University of Manitoba

Price Faculty of Engineering

MECH 4860 - Engineering Design

Optimization and Automation for the Murphy Bed

Final Design Report

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Date of Submission: Dec. 7, 2022

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Dear Insert Name:

From the members of Team 5, we are honored to present our final report entitled "The Optimization and Automization of a Murphy Bed", to Dr. P. Labossiere and his associates. An electronic copy of the report was submitted on the UM Learn MECH 4860 course assignment page; the report was also submitted via email correspondence. The creation of the report was made possible due to the collaboration of the four engineering students within Team 5: Emanuel Arzobal, Paolo Endrinal, Johanna Maghirang Goot, and Josh Pries. From the members of Team 5, we are honored to present our final report entitled "The Optimization and Automization of a Murphy Bed", to Dr. Q. Peng and his associates. An electronic copy of the report was submitted on the UM Learn MECH 4860 course assignment page; the report was also submitted via email correspondence. The creation of the report was made possible due to the collaboration of the four engineering students within Team 5: Emanuel Arzobal, Paolo Endrinal, Johanna Maghirang Goot, and Josh Pries.

From the members of Team 5, we are honored to present our final report entitled "The Optimization and Automization of a Murphy Bed", to Mr. Enns and Mr. Solmundson at Wood Products Unlimited. An electronic copy of the report was provided via email correspondence. The creation of the report was made possible due to the collaboration of the four engineering students within Team 5: Emanuel Arzobal, Paolo Endrinal, Johanna Maghirang Goot, and Josh Pries.

The purpose of the attached enclosure is to provide a detailed design for the optimization and automation of an existing Murphy Bed. The report will focus on the design and analysis of a desk accessory for a Murphy Bed as well as an automation system for opening and closing the wall bed.

To corroborate the purpose of the report, three main sections are provided: the Design Methodology, the Design Overview, and the Detailed Design and Optimization. Each section was authored in collaboration of the members of Team 5.

Team 5 would like to express our appreciation and gratitude to all those involved in the process of completing this report. Thank you to Dr. Q. Peng, Dr. P. Labossiere, Professor A. Topping for the valuable feedback and guidance that helped the members of Team 5 to improve not just as engineers but also as authors. Thank you to Professor Topping's teaching assistant, Jaime Campos, for his guidance and input throughout the term. Thank you to the Mr. Enns, Mr. Solmundson, Mr. Ingimundson, and Mrs. Deleske at Wood Products Unlimited for their valuable feedback and support throughout the course of this project. Thank you to the Hunter Wire and Veracity for their valuable design inputs and considerations for this project. Furthermore, Team 5 would also like to acknowledge our cohort team, Team 6. Team 6 provided us with valuable feedback to consider during the peer review sessions. If any questions or concerns about the report arise, Team 5 will happily be available for further consultation.

Team 5 authorizes the Department of Mechanical Engineering to use our report for teaching and educational purposes.

Sincerely,
Emanuel Arzobal,

Paolo Endrinal,

Johanna Maghirang Goot,

Josh Pries,

Executive Summary

This report will present the process of design and analysis of a desk accessory that will function as a nightstand, sitting desk, lap desk and standing desk. It will also present the design and analysis for an automation system for the EMBED. The bed automation system features two linear actuators attached to tabs that are welded to the bed frame and EMBED frame. The desk accessory features a linear actuator for the vertical movement and housed in a square tube attached via hinge to the EMBED frame. A shaft inside a flange bearing facilitates rotation of the desktop. The maximum deflection for the desktop for a 60 lbf load is 3.732 mm. The total cost for the desk accessory is 622.03 CAD and the bed automation system is 568.78 CAD.

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1 Introduction and Project Overview

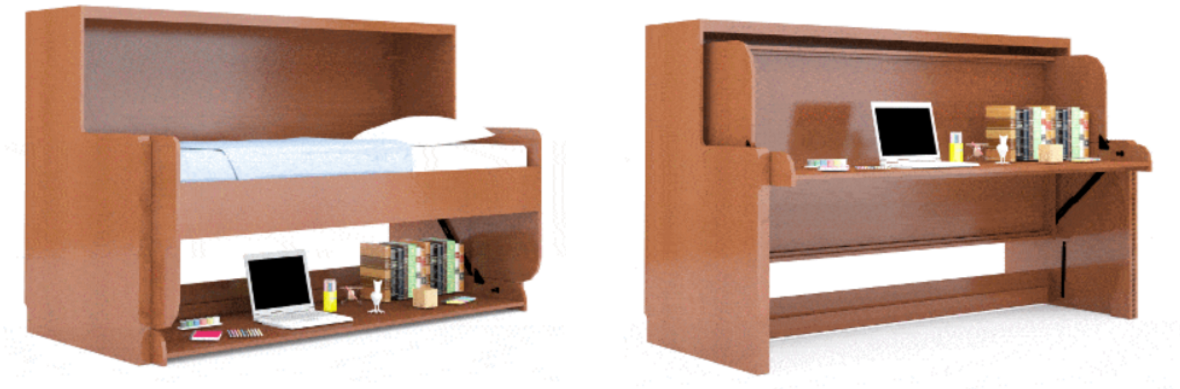
The group's client for this project is Wood Products Unlimited Inc. (WPU). Established in 2005, WPU strives to create innovative long lasting product solutions and to go beyond the limits of what is possible with furniture, modernizing residential homes [1]. WPU is a company that focuses on research and development to be able to create new ways for consumers to utilize furniture to take advantage of limited spacing and floor plans [1]. WPU is also dedicated to implementing sustainable practices and manufacturing, utilizing local and recyclable products as much as possible to reduce the company's carbon footprint.

With an impressive and extensive background in product development and design, WPU is a company with involvement in niche markets such as custom cabinetry [1]. Additionally, WPU also has over 10 years of experience with space saving furniture such as the Murphy Bed and the Hidden Bed [2]. With changing times and trends, and increasing real estate costs, WPU has designed their own innovative wall bed product, known as the Embed. Having sold and manufactured both traditional Murphy Beds and Hidden Beds in the past, WPU is setting out to the change the market for space saving furniture with the Embed; it is set to be the stepping stone for further fixed furniture designs with future iterations and designs for the Embed currently in the planning phase.

1.1 Wall Bed Background

The Murphy Bed was created in the 1900s by William Lawrence Murphy to allow him use his one room apartment as a place to also entertain guests [3]. It revolutionized the market for folding beds by implementing a pivoted and counterbalanced design and are now more commonly used for space-saving purposes [3].

As technology and science advanced, the Murphy Bed has had many different iterations since it was patented. A popular iteration of the Murphy Bed is the Hidden Bed. The Hidden Bed combines the wall bed with a permanently attached desk that can be used when the bed is hidden away, this can be seen in the Figure 1.



(a) Opened Hidden Bed. (b) Closed Hidden Bed.

Figure 1: Hidden Bed configurations [4].

WPU's Hidden Bed had operated under a 'dead-man switch' condition meaning that the consumer had to operate the automated controls until the wall bed reached their desired configuration to prevent accidents and collisions. However, when WPU was manufacturing the Hidden Bed, they had found some issues with the design. The main issue they found involved the 2 piston cylinders attached to a motor used to lift each side of the Hidden Bed [5]. They found that when items were left on the desk, it caused the pistons to become unbalanced resulting in difficulty when opening and closing the bed. Due to this issue, WPU is looking to develop a brand new desk attachment for a wall bed .

1.2 Embed Background

WPU's new wall bed design, the Embed, is constructed out a steel frame and wooden panels utilizing a modular design. The steel frame consist of steel bars that are cut, welded, and bent to appropriate length and angle by a third party company, Hunter Wire [5]. The wooden panels are manufactured in-house and require no edge work making them easily customizable to suit the consumer's preference [5]. The following renders in Figure 2 below depicts the Embed in both its opened and closed configuration.

(a) Opened configuration.

(b) Closed configuration.

Figure 2: Embed configurations [Provided by WPU].

The mechanism currently used to open and close the Embed uses custom springs, manufactured by Veracity, as opposed to piston cylinders that WPU had previously used for their Hidden Beds and Murphy Beds. Per research conducted by WPU, using a spring mechanism allowed for greater tension adjustability when opening and closing the wall bed; the process of manually opening and closing the bed became a smoother movement using the spring mechanism instead of cylinders [5].

WPU's priority with designing the Embed is the product's longevity and user safety. This is satisfied by the Embed not being a free standing unit like a Murphy Bed or Hidden Bed; instead it is built onto of the wall for further support and stability of the unit as well as to prevent the unit from potentially harming an individual in the case of an accident [5]. Moreover, the Embed's spring mechanism currently requires manual operation which can be daunting WPU's primary demographic for the Embed, the elderly and those who are looking to downsize their space. Therefore, a goal of this project is to transform the manual operation of opening and closing the bed into an automated operation so the product is safe and easy to use for all demographics.

Another difference between the Embed and the Hidden Bed is that the desk attachment can be detached from the wall bed and can be utilized when the bed is open. With the Hidden Bed, the desk attachment is hidden away and cannot be used when the bed is opened. WPU's plan for the Embed's desk attachment is that it can pivot in and out of position in conjunction with being adjustable in height so that it can used as a traditional desk, a standing desk, a lap desk, or a nightstand. With the new upcoming desk design created by the team, WPU hopes to eliminate the problem they found with the Hidden Bed and allow up to 40 lbs to reside on the desk at all times without hindering its movement. Moreover, WPU has also expressed their desire to the group of having the desk attachment be compatible with competitor's wall bed and with future iterations of the Embed.

1.3 Problem Statement

WPU has already developed a wall bed, however, the desk accessory is currently in the design and development phase and is one of Figure 3 is a top view of the client's layout for their new innovative wall bed design, the Embed.

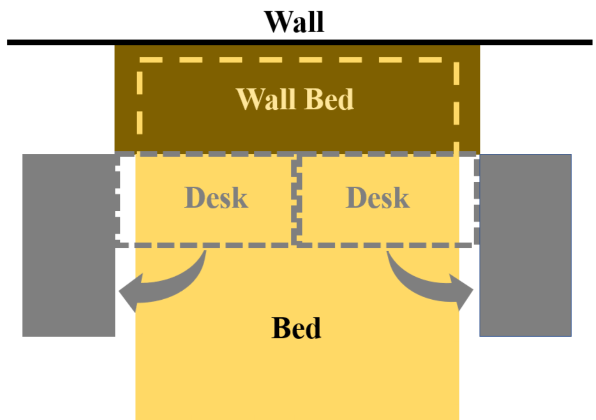


Figure 3: Top view of the wall bed layout, adapted from, and used with permission by, WPU.

The purpose of this project is to provide WPU with an innovative design for a desk accessory that is compatible with the Embed and to automate the opening and closing of the Embed to satisfy their consumer's needs and expectations.

1.4 Project Objective

The primary objectives of this project is to design a desk attachment for the Embed that can be used in multiple configurations. The secondary objective of this project is to make the process of opening and closing the Embed automated. These objective are to be met by the design team comprised of four mechanical engineering students from the University of Manitoba.

To satisfy the project objectives, the following criteria must be met:

- The designed desk attachment for the Embed can be used as a sitting or standing desk when the bed is hidden and can be used as a lap desk when the user is in the bed.
- The vertical motion of the desk attachment must be powered so that it can be controlled either electronically or manually.
- The desk attachment must allow the Embed to open and close.
- The ability to open and close the Embed is an automated motion.

- The desk accessory can be attached to, or be modified to attached to, other wall beds on the market.

1.5 Project Constraints and Limitations

The constraints depict parameters that the design must abide by to accomplish the objective of this project. The following table lists constraints and limitations that must be taken into consideration.

TABLE I: CONSTRAINTS AND LIMITATIONS

Constraints and Limitations	
Cost	• The desk accessory can be manufactured at a cost of $700 or less. • The implementation of the automation system used for opening and closing the Embed cannot exceed $500
Time	• All design documentation and drawings must be submitted to the client by December 7, 2022.
Resources	• All purchased components of the product must be sourced from within North America • Manufacturing is to be done in-house when possible
Quality	• The product must be designed to withstand a 10 year lifespan. • Product must adhere to "California Proposition 65"
Performance	• The vertical motion of the desk attachment must have a minimum range of 18" • The rotational motion of the desk must move a minimum of 90° (180° is preferred) • Attaching the desk accessory to the Embed must not hinder the opening or closing of the wall bed • The desk must be accessible while the bed is open or closed • The desktop must be at least 16" wide and 30" long • The bed will not close when the bed is occupied • The bed will not open when there is an obstacle • Controls for the automated systems are intuitive to use

WPU has stated to the team that they prefer to use and source materials that are available in North America [6]. This is to reduce their carbon emissions as a company and to ensure that workers are compensated a fair wage for their work [6]. If this is not possible, the client would be willing to look at sourcing parts and materials out of North America as long as the material is coming from a reputable source [6]. Moreover, since WPU values longevity of their products, the team's product must be designed to withstand a minimum 10 year lifespan and adhere to California Proposition 65, which require businesses to provide warnings about exposures to material that induce cancer, birth defects or other reproductive harm in products that are used in residential or commercial settings [6], [7].

The performance constraints of the project are to be taken into consideration during the concept generation phase; all concepts considered must abide by the limitations and constraints listed above. Any concept that cannot fulfill or satisfy these constraints are immediately taken out of consideration for the final design concept.

1.6 Project Assumptions

As a team, the following assumptions were made to aid in creating the optimal design with the tools available. These assumptions are stated below:

- The desk accessory prototype will be sent by WPU to a third party for testing and is not the responsibility of the team.
- The wall the Embed is built upon is structurally sound and will not fail.

1.7 Project Needs

The project needs consist of both requirements that were given to the team by the client as well needs created be the team to satisfy the project objective. Each need was assigned an importance value that ranges from 1 to 5 with 5 being the highest priority, and 1 the lowest. These needs and values were confirmed with the client before it was finalized [6]. This will help the team prioritize certain design objectives and, later on, evaluate design ideas. Below in Table II are the identified needs for the desk and bed.

