Fall 2016

MEMS 411 Design Report Group O: Naked Mole Rat Trap

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Our Design Project is to improve an aspect of Dr. Stanton Braude's naked mole rat trap. These traps are used in the dessert to attract naked mole rats in a shallow tunnel underground and capture them once within the trap. There are a number of specific issues associated with these traps, but the ones we are focusing on are creating a detection mechanism when the trap entrance is blocked by soil, creating a locking door mechanism with a better failure rate, and creating a mechanism that prevents the locking door from be blocked by dirt from the surroundings. The mechanisms we create for these improvements will be added on to the modular design of the current product, allowing for inexpensive solutions to the problems Professor Braude faces.

MEMS 411 Design

Naked Mole Rat Trap II

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1 INTRODUCTION

1.1 PROJECT PROBLEM STATEMENT

Naked mole-rats are mouse size rodents that live in underground colonies in East Africa. They are best known for having a queen and workers like bees. Prof Stan Braude has been studying them in Kenya and Ethiopia for over 25 years and has trapped over 10,000 of these animals, marked and released them. He is the world's expert at trapping naked mole-rats and yet, he still needs a better trap. Prof. Stan Braude is looking forward to working with a team of real engineers and designers who can help him complete this project.

1.2 LIST OF TEAM MEMBERS

Figure 1: List of Team Members

2 BACKGROUND INFORMATION STUDY – CONCEPT OF OPERATIONS

2.1 A SHORT DESIGN BRIEF DESCRIPTION THAT DESCRIBES THE PROBLEM

Our naked mole rat trap will build on the existing design of leading naked mole rat researcher, Stanton Braude, by allowing detection when the trap is blocked by soil, reducing the failure rate of the shutter's lock mechanism, and preventing dust and rocks from clogging the shutter.

2.2 SUMMARY OF RELEVANT BACKGROUND INFORMATION

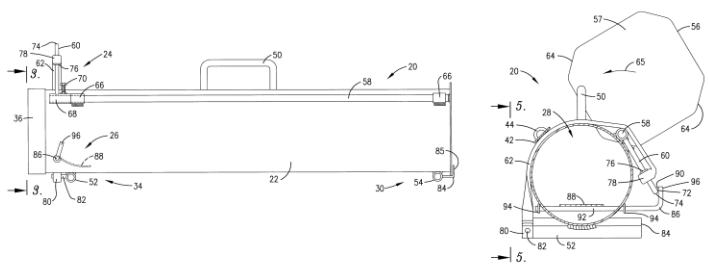
Our work is largely based on the existing work of Stanton Braude who is the leading expert at trapping naked mole rats. We met with him to better understand how the current traps can be improved, and we will seek to improve the parts listed above. Below is a picture of the current device and it's parts:

Figure 2: Original Design

There are no known competitors due to specific nature of the trap designed specifically for naked mole rats and a small "market", i.e., the small number of naked mole rat researchers, most importantly Stanton Braude himself. Thus the purpose of this project is to advance science rather than maximize profitability, but we will seek to optimize our design for functionality and repeatability while minimizing cost for the researchers.

Other than understanding the current naked mole rat trap design by meeting with Stanton Braude, it was also useful to investigate other animal traps to better understand potential trapping mechanisms for our design. Other live animal trap designs include cage traps and trapdoors. Patent US 6178686 B1 has a swinging door similar to Braude's shutter design, but is made for larger animals such as skunks. Furthermore, given that naked mole rat traps are placed at the end of the animal's underground tunnels, there are space constraints that make this and most options unfeasible.

Figure 3: Patent US 6178686 B1



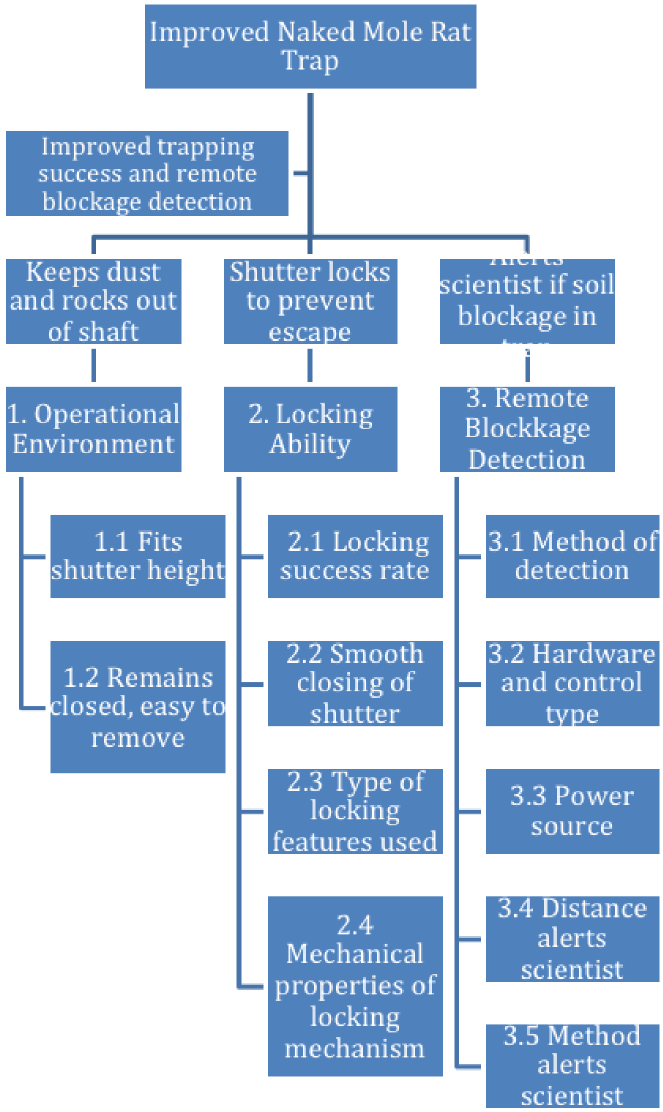
Thus this design is not a competitor to Braude's, which is specialized for naked mole rats.

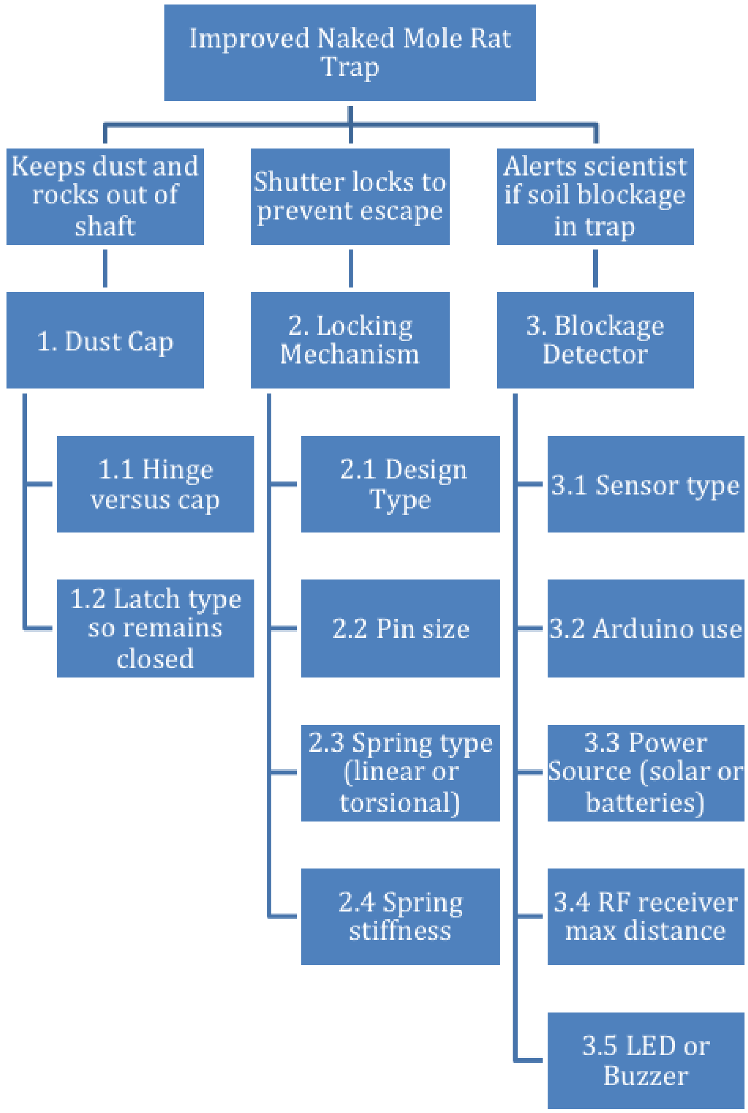
Many of the risks have been discovered through our discussions with Stanton Braude. The greatest risk is with the designing a device to detect soil blockage in the trap. Any electronics or cameras require a power source and are sensitive to the rough environmental conditions, thereby increasing the likelihood of failure. Another risk is improving upon the locking mechanism, which is already relatively effective. Our new design must improve the locking success rate, while maintaining simplicity and repeatability and reducing cost. The device mechanisms are also subject to difficult environmental conditions and wear as they are buried in the ground.

3 CONCEPT DESIGN AND SPECIFICATION – DESIGN REQUIREMENTS

3.1 OPERATIONAL REQUIREMENTS ALLOCATED AND DECOMPOSED TO DESIGN REQUIREMENTS

3.1.1 List of identified operational and design requirements





3.1.2 Functional allocation and decomposition

Functional Allocation is the definition of what system component performs each function.

Functional Decomposition is the process of taking a complex process and breaking it down into its smaller, simpler parts.

