

ENGINEERING SENIOR DESIGN PROJECT:

MOUSE POSITIONING CRADLE

BY

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In Partial Fulfillment of the Bachelor's Degree
With Honors in

Biomedical Engineering

THE UNIVERSITY OF ARIZONA

MAY 2013

Approved by:



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Abstract

The goal of this project was to design a cradle for restraining and positioning mice in an MRI machine. The sponsor, University of Arizona faculty member Dr. Marty Pagel, collects MRI images of animals for cancer research. Previously, the best option available for restraining the anesthetized mouse subject in the MRI consisted of little more than taping the subject to a PVC pipe. The engineering team created a new cradle designed to be easy to use while also removing the necessity of applying tape directly to the mice subjects for restraint, and providing a more even heat dispersion over them while in the MRI. The new cradle system features a removable sled that secures the mouse, and it provides spaces for catheters and monitoring devices, a connector for the existing heater tube that directs the hot air around the subject from under the sled, and an adjustable vertical positioning screw for improved target-centering capability in the MRI machine. The new design improved the repeatability of MRI scans and reduced potential sources of injury to the animal subject while maintaining the ease of use similar to the previous cradle.

Final Report

Mouse Positioning Cradle

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Introduction

Scope of Document

The scope of the document provides a complete design review of the Mouse Positioning Cradle project. Included in the document are system requirements, SolidWorks designs of the device, analysis, budget, acceptance test plans, and future plans for the project.

Changes Since CDR

One major change since the CDR report is the sled design. Performance testing revealed that the front 6 holes on the sled blew hot air onto the vital pneumatic sensor, causing signal noises and reducing the efficiency of the gating feature in the MRI software. To fix this, these six holes were removed, and new holes were placed in between the slots for the straps to ensure a similar air velocity was achieved. Another small change in the design was the size of the entire cradle. After testing, the initial length of the PVC pipe was reduced by a foot in order to make the whole piece easier to maneuver within the lab. Finally, the last change since the CDR was a reduction in the size of the fin underneath the end plate that sits within the groove of external MRI track. The groove does not have a uniform width straight down but rather it was trapezoidal shaped, and therefore the original end plate fin was too large to fit in the track. The cradle would not sit in the track leading to the MRI. The fin was thinned by $\frac{1}{4}$ " in order to fix this problem. These changes are represented in the new Appendix B drawings and reviewed in the Hardware Subsystem section.

Problem Statement and Background Information

Currently there are two designs available to the sponsor, a rudimentary design and a stock cradle that came with MRI machine. The rudimentary design is the preferred cradle used by the customer and is constructed from duct tape and PVC pipe. This design is favored over the stock cradle due to its ease of use. The goals for the project were to create a cradle that is manageable, easy to use, and creates more replicable data. While initially the project was to include ultrasound and CT modalities, the sponsor removed those requirements, as they are not priorities for the cradle.

Scope and Expectations of the Project

The scope of the project was to design a system that can securely position a mouse inside the Bruker animal imaging MRI. In this system, the mouse must be kept at a constant body temperature and be secured in anatomically feasible, repeatable positions in order to ensure optimal data collection. The mouse must be restrained in a system that can securely and accurately deliver the mouse to the center of the MRI. The system shall henceforth be referred to as the "cradle."

Description of Customer

The customer was Dr. Marty Pagel, a faculty advisor for Biomedical Engineering and associate professor at the University of Arizona. His work involves small animal imaging and cancer research. The current cradle used for imaging is rudimentary at best and needed great improvement. When imaging, ease of use is as important as the quality of the images, since running an MRI is more costly the longer it takes. The veterinary technician in the lab is Christy Howison, who works directly with the cradle and has provided inputs into the designs and improvements for the cradle by testing ease of use. Dr. Pagel and Christy Howison set the requirements for and approved the cradle design.

System Requirements

System requirements of the cradle were mainly derived from meetings with the veterinary technician, Christy Howison. These meetings and revisions helped narrow down possible designs and rate them based on ease of use, requirements, and tolerances within the system. Dr. Pagel helped the team select a material for the device that will not interfere with the MRI. The material needed to be a resilient polymer, easy to clean, and not obstruct the MRI signals. The design process was broken down into five main design sections based on specific functions.

The basic requirements for the project that allowed the group to decide between the design alternatives are listed in Table 1. There are also many sub-requirements that were taken into consideration, detailed in Appendix C Table 8: Requirements Review.

Table 1: Summary of Requirements

103 Technology	The system shall allow for MRI scans of mice to be repeatable within 2mm
3 Functional	The system shall incorporate restraints that adequately secure mouse and minimize movement
202 Performance	The system shall maintain mouse body temperature at $37^{\circ}\text{C} \pm 0.3^{\circ}\text{C}$
201 Performance	The system shall allow incorporation of vital pneumatics sensor, anesthesia line, temperature probe, and variable catheters
5 Functional	The system shall allow tumor to be centered in scanning area within 5mm
304 Utilization	The system shall not exceed \$3000 in budget

Summary of Preliminary Design

Preliminary Design

The preliminary design review (PDR) was broken into five sections: Cradle and Sled, Restraint, Heat Diffusion, Centering, and Stabilization. Sled refers to the piece that holds the mouse itself, and Cradle includes the sled and the extension from it. Restraint is the method used to hold the mouse still and in place. Heat Diffusion is the mechanism for dispersing the heat over the mouse. Centering refers to the technique used to position the mouse in the center of the MRI. Stabilization is the piece that keeps the whole system from tipping while in use.

Cradle and Sled

The current cradle design (Design 0) is a PVC pipe cut in half with a flat plastic piece that the mouse is taped to, and a string and ruler are used to position the system in the MRI. Design 1 was a flat piece of plastic with a numbered grid for repeatable mouse positioning and a ruler-slider system (Figure 29) for positioning within the MRI. Design 2 was a cradle molded to the shape of an average mouse, with tick marks down the length of the sled for MRI positioning. Analysis of these concepts, as shown in Appendix C Table 9, ranked the precision of mouse placement, precision of placement in the MRI, capacity to build the cradle, and mouse comfort/risk of injury. Based on these rankings, it was decided to move forward with Design 1. This design was determined to provide precision in reproducing the positioning of each mouse, both on the sled and into the center of the MRI.

Restraint

Design 0 for mouse restraint is simply using a lot of tape to strap the mouse down. Design 1 was a notched rubber strap, similar to a goggle strap or zip tie that can be pulled through slots in the cradle. Design 2 involved putting two parallel slots in the sled of the cradle for the straps to be weaved through in order to hold them tight. Designs 1 and 2 both involved placing straps at a set interval down the length of the mouse (as determined by the slots in the cradle) that could be fastened in a parallel or crossing fashion (Appendix C Figure 30). The analysis, shown in Appendix C Table 10, was based on the ease of cleaning, potential movement of the mouse's limbs, potential movement of the mouse's head, and whether the straps are reusable or not. Based on this analysis, the notched Design 1 was chosen. This design would restrain the mouse well without the potential of injury, and be more secure than Design 2.

Heat Diffusion

Design 0 for the heat diffusion mechanism is placing some cotton in the path of the heated air as it blows out of the heat tube. Design 1 was to create a diffuser for the end of the heat tube that had an initial diameter small enough to snap over the tube and a larger final

diameter for air diffusion. Design 2 was placing holes in the sled and blowing the heated air under it so the heated air would diffuse along the length of the mouse's body. The analysis, shown in Appendix C Table 11, ranked each concept on the ability to snap onto the existing heat tube, the team's capacity to build the design, the risk of burning the mouse, and the design's projected ability to disperse the heat. Based on this analysis, it was decided to proceed with Design 2. This design would be easy to build, was low risk, and was projected to give adequate heat distribution.

Centering

The centering mechanism for Design 0 is a thick sponge for height attached to the end of the cradle that extends outside the MRI when the mouse is positioned inside. Horizontal centering is accomplished by visual inspection. Design 1 was an inflatable balloon, similar to a blood pressure cuff (Appendix C Figure 31: Design 1 for Centering from PDR was an inflatable balloon around the circumference of the cradle.) that would go around the cradle and center the device in the MRI when fully inflated to the circumference of the MRI. Design 2 was a system of gears that would center the device in the MRI when the gears were cranked open to the radius of the MRI (Appendix C Figure 32). The analysis (Appendix C Table 12: Centering PDR Analysis) was based on the accuracy of the centering mechanism, ease of use, stability when in use, and capacity to build the mechanism. Based on these parameters, it was determined that Design 2 would be the best. Despite being the most difficult to build, this design would give the most repeatability and centering precision, in addition to being easy to use.

Stabilization

Design 0 for the stabilization method is a large plate attached to the end of the cradle that sits outside the MRI. This plate sits on top of an existing track on the cradle support platform that has a trapezoidal groove along its length. Design 1 was a plate with a square slot that would fit into the groove in the track but would not fully match the shape of the groove. Design 2 was a plate with a trapezoidal slot in the same shape as the groove in the track. These designs can be seen in Appendix C Figure 33: Three designs for Stabilization from PDR. Design 0 sits on top of the track, Design 1 rests in the track to prevent tilting, and Design 2 fully fits into the track for maximum stability.. The analysis of this mechanism (Appendix C Table 13) was based on the stability provided by the mechanism, the capacity of the team to build the mechanism, and ease of use. This analysis led to the conclusion that Design 1 would be the best. This design would provide more stability than Design 0 by using the existing grooved track for additional support, and avoid the large addition of friction that Design 2 would have.

Final Design and System Build

Top-Level Design

Previously, the sponsor identified the key components of the device in the following way: the piece of material that the mouse rests upon is known as the *Sled*; the piece that the sled fits into is known as the *Cradle*; the block that protrudes from the end of the MRI and serves to balance the device is known as the *End Plate*; and the location in which the heating tube plugs in is referred to as the *heating element*, or sometimes *heating diffuser*. In the interest of clarity, the nomenclature of the device will largely remain unchanged. In the proposed design, the sled, as shown below in Figure 1, snaps into the combination heating element/cradle piece shown in Figure 2. This connection is physical, and no binding or glue is used to keep the connection static. The end plate (Figure 3) connects with the rear end of the heating element and is secured via a water-free epoxy so as to adhere to the strict restrictions of the MRI. Finally, the peg design system (shown in Appendix B Figure 24: Final Peg System Design) slides over the rear tubing of the end plate. This interface is secured based on form fitting and is designed to be dynamic in its ability to slide along the back of the cradle.

The proposed design encountered problems in the areas of mouse restraint, heat distribution, vertical positioning, horizontal centering, and stability. With a redesign of the aforementioned components, these issues have all been resolved. Specifics of each component and the designed solutions are located in Hardware Subsystem.

Hardware Subsystem

Description of Subsystem

In order to reduce the noise artifact caused by the mouse movements within the MRI, a restraint mechanism better than tape needed to be made. The solution was a silicon or rubber strap system that interfaces with parallel slits along the sides of the sled (Figure 1), analogous to the strapping mechanism of a swimming goggle. These four straps not only function to better impair movement, but also protect the sensitive skin of the mouse subject from harmful and painful tape wounds. In order to ensure that the straps cannot be pulled out by normal mouse agitation, a series of clips was added to the restraint design. These clips are sized .05" smaller than the slits for the straps, and can be pressed into these slits to create a stronger seal on the sled-strap interface. These clips are pictured in Appendix B Figure 23.

