Advanced Mechanical Design, University of Rochester
Final Design Report
Spring 2022

RADIATION TREATMENT PLATFORM FOR STRONG HOSPITAL

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ABSTRACT

The Strong team created a bed attachment for the Strong Memorial Hospital to use with the CT scan and Irradiation machines to allow technicians to rotate lying patients 180 degrees without requiring the patient to move themselves. This attachment needs to fit into both machines. Every time the bed attachment is locked in, it must remain within 2 mm of the previously established 0- and 180-degree settings. This project serves as the conclusion to ME205: Advanced Mechanical Design and gave the Strong team opportunities to practice all aspects of the design process.

PROBLEM DEFINITION

Patients receive radiation therapy treatment at Strong Memorial Hospital for various medical conditions. Total body irradiation (TBI) therapy is a treatment necessary for a limited number of patients, an average of 12 people a year at the URMC, that would benefit from a simpler and more accurate procedure for their treatment. While the treatment requires the whole body to be accessible, the current bed only allows the machine access from the head to the top of the legs at most, so if the rest of the body were to be treated the patient would be required to get up and rotate themselves. However, due to the nature of the treatment the dosage needs to be exact and having the patient get up and move themselves is too imprecise. The current method for TBI treatment at the hospital involves having the patient lie down across the room with the radiation machine pointed at them. This method allows the machine to dose the whole body at once; however, using this method dilutes the dosage and makes precise dosage harder to calculate for the doctors than if the patient were directly under the machine. This method also has the side effect of exposing certain healthy tissue to unnecessary radiation. Designing and creating a rotating bed attachment for the current couch setup will allow all patients undergoing total body irradiation therapy to receive high quality treatment without having them move, by having technicians rotate the table 180 degrees to treat the second half of the patient.

REQUIREMENTS, SPECIFICATIONS, DELIVERABLES

For this project, the team is creating an assembly of five distinct parts to create a final deliverable of a rotating bed attachment. The 5 parts making the final deliverable are the bottom bed/table attachment mechanism, the locking mechanism, the rotating mechanism, the latching mechanism, and the top bed. Additionally, the team will also deliver a final report and an operation manual. The main deliverables are:

1. Rotating Bed Attachment for couch
2. Testing Documentation/report
3. Theory of operation manual

The main requirements for the rotating table attachment are:

- Material used must be invisible to X-Ray
- Must be manually operated by two people
    - Operated meaning it can be assembled and attached/detached from the couch
- Must safely support the weight of human plus a safety factor
- Must attach securely to the couch
- Must fit patients that otherwise would fit on the couch

The main specifications for the table attachment include:

- Must lock into position at 0 and 180 degrees (with tolerance of 0.11 degrees) rotation around normal axis through center of the couch
- Must support a downwards force of 155 kg or 340 lb. distributed along the surface of the couch attachment without material yielding
- The top table must have a width of 535 mm (tolerance of +25/-25mm)
- The top table must have a length of 2160 mm (tolerance of +50/-50 mm)

CONCEPTS

Table Attachment: Part of the structure that will connect and secure the rotating bed to the couch already present in the hospital

o Requirements: cannot damage the table, must be designed to be removable and re-attachable.

o Concepts (refer to Table 1: Table Attachment Pugh Matrix):

- Index Bars
  - o Create non-metal copies of Lok-Bar currently used as the base of the radiation table.
  - o These index bars use off-center cylinders that rotate and lock into the semi-circular holes along the sides of the couch.
- Phone Case
  - o The lower piece of the radiation table would be held onto the couch surface using silicon or other rubbery material grips that would stretch around the edge of the couch and then close on the other side, like a modern phone case.
- Index Bars Over
  - o Use index bars just as with other index bar concept except this time make them taller and use them to go over the bottom of the table and hold it down from the sides when it attaches to the table.

Aspect: Table Attachment

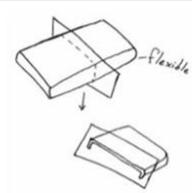
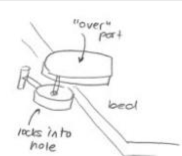
Concept	Baseline: Nothing	Index Bars	Phone Case	Index Bars Over
Sketch	[nothing]			
Simplicity	0	-2	-2	-2
Estimated Cost	0	-1	-2	-1
Test Complexity (est.)	0	+1	-2	+1
Build Complexity (est.)	0	+1	-2	+1
Fit	0	+2	+2	+2
Complexity (# of parts)	0	-1	0	-1
Safety	-2 [none]	+2	+2	+2
Durability	0	+1	-1	+1
Assembly	0	-1	-2	0
Total	-2	+2	-8	+3

Table 1: Table Attachment Pugh Matrix

The table attachment has evolved since the decision shown by the Pugh Matrix. Fearing that machining into the soft composite interior would harm the structural integrity, the material of the bottom bed was changed to ultra-high molecular weight polyethylene (UHMWPE) because it is easy to machine and free for the team. Due to this change in material, the table attachment mechanism was designed to be part of the bottom bed. Replicating the mechanism used by the index bars, two holes were placed/made at either end of the bed to locate the first of three locking mechanisms. To accommodate the tolerance issues that might be caused by machining with the ShopBot, the locations of the other two locking mechanisms were manufactured as slots instead of holes. The cam locks were connected to these slots and holes via glue and pressed pins to secure the bed to the couch.

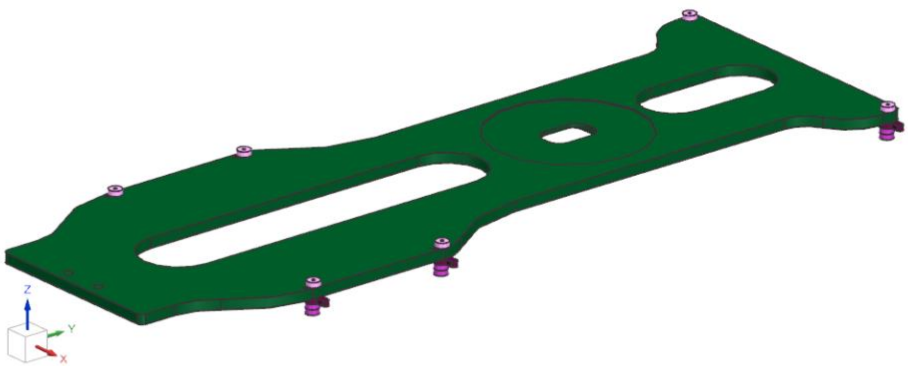


Figure 1: CAD of Table Attachment/Bottom Table

Locking Mechanism:

- o Requirements: no metal, must be easy to use by two operators
- o Concepts (refer to Table 2: Locking Mechanism Pugh Matrix)
  - Medieval Doors (slides)
    - o Bars or blocks that can slide through the width of the table from the side and stop rotation
  - Side stoppers
    - o Similar to the medieval doors idea except these stoppers would not go through the entire width of the table, they just fit into cut out pockets on the side.
  - Corner pins
    - o Holes will be drilled in the corners of the table that would allow locking pins to be dropped in and pulled out as necessary.

