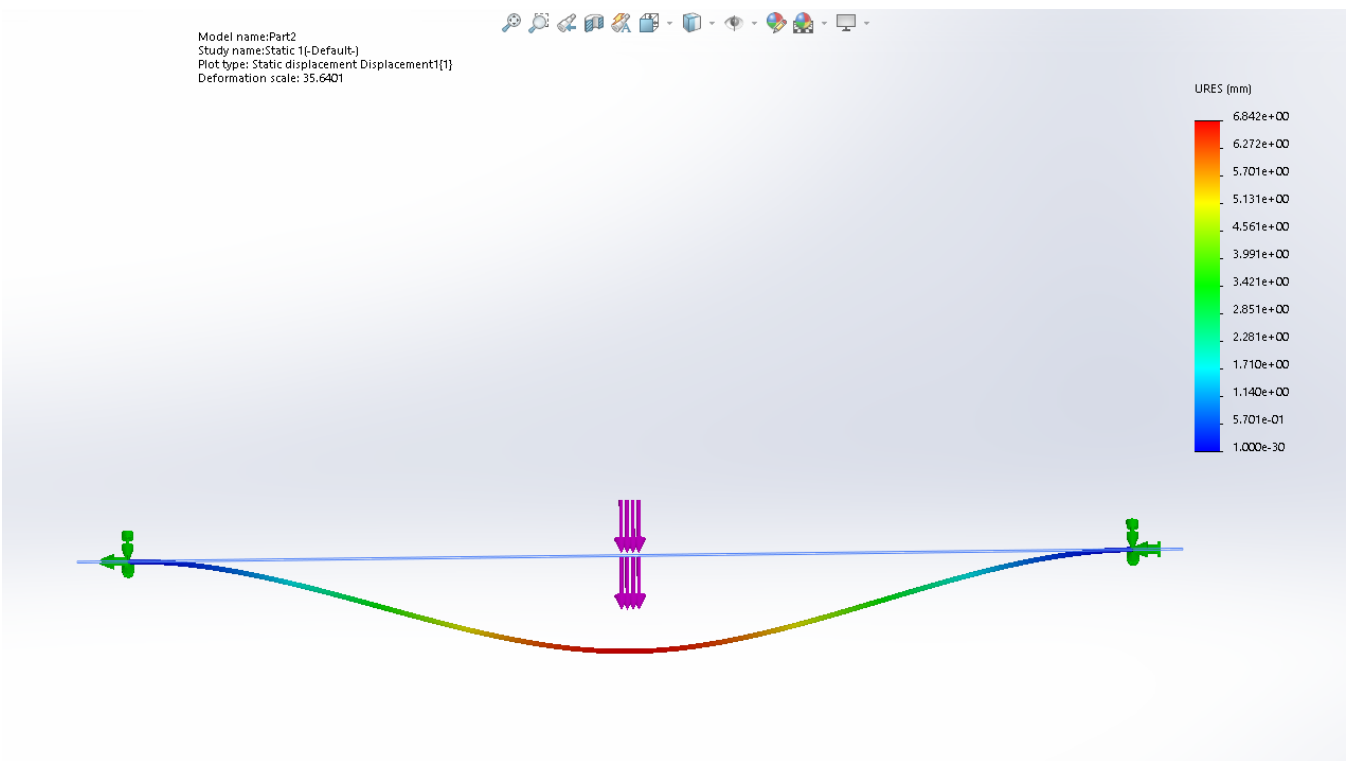


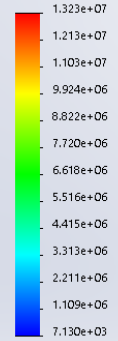
Figure 43: Displacement plot of the 8 feet rod with deformation scale 35.64



Model name: Part2  
Study name: Static 1f-Default-1  
Plot type: Static modal stress Stress1  
Deformation scale: 35.6401



von Mises (N/m<sup>2</sup>)