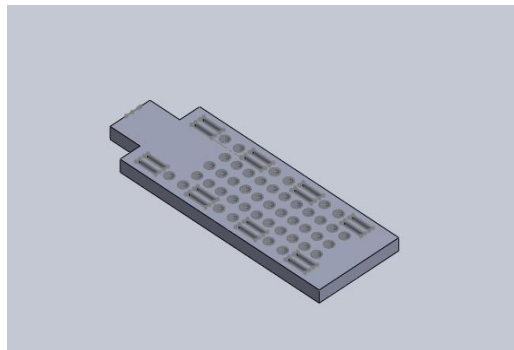


Figure 1: Updated Sled Design

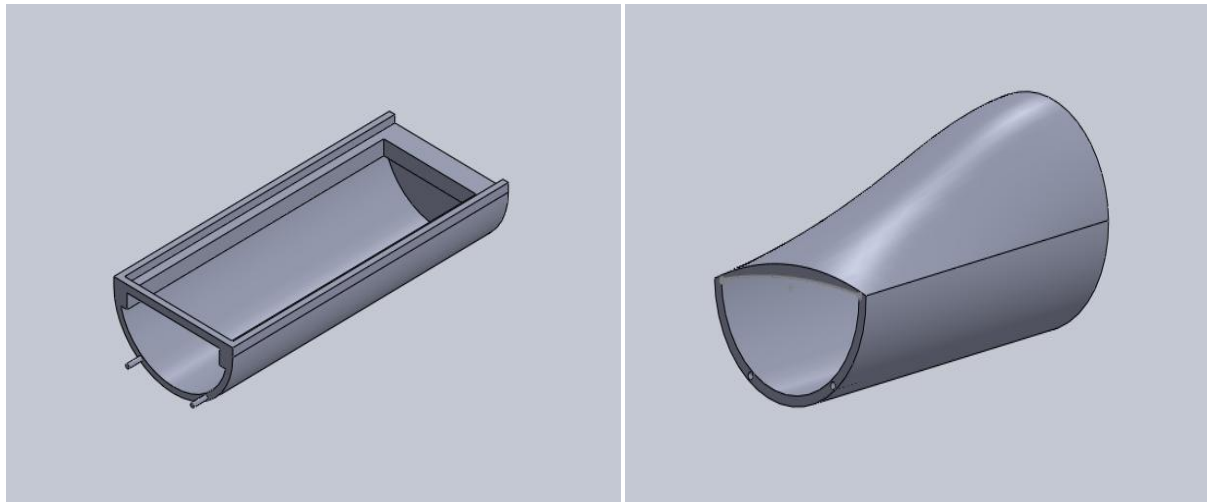


Figure 2: Heat Diffuser Design

Heat diffusion is another problem with the current system; the flow is directed straight onto the rear of the mouse, causing burns and improper heat distribution within the MRI. The design includes 45 0.2" diameter holes along the sled (Figure 1), which cooperate with the heating element/cradle (Figure 2) to divert hot air under the sled and diffuse it across

the length of the mouse. The result was a much more evenly distributed heat profile, which targeted the trunk of the mouse rather than the rear end. Both of these pieces were made out of ABS plastic and assembled using a 3D printer located in the University of Arizona machine shop at the Aerospace and Mechanical Engineering Building. The heat diffuser piece, unfortunately, was too large to print in one whole piece; therefore, two separate pieces were modeled and printed separately using the rapid prototyper, then glued together (See Figure 2). The fact that the manufacturing process is located on the University of Arizona campus ensures that the sponsor's lab can easily replace these parts if any accidents or defections occur.

The final three important issues, vertical positioning, horizontal centering, and stability, were all attended to in the design of the end plate and peg attachment. The end plate (Figure 3), which is attached to the heating element/cradle, employs a relatively simple solution to tackle the requirement of adjustable vertical positioning: a screw hole system. The tubular section of the part in Figure 3, constructed out of 2" ID PVC pipe cut to shape with a band saw, has a $\frac{1}{4}$ " hole drilled into the underside of the cylinder. A plastic screw has been inserted into the hole, providing a platform for the device to rest on. The vertical positioning of the cradle and sled can be manipulated via directed rotation of the implanted screw. This allows for the end of the device holding the mouse subject to be adjusted to variable heights within the MRI in order to ensure proper centering of the target area on the mouse. In addition, the rear of the end plate contains a cuboid-like structure with an extruding inferior fin (see Appendix B Figure 20 for detailed design). This fin interfaces with the guided track found outside the bore of the MRI in order to prevent rotational movement of the whole device. Previous commercially available solutions employ a trapezoidal-shaped fin that corresponds exactly to the shape of the groove found in the MRI track. This interaction generates far too great of a frictional force, which was irritating to the customer. The newly designed rectangular fin still interfaces snugly with the groove to achieve maximum rotational stability, but the in-contact surface area is drastically reduced in order to cut back on frictional side effects. Due to its relatively unique shape, the rear box and protruding fin were also manufactured out of ABS plastic using the 3D printer.

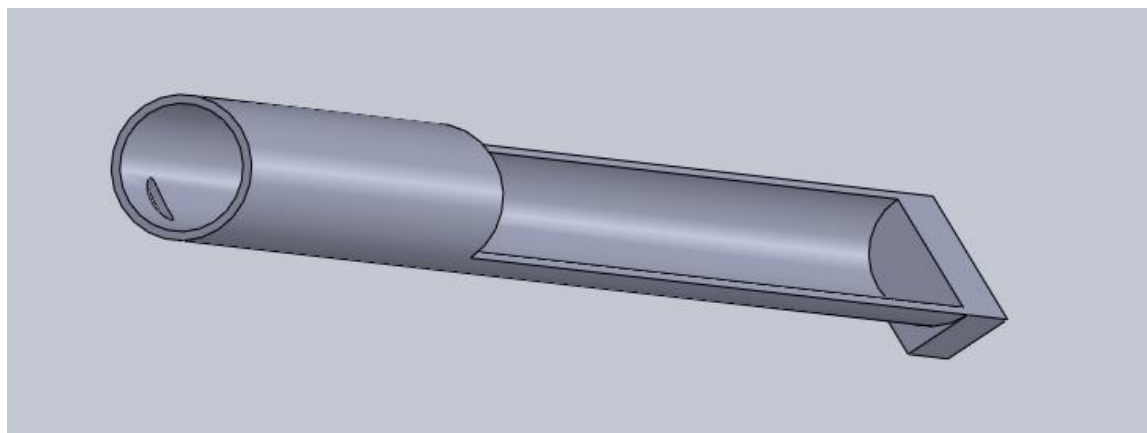


Figure 3: End Plate Design

Lastly, it was important to the sponsor that a reliable method for establishing horizontal centering of the device within the MRI be designed. The solution designed by the team is a peg system (Appendix C Figure 24) that, when attached to a 2" electrical gasket, fits snugly over the PVC shell of the cradle. This piece, which was 3D printed, can slide along the length of the open tubular section of the end plate and extends beyond the width of the bore of the MRI to provide a mechanical stop at the exact distance that ensures the target area is centered in the scanning frame. The method currently in use involves string and estimation, and is much less accurate but no easier to employ.

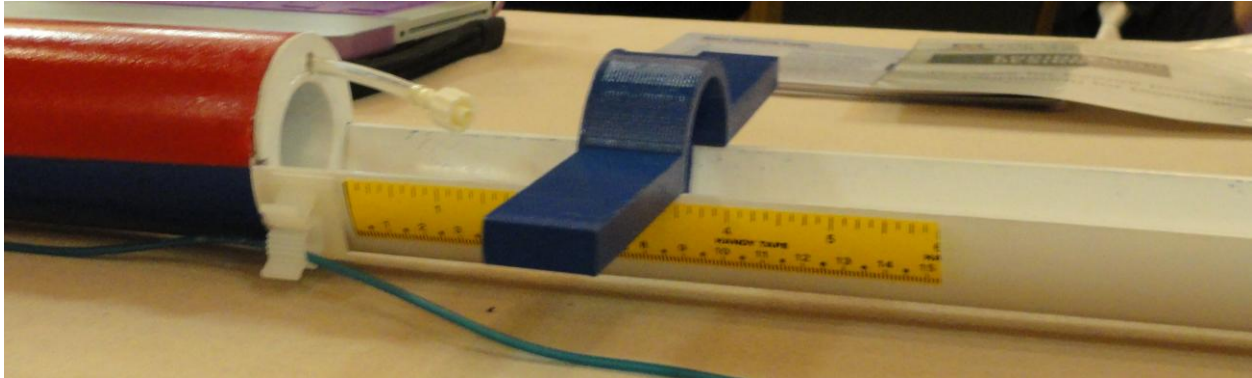


Figure 4: Final Peg System on the cradle with the electrical gasket (painted in blue).

Analysis

In the beginning, the analysis in this project included looking for cradles that already exist, which the team could use as a starting template. The cradle in use in the lab was very rudimentary (Figure 5). It was made from convenience and of tools easily accessible in the lab, which included lots of tape. The sponsor also has another, commercially available cradle, but it is not used because it is too bulky and difficult to maneuver (Figure 6). This cradle has a stability fin on the bottom that fits too snugly in the groove on top of the track leading into the MRI. The lab technicians have trouble sliding this cradle into the MRI, even with baby powder on the track to make sliding easier. Both cradles were decent starting points for size and shape of the cradle. A third reference cradle was found in a paper about a cradle and sled built by a different group (Figure 7 and Figure 8).

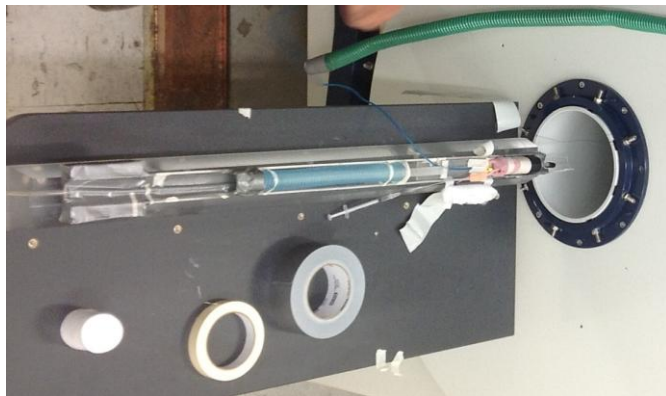


Figure 5: This figure illustrates the cradle currently in use

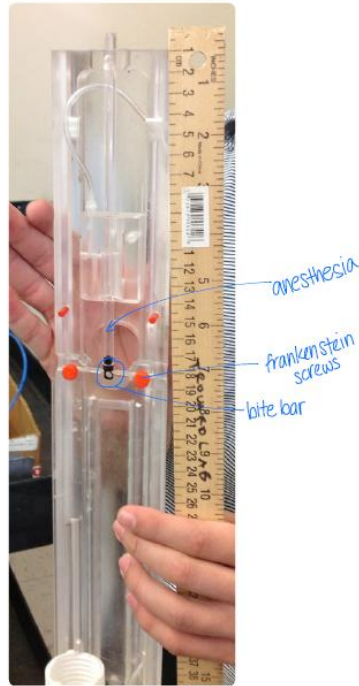


Figure 6: This figure illustrates the commercial cradle, which includes head stabilization

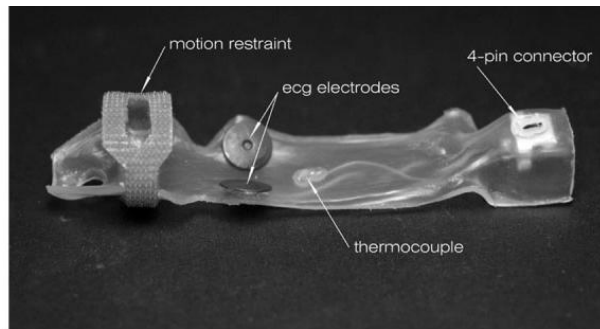


Figure 7: This figure illustrates a mouse-molded sled design (Dazai 711)

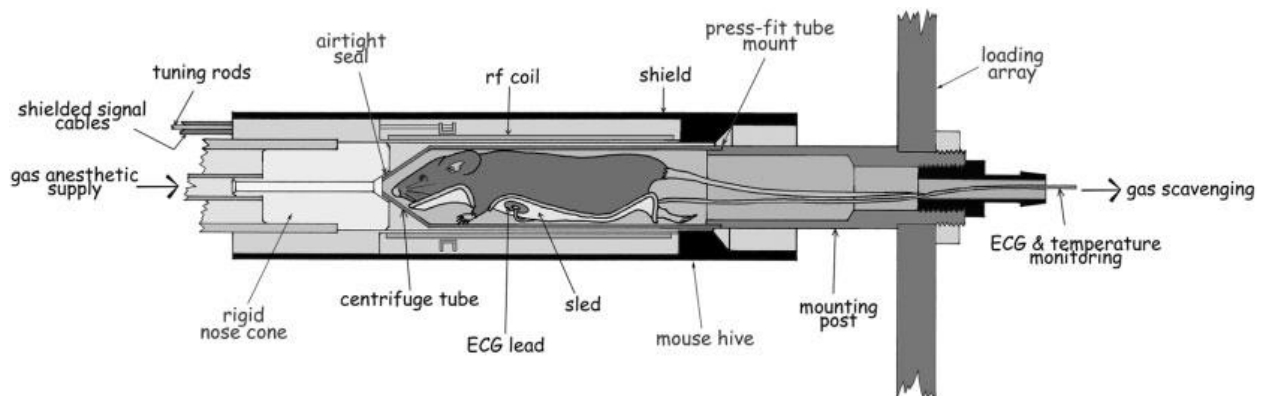


Figure 8: This figure illustrates the cradle for the mouse-molded sled (Dazai 710)

The ideas considered from these cradle designs include a sled that can be removed from the cradle, screws and bite bars to stabilize the mouse head, and a mouse-molded sled. The removable sled idea was ideal for the veterinary technician to be able to prepare a mouse on one sled while another mouse was being scanned. This allows the mice to be switched out more quickly, minimizing the amount of MRI time used. The idea of using screws and bite bars was considered for stabilization of the mouse head for brain MRI scans. The customer wanted this capability in the new cradle design, but was not included due to the difficulty of construction and to being outside the scope of the project. The final idea considered was the mouse-molded sled; this was not incorporated into the final design because the mice used by the customer may be different enough in size to merit multiple molded sleds. Therefore, the simpler flat sled design was adopted in order to fit all potential mouse subjects.