Aspect: Locking Mechanism

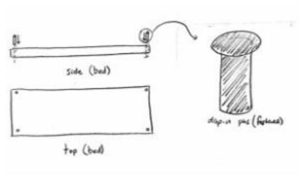
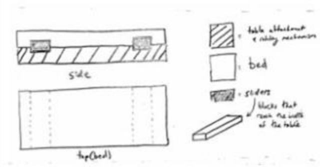
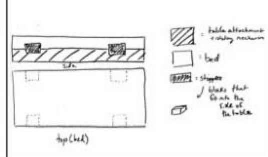
Concept	Baseline: Corner Pins	Medieval Doors	Side Stoppers
Sketch			
Simplicity	0	-1	-2
Estimated Cost	0	+1	+1
Test Complexity (est.)	0	+1	0
Build Complexity (est.)	0	-1	-1
Support	0	+2	+1
Fit	0	+1	+1
Complexity (# of parts)	0	+1	0
Ease of Operation	0	-1	-2
Total	0	+3	-2

Table 2: Locking Mechanism Pugh Matrix

Initially, the team decided on medieval doors as it was a novel idea that would allow for easy and precise locking. After brainstorming with Professor Muir, several potential problems were identified: it would be difficult to push the "doors" into the channels while holding onto the end of the table, the composite material should not be machined into, and wear on the "doors" by the sharp internal edges would affect the reliability of the locking mechanism (not within tolerance). As a result, the team moved to a pinhole locking mechanism where there is a vertical block on one end of the bottom bed with a horizontal pin that will fit into a hole on either end of the top bed. This would allow the bed to rotate freely and lock at 0 and 180 degrees. There are two parts to this design. First is the semi-circle ends that attach to the composite and protect the softcore while allowing the pin to stop the table. The second is the vertical block and pin (figure 2). After several rounds of concepts, the team decided to go with a friction lock pin so that the locking mechanism could still work precisely after minor wear and tear. The large, tapered pin will be pushed and then turned as the locking pin will climb the ramp and lock into place. The angle of the ramp was calculated based on Newton's second law and friction testing conducted on the material.

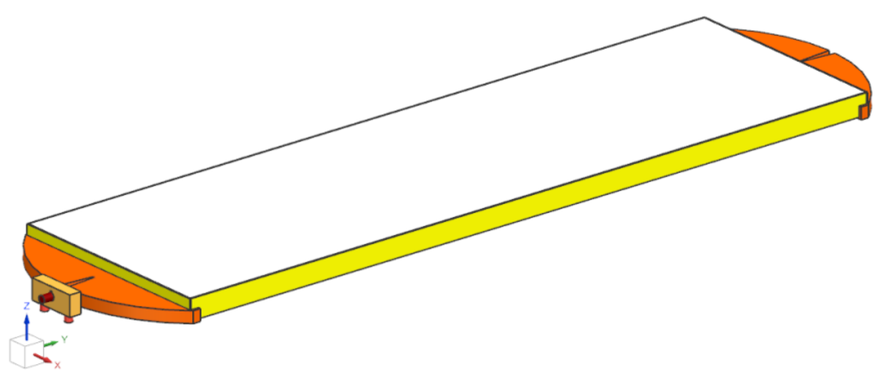


Figure 2: CAD of Locking Mechanism & Top Bed

Rotating Mechanism:

- o Requirements: no metal, durable, as thin as possible
- o Concepts (refer to Table 3: Rotating Mechanism Pugh Matrix):
  - Texas
    - o This is the concept implemented by the team at UTSW which has a thin flat core that has pockets for rollers oriented radially out from the center point.
  - Vertical Texas
    - o This concept is derived from the Texas idea by putting the rollers on the side of a vertical cylinder that the table lays on top of. The table would have a cut out slot that fits over this vertical core and contacts the rollers in the horizontal direction.
  - Slanted Texas
    - o This concept combines the vertical and original Texas ideas by having conic rollers on a sloped surface (a trapezoid if cut down the middle). Angle to be determined by analysis.
  - Cat Toy
    - o This concept takes inspiration from a common cat toy. It has a circular track that holds in plastic balls that the table can roll on as it rotates.
  - Open Ball Bearing
    - o Similar to the cat toy design, but this concept leaves the top of the mechanism open to reduce manufacturing complexity. During operation, the ball bearings would not be able to fall out due to the downward force from the table itself as it rests on top of them.
  - Gears/Pulleys
    - o Obtain mechanical advantage using combinations of cranks and gears or cranks and pulleys to rotate the center of the table using a low amount of force.

Aspect: Rotating Mechanism

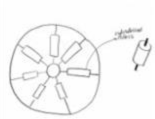
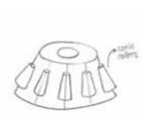
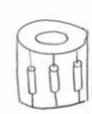
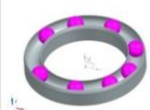
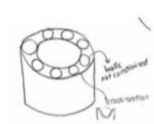
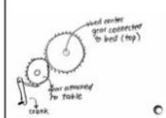
Concept	Baseline: Texas	Texas Slanted	Texas Vertical	Cat Toy	Open Ball Bearings	Gears/Pulleys
Sketch						
Simplicity	0	-1	-1	+1	+1	-2
Estimated Cost	0	0	0	+2	+2	-1
Test Complexity (est.)	0	0	0	+1	+1	-2
Build Complexity (est.)	0	-1	-1	+1	+2	-1
Support	0	+2	-1	-1	-2	-2
Fit	0	+2	+2	0	0	-2
Complexity (# of parts)	0	0	0	+2	+2	-1
Total:	0	+2	-1	+6	+4	-12

Table 3: Rotating Mechanism Pugh Matrix

The Pugh Matrix helped the team decide on the "cat toy" design, essentially an open-ended ball bearing with a lip so the balls would not fall out. While this idea was creative, it raised some issues when it was time for manufacturing. The lip was hard to manufacture and not worth the effort. The lip was eliminated and a lid with a track matching the bottom piece was added to be attached to the underside of the top bed. This modification allowed the top and bottom to rotate freely. Once constructed and assembled, another problem was discovered. While testing, the balls appeared to bunch up resulting in unequal weight distribution on the bottom piece and potential choppy motion/rotation. To resolve this issue, a race was laser cut to ensure even spacing between all the balls. Final CAD drawing of the RM assembly is shown below (figure 3).