3.2 FOUR CONCEPT DRAWINGS

Figure 4: Overall Design Schematic

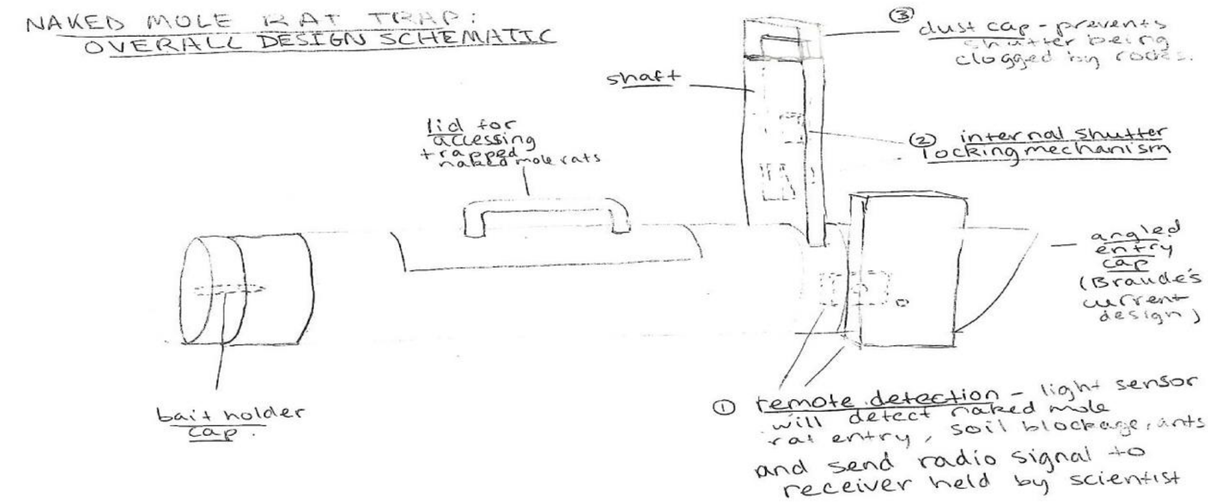


Figure 5: Remote Detector System Schematic

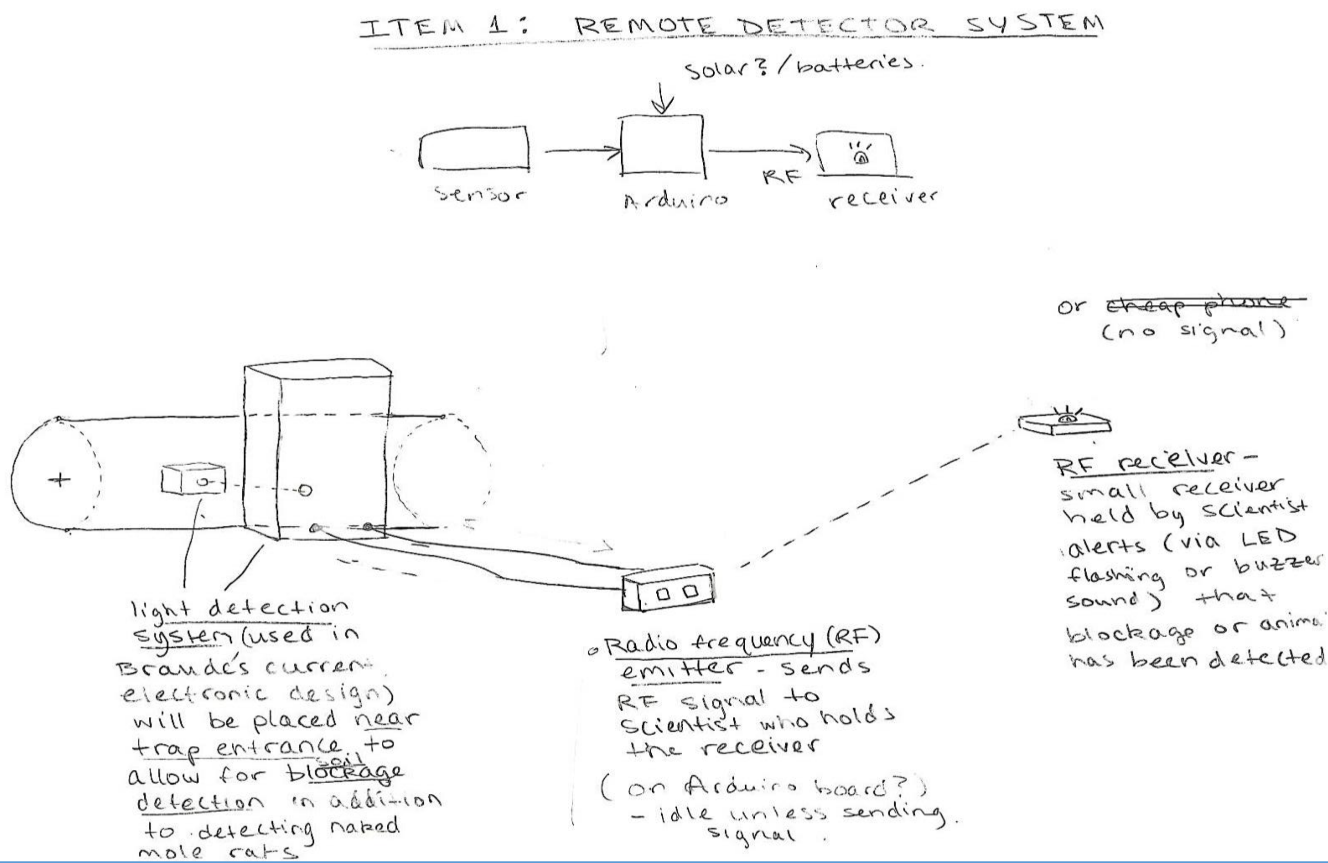


Figure 5: Locking Mechanism Schematic

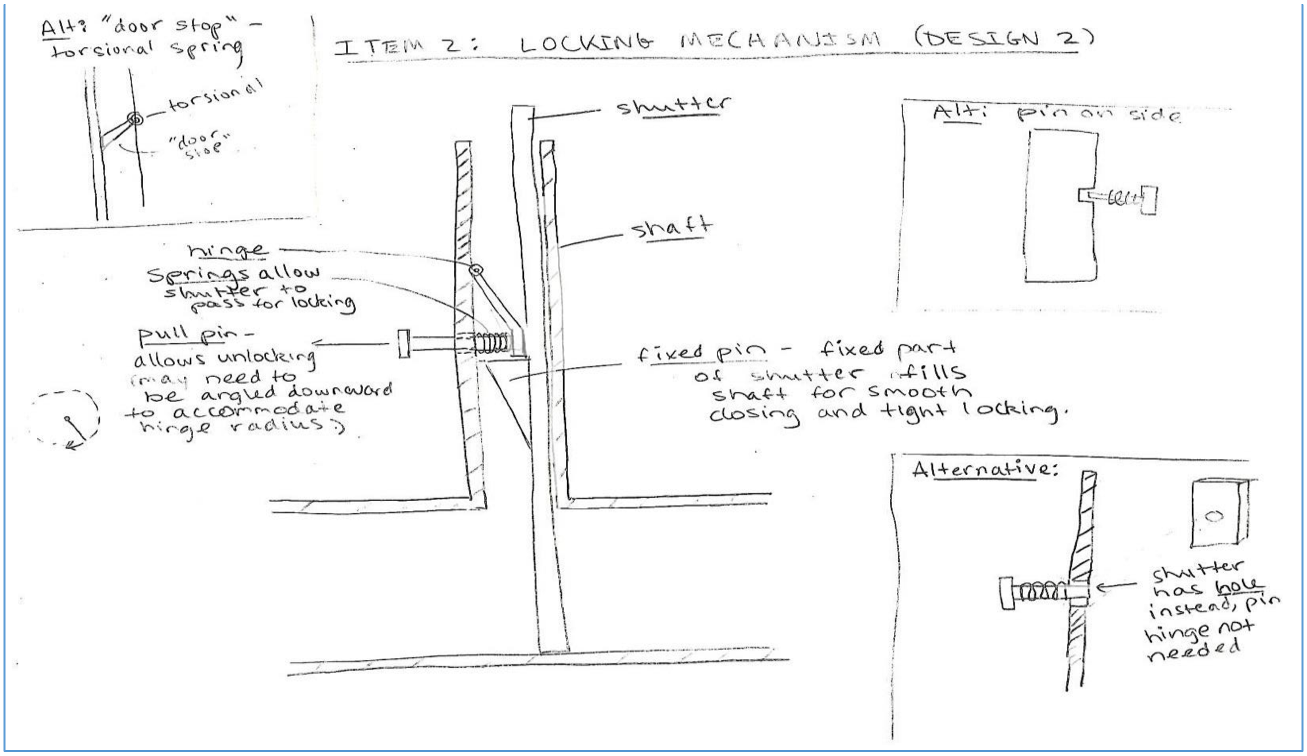
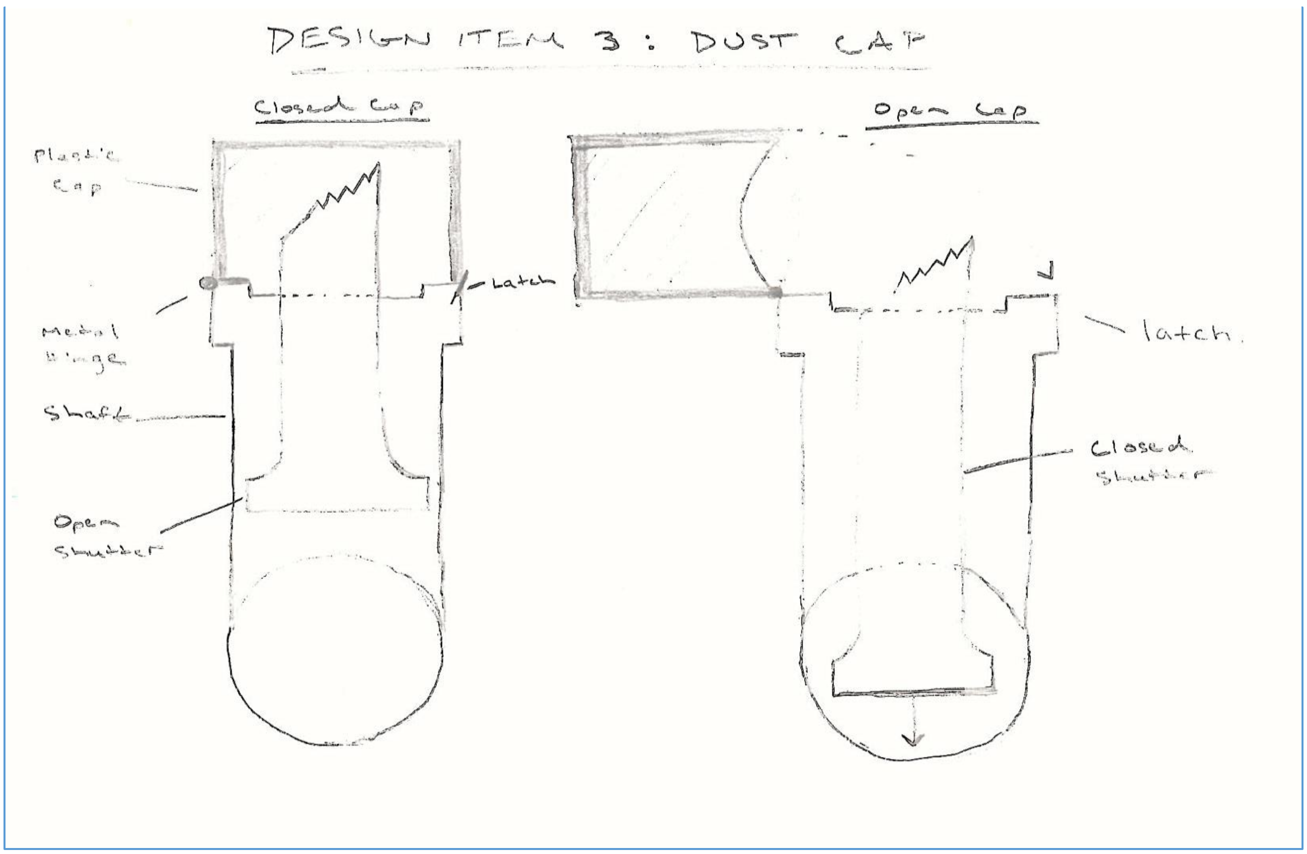