Developmental Plan

Table 2: Developmental Plan

Date	Details	Status
8/28/12	Project Group Assigned	Complete
8/28/12	First meeting with Mentor	Complete
8/30/12	Project initiation began	Complete
9/05/2012	First meeting with sponsor	Complete
09/27/2012	Complete system requirements	Complete
10/09/2012	Draft conceptual designs	Complete
10/18/2012	Preliminary Design	Complete
11/09/2012	Complete Risk Analysis	Complete
11/13/2012	Modify and finalize conceptual designs	Complete
11/14/2012	Draft design on SolidWorks software	Complete
11/15/2012	Critical Design Review	Complete
12/11/2012	Finalize ordering materials	Complete
1/25/2013	Begin the cradle and Heat diffusion construction	Complete
2/01/2013	Begin restraint construction	Complete
2/04/2013	Complete cradle, heat diffusion, restraint construction	Complete
2/04/2013	Begin cradle, heat diffusion, restraint component testing	Complete
2/07/2013	Complete restraint system testing	Complete
2/07/2013	Begin resolving issues on restraint system	Complete
2/09/2013	Complete cradle and heat diffusion system testing	Complete
2/09/2013	Begin resolving issues on cradle and heat diffusion system	Complete
2/10/2013	Begin construction of centering and stabilizing system	Complete
2/20/2013	Complete construction of centering and stabilizing system	Complete
2/20/2013	Being centering and stabilizing system testing	Complete
2/24/2013	Complete resolving issues on cradle and heat diffusion system	Complete
2/25/2013	Complete centering and stabilizing system testing	Complete
2/25/2013	Begin resolving issues on centering and stabilizing system	Complete
2/25/2013	Begin assembly of all the parts	Complete
2/28/2013	Complete assembly of all the parts	Complete
2/28/2013	Begin assembled cradle system testing	Complete
3/07/2013	Complete resolving issues on centering and stabilizing system	Complete
3/08/2013	Complete assembled cradle system testing	Complete
3/09/2013	Project pause – Spring break starts	Complete
3/17/2013	Project resume - Spring break ends	Complete
3/18/2013	Begin resolving issues on the assembled cradle system	Complete
3/22/2013	Complete resolving issues on the assembled cradle system	Complete
4/01/2013	Finalize system performance analysis and testing	Complete
4/30/2013	Presentation at Design Day	Complete

Acceptance Test Results

All necessary requirements and some desired requirements were met, as can be seen from the following acceptance test plan. Only minor changes were made between the chosen cradle design and the final design.

Heat distribution Test

In order to test how well the new sled distributes heat, the system was set up with the heat source connected but without a mouse secured to the sled. The temperature probe was placed on a designated spot on the sled, and then the cradle was inserted into the MRI for 5 minutes. Temperature information was recorded at 30-second intervals throughout this period. At the end of the 5 minutes, the cradle was taken out of the MRI, the temperature probe was moved to the next designated point on the sled, and then the cradle was inserted into the MRI once more to record temperature data for another 5 minutes. This was repeated until sufficient data was gathered from various points across the entire sled (see Figure 9). Ambient temperature was recorded at the beginning of each temperature test to allow for easy identification of the beginning of each new test point. The results of this test are shown in Figure 10.

It was found that the temperature was constant within a 4°C range across the length of the sled with the system set up to mimic a real scanning scenario. This demonstrated that the heat is distributed as predicted, and can provide much more even heating to the mouse subject than the previous system, which only delivered heat to the posterior of the mouse. This test also demonstrated that the system's snap-in capability for the existing heat tube worked and could sufficiently contain the hot air inside the cradle.

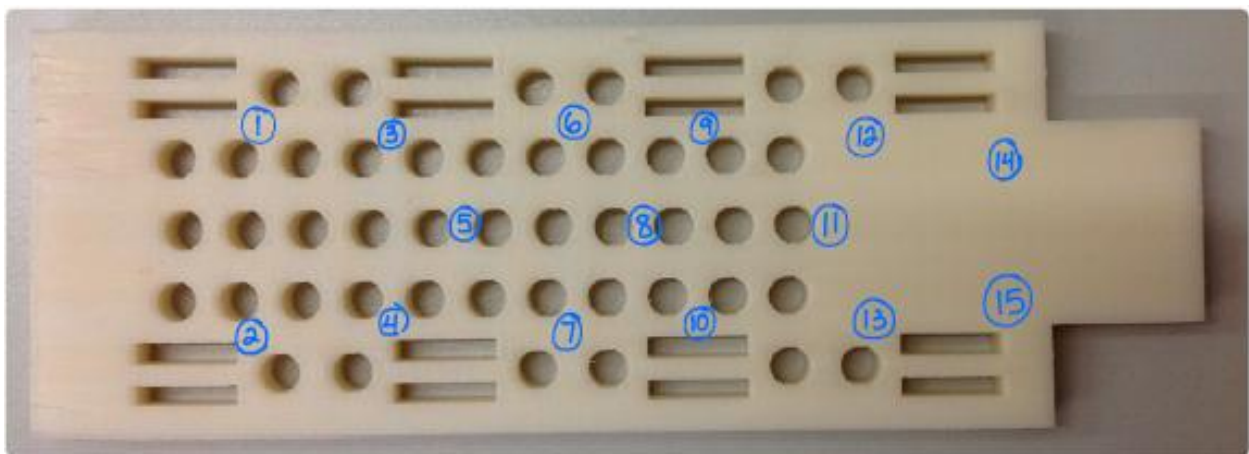


Figure 9: Labeling for various points where heat was tested along the sled of the cradle.

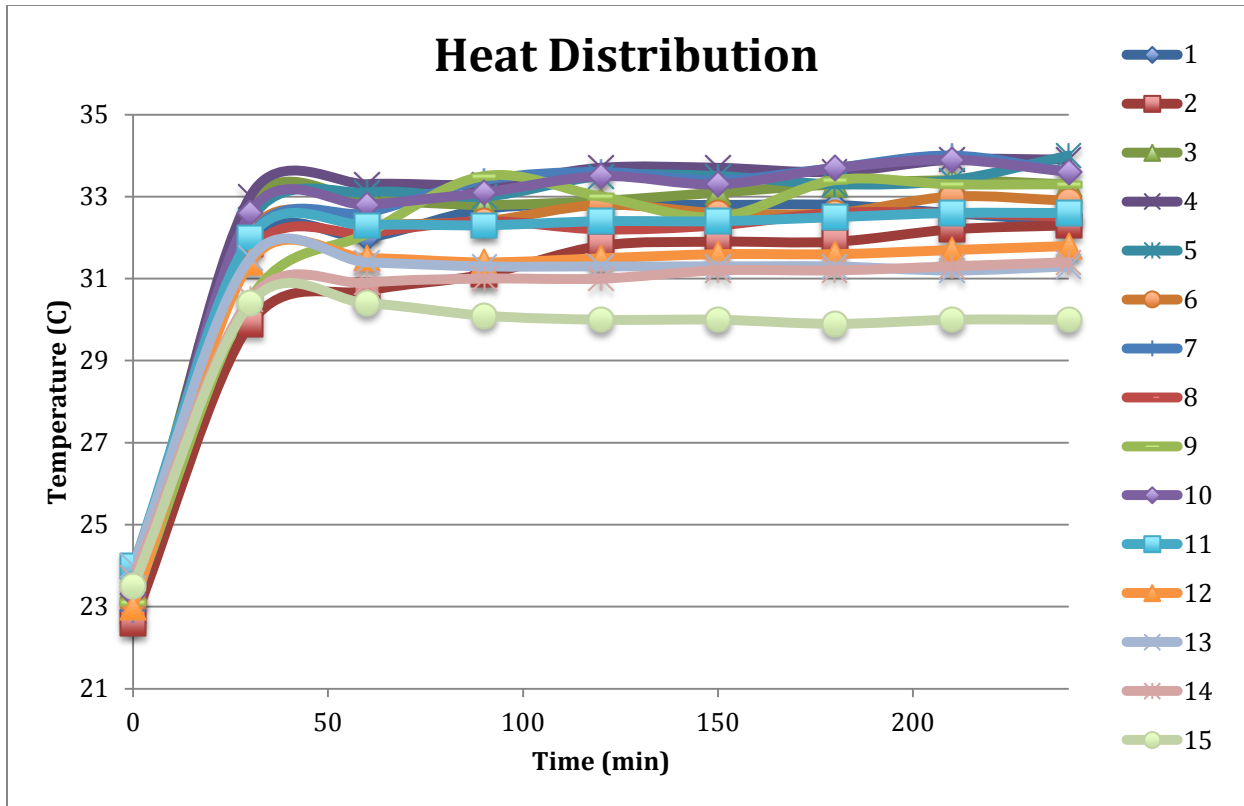


Figure 10: Heat Distribution Chart

Animal Test

Accepting the bulk of the requirements relied on using the system in a realistic scanning scenario. This was accomplished by securing a mouse subject to the sled (see Figure 11), with all typical monitoring and catheter lines attached, and running two real MRI scans.



Figure 11: Mouse with restraints on new sled design.

In securing the mouse to the sled, it was found that the reusable rubber band restraints sufficiently restrained the mouse, and that the vital pneumatics sensor, tail catheter, and anesthesia line were all sufficiently incorporated into the device. The customer desired a

way to better secure the vital pneumatics sensor so that it is not necessary to tape the line to the sled. If there had been more time, the team would have improved this feature in a revision of the sled.

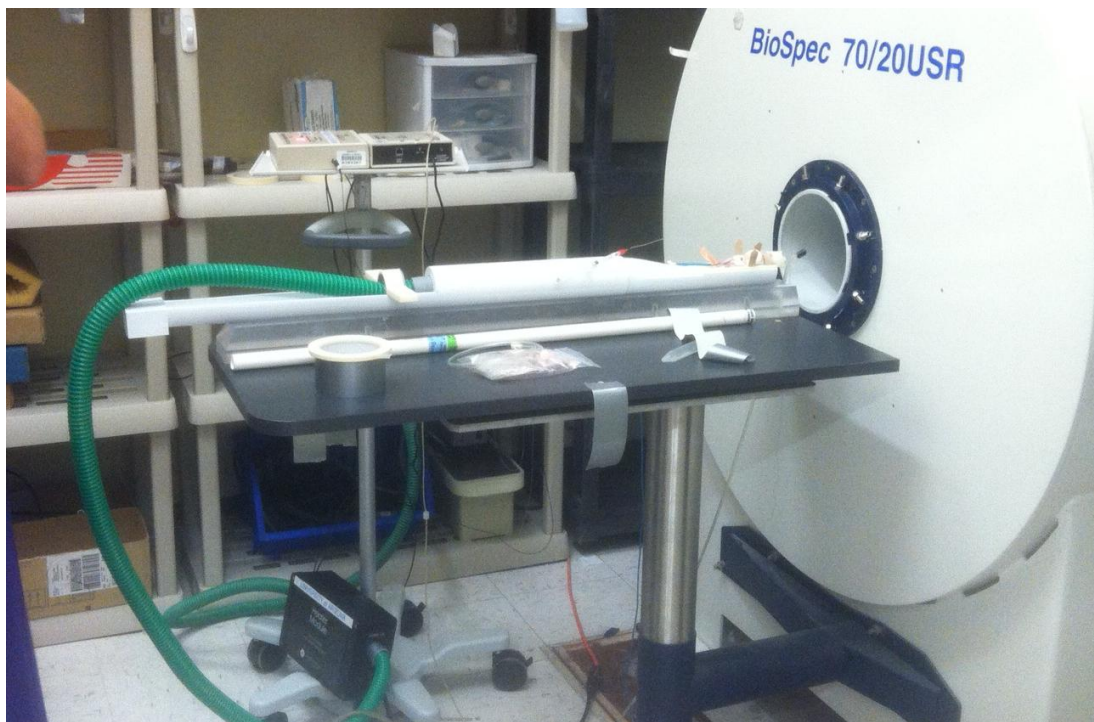


Figure 12: New cradle with mouse in sled before going into MRI.

In positioning the system within the MRI, it was found that the system does fit into the 72mm rat coil, and that the cradle allows for centering of the tumor in the scanning field. While positioning the cradle, it was found that the block at the end of the cradle used for stabilization prevents the heat tube from resting in the cradle. With more time, the team would have created a new block piece for the end plate in order to accommodate the heat tube. During this phase of the test, it was also found that repositioning the mouse subject is more difficult with the current system than with the original cradle. The customer desired a way to re-secure the mouse without having to remove the sled from the cradle. This feature would have been added if more time and resources had been available.

In scanning the mouse subject, it was found that the heat distribution system adequately maintained the subject's body temperature throughout the scanning process, that the mouse was secured well enough to produce clean images, and that none of the system's materials interfered with the MRI or the quality of the scans. One scan was performed, and then the entire system was removed from the MRI and the mouse subject was completely removed from the sled. The mouse was then re-secured and the system was replaced in the MRI for another scan to be performed. This process was then repeated for a third scan. Analysis of the three scans based off kidney position showed a difference of less than 1mm. This was well within the requirement for scanning repeatability, and thus this requirement was accepted.

