Assisted Bench Press

A Baccalaureate thesis submitted to the
Department of Mechanical and Materials Engineering
College of Engineering and Applied Science
University of Cincinnati

in partial fulfillment of the
requirements for the degree of

Bachelor of Science

in Mechanical Engineering Technology

by

Brian T. Wirthlin

April 2018

Thesis Advisor:

Professor Moise Cummings

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The barbell bench press is widely considered to be the ultimate test of overall upper body strength, and it offers a wide variety of benefits to those who use it in their training routines. It also presents a danger that most other lifts do not; if a lifter drops the barbell then he or she may get trapped between the weight of the bar and the bench itself. It is not uncommon for a trained lifter to have experienced this at one point or another. Often times the only way to get out of the trap is to roll the bar off of oneself, or to tilt the bar from side to side in order to drop the weights. This failure can possibly result in severe injury to the head or neck, and occasionally ends in fatality for the lifter. The easiest way to avoid this problem is to have another person spotting the lifter for the entirety of their repetitions. But this presents problems for those who work out by themselves at home, and those who cannot afford high end gym equipment with safety features.

This past summer, I spent two months serving in Malawi as a volunteer missionary while doing engineering design work on the side. The man I lived with was an American, and he had an old bench press in a small brick house in the back of his property. He had never used it while in Malawi because there was no one around to spot him, and he wasn't able to communicate with the locals well enough to explain the help he needed. This is what sparked the idea for the assisted bench press machine. This design is meant to serve as a simple, affordable option for those who work out alone, and may need that small additional spotting force to complete their final repletion. It uses existing equipment and materials that would be easily accessible to people in all different areas of the world, and it can be easily assembled by the end user. This solution will provide peace of mind to those who bench press in their routine, knowing that there is something there to help them in an emergency situation.

PROBLEM DEFINITION AND RESEARCH

The barbell bench press is one of the most effective weightlifting techniques for developing a healthy upper body strength, but there is also a serious risk of injury if the bar falls on the lifter (1). To combat this risk, there should always be a person there to assist the lifter if he or she fails to return the bar to its racked position. If no one is available to assist the lifter, he or she runs the risk of serious injury or fatality if they fail in their lift.

BACKGROUND

The barbell press began in 1899 with George Hackenshmidt, while lying on his back on the ground, he rolled a barbell over his body and pressed 350lb over his head. This demonstration of strength created a wide popularity in this new lift. By the 1930's, it became much more common to lie on a wooden box or a bench, resulting in the name that we now know as the bench press (2). Initially a spotter was needed to assist the lifter in setting up for the exercise, watching out for failure, and removing the weight. Nowadays when using a modern bench press, the lifter is able to secure the bar in a rack that sits directly above their head. This removes the need for a spotter to help setup the exercise and unload the weights, but what happens when the lifter fails and no one is there to help?

RESEARCH

SCOPE OF THE PROBLEM

The bench press is one of the most common weightlifting techniques, and arguably the most beneficial upper body exercise. As a compound exercise, this press works a large amount of your upper body muscles (pectoralis, deltoids, triceps, and biceps), and helps increase bone density. It also helps increase your overall endurance, lowers cholesterol, and helps your body process sugar (3). With all of these benefits available, everyone should have the opportunity to perform this exercise in a safe and comfortable manner.

Barbell lifts can be very dangerous and often result in injury if not done properly. Sometimes these failures can even be fatal. In December 2010, a 16-year-old high school football player in Wisconsin passed away after dropping a barbell on his neck while performing a bench press in his basement (4). I want to come up with a solution that prevents any further incidents such as this from happening.

CURRENT STATE OF THE ART

One common solution has been the smith machine, which can be used for many barbell lifts, such as bench press and squat. The barbell is attached to two guide rails that direct the motion of the bar in a vertical direction, and both a flat bench or an incline bench can be used. If the user gets stuck on a lift, they are able to rotate the bar and lock it into place on the guide rail. This is an effective safety feature, but it removes some key benefits of the bench press exercise, such as muscle stability and overall endurance.

Another recent solution is the Maxx Bench, which has a gravity release foot lever that lowers the bench so that the barbell can rest safely on two side rails (5). This is a very effective solution because it utilizes the downward force of gravity instead of an upward force on the bar. Although, this solution does not allow someone to perform an incline press, only a standard press on a flat bench. It also cannot be adapted to other exercises that do not use a bench such as the barbell squat.

