Fall 2022

MEMS 411: Graphene Flake Finder

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Mechanical Engineering Design Project
MEMS 411, Fall 2022

Graphene Flake Finder

Graphene is an allotrope of carbon, a monolayer of carbon atoms arranged in a honeycomb-like structure. It is a zero-gap semiconductor, has a high opacity, has a large thermal conductivity, and has the largest intrinsic tensile strength known to humankind so far. It is not yet utilized in the industry as graphene is not efficient or cost-effective to mass produce. The production of graphene is done by flakes with tape at Dr. Erik Henrikson's lab. We will make a motorized microscope stage that helps automate the location identification of graphene flakes that have been mechanically exfoliated onto silicon wafer chips. The motorized microscope stage will work in tandem with another team's location identification and characterization of graphene flakes.

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1 Introduction

The goal of the graphene flake finder project is to automate the identification of layers of graphene. This process is tedious and time consuming; to identify layers a lot of time is spent under a microscope looking for different colors and contrast in various images. The slides are prepared by using a piece of tape to peel off the layer and placing it on a wafer. The microscope slides are a three by three grid containing nine wafers. Our project will be designing a system that move the slide under the microscope, allowing the computer to identify the atomic graphene layers on all nine wafers. This project focuses on the mechanical side and all the moving components and none of the artificial intelligence identification software. Our machine will still need to be able to speak with the computer and relay information from the computer.

2 Problem Understanding

2.1 Existing Devices

There are already on-market products that achieve what we are seeking to. Motorized microscope stages, also known as XY stages, are microscope stages that position and hold samples along two orthogonal, horizontal axes. They often require high accuracy and smooth movement of the samples. There are a number of companies that make motorized microscope stages. Three companies of interest that produce such microscope stages are Thor Labs, Zaber, and Prior.

2.1.1 Existing Device #1: Thor Labs Motorized Stage

Figure 1: Thor Labs Motorized Stage (Source: Thor Labs)

Link: https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=5360
Description: Thor Labs has a motorized microscope stage with various options. It features the ability to integrate itself into various microscopes, has a range of sample holders, integrated brushless DC linear servo motor actuators, linear optical encoders, and precision-engineered linear bearings. This device has a travel range of 110 mm x 75 mm, a velocity of 250 mm/s, and position repeatability of 0.25 μm.

2.1.2 Existing Device #2: Zaber

Figure 2: Zaber's motorized microscope stage

Link: https://www.zaber.com/products/scanning-microscope-stages
Description: Zaber has a motorized microscope stage with various options and can be adapted to user needs upon discussion with the company. It offers motor encoders to recover from slips or stalls, linear encoders for accurate positioning, and quiet operation. This device has a travel range of 250 x 100 mm, a velocity of 750 mm/s, and position repeatability of 0.5 μm.

2.1.3 Existing Device #3: Prior

Figure 3: Prior's 120 x 72 mm ultra high precision linear stage)

Link: https://www.prior.com/product/hld117-linear-motor-stage

Description: Prior has a motorized microscope stage. It features "ultra quiet" operation, high precision positioning, a low profile design, and smooth motion. This device has a travel range of 120 x 72 mm, a velocity of 300 mm/s, and position repeatability of 0.15 μm.

2.2 Patents

2.2.1 Position data-powered control system for camera and stage equipment for automated alignment to defined mobile objects (DE202010013678U1)

This patent combines the use of known components in the Spidercam with a data processing program to automatically align, position, and move camera and lighting units versus manually. The unit is fitted with a device that allows for position data determination, which is sent to a digital interface for processing. The same device allows for coordinates to be sent to the carrier unit to orient the camera to the desired position. Though the system as a whole can be oriented autonomously with remote-control, this may be enabled or disabled as desired.

2.2.2 System and method for relocating an object in a sample on a slide with a microscope imaging device(KR101274088B1)

This patent delves into a system and method that are used to relocate an object in a sample using a microscope imaging device. Objects are mapped respective to each other which have stored coordinates respective to their slides.

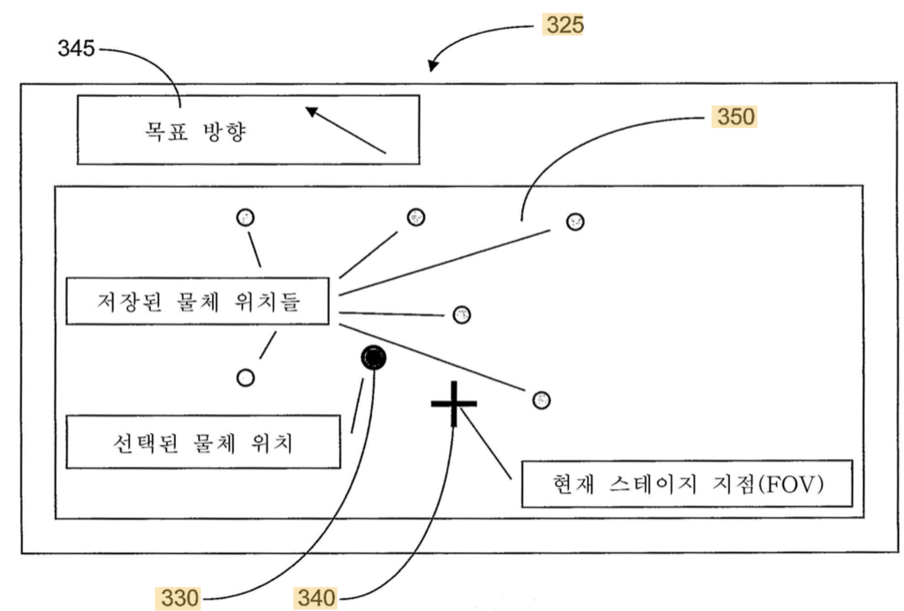


Figure 4: Patent images for the system and method for relocating an object.

2.2.3 Motorized table apparatus and microscope stage (EP1879063A1)

This patent is a motorized apparatus that can be attached to a table. Once attached to a platform the platform can extend in one direction. The platform can extended the equivalent of the table or beyond. The platform is moved by a ultrasonic oscillators, and a pressure application unit. The patent is showed in Fig 5

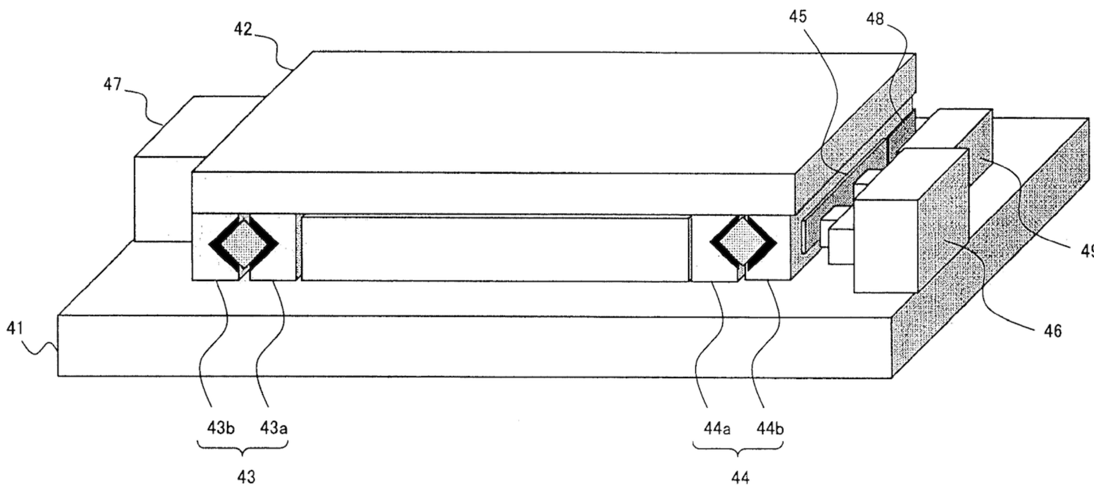


Figure 5: Patent images for motorized apparatus

2.3 Codes & Standards

2.3.1 Standard Specification for Motorized Treadmills (ASTM F2115-19)

The ASTM F2115-19 standard goes into the design and manufacture of motorized treadmills. Stop mechanisms and user safety features are included. This could aid our motorized stage keep users safe during use. We do not want pinched or entrapped fingers as the stage moves along its track. A stop mechanism would also be very useful in case an emergency of some kind occurs.

2.3.2 Industrial Robots And Robot Systems - Safety Requirements (ANSI/RIA R15.06-2012)

The ANSI/RIA R15.06-2012 standard looks into safety requirements for inherent safe design of robots, protective measures in case of a malfunction, and information for use of industrial robots. While our device will not be an industrial robot and will be on the smaller side, safety concerns should be key to all design of automated systems. It is of utmost importance to create a safe working environment around our machine.

2.4 User Needs

The user needs were decided by two different methods. The first was the most direct way, a conversation with the customer of this project. Dr. Henriksen laid out what the project needed a several constraints that the project had to stay within. The second method was from looking back at the conversation, and interpreting what Dr. Henriksen needs based on the conversation.

2.4.1 Customer Interview

Interviewee: Dr. Erik Henriksen
Location: Crow 201, Washington University in St. Louis, Danforth Campus
Date: September 09^{th}, 2022
Setting: Showed process of graphene slide production and identification with Systems Engineers. Analyzed microscope and base to understand goal of replacing base with motorized table to overnight scan graphene slides. The whole interview was conducted in the basement of Crow hall, and took ~50 min.
Interview Notes:
What would you like us to do?

- Goal to create a program and a microscope stage to work in tandem with one another
- Microscope stage to work overnight to eliminate the tedious process of researchers identifying the flakes themselves
- Stage should move in a pattern to look at the nine samples on one slide

Are there dimensions to stay in?