Figure 7: Dust Cap Schematic



3.3 CONCEPT SELECTION PROCESS

3.3.1 Preliminary analysis of each concept's physical feasibility based on design requirements, function allocation, and functional decomposition

Remote Detection System

The most important design enhancement articulated to us by Prof. Braude was the addition of a sensor that would detect both when an animal has entered the trap along with when an animal has blocked the entrance to the trap with soil. To address the first point, the Professor currently has to maintain a clear line of sight with all of the active traps he has set and watch to see if a shutter is triggered and goes down. In terms of detecting soil blockage, the Professor has to physically remove the lid to the trap's main chamber and look at the entrance to see if blockage exists. Our design enhancement includes a small LED light and a sensor that detects small changes in light caused by shadows within its line of sight. This detection system would then be connected to an arduino or another similar type of microcontroller containing a radio frequency (RF) emitter. The professor would keep an RF receiver with him on site that alerts him when an animal has either entered or blocked the trap via a flashing light or a buzzing sound (see Figure 4 above). Although this design need has been identified as Prof. Braude's biggest concern, our group is slightly concerned as to how feasible its implementation is. Our primary worry stems from how much power this system will require. The Professor currently does not have any power sources on site in Africa other than 6V battery packs. We have considered the possibility though of supplementing the battery packs with solar power captured on panels that could be wired to the system. We will continue to explore these concerns and actively find ways to address them as we move forward with the design phase of this project.

Locking Mechanism

We are designing a new locking mechanism for Prof. Braude's trap in an effort to minimize the chances that a naked mole rat is able to pry open the shutter and escape. Figure 5 depicts the current design we are pursuing as well as some other alternative options. The shutter would have a triangular piece of plastic attached to its face, which would be flush with the pull pin once the shutter is closed. The pull pin would be small in size (diameter of a half inch or less) and would be accessible from the outside face of the shaft. The spring attached to the pull pin would need to possess a low stiffness level. The low k-value is essential because the shutter is made of fairly lightweight plastic. If the spring constant is too stiff, the shutter will not be able to push past the pull pin once the trap is triggered. Additionally, the pull pin's material must be one that produces low friction when in contact with the plastic shutter so the door is not hindered after being triggered. An additional design we are also considering involves boring a hole in the face of the shutter so that the pull pin simply enters this opening and holds it in a fixed position until someone pulls the pin out and lifts up the shutter.

Dust Cap

The design of the dust cap is relatively simple, but this piece nonetheless serves a very important role in the trap's overall success rate. As things currently stand, dust, rocks, and other debris often blow into the shutter's small opening of space inside the shaft. Once this occurs, the shutter becomes clogged and cannot close when triggered due to the added blockage and friction. In order to combat this situation, we plan to add a lightweight plastic cap to the top of the shaft. The plastic cap will be attached to the top of the shaft via a small metal hinge, which will allow the cap to be flipped off when the shutter is being reset, as seen in Figure 6. One concern with the cap though is that it must be able to stay in place on windy days. Thus, we plan on also installing some sort of latch to fasten the cap to the top of the shaft. Along with this concern, we have also considered the need for the cap to be made of clear material so Prof. Braude is able to visually detect when the shutter has been triggered without needing to remove the cap each time to do this. It is important to note though that our remote detection solution discussed above will likely address this concern.

3.3.2 Concept scoring

Figure 8: Parts Specifications

Parts Specifications			
Mechanism	Part	Material	Size
Remote Detection System			
	Emitter		
	Detector		
	Radio Frequency Emitter		
	Radio Frequency Reciever		
Internal Shutter Locking System			
Design 1 (Shaft Notch)	Notch (Door)	Polymer	5 mm
	Notch (Shaft)	Polymer	5 mm
Design 2 (Spring Loaded Notch)	Spring	Chrome Vanadium ASTM A 231	5 mm
	Pin	Steel	1 cm
	Hinged Notch (Shaft)	Stainless Steel/Brass	1 x 1 cm
	Notch (Door)	Polymer	5 mm
Design 3 (Spring Loaded Pin)	Spring	Chrome Vanadium ASTM A 231	5 mm
	Pin	Steel	1 cm
	Notch (Door)	Polymer	5 mm
Dust Cap	Cap	Polymer	2 x 4 x 6 cm
	Hinge	Stainless Steel/Brass	1 cm

3.3.3 Design requirements for selected concept

3.3.4 Final summary

One of the main problems with the current system is the lack of a detection mechanism if the doorway becomes blocked by dirt. Often, the rats will build up dirt in the doorway to close off the passage. With the current system, this can go undetected for long periods of time, rendering the traps inoperable. Our detection system will use a light detector, much like the current system in place that is used to trigger the trap door, with an emitter inside the doorway and a detector at the entrance outside the doorway. This detector will use a radio frequency emitter to send the signal that the door has been blocked to the scientist who is holding the radio frequency receiver. This way, if anything blocks the entranceway, like a rat going through, the detector will send the signal to the receiver, and the receiver's light will turn on. If the light is turned on for a prolonged amount of time without the trap door being triggered, then the observer knows that the doorway is blocked and thus the trap is inoperable and has to be reset.

The locking mechanism is what locks the door in place once the mouse sets the trigger. There are a couple different design possibilities. The first is a spring-loaded mechanism that locks the trap door in place once it falls. This works by using a spring that pushes a pin against the door. As it falls, the pin keeps a light pressure against the door, allowing the door to fall without obstruction. When it falls completely, there is a notch in the door that will sit just under the pin, locking the doorway in place so that it can't be lifted out without pulling the pin out first. The notch system can work in one of two ways. Either there is a hole in the door and the spring pushes the pin into it, or there is a notch extruding out of the door and the spring pushes a hinged plate over the notch once it falls into place. Either way, this locks the doorway in place so the rat can't dig under the door to lift it and escape.

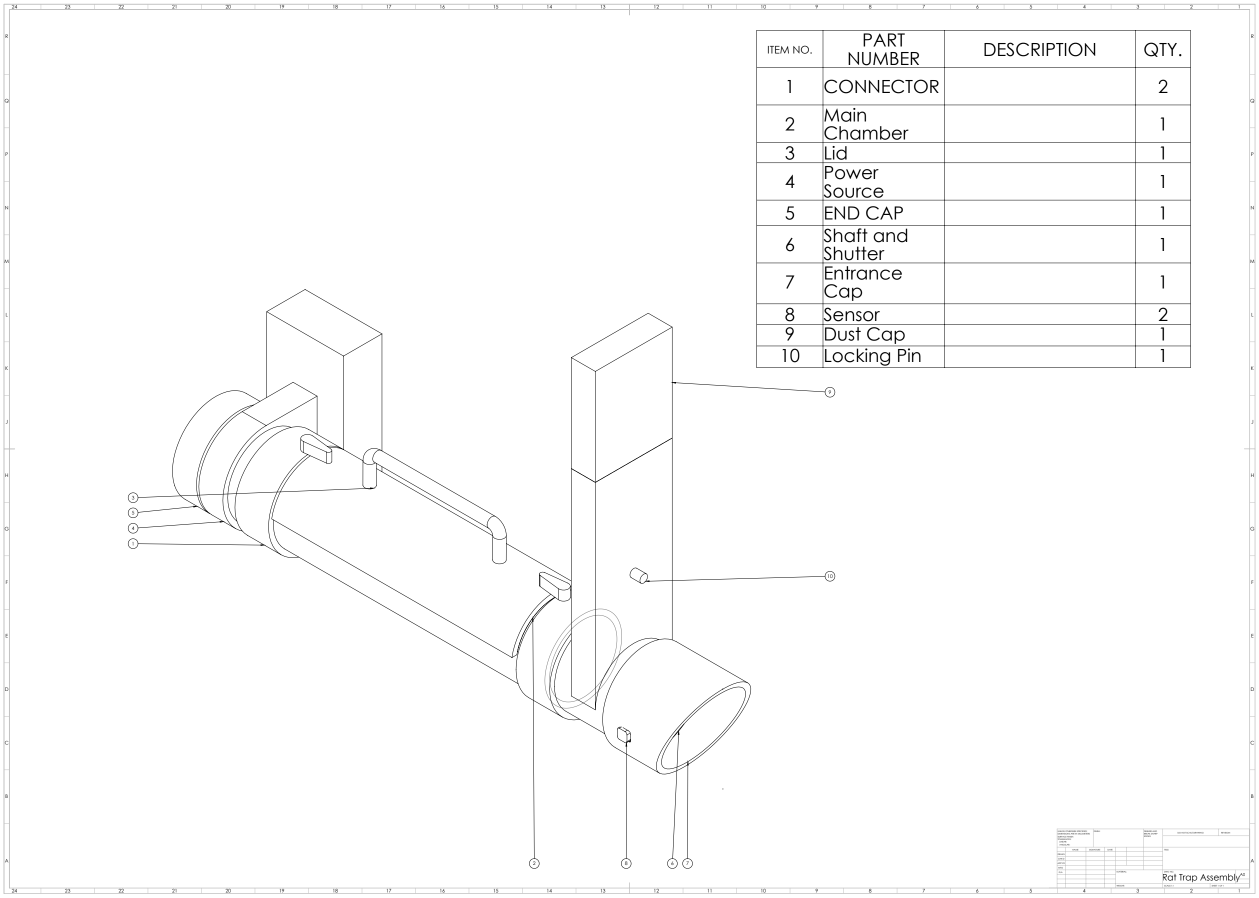
The second design is similar. However, instead of using a spring-loaded pin mechanism, the door falls freely at a slight angle. When it falls completely, there is a notch on the door that sits directly under a notch in the housing shaft, locking the door in place. The door can be removed by applying a counter pressure at the top to shift the door and disengage the notches. However, any kind of pressure the rat could put on the door by pushing or lifting it would not disengage the notches.