After the mouse was removed from the system, the sled was cleaned. It was found to be easily and quickly sanitized, meeting the requirement for easy sanitization. All essential requirements were accepted, as well as the desired requirements of having reusable restraints and of having snap-in capability for the existing heat tube. Except for the few adjustments not made due to time constraints noted above, the customer and team were both satisfied with the cradle design.

Risk Analysis and Mitigation

Risk Analysis for the mouse cradle design was carried out using a scoring system. Each risk was weighted for likelihood of occurrence and severity if the risk occurred. The most severe risks in this project were if the plastic breaks over time from wear or that the ventilation holes become clogged, possibly by the use of adhesive tape. The plastic breaking has low severity because it is most likely to break while the user is in the set-up area, attaching the mouse to the cradle. Due to the extremely low cost of this project, multiple sleds have been made to replace any parts that break due to wear. Additionally, clogging of the ventilation holes is a risk that can be observed and easily corrected before the mouse is inserted into the MRI. As the need for tape has been eliminated in this design, this risk is minimal as well.

Because the chosen plastic is safe with alcohol (the cleaning solvent used in the sponsor's lab) and can withstand the maximum temperature of the heating system in the MRI, the risk of these to fault conditions is zero.

Table 3: Risk Analysis Summary

Date of Analysis	11/9/12
Name of Individual Performing Analysis	5323 Team
Product Name	Mouse Cradle
Product Description	Device to contain mice during MRI testing
Intended Usage	Use in MR scanning of mice
List of foreseeable misuses, if any	N/A

Table 4: Risk Analysis Process

Normal Usage		Probability (0-10)	Severity (0-10)	Score	Risk number
Electrical Safety		0	0	0	
Physical Safety	The straps come undone, freeing the mouse	1	7	7	1
	The plastic breaks from wear	6	2	12	2
Bio Hazard		0	0	0	
Other Hazard	Plastic warps over time	0.5	5	2.5	3
	Ventilation holes become clogged	3	7	21	4
Fault Condition					
Electrical Safety		0	0	0	
Physical Safety	The plastic melts from overheating/heating system malfunction	0	7	0	5
Bio Hazard	The plastic melts from chemicals when sterilizing	0	7	0	6
Other Hazard		0	0	0	

Risk Analysis: Chart

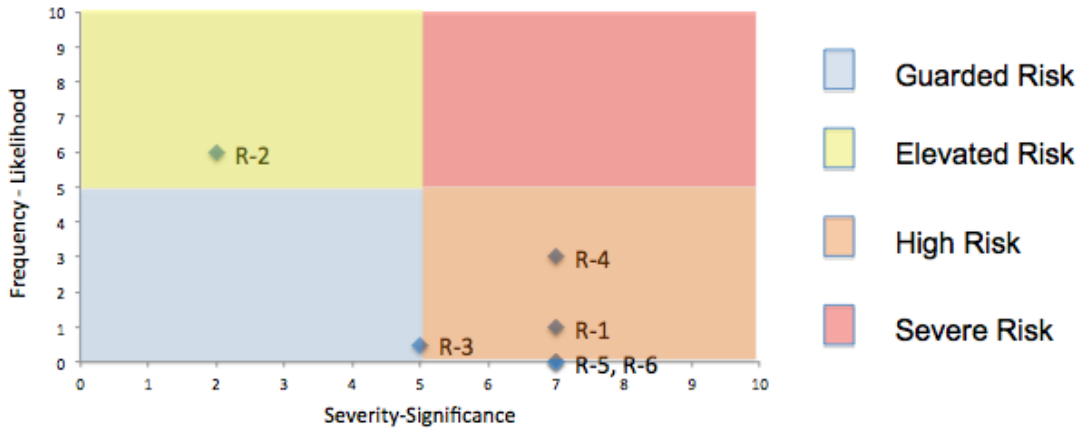


Figure 13: Risk Analysis Chart

Table 5: Risk Definition

Number	Description	Probability	Severity	Score
R-1	The straps come undone, freeing the mouse	1	7	7
R-2	The plastic breaks from wear	6	2	12
R-3	Plastic warps over time	0.5	5	2.5
R-4	Ventilation holes become clogged	3	7	21
R-5	The plastic melts from overheating/heating system malfunction	0	7	0
R-6	The plastic melts from chemicals when sterilizing	0	7	0

Closure

Summary

The major elements of this report include the five major parts of the final design changes since the CDR, and the acceptance test results. The five major parts of the mouse positioning cradle design are the cradle itself, the restraints, heat diffusion, the centering mechanism, and stabilization. The final design (see Figure 14) is composed of a flat plastic grid with a peg and ruler system for the cradle (see Figure 4), rubber restraints that go into the slits in the cradle and can be secured with plastic clips (see Figure 15), holes in the cradle that act to diffuse heat under the mouse (see Figure 16), a screw to change the vertical height of the cradle within the MRI so that the target area of the mouse may be centered, and finally a square slotted fin for stabilization of the cradle (see Figure 17). The acceptance test results were very successful, demonstrating that the design met all of the essential and some of the desired requirements set by the sponsor. Additionally, the project was completed well below the allotted budget of \$3,000. There were very few hurdles in this project, which was completed successfully to the requirements of the sponsor.

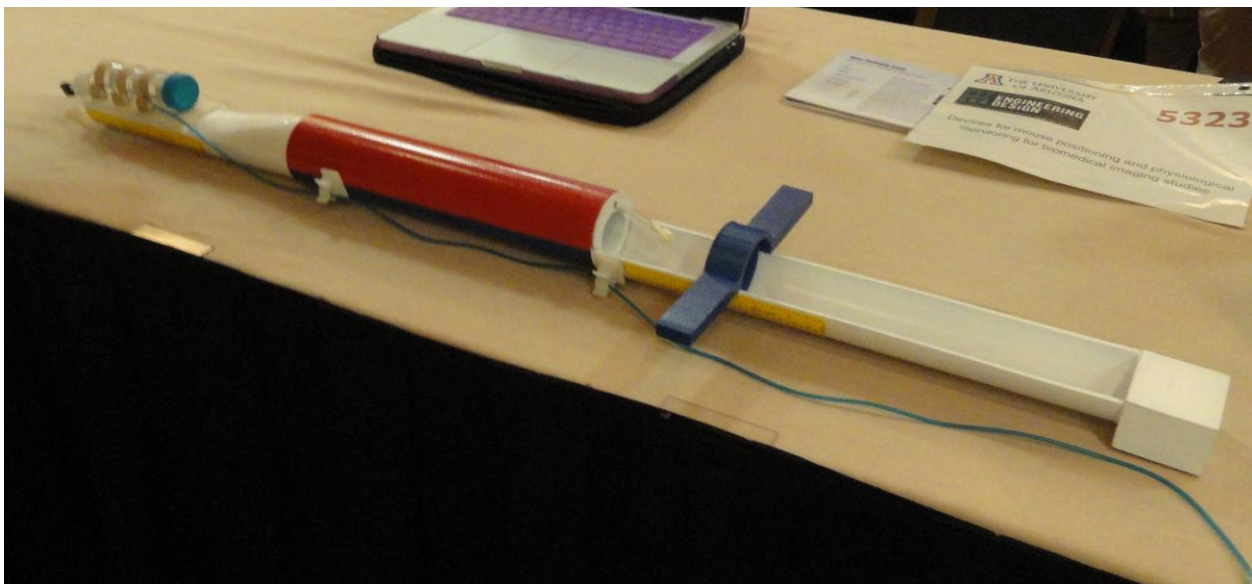


Figure 14: Final Cradle Design

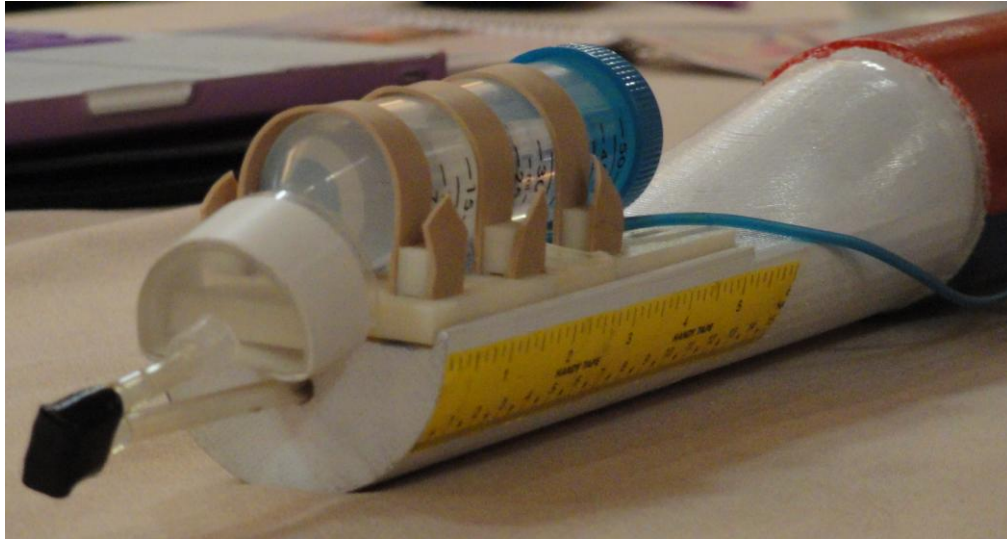


Figure 15: Front view of final cradle with mouse analog strapped in place.

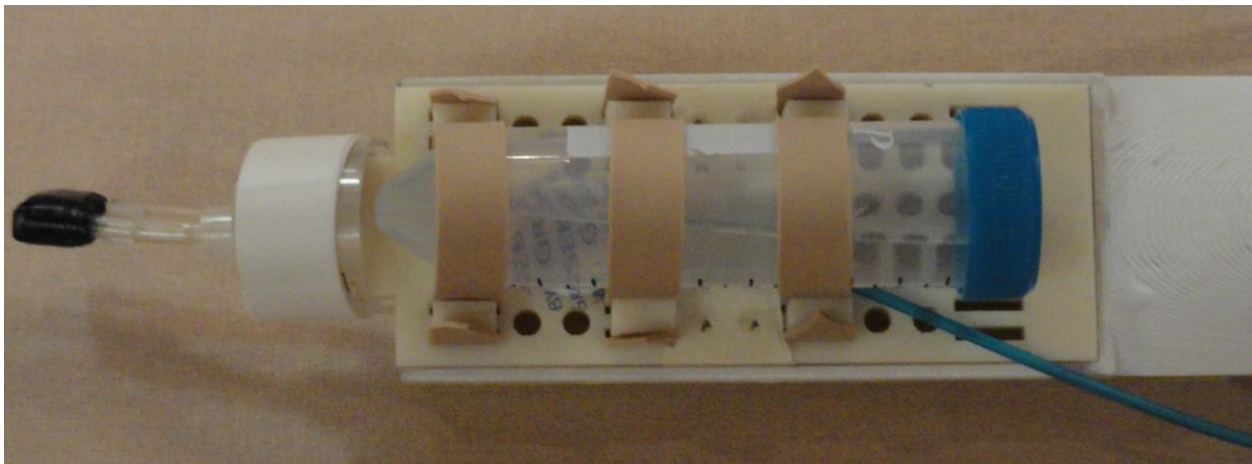


Figure 16: Top view of final cradle

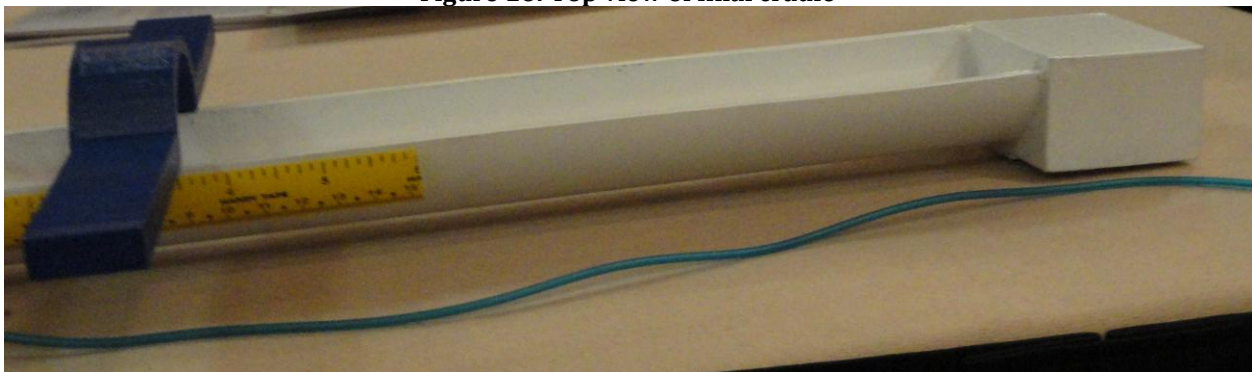


Figure 17: Peg system with ruler, and end plate block with fin on bottom.