- Yes, the maximum distance to lower the microscope and the highest we can get to the lenses given us about 2.75 inches to work within.
- The width of the device doesn't really matter, it can sit on the table. We can move things around to make it fit.

Will machine learning used as the camera used to image slides up to now is possibly going to replaced?

- No, a color matrix will be used for location identification and characterization, so that previous images taken can be compared even if/when a new camera is implemented.

What should are next steps be?

- Investigate other projects on the market, other universities are doing similar projects.
- I would like you guys to call some of the companies that make these stages and ask if they have advice. See if they will tell you some of the pitfalls they have run into.
- Is it possible to buy the bare minimum from them and we can use our parts to bring it together.

2.4.2 Interpreted User Needs

There is a hierarchy of user needs that must be established. This aids in clearing what must be accomplished first.

Table 1: Interpreted Customer Needs

#	Need	Importance (5 most)
1	Motorized rasting in XY plane in cm increments	5
2	The top needs to stay level for microscope focus	5
3	Table needs to by sturdy	4
4	Intuitive and Easy to use	3
5	Calibration test with adjustment	3
6	Manual movement capabilities	4

2.5 Design Metrics

These design metrics were decided from the customer interview. By getting a look at the surrounding area and the size of the microscope, dimensions were estimated. The relevant example products mentioned earlier were used to help find target specifications. Several of their target numbers are a goal for this project.

Table 2: Target Specifications

Metric Number	Associated Needs	Metric	Units	Acceptable	Ideal
1	3	Total weight	kg	1	0.5
2	1	Horizontal Load Capacity	kg	0.25	0.5
3	3	Total volume	mm^3	< 8000	< 6000
4	3	Height	m	0.3	0.3
5	1	Max Velocity	mm/s	100	250
6	1	Max Acceleration	mm/s^2	1000	2000
7	5	Position Repeatability	μm	10	0.25
8	2	Temperature	deg C	> 20	> 100
9	4	Compatibly with computer	USB	Pass	Pass

2.6 Project Management

The Gantt chart in Figure 6 gives an overview of the project schedule.

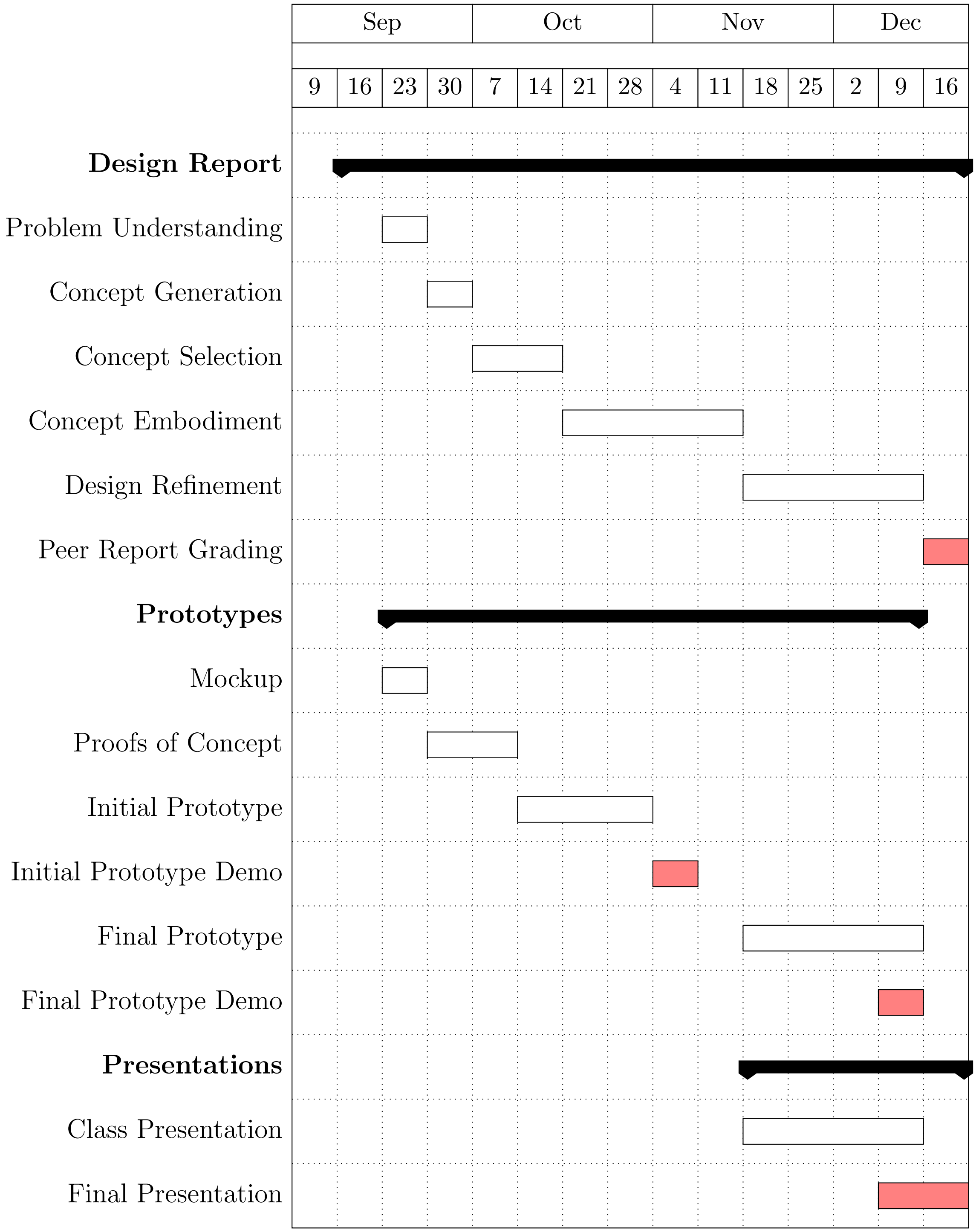
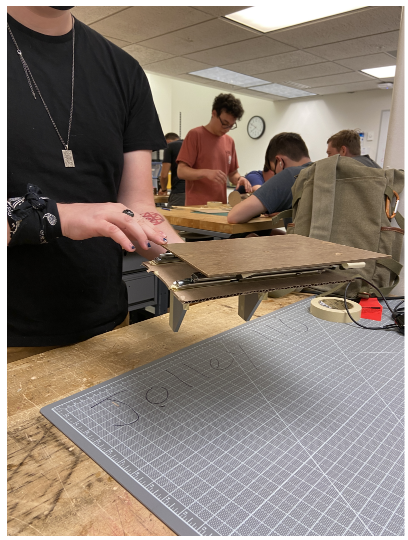


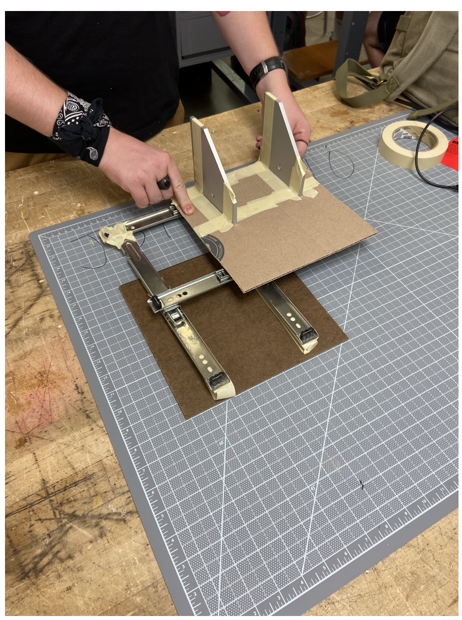
Figure 6: Gantt chart for design project

3 Concept Generation

3.1 Mockup Prototype

The prototype was inspired from the desk drawer sliders found in the basement of Jubel Hall at Washington University in St. Louis. When we stumbled upon this we realized we could stack two on top of two, creating a movement mechanism in the X-Y direction. Once we found how our microscope platform was going to move, we needed a stand to keep it steady. We decided that screwing directly into the microscope stand would be best, so we mimicked the L-brackets that are attached to the stand. The Prototype photos below shows the complete build with our stand and working movement mechanism. A piece of cardboard was attached to the L-Brackets to create a sturdy base, and our sliders were taped to a thin piece of wood, representing our moving microscope platform.





3.2 Functional Decomposition

Bringing all of our function trees together, there were three functions that overlapped. A movement mechanism, stand to support a force, and position reliability are all necessary. After discussing together, the two more functions were added because they are crucial. Those two functions were a computer connection, and a system to hold the microscope. The following Figure shows our function tree with all necessary functions.