The third mechanism is the dust cap. Often, rocks and small debris can get lodged between the trap door and its shaft in the trap. This shutter cap is a small plastic cover that will be placed over the trap door while it is open to prevent any dust and debris from becoming lodged and allow for a higher success rate of the door shutting properly. The cap will be secured to the trap door shaft by a durable metal hinge that allows the scientist to open it to set the trap door and close it once the trap is in place.

4 EMBODIMENT AND FABRICATION PLAN

4.1 EMBODIMENT DRAWING

Figure 9: Assembly Drawing



4.2 PARTS LIST

Table 1: Parts List

Part	Source	Model No.	Quantity	Cost ($)
Arduino Leonardo	WUSTL MakerSpace	A000057	1	0.00
IR Sensor	WUSTL MakerSpace	Sharp GP2Y0A21YK0F	1	0.00
Zinc Clevis Pin	MEMS Storage	SEN-09088	1	0.00
Metric Compression Spring	MEMS Storage	Gardner Spring MC041-0240-S	1	0.00

4.3 DRAFT DETAIL DRAWINGS FOR EACH MANUFACTURED PART

Figure 10: Shaft and Shutter Drawing

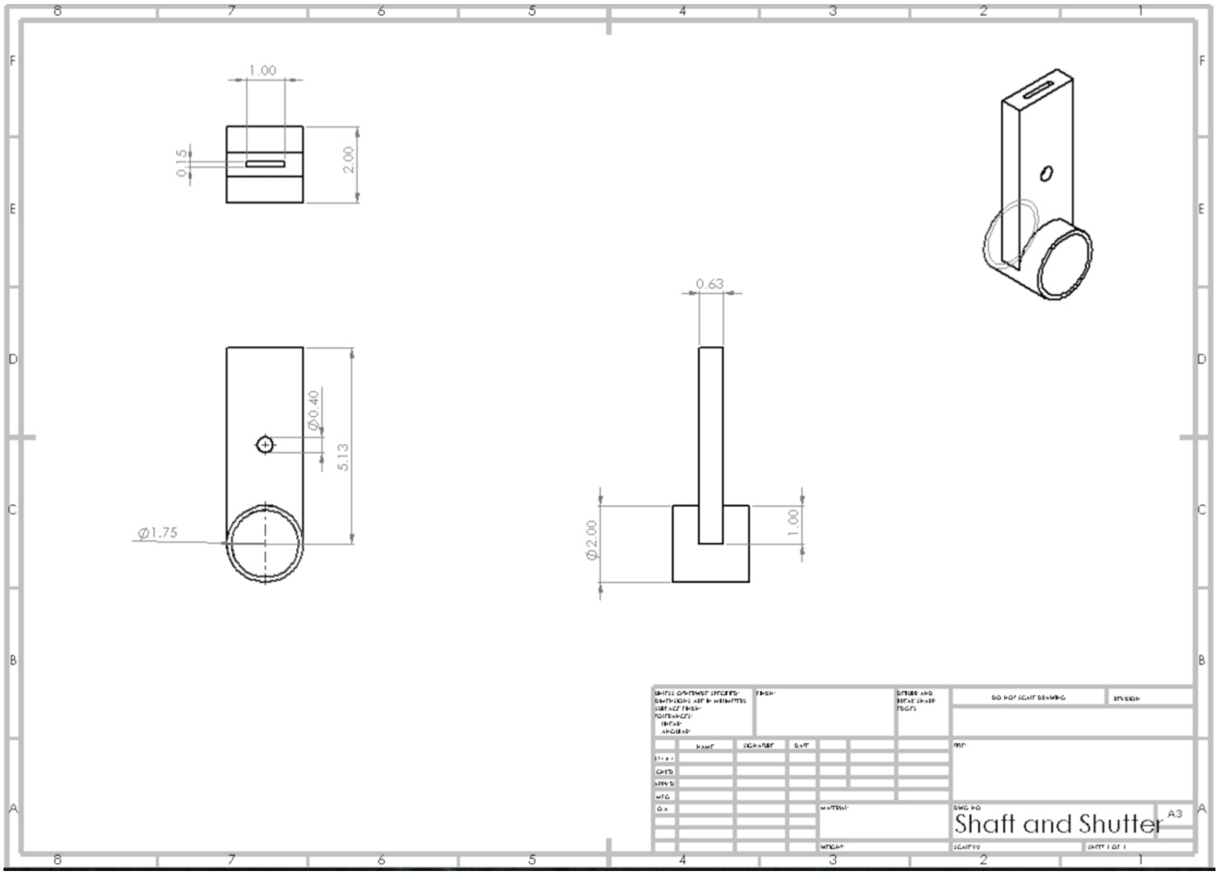


Figure 11: Shaft Attachment

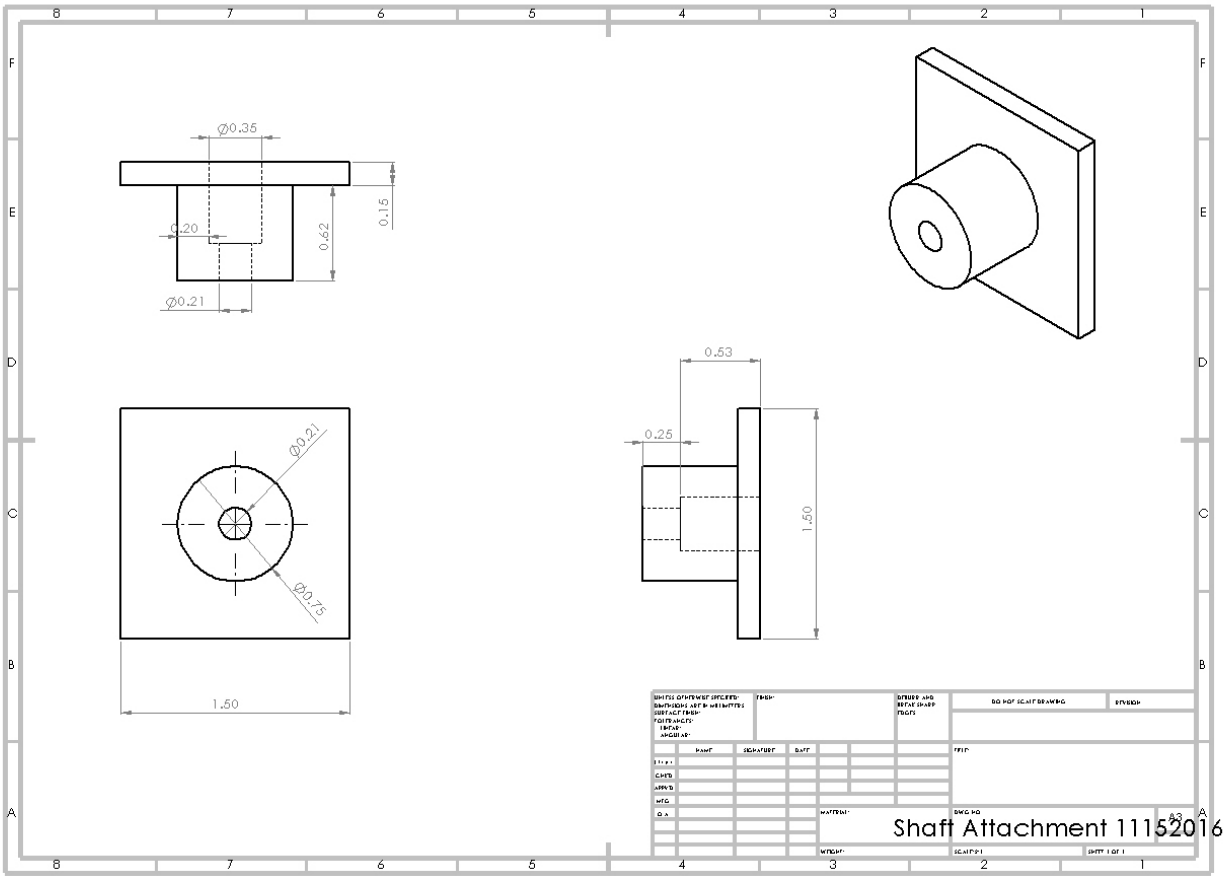


Figure 12: Entrance Cap Drawing

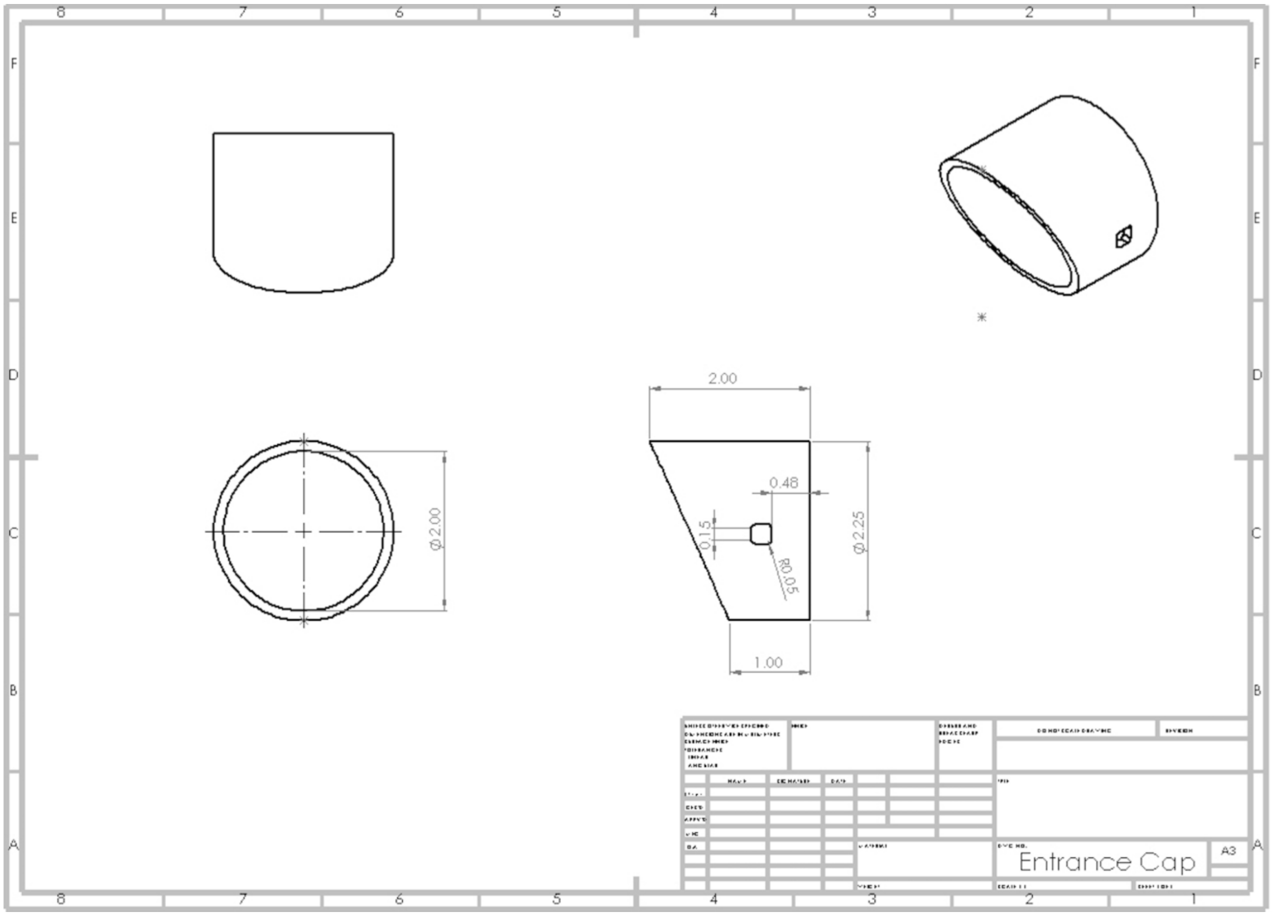
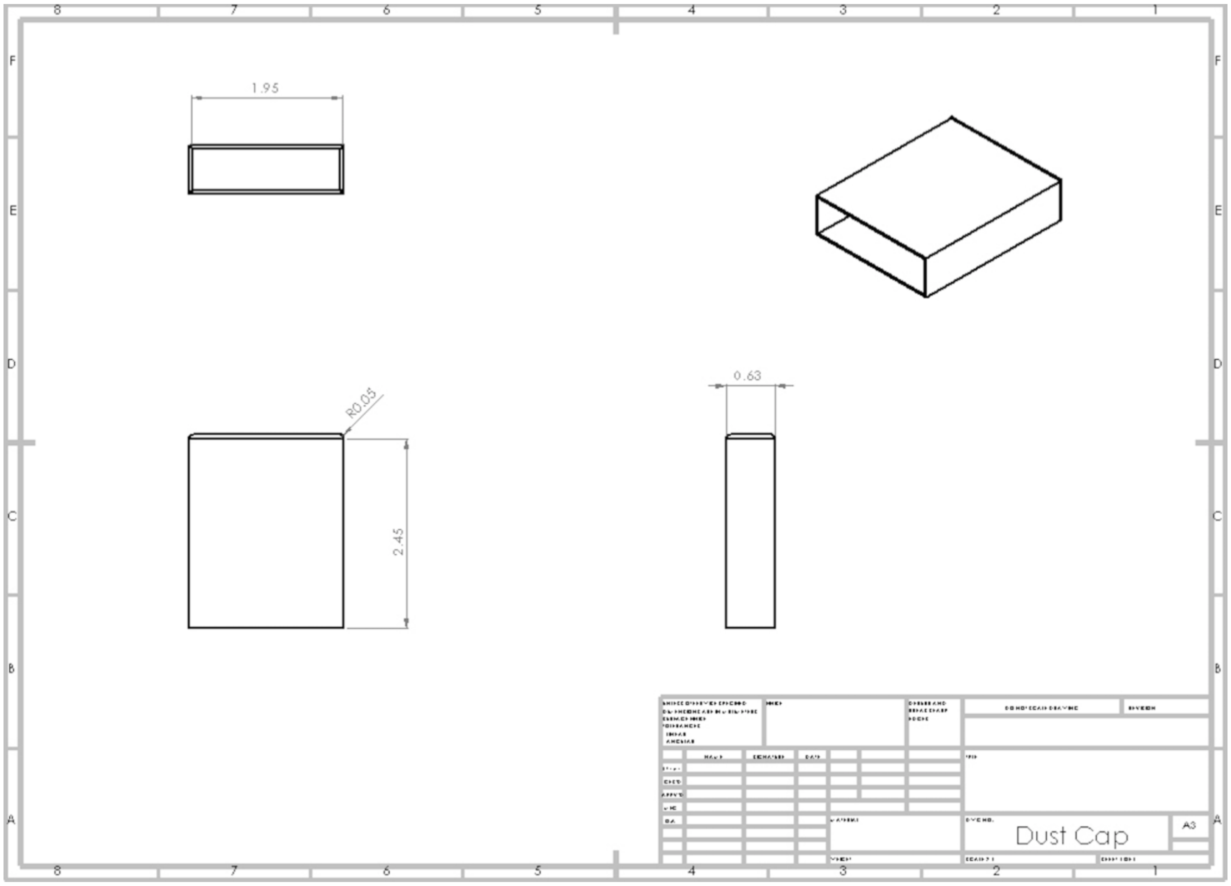


Figure 13: Dust Cap Drawing



4.4 DESCRIPTION OF THE DESIGN RATIONALE FOR THE CHOICE/SIZE/SHAPE OF EACH PART