→ Yield strength: 9.000e+07

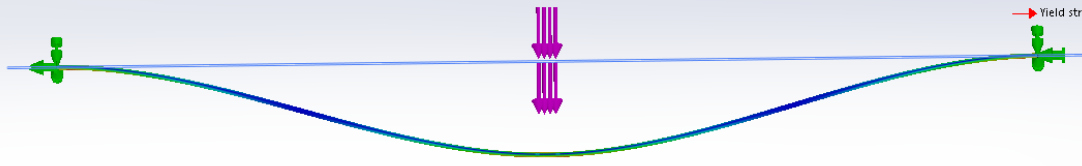


Figure 44: Stress plot of the 8 feet rod with deformation scale 35.64

## 7.2 Design for Safety

### 7.2.1 Risk #1: Detachment from board

**Description:** The risk of the entire system detaching from the board is very serious. It is held to the board by suction cups so if any external force is applied it could potentially cause a suction cup to release. The more suction cups that release the less structural integrity of the system to the board.

**Severity:** Catastrophic

**Probability:** Unlikely

**Mitigating Steps:** Ways to prevent the system detaching from the board can done by the following ways: screwed in attachment to the board, lock and clamp suction cups, or hook and lock system that hangs over the top edge of the board

### 7.2.2 Risk #2: Item of clothing getting caught in system

**Description:** The risk of having clothing items caught in the system is a dangerous scenario. If someone stands too close to the moving system an item of loose clothing may get caught in the system and potentially hurt the system or the person involved. The system can be shut down to stop all movement and allow a person to be freed.

**Severity:** Critical

**Probability:** Seldom

**Mitigating Steps:** Ways to prevent this risk is to keep a safe distance of a few feet from the board while the system is in use. Also keeping loose clothing such as baggy shirts and sweatshirts clear of the moving parts of the system

### 7.2.3 Risk #3: Possible fire from overheated motors

**Description:** The possibility of having a motor catch on fire is a very unlikely thing to happen but is still possible.

**Severity:** Catastrophic

**Probability:** Unlikely

**Mitigating Steps:** The best way to prevent this risk are to not have the motors run for a long unsupervised time. Having someone always be present in the use of the system is a safety rule that should always be followed in order any risk or damage happens to the system.

### 7.2.4 Risk #4: Bands breaking causing horizontal arm to collapse

**Description:** The band breaking on the system is a very serious thing to take into account. If any band were to break it would cause the entire system to fail. If the two side bands broke the horizontal arm could fall and damage the board and system itself.

**Severity:** Critical

**Probability:** Unlikely

**Mitigating Steps:** Ways to prevent this risk is to by using a heavier duty band, have a stronger method of connecting the band or having a fixed band sized for the system.

### 7.2.5 Risk #5: Items getting caught in eraser

**Description:** Having items on the board can cause an issue with the system. As the eraser moves up, down and across the board any item on the board can cause disruption to the eraser.

**Severity:** Marginal

**Probability:** Seldom

**Mitigating Steps:** Ways to prevent this risk from happening is clearing the board of all magnets or magnetic markers. Having a clear board allows the eraser to have clear path and no disruption.

		Probability that something will go wrong				
Category		Frequent Likely to occur immediately or in a short period of time; expected to occur frequently	Likely Quite likely to occur in time	Occasional May occur in time	Seldom Not likely to occur but possible	Unlikely Unlikely to occur
Severity of risk	Catastrophic					<ul style="list-style-type: none"> <li>o Detachment from board</li> <li>o Fire from motors</li> </ul>
	Critical				<ul style="list-style-type: none"> <li>o Clothing getting caught</li> </ul>	<ul style="list-style-type: none"> <li>o Bands breaking</li> </ul>
	Marginal				<ul style="list-style-type: none"> <li>o Items caught in eraser</li> </ul>	
	Negligible hazard presents a minimal threat to safety, health, and well-being of participants; trivial					

Figure 45: Probability that something will go wrong

From the heat map above we can see the top three most prominent risks are: the detachment from the board, a fire starting from the motors and clothing getting caught. The next two most prominent risks of the system are the bands breaking and items in the path of the eraser. The first three risks listed are highest priorities to watch for and prevent. All three of these risks can cause major damage to the board, the system and the person operating the system. The next two lesser risks are still issues that need to be addressed while operating the system. Items being in the eraser's path prevents the effectiveness of the system and counters the purpose of the system. The risk of the bands breaking is critical but not likely to happen due to the durability of the bands.

