Peluchi: Product Development of a Programmable Robotic Toy to Stimulate Interest in the Fields of Science and Technology amongst Young Girls

by

My Vu

Submitted to the Department of Mechanical Engineering
in partial fulfillment of the requirements for the degree of

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Abstract

Statistically speaking, science, technology, and engineering are male dominated fields. Peluchi is a second-generation prototype of a programmable robotic toy targeted towards young girls in hope of promoting more interest in these areas. Peluchi is an educational toy designed to both appeal to girls aesthetically and stimulate them creatively and intellectually. The toy began as a group project for a class called SP. 779: Advance Toy Product Design in the fall of 2009. It existed as a much simpler prototype with a limited set of programmable actions. Since then, the group has continued to develop beta prototype within the course of a semester under the class 2.752: Design of Mechanical Products. Additional work has been done to add complexity and allow more user customization. This is achieved through the addition of modular accessories disguising different servos and sensors that can be plugged into the base unit. The prototype itself was also refined to be more seamless and robust. Analysis and extensive design work were concentrated on the custom ports for the accessories. Finally, manufacturability and marketing strategies were then explored and future plans were considered for the toy.

Thesis Supervisor: Maria C. Yang
Title: Assistant Professor of Mechanical Engineering and Engineering Systems

Acknowledgments

First and foremost, I would like to thank the members of my team. Emily Conn has worked with me from the initial stages of concept generation and ideation to the creation of final prototype. She has always been a pleasure to work with. She has immense dedication and passion for the project that always helps to keep things moving and the morale up. In addition to her contributions to the development and fabrication of the prototype, she is largely responsible for the market analysis and development the marketing strategy for our product. My second team member, Ade Ogunniyi, was new to the team this semester. She enthusiastically joined our group after hearing our idea and has offered invaluable time and effort into molding the second-generation prototype into what it is. I want to thank both of them for all their work towards making the Peluchi project a reality. Lastly, I would like to thank Matt Udomphol, a previous member of my team for his contributions to the alpha protoype and continued support and encouragement with the project.

Next, I would like to thank Professor Barry Kudrowitz. The idea for this thesis began in a class that he taught, SP.779 Advanced Toy Product Design, and it was through his guidance and encouragement that my team and I were able to bring our concept from a simple idea into a first level prototype. He was always there to give valuable design advice and offer a different perspective that might not have considered. Additionally, he has always been an inspiration to me throughout my MIT career, offering me guidance and mentorship along the Product Design and Development track.

I would also like to thank Professor Alex Slocum for his advice during the development of the beta prototype. Peluchi, the current prototype, was developed through his class, 2.752 Development of Mechanical Products. I would also like to thank my mentors, Nikolai Begg and Danielle Zurovcik, for their continued support, encouragement, and consultation. They were extremely helpful in developing analytical models and keeping my team and me on track.

With respect to the fabrication of the current prototype, I would first like to thank Professor David Wallace for his guidance and support. He helped immensely in the process and was always willing to lend a hand and offer valuable advice. He has always been extremely encouraging and helpful in any design endeavors I have taken, and without him, this project would not have been successful. In making the prototype, graduate student James Penn and the Pappalardo staff also played a pivotal role in facilitating the process.

Finally, I would like to thank my thesis supervisor and advisor, Maria Yang. She has always been there to offer me valuable advice whenever I needed it. It was her who originally encouraged me to pursue this project for my thesis after realizing how excited and passionate I was about it. I am grateful to have had her as my advisor the last two years since she has always been extremely supportive and encouraging.

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Introduction

1.1 Objective and Motivation

It is a statistical fact that science, technology, and engineering fields are male dominated. Women constitute almost 50% of the workforce but less than 20% of them end up pursuing careers in these fields. In an attempt to foster an interest in these areas, we look to the development of a robotic STEM toy, Peluchi. The toy is targeted towards young girls between 6 and 9, when children show high interest and self-confidence in the area of science [5].

Looking at the current market for robotic toys, there are not many targeted towards girls. The ones that do exist do not tend to be very stimulating creatively or intellectually. This presented an opportunity to design and prototype a toy that would allow girls to channel their creativity into programming life into their toy.

Girls will be able to truly customize their toy as they gain the ability to control the way that it reacts and moves through a drag-and-drop programming interface. As they get older, they can continue to experiment with more complicated programming. The goal is that by providing girls with a fun and creative outlet through a STEM toy at this young age, we can spark an interest in science and technology that will pervade into their older years.

1.2 Background

1.2.1 Toys on the Market

There are many robotic toys that currently exist. The toys range from simple remote controlled robots to interactive robots that reacted with preset response to fully programmable and customizable robots.

Some of the reactive robotic toys included Pleo, Furby, FurReal Friends, and Penbo. All these toys are designed to respond in different ways to the user through sound or touch. These different toys mimic different types of pets and can be fed or played with. These toys can be very sophisticated in the intricacies of their movements or breadth of responses that they can generate. However, all these reactions are predetermined when the toy was built and the user cannot do much to further customize the toy.

The more customizable toys include ones such as LEGO Mindstorms and Robosapiens. Both of these toys allow the user to program the way the toy will move and react. Robosapien is futuristic looking robot that users interact with using a remote. Using the remote, users can directly control him or program a set of actions for him to perform. LEGO Mindstorms, however, takes a very different approach and allows users a lot more flexibility and creativity in their play. The users are given a set of building blocks, some which contain different electrical components including motors and sensors, and allowed to build whatever they want. The users can then program their creation using a drag-and-drop programming interface.

1.2.2 An Unoccupied Niche

The current robotic toys on the market can first be divided into to clear categories—girl's toys versus boy's toys. The toys targeted towards girls tend to have a different aesthetic appeal. The toys tend to be more attractive and "cute" as well as have a nurturing nature to them whereas the ones targeted towards boys had a rougher appearance [7].

Within each of these categories, the toys could be further divided into passive and active toys. The passive toys refer to those in which the child has no input as to how the robots will react to different stimuli. Manufacturers have predetermined the actions of the toy. On the hand, active toys refer to those in which the child can directly program and control the robot's actions. These active toys also tend to be more intellectually stimulating than the passive ones.

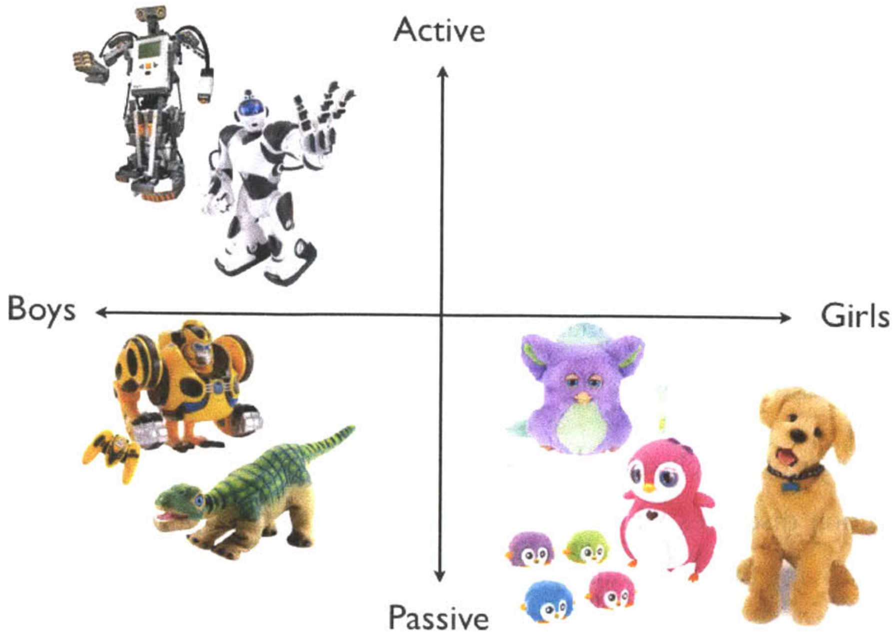

Figure 1-1: Robotics toys on the market can be mapped into four groups. Active Boys: *LEGO Mindstorms and Robosapien*. Passive Boys: *Pleo and Prime-8*. Passive Girls: *Furby, Penbo, and FurReal Friends*.

The figure shows how the different toys currently on the market fall into the four categories. The toys designed for boys exist in both active and passive forms. However, it can be noted that all the robotic toys targeted towards girls falls solely in the passive zone. This leaves an unoccupied niche that Peluchi would fit into.

1.3 Outline of Thesis

This thesis is organized into the following chapters:

Chapter 2: Initial Prototype – A review and critique of an earlier alpha prototype for the toy. This section looks at the initial design, results from user testing, and discusses areas for improvement.

Chapter 3: Concept Selection – A look at the different concepts for what the beta prototype should be and ultimate selection. This section then focuses on the functional requirements developed and different ideas for the connector designs.

Chapter 4: Detailed Design – A detailed discussion of the prototype design and fabrication process. This section also discusses the electronics and programming used in this iteration of the robot.

Chapter 5: Business and Implementation – A look into manufacturing and the robotic toy market. This section discusses design for manufacturing and costs. It then discusses the current market for robotic toys and gives profitability estimates for bringing Peluchi to market.

Chapter 6: Conclusion – A summary of the work and discussion of future plans. This section discusses what was learned from the current prototype and the next steps in improving the design and possibilities for future endeavors.

Chapter 2

Initial Prototype

2.1 Original Design

The original prototype was a fuzzy blue robot with an egg-like shape with no arms or legs. It went by the name of Peluche, instead of Peluchi.[1] It had an embroidered face that consisted of large eyes and a smile and was topped with a pink bow. These aesthetic features were chosen to make her more attractive to young girls.

Figure 2-1: Peluche, the original prototype for a programmable plush robotic toy.

The abstract form was chosen for several reasons. Since this was the first iteration, we chose to reduce the number of servos and joints being used so we eliminated arms or wings, and focused solely on "hip" and "neck" movements. Additionally, we chose to have the robot not resemble any existing creature so that girls would not be constrained to preexisting notions

[1] Peluche is a French term meaning "plush." We renamed the second-generation prototype Peluchi, which is a shortened version of Peluchina, where –ina is an Italian suffix added to words to make them "small." Effectively, Peluchi is simply a small Peluche.

on how it should act. Peluche was designed to be a creature whose story the user would make up and could then control and act out through the programming.

Below the fur, the prototype consisted of an internal framework made of ABS. The pieces were designed in SolidWorks, waterjetted, and press-fit together.

Figure 2-2: Internal framework of original prototype.