TABLE II: NEEDS IDENTIFIED FOR THE DESK ACCESSORY AND BED AUTOMATION

#	Needs	Importance
	Desk	
1	The desk does not yield at maximum load	5
2	The desk can detect collision or obstructions	5
3	The desk can change heights	5
4	The desk occupies minimal space	5
5	The desk has minimal deflection at maximum weight	4
6	The desk is serviceable	4
7	The desk can be attached to Wall Beds (Murphy Beds)	4
8	The desk can be used for a long time	3
9	The desk can be installed or assembled by one person	3
10	The desk can be sold for a competitive price	2
11	The desk is made with minimal material	2
	Bed	
12	The bed automation mechanism occupies minimal space	5
13	The bed is serviceable	4
14	The bed automation mechanism will not fail within the warranty period	3
15	The bed automation can be marketed at a competitive price	2

The most important features given by the client are the safety features such as needs number 1 which states that the desk will not fail, or yield, at maximum loading conditions, and needs number 2 which is a preventative safety feature the client wants to be included. The other high importance features are the features that will distinguish the product from the competition. These are exemplified in needs number 3 which requires the desk to be able to have adjustable heights; a feature that no wall-bed desk accessory in the market currently possess.

1.8 Project Metrics and Specifications

Metrics are measurable parameters that will be used to evaluate the fulfilment of the needs outlined previously. Meanwhile, marginal values are the minimum values for the corresponding metric; each value was defined by the client in meetings, emails and other types of communications [6]. Below in Table III are the metrics and specifications identified for the desk and bed.

TABLE III: METRIC AND SPECIFICATION FOR THE DESK ACCESSORY AND BED AUTOMATION

#	Needs	Metric	Unit	Marginal Value	Ideal Value
1	1,6	Desk maximum load capacity	lbf	60	>60
2	3	Desk minimum desk height	in	30	>48
3	3	Desk maximum desk height	in	48	<30
4	4	Desk space occupancy	in^3	1960	<1960
5	5	Desk deflection at maximum loading conditions	mm	5	< 5
6	6,13	The desk and bed can be disassembled and reassembled without damaging the product	Binary	1	1
7	6,13	Percentage of parts that are replaceable	%	90	100
8	7	Desk accessory compatibility with wall beds	Binary	1	1
9	8,9	Lifetime of desk accessory	years	10	>10
10	9	Desk assembly or installation time	min	30	<30
11	14	Number of steps for desk assembly or installation	#	10	<10
12	10,11	Total material cost for production of desk attachment	CAD	700	<700
13	10,11	Desk weight	lbm	100	< 100
14	12	Bed automation mechanism space occupancy	in^3	976	<976
15	14	Bed automation mechanism safety factor	#	5	>5
16	15	Total material cost for production of bed automation	CAD	500	<500

The crucial metrics that the team would need to monitor are metric number 2 and 3 which are the range of the desk's vertical motion. These two metrics are integral in the function of the desk as a standing desk, lap desk, or sitting desk. Another set of crucial metrics are metrics 4 and 14 which are the space occupancy of the desk and bed automation mechanism. The Embed is a product which aims to get more out of the same amount of space. Minimizing the space occupied by the desk and bed automation system is inline with the products goals.

1.9 Project Scope

The group's goal is to design an automation system for the Embed that will operate under 'deadman switch' conditions and to design a corresponding movable and detachable desk accessory for the wall bed. The desk will have multiple configurations and can be adjusted to different heights according to the consumer's preferences. WPU has specified the following conditions to be essential in regards to success of this project: user safety, local material sourcing, and profitability.

Given the client's requirements for a solution to the problem statement, the following parameters are considered to be out of the scope of this project: the process in the which the wall bed itself is designed and manufactured and also testing of the desk accessory prototype is not part of the team's objective.

Furthermore, this report will outline and detail the process and development of a solution to the problem statement above. It will encompass the following sections: the Design Methodology, the Design Overview, the Detailed Design and Optimization, and the Conclusion. Within these sections, designs will be created, chosen, analyzed, optimized, verified, and validated to be the best possible solution.

2 Design Methodology

To satisfies the client's needs and requirements, various design ideas were considered. The final design for the client consists of 2 separate products, a desk attachment for their wall bed, the Embed, and a system to automate the Embed's opening and closing motion. The major design components considered include:

- A method of turning the desk attachment from sitting desk to a standing desk,
- A method of allowing the consumer to use the desk whether the Embed is opened or closed.
- A system to automate the Embed's opening and closing motion.

To achieve the vertical range of motion that the client wanted for the desk accessory, 5 different concepts were considered: a linear actuator, a ball screw drive, a rack and pinion, a scissor jack, and a crank shaft. these concepts were assessed using a weighted decision matrix (WDM) to compare their load capacity, cost, weight, volume, complexity, and serviceability. By utilizing the WDM and including the client's input, the final lifting column concept was chosen to be a linear actuator.

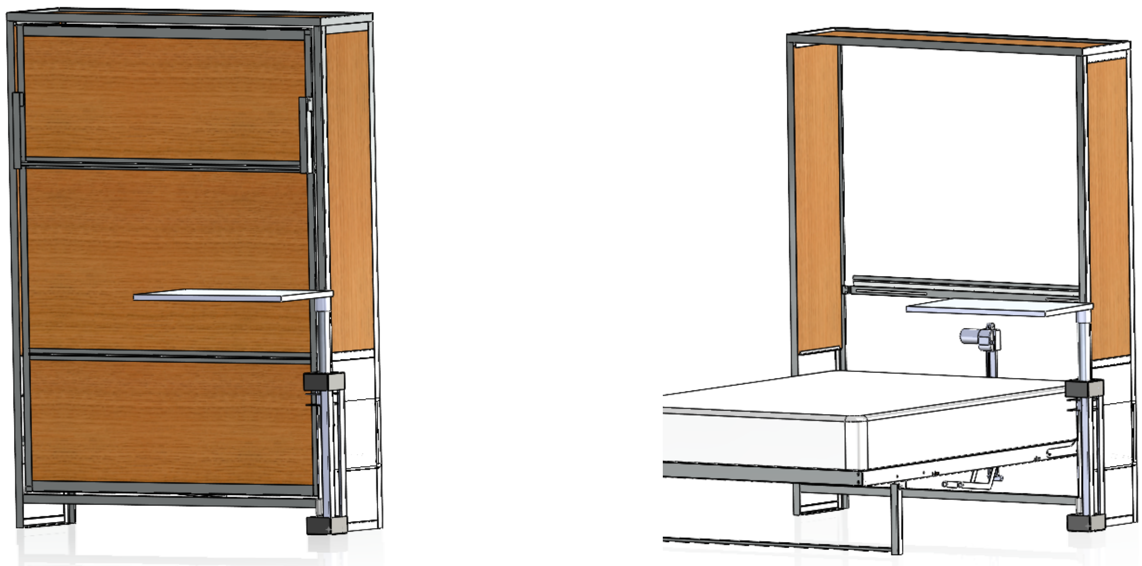
Various methods for pivoting the desk accessory were taken into consideration. These methods involved either pivoting the desktop or pivot the lifting column. Each method conceptualized was assessed based on its strength, volume, weight, complexity and estimated cost of manufacturing. The pivot mechanisms that were considered include a u-joint, a hinge, a turntable/bearing, and concentric tubes with a bearing. By using a WDM, the method of concentric tube was chosen to be the final concepts. However, the client also specified that they would like to move the lifting column out of the way of the Embed and its shelving accessory [8]. Thus, the team decided to include the hinge pivot mechanism to the lifting column.

Several ideas for the automation of the bed opening and closing were considered. All of them involved the use of actuators and each idea were assessed on their overall complexity, volume, cost, and the degree of modifications required to the current bed assembly to mount and accommodate the actuators. Some of the concepts that were generated included a single linear track actuator mounted at the centre of the wall behind the bed with two push arms attached to the actuator and the bed frame.

Ultimately, the final design chosen consisted of two optical feedback actuators attached at the far left and far right side of the bed frame, respectively. The final design was chosen due to its simplicity, compact design, and the minimal amount of modifications to the current bed assembly required to accommodate the system.

Stress analysis were carried out for the mounts that held the actuators to ensure that they have the capacity to withstand the magnitude of forces that the linear actuators exert towards them, in both tension and compression loading cases.

Depicted in Figure 4a below is the proposed final design to meet the client's requirements and criteria.



(a) Full assembly with the bed closed

(b) Full assembly with the bed open

Figure 4: Full assembly implementing the finalized concepts.

This design is further iterated and analyzed in Section 4. For each component, there are various design considerations that must taken into account to satisfy the clients needs and requirement.

2.1 Design Analysis Methodology

To ensure that the team is able to develop a solution that satisfies the specified requirements of the project, detailed analysis must be done on the concepts that were developed. Based on these analyses, the team can further optimize the chosen design concepts. The main analyses were done using SolidWorks' built in FEA studies, due to the complex geometries that were developed by the team. The following section will outline some of the theory behind the various analyses the team carried out.

2.1.1 Finite Element Analysis

Finite Element Analysis (FEA) is a method of study that helps combine the use of models, simulations, and calculations to discover potential vulnerabilities within a given structural design. With the utilization of FEA within SolidWorks, we were able to conduct the various static studies involved within our structural designs. FEA studies employ a numerical technique known as the Finite Element Method (FEM), which separates various sections of a structure into multiple elements called nodes. This series of nodes are then recombined together, simplifying the model and allowing it to be analyzed much more accurately. The recombined structure is what we know as the "mesh" model. As we increase the nodes and elements within our mesh, the more accurate it is able to represent our given structure. This process of increasing the nodes helps create a much more refined mesh. The Finite Element Method also has its computing limitations as we are not able to create infinite amounts of nodes within the mesh model, it will never be an exact representation of the model geometry.

Within a Static study, SolidWorks sets up the mesh of the model with the use of the following equation:

$$f = [K]u \tag{2.1}$$

Where K is the matrix of the stiffness of each node or element, u is displacement on the element, and f represents the forces on each element. The static study solves this system of equations by using the inverse of the stiffness matrix. The inverse of the stiffness matrix is obtained based on the boundary conditions, which are the user-defined fixtures within the given model.

Better accuracy on the static study results will be dependent on the user-inputted nodes. Higher nodes will create a much more refined mesh but will require more time and computing power for the software to simulate and run. It should be suggested that the study should be run in various iterations with increasing nodes to gain multiple results. As we see a convergence in our results, we are able to ensure that the study has been set up properly for our Finite Element Analysis.

2.1.2 Mesh Refinement

When performing simulations using SolidWorks, it is important to ensure that the level of mesh refinement used is adequate to produce accurate results. An overly coarse mesh will produce inaccurate results; an overly fine mesh will require more time and computer resources than necessary to calculate numerical results. Mesh convergence is obtained when refinement of the mesh produces negligible changes to the results of the study.

Mesh convergence was determined by first creating a coarse mesh of the structure, running a static study analysis to determine stresses and deformations within the structure, and then probing # different points within the structure to evaluate the stresses at those specific points. The element sizes were then decreased in order to increase the overall number of elements within the mesh and thus creating a finer mesh. As a result, the finer mesh produced more accurate values of stress. Another static study was then performed to determine stresses and deformations within the structure, and then probing the same # points that were previously examined. The exact same steps were then carried out, creating a finer mesh after each iteration until there were negligible changes in stress values after consecutive iterations signifying mesh convergence and thus accurate analysis results.

2.2 Design Validation

Validation of the design is done by completing hand calculations in conjunction with FEA studies done on in SolidWorks. Analytical calculations are completed to verify the deflection of the desktop and the pivot mechanism desk supports. Hand calculations are also done to determine stresses and the overall safety factor of the lifting column and pivot mechanism.

2.2.1 Desk Accessory Analytical Methodology

To calculate the deflection at the tip of the desk for a given loading condition, classical beam theory will be used to calculate the deflection of the cantilevered beams. The following equations[9] will be used:

$$\delta = \frac{FL^3}{3EI} \tag{2.2}$$

Where F is the applied load, L is the length of the beam, E is the Modulus of Elasticity (MOE) and I is the moment of inertia.

Additional equations will need to be used to calculate the deflection at the tip for other loading conditions. To calculate the deflection for the loading condition shown in fig: the torsion applied to the main branch must be taken into account alongside the deflection due to bending. The angle of twist is given by[9] :

$$\phi = \frac{TL}{JG} \tag{2.3}$$

Where T is the torsional moment applied at the tip, L is the length of the beam, J is the polar moment of inertia or the second polar moment of area, and G is the shear modulus of the material. After the angle of twist is calculate the deflection due to the twist will be calculated using trigonometry. Due to the complex geometry of the beam's cross-section, the following relationship[9] will be used to calculate the polar moment of inertia, J.

$$J_o = I_{xx} + I_{yy} \tag{2.4}$$

Where, J_o is the polar moment of inertia, I_{xx} is the moment of inertia about the axis perpendicular to the axial direction and I_{yy} is the moment of inertia about the axis perpendicular to the other two axes.

After the deflection due to torsion of the beam and deflection due to bending for all members are calculated, all the deflections are added together to calculate the final deflection at the tip.

The highest stress area for all loading conditions will be the area near the pivot. To calculate the stress near this area,

$$\sigma = \frac{Mc}{I} \tag{2.5}$$

Where M is the bending moment, c is the distance to the neutral axis from the top or bottom of the beam, and I is the moment of inertia.

For this application, the deflection will be the bottleneck parameter, as long as the deflection requirement is met the structure will be sufficiently rigid and strong to not yield. As such, the focus of the design process will be on the deflection requirement and yielding will be checked after the deflection requirement is met.

Analytical calculations and numerical analysis is performed on the design. Three loading conditions were examined, first, the load is placed on the furthest corner from the pivot point diagonally across the desk. Second, the load is placed on the along the longer side edge. Third, the load is placed along the shorter side edge as seen in Figure 5.