There are a number of parts depicted in the embodiment drawing. While all of these parts are used in the final assembly, we are only modifying a few of them from the original assembly. The rest of them are fixed parts of the assembly that are constraints we have to accommodate. For this assignment, we've including the drawings and descriptions only for the parts we are designing.

Shaft and Shutter

The shaft and shutter are the components that make up the door of the trap. The entrance cap fits on the front side of the shaft, and the backside fits snugly into the main tube of the trap. The shutter will sit loosely inside the shaft. However, this can't be too loose as to allow large debris to become lodged and the shutter to not lock. There is also a slot much like the existing design for the release pin to hold the shutter up while the trap is set.

Entrance Cap

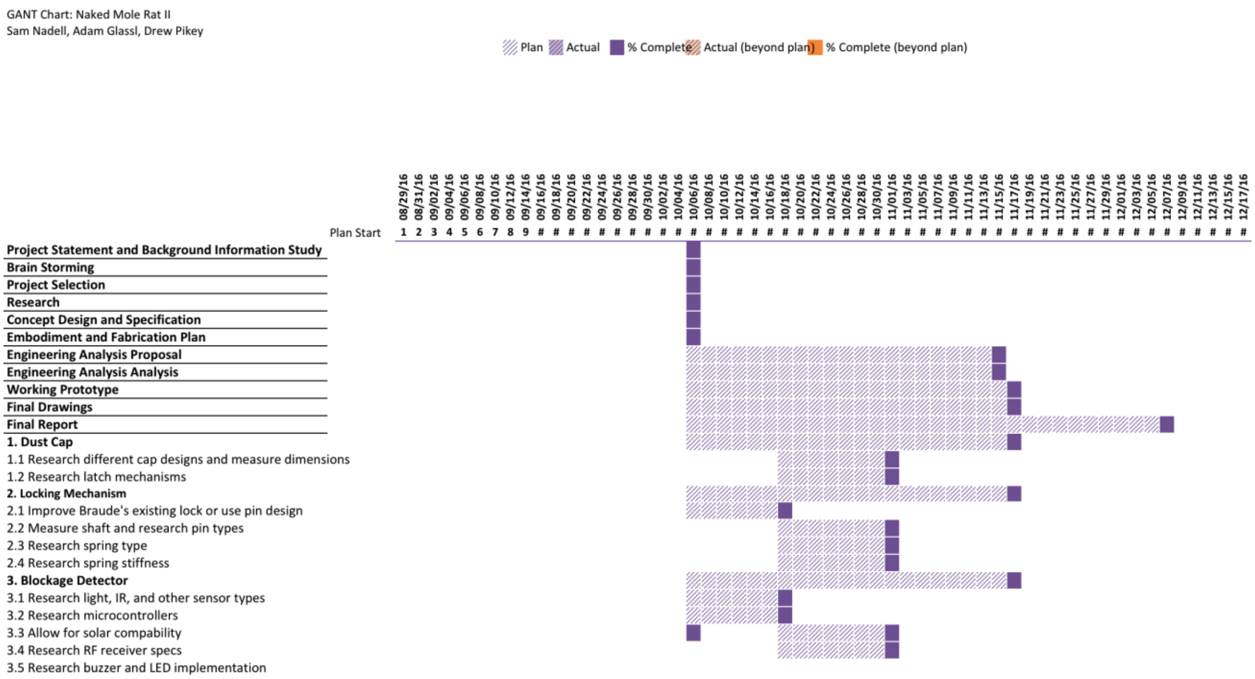
The entrance cap is the modular covering for the main tube of the trap. This will have a snug fit onto the front of the shaft for the tube. There are slots on each side of the cap that will be the housing for the motion detecting sensors that trigger when a rat enters the trap. Considerations for this design are the tolerances of both the fit onto the tube and the slots for the sensors. The slots for the sensors have to be slightly larger than the sensors, because they aren't a snug fit. Also the inside of the cap has to be very smooth as to not deter the rats when they are entering the tube.