This internal structure consisted of a base where the wheels, speaker, switch, and microcontroller rested. The electronics were shielded within the ABS and the wheels had guards to prevent the outer foam core from interfering with them. The framework also had a pan and tilt structure above the base actuated by two HITEC HS-77BB servos. This gave Peluche a forwards and backwards "nodding" motion and a side-to-side "swaying" motion. Peluche was able to move around with two wheels powered by Parallax continuous rotation servos and two halves of a golf ball served as sliders for the toy to balance. The speaker unit allowed us to record a 30 second clip which could then be played back. The entire robot was controlled by a Basic Stamp BS2 board and powered with two 9V batteries.

To keep Peluche soft and huggable, we encompassed the ABS structure with memory foam. The foam served to provide shape to the robot as well as cushioning and consisted of a small ring of foam on top of a larger ring. The foam rings were sewn together from strips of cut memory foam. Finally, her plush fur was used to cover the foam and she was topped off with a pink bow.

2.2 Playtesting and User Feedback

Initial user feedback was first gathered through a focus group consisting of girls between the ages of 11 and 14. The girls served as mentors to younger girls in an after school program called Science Club for Girls. We pitched the idea of our toy and asked for comments, advice, and suggestions for what they would like to see the product become. We also presented concept drawings of how Peluche could possibly to help us design her aesthetics. Overall, we had a positive reception to the idea. There were different suggestions to make the robot dance or play music, but ultimately, the girls thought that the ability to program a toy to be able to do these things increased its play value and novelty. Though the toy was going to be designed for a younger audience, girls in our focus group commented that the flexibility in programming could add a degree of challenge that could still interest girls of an older age group. The positive reception and comments helped us to craft our alpha prototype and gave us valuable insight for improvements and future work.

Playtesting was done upon completion of the alpha prototype. The original Peluche was brought to a science festival hosted by Science Club for Girls and tested with a group of girls between the ages of 5 and 12. The girls were introduced to the concept and given a nonfunctional GUI to interact with.

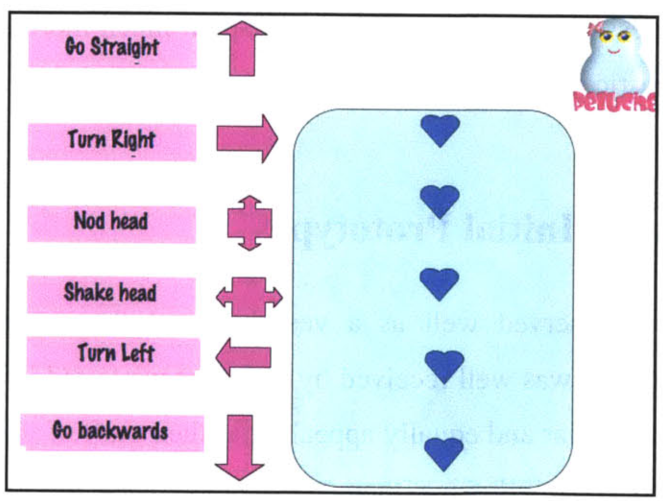

Figure 2-3: PowerPoint GUI used to simulate the drag-and-drop programming interface.

The GUI, created in PowerPoint, was used to simulate the drag-and-drop programming interface we imagine the product to employ. The girls would pick a set of actions they wanted the robot to perform, and we would program the prototype through the Basic Stamp accordingly. From this playtesting, we received a lot of positive feedback. The programming interface was very simple and intuitive. The girls picked up on the programming very quickly and were very enthusiastic about getting a chance to try it.

Figure 2-4: Enthusiastic girls playtesting the alpha prototype, Peluche.

Additional feedback we got was that they liked Peluche's abstract form; it allowed them more creative flexibility in shaping its character because there were no preexisting expectations as to how such a creature should act. They also appreciated the softness of the robot and its likeness to a stuff animal which made it much more appealing than something that was purely plastic. Some did, however, request that the next version have arms or similar appendages on it.

2.3 Critique of Initial Prototype

The initial prototype served well as a vessel to test the concept of a soft and plush programmable robot. It was well received by girls that we tested it with. They loved the idea of a robot that was similar and equally appealing as their stuffed animals but added a level of challenge to the play by allowing them to program it. It was adequate for a first level prototype and proof of concept model in that it could perform a variety of basic functions. However, the extent that girls could customize it was limited to the few actions it was capable of performing: moving via its two wheels, tilting left and right, tilting forwards and backwards, and producing sound. We hoped to improve in this area with the next prototype by allowing a little more customization through modular body parts, accessories, or some other way in which the girls could both alter the appearance of the robot as well as add additional functionality.

Peluche was designed to be similar to a stuffed animal by allow girls to still hug and cuddle with it. However, the internal structure of the toy was not robust enough for this purpose. Also, the enclosure of the framework in memory foam provided sufficient cushioning, but it was also the source of several problems. The foam was not custom casted to the right shape, so it dampened the motions created by the servos making it difficult to tell when Peluche was bending. Additionally, the foam was also difficult to put over the internal framework making assembly of the prototype very awkward. This made it clear that the next iteration of the toy would need a new form of cushioning or a custom casted foam cover.

There also some minor details that could use refinement in the design and fabrication of the prototype. For example, Peluche had some balance issues due to the positioning of the two base wheels and so she utilized two golf balls as casters. Ideally, we wanted a more polished look with actual caster wheels. Also, the speakers were placed at the bottom of the prototype and this seemed a little counterintuitive for the sound to be coming from the toy's base rather than its mouth. We also wanted to keep the internal framework of the robot enclosed and out of contact with the users. Unfortunately, there was no place for the batteries and changing them required going beneath the foam and plush exterior.

Next, we needed to look into the power consumption of the toy to make sure that the electronics were not drawing too much power. This was essential because the existing prototype did not have substantial battery life. This would be critical in our decision to add additional electronics and choice of battery that we wanted the robot to use.

Finally, additional work needed to be done on the programming. The existing Basic Stamp code did not function consistently and was still difficult to use. Ideally, a user friendly GUI, like one simulated through PowerPoint, was the ultimate goal.

Chapter 3

Concept Selection

3.1 Design Ideas

After creating the alpha prototype and playtesting with girls, we analyzed all the feedback and discussed the possibilities for the current prototype. For the semester, the main objectives were to increase user customization, expand functionality, improve mechanical robustness, and overall refinement of the prototype. In doing so, many concepts were considered before one was decided on. From this, functional requirement were drafted and considerable design was done on the connectors.

3.1.1 Buildable Robot

The goal of the toy is to be an educational one, which would inspire girls to pursue and interest in science and technology. As a result, discussion came up as to whether or not the girls should have any part in building the actual creature itself. The idea was to present the toy as a kit and allow the girls to build the base and then add on different appendages using screws. Ultimately, the girls could then program the entire creature to function as they pleased.

This concept had a range of promising features. It first allowed for an extensive range of customization by allowing different appendages to be attached and create a completely unique look. It also would introduce the girls to the concept of building robots as well as programming them. However, going with such a concept would result in trickier issues with electronics and programming. Additionally, by allowing the girls to be able to screw together a variety of parts meant more potential pinch points and a lot aesthetic issues. For example, it would be difficult to hide the screws or blend the joints into the body. Additionally, it would be much hard to create any foam cast for a completely unique shape. Finally, the target age group was still very young and so adding in screws might be beyond their skill level. Also, in terms of safety, it was more desirable to enclose a lot of the electronics rather than leave them exposed to the user.

3.1.2 Modular Components

The second major concept was to create a base unit, which would house the power source and microcontroller and had additional components that could plug into this unit. The components could contain a variety of different electrical components or carry out a set action. These components could be disguised as accessories or appendages to alter the physical appearance of the robot. The accessories plugged in would then control the complexity of the actions the robot could perform.

This concept was promising in that it provided potential for constant expansion with the addition of new accessories if the project were to continue further. It also allowed us to create the base as we chose and ensured that all the electronics would be properly housed and made so that the user could not tamper with them. This meant that we also had some control over the aesthetics of what a Peluchi would look like to give the product a more concrete vision. However, the flexibility was still there for users to modify the appearance and give a personality to the robot by adding different accessories.

In such a design, however, users would be limited in how many accessories they could plug in at once. This meant that the number of sensors that could be working at one time was limited. Also, children would not gain much insight into building the actual robot. Therefore, the educational value of the toy would be limited to the programming aspect.

3.1.3 Final Selection

The pros and cons of each idea were discussed in relationship to the scope of the class, the target audience, the relevance to the creative and educational objective of the toy, and the potential for future development. Conclusions were drawn that the modular accessories were more appropriate to pursue this semester. It offered the flexibility and creativity the toy should provide by allow the users to customize the appearance and functionality of the robot, but was did so in a simple enough manner for our target audience of girls between the ages of 6 and 12. Additionally, it would preserve the aesthetics of the toy and allow us, as the designers, some degree in how a basic Peluchi would look. The fact that additional complexity could be added through the development of different accessories also presented opportunities for future work, which was not so clear with the other concept. From this concept, the functional requirements were laid out.

Table 3-1: FRDPARRC chart for the prototype.

Functional Requirements	Design Parameters	Analysis	References	Risks	Countermeasures
Modular	plug & play ports intuitive design attachments have self-contained servos or sensors	research of existing port designs, CAD, sketch models, testing.	LEGO Mindstorms, AMK, Meccano, Penguin Bebop, & Electroplushies.	high: safety concerns w/pinch parts, small pieces, & electronics. low: easy to make distinguishable. low: existing electronic toys out there that do this (AMK).	design ports to cover potential pinch points. use form & color to make function obvious. use existing designs as reference.
Programmable	drag & drop block programming intuitive & simple	create different GUI layouts, write simple program & test.	Scratch & LEGO Mindstorms.	medium: these types of programs already exist & can be adapted to our purposes. low: block programming is innately simple & intuitive.	use Scratch, find a programmer, or stick with Basic. playtest & design an even simpler UI.
Safe	no exposed small parts or wires no pinch points durable	CAD, sketch models, FEA & experimentation/testing (i.e. drop-testing).	reference material linked from 2.00b toy product design: http://web.mit.edu/2.00b/www/pages/material.html.	low: parts are contained. medium: ports & joints may pose a concern. medium: difficult to make something light & soft strong . kids play unpredictably.	house all small parts & electronics in a modular unit. design product to hide/cover areas of concern. build a sturdy frame & use foam. try to anticipate play.
Aesthetically Appealing	soft & huggable small, round, & cute	test & research different foam or materials, user-testing & feedback.	cartoons or current girl toys: FurReal Friends Furby Build-A-Bear	low: easy to cast a foam mold to encase the parts. low: experience with making toys & dealing with young girls.	cast with foam, cut pieces of memory foam, or stuff with another material. get feedback from girls & other people.

3.2 Connector Design

After modular accessories were decided upon, the connectors had to be designed. Different construction and existing modular toys were researched to develop potential ideas. Ultimately, we decided to look at screws, twist and locking tabs, and a two-peg press-fit.