Next Steps

Future improvements to this design would include redesigning the restraint attachments for easier re-securing of mouse, better incorporating the vital pneumatics sensor to eliminate the tape currently used to secure it, and improving the stability of the cradle when outside the MRI. The future cradle design and stability mechanism (to replace the block on the end plate) are pictured in Figure 18 and Figure 19, respectively.

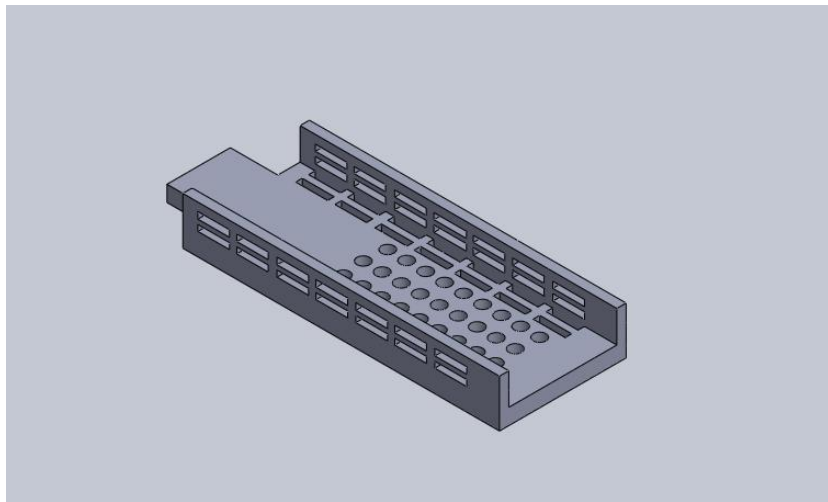


Figure 18: Future Cradle Design

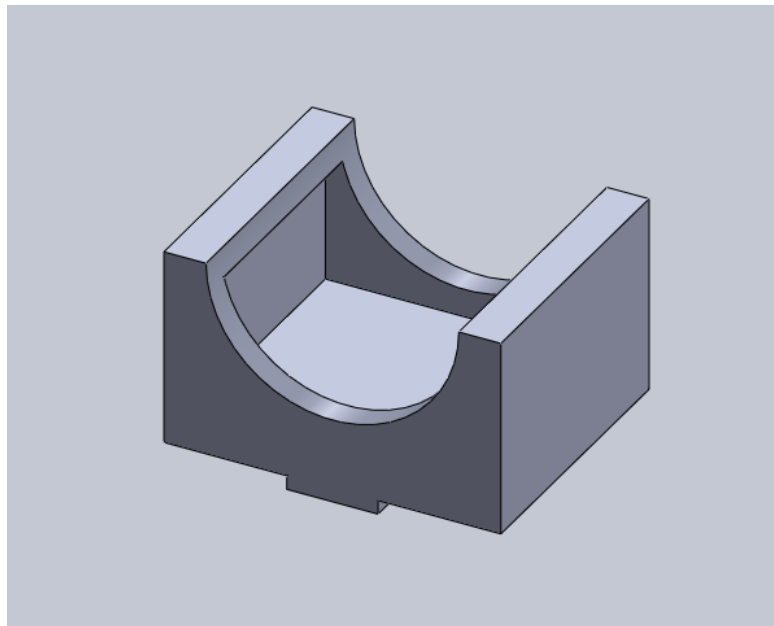


Figure 19: Future Stability Design

Appendices

Appendix A: Team Members

Table 6: Member Roles

Johnny Vogel	Team Lead	Concept design, Technical writing, Communications with sponsor, Engineering notebook
Kelsey Newman	Presentation Lead	Concept design, Technical writing, Material design, Editing, Presentations
Thomas Cahir	Design Lead	Concept design, Technical writing, Material design, SolidWorks/3D printing, Presentations
Ariana Lamanda	Documentation Lead	Concept design, Technical writing, Editing, Meeting notes, Engineering notebook
Si Woo Lee	Purchase Lead	Concept design, Technical writing, SolidWorks/3D printing, Budget/financing
Samantha Bernau	Time Management Lead	Concept design, Technical writing, Editing, Budget/Financing, Timeline

Table 7: Member Writing Contributions

Johnny Vogel	Introduction, Systems Requirements
Kelsey Newman	Summary of PDR, Requirements Review, Acceptance Test Results, Final Editing
Thomas Cahir	Top-Level Design, Subsystem Interface Design
Ariana Lamanda	Analysis, Closure, Final Editing
Si Woo Lee	Development Plan, Budget, Final Editing
Samantha Bernau	Risk Analysis, Project Management