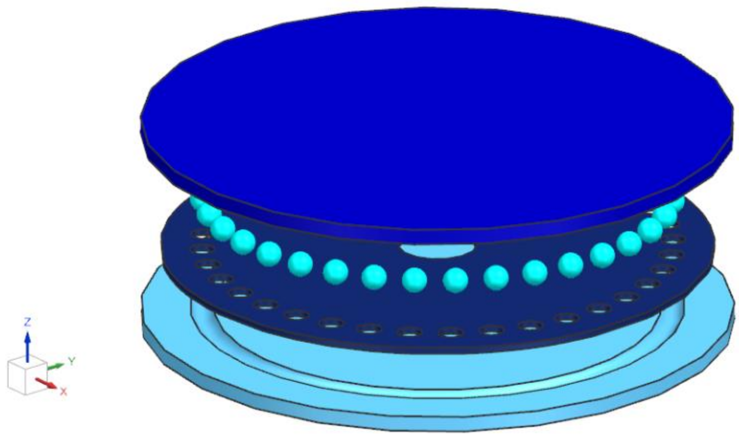


Figure 3: CAD of Rotating Mechanism

After a meeting with Dr. Matt Webster, the idea of sideboards was scrapped as they served little mechanical purpose and deemed unessential to the project. Sideboards would just add weight to the assembly and an unneeded cost and complexity to the project.

With no metal allowed in this design, much of the bonding relies solely on adhesives. This problem birthed the idea of a latching mechanism (figure 4). This internal system attaches the top table to the bottom table, keeping the assembly together in the event of a patient getting up mid procedure or some unseen force tipping the top bed, while not interfering with the rotating mechanism. The mechanism, seen in bright green, has a rectangular bottom that can fit in the rectangular hole in the bottom bed (dark green) only when oriented at 0 and 180 degrees. The latching mechanism rotates with the top table and when the top table is rotating the rectangular holes no longer align. This will keep the assembly together while rotating even in the presence of an unknown force.

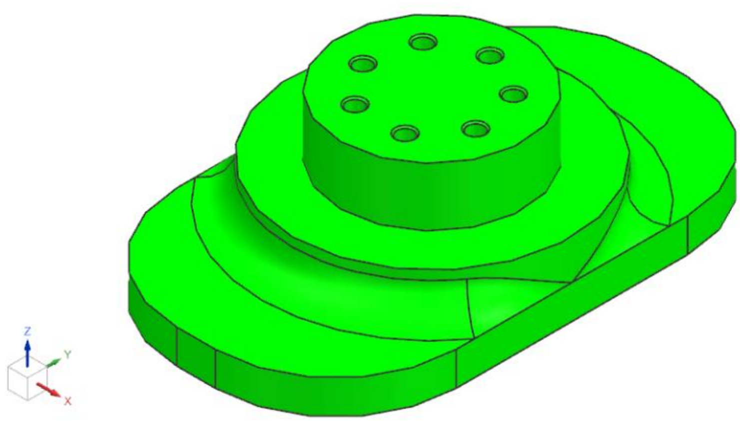


Figure 4: Latching Mechanism CAD

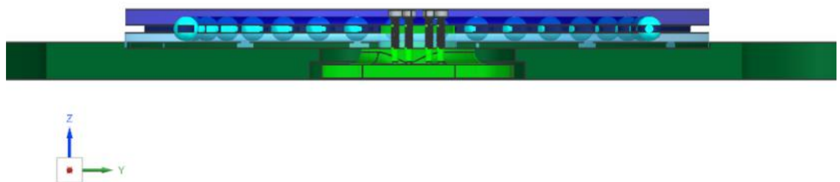


Figure 5: Section view of CAD of Latching Mechanism Assembled with the Rotating Mechanism

MECHANICAL ANALYSIS

The tolerance analysis was conducted to see if the locking mechanism would still be operational under a worst-case scenario. This analysis spans several internal systems. Combining the possible offset of the peak of the tapered pin slot to the center of the top bed, the rotational mechanism glued improperly, the placement of the locating pins (for the locking mechanism) on both the bottom table and the locking block, and placement of the locking pin on the tapered pin. In the worst-case scenario, all errors are summed to show the additional vertical distance the locking pin must climb up the ramp. For all parts manufactured by Bill Mildenberger, a tolerance of 0.001in (or 0.0254mm) was placed. This is a fair estimate as he is a master machinist. For parts created by the team a tolerance of 0.05in (1.27mm). The sum of these tolerances is 3.86mm. Using Pythagorean's theorem, a maximum ramp height of 6.885mm using a diameter of 39.05mm and an angle of 10 degrees, the assembly passes tolerance analysis as the maximum height of the ramp exceeds the worst possible error.