The screw idea was basically just one in which the connecter was threaded and would screw into the main base. Electrical leads could be placed at the base or along the threads similar to a flashlight.

Twist and locking tabs referred to a set of tabs that would sit into a groove in the base. The user would then twist the accessory piece until it hit a stop and locked into place. Electrical leads could be placed anyways along this configuration, most likely at the tabs.

Finally, a friction or press-fit design can be used. Multiple pegs can be used to restrict rotation within the plane. Different shape pegs can help with alignment so the accessories will always go in the correct orientation.

Ultimately, the connectors had to be able to take some load and torque. Although the first two concepts would hold up well against the axial force exerted by a child, and torque on connector in the release direction would disengage it. The friction press-fit was just the opposite. However, the press fit using two pegs provided a slight advantage in alignment. Additionally, if the two pegs were different shaped, the alignment of whatever accessory was put on would be ensured each time. Due to this feature, we chose to go with the press fit.

Chapter 4

Detailed Design

4.1 Physical Prototype Design

4.1.1 Connector Design

The connectors were designed to be two shafts, one with a square cross-section and the other with a circular one. This is important to help line up the male to the female ports and ensure that the correct electrical connections were being made. For the actuated accessories, the male connector interfaced with the servo housing. The servo housing was able to rotate within the male connector 90° due to hard stops in the connector. This would allow users to manually position the appendage and control the axis of rotation.

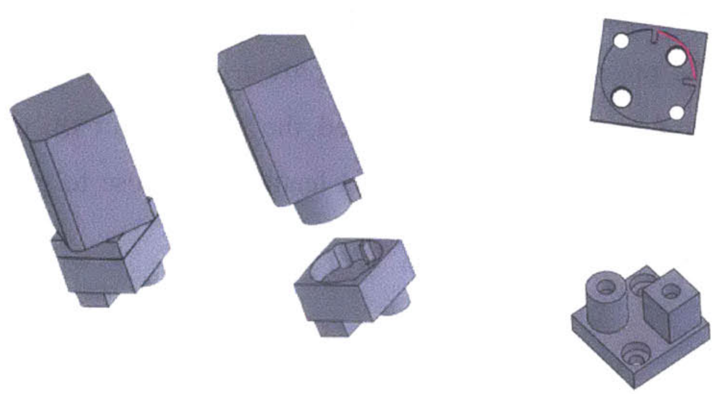

Figure 4-1: Servo housing and male Connector

The connectors were designed to employ a friction fit. The following equation was used to help determine the dimensions of the shaft and hole. Here, *P* represents interference pressure,

Δ represents the interference, the shaft is the inner body, the hole is the outer body, and $D_{interference}$ is the nominal interference diameter.

$$P = \frac{\Delta}{D_{interference}\left[\frac{1}{E_{out}}\left(\frac{D_{interference}^2 + D_{out}^2}{D_{out}^2 + D_{interference}^2} + \eta_{out}\right) + \frac{1}{E_{in}}\left(\frac{D_{in}^2 - D_{interference}^2}{D_{interference}^2 - D_{in}^2} + \eta_{in}\right)\right]} \quad (1)$$

A spreadsheet [3] was used to vary the different parameters. We specified the applied axial force to pull the connectors in and out to be a reasonable 2 N and the interference to be .0025". By varying the geometric parameters of our connectors, we were able to observe the stresses and make sure that safety factors were still within reason. For the design, the resulting safety factors were $N_{hole} = 3.181$ and $N_{shaft} = 1.134$. The spreadsheet can be found in Appendix A.

A SolidWorks FEA analysis was performed on the plugs under a maximum material condition (MMC) situation. By modeling the plugs as cantilever beams, a force was determined for the plugs in the case of misalignment of the pegs. This displacement force along with the pressure force found from the spreadsheet was used for the FEA analysis. The results for the FEA can be found in Appendix B. The analysis was performed for designs for the female connectors. In one design, the port is completely solid while in the other the back has been hollowed out. The results are summarized in the following table:

Table 4-1: FEA results. All cases examined under MMC press fit with smallest hole at .365" and largest peg .380". Case 1: *Pair is misaligned 0.014" away from the center. Case 2*: *Pair is misaligned 0.014" towards the center.* Case 3: *Centered.*

Case		Max Von Mises Stress (GPa)	Max Displacement (mm)	Safety Factor
Hollow	**Case 1**	2.96	1.63	8.6
	Case 2	1.05	.22	24.7
	Case 3	.014	.0071	1810
Solid	**Case 1**	2.93	16	8.7
	Case 2	1.07	1.91	23.3
	Case 3	.013	.072	1870

Ultimately, we went with the hollowed out design. There was not much noticeable difference in terms of safety factor or stresses, but the displacement due in the solid pieces were much larger and undesirable.

4.1.2 Base and Internal Structure

The internal structure is a cube formed by press fitting pieces of ABS. The top and side pieces have holes cut out of them where the female audio jacks will fit. There is a hole cut out of the front piece to allow the speaker and microphone unit to fit through. On the back piece, holes exist for the battery wires. A battery holder will attach to the back piece of the cube.

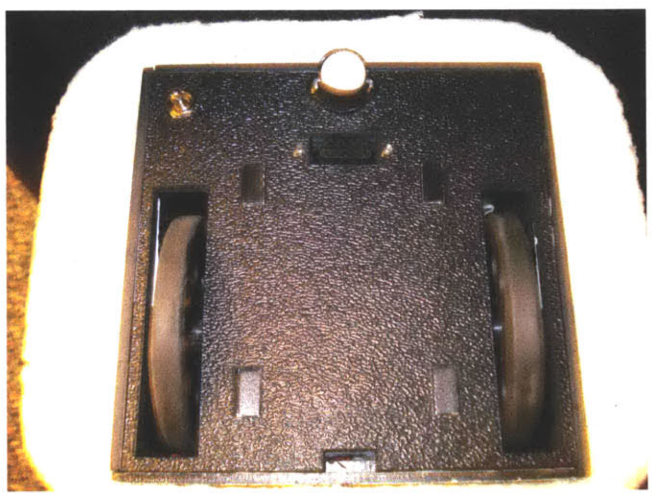

Figure 4-2: Base of the prototype

On the base, appropriate holes are cut for the wheels, servos, serial port, switch, and caster wheel. This base is made so that it fits snugly into the lip formed by the sides of the cube. The drive wheels are placed near the front of the robot and a third caster wheel sits in the center by the back of the toy for balance.

4.1.3 Electronics and Programming

The primary electronics did not change much between the previous prototype and this one. The microcontroller was once again the Basic Stamp BS2. However, since space was not a huge concern in this iteration, a Homework Board was employed to eliminate the complication of soldering up a circuit. The base wheels were run actuated with parallax continuous rotation servos. There was also a simple speaker and microphone unit used to record and play back sound. There was a switch and connectors for two 9V batteries. Additional electronics in the accessories included HITEC HS-55 micro-servos for the actuated arms and wings. Three sensors from Parallax were also chosen for this iteration—ColorPal color sensor, 4-directional tilt sensor, and sound/impact sensor. These sensors were then wired so that the ground and signal wires corresponded to the square shaft, which the red signal wire corresponds to the round shaft.

Table 4-2: Power budget showing the power consumption of electrical components.

Item	Number	Current (A)	Voltage (V)	Power (W)
Micro-Servos	2	0.2	6	2.4
Wheel Servos	2	0.19	6	2.28
Sound Module	1	0.04	9	.36
Voice Recorder	1	.03	5	.15
Stamp Board	1	.03	5	.15
I/O Pin	8	.025	5	1
			Total	6.34

To power the unit, two 9V batteries were employed. A quick power budget created to estimate the number of additional sensors and servos that could be supported by the Basic Stamp and still provide a reasonable battery life from the two 9 V. This number was found to be three accessories—two actuated servo pieces and one sensor. The estimated total life of from two 9V batteries each with a capacity of 0.6 Amp/hr for a toy requiring 6.34 W was found to be 1.42 hr.

During the course of this semester, extensive progress was not made on the programming. The program was simple written up and saved as a series of functions that would enable it to perform different actions or respond accordingly depending on which sensor it had plugged in. The functions were simply called within the program and then time for each set of actions was typed in as one of the variables.

4.2 Fabrication

To create the internal structure, the pieces were designed on SolidWorks and cut from ABS plastic with the laser cutter. The laser tended to melt off about .005" of the ABS so this was adjusted for in the dimensions of all the pieces to maintain a press fit. Once the sides were all cut, a small groove was milled into the bottom of each of the sidepieces. Once press fit together, this formed a lip for the base of the robot to press fit into. The wheels and switch were then put onto the base. This body will serve as a housing for all the

The connectors were then fabricated through 3D printing. The parts were designed on SolidWorks and double-checked to make sure all dimensions were correct and wire holes were accounted for. Once completed, the pieces were sanded and tested for fit. The female connecters were sanded down and epoxied in place onto the ABS structure. Next the audio jacks were soldered to wires. The servo wires were cut and soldered to appropriate audio jacks. Once completed, the servos were placed inside the servo housing and male connector pieces and all assembled. The male audio jacks were epoxied to the male connectors and the female audio jacks to the ABS structure. The battery pack was then created by cutting and epoxying acrylic to form a rectangular box. This was then epoxied to the ABS structure.

After the internal structure was assembled, a polyurethane foam core needed to be made to encase it. The foam core was custom casted from a three-part mold and made to be an inch thick all the way around.

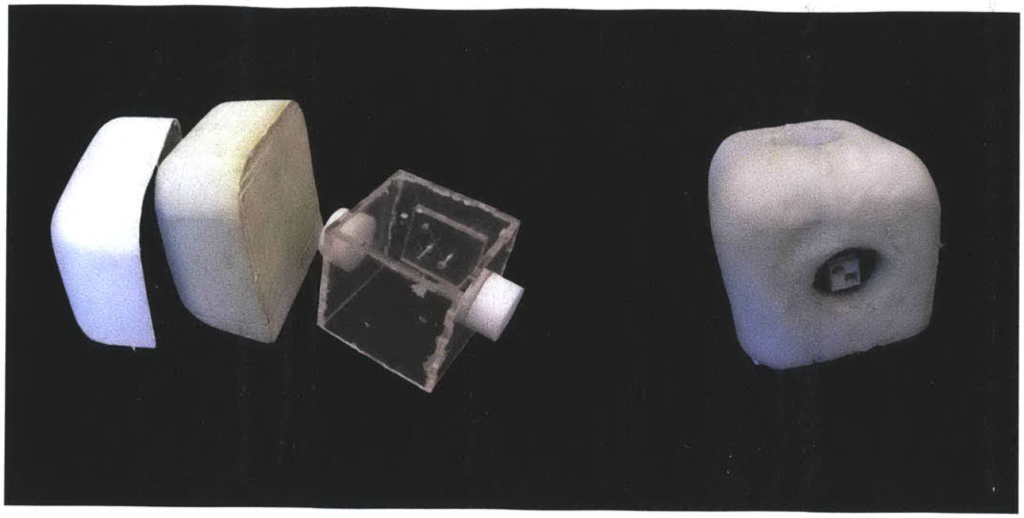

Figure 4-3: On the left, the mold used to cast the foam is shown. On the right, the resulting custom foam cast is shown.