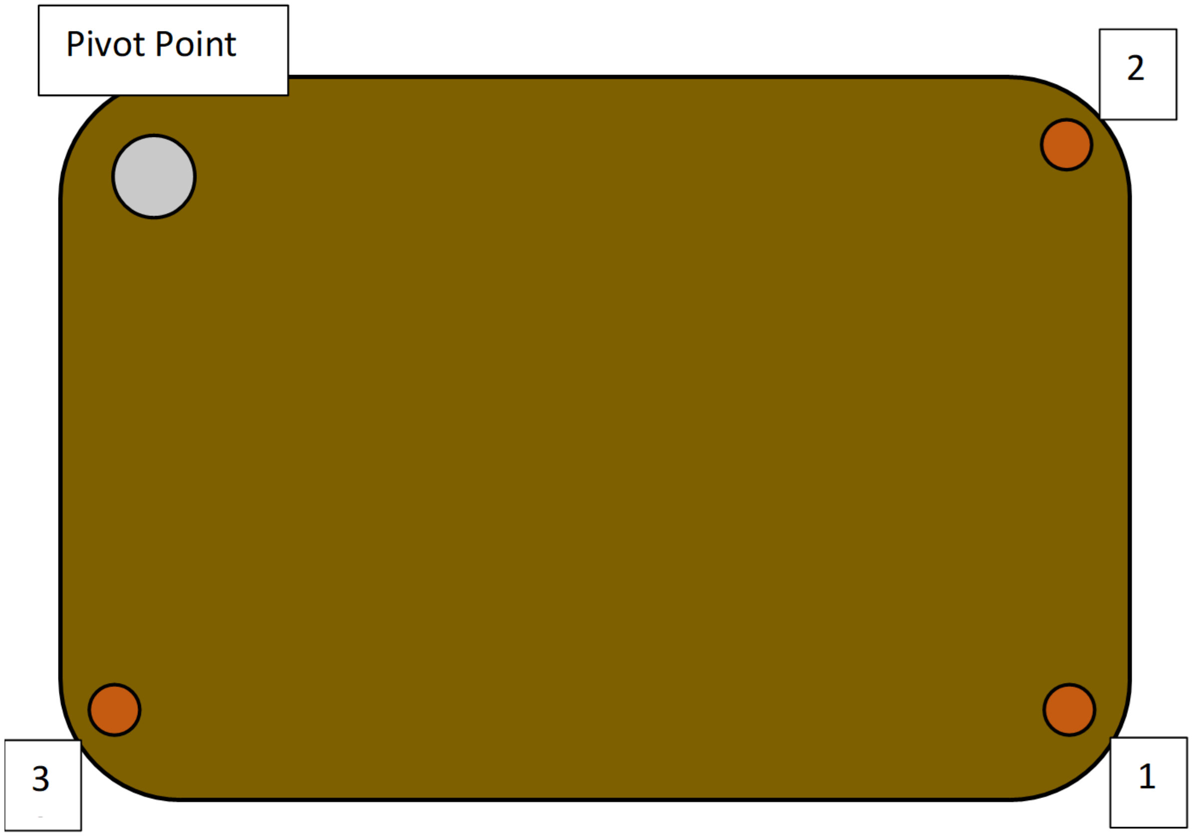


Figure 5: Locations for Extreme Loading Conditions

3 Design Overview

To make sure the team was able to complete the design for the client, the team split the final design into 4 sub-designs: a lifting column, a pivot mechanism, a desktop, and a bed automation system. For the desk accessory, 3 sub-designs are integrated to into one final design; the automation system is its own separate design. The final design for WPU is summarized in the succeeding subsections.

3.1 Desk Attachment Overview

The finalized design for the Embed desk accessory consists of lifting mechanism utilizing a linear actuator and a pivot cap attached to the lifting column with an arm that is embedded into the desk top, The desk accessory design can be seen in the following figure, Figure **??**.

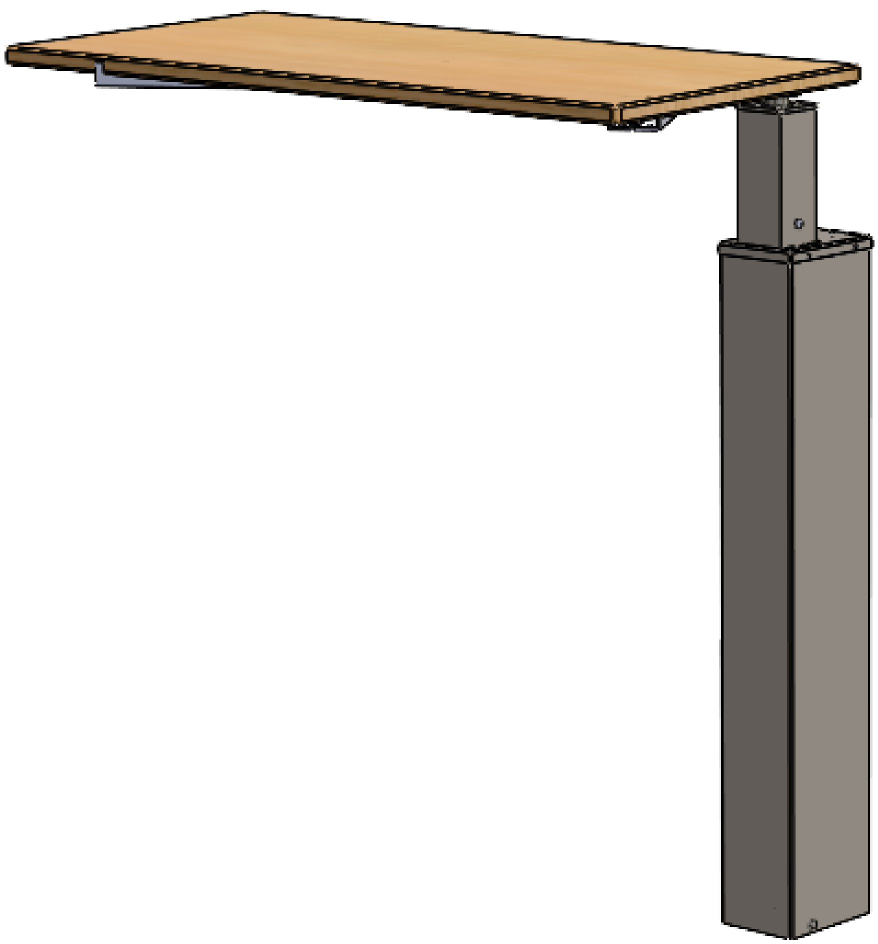


Figure 6: Full desk accessory assembly

The lifting mechanism design consists of a steel enclosure that houses a linear actuator and a vertical lifting column. The linear actuator has a load capacity of 200 lbs and stroke of 18”. the steel housing is attached to the EMBED frame via 2 commercial grade hinges. A steel plate is welded to the top of the vertical column to support a flanged bearing for the pivot mechanism to mate with. A linear guideway system is utilized to support the entire moment load that is applied to the vertical column due to the offset loading condition of the desktop.

The pivot mechanism chosen for the final design is a shaft rotating using a flange bearing. A flange bearing enables the use of ready-to-order square tubing that is to be cut to size to fit within the lifting mechanism; increasing the strength of the lifting column shaft.

A 1” solid steel shaft is fitted into the flange bearing. 1”x1” hollow square tubes with 0.12” wall thickness will be cut to size and welded together to create the support structure for the desktop. A-500/ A-513 mild steel is chosen as the material due to its high availability, lower cost and ease of welding. The square tubing is chosen due to it’s higher stiffness to weight ratio compared to solid square tubing. Square tubing is also more common than rectangular tubing and are available in more combination of dimensions. This enables easy adaptations/modifications of the design should the need to change dimensions exist and to lower cost.

The geometry for the support structure is shown in Figure 7 below:

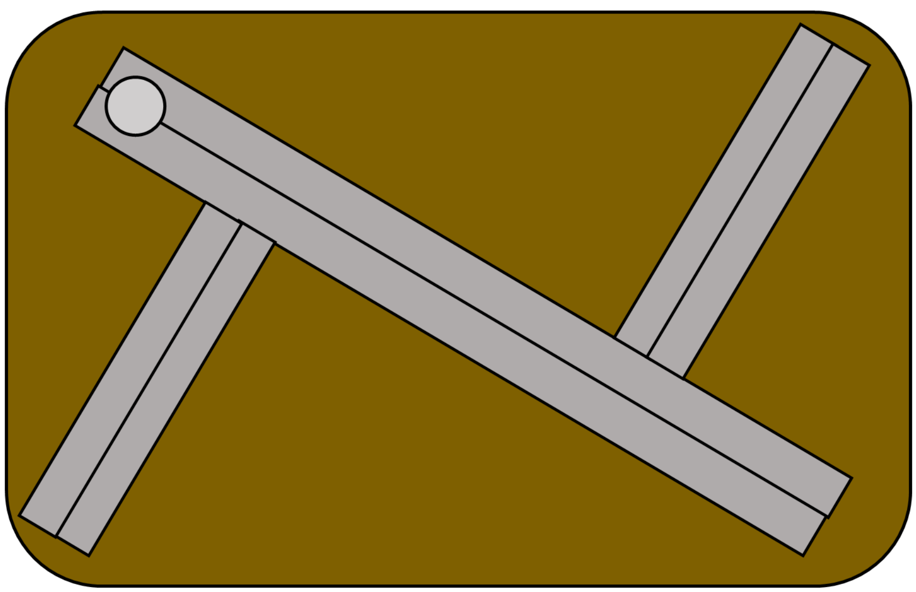


Figure 7: Geometry of the Desktop Support Structure

The main member runs diagonally across the desk with 2 smaller, 9 5/8" long, members welded perpendicular to the main member. The smaller members are positioned along the main member such that they are oriented towards the corners of the desk. The length of the secondary members are such that it extends as close as it can to the corner to increase it's supporting capabilities without extending past the desktop. The angle from the main member at 90°is chosen to minimize material requirements and reduce possibilities for error during fabrication caused by eccentric welding angles. The support desktop support structure will be attached to the desktop with 8 wood screws located near the corners to prevent the desktop from being pried off the supports. Due to the lifting column, the corner near the pivot point cannot be fastened using the wood screws as they will collide, instead a pair of screws are added in the centre of the main member.

The desktop is constructed of MDF and will be melamine coated and edge treated as per the clients preference to maintain the same aesthetic as the panels used for the Embed. The average thickness for a desktop constructed from is 0.75in to 1.0625in depending on the desk material, length, and intended purpose [10]. However, using MDF as the material for the desktop, the desktop will deflect from 2.14 in to 0.75 in depending on the thickness of the desktop.

To mitigate deflection in the desktop, a support structure constructed out of square tubing is attached to the pivot mechanism to provide the desktop rigidity. This support structure is embedded into the desktop to try to maintain the clients minimum height specification of 30 in for the desktop. Figure **??** below depicts the structure embedded into the desk.

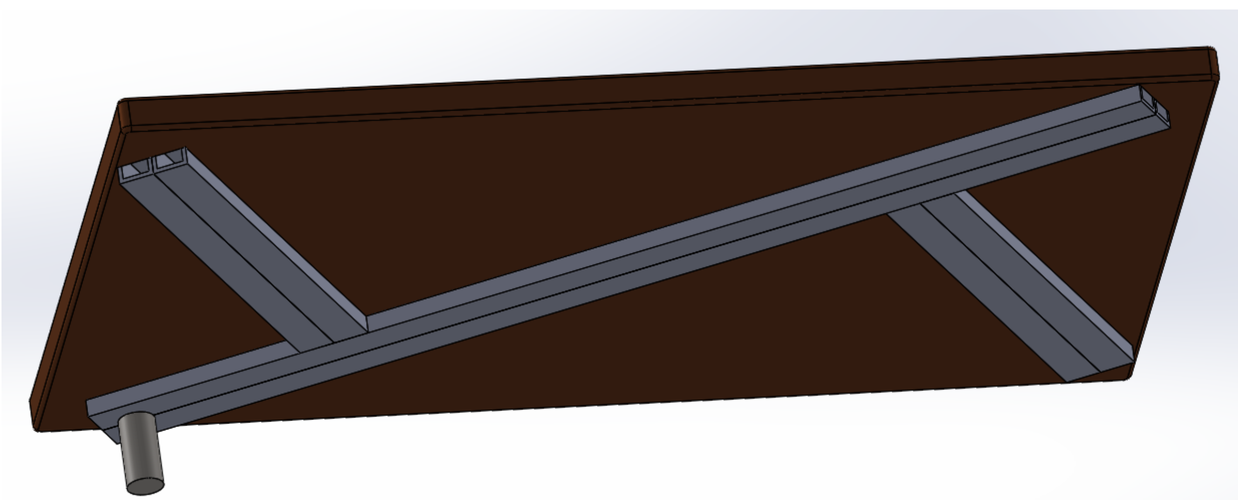


Figure 8: Support structure embedded into the desktop.

By using the tube to maintain the rigidity of the desktop and choosing a desktop thickness of 0.75 in, the maximum deflection of the desktop, when subjected to the worst case loading scenario, is just over 0.2 mm which is within the clients specification of less than 5mm.

3.2 Bed Automation System Overview

To automate the Embed's opening and closing motion, two optical linear actuators with 400 lbf outputs are installed at each side of the bed. It was determined through calculations that 2 separate 400 lbf actuators are required to open and close the bed with a safety factor of 1.5. The top end of the actuators are mounted on the back end of the bed support through the use of 3/8" thick steel angle irons while the bottom end of the actuators are mounted on the bed frame through the use of 3/8" custom steel mounting brackets. The actuators are designed to move at the exact same time, at the exact same rate, and be at the exact same positions. The actuators are controlled through the use of a remote where the buttons are required to be fully pressed to either open or close the bed.

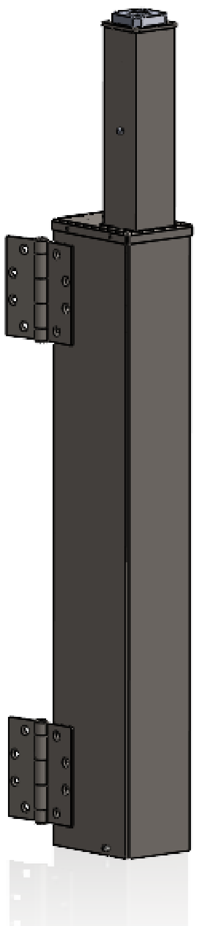
For the desk attachment, the total cost of bought parts equate to \$645.31. This is the price for one desk half and includes a linear actuator, fasteners and hardware, a flanged bushing used for the desktop pivot, 2 hinges to connect the lifting column to the wall bed and any raw material that will need to be manufactured. The total cost of the bed automation system was found to be \$568.78. This cost includes the two actuators, the remote system required to operate them according to 'dead-man' switch conditions, the mounts, and all of the required fasteners. The cost of bought components and raw materials are retail prices and do not reflect the prices that the clients may get if they were to buy in bulk or wholesale. Furthermore, machining of the raw material for the desktop and lifting column is not considered in these cost. The machining cost for the desktop pivot mechanism is estimated to be \$28.06. The machining cost for the bed automation system is estimated to be \$.