Dimension	Description of Dimension	Tolerance (mm)
D1	Top table edge of pin slot to center of table	1.27
D2	Rot Mech glued off center	1.27
D3	Placement of locating pins on bottom table	1.27
D4	Placement of locating pins on locking mech	0.0254
D5	Placement of lock pin on the tapered pin	0.0254

Worst Case	3.8608
Max locking Position	6.8855

Table 4: Tolerance Analysis (one pager found in appendix)

Finite element analysis in Siemens NX software was used to simulate and understand the stresses present in the locking mechanism during worst-case situations. A reasonable worst-case scenario involved an operator applying force to rotate the top bed without unlocking and disengaging the locking mechanism pin. This was represented by applying a horizontal force of 50 lbf. on the tapered end of the pin, fixing the base of the locking mechanism block (as it is glued to the bottom bed), and applying surface contacts at all applicable locations. For this analysis, the displacement of the pin was not of peak importance. While it did slide forward in the slot, the donut grip at the back of the pin did not come into contact with the block. More importantly, the stresses experienced by the assembly were compared to the known failure stresses of acrylic (the material used for all parts of the locking mechanism). The peak stress in the system was less than 26 MPa, while the yield strength of acrylic is at least 65 MPa [1]. This gave the team confidence that no aspect of the locking mechanism would fail during any reasonable operation or worst-case scenario. This analysis did not consider the possibility of the parts being dropped, crushed, or handled in some other unpredictable way that could lead to a force greater than 50 lbf being applied.

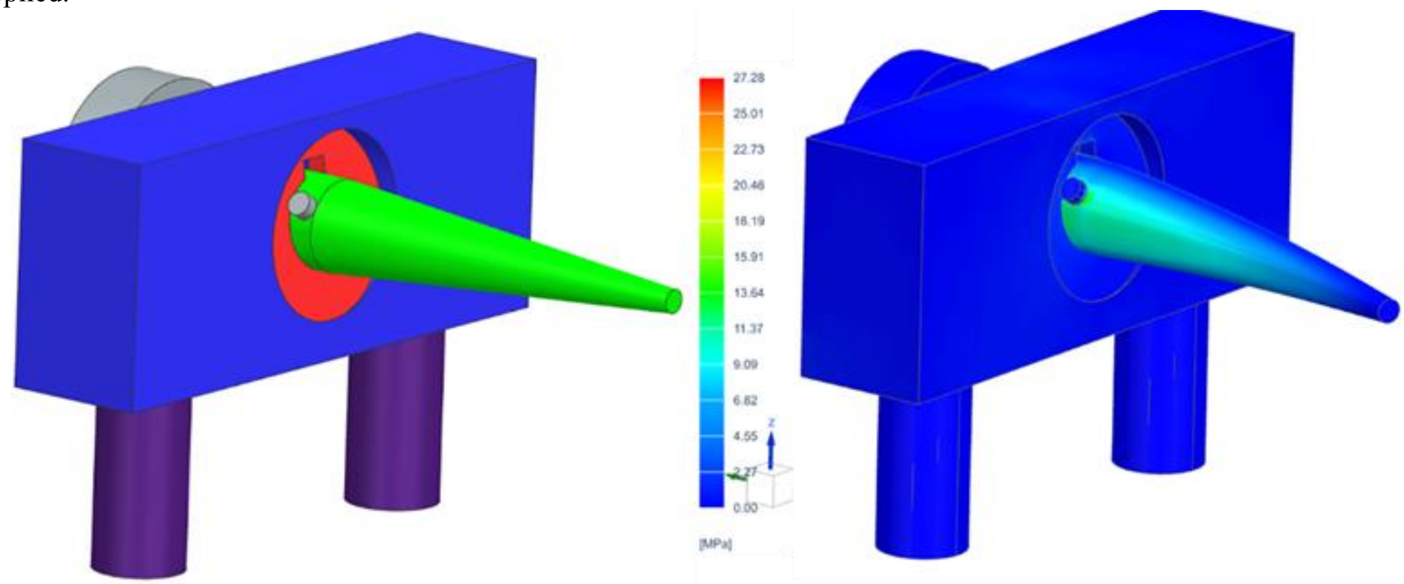


Figure 6: Latching Mechanism CAD

See appendix A1 for a one-pager of this analysis.

Standard handwritten/MATLAB analyses were used to inform the team's understanding of the stresses and forces experienced by the balls in the rotating mechanism. First, a statics analysis was undertaken to determine how the number of spheres used in the design affects the normal force experienced by each sphere. Then, that calculated force was used in a contact analysis to understand the maximum contact stress experienced by the balls. To plan for a worst-case scenario, the team assumed that the balls only contacted the track they ran in at their base while still being close to the size of the track. To simplify the analysis, it was assumed that the table distributed the overall load equally between the balls and that the socket was spherical. The results gave the team confidence that the materials chosen would not yield. Other assumptions and the detailed analysis can be found in Appendix A2.

As the pin in the locking mechanism is tapered, any horizontal force on the table will lead to a force component that pushes the pin out of its tapered slot. Therefore, the team needed a solution to keep a passive force on the pin that held it in its slot, unless disengaged by an operator. The method used was to incorporate a friction lock, where the pin can be rotated and have a smaller knob that sticks out of it and contacts the ramp, creating a normal force pointing into the slot. The intended angle of the ramp was to be 10 degrees, and in order to confirm the efficacy of this angle, a small friction lock test was performed.