Appendix B: Hardware

All measurements are in inches

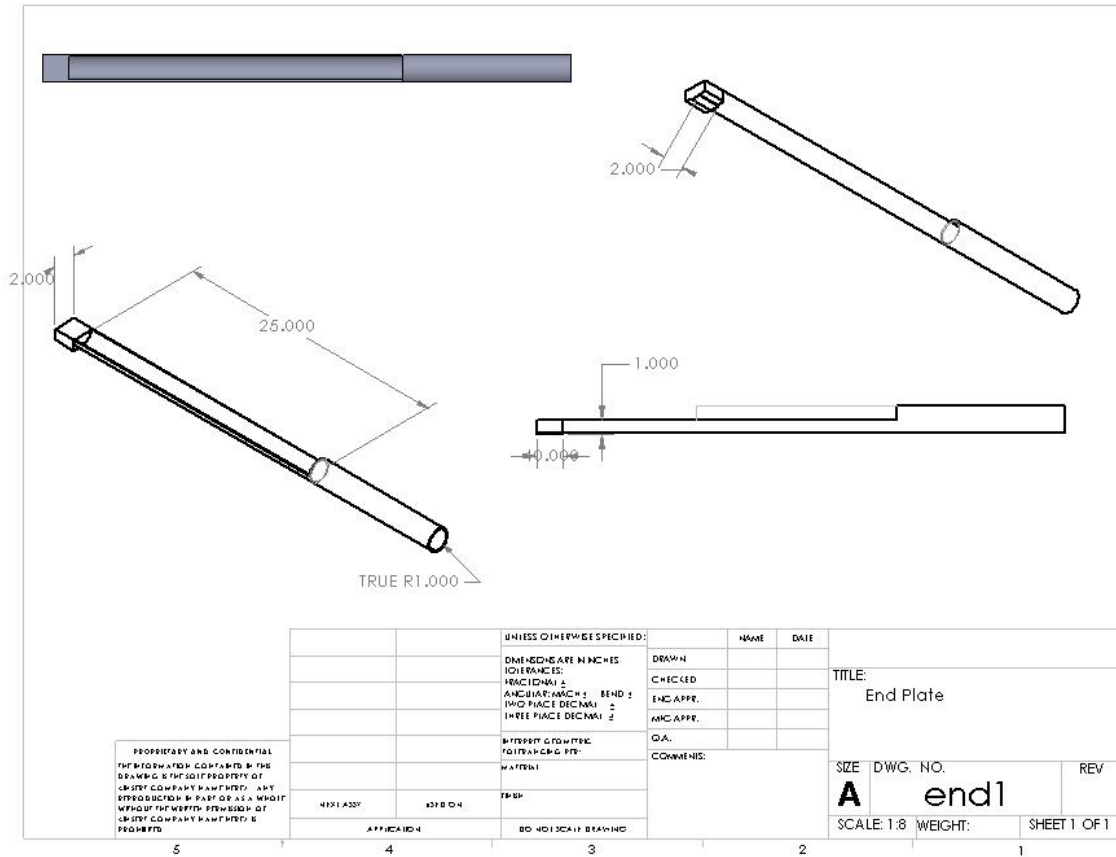


Figure 20: Final End Plate Design

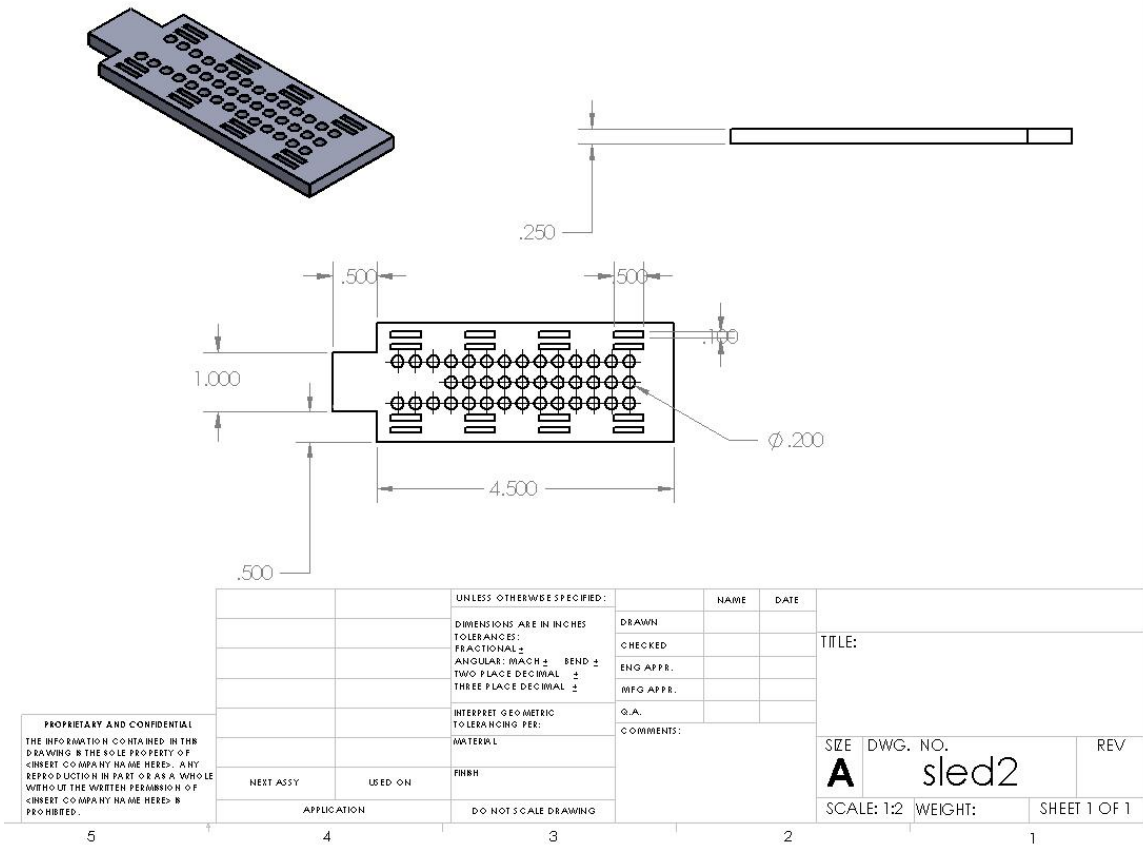


Figure 21: Preliminary Sled Design

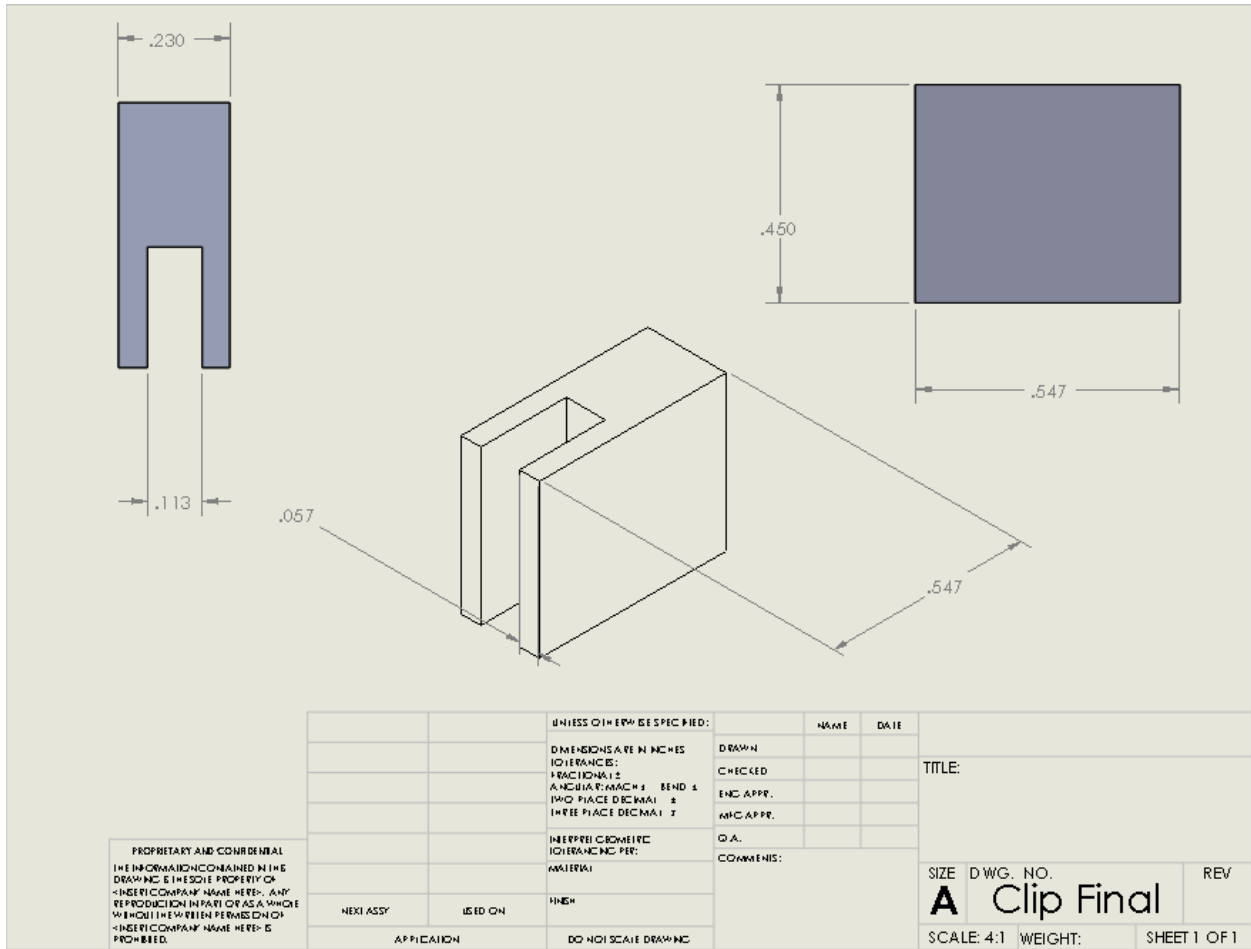


Figure 23: Final Clip Design used to fit into slots in the sled to hold restraints tightly.

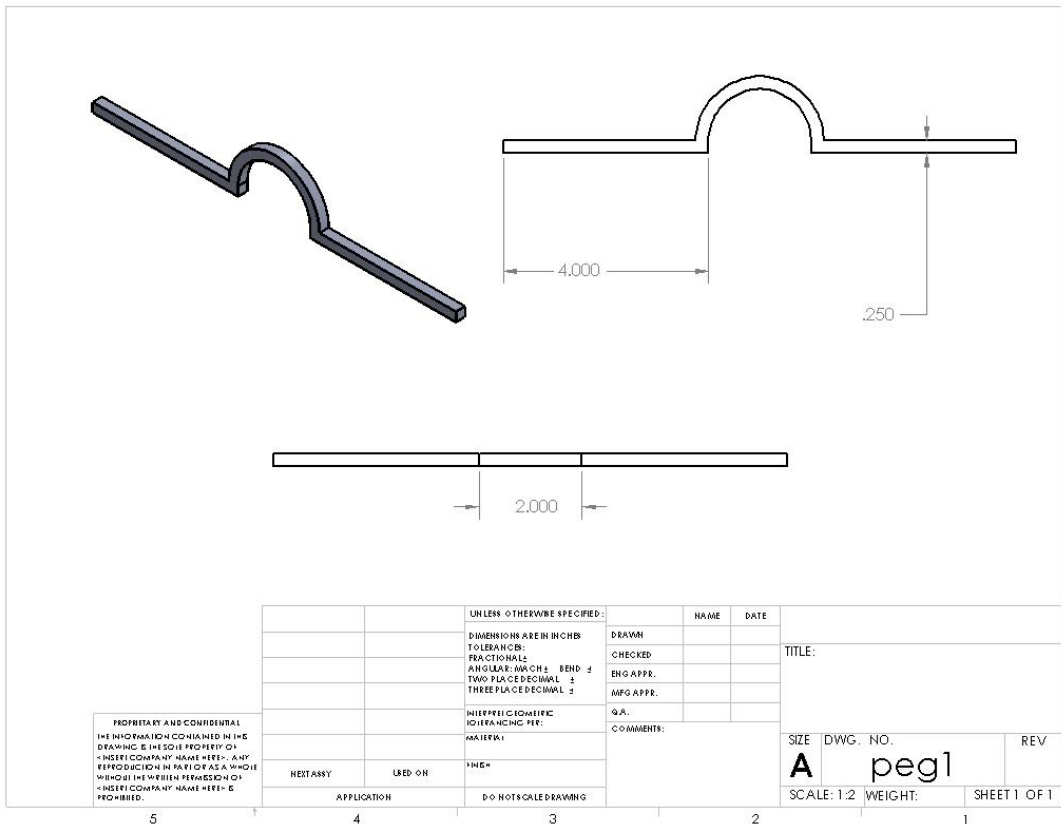


Figure 24: Final Peg System Design

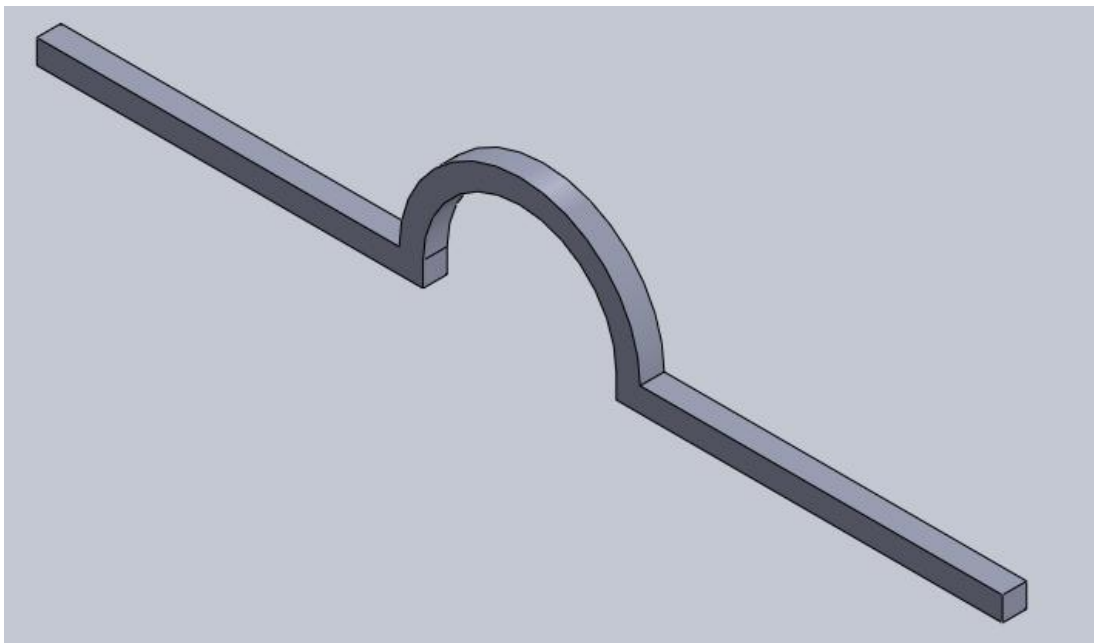
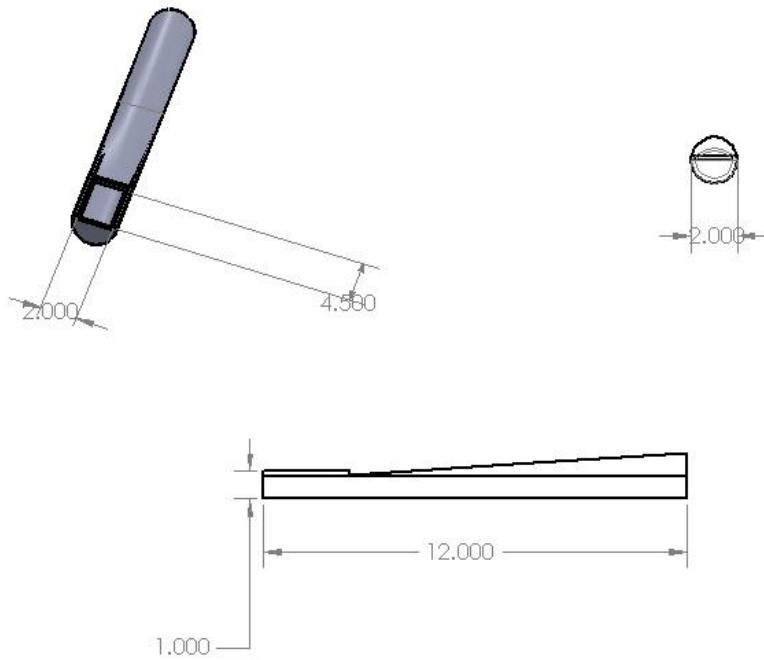


Figure 25: Horizontal centering device, to be used in conjunction with ruler marks along cradle to help horizontally center the cradle in the MRI. This device, which sits on the cradle, acts as a stopper so the user knows how far to push the device into the bore of the MRI.



	UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
	DIMENSIONS ARE IN INCHES	DRAWN			
	TOLERANCES:	CHECKED			TITLE:
	FRACTIONALS	ENG APPR.			
	ANGULAR: \pm .003				
	BEND: \pm .003				