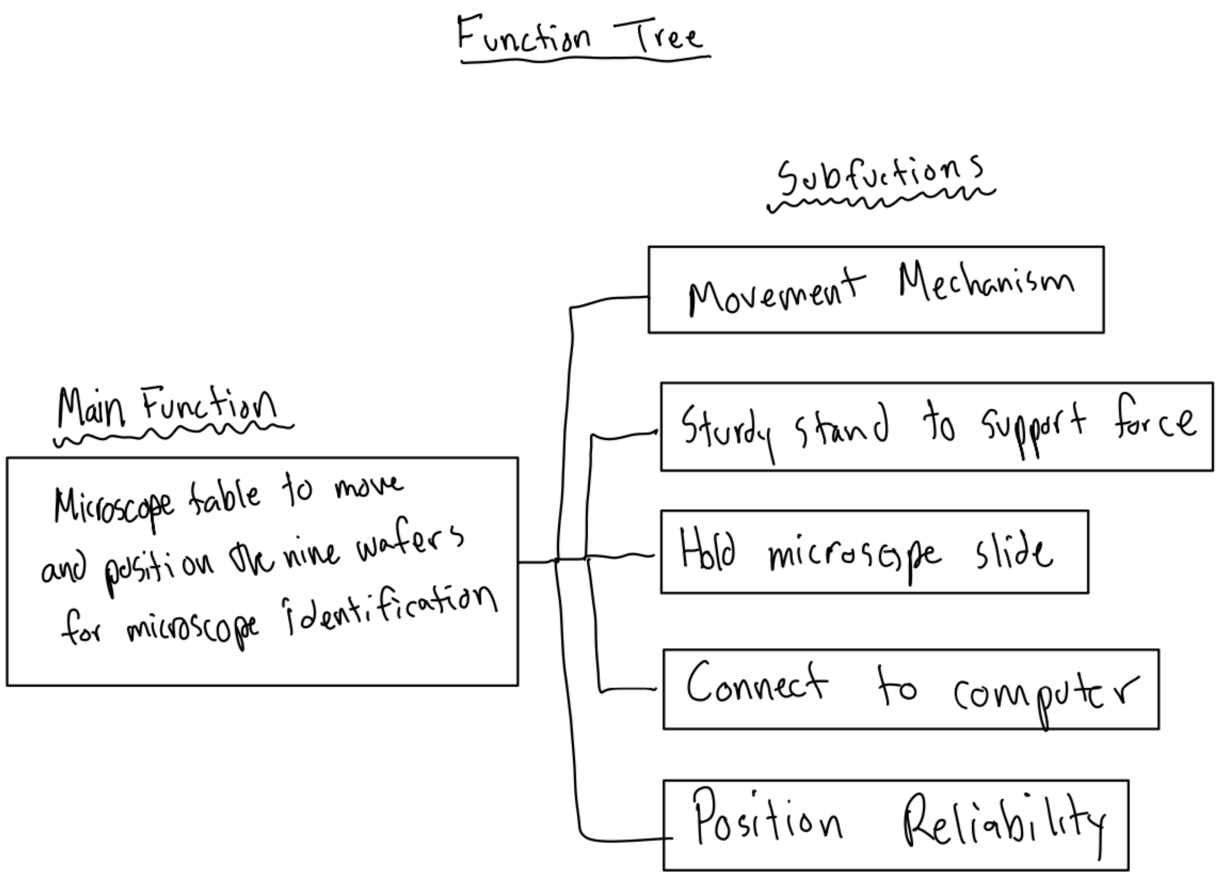


Figure 7: Function tree for Graphene Flake Finder, hand-drawn and scanned

3.3 Morphological Chart

The following figure shows the hand drawn Morphological Chart. The chart breaks down the sub-functions and comes up with three different ideas for each function. The Morphological Chart helped stimulate ideas that inspired ideas for our design concepts.

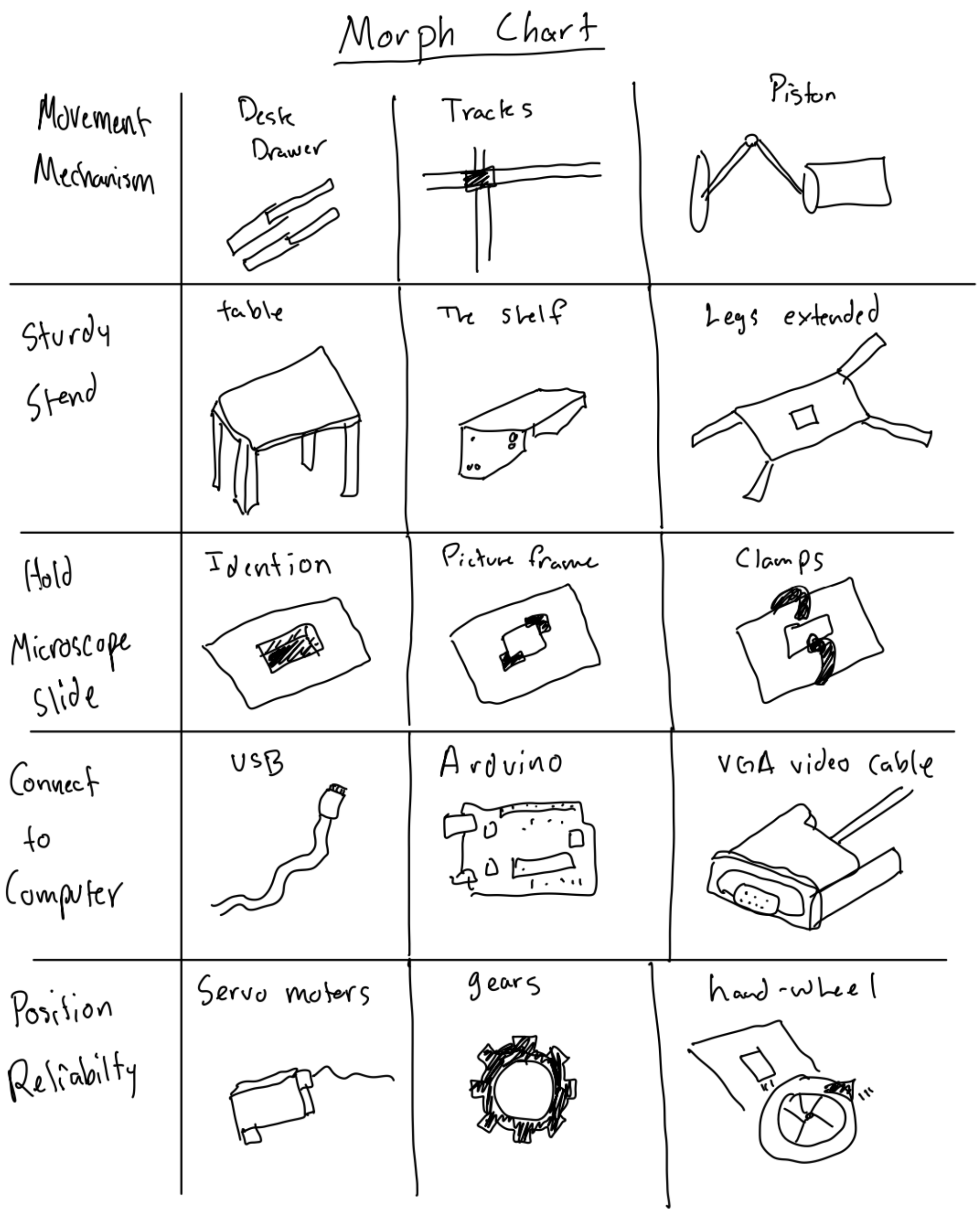


Figure 8: Morphological Chart for Graphene Flake Finder

3.4 Alternative Design Concepts

3.4.1 Concept #1: Piston-Slider Movement Table

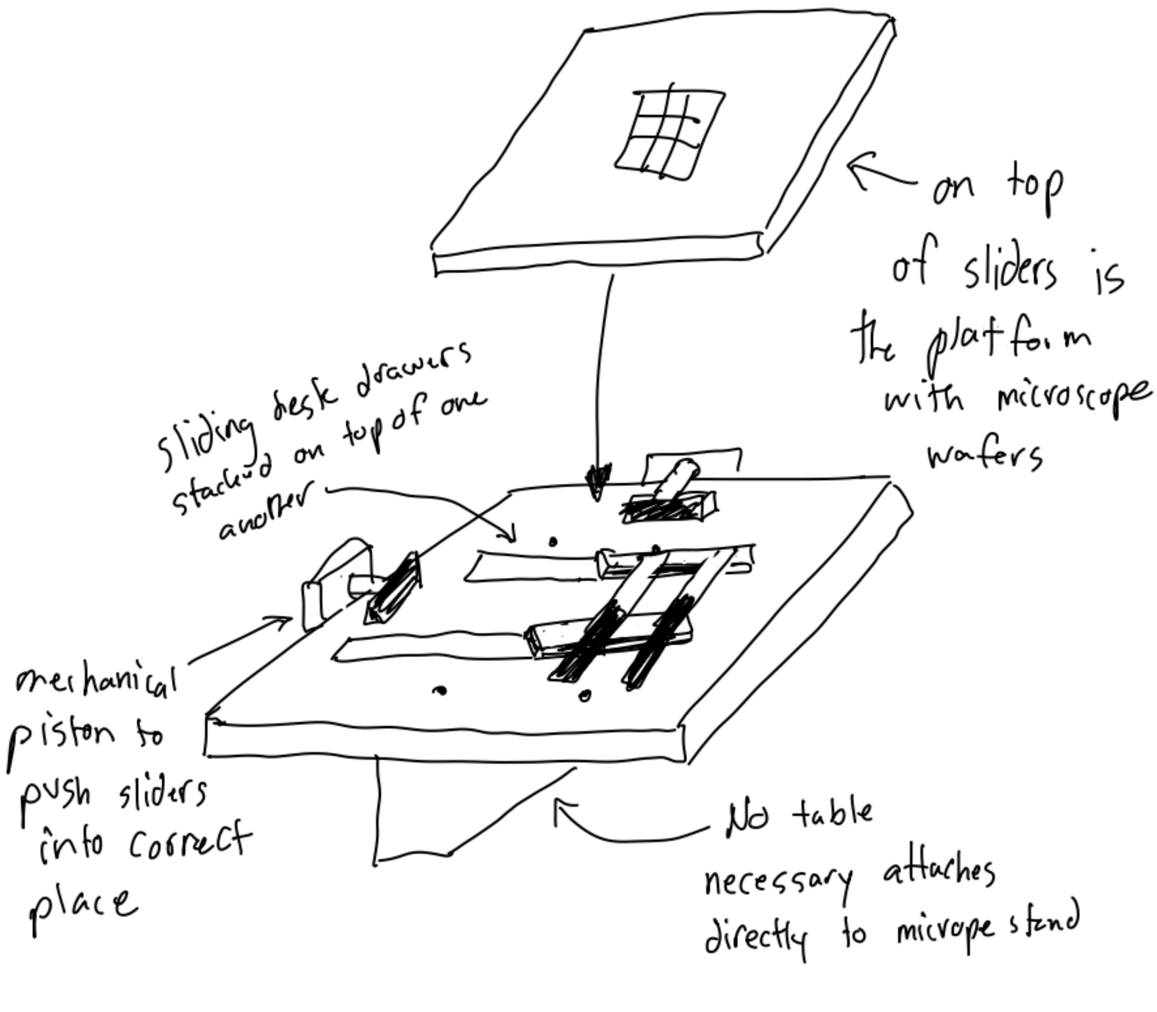


Figure 9: Sketch of Piston-Slider concept

Description: Two pistons are attached to the side of microscope table. Two sets of desk drawer sliders are stacked on top of one another, placed on the stand. On top of the sliders is the second platform that can move into the correct position under the microscope. The pistons can be connected to the computer or Arduino board and can push the plate into the correct position.