4 Detailed Design

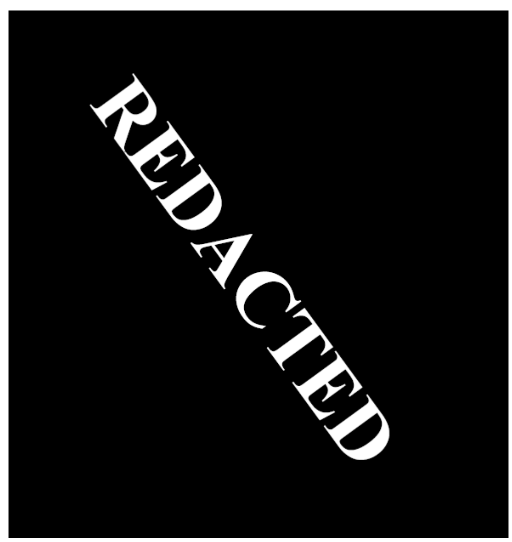
This section will provided further detail on the analyses conducted to produce the final design for the client, WPU, as summarized in Section 3, Design Overview.

4.1 Lifting Mechanism Design

The lifting mechanism is the component of the desk attachment that provides vertical motion to the desktop, and attaches the desktop to the wall bed. The design process of the lifting mechanism includes analytical, and numerical methods to ensure that the mechanical requirements of the project are met.



(a) Lifting column outside view



(b) Inside view of lifting column components

Figure 9: Lifting Column Assembly

This section provides an outline of the lifting mechanism and each of the individual components. As seen in the figure below, the lifting mechanism is composed of many individual components. The components that will be manufactured are listed below,

- Lifting Column Enclosure
- Lifting Column
- Lifting Column Support Bracket
- Support Bracket Spacer
- Enclosure Cap
- Pivot Plate

The lifting column enclosure is the component that houses all of the lifting column components. This component serves the purpose of making the lifting mechanism assembly more aesthetically pleasing as well as attaching the lifting mechanism to the EMBED frame. The material that is selected to manufacture the enclosure is steel sheet because it will be more economical to procure than steel tubing and allows the designer to have more freedom with the dimensions of the component because a break press will be used to make the enclosure. The thickness of the steel sheet is to be determined using FEA in Solidworks.

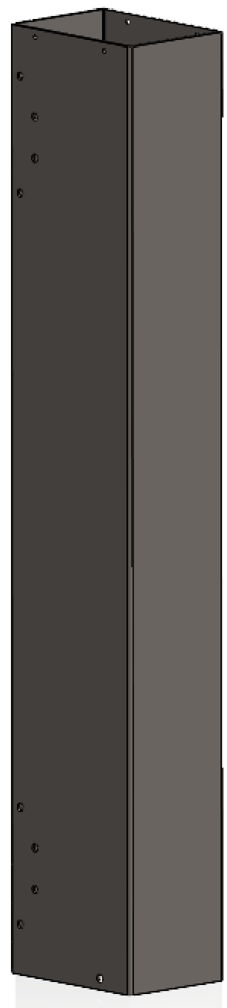


Figure 10: Lifting column Enclosure

The vertical column is the component that extends vertically out of the lifting column enclosure and provides the lifting motion to the desktop. The lifting column is fastened to the end of the linear actuator and to the desk pivot. The lifting column will be manufactured from a length of steel square tubing. Steel tubing is used instead of formed steel sheet because this component requires a lot of strength to provide minimal deflection when the desk is loaded. Also, the limitations of standard square tube dimensions is not an issue because the the tube must only be able to fit the linear actuator inside it.

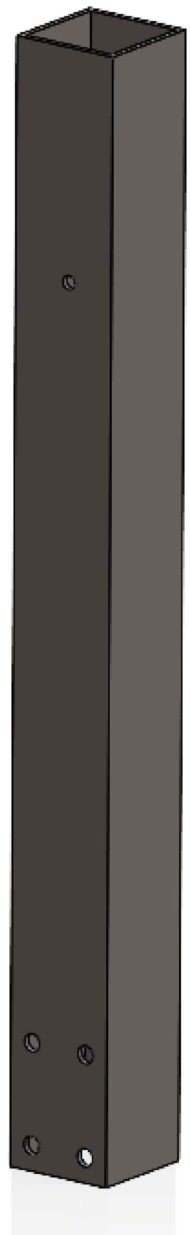


Figure 11: vertical column

The lifting column support bracket is the component that fastens the lifting column to the linear guideway. This component carries the full moment that is transferred to the lifting column from the desktop when loaded. It is important that this bracket is strong because any deflection that is seen in this bracket will be multiplied at the end of the lifting column. FEA will be used to determine the thickness of the steel sheet that will be used for this component.

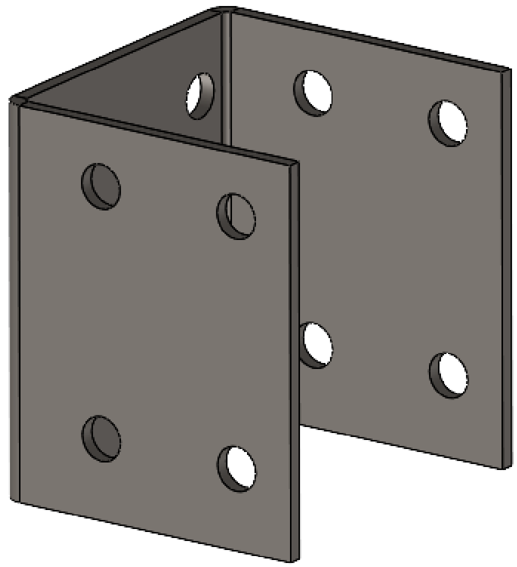


Figure 12: Lift column support bracket

The support bracket spacer is manufactured from steel sheet and the function of the component is to fill the space between the support bracket and the lifting column. The lifting column is wider than the support bracket due to space limitations. The support bracket spacer is designed to fill the space between the lifting column and the support bracket so that sufficient clamping force can be applied between the support bracket and the lifting column without deforming the support bracket.

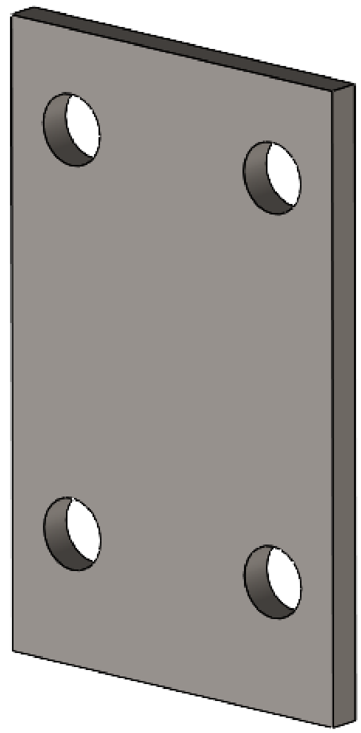


Figure 13: Lift column support bracket spacer

The enclosure cap is designed for safety and aesthetics. The cap itself does not support any load and it is fastened to the top of the enclosure with a square shaped cutout for the lifting column to pass through it. The enclosure cap will be manufactured from sheet steel so that it can be easily bent and painted. The thickness of the sheet metal to be used will be determined by cost and and ease of procurement as there is no load requirement for this component. The enclosure cap is a safety feature as it prevents users from being injured from the mechanical components housed by the enclosure.

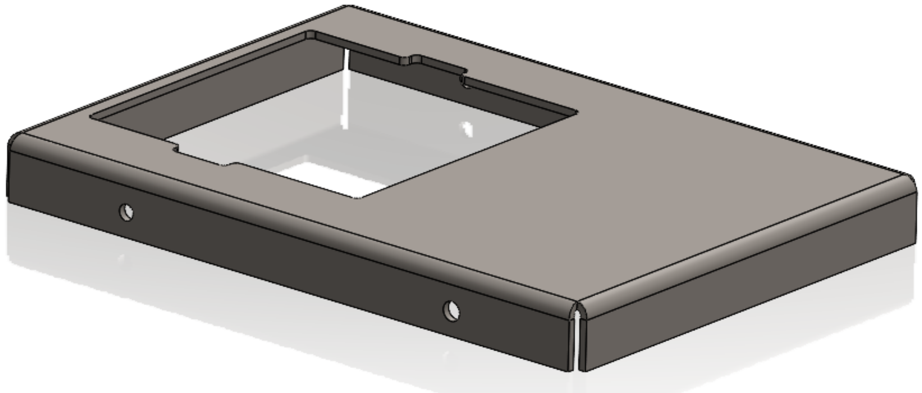


Figure 14: Lift column enclosure top cap

The pivot plate is component that is located at the top of the lifting column and its purpose is to provide a surface to mount the flanged bearing to. The pivot plate will be manufactured from steel sheet so that it can be welded to the top of the lifting column and the assembly can be painted easily. The pivot plate will have laser cut holes to mount the flanged bearing to. The thickness of the pivot plate will be determined using FEA in Solidworks.

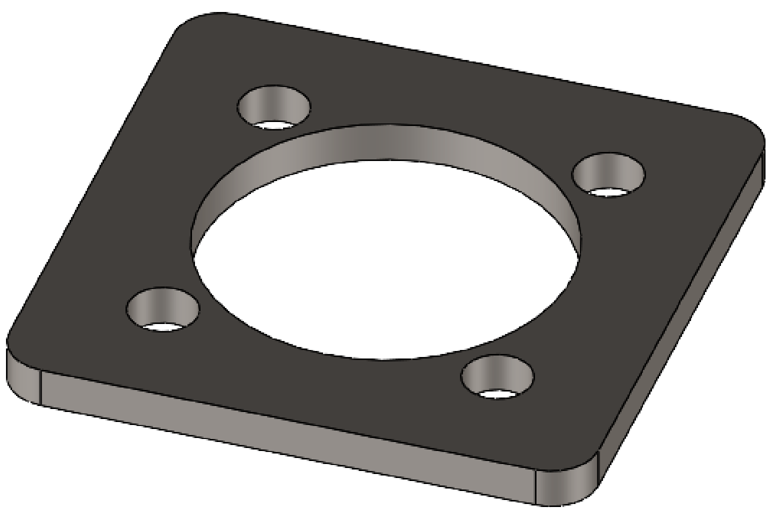


Figure 15: Lift column Pivot Plate

Before using analytical and numerical methods to verify the design, preliminary design considerations were considered to choose materials and dimensions as a starting point for the final design.

The customer would like the final product to be powder coated to their specified colour, so steel was the chosen material for it's ease of powder coating, as well as it's ductility for bending in manufacturing. The lift column will be a hollow geometry with an inside dimension of at least 1.75 inches to fit the linear actuator inside the lift column. The lift column support bracket, lift column housing, and lift column pivot plate will all be manufactured from sheet steel using laser cutting and break press for economics, and added freedom in sizes.

Various components of the lifting mechanism are off the shelf components to save on cost and time. Specifically, the hinges, linear guideway system, clevis pins, and pivot bearing are all off the shelf components. An assumption is made that all off the shelf components are tested by there respective manufacturers and the data given for each components load capacity is valid.

4.1.1 Analytical Analysis

The most extreme case load conditions for the desk attachment are defined as a 60 lbf load that is located at the end of the desk which is a distance of 34 in from the center of the lifting column. From these loading conditions, it is known that the vertical column that supports the desktop must be able to support a compressive axial force of 60 [lbf] and a moment of 2040 [lbf-in].

The following table lists the individual components of the lifting mechanism, the chosen material, and the rated load or yield load for each component.

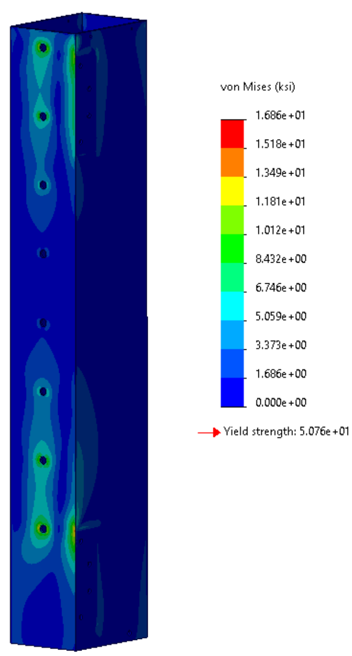
Component	Material	Rated Load / Yield Load
Vertical Column	1020 Steel	50.8 KSI
Pivot Plate	1010 Steel	44.2 KSI
Support Bracket	1010 Steel	44.2 KSI
Enclosure	1010 Steel	44.2 KSI
Enclosure Cap	1010 Steel	44.2 KSI

Before numerical simulations were completed for each component of the lifting column, the critical load case was defined. The critical load case for the lift column was defined as the bending moment that is created by the offset load of the desk. The critical load case of the lift column support bracket is defined as the bending moment that is transferred to the bracket from the lift column. The vertical force of the desk is not carried by the lift column bracket because the actuator is connected to the lift column which supports the vertical load. Finally, the critical load case of lift column pivot plate is the moment transferred to the plate from the desktop. Because some of the geometries and load scenarios cannot be calculated with simple formulas numerical methods will be used to finalize the design.

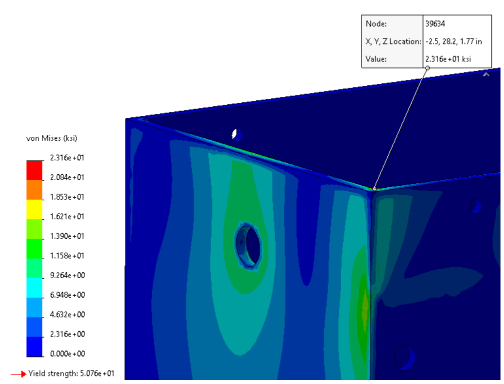
4.1.2 Numerical Analysis

Finite Element Analysis was used as a numerical tool to optimize the design of each manufactured component of the lifting column. Solidworks is the platform used to execute FEA studies for all components of the lifting column because it is the most accessible platform for students at the University of Manitoba. A mesh convergence study is performed for each FEA study that is required. This is done to build confidence in the FEA results. The mesh convergence plots for each component of the linear actuator can be found in Section 7 The proceeding paragraphs will provide a brief summary of the FEA results that have been obtained for each manufactured component.

The figure below shows the FEA results for the lifting column enclosure. As can be seen in the figure, the enclosure caries the majority of stress at the location where the linear rail is mounted to it. The high points of stress can be seen at the top and bottom of the enclosure which reflects the moment load that the linear rail transmits to the enclosure. The max stress in the enclosure under loaded conditions is approximately 23 KSI. The optimal material for this component is 1010 hot rolled steel sheet because it has a yield stress of 44.2 KSI resulting in a safety factor of approximately 1.9.