Figure 26: Preliminary Heating Element/Diffuser Design

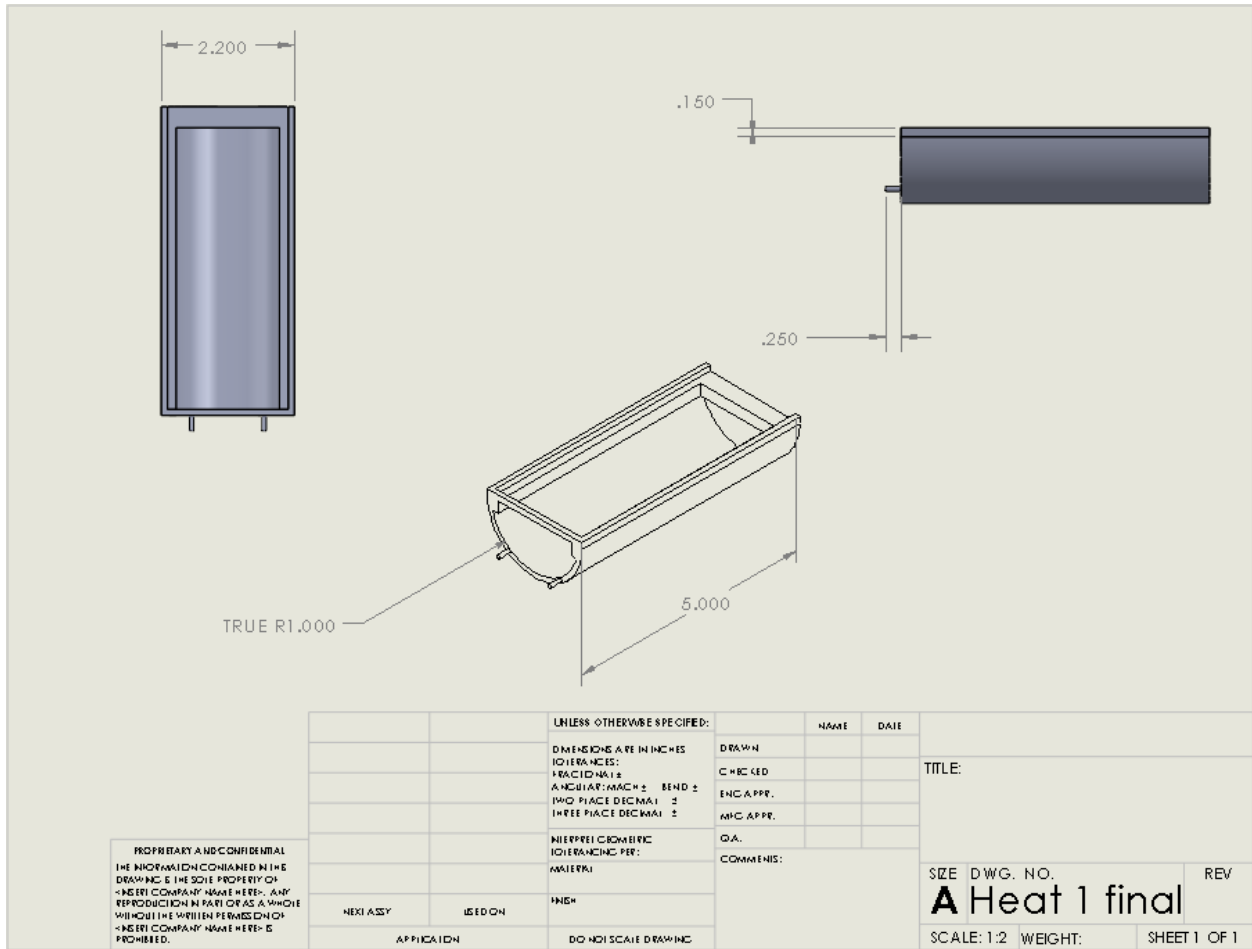


Figure 27: Final Heat Diffuser Design, Piece 1

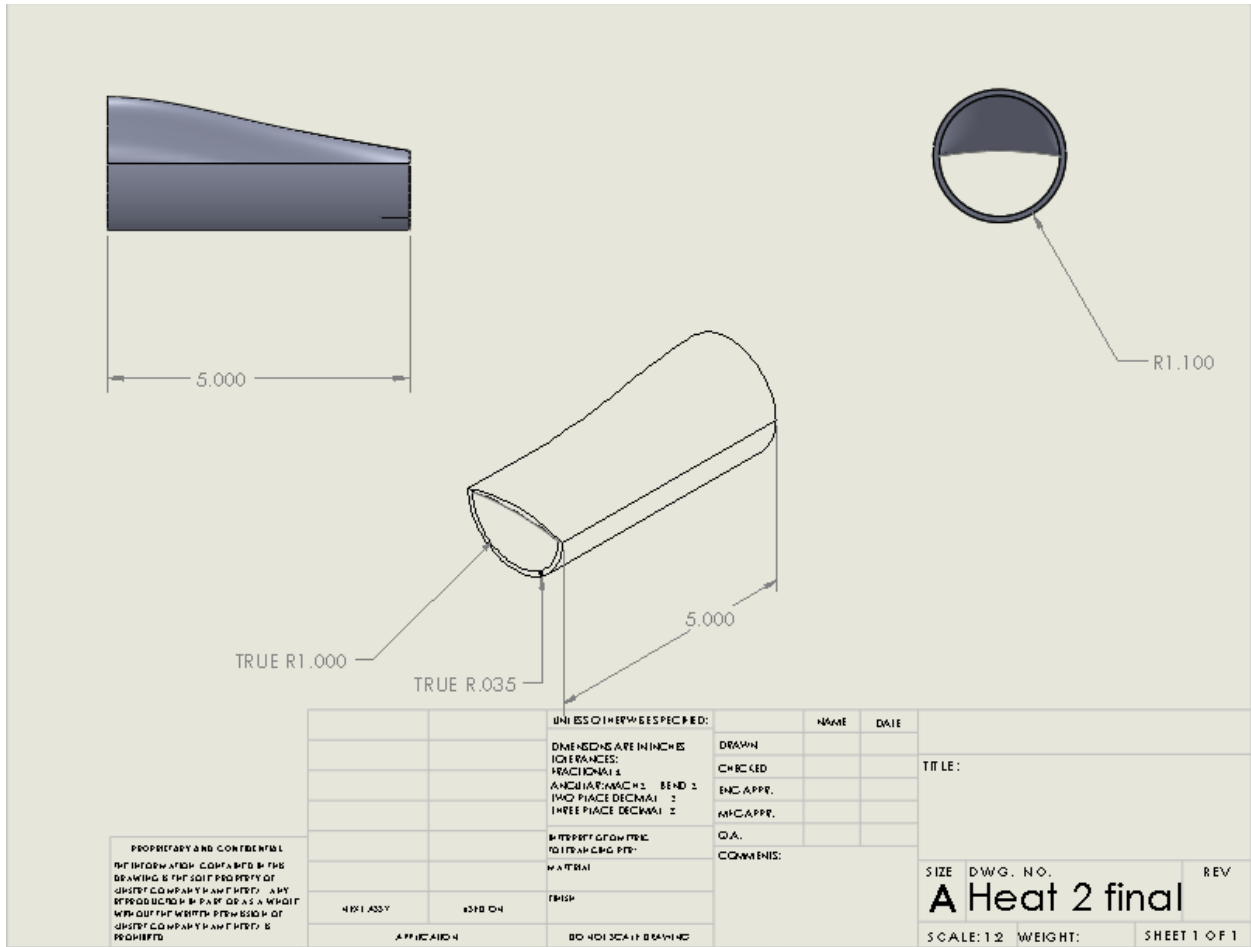


Figure 28: Final Heat Diffuser Design, Piece 2

Appendix C: Requirements Review and Analysis

Table 8: Requirements Review

Number	Type	Description	Priority	Requirement Met?	History
1	Functional	The device shall be placed so that tumor is at the center of the coil	Must	Yes, Animal Test	Created 9/6/2012, Modified 9/13/2012
2	Functional	The device shall secure the mouse's head	Must	Yes, Animal Test	Created 9/6/2012, Modified 9/13/2012
3	Functional	The device shall securely restrain the limbs of mice	Must	Yes, Animal Test	Created 9/6/2012, Modified 9/13/2012
4	Functional	The device shall be easily sanitized	Must	Yes, Animal Test	Created 9/14/2012
5	Functional	The device shall be placed 133mm into the MRI	Must	Yes, Animal Test	Created 9/20/2012
6	Functional	The device shall work in CT scanner	Want	No	Created 9/6/2012, Modified 9/13/2012
7	Functional	The device shall work with ultrasound machine	Want	No	Created 9/14/2012
8	Functional	The device shall direct the subject's breathing movement in one direction	Want	No	Created 9/14/2012
9	Functional	The device shall secure the mouse with re-usable restraints	Want	Yes, Animal Test	Created 9/15/2012
101	Technology	The device shall incorporate vital pneumatics sensor	Must	Yes, Animal Test	Created 9/6/2012, Modified 9/13/2012
102	Technology	The device shall allow for interchangeable and versatile catheter placement	Must	Yes, Animal Test	Created 9/13/2012, Modified 9/13/2012
103	Technology	The device shall securely hold instruments for measuring physiological parameters	Must	Yes, Animal Test	Created 9/15/2012
104	Technology	The device shall allow for adjustable anesthesia lines	Must	Yes, Animal Test	Created 9/15/2012
105	Technology	The device shall have a snap-in capability for the heating system	Desired	Yes, Heat Diffusion Test	Created 9/20/2012
201	Performance	The device shall secure the mouse in repeatable positions	Must	Yes, Animal Test	Created 9/6/2012, Modified 9/13/2012
202	Performance	The heating system shall maintain mouse's body temperature at 37°C +/- 0.3°C	Must	Yes, Animal Test	Created 9/20/2012
301	Utilization	The device shall fit into the	Must	Yes, Heat	Created 9/6/2012,

		72 mm diameter (rat) coil of MRI		Diffusion Test	Modified 9/13/2012
303	Utilization	The device shall not interfere with MRI (Non- Magnetic)	Must	Yes, Animal Test	Created 9/13/2012
304	Utilization	The cost of the project shall not exceed \$3000	Must	Yes	Created 9/14/2012
305	Utilization	The project shall be completed no later than April 29, 2013	Must	Yes	Created 9/27/2012
				No	Created 9/11/2012, Modified 9/13/2012
306	Utilization	The device shall fit in 35mm diameter (mouse) coil	Desired		

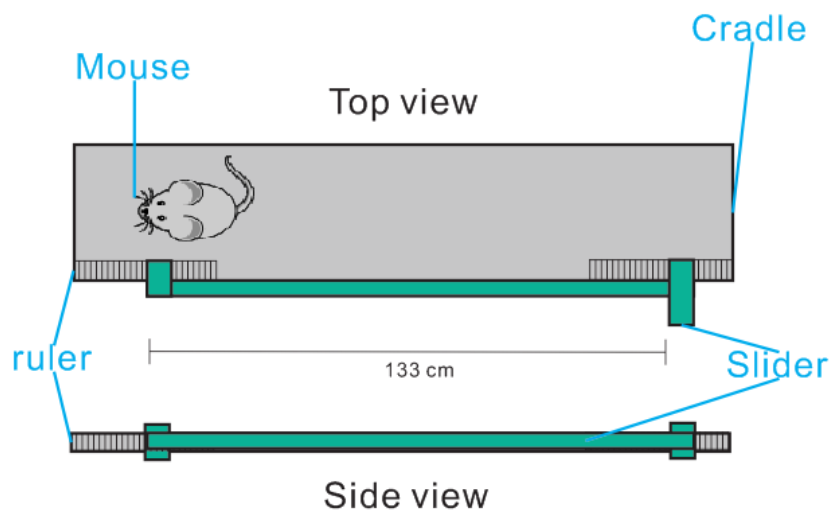


Figure 29: Design 1 for Sled from PDR was a flat piece of plastic with a grid system for repeatable positioning. The design also had a ruler system with a slider to determine the distance the cradle should be pushed into the MRI

Table 9: Cradle and Sled PDR Analysis

Design	Mouse Placement Precision	weight = 0.3	MRI Placement Precision	weight = 0.3	Building Capacity	weight = 0.2	Mouse comfort/ Risk of injury	weight = 0.2	Totals
PVC	2	0.6	3	0.9	5	1.0	2	0.4	2.9
Grid	5	1.5	4	1.2	4	0.8	3	0.6	4.1
Mold	4	1.2	4	1.2	3	0.6	4	0.8	3.8

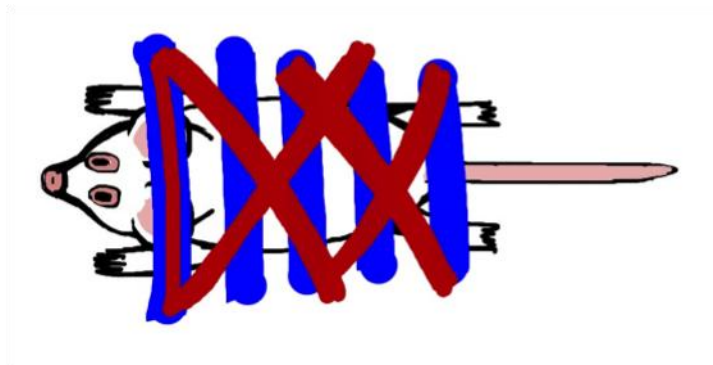


Figure 30: Multiple slotted sled possible restraint configurations

Table 10: Restraint PDR Analysis

Design	Cleanliness/ Ease to Clean	weight = 0.15	Limb move- ment	weight = 0.25	Head move- ment	weight = 0.5	Re- usable	weight = 0.1	Totals
Tape	1	0.15	4	1.00	3	1.50	1	0.10	2.75
Goggle Strap	5	0.75	5	1.25	5	2.50	5	0.50	5.00
Belt Weave	3	0.45	4	1.00	4	2.00	5	0.50	3.95

Table 11: Heat Diffusion PDR Analysis

Design	Snap-in Capability	weight = 0.1	Building Capacity	weight = 0.5	Risk of Burns	weight = 0.2	Heat Distribution	weight = 0.2	Totals
Direct	2	0.2	4	2	2	0.4	1	0.2	2.8
Diffuser	5	0.5	2	1	3	0.6	3	0.6	2.7
Holes in Cradle	4	0.4	4	2	4	0.8	4	0.8	4.0

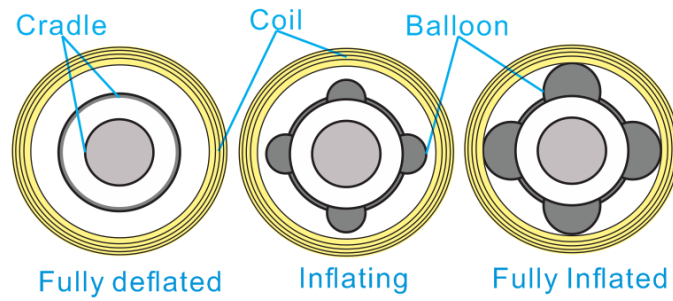


Figure 31: Design 1 for Centering from PDR was an inflatable balloon around the circumference of the cradle.

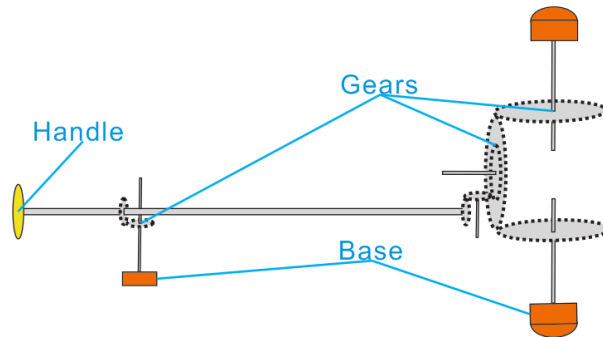


Figure 32: Design 2 for Centering from PDR was a system of gears that could be cranked out to center the cradle in the MRI.