### 7.3 Design for Manufacturing

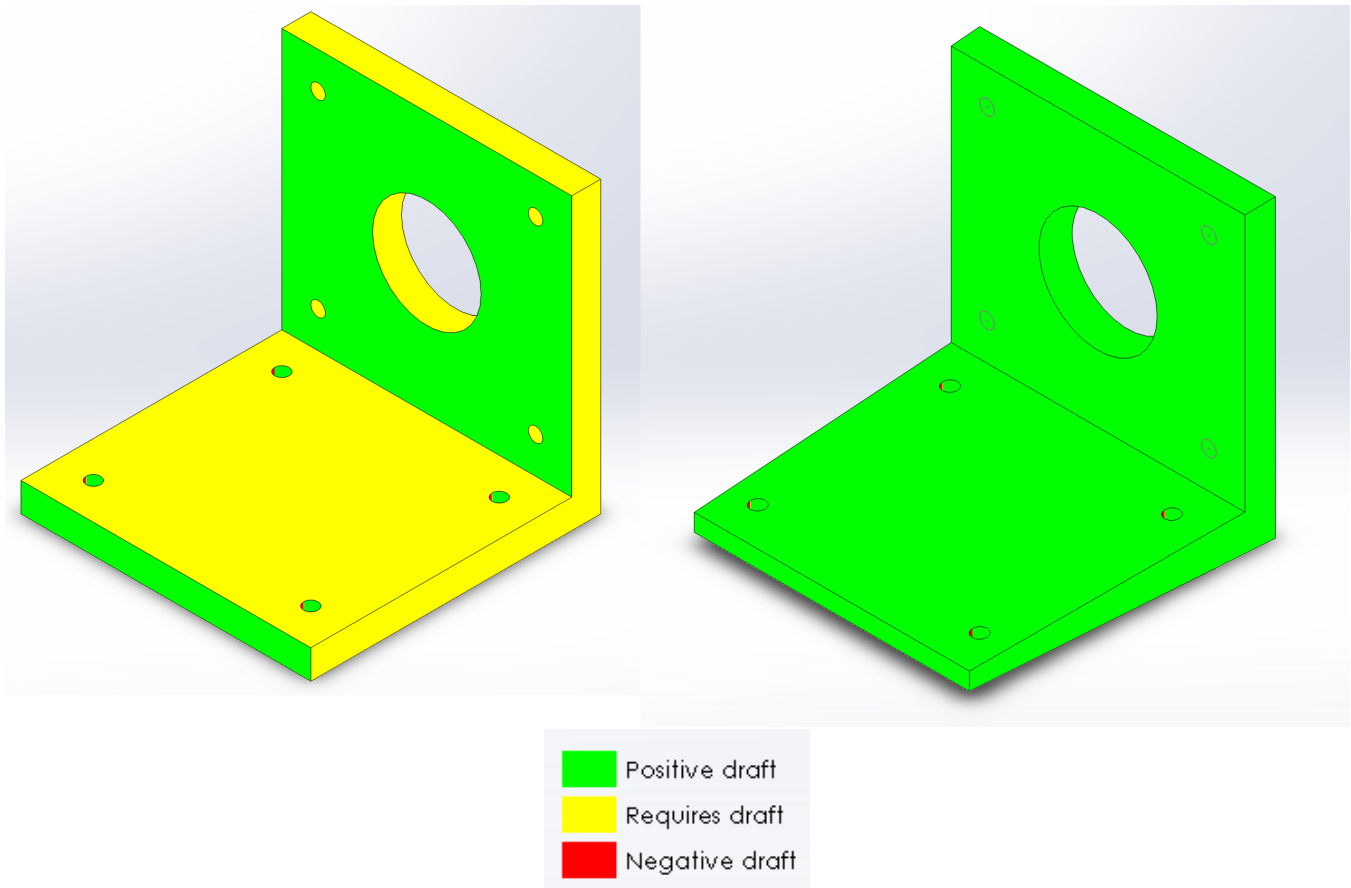


Figure 46: Before and after images of a SolidWorks motor bracket using the "Draft Analysis" feature