The inner mold was made with acrylic and Delrin. The acrylic was epoxied together and laser cut from the same pattern as the ABS box structure, but without all the holes. Delrin cylinders 1.5" in diameter and 1" high were screwed onto the acrylic where the connection ports would be. On the back of the box, an acrylic rectangular box was placed there to represent the area for the battery holder. The outer mold consisted of ABS shells. To create these shells, a mold was carved from high-density green foam and 1/8" ABS was thermoformed over it. The thermoforms were then carefully cut and then taped together. All the pieces were then coated with a releasing agent. The inner mold was placed inside the shell and an acrylic cover was made. An expanding flexible polyurethane foam casting mix, FlexFoam-iT! III, was mixed, poured into the mold, and allowed to cure over night. Once the foam was cast, the three-part mold was carefully peeled off to leave a custom foam cast to fit over the internal ABS structure.]

Figure 4-4: The beta prototype, Peluchi, with no accessories attached.

The plush cover for Peluchi was hand sewn and holes were cut out from the fur where the connectors would plug in. Velcro was used in the back to access the batteries. The eyes and mouth were drawn up using a vector-based program and the images were sent to be embroidered. When Peluchi has no accessories plugged in, the holes were they would normally go are filled with stuffed plugs sewn from her fur and stuffed with polyester filling.

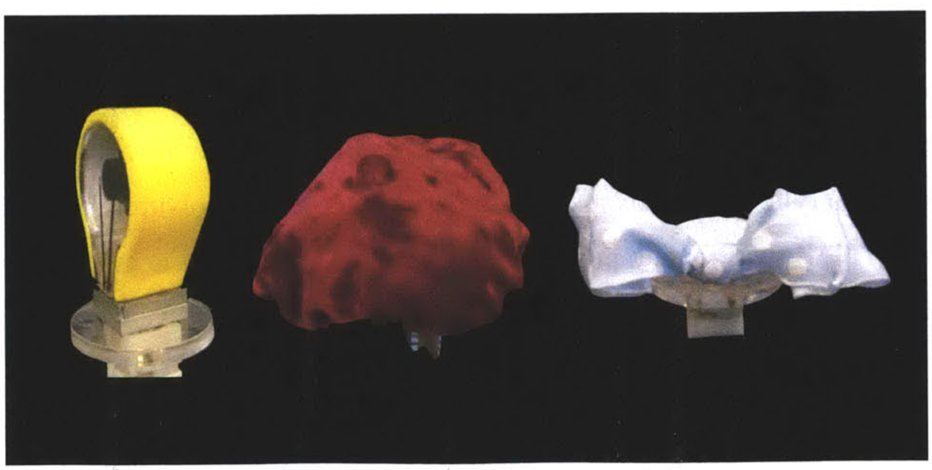

Figure 4-5: Three sensors disguised as a light bulb (color sensor), beret (sound sensor), and bow (tilt sensor).

To create the accessories, acrylic was to laser cut and bolted together to create housings for the sensors. The male connectors were bolted to these acrylic housings and the wires were connected to the sensors. These housings were then disguised using fabric, ribbon or foam. A beret sewn from cloth and stuffed lightly with polyester filling was used to contain the sound sensor. Blue ribbon was tied and glued over the sensor housing for the tilt sensor. Finally, a light bulb was carved out of high-density foam, painted, and then capped with acrylic to contain the color sensor.

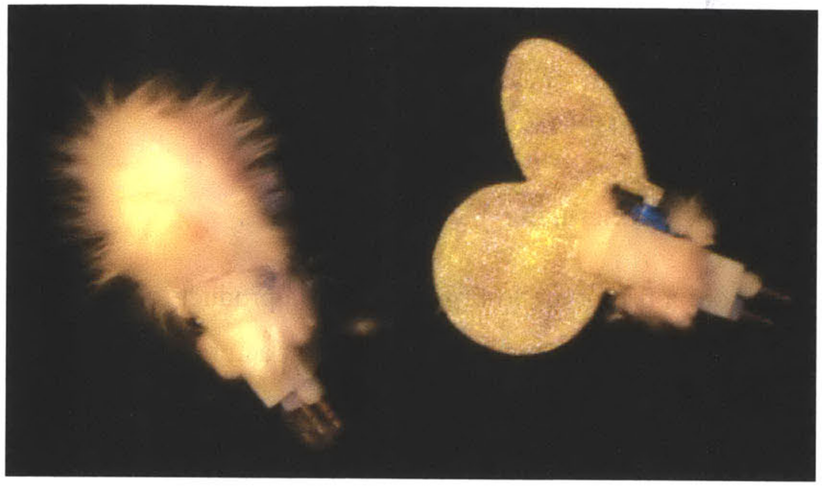

Figure 4-6: Actuated arm and wing attachments.

For the servos, arms and wings were created. The general shape of the arms and wings were laser cut from acrylic and drilled so that they could be attached to the servo housing and horn. The arms were then covered with a sleeve sewn from the fur and the wings were covered with a gold translucent fabric. The servo housing then had fur glued onto them to help them blend into the sides of the robot.

Chapter 5

Business and Implementation

5.1 Manufacturing

5.1.1 Design for Manufacturing

In transitioning from a prototype to bringing such a product to market, several changes have to be made to the design so that it can be mass manufactured.

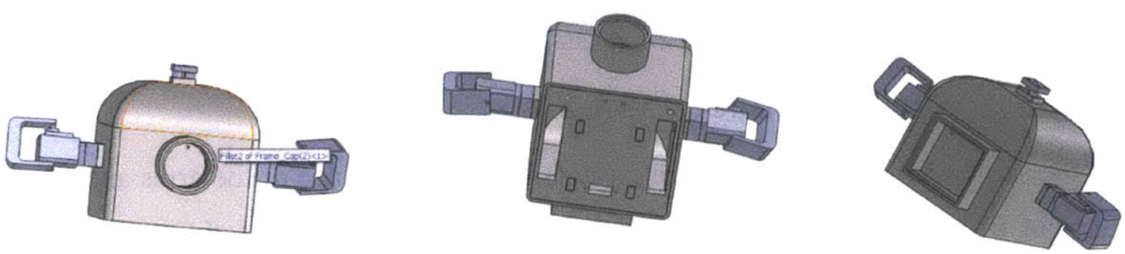

Figure 5-1: Model for manufacturing: front, bottom, and back.

The first change would be to create the ABS structure in two parts rather than six that are press-fit together. This would allow filleting of the edges to create a dome-like shape. This structure would also already have the female half of the connectors designed into it. Additionally, in the base piece, there would be wheel guards rather than large slots for the base wheels. This helps to ensure that the electronics cannot be accessed easily through the bottom and small object cannot get into the robot. Finally, each of the connectors would no longer use audio jacks but have the electrical leads built in.

5.1.2 Manufacturing Costs

Most of the pieces will be injection molded using two or three part cavities. The more complex pieces will have slides that move in and out to create overhangs or holes. The injection molding will be outsourced so only an initial investment needs to be put in for the creation of the molds. For the polyurethane foam core, a permanent mold will be made and casted. Finally, the fur will be hand sewn. Accessories will range from fully plastic pieces to fully cloth pieces. These will either be injection molded ABS or hand sewn fabric. The main electronics are ideally consolidated onto a printed circuit board. Additional electronics such as motors, sensors, and speakers can all be bought from outside vendors. Once all the individual components are made, everything will be hand assembled.

Table 5-1: Manufacturing costs.[2]

Injection Molding		
Object	**Amount**	**Unit Price**
Mold and machine	Fixed amount	$129,924.00
Body	50k	$1.43
Base	50k	$0.88
Foam & Fur		
Foam insides & fur outsides	60k	$3.00
Electronics		
Electronics	40k	$8.50
Accessories		
Rotating Male Connector	100k	$0.28
Stationary Male Connector	50k	$0.31
Servo housing	100k	$0.53
Sensor housing	50k	$0.69
Servo	100k	$2.00
Sensor	50k	$1.00
Total	**1 Peluchi base**	**$16.08**
Total	**1 Servo Attachment**	**$3.60**
Total	**1 Sensor Attachment**	**$2.57**

[2] Injection molding quotes from: http://kazmer.uml.edu/software/javacost/index.htm. Polyurethane foam and plush quote from: http://www.cusomplushtoys.com.

The different major components are organized into their manufacturing processes in the previous table. Assuming that the parts would be outsourced to plastic and foam manufacturers, we estimated the cost through quotes from different vendors.

5.2 Market Analysis

The market for robotic toys is a lucrative one. The personal and lifestyle robotics market, which includes robotic toys, is predicted to grow greatly in the next few years. The Japanese Robotics Association estimates a growth up to $15 billion dollars by 2015 [4] and ABI research predicts that it will top $19 billion by 2017 [1]. When looking solely at the market for toys, it can be noted that although most of market suffered from the economic downturn, toymakers witnessed an increase in sales of robotic toys [3]. Additionally, there was an increase in the market for robotic toys between 2007 and 2008 when the revenues went from $11 million to $93 million.

Pricing is a difficult issue especially in the toy industry, where targeted users are unable to pay for their own toys. As such, any toy must dually appeal to both the parent and the child, which makes it necessary to approach pricing in three different ways: cost-based, customer-based and competition-based.

The cost based approach considers our manufacturing cost, and as a general rule of thumb, pricing at approximately triple to quadruple the manufacturing cost is advised – this gives us leeway to consider other costs such as selling through a distributor, who would then take a portion of the profits. This would put our costs at approximately $50 - $65.

With a fickle market, however, we also need to consider the customer, and how much they are willing to pay. As children tend to quickly tire of a toy, many parents are wary to spending a lot on a toy, especially with younger children. For a six-year-old child, a common toy on the more expensive end might be a Tickle Me Elmo, which is priced at $30. It is reasonable to expect, then, that parents may not want to spend more than about $30 when it comes to buying a toy for a six-year-old child. For a nine-year-old child, parents may be more inclined to spend a bit more: a Furby costs around $60.

Figure 5-2: Priceline of popular robotic toys on the market.