Dust Cap

This shutter cap is a small, clear plastic cover that will be placed over the trap door while it is open to prevent any dust and debris from becoming lodged and allow for a higher success rate of the door shutting properly. The cap will have a snug fit onto the shaft that will still allow the user to easily remove it for access. Tolerances and the type of material were a consideration when designing this part.

4.5 GANTT CHART

Figure 14: Gantt Chart



5 ENGINEERING ANALYSIS

5.1 ENGINEERING ANALYSIS PROPOSAL

5.1.1 A form, signed by your section instructor

Not Applicable

5.2 ENGINEERING ANALYSIS RESULTS

5.2.1 Motivation

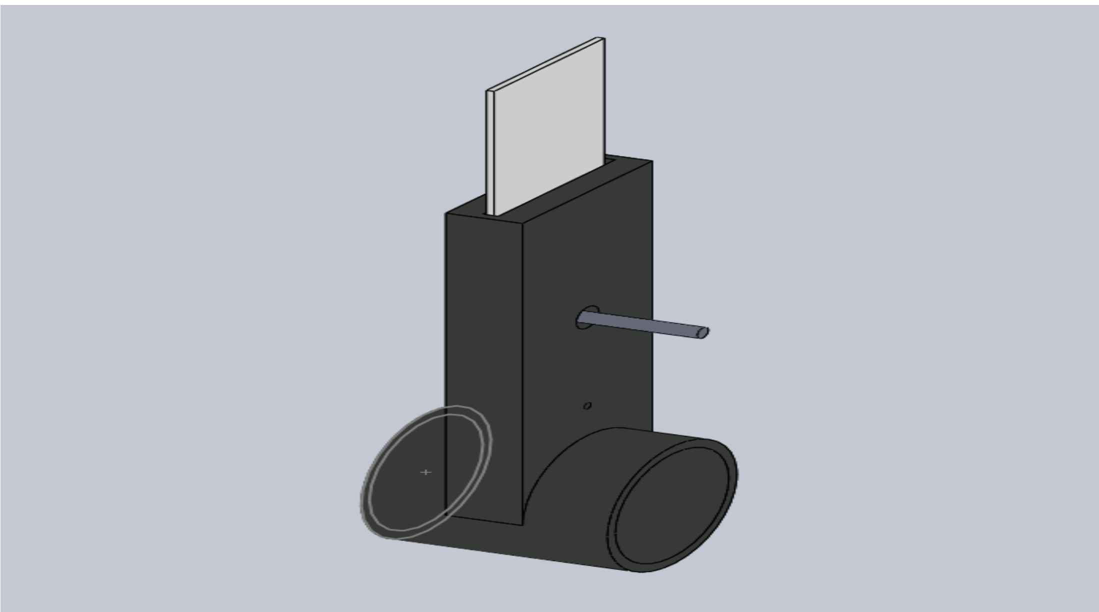
Our engineering analysis tested the amount of force resulting from the free fall of the shutter from the height of the trigger pin to the bottom of the main trap chamber. The motivation of this analysis was to determine whether the force of the shutter in free fall would cause any harm to a naked mole rat in the shutter's path (particularly the babies). This is important to the project moving forward as it will help us to measure the risk of injuring or killing naked mole rats, which are trapped for research. It is also important in design specifications because the force is directly dependent on the weight of the shutter and the friction force between the shutter and internal wall of the shaft.

5.2.2 Summary statement of analysis done

The engineering analysis involved three tests to determine the force resulting from the shutter falling from the height of the trigger pin where it was released to the bottom of the main trap chamber.

For each of the tests, the material was set as acrylic for the shutter and shaft (thus determining the weight of the shutter) and steel (dry) for the pin. The height of the trigger pin was used as the initial height. Force was measured as the shutter collided with the bottom of the main trap chamber. An image of our SolidWorks assembly model used in this motion study with the shutter in the initial, loaded position is shown below:

Figure 15: SolidWorks Prototype Model



The first test involved releasing the shutter in free fall, without any added weight or friction. The second test involved releasing the shutter with friction, which added resistance to the falling shutter and thus reducing the force on collision. The third test involved adding additional weight to the shutter. Additional weight may be used to overcome friction to obtain smoother closing of the shutter. Other design methods to overcome friction include sanding the shutter, reducing the stiffness of the spring, and adjusting the shape of the pinhead.

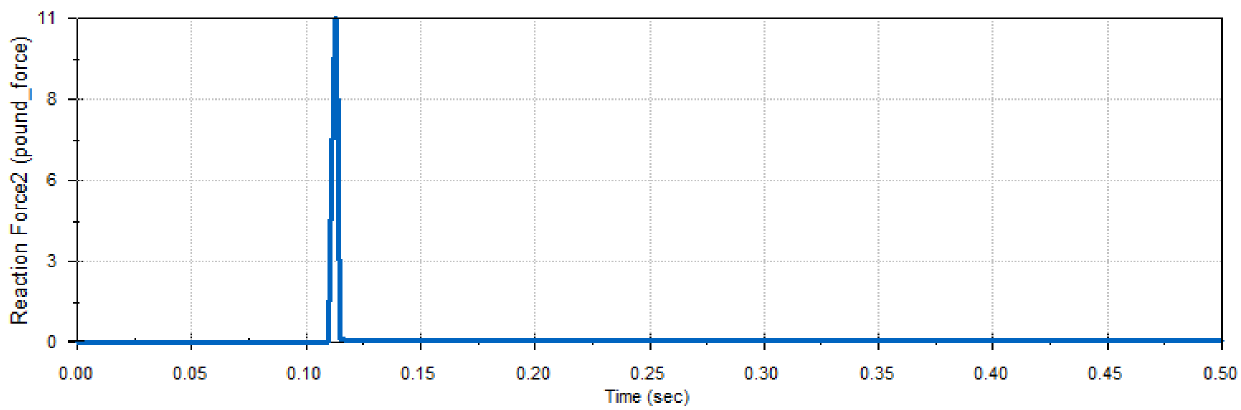
5.2.3 Methodology

Our engineering analysis was completed using a SolidWorks motion study. The shutter, shaft, and pin were all included in our assembly. Gravity was turned on thus allowing the shutter to freely fall once the motion study commenced. A contact set was established between both the shutter and the bottom of the shaft chamber along with the shutter and the pin. In order to simulate the friction force caused by the contact of the pin against the shutter, a force was added to the back of the pin. SolidWorks is able to measure magnitude values for impact forces so plots were made to determine the peak values of the impact forces.

5.2.4 Results

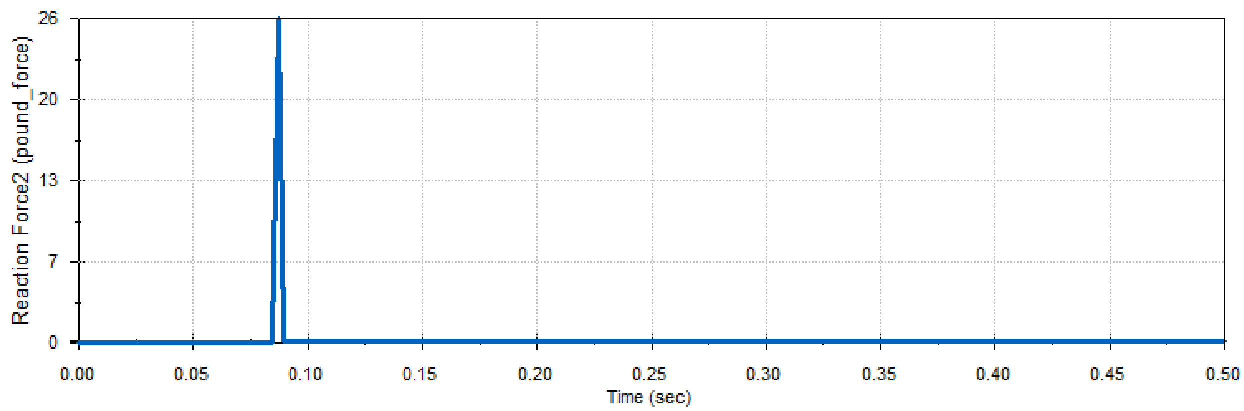
The small amount of force produced seems logical since the weight of the shutter (even with a small amount of added weight) and the distance for free fall are small. Without adding any additional weight or resistance force from the pin, the impact force caused by the shutter's free fall is 11 lbf, as seen in the plot below:

Figure 16: Engineering Analysis without Weight



We then added a downward force of 0.1 lbf to the shutter to represent the effects of additional weight on that component as seen in our working prototype. As expected, this additional weight increased the impact force of the shutter by more than doubling it. The value of 26 lbf is seen in the plot below:

Figure 17: Engineering Analysis with Weight



Lastly, we established a contact, friction force between the pin and the shutter to represent the resistance the spring-loaded pin would induce on the shutter during its descent. A force of 1 lbf was also added to the back of the pin to increase amplify the frictional effects. Our findings indicate that the impact force is reduced in both cases to 22 lbf with weight added to the shutter and 9 lbf with no added weight to the shutter.