The changes to this part are fairly straightforward. They include lofted cuts for the holes and angled extruded cuts to all faces requiring draft. All faces were cut at an angle of  $2^\circ$  and thickness was increased to account for lost material. The holes were lofted from the original diameter to a diameter 0.05 in. greater. This part was difficult to due to the  $90^\circ$  angle and the several holes and would likely be an easier part to cut the holes after the injection molding process.

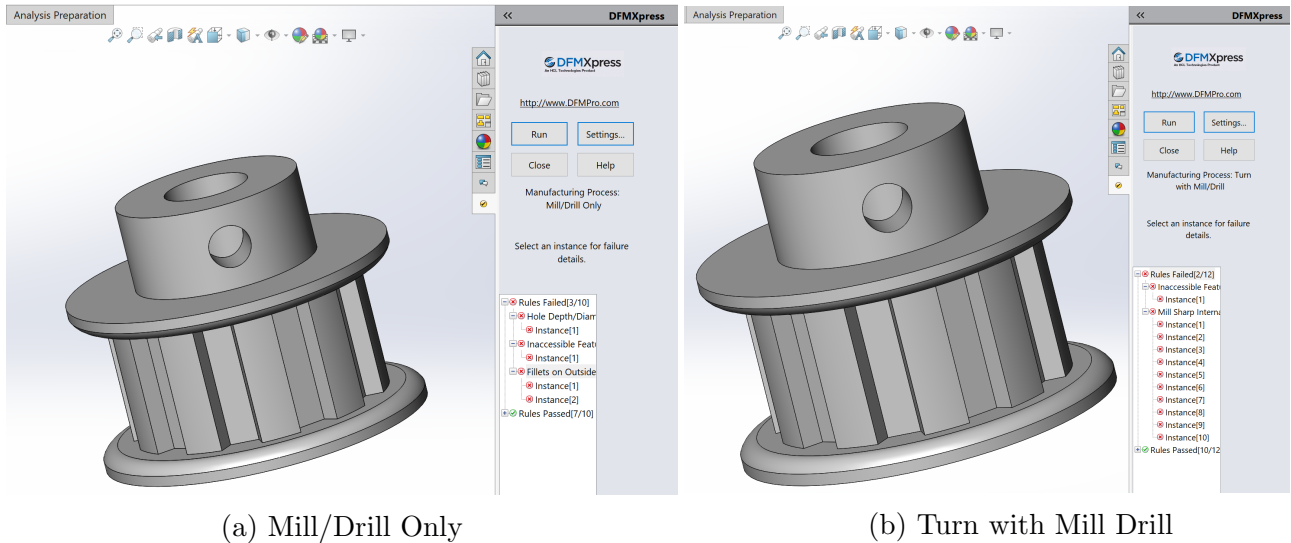


Figure 47: DFMXpress Analyses for a timing belt pulley

The Mill/Drill only analysis failed 3 out of the 10 rules including the hole for the shaft and the set screw hole. The other rule failed was the fillet on the wall edge. The Turn with Mill Drill failed 2 of its 12 rules. Similar to the Mill/Drill analysis, the set screw hole failed in this analysis as well. However, the other failed rule was the teeth connection to the walls due their sharp nature. This could be solved by reducing the angle between the teeth and wall and drilling the set screw hole after milling.

## 7.4 Design for Usability

People with vision impairment would not have any influence with using the automatic whiteboard eraser. People who need to use the wiping function of our product just need to click a single button attached on the right corner of the board. The only concern will be the color of the 'start' button. In order to satisfy all the needs by people with vision impairment, we can put a noticeable word 'start' on the top of the button, because no matter what kind of vision impairment people have, they are still able to recognize the word.