Examining the competition, toys are priced at anywhere from $10 to $300 as shown in the above figure. Our team, therefore, suggests pricing the base unit for Peluchi at a relatively low price with a minimal profit margin, and gaining the bulk of our profits from the accessories. This would allow parents to "test" the system before fully committing to it: they would pay a relatively low price for the base, which would attract more customers. An older child might want more complexity in her toy and therefore buy more accessories, while a younger child might be happy enough with the base before growing older and asking for accessories. This is similar to the Build-A-Bear model, where the stuffed animal itself can be priced at $10, while clothes sell for up to $50. By pricing the base unit low, we would hope to gain many customers in our first few years, and with a toy that is a new concept, the initial market education is important – customers are unused to the idea of a programmable plush toy, so many might be wary of committing $60+ on a foreign idea.

The bare Peluchi would have two motors and one speaker, making it a toy similar to current toys. However, unlike other toys at this price range, Peluchi would also come with programming capabilities and software. For this extra degree of complexity, we feel that pricing her around $25 dollars is reasonable.

Looking at the current robotics toy market, $25 is a reasonable estimate to price the base unit for Peluchi. Once again, the base unit would include the body, wheeled base, and speakers. Accessories would be priced from $10 to $40. Assuming a child has on average, 5 accessories (say, a pair of arms, a pair of wings and three sensors) the total amount spent would be $25 for the base and approximately $125 on accessories, or $150 total, while the costs would have been $16 for the base $20 for accessories, or $36 total. This is how our cost-based analysis would ultimately be resolved, since this leads to our desired quadrupling of costs to selling price.

After looking annual sales from different robotic toys, we can conservatively estimate that around 50,000 units will be sold a year. Ultimately, the business model that we would like to most closely resemble will be that of Build-A-Bear and to that end, one possible means of entry would be by strategically aligning with them: we share a similar customer base, pricing strategy and philosophy of "customizing" a toy. They are widespread through the US and have a strong name and network. While a toy stores target children of both genders and ages toddlers through tweens, Build-A-Bear has a strong connection with their audience and their "customer profile" is a ten-year-old girl. Our toys are also reaching a similar segment, and instead of risking alienation with possible customers by going the "tech route" (through Radio Shack or with LEGO Mindstorms), we feel that we could better exploit our market niche by marketing to all young girls, instead of a sub-segment who may already be interested in science and technology.

It should be noted, then, that our robot would not be branded a "tech" toy or a "geek" toy. Especially at the start, this is too risky of a branding image to go with, as it risks alienating both parents who are not interested in technology, and girls who may not yet realize that robotic toys can also be made for girls. This is a subtlety of the toy: it is an interactive toy that allows girls to be creative and add personality to a cute toy; it is a "new age" toy that is a natural progression from Neopets or the Sims. For more technologically-savvy parents, however, this is clearly a tech-oriented toy, so we are not excluding them by presenting a "softer," less analytical side of the toy, but there is no need to alienate customers who may not have prior inclination to tech-based toys.

Chapter 6

Conclusion

6.1 Summary of Work

With the completion of the beta prototype, we were able test the concept of modular accessories. The robotic toy took on a very different look this time and the increase in functionality added to the initial play value. Unlike the initial prototype, the beta prototype sacrifices to two degrees of freedom in the base unit to allow the addition of the accessories. This reduces the complexity of the internal framework and allows more customization to the toy both aesthetically and functionally. The internal structure could also be made much more robust, and worries about foam or fur getting caught in the joints were eliminated.

This prototype also had many more improvements in its fabrication as well. The aesthetics were greatly improved with the custom casting of the foam. The interface between the user and the actual robot itself was also improved with the addition of a battery pack and accessible switches. Unlike the previous version, the user would never have to see the inner workings of the robot to use it. An actual caster wheel was also added and the two wheels on the base were moved forward to fix the previous issue with balance.

The current prototype also exhibited areas for improvement and refinement. Specifically, the electronics presented several issues. The extensive amounts of wire and soldering and resoldering created problems with functionality. Loose wires and faulty electrical connections resulted in the failure of sensors and servos from time to time.

Lastly, the use of audio jacks for the electrical connections was not as ideal as we would have hoped. The audio jacks had a press fit of their own and that added extra force to the design for our connectors. Additionally, the jacks tended to come out of the connectors even with epoxy after extended usage. The resulted in the jacks being stuck in the base while the connectors themselves had disengaged. This created a messy situation with the wires and made it very difficult to remove the jacks.

Ultimately, the programming interface did not change much, but the variety and functionality were greatly increased. If time had permitted, playtesting would have been very valuable.

6.2 Future Work

There is a lot of potential for future work with the robotic toy project. Though this prototype extended the functionality and took the original concept in a new direction, it only serves as a foundation for where the project could go.

In pursuing the next prototype, refinements would be made to the electronics to reduce the number of extraneous wires and parts. A custom printed circuit board would definitely be something worth considering, as it would help to minimize the product and consolidate everything. This would prevent problems with loose wires and shorting.

Additionally, something different would be pursued for the electrical connections. For example, it might be worth looking into a way of incorporating the electrical connections into our customized connector designs. This would help to eliminate the sticking issue experienced with the audio jacks now. It would also bring the prototype closer to the manufacturing design.

The internal framework could be shrunk down so that more foam can be used to provide greater cushioning. In the current model, the ABS housing has a lot of empty space. Additionally, the servo houses could be redesigned to better hide the servos and blend into the robot better. The accessory design for the arms and wings can be modified to be more robust as well.

In expanding on the current prototype's design, we could consider incorporating more sensors into the design. Also, we could look into making the sensors stackable so that multiple sensors could be used. This would require us to look into increasing the power through the use of a battery pack or something rechargeable. Different servos could also be used that are more reliable and quieter.

More focus on the software is essential in moving forward with the project. The concept for a programmable robot for girls has received a lot of positive reception. The aesthetics, play potential, and customizability have all been explored, but the software has not been developed thoroughly. This would involve possibly exploring different microcontrollers that may allow for more complex programming and a different language to create the GUI or somehow interfacing the Basic Stamp language to pre-existing interface such as Scratch. Extensive user testing should be done with the interface's design and programming capabilities.

With some minor improvements in a new prototype and more focus on the electronics and software, Peluchi has the potential to become a viable product in the robotic toys market. It differs from the current products on the market and would serve as effective tool in introducing the basics of programming and robotics to young girls. Hopefully, by providing them with this fun and creative outlet to do so, it will help to successfully stimulate and foster an interest in science that will last with them as they get older.

Appendix A

Interference Fit Design Spreadsheet

In designing our connectors, we varied our parameters and used a spreadsheet associated with Alex Slocum's *Fundamentals of Design* [6], to ensure our choices were within reason. It let us look at the interference pressure, the resulting safety factors, and the stresses present.

Table A-1: Joint Interference Fit worksheet used in the design of the connectors:

Joint_interference_fit.xls
By Alex Slocum
Last modified 4/16/07 by Alex Slocum, with thanks to Xue'en Yang, Stephen Jarman, Richard Blakelock, Alexandra Nelson, Kurt McMurtrie
Clearance and pressure in shrink-fit bodies
***Enter numbers in* BOLD.** Results in RED

Loads			Interference parameters			Equations Ref
Torque to be transmitted (N-mm)	torque	**0**	Interference interface pressure to cause yielding in inner body (N/mm2)	Pobmax	33.18	
Axial force to be transmitted (N)	force	**2**	Interference interface pressure to cause yielding in outer body (N/mm2)	Pibmax	9.35	
Coefficient of friction	mu	**0.2**	Maximum interface pressure (interference fit causes yielding)	Pimax	9.35	
Operating temperature (°C)	ot	**20**	Minimum required interface pressure (N/mm^2)	rPI	0.04	
Rotation speed (rpm)	rpm	**0**	Differential Poisson radial interference due to axial force (mm)	ddp	-4.82E-05	1
Outer body input parameteres			Differential thermal radial expansion (mm)	ted	0.00E+00	2
Outside diameter (mm)	obod	**22.098**	Outer body rotating inner diameter radial displacement (mm)	robd	0.00E+00	3
Inside diameter (mm)	obid	**9.390**	Inner body rotating outer diameter radial displacement (mm)	ribd	0.00E+00	4
Plus tolerance (mm)	obptol	**0.0254**	Total additional diametrical interference amount to be added (to ibod) (mm)	addi	-9.65E-05	
Minus tolerance (mm)	obmtol	**0.0254**	Interference fit calculations (assumes addi has been added to ibod)			
Outer body stress concentration factor	obscf	**1**	Maximum diametrical interference (mm)	maxdelta	1.86E-01	(See diagrams)
Modulus of elasticity (N/mm^2)	obe	**2.90E+03**	Maximum resulting interface pressure (N/mm^2)	maxip	8.88E+00	5
Yield strength (N/mm^2)	obsy	**60**	Minimum diametrical interference (mm)	mindelta	8.41E-02	(See diagrams)
Poisson's ratio	obn	**0.38**	Minimum resulting interface pressure (N/mm^2)	minip	4.02E+00	5
Coefficient of thermal expansion (1/°C)	obcte	**2.34E-08**	Minimum safety margin (min obtained pressure/required pressure)	msmp	90.36	
Density (g/cm^3)	obrho	**1.21**	Maximum sustainable torque (N-mm)	maxt	1.87E+03	
Inner body input parameters			Minimum sustainable torque (N-mm)	mint	8.48E+02	
Engagement length (mm)	L	**7.620**	Maximum torque limited by interference fit causing yielding	yieldt	1.97E+03	
Outside diameter (mm)	ibod	**9.525**	Minimum safety margin (min obtained torque/required torque)	msmt	#DIV/0!	
Inside diameter (mm)	ibid	**7.76244**	Outer body material stresses at maximum interface pressure			
OD if to compensate for rotational expansion (mm)		9.525	Radial displacement of inner surface (mm)		2.62E-02	6
Plus tolerance (mm)	ibptol	**0.0254**	Radial press-fit stress at ID (N/mm^2)	obsr	-8.88E+00	7
Minus tolerance (mm)	ibmtol	**0.0254**	Circumferential press-fit stress at ID (N/mm^2)	obsc	1.28E+01	8
Inner body stress concentration factor	ibscf	**1**	Axial stress from applied axial Force (N/mm^2)	obsz	6.36E-03	9
Modulus of elasticity (N/mm^2)	ibe	**2.90E+03**	Shear stress from applied Torque (N/mm^2)	obtau	0.00E+00	10
Yield strength, obsy (N/mm^2)	ibsy	**60**	Max radial centrifugal stress (N/mm2)	obrc	0.00E+00	
Poisson's ratio	ibn	**0.38**	Max circumferential centrifugal stress (N/mm^2)	obcc	0.00E+00	11
Coefficient of thermal expansion (1/°C)	ibcte	**2.34E-08**	Max Von Mises stress (N/mm^2)	obvm	1.89E+01	12
Density (g/cm^3)	ibrho	**1.21**	Resulting safety factor (yield stress)/(scf*Von Mises stress)		3.181	
Shrink-fit design			Inner body material stresses at maximum interface pressure			
Desired assembly clearance at deltaT (mm)	ddt	**0**	Radial displacement of outer surface (mm)		-6.67E-02	13
Required differential temperature if heating outer body (°C)	robdt	8.45E+05	Radial press-fit stress (N/mm^2)	ibsr	-8.88E+00	14
Required differential temperature if cooling inner body (°C)	ribdt	8.33E+05	Circumferential press-fit stress (N/mm^2)	ibsc	-4.40E+01	15
Press-fit design			Axial stress from applied axial Force (N/mm^2)	ibsz	8.36E-02	16
Maximum assembly force to press fit (N)	Fpfmax	3.99E+02	Shear stress from applied Torque (N/mm^2)	ibtau	0.00E+00	17
Minimum assembly force to press fit (N)	Fpfmin	1.81E+02	Max radial centrifugal stress (N/mm^2)	ibrc	0.00E+00	
			Max circumferential centrifugal stress at ID (N/mm^2)	ibcc	0.00E+00	18
			Von Mises stress at ID (N/mm^2)	ibvm	5.29E+01	19
			Resulting safety factor (Yield stress)/(sff*Von Mises stress)		1.134	