3.4.2 Concept #2: Layered Modular Stage

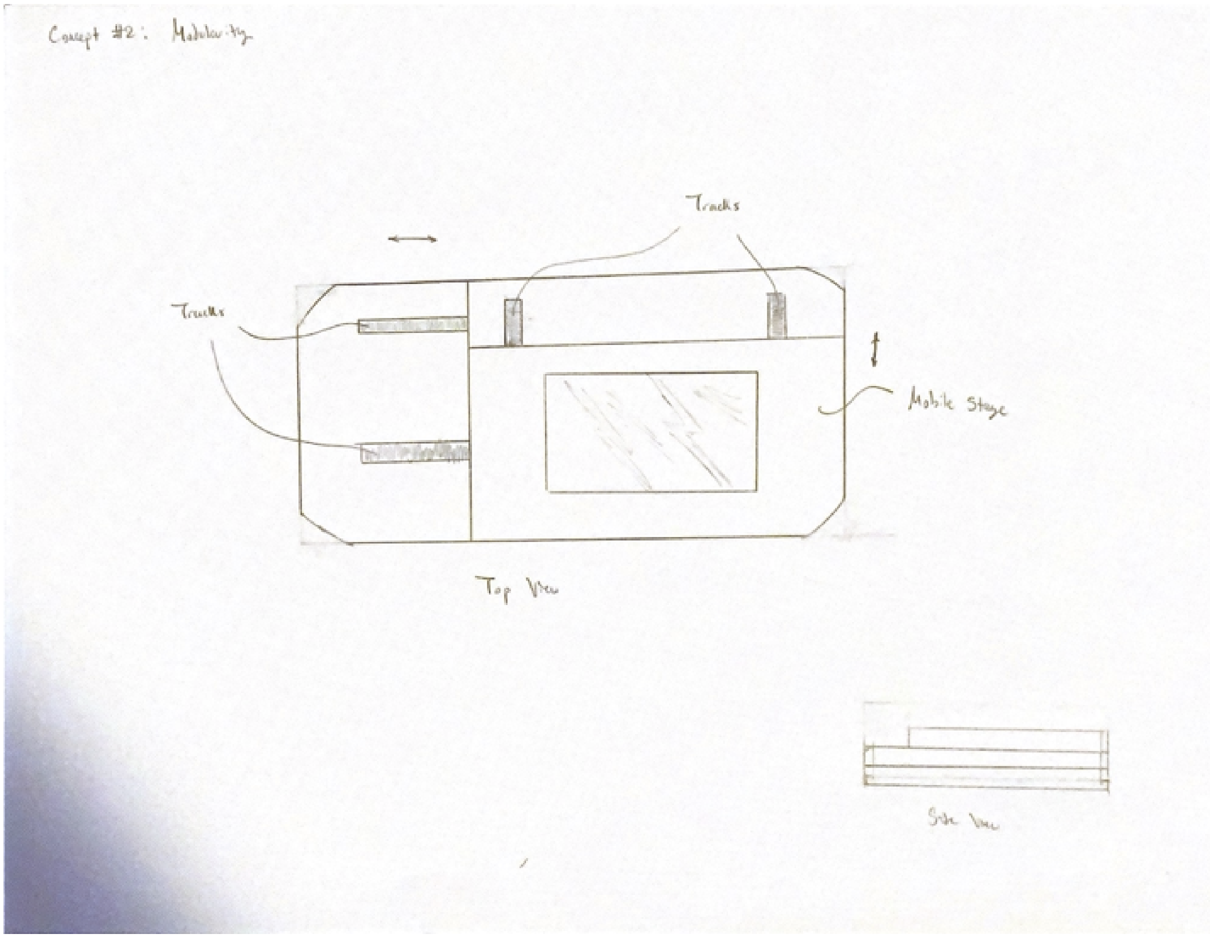


Figure 10: Sketch of Layered Modular Stage

Description: Pictured in Figure 10 is a tri-layer stage. The bottom layer moves the upper two layers in the x-direction. The middle layer moves the stage in the y-direction. Both the bottom and middle layers utilize motors and motor encoders for precise movement of the stage. These motors would be connected to a motor controller and that to either a computer or an Arduino board. This device could be compact and lightweight at the cost of being slightly thick. Research and cooperation with the other engineering teams on this project will need to be done for the electronics work. In hindsight, this concept can be made into a bi-layer stage with the same logic as the original.

3.4.3 Concept #3: A Third Concept

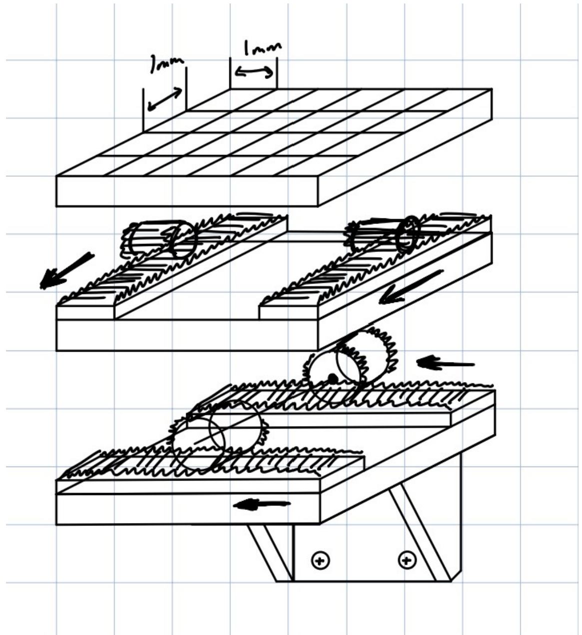


Figure 11: Sketch of Double Layered Gear Stage

Description: Pictured in Figure 11 is another tri-layered stage that prioritizes the use of motors and gear tracks to facilitate the x-y plane movement of the top stage. This layering moves the stage in the same way as Concept 2 as well as would use the same motor encoders for the precise movements. This concept design would be less compact and less lightweight than Concepts 1 and 2, and in exchange could benefit from being set further down in the microscope stage slot and accommodate for different gears if finer movement were to be desired. In hindsight, the current drawing of the concept does not include a leveling concept for each of the stages.

4 Concept Selection

4.1 Selection Criteria

The selection criteria for this project are being sturdy, moving precisely, moving quickly, moving silently, and being portable. Moving precisely is of the utmost importance as repeatable pictures of the graphene flakes must be done. It is clear that moving precisely, being sturdy, and being portable to be the most important aspects to consider when creating our device.

	Sturdy	Moves precisely	Moves quickly	Moves silently	Portable		Row Total	Weight Value	Weight (%)
Sturdy	1.00	0.14	3.00	9.00	1.00		14.14	0.29	28.87
Moves precisely	7.00	1.00	3.00	5.00	1.00		17.00	0.35	34.70
Moves quickly	0.33	0.33	1.00	0.33	0.33		2.33	0.05	4.76
Moves silently	0.11	0.20	3.00	1.00	0.20		4.51	0.09	9.21
Portable	1.00	1.00	3.00	5.00	1.00		11.00	0.22	22.45
						Column Total:	48.99	1.00	100.00

Figure 12: Analytic Hierarchy Process (AHP) to determine scoring matrix weights

4.2 Concept Evaluation

We found concept #2 to be superior to others in terms of sturdiness, moving precisely, and being portable. It would not require disassembly while being small and lightweight. We found concept #1 to be superior in terms of moving quickly.

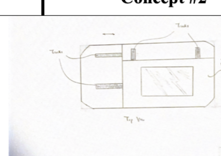
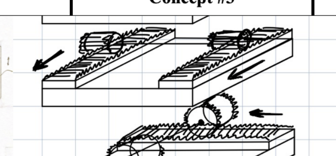
Alternative Design Concepts		Concept #1		Concept #2		Concept #3		Concept #4	
								Concept #4	
Selection Criterion	Weight (%)	Rating	Weighted	Rating	Weighted	Rating	Weighted	Rating	Weighted
Sturdy	28.87	2	0.58	4	1.15	3	0.87		0.00
Moves precisely	34.70	1	0.35	4	1.39	3	1.04		0.00
Moves quickly	4.76	3	0.14	2	0.10	2	0.10		0.00
Moves silently	9.21	2	0.18	3	0.28	1	0.09		0.00
Portable	22.45	1	0.22	4	0.90	2	0.45		0.00
	Total score	1.476		3.812		2.543		0.000	
	Rank	3.000		1.000		2.000		4.000	

Figure 13: Weighted Scoring Matrix (WSM) for choosing between alternative concepts

4.3 Evaluation Results

The selected concept was #2, this concept was chosen because it offered the highest precision movement. This criterion is important because our project relies on our machine to be in the exact same place under the microscope all the time. If our slide moves to a position that is slightly out of place, our design will not work. Concept #2 offered the highest sturdiness which was the second most favorable criterion. This is because the precision of our machine relies on how sturdy it is. Slight movements or a stand that is off the balance will require re-calibration and put our slide out of place regularly. The sturdiness of our machine allows for consistent results which are necessary for our project. The next criterion is portability and concept #2 scored the highest in this category. Portability is important because being able to replicate our project on other microscopes is important. The last two criteria are the least important and concept #2 was not the best in this criterion. For moves silently and moves quickly design #1 scored the best. Because these qualities are the least desirable we were willing to sacrifice these qualities for better quality elsewhere.