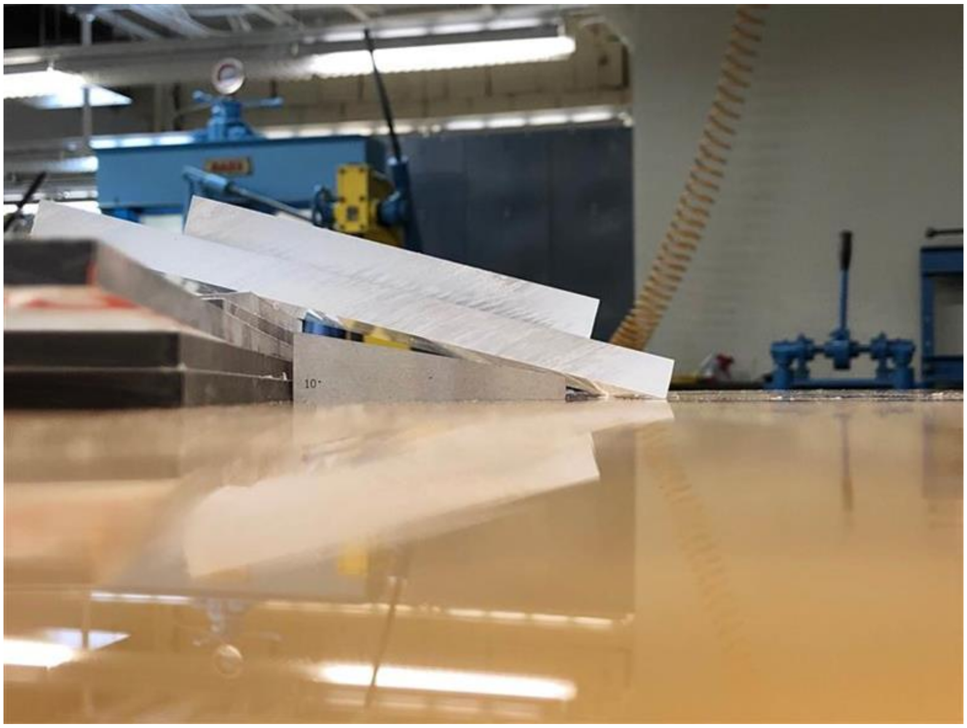


Figure 7: Friction Test

The test resulted in the understanding that the coefficient of static friction between two pieces of acrylic is *at least* tan(10) = 0.17. Values from the internet range from 0.5-0.6. This gave the team confidence to push on with a ramp design of 10 degrees so that the lock could be engaged by an operator but remain static on its own.

MANUFACTURING

The balls for the rotating mechanism were purchased from McMaster. Torlon PAI balls were the strongest plastic balls available from this provider and their strength was verified with an in-house compressive test using the MTS machine. The top and bottom track of the rotating mechanism were CNC milled by Bill Mildenberger out of acrylic, because it is easy to work with and its strength passed verification based off finite element analysis performed for these components. The top track's holes were tapped to allow for connection with the latching mechanism. The race for the rotating mechanism was laser cut using acrylic since it is easy to laser cut. The latching mechanism piece was CNC programmed and machined by Professor Muir on the HAAS machine. To completely assemble the RM, #8-32 Glass filled Nylon screws were placed through the top track of the RM and into the latching mechanism.

UHWMPE was used to manufacture the bottom table with the 3-axis CNC ShopBot. The material is heavier than other plastics used in the project, however it was made available to the team for free and the assembly still met the overall weight goal with this component.

The top bed was manufactured by cutting a large sheet of fiberglass Plastic Honeycomb composite into two identical layers using a table saw. These layers were then glued together using 3M Scotch-Weld DP 100 Plus and left to cure for 48 hours.

The table attachment pins were cut from an acrylic pin since it is light, cheap, and easy to cut.
All the cylinders for the table attachment mechanism were laser-cut out of acrylic. The cylinders were then glued together in a stack and the holes were rimmed to size using a mill since the laser cut holes' tolerance is not low enough to have a

press-fit with the acrylic pin. The table attachment pieces were assembled by pressing the pin into the holes and then connecting this stack into the bottom bed's locating holes by pressing and gluing the pins.

The locking mechanism was made of acrylic since it is cheaper than alternative materials like polycarbonate and it passed the FEA load cases without plastically deforming. The locking mechanism block was cut to size and drilled using a mill and the locking pin gap was broached. The ramp was CNC milled and then solvent welded to the block. Two acrylic locating pins were turned on the lathe to get the right fit and pressed into the locking mechanism block. The block was then glued to the bottom bed via the locating holes in it. The tapered pin of the locking mechanism was first milled to locate the hole for the locking pin. It was then turned on a lathe to achieve its shape. Finally, an acrylic pin cut to size from stock was glued into the hole to give the tapered pin assembly its final shape. The locking mechanism semi-circle pieces were CNC milled and glued onto either edge of the top bed. All components of the LM were manufactured by Bill Mildenberger.

Once the team had designed the rotating table and acquired the materials, the manufacturing process only took about 3 weeks. However, if this project were scaled up to be the production of 1000 rotating beds, it would be extremely beneficial to simplify the manufacturing process where possible. The most time-consuming aspect of creating some of the larger parts, like the locking mechanism semicircle boards, the latching mechanism, and the rotating mechanism, was creating the CNC code. If the project was scaled up significantly, the CNC code would be the same for all the parts, and the efficiency of production would mainly depend on the time for setting up and running the code. On the other hand, there are parts that are handmade in the assembly such as the milled locking block and pin, and the top bed. The top bed requires special blades to cut and glue two fiberglass composite slabs. All in all, the process of cutting the top table to length and gluing took about half an hour with 2 people. The more significant time constraint would be in the time left to cure, which is currently around two days. The locking mechanism parts could possibly be redesigned in order to make them mass producible; however, a lot of time and effort went into designing the current locking mechanism as it affected the team's most restricting specification. The table should not be able to move more than 2 mm laterally, and if this specification is kept for the mass production of 1000 rotating tables, the locking mechanism would logically be the piece that would have the tightest constraints and would require the most time to manufacture. Therefore, redesigning it to be mass producible would be extremely difficult and expensive. Otherwise, the rest of the rotating table could be put together in a few days with the right resources. Materials would have to be sourced but are not hard to acquire, though specific machinery is important to the manufacturing of this product.

The team compiled total hours worked and manufacturing/material cost in order to estimate total cost of the project. The materials altogether measured in at $879. This is $121 under the specified budget of $1000 for this project. The team estimates that Bill Mildenberger spent about 15 hours working on manufacturing this project, which at a cost of $50 an hour adds up to $750. By the project's completion, the team will have spent an estimated 635 hours on research, design, manufacturing, testing, and organizing. At a rate of $100 an hour, this is $63,500. This leads to a total estimated cost of the project of $65,128.

TEST PLAN AND RESULTS

To ensure the completed table will satisfy all requirements, there are a series of tests that the team will conduct. First, to ensure the table will fit into the CT machine, there are certain length and width requirements (Width: 535mm (+25mm/-25mm), Length: 2160mm (+50mm/-50mm)). Initially the requirement for the maximum width of the table was set to avoid interference between the completed table and the CT machine, but this maximum was increased to allow for the locking mechanism to have a solid bond with the composite tabletop as the bond with the soft internal material is softer. After a meeting with the mechanical team at UTSW it was determined the width of the bed could be much larger as their new design is and have recorded no interferences with the CT machine. The tolerance for length is much looser as it is less important for the fit, but more for ensuring the bed can rotate without obstruction. To test these tolerances, the team will measure the table from the correct drawing datum. The current bed structure has a weight limit of 450 pounds, but with the addition of the table attachment the maximum patient weight will be less. An American man in the 99th percentile for weight is 340 pounds (~155 kg). Lastly, the locking mechanism must have an extremely tight tolerance as any fluctuation in position during the procedure could negatively affect the patient. This tolerance of the gantry is 2mm so using Pythagorean's theorem (and distance from center of rotation mech to end of the table) the angle was determined to be 0.11 degrees. According to Dr. Webster, this device will be used on about twelve patients a year. This means that it will be rotated about 25 times a year (once to get patient into position and once back). To ensure the locking mechanism satisfies this tolerance, the team will rotate the bed 50 times meaning rotate 180 degrees and lock into place and measure the angle using an angle locator after each rotation.