The results support that the shutter without added weight will not harm the naked mole rats. Furthermore, it was determined that a small amount of additional weight to improve the sliding of the shutter should also not harm the naked mole rats. We also discussed our concerns of the shutter harming a naked mole rat (especially the babies) with Dr. Braude, the head researcher of naked mole rats we are building the trap for. He alleviated any concerns and told us that there was nothing to worry about, even for the babies. These results suggest that we are able to move forward with the current design, although we may need to make some adjustments to reduce friction and thereby optimize the design (see the next section on Significance).

5.2.5 Significance

The engineering analysis in combination with our discussions with Dr. Braude suggests that the current design (even with a small amount of added weight) should be successful in trapping naked mole rats with little risk of harming them. However, the design should be further optimized to reduce the amount of friction between the shutter and the internal wall of the shaft.

With the current design, the spring-loaded pin presses the shutter against the wall. If the shutter does not have sufficient weight then it will not fall when the trigger pin is released due the static friction force between the internal wall of the shaft, the shutter, and the pin. This results in the failure of the shutter closing, locking, and thus trapping the naked mole rat.

While adding weight is one method to overcome the friction force, it has the drawback that too heavy a weight adds to the risk of harming a naked mole rat in the path of the closing shutter. Thus we will explore other options to reduce the friction force.

The first and easiest option is sanding the shutter and internal wall of the shaft so it is smoother. For the prototype, both parts are made out of 3D print material, which has bumps and defects that catch on each other and therefore increase the amount of friction. Sanding will help to mimic the finished product, which Dr. Braude currently makes out of acrylic and smooth plastic, which have a smaller amount of friction.

A second option is to reduce the stiffness of the spring. This would reduce the friction, which is directly dependent on the spring-loaded pin pressing the shutter against the internal shaft wall.

A third option is to round out the shape of the pinhead. This would minimize the amount of surface area and thus the amount of friction between the pin and shutter. However, we believe that the largest amount of friction is between the shutter and internal wall of the shaft, so it may be more important to reduce friction on those two surfaces.

5.2.6 Summary of code and standards and their influence

We used the code and standard for live animal, specifically mammal traps, ISO 10990. This standard provides "test methods for performance evaluation of traps in the areas of animal welfare, capture efficiency, selectivity and user safety." We reviewed this particular standard and all of our trap design enhancements and alterations with Dr. Braude. We concluded that our design is compliant with ISO 10990 because it humanely traps the naked mole rats without causing them any substantial physical harm in the process.

6 WORKING PROTOTYPE

6.1 A PRELIMINARY DEMONSTRATION OF THE WORKING PROTOTYPE

Not Applicable

6.2 A FINAL DEMONSTRATION OF THE WORKING PROTOTYPE

Not Applicable

6.3 AT LEAST TWO DIGITAL PHOTOGRAPHS SHOWING THE PROTOTYPE

Figure 18: Trap Door and Shaft Attachment

Figure 19: Zinc Clevis Pin with Spring

6.4 A SHORT VIDEOCLIP THAT SHOWS THE FINAL PROTOTYPE PERFORMING

https://youtu.be/K2b2PIetwuY

6.5 AT LEAST 4 ADDITIONAL DIGITAL PHOTOGRAPHS AND THEIR EXPLANATIONS

Figure 20: Left – Assembled Prototype. Right – Original Trap Door

Figure 21: Arduino used for Remote Detection System

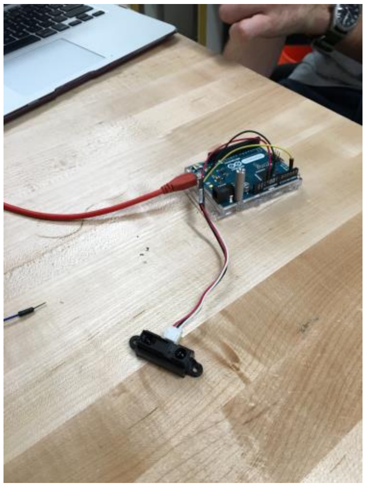


Figure 22: Demonstration of Original Trap Model

Figure 23: Original Trap Design in the Field

7 DESIGN DOCUMENTATION

7.1 FINAL DRAWINGS AND DOCUMENTATION

7.1.1 Engineering drawings

See Section 4.3 for Draft Drawings.

7.1.2 Sourcing instructions

The shaft, shutter, and shaft attachment were all 3D printed parts and the respective CAD models for these parts can be found in Appendix C. The pin and spring used for the locking mechanism were both acquired from the Washington University MEMS Storage Unit and the relevant model numbers and manufacturers of these parts is found in Section 4.2.

7.2 FINAL PRESENTATION

7.2.1 A link to a video clip

https://youtu.be/5liJkmqCR0k

7.3 TEARDOWN

Figure 24: Teardown Tasks Agreement

TEARDOWN TASKS AGREEMENT

PROJECT: Naked Mole Rat II NAMES: ADAM GLAST INSTRUCTOR: MALAST JAKIELA

DREW PIKEY

SAM NADELL

The following teardown/cleanup tasks will be performed:

Return trap components borrowed from Prof. Brande.

Cleaned up work area.

Figure 25: Teardown Instructor Signature

Instructor comments on completion of teardown/cleanup tasks:

Instructor signature: Mary Malast Print instructor name: MARY MALAST

Date: 12/9/16

(Group members should initial near their name above.)

8 DISCUSSION

8.1 HOW WELL WERE THE NEEDS MET? DISCUSS THE RESULT.

Our goals when designing the project were to create a simple and mechanically sound prototype that had a locking success rate of 95%. Our prototype met and surpassed these needs. It works 100% of the time in all types of tests that we found accurately depicted true field-testing. The design itself is simple and elegant, meeting and exceeding Dr. Braude's expectations. Dr. Braude wants us to create an additional 10-15 models for future field-testing and use, which constitutes a huge success for us. The ultimate goal is for our project to be implemented for real world use, and we are well on track to achieve this.

8.2 DISCUSS ANY SIGNIFICANT PARTS SOURCING ISSUES? DID IT MAKE SENSE TO SCROUNGE PARTS? DID ANY VENDOR HAVE AN UNREASONABLY LONG PART DELIVERY TIME? WHAT WOULD BE YOUR RECOMMENDATIONS FOR FUTURE PROJECTS?

We did not find any barriers in part sourcing throughout the project. When designing, we were faced with the issue of finding the appropriate pin and spring for the prototype. Fortunately, we found both in the parts inventory here. The parts we found came with part numbers for duplication purposes. However, I can foresee issues if we found parts without part numbers and would not be able to duplicate the parts for additional prototypes. I would recommend finding parts that have the associated part numbers so that the project can be replicated. Our prototype, however, will be easily duplicable for future designs and uses.

8.3 DISCUSS THE OVERALL EXPERIENCE:

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

The project ended up being less difficult that we expected. While there were plenty of hurdles to overcome, we received extensive help from Dr. Braude to overcome any problem we faced. Overall, with the combination of our skillsets, available knowledgebase, and resources at hand we were able to complete our project in a smooth and timely fashion.

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

Our project results align remarkably well with our project description. Ultimately, we wanted a tangible product that will be functional and repeatable in the field and that Dr. Braude will implement into all of his traps in the future. Dr. Braude now wants a number of copies of our final product so he can begin to implement them into his existing model for his next trip abroad.

8.3.3 Did your team function well as a group?

Our team functioned excellently as a group. Our skills complemented each other remarkably well in the sense that no matter what problem we faced we were able to find solutions in a balanced and efficient manner. We all shared the workload evenly, worked diligently to create a final product, and enjoyed our time together while we were working together.

8.3.4 Were your team member's skills complementary?

Each member of our team has skills that complemented each other's very well throughout the course of this project. Between the three of us, valuable skills such as brainstorming, SolidWorks design, communication, and presentation were all accounted for. This allowed us to work in a complementary fashion to quickly finish tasks at hand.

8.3.5 Did your team share the workload equally?

In order to maintain the functionality of our group, we divided up the workload equally throughout the project. Our complementary skills allowed for a simple and straightforward task load separation, allowing each individual member of the teamwork equal amounts on the work that suited him best.

8.3.6 Was any needed skill missing from the group?

There were no missing skills that kept us from completing our project in an efficient manner. However, there are many skills we could have been more adept at that would have led to a smoother project. For example, SolidWorks designing could have been more efficient throughout the iterations. Along with this, having a more robust knowledgebase in the naked mole rat field would have expedited the process immensely. These were hurdles that we easily overcame through hard work, persistence, and communication with Dr. Braude.

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

We consulted the customer regularly throughout the process. Dr. Braude has an extensive knowledgebase on the subject and was an excellent resource for us along the way, helping us move past design hurdles and enlightening us to design constraints we might not have otherwise been aware of. Ultimately, this open communication was paramount in our success as a group and in developing our solution.

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

Throughout the course of the project, the overarching expectations from the customer remained the same. However, as we moved through the process, we stumbled across a lot of design stipulations that we were not aware of before. We adapted to new design constraints quickly, allowing us to develop a solution to meet every need of the customer.

8.3.9 Has the project enhanced your design skills?

This project has significantly enhanced our design skills throughout the multiple iterations of the design process. Not only did we have to design a solution to a complicated problem, but we also had to make sure that solution was plausible and turn it into a reality. This taught us awareness for realistic design expectations and gave us a sense of forward thinking throughout the process, allowing us to efficiently develop a solution to meet the project needs.

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

Each member on the team enhanced his skillsets in a number of different areas this semester, including designing, reporting, and presenting. After such a productive and insightful project, we our confident we could take on more difficult engineering projects in the future.