4.4 Engineering Models/Relationships

Model 1, shown in Figure 14, shows how much movement will be required for our graphene flake finder. It is important to know because cutting down on movement can make our project more efficient and save time. The movement also needs to be very precise, therefore knowing exactly how much movement is required is necessary.

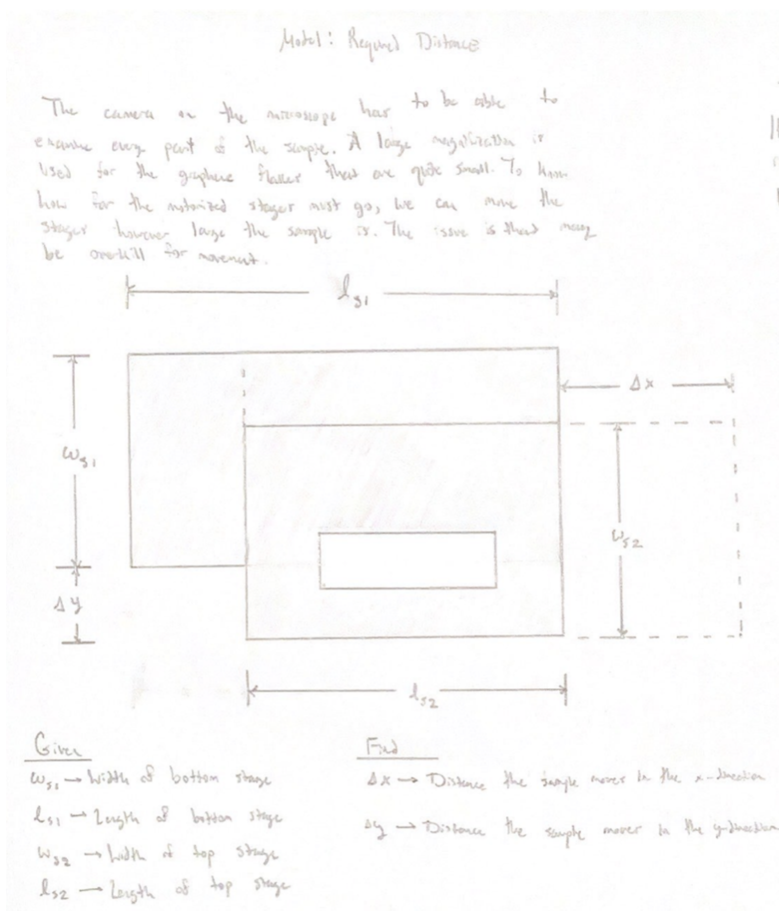


Figure 14: Model 1: Movement Engineering Model

Model 2, shown in Figure 15, is a static deflection problem. The model asks if one of our plates has to move off the edge of the other plate will our concept see static deflection? This is important because over time this could make our project less accurate, and precise and wear down our project over time.

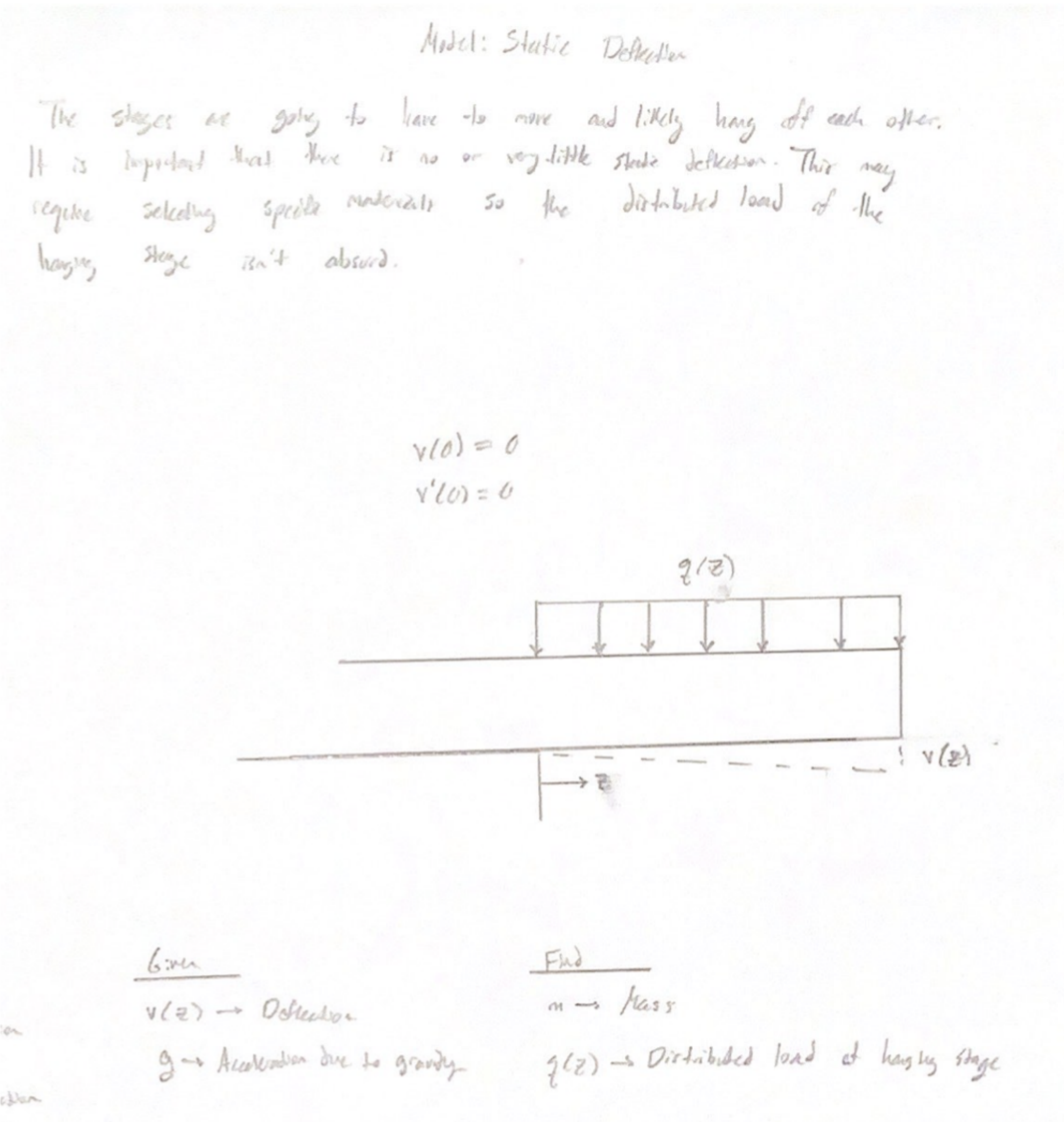


Figure 15: Model 2: Static Deflection

Model 3, shown in Figure 16, is a gear problem. The only constraints we have are the thickness, t, in the z-direction and the width in the y-direction, except with the graphene slide deck, the width constraint is far larger than needed so it can be neglected. The problem of the gears are finding a thread angle and thread distance that would provide the 10 μm, calculating the torque needed to overcome the friction caused by the whole systems weight, and keeping the system in the constraint thickness.