Currently the team is in the process of assembling the completed table and will be spending the week testing. The top table is completed and is within the length and width specifications. Regarding the table displacement requirement, the team placed the top composite bed on a wooden support that resembled the rotational mech in size, then recorded displacements of each corner after two team members (~290 lb. combined) and six jugs of water (8.48 lb. each) totaling approximately 340 lb. This load covered the entire surface area of the table. The maximum deflection was 7mm. Regardless of that slight deflection, the material was not close to yielding thus satisfying the team's specification. If the assembly were to come up short, there are some ways to increase stiffness in the final days. Attaching bars of polycarbonate to the sides of the composite will increase the stiffness of the bed whilst also giving a nice finish to the bed. Another option is to attach thicker bars of HDPE along the bottom of the top bed to increase the stiffness. An update here is needed to include the results of the team's rotational testing. If this were to fail the requirement, one option is to include simple pins in the corner that will provide stable locking but will be slightly more difficult for the technicians to operate while supporting the patient. This idea stems from the latest version of the Texas' team rotating table.

INTELLECTUAL PROPERTY

The original concept design is based on the rotating table designed and built by a team located at the University of Texas Southwestern. The project's sponsor at Strong Memorial Hospital, Dr. Webster, first asked the Strong team to contact this group in Texas to replicate the product they had made. The team met with project leaders from the original rotating table in Texas, where they learned the general concept of the Texas rotating table but could not be told any measurements or numbers due to liability issues. The Texas design consisted of two tables connected by a central cylinder block which allowed the top table to rotate due to the low friction coefficient of the material used: polyethylene. While the Strong team saw this design as a good place to start, they saw many places to improve upon the original design, instead of delivering the same product to Strong Memorial Hospital. Primarily, the Strong team saw improvements to be made to the rotating mechanism. Relying on a low coefficient of friction material was not as reliable as other methods of allowing rotational movement while keeping axial movement fixed. The Strong team designed a "lazy-susan" type mechanism, composed of two acrylic tracks and a few dozen small plastic balls sandwiched between the two tracks, which would allow these two caps to rotate freely. While the concept of a "lazy susan" is already patented and so is ball-bearing rotation, the team's investigations have shown that there are no patents submitted combining the two to create a medical bed attachment to rotate patients without them moving [2] [3]. The most similar patent the team found was one where a ring gantry moved around the patient, a major difference being that the table where the patient lies remains completely still [4]. The Strong team believes that a patent could be submitted for the final rotating bed attachment. Regardless, the team has not taken any further steps towards a patent as they feel that anyone should be free to pursue better treatment for their patients. The team is encouraged to think that others would like to reproduce their design. The Strong team would intend to support future similar projects as the Texas team supported this project.

SOCIETAL AND ENVIRONMENTAL IMPLICATIONS

For this project, the team designed and built a simpler and more accurate rotating bed attachment to be used during irradiation therapy at Strong Memorial hospital. Completion of this project would significantly reduce unnecessary radiation exposure to patients as well as the amount of time required to treat each patient since the setup time will be shortened. This will enable patients and members of the community to receive access to better- and high-quality treatment. It will also reduce health concerns or complications that might occur as a result of unnecessary radiation exposure to healthy organs that need to be shielded from radiation during treatment. Lastly, because each patient's treatment will take less time, the

Radiation Oncology* team at Strong Hospital would be able to treat more patients.

This project will support the use Volumetric Modulated Arc Therapy (VMAT) Technology which is used to treat prostate, head, and neck tumors, as well as a range of cancerous tumors. Irradiation therapy can cure cancerous tumors, stop, or reduce their growth, or prevent them from recurring. Depending on the type of tumor, this type of treatment has a high success rate in the majority of cases. This treatment relies on the use of photons (W-rays), generated by a medical linear accelerator, to damage the tumor tissue. The bed attachment that the team built will ensure that the irradiation is precisely focused to the area needing treatment, thereby reducing damage to normal tissue. In comparison to traditional static field intensity modulated radiotherapy (IMRT), VMAT can provide additional benefits such as shorter treatment delivery time. One downside of radiation therapy is that during treatment there is a higher chance of healthy cells being exposed to radiation. This chance is increased due to the current procedure used without a rotating bed attachment. Patients can also develop mucosal inflammation and reddened skin because of treatment, but this is extremely rare. Nausea and diarrhea could also result from radiation treatment of the gastrointestinal area.[5]

The materials used for different parts of the bed attachment had high compressive and structural strengths and satisfied the constraints of the requirements and specifications. Although these materials had great features that were necessary for the success of this project, some could be detrimental to the environment. Plastic honeycomb, which is made of PET foam and fiberglass, was used to manufacture the top table. Fiberglass production releases hazardous air pollutants and volatile organic compounds such as styrene. These emissions could have a negative impact on the environment and nearby communities. Studies have also shown that inhaling particles of fiberglass could irritate the alveoli, aggravate asthma and bronchitis, and may cause lung cancer. [6]

The team used acrylic to manufacture the rotating mechanism and locking mechanism. Although it is non-toxic in solid form, acrylic production emits greenhouse gases such as carbon dioxide and carbon monoxide which are harmful to the environment. It is also non-biodegradable which could result in water pollution if it ends up in rivers or oceans. Due to the low quantity of materials used in this project, the team does not foresee any noticeable negative environmental effects due to the production process without the project being scaled up significantly. [7]

RECOMMENDATIONS FOR FUTURE WORK

Moving forward, the team would do some of the things differently to ensure timely and accurate completion of the project. First, a special mixing nozzle, instead of hand mixing, would be used with the epoxy when gluing the composite beds. Additionally, priority would be given to the parts that took a lot of time to manufacture such as the latching mechanism, rotating mechanism and the locking mechanism. The team would also try to schedule more visits to the hospital to ensure the parts being made fit perfectly to the existing couch attachment. An additional feature would be adding adjustable sideboards so that the patient can feel secure during treatment. The team was advised against making any adjustable components as the Clinical Engineering Team at Strong stated the holes could easily fill with bodily fluids and be hard to clean.