Neither of these solutions provide any upward force to assist the lifter, which is one benefit of having an actual spotter. If you are slowly pressing the bar up to the racked position, a spotter can provide a small amount of upward force on the bar to help you complete the last repetition. This is one useful feature that is being missed by previous solutions. Most of these solutions are very expensive as well, and do not utilize existing equipment in a home or gym.

END USER

The customer is any person who works out at home and wishes to perform a barbell bench press. This is also geared toward people that doesn't want to spend an excessive amount of money on equipment, but still want to perform safe lifts at home. This does not provide an emergency catch for someone who cannot complete the lift, but acts as a mechanical spotter which can assist the lifter to the racked position. Ultimately, this product serves a person who works out alone and does not have a person available for assistance.

CONCLUSIONS AND SUMMARY OF RESEARCH

There are several solutions that help reduce the probability of injury during a bench press, but many of them can be quite expensive and require all new equipment to be purchased. Some solutions provide good safety features, but lose some of the primary benefits of performing a barbell lift. Other solutions allow the lifter to use a free bar, but only offer and emergency catch which does not allow the lifter to complete the repetition. My solution will allow the bar to move freely until the spotting feature is activated, and the spotting upward force will assist the lifter in returning the bar to the racked position. The system will also use common gym equipment to reduce the cost of the product.

CUSTOMER FEATURES

There are several features and requirements needed for the final product:

- Create a system which provides an upward "spotting" force on the barbell
- Simple setup using existing/easily accessible equipment
- Keep bulk and clutter to a minimum for at-home use
- Safety release must be operable by the person lifting the weight
- Must be safe for the lifter and others in proximity to the system

PRODUCT OBJECTIVES

The product will contain a counterweight system which can be used with existing weights that the customer may have access to. This will reduce the cost of fabricating the product and reduce the final cost for the customer. It will also have a simple setup by not using complex equipment, and be operable by a single person. There will be a foot release for the counterweight, and as it falls it will transfer an upward force to the bar. Safety features must be included so that the dropping weight does not pose a danger to the user or others.

QUALITY FUNCTION DEPLOYMENT

			Engineering Requirements (units)														Customer Satisfaction Rating (0.00 - 1.00)			
		Importance wt.	Upward Force (lbf)	Foot Release Force (lbf)	Setup Time (Sec)	Low Impact Drop (lb*ft/sec)	Weight of Stand (lb)	Space Needed (ft^2)	Stand Strength (lbf)	Time to Catch (sec)										
	Customer Requirements		1	2	3	4	5	6	7	8	9	10	11	12	13	14	CP	A	B	C
1	Provide Upward Force on Bar	0.25	9				1		9	3										
2	Low Cost	0.20			1		3	3	3											
3	Foot Release	0.15		9						3										
4	Use Existing Equipment	0.10	1		3			3												
5	No Cumbersome Equipment	0.10					3	9	1											
6	Easy Setup	0.10			9		1	1												
7	Safe to Use	0.10	1			9			3	9										
8																				
9																				
10																				
	Total Importance	1.00																		
	Engineering requirement importance		2.45	1.35	1.4	0.9	1.25	1.9	3.25	2.1										
Performance	Current Product		N/A	N/A	N/A	N/A	100	N/A	400	N/A										
	competitor A																			
	competitor B																			
	competitor C																			
	New Product Targets		150	5	30		100	15	400	1										

Table 1. House of Quality

Interaction Matrix															
	Engineering Requirements	Upward Force (lbf)	Foot Release Force (lbf)	Setup Time (Sec)	Low Impact Drop (lb*ft/sec)	Weight of Stand (lb)	Space Needed (ft^2)	Stand Strength (lbf)	Time to Catch (sec)	0	0	0	0	0	0
Engineering Requirements		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Upward Force (lbf)	1				-9			9	3						
Foot Release Force (lbf)	2								3						
Setup Time (Sec)	3														
Low Impact Drop (lb*ft/sec)	4							1							
Weight of Stand (lb)	5							1							
Space Needed (ft^2)	6							-1							
Stand Strength (lbf)	7														
Time to Catch (sec)	8														
0	9														
0	10														
0	11														
0	12														
0	13														
0	14														

Table 2. Interaction Matrix

Using the house of quality method for selecting engineering requirements, it was determined that the strength of the stand and the ability to provide a sufficient upward force were the two most important requirements. When selecting a design concept, it will be important to ensure that it is able to hold a barbell of up to 400lbs, and support a system which provides a reliable upward for onto the bar in an emergency situation.