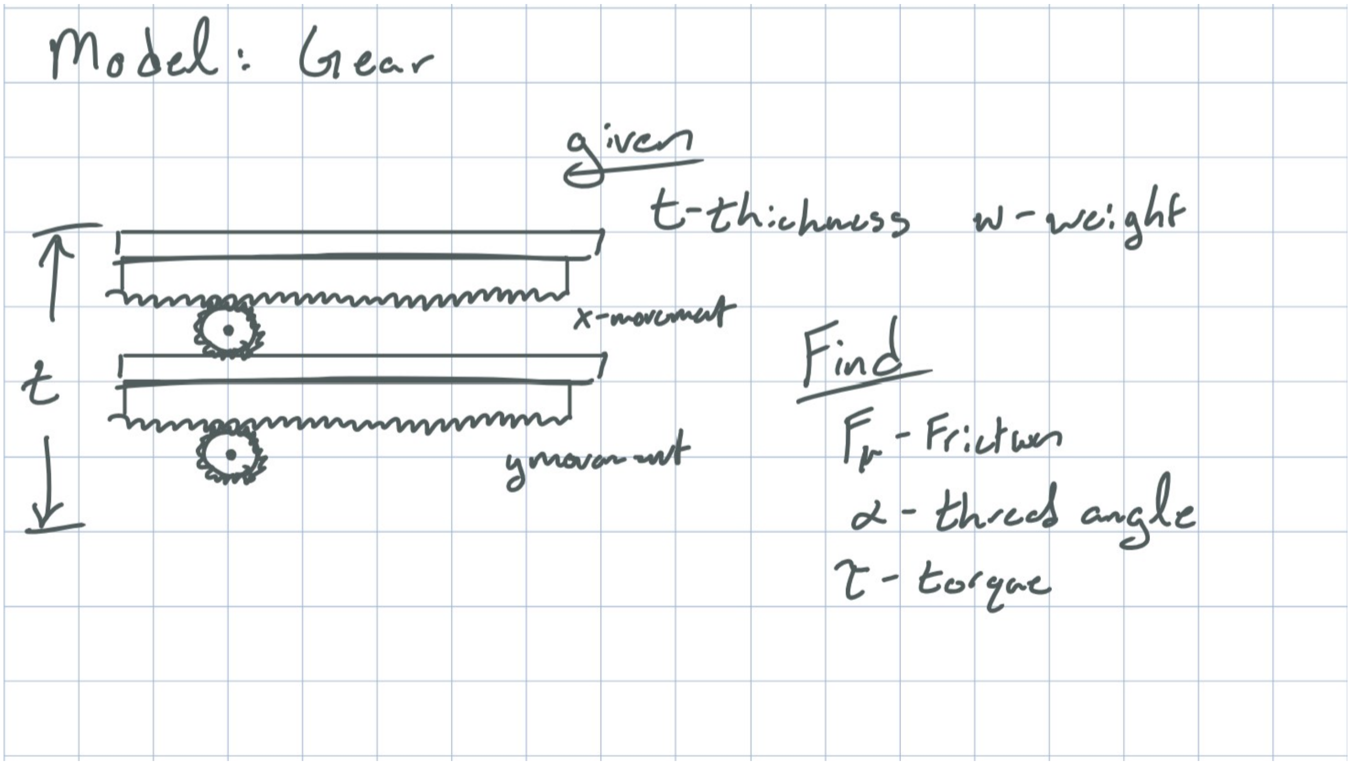


Figure 16: Model 3: Gear Problem

5 Concept Embodiment

5.1 Initial Embodiment

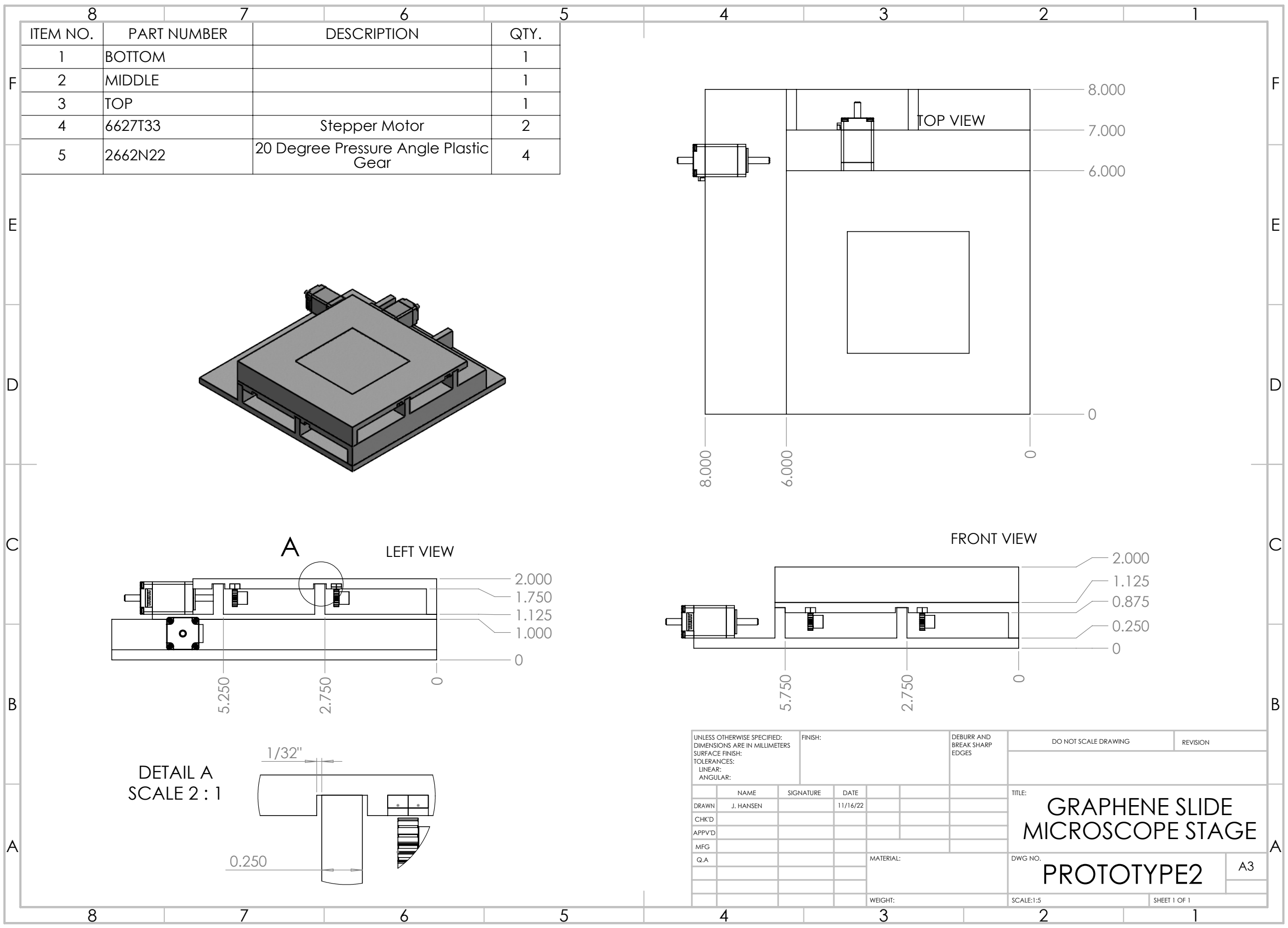


Figure 17: Initial Prototype Assembly

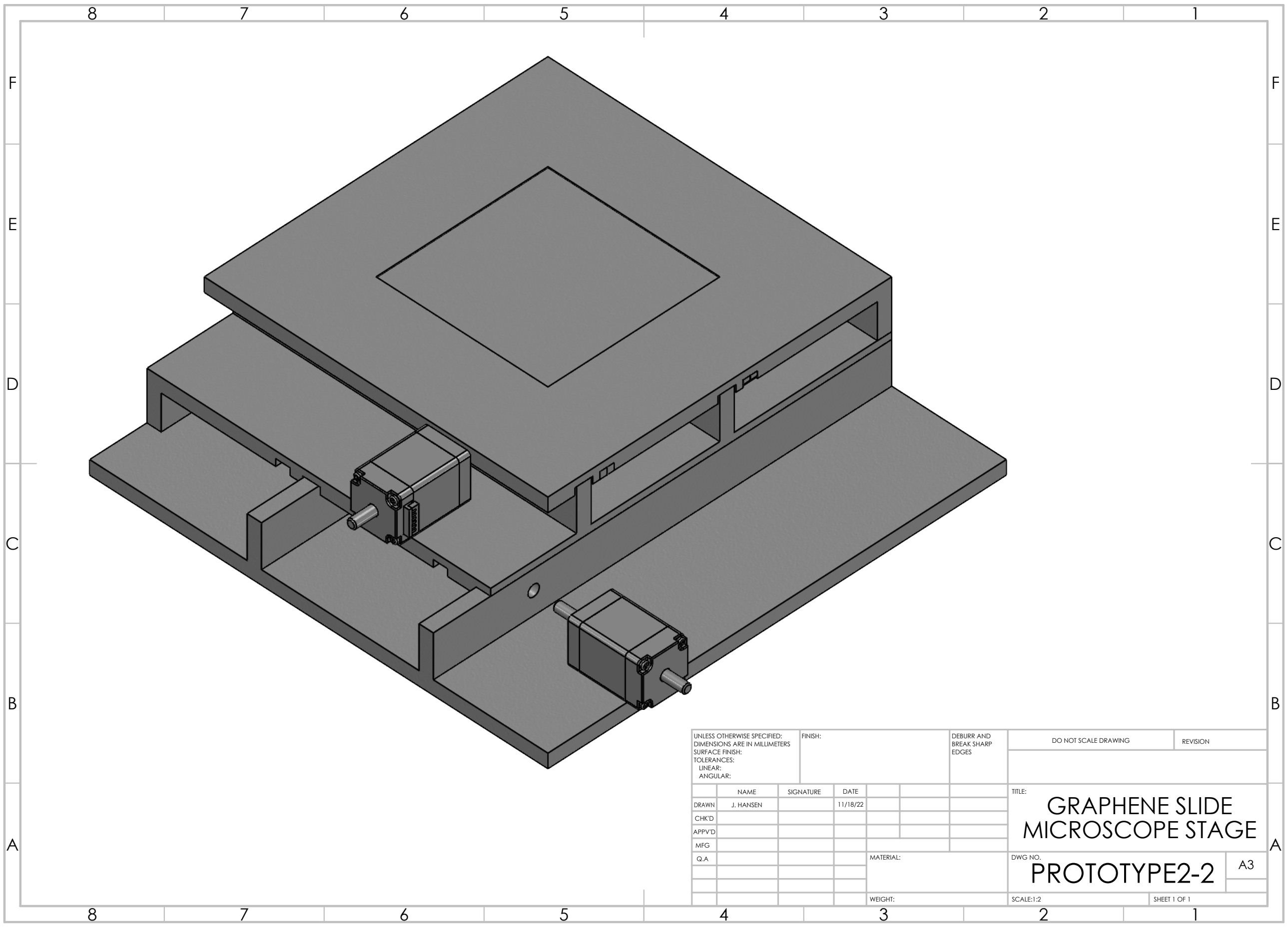


Figure 18: Isometric View of Assembly

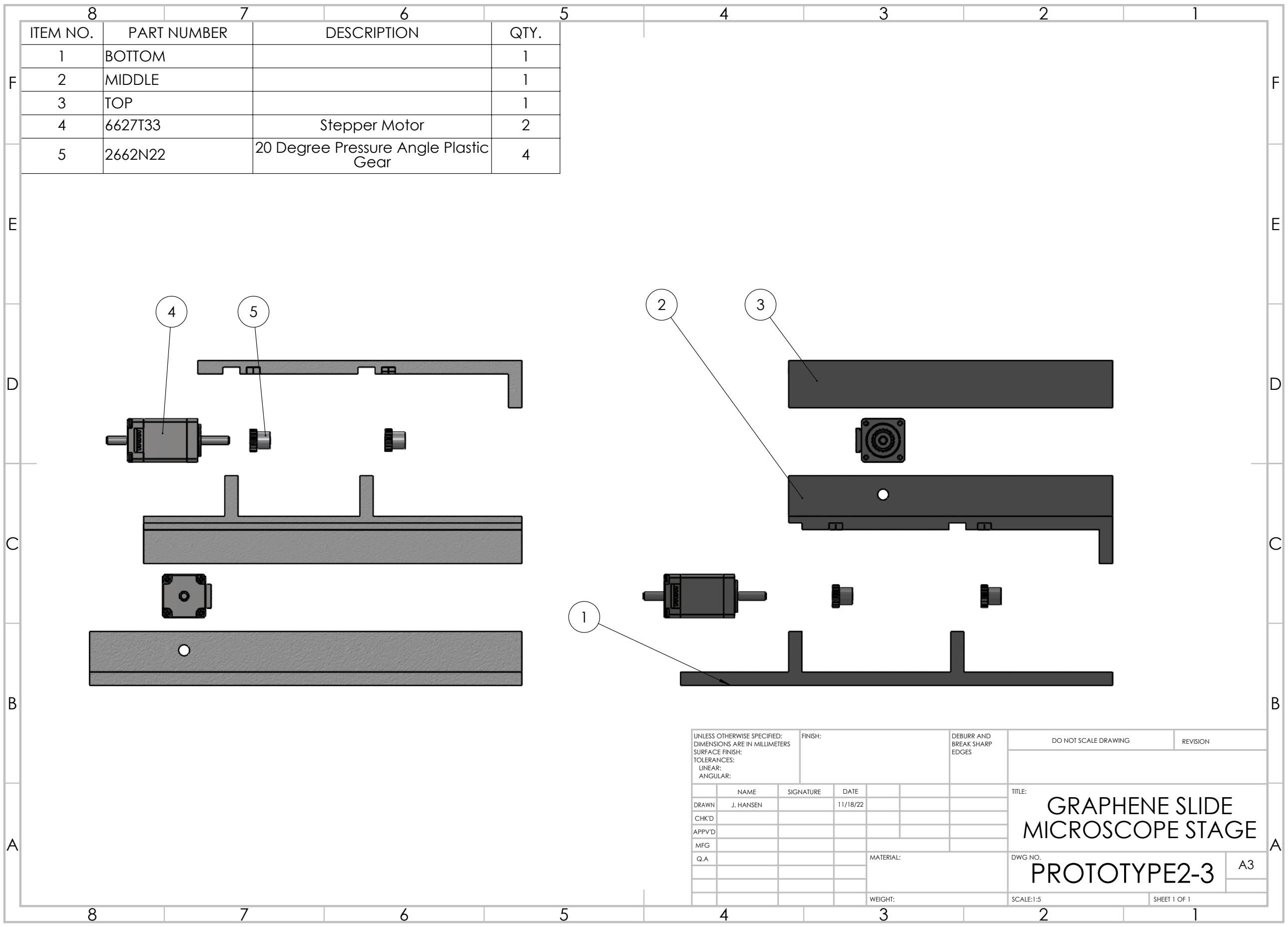


Figure 19: Exploded View of Assembly with BOM

The initial prototype's achievements in regards to the performance goals are underwhelming. The initial prototype was under the acceptable maximum height of 0.3 m. With a lack of stepper motors, the microscope stage was not motorized. The acceptable maximum velocity of 100 m/s was not achieved. The acceptable maximum acceleration of 1000 m/s^2 was not achieved. The acceptable position repeatability of 10 μm was not achieved.

5.2 Proofs-of-Concept

The built initial prototype led to some key discoveries! There were issues of balance, weight, and tolerance. When each layer was active, the upmost layer would tip over and not move from the turning of the gears. This would require tweaking of the material used for the prototype and ensuring the center of balance was never over the edge of a layer. When the layers were stacked on top of each other, the upmost layers would not move. It would simply be too heavy. This would require a redesign of our initial design. In terms of tolerance, sometimes pieces didn't fit together properly. This required cutting away at 3D printed versions which would be frustrating for every future copy of the model. Slots that connected layers together for stabilization would have to be made larger.

5.3 Design Changes

The main design changes were to cut back on material, make the prototype weigh less and therefore easier to move. We made the layers smaller as we worked our way up. The heart of the selected design is still there even though it looks different. The prototype is still moving with the racks on the bottom of the layers like we planned from the selected design. But, while building our prototype additional walls were needed, to keep our stage balanced and fixing any stability issues. The selected design had the three layers flush together. After we starting building the prototype we realized this would be difficult to build and test. Therefore, the initial prototype did not have flush layers but was still within the height requirement.

6 Design Refinement

6.1 Model-Based Design Decisions

Our model was designed based on the principle of microstepping. Stepper motors rotate by means of a step. Microstepping is the division of a step into several steps. This is done by applying a certain amount of current to the electromagnetic coils in the motor. This process is often handled by a stepper motor driver. A certain amount of torque is required to get through every microstep. To avoid empty resolution, the torque produced by the microstep must overcome the friction torque.