ACKNOWLEDGMENTS

This project owes its thanks to Dr. Matthew Webster, Professor Christopher Muir, Mr. Bill Mildenberger, Ms. Christine Pratt, Mr. Jim Alkins, Ms. Anna Remus, and the UT Southwestern team.

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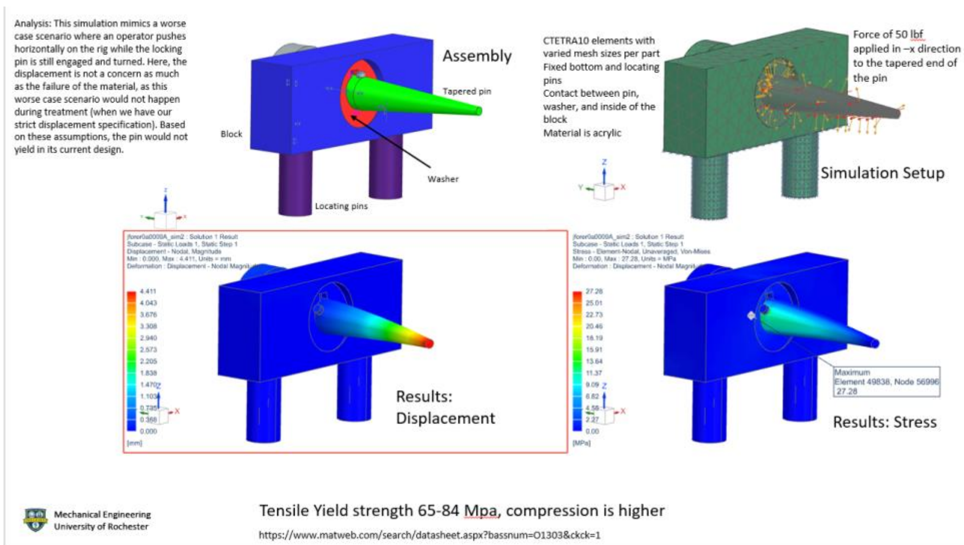
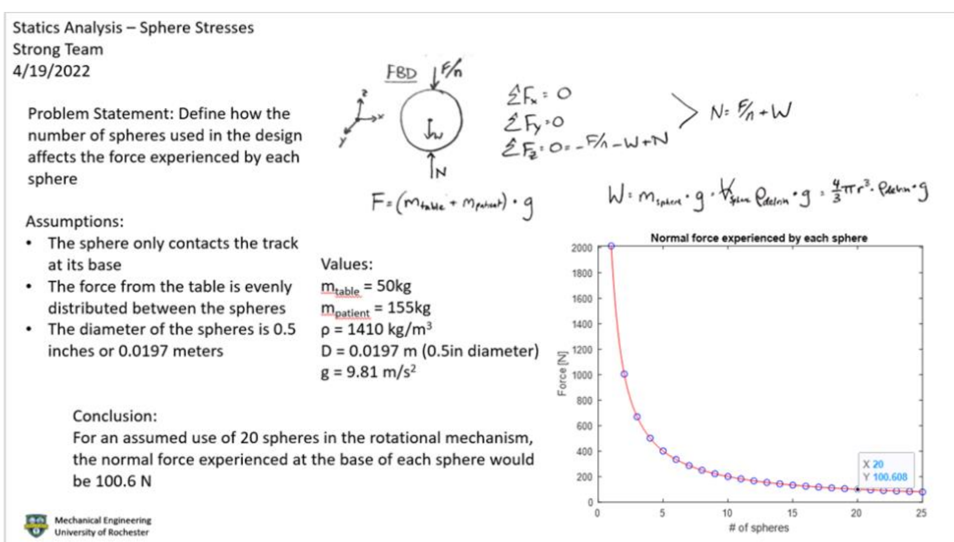
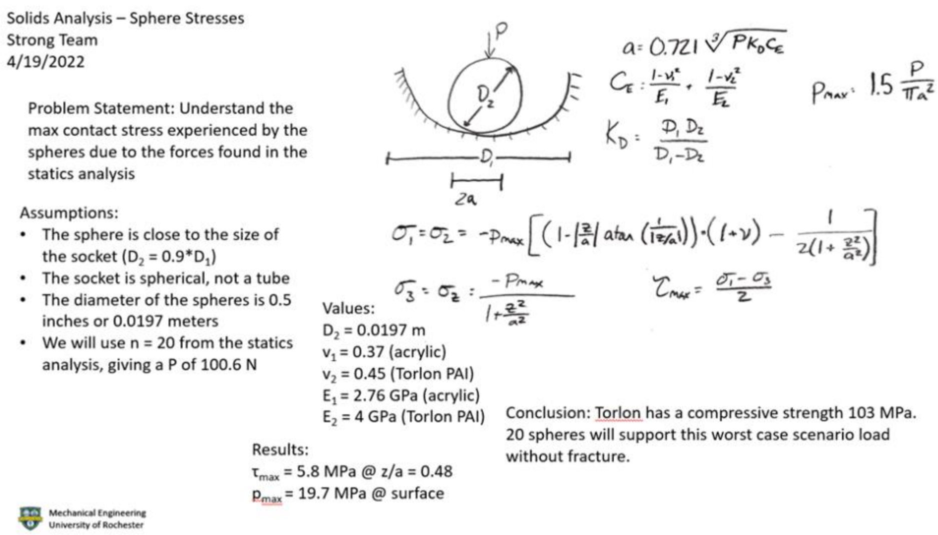
APPENDIX