Evaluate the stresses at inside, outside and sqrt(DiDo) diameters					
For the outer body					
case 1: stresses at inner radius	4.695000	case 2: stresses at outer radius	11.049000	case 3: stresses sqrt(DiDo)/2	7.2024340
Radial press-fit stress (N/mm^2)	-8.876011		0.000000		-2.6469048
Circumferential press-fit stress (N/mm^2)	12.787631		3.911620		6.5585253
Axial stress from applied axial Force (N/mm^2)	0.006364		0.006364		0.0063638
Shear stress from applied Torque (N/mm^2)	0.000000		0.000000		0.0000000
Radial centrifugal stress (N/mm2)	0.000000		0.000000		0.000000
Circumferential centrifugal stress at ID (N/mm^2)	0.000000		0.000000		0.000000
Von Mises stress at ID (N/mm^2)	18.862274		3.908442		8.207027
For the inner body					
case 1: stresses at inner radius	3.881220	case 2: stresses at outer radius	4.762500	case 3: stresses sqrt(DiDo)/2	4.2993384
Radial press-fit stress (N/mm^2)	-0.000001		-8.876011		-4.8904875
Circumferential press-fit stress (N/mm^2)	-52.857080		-43.981071		-47.9665939
Axial stress from applied axial Force (N/mm^2)	0.083573		0.083573		0.0835729
Shear stress from applied Torque (N/mm^2)	0.000000		0.000000		0.0000000
Radial centrifugal stress (N/mm2)	0.000000		0.000000		0.000000
Circumferential centrifugal stress at ID (N/mm^2)	0.000000		0.000000		0.000000
Von Mises stress at ID (N/mm^2)	52.898915		40.338147		45.766313

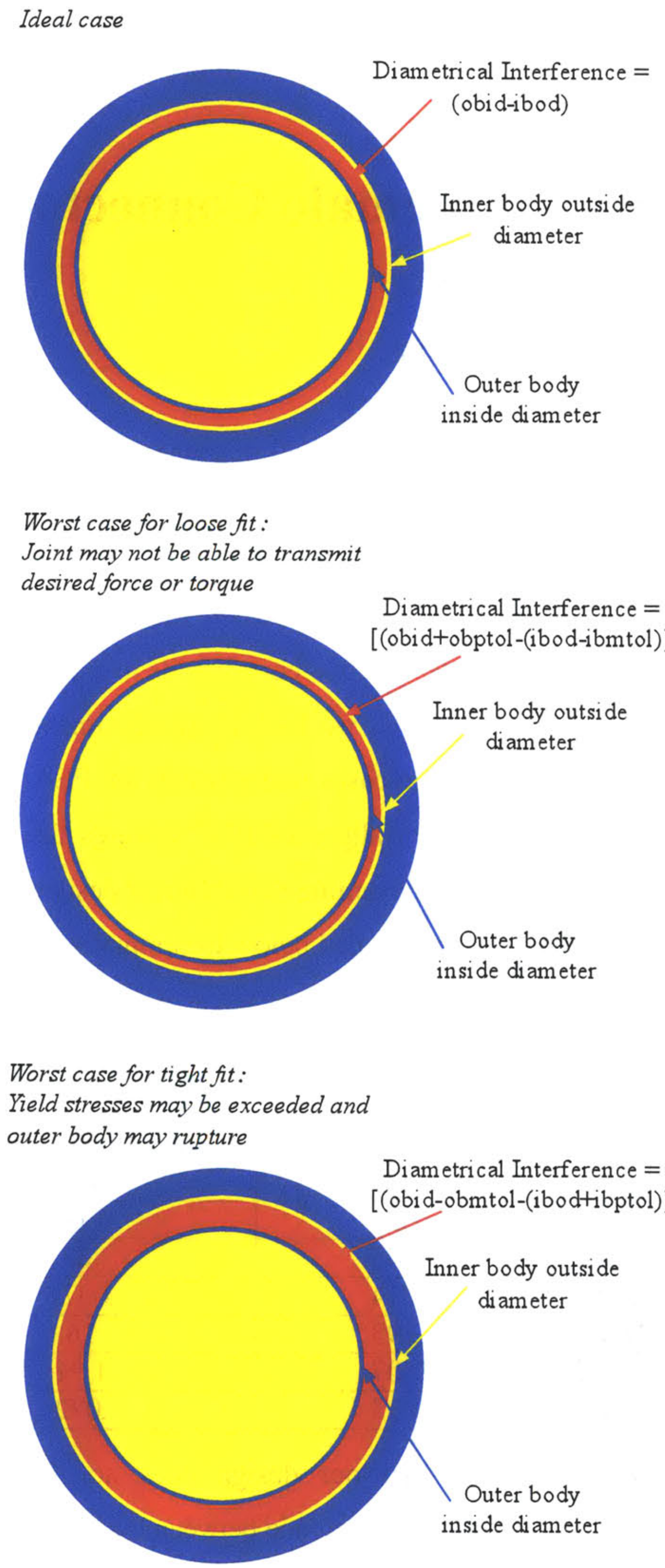

Figure A-1: Interference fit cases: (1) ideal, (2) loose fit, and (3) tight fit.

Appendix B

FEA Analysis of Female Connectors

B.1 Summary of Analysis

Since our design relied on a press fit and not all machines are perfect, we needed to take into account worse case scenarios due to these tolerances. A finite element analysis was done in SolidWorks for the Maximum Material Condition to examine stresses, deflection, and resulting safety factor. MMC refers to the state where the shaft is at its largest and the hole is at its smallest. For our particular design, this corresponds to a shaft diameter of 0.380" and a hole diameter of 0.360". Under MMC, we look at misalignment, which could occur from tolerance issue. This resulted in three cases under which the FEA was done: (1) misaligned 0.014" away from the center, (2) misaligned 0.014" towards the center, and (3) perfectly centered. Furthermore, we wanted to examine two different designs—a fully solid design and hollowed out design. Table 4-1 is duplicated below to summarize the results:

Table 4-1: FEA results. All cases examined under MMC press fit with smallest hole at .365" and largest peg .380". Case 1: *Pair is misaligned 0.014" away from the center. Case* 2: *Pair is misaligned 0.014" towards the center.* Case 3: *Centered.*

Case		**Max Von Mises Stress (GPa)**	**Max Displacement (mm)**	**Safety Factor**
Hollow	**Case 1**	2.96	1.63	8.6
	Case 2	1.05	.22	24.7
	Case 3	.014	.0071	1810
Solid	**Case 1**	2.93	16	8.7
	Case 2	1.07	1.91	23.3
	Case 3	.013	.072	1870

From the FEA, we determined that our design does not fail under these scenarios. Furthermore, there is not a significant difference between the two designs, but we chose to go with hollow design because the amount of deflection is minimized.

B.2 FEA of Hollow Connector

B.2.1 Hollow Case 1: Misaligned 0.014" Towards Center

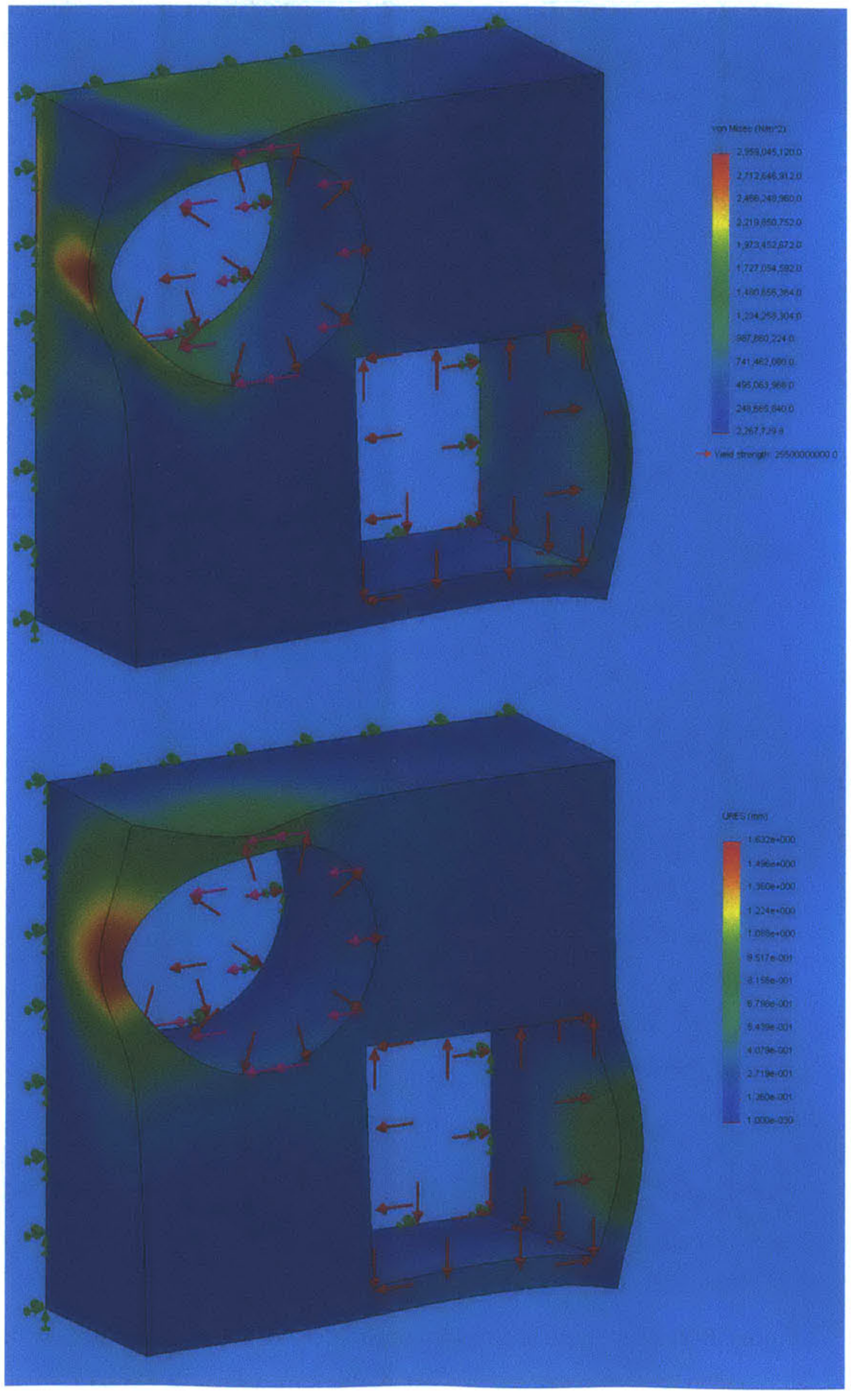

Figure B-1: FEA stress and displacement plots for Case 1 of the hollow design.