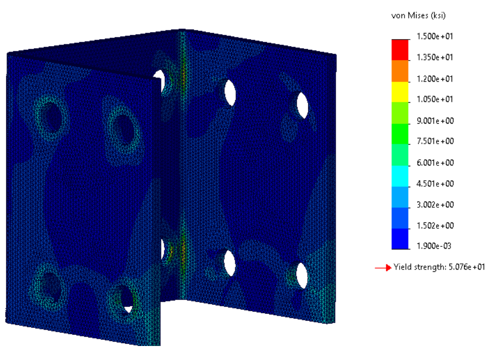
(a) Lift column enclosure FEA overview



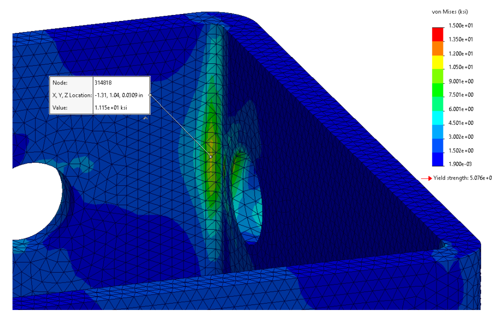
(b) Location of maximum stress for lifting column

Figure 16: Fea Results for lifting column support bracket

An FEA study has been completed for the support bracket and the results can be seen in the figure below. Under the most extreme loading conditions the support bracket is subject to the moment load of the loaded desktop. The thickness of the steel sheet to be used for the support bracket is determined by iterative FEA studies with a range of available sheet steel sizes. The material thickness that is chosen for the support bracket is 11 gauge. As seen in the figure below, the max stress in the support bracket is approximately 11 KSI, and with 1010 hot rolled steel as the material this gives a safety factor of approximately 4. A safety factor of 4 is desireable in this component because the max stress is located in the location of the bend. This means the material has been plastically deformed already which will mean there is residual stresses in this area.



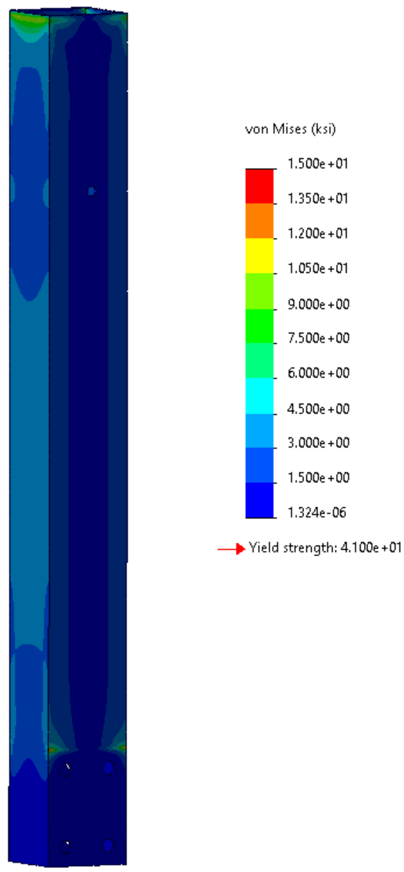
(a) Support bracket FEA results overview



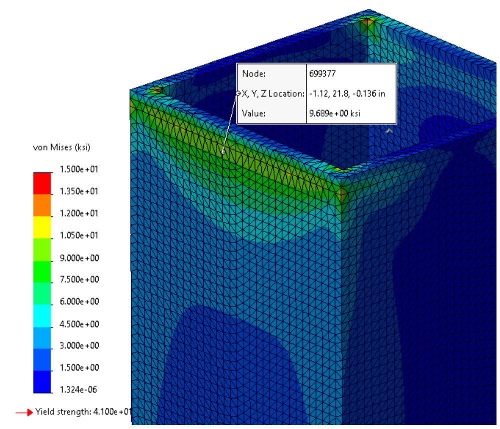
(b) Location of maximum stress for the support bracket

Figure 17: Fea Results for lifting column support bracket

The figure below shows the FEA results for the vertical column. The vertical column is manufactured from a stock length of steel square tubing. The FEA study is useful for determining the required wall thickness of the square tubing that will be used. It can be seen in the figure below that the max stress in the vertical column is located in the zone whore the pivot plate is mounted to the vertical column. The max stress calculated from the FEA study is approximately 10 KSI, which results in a safety factor for the vertical column of approximately 4.4. Although 4.4 is a very high safety factor. The vertical column is designed to have essentially zero deflection, thus the safety factor is quite high.



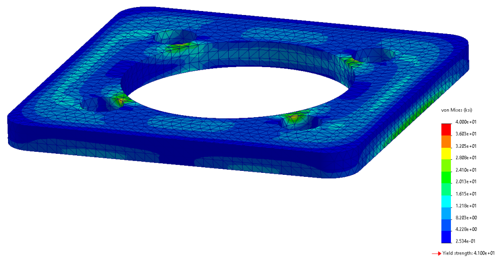
(a) Vertical Column FEA results overview



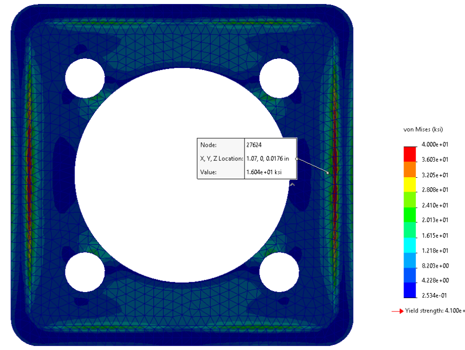
(b) Location of maximum stress for the vertical column

Figure 18: Fea Results for Vertical column

The final component to discuss the FEA results of is the pivot plate. The pivot plate is a flat steel plate that is welded onto the top of the vertical column. the plate has a hole pattern cut into it so that the flanged plain bearing for the desk pivot can be mounted to the pivot plate. Under the most extreme case loading conditions, the pivot plate will experience the moment load of the loaded desktop as well as the vertical load of the loaded desktop. Ignoring the stress singularities at the boundaries of the split line, it can be seen in the figure below that the max stress experienced by the pivot plate is approximately 16 KSI. It is noted that the maximum stress is located just inside of the zone where the plate will be welded to the vertical column.



(a) Pivot plate FEA results overview



(b) Location of maximum stress for the pivot plate

Figure 19: FEA Results for the pivot plate

4.2 Pivot Mechanism Design

The pivot is the component that facilitate rotation of the desktop about the lifting column. This will enable the desk to function as a nightstand and as a regular desk, lap desk or standing desk. The pivot mechanism is comprised of two parts, the bearing and shaft. The shaft is in turn attached to the support structure for the desktop. The pivot design process of the pivot includes analytical and numerical methods as described previously in the design methodology section. This section will show the results and reasons for design decisions as well as design other design ideas considered.

FEA will be performed for each loading condition and the deflection at the appropriate tip will be measured. Analytical calculations will then be done to validate the FEA results.

4.2.1 Analytical Calculations

There are three loading conditions which capture the extreme case scenarios. Each loading condition will be analyzed and a deflection

The first and main member which runs diagonally through the desk is treated as a cantilever beam. The load is placed on the end and the deflection and stress is calculated using classical beam theory. During analysis for the first loading condition, the second and third branches are disregarded due to the low contribution they will have on the deflection of the main branch. The calculated deflection using this method is 3.461 mm and maximum stress near the pin is 7.563 ksi.

During analysis for the second loading condition the other secondary member is disregarded due to it's low contribution and to simplify the analysis. The second member which extends towards the corner along the long edge near loading point 2 is treated as a cantilever beam and the deflection is calculated. Then the main member is also treated as a cantilever beam and a deflection for the load is calculated. Since the load is to the side of the main member, moving the load will come with a moment proportional to the distance from the loading point and the main member. This moment will be a torsional moment and an angle of twist is calculated to go along with it. Using the angle of twist, and the length of the secondary member, a tip deflection can be calculated. With all three deflection calculated, (two due to bending and 1 due to torsion) all are superposed and added together and a total deflection is calculated to be 3.307 mm. The stress is calculated near the pin and a stress of 6.195 ksi was predicted.

Similar to the second loading condition, analysis for the third loading condition will follow the same assumptions and process.The third member which extends towards the corner along the short edge near loading point 3 has a calculated deflection of 0.349 mm and a stress near the pin calculated at 1.088 ksi.

4.2.2 Numerical Analysis

Finite Element Analysis was used to test and iterate about different ideas for support structures for the desktop and to determine ideal dimensions for all loading conditions. The main member going diagonally across the desk with 2 secondary members extending towards the corners was the simplest and most cost effective solution that we found. The results of the FEA done on the desk support structure is shown in the following figures.

The stress distribution for the first loading condition is shown in Figure 20

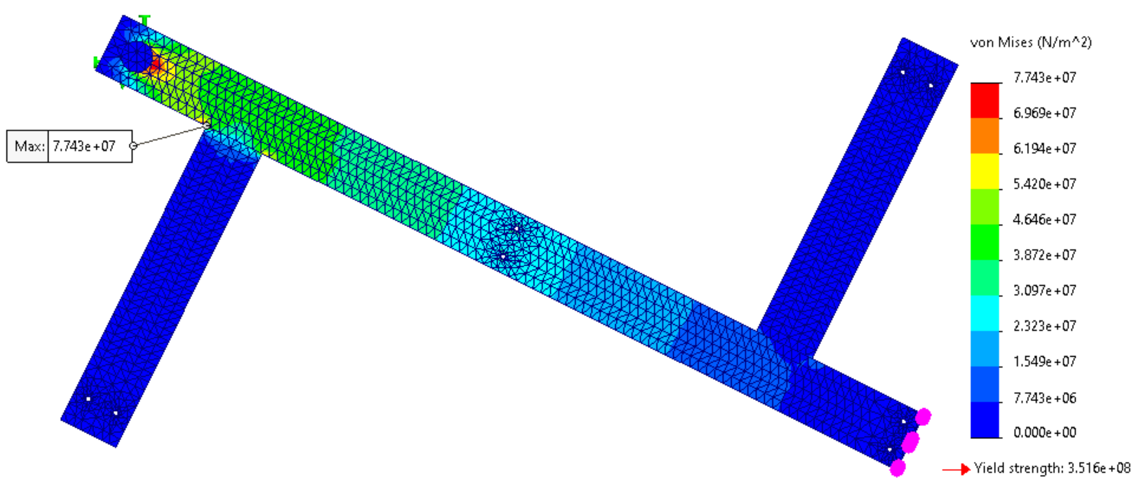


Figure 20: First Loading Condition Stress Distribution

The stress distribution for the second loading condition is shown in Figure 21

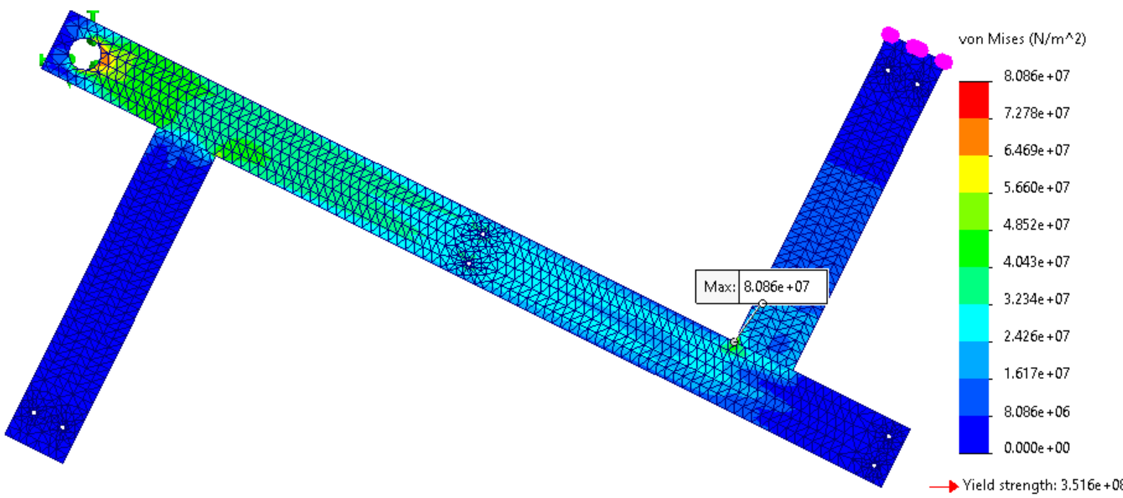


Figure 21: Second Loading Condition Stress Distribution

The stress distribution for the third loading condition is shown in Figure 22

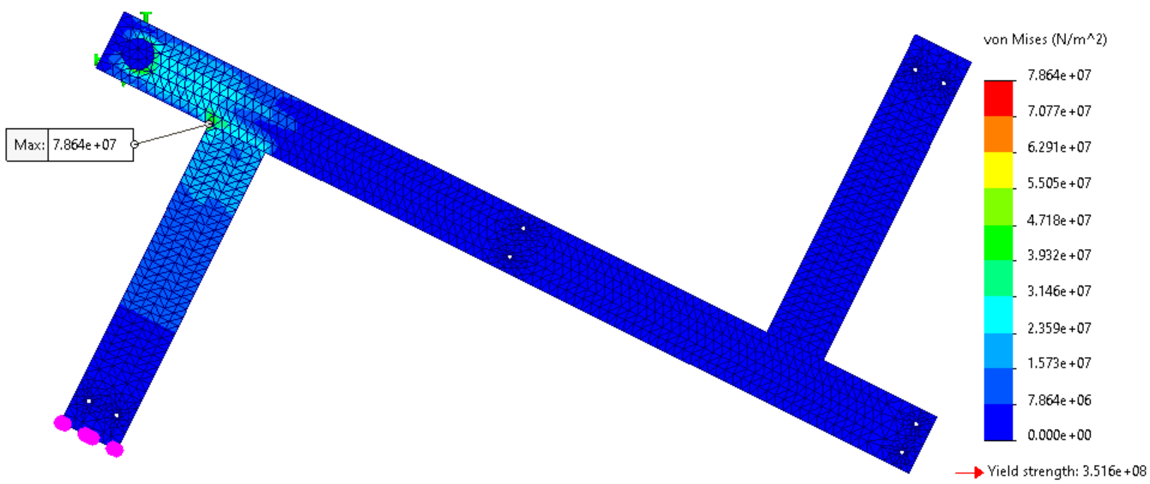


Figure 22: Third Loading Condition Stress Distribution

A mesh convergence study is performed to increase confidence in the results of the FEA and the results are in B.A6 to B.A8.