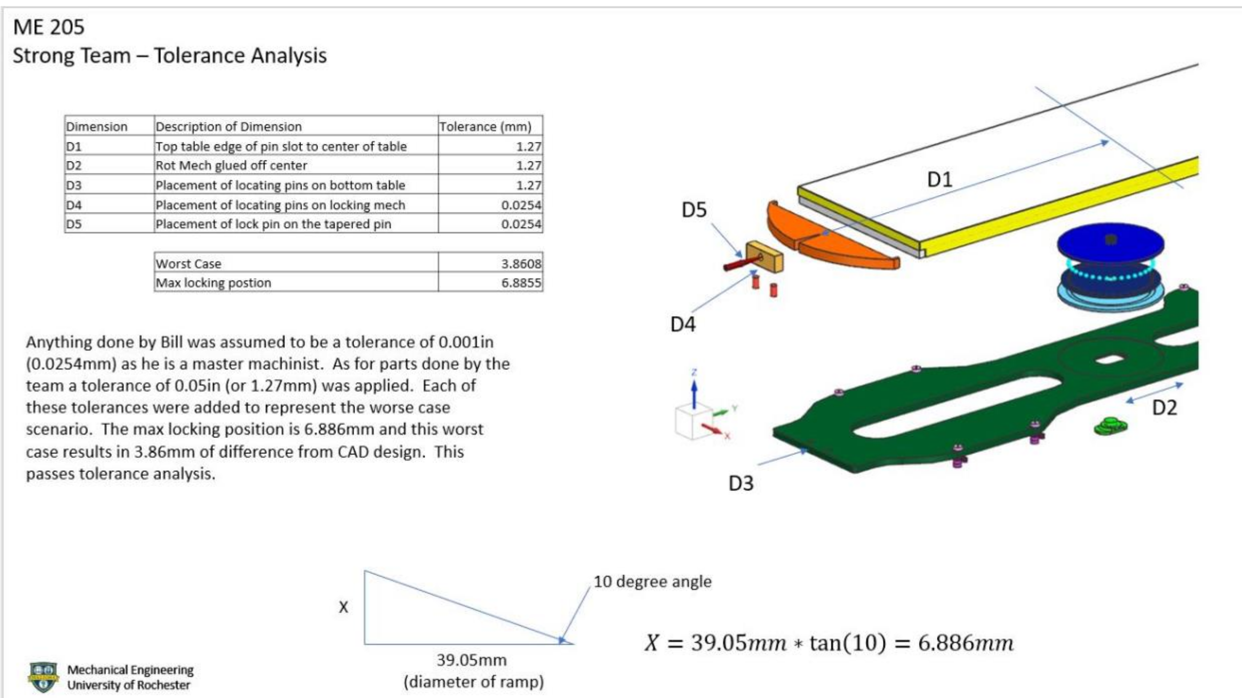
Appendix A1, LM FEA One Pager



Appendix A2, Statics Analysis



Appendix A3, Solids Analysis



Appendix A4, Tolerance Analysis

Section	Writer	Reviewer 1	Reviewer 2
Abstract	Jarod	Shira	Carol
Problem Definition	Jarod	Shira	Carol
Req/Spec/Deliverables	Jarod	Shira	Carol
Analysis	Jarod	Shira	Carol
Manufacturing	Lale	Carol	James
Test Plan	James	Lale	Carol
IP	Shira	Jarod	James
Societal/Environmental	Carol	Lale	Jarod

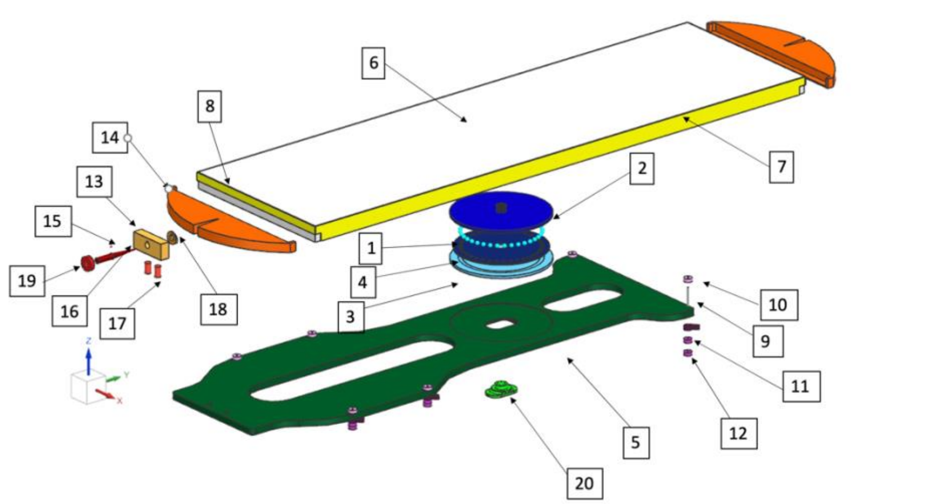
Future Work	Shira	Jarod	James
Appendix	All	All	All
Concepts	James	Lale	Carol

Appendix B, Review Process (all drafts can be found in the Strong Teams Channel: files>GateD>Drafts and will be organized by student ID)

Part Number	Assy	Part Name	CAD File Name	Quantity	Image
1	RM	ball	shersch_0c0001A	36	
2	RM	top track	shersch_0c0002A	1	
3	RM	bottom track	shersch_0c0010A	1	
4	RM	race	lyilmaz0_0c0001A	1	
5	bed	bottom table	shersch_0c0003C	1	
6	bed	top bed	shersch_0c0013A	2	
7	bed	long side lining	lyilmaz_0c0007A	2	
8	bed	short side lining	lyilmaz_0c0008A	2	
9	TA	TA pressed pin	tableAttach_0c0005A	6	
10	TA	centered cylinder	tableAttach_0c0002	15	
11	TA	off-center cylinder w/ handle	tableAttach_0c0004	3	
12	TA	off-center cylinder w/o handle	tableAttach_0c0003	6	
13	LM	LM block	jforer_0c0004C	1	
14	LM	LM semicircle	jforer_0c0001C	2	
15	LM	LM tapered pin	jforer_0c0002A	1	
16	LM	LM locating pin	jforer_0c0008A	1	
17	LM	LM lock pin	jforer0c0006A	2	
18	LM	LM ramp	jforer_0c0005A	1	
19	LM	LM donut	jforer_0c0011A	1	
20	LM2	latching mech center	shersch_0c0014A	1	

RM: rotating mech
LM: locking mech
LM2: latching mech
TA: table attachment
Bed

Appendix C: Spreadsheet with .prt names and actual names corresponding to file showing exploded view of the assembly



Appendix D: Exploded View with parts labeled