B.2.2 Hollow Case 2: Misaligned 0.014" Away From Center

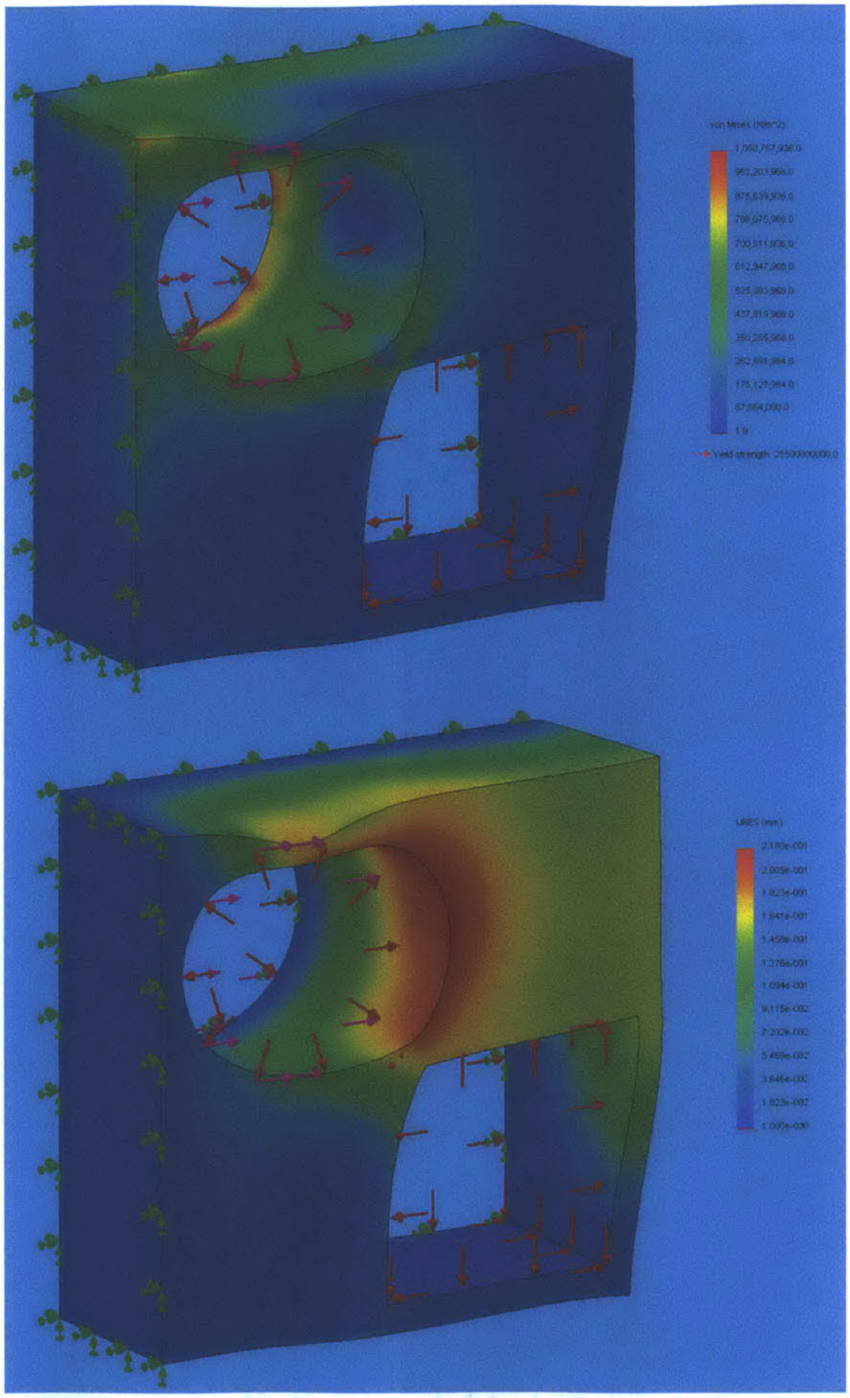

Figure B-2: FEA stress and displacement plots for Case 2 of the hollow design.

B.2.3 Hollow Case 3: Centered

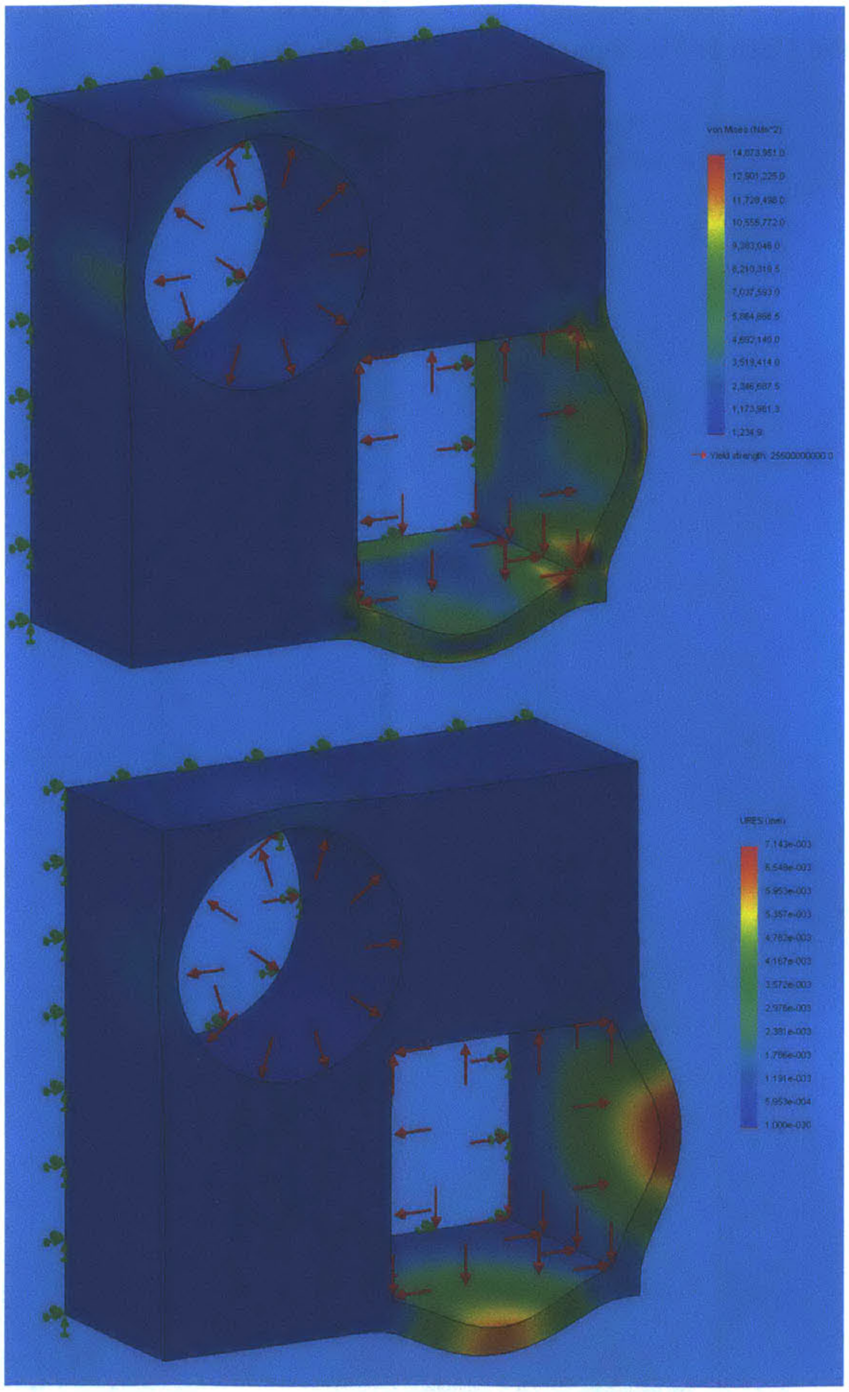

Figure B-3: FEA stress and displacement plots for Case 3 of the hollow design.