$$T_{inc} = T_h \sin\left(\frac{90}{s}\right) \tag{1}$$

where T_{inc} represents the incremental torque by microstepping, T_h represents the holding torque, and s represents the ratio of number of microsteps to one full step. According to the manufacturer, the holding torque is $T_h = 0.018$ Nm. The ideal number of microsteps per full step is $s = 256$ microsteps per every full step. We then find $T_{inc} \approx 1.104 \times 10^{-4}$ Nm. Figure 20 shows the microstepping model used .

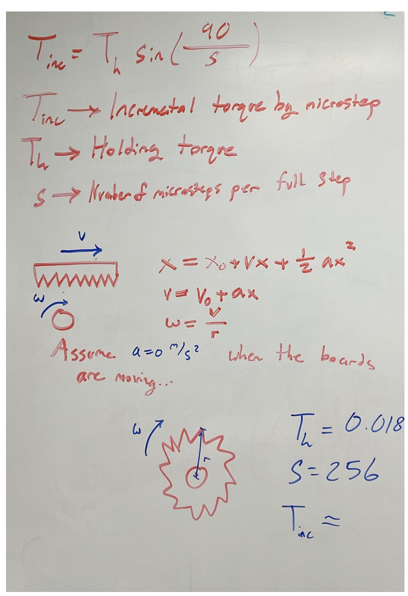


Figure 20: Microstepping Model

Another model created was to find the maximum amount of motor rotations needed so the top plate did not roll off the end of our rack. The model used the length of the rack L, θ the angle of the gear to normal, r the radius of the gear.

$$L = aC = a2\pi\frac{1}{8} \tag{2}$$

The model found that 7.64 motor rotations was the maximum amount of rotations our device could handle. This will be useful when programming our device so we know the max value our motor can handle. Fig 21 shows the designed model.

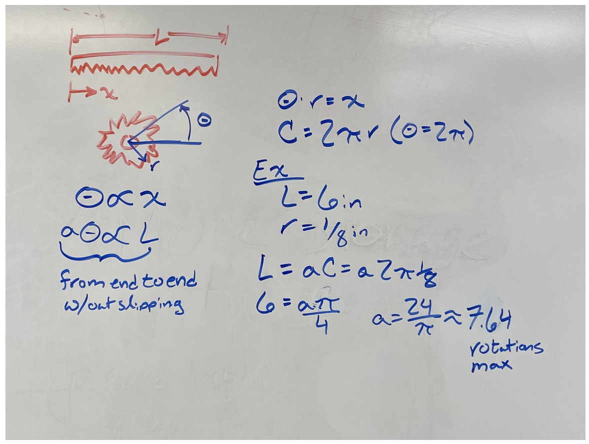


Figure 21: Model 2 Showing Maximum Rotations

6.2 Design for Safety

The following safety risks were taken into consideration while redesigning our initial prototype. There was a need to address the risk of getting someones finger caught in between the motor, the motor's overheating, the battery overheating, cracks within the plates, and the user suffering from carpel tunnel.

6.2.1 Risk #1: Fingers getting caught under moving slide

Description: Our design relies on two moving plates with a gear and rack system. Because of the nature of the design it is possible somebody working close to the stage could accidentally get a finger caught underneath one of the plates while it is moving. This could be a researcher looking underneath a microscope and not paying attention to their hand placement. Anytime the researcher asks to find a certain flake and they are around when the stage is moving puts the researcher at risk to get their hand caught in our device.

Severity: The risk would be critical because best case scenario the the person is only pinched. Worse case scenario somebody could be cut or bruised. Important to stay away while the stage is moving.

Probability: The risk is occasional of happening. Our design has walls covering the gear and rack mechanism but still possible for a hand to get underneath the plate from the side. Always a possible risk while someone is close by.

Mitigating Steps: If a finger were to get stuck the motor would stop and the rack and gear system is not strong enough to keep the hand stuck. The gear and rack system is small and low cause of serious injury. Walls prevent any hand from getting underneath the plate at the most likely angle of someones finger getting stuck.