4.3 Desktop Design

Due to the clients specification of the desk having a maximum load capacity of 60 lbf, consideration was given to the design of the desktop, specifically the material and the thickness of the desktop. If the desk were to experience a point load of 60 lbf at either corner of the desktop, except for the corner above the lifting column, the desktop must not deflect more than 0.25in as per the client's specification; these loading scenarios are the worst case scenario and is depicted in the Figure **??** below.

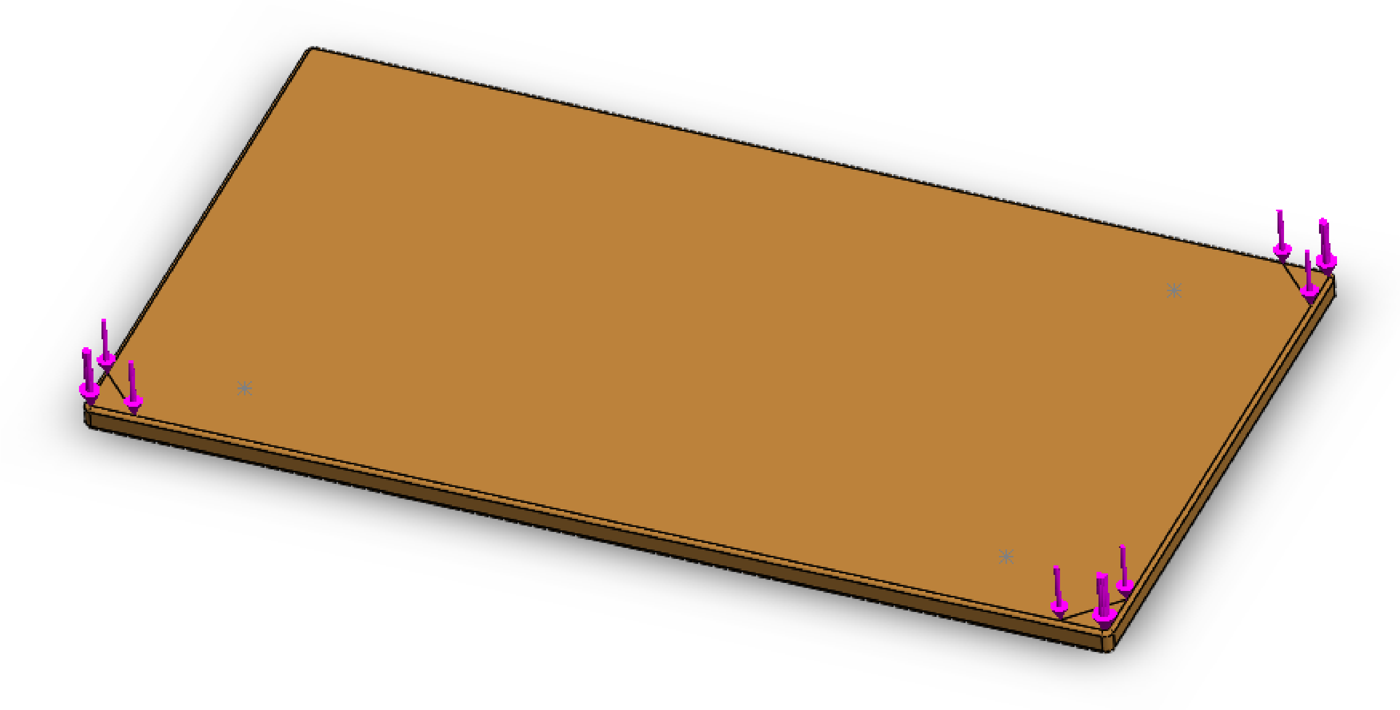


Figure 23: Loading Condition

To ensure that the client's deflection specification is met analytical analysis, as well as finite element analysis (FEA) is conducted on the desktop.

4.3.1 Analytical Analysis

To determine the ideal material and design of the desktop, analytical analysis is used to determine the deflection produced by the maximum load capacity, specified as 60 lbf. During the initial analysis, the desktop is initially treated as a cantilever beam in bending.

According to initial stress and deflection calculations using Equation 2.2, to maintain a deflection of less than 5mm for a cantilever beam, the material of the desktop must have a Modulus of Elasticity (MOE) greater than a certain psi depending on the thickness of the material. Table **??** below lists the minimum required psi needed to maintain the clients deflection specification for varying desktop thickness.

TABLE IV: IDEAL MOE FOR DIFFERENT DESKTOP THICKNESSES

Desktop Thickness (in)	Minimum MOE (psi) Needed to Maintain <0.25 in deflection
0.75	3850000
0.875	2400000
1	1600000
1.125	1130000
1.25	830000
1.5	480000

Analytical analysis is used to as a starting point for analyzing the deflection of the desktop and choosing the ideal material used for the desktop. However, due to the offset loading of the of the worst case loading scenario, FEA will be used to verify the initial calculations conducted.

4.3.2 Material Selection

During initial calculations, we considered the desktop to be a cantilever beam and thus had to consider the properties and specifications of different materials. Table V below list the specifications for materials that were considered for the desktop.

TABLE V: MATERIAL SPECIFICATIONS [11], **mdft +++s**, [12], [13], [14], [15]

Material	Thickness	MOE [psi]	Modulus of Rupture [psi]
Particle Board (Duraflake Standard)	3/8" - 1 1/8"	350000	2000
	1 3/16" - 1 3/4"	325000	1800
Particle Board (Duraflake Plus)	3/8" - 1 3/16"	400000	2400
	1 3/16" - 1 3/4"	400000	2103
MDF (Weyerhauser)	0.354" - 1.25"	500000	4800
MDF (TRUPAN Standard)	1/4" - 1"	449500	3915
	1 1/4"	480000	3800
MDF (TRUPAN Plus)	7/8" - 1 1/8"	495000	3800
HDF (Weyerhauser)	3/8" - 1"	>600000	>6000

Based on the initial analytical analysis, these materials on their own are not enough to maintain a deflection less than 0.25 in. Therefore, further support is needed to maintain rigidity of the desktop. This support structure is welded to the pivot mechanism used for the desktop and can be found in Section 4.2.

For the desktop, the client would like the final product to be melamine coated to their specified colour [8]. Melamine coating is available for various wood products such as those listed in Table

V. The client has also stated their preference for having the edge of the desktop to be treated to prevent sharp edges [16]. Based on client's input and the ability to include a melamine coating and an edge treatment, the team has chosen to use MDF for the desktop. However, the client is welcome to change this design aspect as they wish to reduce the material cost provided they use a material with the similar specification to prevent fracture of the desktop; MDF material specifications are used to be able to conduct analytical and numerical analysis on the desktop.

To mount the desktop to the pivot mechanism, it is placed on the support structure as seen in Figure **??**. The desktop is to be milled to fit upon this structure and to try and maintain the client's minimum height specification of the desktop, a thickness of 0.75in is chosen for the desktop. The pattern milled into the desktop can be seen in Figure 24 below.

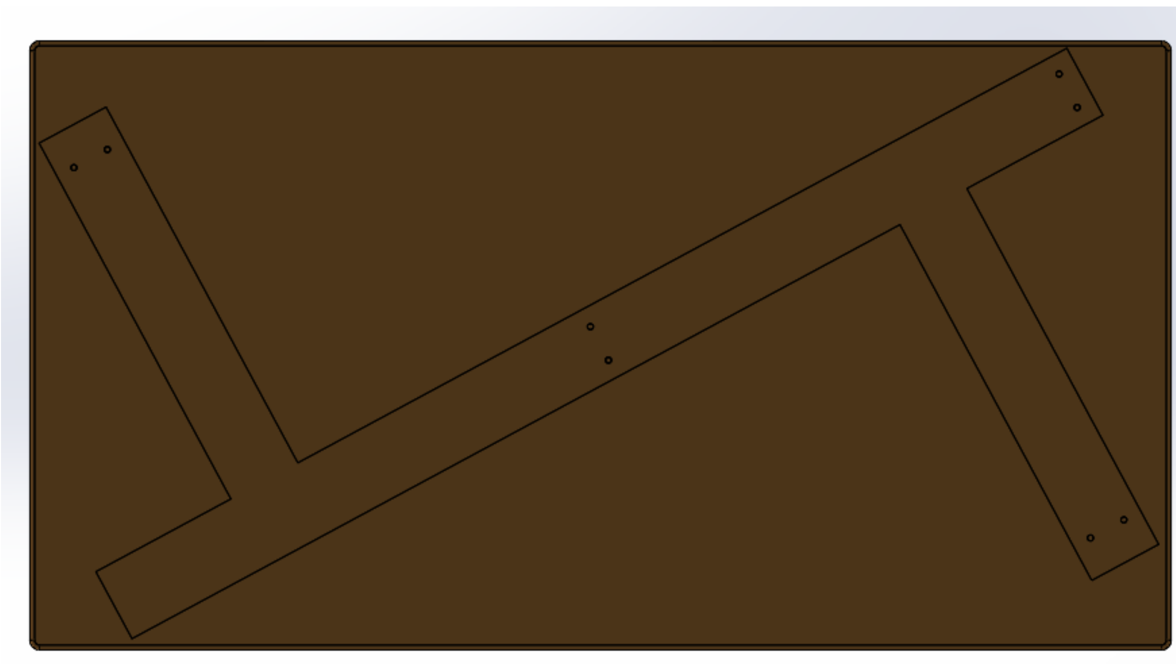


Figure 24: The milled pattern on the bottom of the left hand side desktop.

A 0.75in desk will allow the support structure to be embedded 0.5in into desktop, leaving 0.25in for mounting hardware. However, even with the support structure embedded into the desktop, this thickness brings the minimum desktop height to 30.25 in, 0.25in over the client specified minimum. After consulting and confirming with the client, 30.25in is still considered to be an acceptable height for the desktop [17].

4.3.3 Numerical Analysis

To verify the deflection of the desktop, SolidWork's built in FEA studies are utilized. However, before conducting an FEA study, the ideal mesh size must be determined and therefore a mesh convergence study must be conducted. Following the mesh refinement method explained in Section 2.1.2, the ideal mesh size for the desktop is 0.5in. Figure 25 below illustrates the points probed to determine mesh convergence.

Figure 25: Layout of the Pivot Mechanism Support Structure

Similar to numerical analysis conducted for the pivot mechanism, the desktop is subjected to the three extreme cases of loading at each free corner of the desktop. These loading cases and their corresponding deflections can be seen in Figure **??** below and are summarized in Table **??**

(a) Worst case loading scenario 1.

(b) FEA results for the desktop.

Figure 26: Loading Condition 1 and its corresponding FEA Results.

(a) Worst case loading scenario 2. (b) FEA results for the desktop.

Figure 27: Loading Condition 2 and its corresponding FEA Results.

(a) Worst case loading scenario 3. (b) FEA results for the desktop.

Figure 28: Loading Condition 3 and its corresponding FEA Results

TABLE VI: SUMMARY OF DEFLECTIONS

Loading Case	Max Deflection [mm]
Scenario 1	2.300E-03
Scenario 2	2.395E-03
Scenario 3	2.206E-03

From the FEA studies conducted, it can be concluded that the desktop will not deflect more than 5mm as per the clients specification.

4.4 Bed Automation Mechanism Design

The bed automation mechanism is the component of the bed that allows for the bed to be opened or closed through the use of a remote. The design process of the bed automation mechanism includes analytical, and numerical methods to ensure that the mechanical requirements of the project is met.

This section provides an outline of the bed automation system and each of its individual components. The automation system involves the use of two optical linear actuators, each attached to the left and right sides of the bed, respectively. One end of each actuator is mounted to a tab attached to the back of the standing frame while the other end is attached to a tab located at the back of the frame that holds the mattress. These actuators must be able to generate enough force and have enough stroke length to be able to fully open and close the bed. The components that will be manufactured are the mounts for the actuators. The actuator assembly is shown in Figure 29.

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Figure 29: Assembly of the bed automation system [18].

The top brackets for mounting the top end of the actuators are composed of 3/8” thick 3” x 3” mild steel angle irons that have been cut down to size to be able to properly mount the actuators. Angle iron was used due to it’s relatively low cost as well as ease of modification while having sufficient strength to withstand the forces that the actuators applies to the mounts. The angle iron was bolted down through weld nuts welded to the back of the standing frame to allow the standing frame to be flush with the wall. The top end of the actuator is fastened to the angle iron bracket with a shoulder bolt. The thickness of the angle iron was determined using FEA in Solidworks.

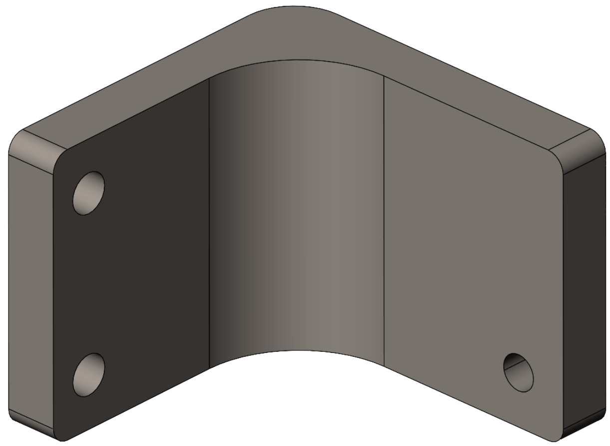

Figure 30: Top mounting bracket for actuators

The bottom brackets for mounting the bottom end of the actuators are composed of bent laser cut 3/8" mild steel plates. The bottom brackets were bolted to the back end of the bed frame since the bed frame already had threaded holes in that location which could be used instead of drilling brand new hole in the bed frame and potentially weakening the frame. The bottom end of the actuator is fastened to the bracket with a shoulder bolt. The thickness of the mount was determined using FEA in Solidworks.