People with hearing impairment would not have any problem with using our product. First of all, there's no sound oriented interaction between the user and our product, which means user does not acquire any information from our product by the sound. The automatic white board eraser will return to its original position on the left upper corner on the board .User can visually confirm the position of the eraser and determine whether it is ready to use again or not.

People with muscle weakness may have some issues with using our product. As for using our product, it requires at least people can lift their arm to push the button on the board. But for the people with muscle weakness, it might be difficult for them to complete this action. As for the improvement according to this specific need, we can design a small Bluetooth remote controller so that people are able to easily hold the controller in their hand and simply click the button to start the eraser.

As for the control impairment, I don't think people will have any problem with using our product even they are under the influence of distraction, excessive fatigue, or medication side effects. As for our design of product, it doesn't require user to pay much attention on it or do any specific complicated manipulation. All they need to do is to click a single button on the board and wait

until the eraser returns to its original position.

## 8 Discussion

### 8.1 Project Development and Evolution

*Does the final project result align with its initial project description?*

- Yes, the final design is nearly identical to the initial prototype, but it includes several improvements including the mounting method and code.

*Was the project more or less difficult than expected?*

- The project was much more difficult than anticipated. The group ran into many design issues that slowed the overall design process significantly.

*On which part(s) of the design process should your group have spent more time? Which parts required less time?*

- The group should have spent more time on the vertical motion. The vertical movement was hindered by the weight of the system and the system as a whole would benefit greatly from reducing the weight.

*Was there a component of the prototype that was significantly easier or harder to make/assemble than expected?*

- Designing an effective method to mount the system to the board was both more challenging and simpler than expected. Several ideas were tested before suction cups were even a thought, but they immediately solved our issue.

*In hindsight, was there another design concept that might have been more successful than the chosen concept?*

- We believe that our design would be very successful if the overall weight were reduced along with other minor improvements. Conversely, we think a better idea might be to remove the vertical motion entirely and have one large eraser move from one side of the board to the other to erase the whole board.

### 8.2 Design Resources

*How did your group decide which codes and standards were most relevant? Did they influence your design concepts?*

- We knew that our design would include stepper motors and thus the standard for stepping motors was the most relevant. The standard sets requirements for rotating motors and standard motor sizes.

*Was your group missing any critical information when it generated and evaluated concepts?*

- We do not believe that any critical information was missing.

*Were there additional engineering analyses that could have helped guide your design?*

- We could have done an analyses on the amount of pressure applied to the board.

*If you were able to redo the course, what would you have done differently the second time around?*

- We would do more research in order to be more prepared for the design process.

*Given more time and money, what upgrades could be made to the working prototype?*

- The main upgrades that we could make with more time and money would mainly focus on the materials of our design, instead of wood we could have used a lighter and more sturdy material.

### **8.3 Team Organization**

*Were team members' skills complementary? Are there additional skills that would have benefited this project?*

- Yes we did have some team members skill that were complementary to our design and assembly process. We had a few team members that were used to using band saws and familiar with arduino coding. The only skill we were missing were an expert in coding. We had a few issues with synching two DC motors together and could have used help with that.

*Does this design experience inspire your group to attempt other design projects? If so, what type of projects?*

- This design experiment did inspire some of our members to continue the path of design. Moving forward some of us will participating in design and manufacturing internships and jobs.

## A MATLAB Code

```
1 t_step = .001; t_end = .1; %(time step and end time, seconds)
2 t = 0:t_step:t_end;          % create time vector
3 m = 20;                      % mass of ball(lb*s^2/in)
4 k = 5;                       % spring rate (lb / in)
5 c = 0;                       % damping (lb / (in/sec))
6 % forcing function: ramp from 0 to 10 lb
7 f = zeros(size(t)); f(1:.01/t_step) = linspace(0,10,.01/t_step);
8 % initialize velocity and position
9 x = zeros(size(t));
10 x(1)=0; v=0; % initial conditions
11
12 for n = 1:length(t)-1
13     a = (f(n)-k*x(n)-c*v)/m; % solve for acceleration
14     x(n+1) = x(n) + v*t_step; % next disp is curr disp plus increment
15     v = v + a*t_step;        % solve for velocity
16 end
```