6.2.2 Risk #2: Plates crack under significant use

Description: It is possible after many uses the PLA material chosen for our project could give to fatigue failure. Or if overtime the motor caused put too much torque on the rack system and caused it to crack. If there were a crack in one of the plates it would be a safety risk. Someone should be careful to pick up the plates or fix the plates because they could get cut doing so.

Severity: The risk is critical because the worse case scenario is someone is getting cut or bruised from our device.

Probability: The risk is unlikely to happen because the material was chosen to within stand the repeated torque from the motor and the forces from the other plates. This fatigue failure will only happen once, unless repaired, and therefore an unlikely event.

Mitigating Steps: The material was chosen because it could with stand repeated use. The motor along with the gear and rack system are small, therefore not causing many forces to allow the plates to crack.

6.2.3 Risk #3: Motor Overworked

Description: The motors chosen for our project are small and lightweight. Because of these properties it is more likely the motor could over heat with overnight use of our device. Overheating of the device would most likely happen when researchers are not around. But if someone accidentally touches the motor would be a safety risk.

Severity: The risk is marginal because if someone is close to the motor they may accidentally touch the motor and burn themselves. There is a possibility of a burn or a welt to appear on the skin.

Probability: The risk is unlikely because the motor would most likely overheat overnight and when nobody is around. If someone is close by they will notice that the motor stop working and realize something is wrong. The heat coming off the motor would hopefully stop someone from touching the motor itself. If a researcher is not paying attention and accidentally touches the motor is the most likely case of injury happening.

Mitigating Steps: The device will run at night which will mitigate the risk of a researcher being close by. The motor and wiring will be placed on the moving plates themselves, therefore the researcher will have no need to place their hands or fingers near the motor.

6.2.4 Risk #4: Carpal Tunnel from computer use

Description: It is possible that a researcher using the microscope and our stage could spend a lot of time looking for flakes and therefore being typing a lot on the computer. The device will run in tandem with a program to locate the flakes, making the s at risk of carpal tunnel from too much use.

Severity: The risk is marginal because the carpal tunnel case would not be very severe. If the researcher suffered from carpal tunnel they would not experience any critical injuries or bleeding.

Probability: The risk is unlikely to happen because the nature of our project is to have an autonomous program to find the graphene flakes. But, it is possible after the flakes are found a researcher will spend time going back to examine the flakes putting themselves at risk because they will use the computer for long periods of time.

Mitigating Steps: If the researcher suffered from carpel tunnel, it is possible to run the program and our device with the push of a button. Our device will be able to scan the microscope slides by autonomously. Mitigating the steps to get the program started will allow for less risk of the user getting carpal tunnel.

6.2.5 Risk #5: Battery Overheat

Description: The battery could overheat overnight or if there was a power surge overnight. If there was a freak accident that occurred it is possible our battery could cause a risk to our user.

Severity: The risk is marginal because the battery is small enough it would most likely cause no damage to the user. The battery damage would have a high chance of causing more damage to the other components on our device. In the event other components getting damage this domino affect could hurt our user. Burns or bruises are the worse case scenario from the battery overheating.

Probability: The risk is unlikely because the battery overheating will most likely happen when the researchers are away. This is because our device is designed to work autonomously overnight. If the battery does overheat with someone around, there will most likely be heat radiating off the motor or smoke. The user unless unaware should stay away from the motor.

Mitigating Steps: The battery will be running at times when nobody is around so nobody is at risk of getting hurt. If someone is around the battery will be tucked away in our device and the user has a low chance of accidentally touching the overheated battery.

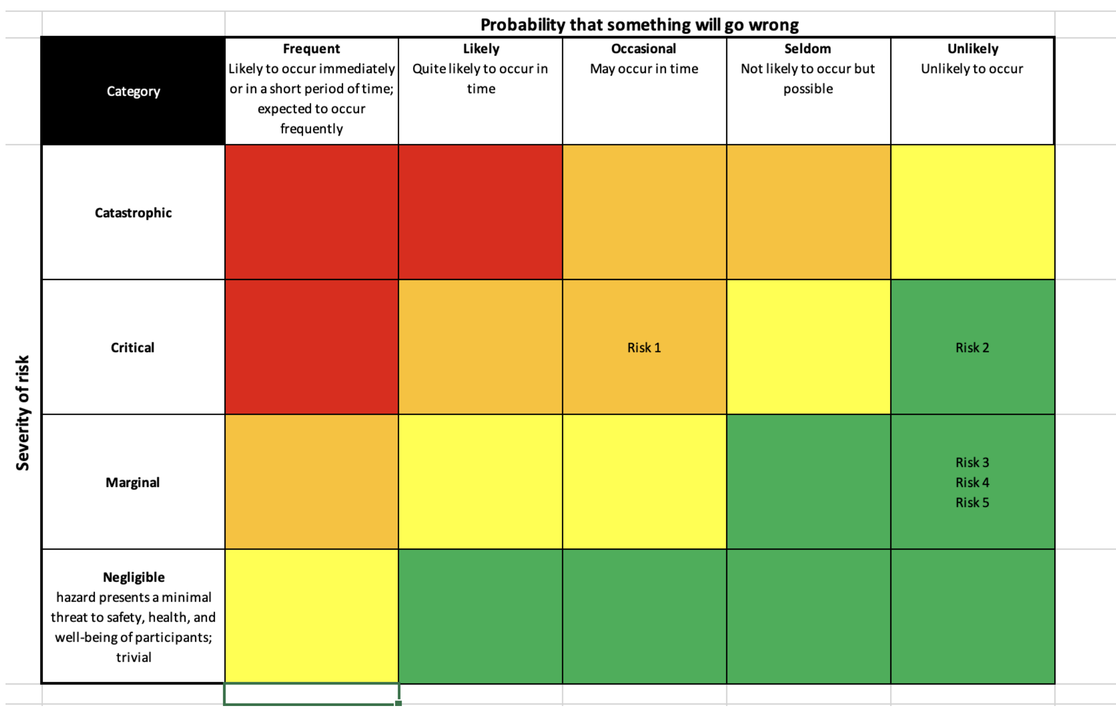


Figure 22: Heat Map of Identified Risks

Briefly describe the prioritization of different risks as recommended by the heat map. Which should be the highest priority, next highest, and so on... (minimum 100 words).

The highest priority safety risk was getting the finders or hand caught underneath the plates. This was the highest priority because it was the most likely to happen and cause the most damage to the user. The second priority was the battery and motor overheating. This is the second most likely incident to occur. Because of the nature of our project it is unlikely for someone to be injured if this incident happens but has the potential to cause harm to the user and damage the our device itself. The next priority was making sure our plates do not crack. This would damage our device from further use, the quality of our project, and possibility of cutting our user. The probability of fatigue failure is unlikely and therefore one of the lower priorities for our project. The lowest priority risk is the carpel tunnel. The user will be able to start our program with a few clicks on the computer and our device will work autonomously. Therefore this risk was the lowest likely to happen and in the case it does would not be a severe case of carpel tunnel.

6.3 Design for Manufacturing

Our group's design for this slide stage was initially set as a one time production process. Our customer has specific needs for their graphene flake research so a quickly repeatable manufacturing process was not in mind during our design process. Our manufacturing process though was split up in two main ways: 3D Printing the structure and Purchasing our electronics

The 3D printed components make up all of the design of the 3 piece slide stage (bottom, middle and top plates) and the gears used for the motion. In our goal of keeping the stage level while stationary and while in motion, we incorporated walls and slots into the plates design to refine the specified motion that each piece will take. For example, the bottom plate has two extruded walls that fit into two slots cut into the middle plate to define the motion of the middle plate to go left or right, or forwards and backwards. Also amoung the part consolidation effort, the gear racks that move the plates from the motion of the gear were cut and doubled into the 3D printed model to reduce the error that the gears would be allowed to fall off the rack

The stepper motors, motor drivers and programmable modules that make up the bulk of our electronic purchased components were purchased through the McMaster-Carr website from Pololu robotics and electronic. The need for purchasing the electronics as well as the great deal of programming and wiring proves to be the greatest challenge for our design to become reproducible and have a shorter manufacturing time.

6.4 Design for Usability

Vision impairments will not alter the design of our project. Our motorized microscope stage does not require user input that is dependent on vision. The stage is planned to be used overnight in a lab. No lab personnel will depend on visual cues for manual input. Users will note that the device may be malfunctioning if the device no longer moves or is vibrating from the gears not being properly aligned on the racks.

Hearing impairments will not alter the design of our project. Our motorized microscope stage does not require user input that is dependent on hearing. The stage does not intentionally produce noise to signify external adjustments. The only intentional noises are whirring from the stepper motors and noise from the gears on the racks. A user will be informed by the device malfunctioning when there is a chattering noise.

Physical impairments will not alter the design of our project. Our motorized microscope stage does not require manual user input. This avoids the issues of interaction between the device and users with muscle weakness, limb immobilization, or arthritis. Every layer of the device is light, made from polyactic acid (PLA) through an additive process. Deconstruction and construction for whatever reason will not be an issue of strength but potentially of accuracy. The pieces fit snugly together with little room for tolerance.

Control impairments will not alter the design of our project. Our motorized microscope stage is intended to be used without the interference of a user. It does not require constant attention, can be used while intoxicated, and does not require any effort at all. If the device is malfunctioning, it can be repaired easily when intoxicated or under medication.

7 Final Prototype

7.1 Overview

The final prototype was able to meet two of our three goals. The prototype was 3D printed and a little out of tolerance. When one of our goals was to be within 10 micrometers every time, it hurt that our project was out of tolerance because of the 3D printer. The prototype could stay level throughout its usage and move at our goal speed of 250 millimeters per second. In the future, we would have liked to add a manual adjustment to the device, use another method to create our parts allowing the parts to stay in tolerance, and customize the device to work more efficiently underneath the microscope.