B.3 FEA of Solid Connector

B.3.1 Solid Case 1: Misaligned 0.014" Towards Center

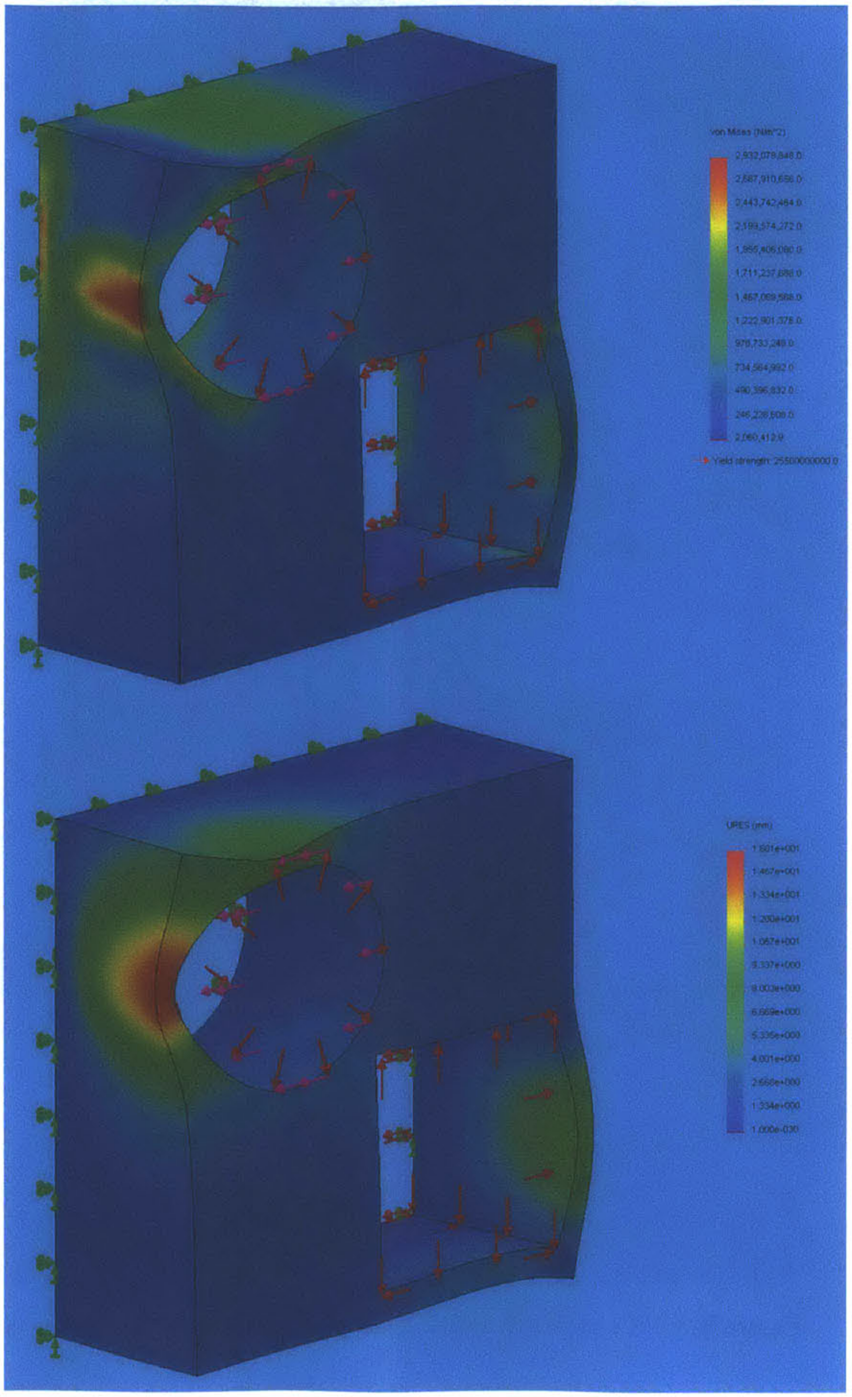

Figure B-4: FEA stress and displacement plots for Case 1 of the solid design.

B.3.2 Solid Case 2: Misaligned 0.014" Away From Center

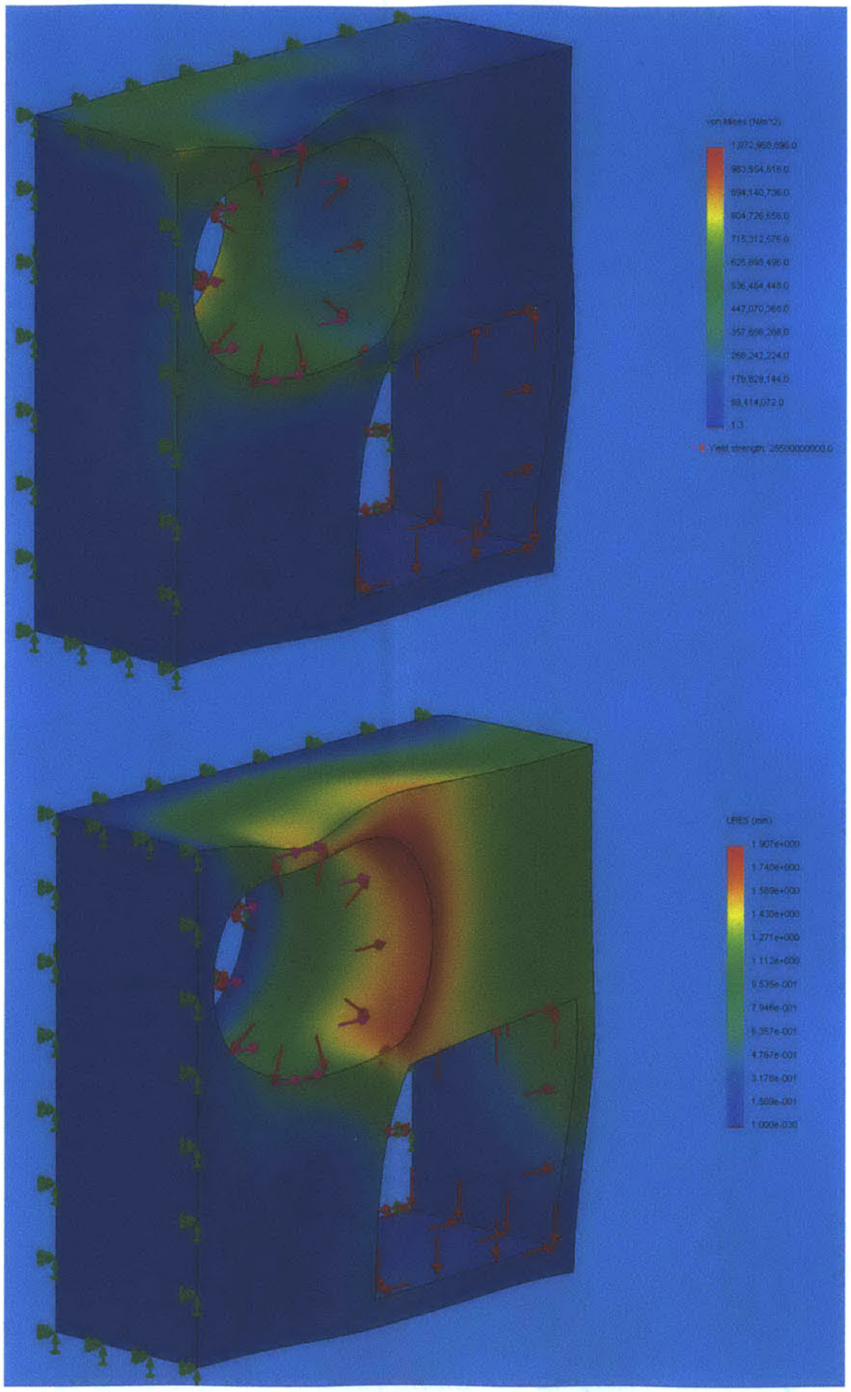

Figure B-5: FEA stress and displacement plots for Case 2 of the solid design.

B.3.3 Solid Case 3: Centered

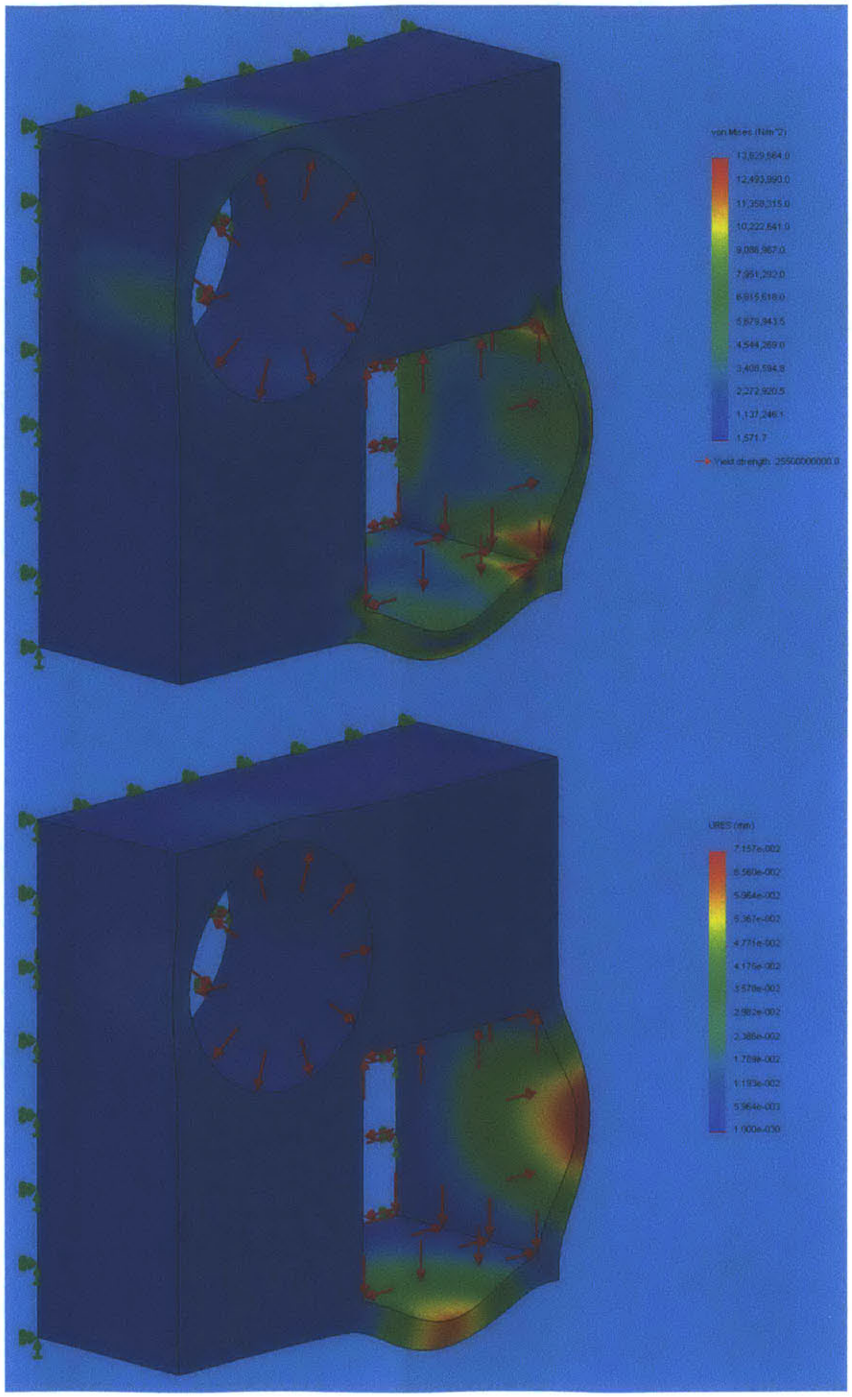

Figure B-6: FEA stress and displacement plots for Case 3 of the solid design.

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