Table 12: Centering PDR Analysis

Design	Centering Accuracy	weight = 0.4	Ease of use	weight = 0.2	stability	weight = 0.3	Building Capacity	weight = 0.1	Totals
Thick sponge	1	0.4	5	1.0	1	0.3	5	0.5	2.2
Inflating Balloon	4	1.6	3	0.6	3	0.9	3	0.3	3.4
Gear System	5	2.0	4	0.8	4	1.2	1	0.1	4.1

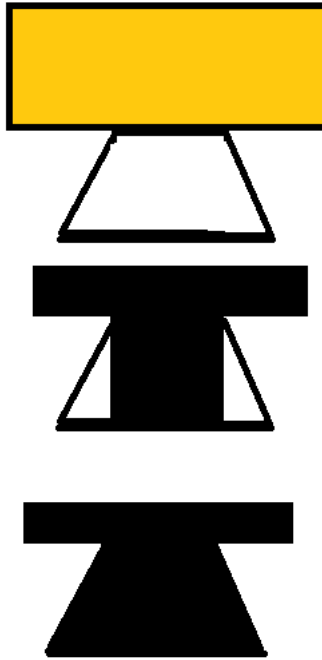


Figure 33: Three designs for Stabilization from PDR. Design 0 sits on top of the track, Design 1 rests in the track to prevent tilting, and Design 2 fully fits into the track for maximum stability.

Table 13: Stabilization PDR Analysis

Design	Stability	weight = 0.5	Building Capacity	weight = 0.1	Ease Of Use	weight = 0.4	Totals
Plate	1	0.5	5	0.5	5	2.0	3.0
Square	3	1.5	4	0.4	4	1.6	3.5
Trapezoid	4	2.0	3	0.3	1	0.4	2.7

Appendix D: Budget and Suppliers

This project was supported with a \$3,000 base budget from the College of Engineering as a part of the Capstone project. The majority of the components came from the 3D printer material used to manufacture the mouse cradle.

Table 14: Main Components Budget

Part	Vendor	Item cost	Delivery /usage cost	Delivery time	Total cost
PVC pipe (2"X10')	ACE Hardware	\$.95 / ft. x 3.5 ft.	\$ 0.00	N/A	\$ 3.33
Adhesive (Cement all purpose 4oz with primer PVC purpose 4oz)	ACE Hardware	\$ 12.98	\$ 0.00	N/A	\$ 12.98
Rubber Bands (45 quantity)	Staples	\$ 3.29	\$ 0.00	N/A	\$ 3.29
3D printing material (ABS)	UA AME Department	\$0.00 (~\$350.00) (no charge for use)	\$ 0.00	N/A	\$ 0.00 (~\$350.00)
MRI usage	Dr. Pagel	3 hours	\$ 93.00 /hr	N/A	\$ 279.00
Adhesive measuring tape	AMAZON	\$ 6.26	\$ 0.00	3-5 days	\$ 6.26
Spray paint	ACE Hardware	\$5.99 x 3	\$ 0.00	N/A	\$ 17.97
Grommet comp.	ACE Hardware	\$4.29 x 2	\$ 0.00	N/A	\$8.58
Miscellaneous (screws, hose, clips)	ACE Hardware	\$ 10.58	\$ 0.00	N/A	\$ 10.58
Design Day Poster Printing	UA Main Library	\$66.00	\$4.50	24 hours	\$70.50
Poster Board for printed poster	Office Max	\$22.35	\$0.00	N/A	\$22.35
Tax	-	\$4.84	-	-	\$4.84
Total	-	-	-	-	\$439.68

Receipts



THANK YOU FOR SHOPPING AT
Mark's ACE Hardware
(520) 325-2432

MARKS ACE MATCHES COUPONS, PRICES & ADS
WHY SHOP ANYWHERE ELSE!
1/24/13 5:12PM VG 573 SALE

42639	3.5PE	.95 PE	
PIPE PVC DWV 2"X10'			3.33
3.5/PER FT - \$.95		per PE	
NB	3 EA	.60 EA	
FASTENERS, NUTS, BOLTS, SCREW			1.80
49806	1 EA	5.99 EA	
PRIMER PVC PURPLE 4OZ			5.99
4039426	1 EA	6.99 EA	
CEMENT ALL PURPOSE 4OZ			6.99

SUB-TOTAL: 18.11 TAX: 1.65
TOTAL: 19.76
BC AMT: \$19.76

BK CARD#: XXXXXXXXXXXXX8477
ID: 17373021
AUTH: 171735 AMT: 19.76
Host reference #:498331 Bat#0023
SWIPED
CARD TYPE:VISA EXPR: XXXX

Trace # 754346307



==>> JRNL#E98331/1 <<==
CUST # *1111

I agree to pay above total amount
according to card issuer agreement
(merchant agreement if credit voucher)
Acct: DEFAULT CASH ACCOUNT-CAH

Customer Copy

Figure 34: Receipts of Materials (rubber bands, PVC, cement/primer, screws)

THANK YOU FOR SHOPPING AT
 Mark's ACE Hardware
 (520) 325-2432

MARKS ACE MATCHES COUPONS, PRICES & ADS
 WHY SHOP ANYWHERE ELSE!
 4/04/13 10:33AM VG 573 SALE

1206739	1	EA	5.99	EA
SPRYPNT FUSION PATBLU120				5.99
3013422	1	PK	4.99	PK
CLIP KWIK 3/8" CD6				4.99
1206630	1	EA	5.99	EA
SPRYPNT FUSION GLSWHT120				5.99
1206721	1	EA	5.99	EA
SPRYPNT FUSION REDPEPR12				5.99
3172	2	EA	4.29	EA
GROMMET COMP.				8.58
4027728	1	FT	3.79	FT
HOSE BILGE 1-1/8I X 5/80				3.79

SUB-TOTAL:	35.33	TAX:	2.89
DISCOUNT:	-3.53	TOTAL:	34.69
		BC AMT:	\$34.69

BK CARD#: XXXXXXXXXXXX9187
 ID: 17373021
 AUTH: 023053 AMT: 34.69
 Host reference #: 539648 Bat#0093
 SWIPED
 CARD TYPE: VISA EXPR: XXXX

OfficeMax®
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 OfficeMax #1183
 860 EAST BROADWAY AVENUE
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 (520) 882-6659

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OfficeMax®
SALE

071064268132	\$18.29
Foam Board Wht 40 x 60	
998100002003	\$2.20
Hand Trimming-Per 5 Minute	

SubTotal	\$20.49
Tax 9.100%	\$1.86
TOTAL	\$22.35

Cash	\$25.00
Change	\$2.65

31180-70001-53190-02991-98132-10024



OfficeMax®
 Tell us about your shopping experience
 and get \$5 off your next \$25 purchase.
 Visit officemaxfeedback.com and enter
 the following Survey Code:
 1183-09-2592-9

Figure 35: More Receipts of materials (spray paint, clips, grommets, hose, foam board for poster)

The University of Arizona Libraries
EXPRESS DOCUMENT CENTER **Large Format Print Order Form**

Date / Time Received: April 26, 2013; 3:47pm		Library Staff Taking Order: FM	
Last Name: Lamanda		First Name: Ariana	
Address:			
City, State, ZIP:			
Phone: 520-780-0118		UA Team/Dept: Engr Senior Design 498 A/B	
<input type="checkbox"/> Cash	<input checked="" type="checkbox"/> Credit Card	<input checked="" type="checkbox"/> UA Dept Charge, Account #: 30070000	
Disk Type (Put your NAME on your DISK!): <input type="checkbox"/> CD <input checked="" type="checkbox"/> USB Flash/Jump drive Returned flash/jump <input checked="" type="checkbox"/> Y/N			

One file per form!

ESTIMATED MINIMUM COST	FINAL COST
Paper fee: \$ NOTE: 'proofs' printed on the Large Format Printer will be charged at standard rates	Paper fee: \$ 66.00
Setup fee: \$4.50 per file	Setup fee: \$4.50
ADDITIONAL SERVICE FEES MAY APPLY @ \$25 per hour! We won't know until we try to print your file.	Additional Service Fees: \$ _____ @ \$25 per hour
Laminating Services: Prices vary _____	Laminating Fee:
Mounting Services: Prices vary _____	Mounting Fee:
RUSH fee: \$15 per print	RUSH fee:
Trim fee: \$5 per print	Trim fee:
Tube: 36" \$4.50 each 42" \$9.00 each	Tube:
CD / Disk: (cost varies)	CD / Disk:
ESTIMATED COST: \$ ADDITIONAL FEES MAY APPLY!	TOTAL COST: \$ 70.50

Figure 36: Receipt for printed poster

Appendix E: Project Management

Timeline

Below are the table and graph of the final Gantt Chart. The project was completed on schedule and well below the allotted budget. The team also stayed within the scope of the project, as stated in the introduction.

Table 15: Timeline

Column1	Start Date	Completed	Construction	Analysis	Resolve Issues of Build
Project Group Assigned	8/28/12	5	0	0	0
First meeting with Mentor	8/28/12	5	0	0	0
Project initiation began	8/30/12	5	0	0	0
First meeting with sponsor	9/5/12	5	0	0	0
Complete system requirements	9/27/12	5	0	0	0
Draft conceptual designs	10/2/12	5	0	0	0
Preliminary Design	10/18/12	5	0	0	0
Complete Risk Analysis	11/9/12	5	0	0	0
Modify and finalize conceptual designs	11/13/12	5	0	0	0
Draft design on SolidWorks software	11/14/12	5	0	0	0
Critical Design Review	11/15/12	5	0	0	0
Finalize ordering materials	12/11/12	5	0	0	0
Cradle and Heat diffusion construction	2/10/13	10	0	0	0
Restraints	2/19/13	5	0	0	0
Centering and stabilizing system	2/10/13	10	0	0	0
Assembly	2/25/13	1	0	0	0
Testing: Repeatability	4/13/13	10	0	0	0
Interference	4/13/13	10	0	0	0
Testing: Temperature	4/13/13	10	0	0	0
Testing: Resolution	4/13/13	10	0	0	0
Testing: Sanitation	4/13/13	10	0	0	0
Testing: Insertion into MRI	4/1/13	10	0	0	0
Testing: Vital Pneumatics	4/13/13	10	0	0	0
Testing: Catheter Placement	4/13/13	10	0	0	0
Testing: Centering	4/13/13	10	0	0	0
Present work at Design Day	4/30/13	1	0	0	0

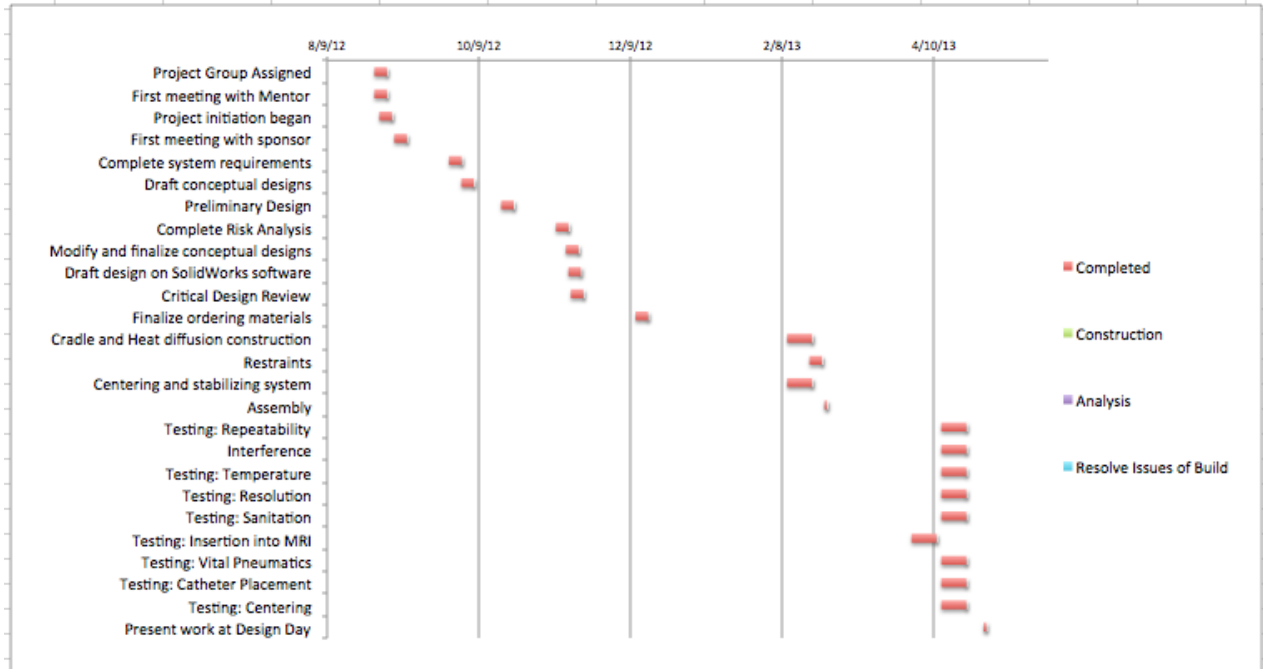


Figure 37: Gantt Chart

Glossary

Sled: The piece of material that the mouse rests upon and is strapped to

Cradle: The entire system that holds the mouse

End Plate: The PVC extension that protrudes from the end of the MRI, including the stabilization block that serves to balance the system

Heating Element (Heat Diffuser): The piece at the front of the end plate into which the heating tube snaps in

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