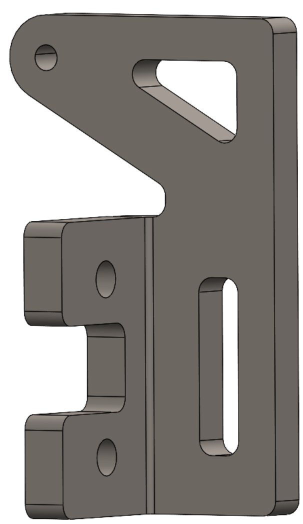

Figure 31: Bottom mounting bracket for actuators

Similar to the other mechanisms, numerous components of the bed automation mechanism are off the shelf components to save on cost and time. Specifically, the actuators, threaded bolts, shoulder bolts, and nuts are all off the shelf components. An assumption is made that all off the shelf components are tested by their respective manufacturers.

4.4.1 Analytical Analysis

The linear actuators were sourced by determining the amount of force that is required to lift the bed up when it is in the open configuration. It was estimated that the bed frame with a queen mattress weighs 200 lbs. The bed opening and closing mechanism is also assisted by springs attached near the pivot point of the bed and the forces imparted by the springs were also considered when determining the amount of force required for the actuators to produce. The entire assembly has 16 springs in total, with each spring having a spring constant of 9.75 lbs/inch. It was found that each actuator would need to impart 270 lbf to lift the bed and therefore, linear actuators able to impart 400 lbf were required on either side of the bed in order to reach a safety factor of 1.5.

4.4.2 Numerical Analysis

Similar to the other mechanisms, FEA was utilized for optimizing the design of the mounts for the actuators. This entailed iterative design involving incremental changes to the parameters of the design to reach an optimized design, as well as performing mesh convergence studies to ensure that the FEA study was carried out properly.

For each mount, two load cases were considered, which consisted of tensile loads of 400 lbf for both mounts when the actuators are used to close the bed while compressive loads of 400 lbf for both mounts were considered when the actuators are used to open the bed. The figures below shows the FEA results for each loading case for each mount. It is evident that for the top mounting bracket, the majority of the stress is located on the top bolt mounting hole. The maximum stress measured at this location for the tensile load case was 21560 psi which results in a safety factor of 1.7, while the stress was 21560 psi for the compressive load case which results in a safety factor of 1.7. It is also evident that for the bottom mounting bracket, the majority of the stress is located on the neck of the mount where the highest point of the bend is. The maximum stress measured at this location for the tensile load case was 24370 psi which results in safety factor of 1.5, while the stress was 24400 psi for the compressive load case which results in a safety factor of 1.5.

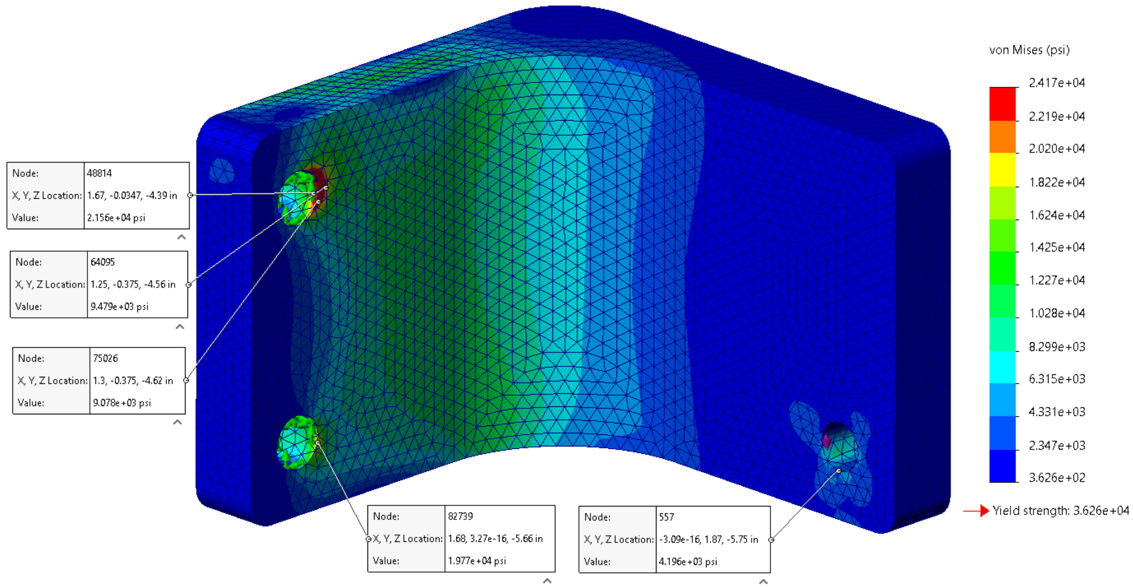

Figure 32: FEA results for tensile load case of the top mounting bracket

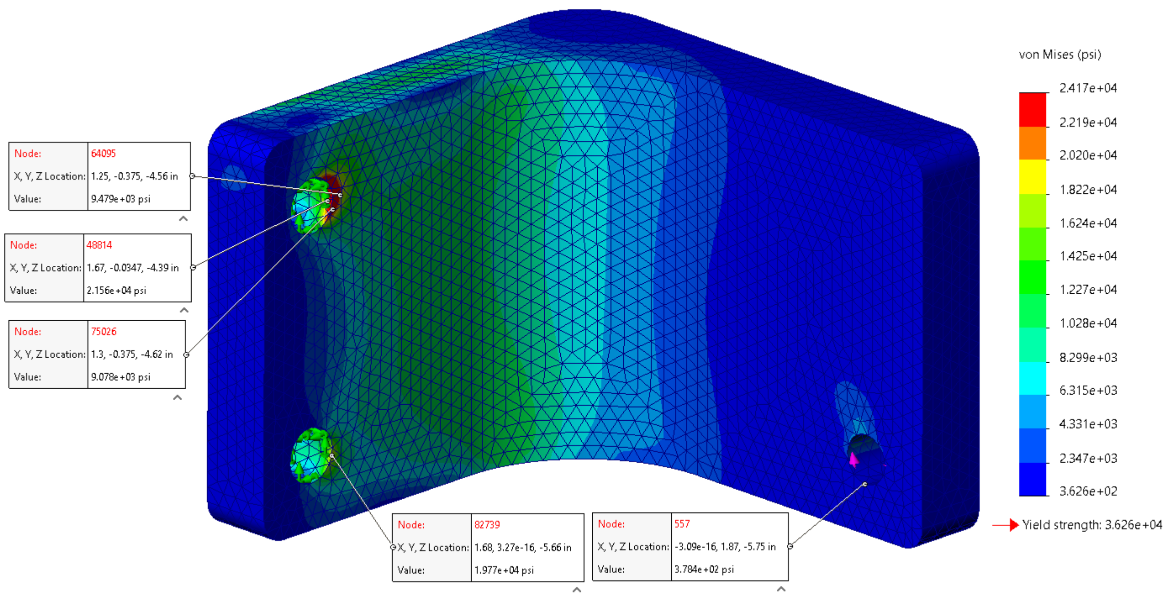

Figure 33: FEA results for compressive load case of the bottom mounting bracket

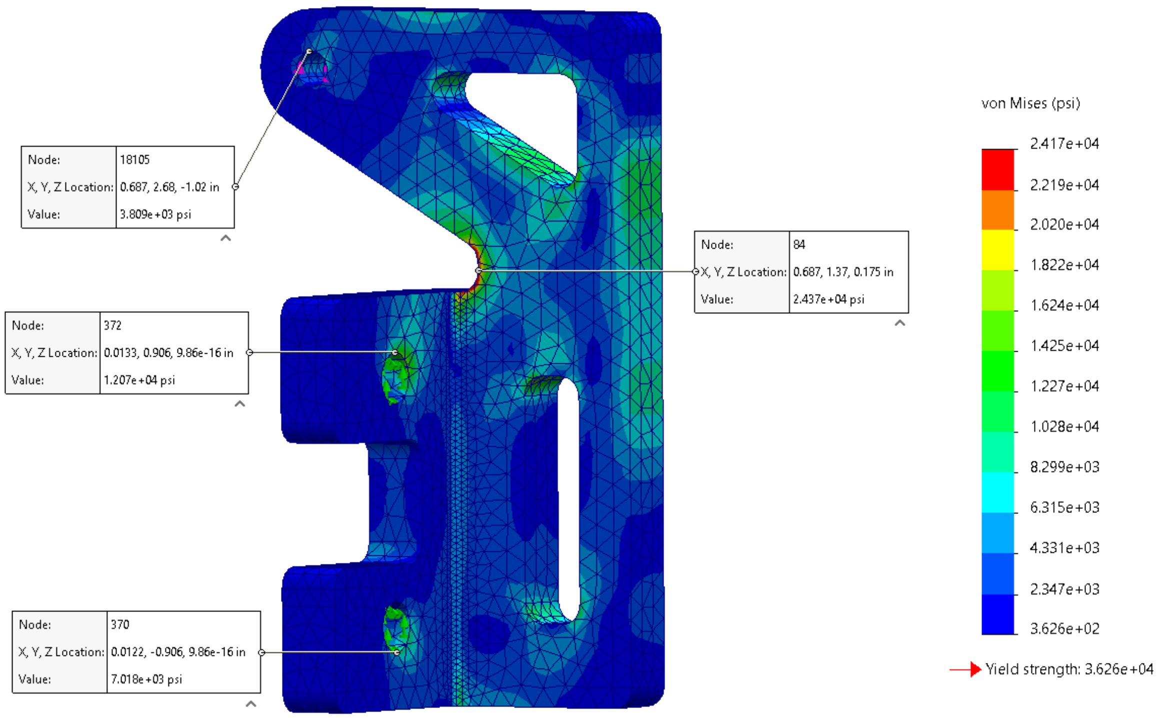

Figure 34: FEA results for tensile load case of the bottom mounting bracket

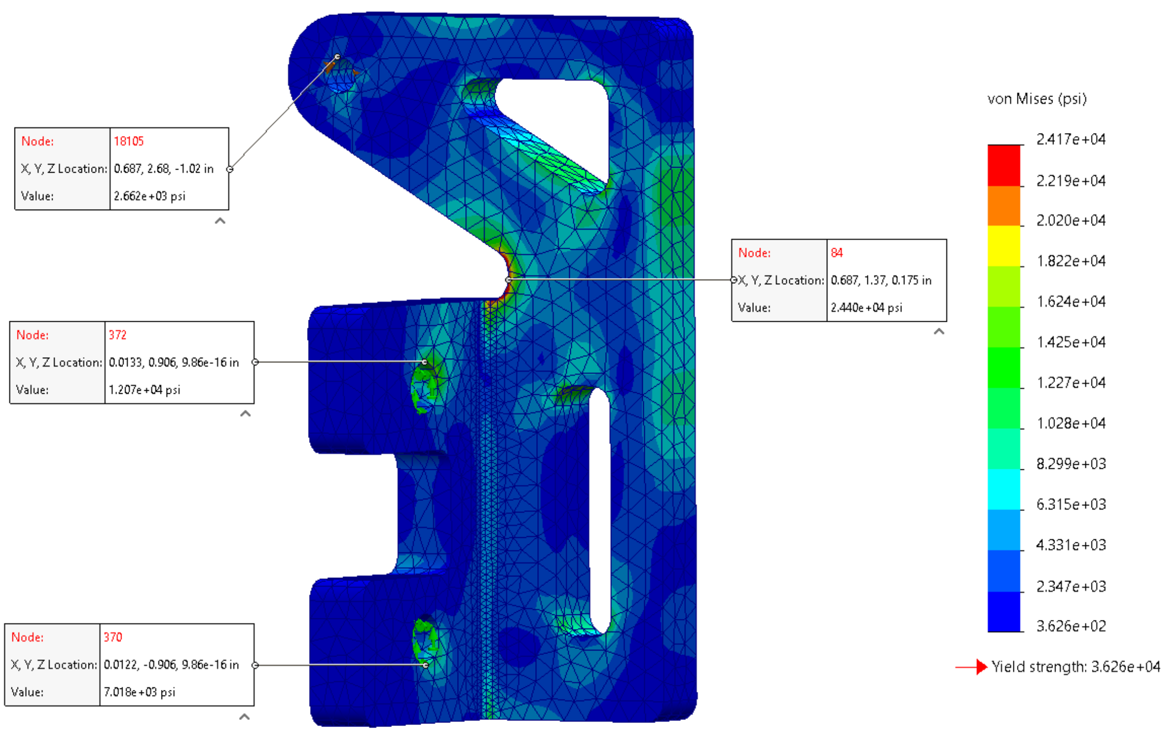

Figure 35: FEA results for compressive load case of the bottom mounting bracket

The thickness of the both the angle iron for the top mounting bracket and the steel sheet used for the bottom mounting bracket were determined by iterative FEA studies with a range of available appropriate steel sizes. The final material thickness that were chosen for both the support brackets were 3/8”. In order to gain more confidence in the results obtained from the FEA, mesh convergence studies were carried out for all load cases for both mounts. The points that were probed were the exact same points that were probed in Figures 32, 33, 34, and 35. The results of these convergence studies are shown in the Appendix.

5 Conclusion and Recommendations

The main objective of the project is to work with Wood Products Unlimited (WPU) to automate their brand new wall bed product, called the Embed, and design a compatible desk attachment that will meet their consumers' needs. The process of opening and closing the bed must be automated and the desk attachment must be detachable and automated. The desk attachment is to be usable in multiple configurations whether the bed is open or closed.

The target demographic of the Embed products are elderly people and people who are looking to downsize the space they are living in. With the given demographic, it is important that both the bed and the detachable desk are easy to operate and can be installed by a single person. Safety is also paramount for the design of the bed and the detachable desk. The automation of the bed must operate under 'dead-man switch' conditions and proper measures must be set in place to ensure that the opening and closing of the bed, as well as the full motion of the desk attachment will never result in harm towards its users.

The Embed was designed by WPU with longevity in mind and both the desk automation device and the desk attachment will be designed to have a minimum life of 10 years. The desk attachment is required to be able to withstand up to 60 lbs of force applied at the furthest point along the desk. Furthermore, WPU also wishes for the desk attachment to be compatible with their competitor's wall beds.

5.1 Design Summary

The final product provided to the client consists of a fully designed desk attachment for the Embed as well as a automation system for the opening and closing motion of the wall bed. The desk accessory consists of the following:

- A lifting column that utilizes a linear actuator to allow 18in of vertical movement for the desktop.
- A hinge attachment between the lifting column and wall bed frame to prevent the desk accessory from hindering the performance of the Embed.
- A flanged bearing to allow 180° rotational movement of the desktop.
- A support structure embedded into the desktop to prevent deflection greater than 5mm.