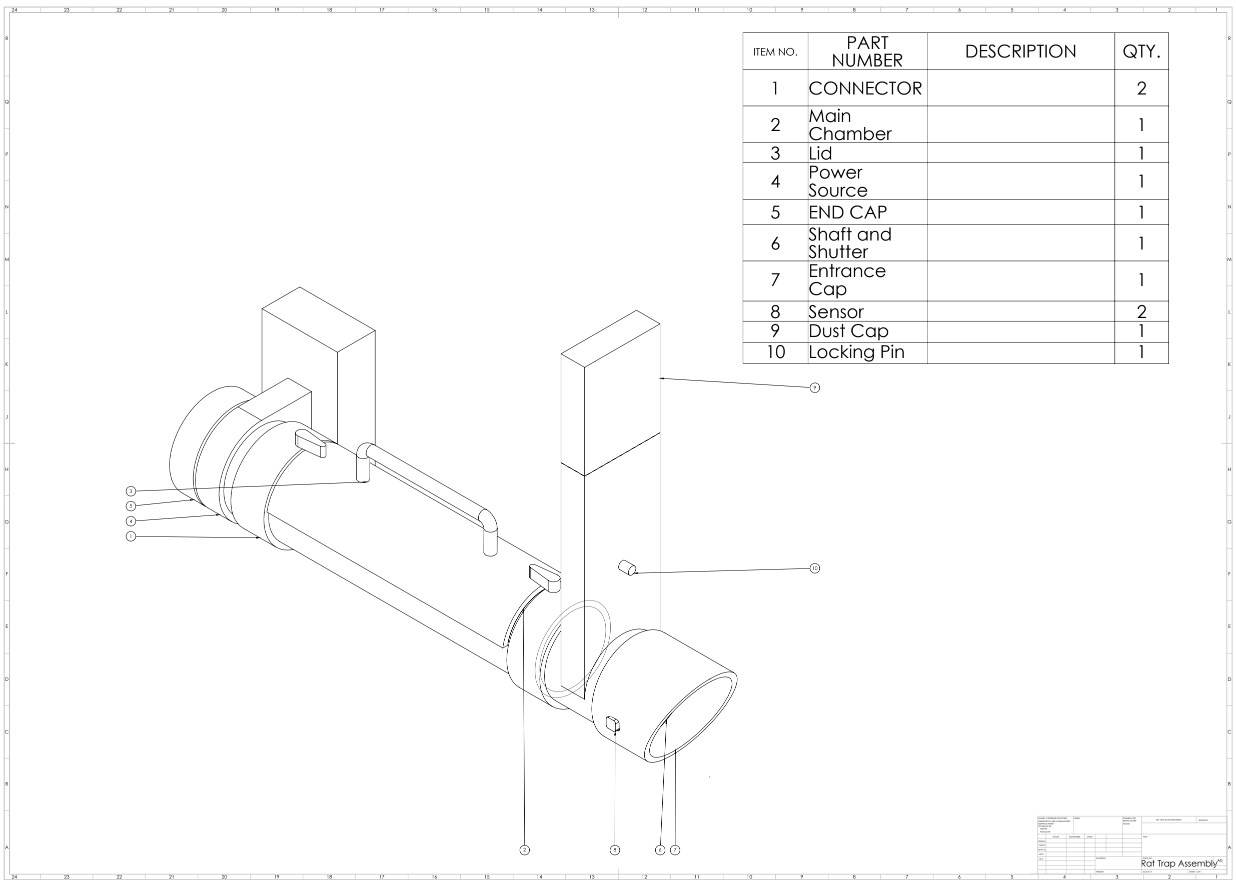
8.3.11 Are there projects that you would attempt now that you would not attempt before?

Coming into this project, each member on the team had very little experience in a number of areas that were developed upon throughout the course of the semester, including designing and presenting. After completing this project, we feel comfortable in attempting some designing and presenting roles that we may not have before and are confident that we would perform an exceptional job.

9 APPENDIX A - PARTS LIST

Part	Source	Model No.	Quantity	Cost ($)
Arduino Leonardo	WUSTL MakerSpace	A000057	1	0.00
IR Sensor	WUSTL MakerSpace	Sharp GP2Y0A21YK0F	1	0.00
Zinc Clevis Pin	MEMS Storage	SEN-09088	1	0.00
Metric Compression Spring	MEMS Storage	Gardner Spring MC041-0240-S	1	0.00

10 APPENDIX B - BILL OF MATERIALS

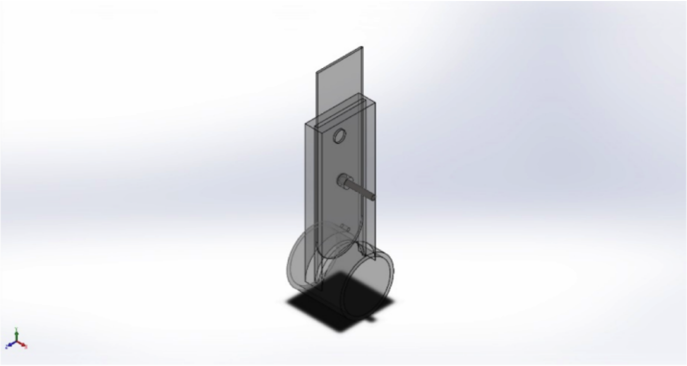


11 APPENDIX C - CAD MODELS

Follow link to view CAD models in Google Docs:

https://drive.google.com/drive/folders/0B59Pls6BmusrVlBINWpMSHM3bnM?usp=sharing

12 APPENDIX D – SIMULATION OF SHAFT AND SHUTTER



Simulation of Shaft and Shutter

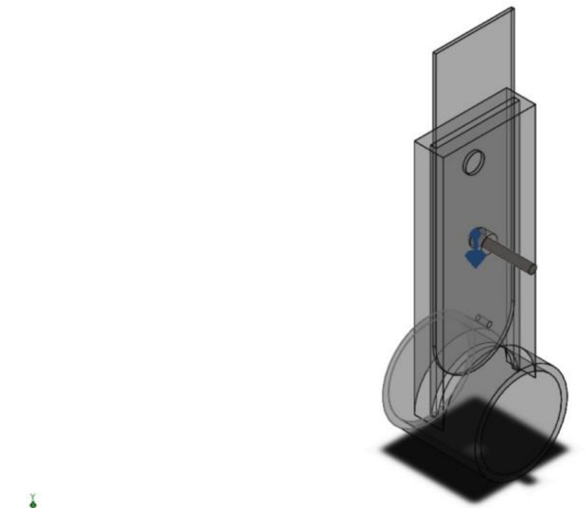
Date: Friday, December 9, 2016
Designer: Solidworks

Study name: Static 1

Analysis type: Static

Table of Contents

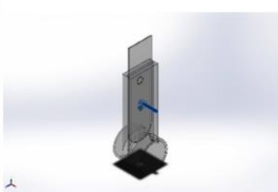
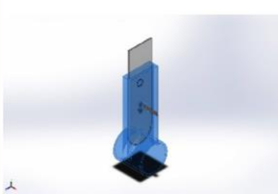
Model Information

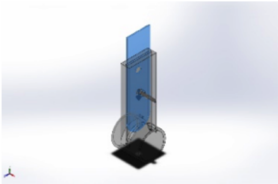


Model name: Shaft and Shutter

Current Configuration: Default

Solid Bodies

Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Boss-Extrude2 	Solid Body	**Mass:0.00368111 kg** **Volume:5.04261e-007 m^3** **Density:7300 kg/m^3** **Weight:0.0360748 N**	**D:\Pin11082016.SLDPRT** Dec 08 17:25:44 2016
Cut-Extrude6 	Solid Body	**Mass:0.115369 kg** **Volume:9.61408e-005 m^3** **Density:1200 kg/m^3** **Weight:1.13062 N**	**D:\Shaft.SLDPRT** Dec 08 17:25:44 2016

Cut-Extrude1 	Solid Body	**Mass:0.0127318 kg** **Volume:1.06098e-005 m^3** **Density:1200 kg/m^3** **Weight:0.124772 N**	**D:\Shutter.SLDPRT** Dec 08 17:25:44 2016

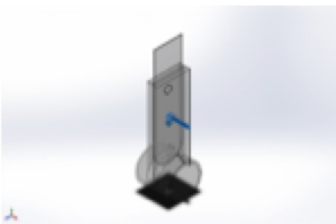
Study Properties

Study name	Static 1
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off
Solver type	FFEPlus
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SOLIDWORKS document (D:)

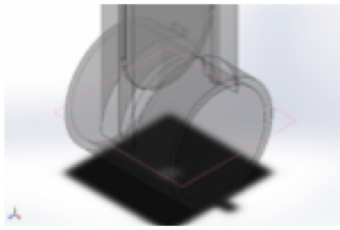
Units

Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

Material Properties

Model Reference	Properties	Components
	**Name:** Cast Alloy Steel **Model type:** Linear Elastic Isotropic **Default failure criterion:** Unknown **Yield strength:** 2.41275e+008 N/m^2 **Tensile strength:** 4.48082e+008 N/m^2 **Elastic modulus:** 1.9e+011 N/m^2 **Poisson's ratio:** 0.26 **Mass density:** 7300 kg/m^3 **Shear modulus:** 7.8e+010 N/m^2 **Thermal expansion coefficient:** 1.5e-005 /Kelvin	SolidBody 1(Boss-Extrude2)(Pin11082016-1)
Curve Data:N/A		
	**Name:** Acrylic (Medium-high impact) **Model type:** Linear Elastic Isotropic **Default failure criterion:** Unknown **Yield strength:** 4.5e+007 N/m^2 **Tensile strength:** 7.3e+007 N/m^2 **Elastic modulus:** 3e+009 N/m^2 **Poisson's ratio:** 0.35 **Mass density:** 1200 kg/m^3 **Shear modulus:** 8.9e+008 N/m^2 **Thermal expansion coefficient:** 5.2e-005 /Kelvin	SolidBody 1(Cut-Extrude6)(Shaft-1), SolidBody 1(Cut-Extrude1)(Shutter-1)
Curve Data:N/A		

Loads and Fixtures

Load name	Load Image	Load Details
Gravity-1		**Reference:** Top Plane **Values:** 0 0 -9.81 **Units:** SI

Contact Information

Contact	Contact Image	Contact Properties
Global Contact		**Type:** Bonded **Components:** 1 component(s) **Options:** Compatible mesh