The total cost of the desk accessory is found to be $645.31.

The bed automation system consists of:

5.2 Recommendations for Future Work

With the completion of this project, there are some further considerations and recommendations that would be beneficial when building and prototype the team's design. One major additions that could be made is adding sensors to the automation systems such that they are able to detect if a person is occupying the bed.

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7 Appendix

A Detailed Cost Analysis

SubAssembly	Part	Quantity	length	Cost/unit	Cost
Pivot	Main Branch	2	29	0.104722	$6.80
	Side branch	4	9.625	0.104722	$4.52
	Machined Steel Rod	1	3	1.1185	$3.76
Desktop	One Desktop Half	1	1	7.0775	$10.78
	Woodscrews	8		0.0854	$0.68
Lift column	Linear Actuator	1		190	$190.00
	Encloure	1		25	$25.00
	Enclosure Cap	1		10	$10.00
	Support Bracket	1		10	$10.00
	Support Bracket Spacer	2		5	$5.00
	Vertical Column	1		30	$30.00
	Pivot Plate	1		5	$5.00
	Linear Guideway	1		129.95	$129.95
	Linear Rail	1		109.19	$109.19
	Flanged Bushing	2		65.42	$65.42
	Lower Clevis Pin	1		$0.59	$0.59
	Upper Clevis Pin	1		$0.41	$0.41
	Hinge	2		14.93	$14.93
				Total	$622.03
Bed Automation	Optical Feedback Linear Actuators	2		210	$420.00
	Low-Carbon Steel 90 Degree Angle	2		3.17	$6.34
	18-8 Stainless Steel Shoulder Screw	4		11.41	$45.64
	18-8 Stainless Steel Thin Nylon-Insert Locknut	4		0.14	$0.56
	Steel Round-Base Weld Nut	4		0.17	$0.68
	Zinc Yellow-Chromate Plated Hex Head Screw	4		0.23	$0.92
	Zinc Yellow-Chromate Plated Hex Head Screw	4		0.4	$1.60
	Aluminum Unthreaded Spacer	2		1.52	$3.04
	Steel plates	2		15	$30.00
	Two Channel Remote Control System	1		60	$60.00
				Total	$568.78

B FEA Mesh Convergence Plots

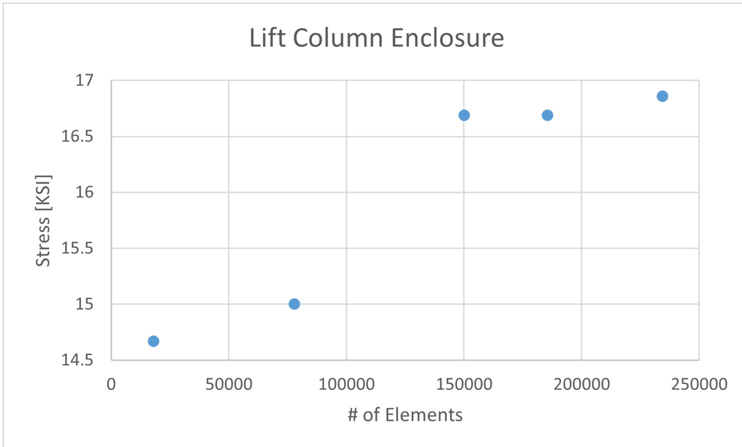

Figure B.A1: Mesh convergence plot for lift column enclosure

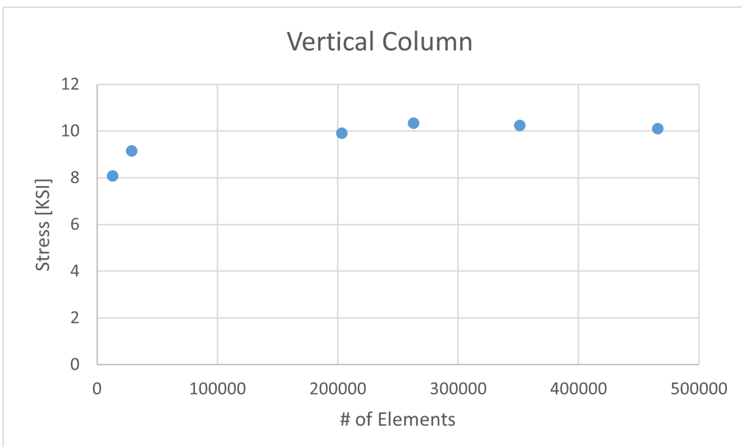

Figure B.A2: Mesh convergence plot for vertical column

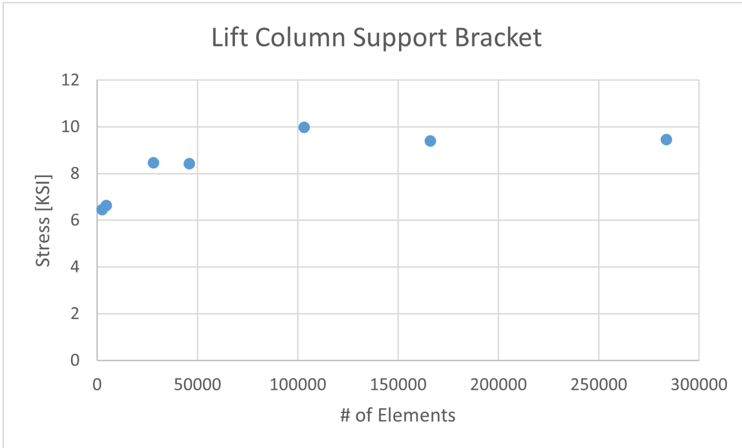

Figure B.A3: Mesh convergence plot for lift column support bracket

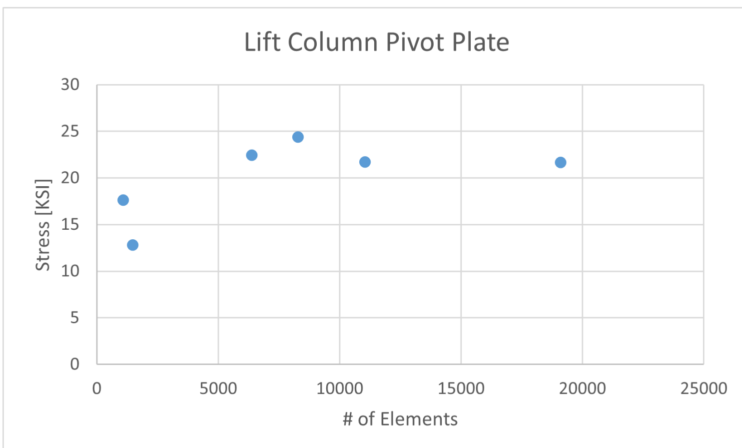

Figure B.A4: Mesh convergence plot for lift column pivot plate

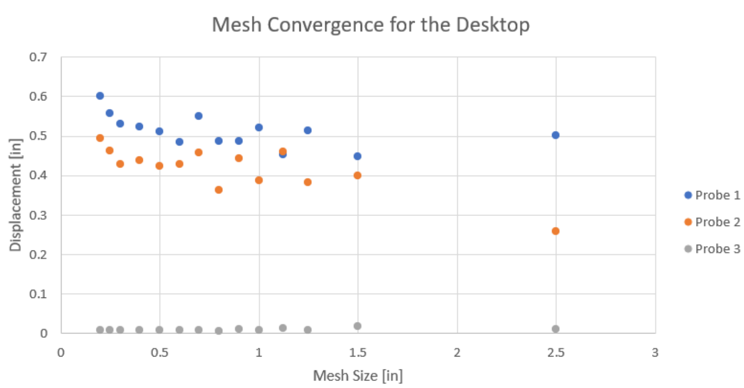

Figure B.A5: Mesh Convergence Plot for the Desktop.

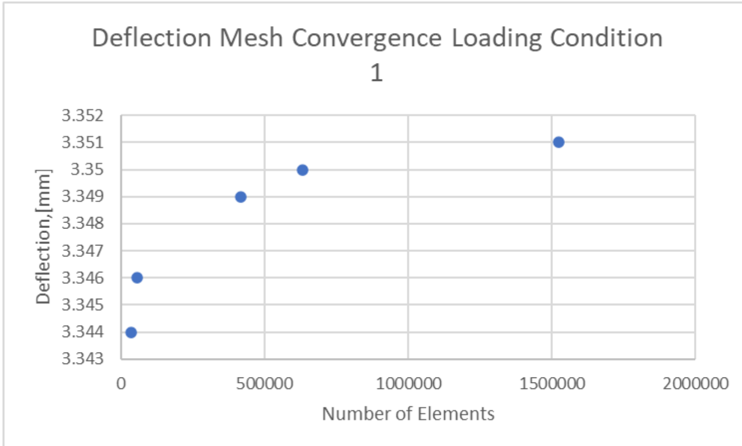

Figure B.A6: Mesh Convergence Plot for the Desktop Support Structure in 1st Loading Condition

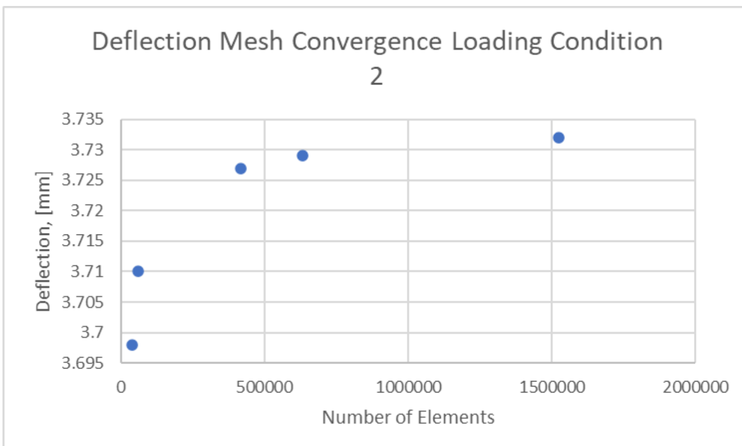

Figure B.A7: Mesh Convergence Plot for the Desktop Support Structure in 2nd Loading Condition

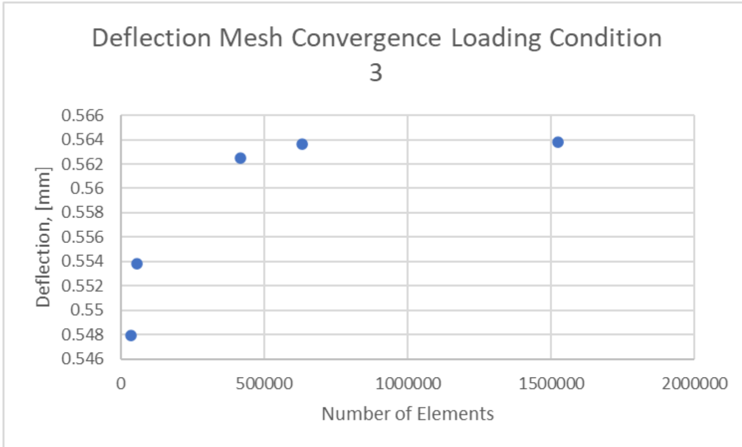

Figure B.A8: Mesh Convergence Plot for the Desktop Support Structure in 3rd Loading Condition

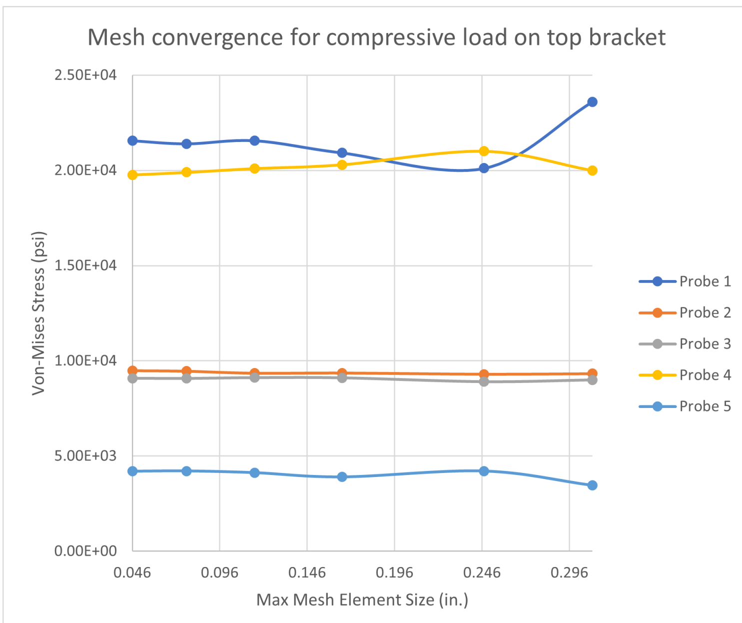

Figure B.A9: Mesh convergence plot for tensile load on top bracket

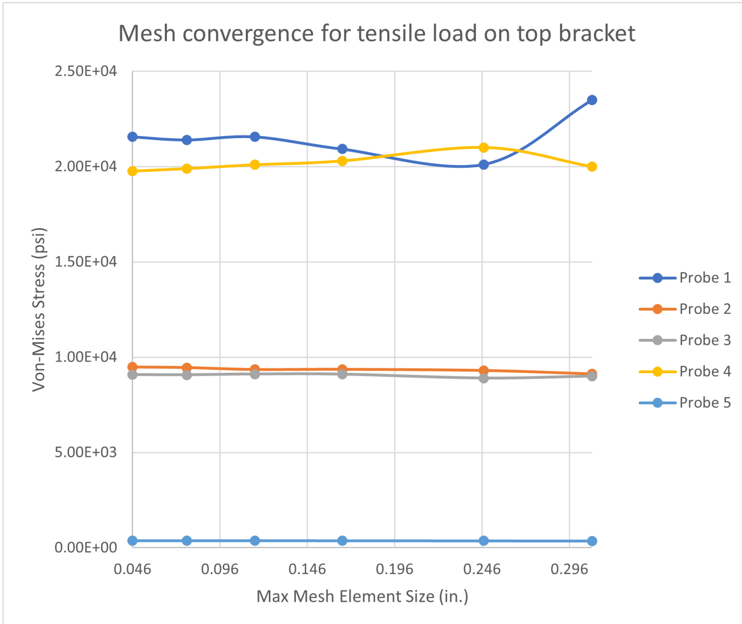

Figure B.A10: Mesh convergence plot for compressive load on top bracket