DESIGN

DESIGN ALTERNATIVES AND SELECTION

Three concepts were generated for the assisted barbell press machine. The first concept is to use two safety rails which are actuated upwards by a hydraulic press (Figure 1). A foot pedal could be used in case of emergency, and once pressed it would actuate the hydraulic press and force the safety rails upwards to catch the bar. This would be a relatively compact design, but the hydraulics would have to have at least a two-foot stroke to return the bar to the racked position, therefore making it more of a safety catch than a spotting force. This concept would also be expensive, and have the potential for the hydraulics to malfunction when they are required in an emergency situation.

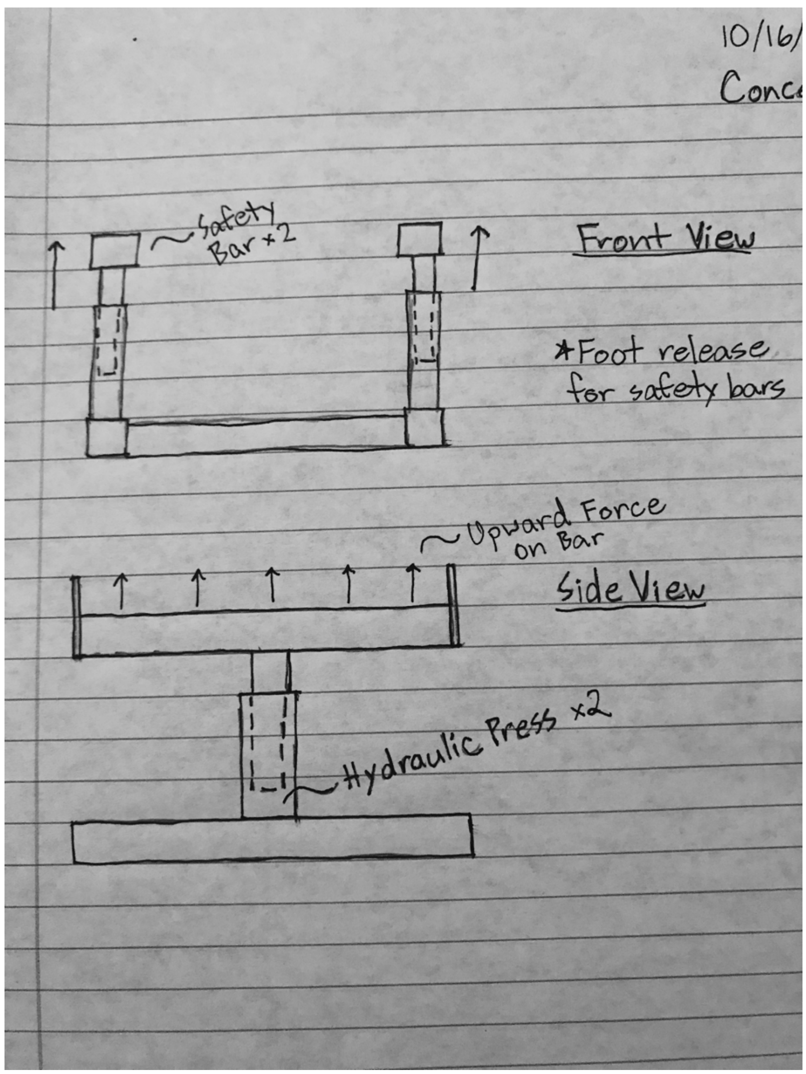


Figure 1. Design Concept 1

Concept 2 implements the idea of using a counterweight system to employ the upward force onto the barbell (Figure 2). The idea is to have two safety rails which are attached within guided slots in each of the pillars. A cable is then attached to each of these safety rails, and runs through a pulley system over the top of each pillar and is attached to a counterweight on the backside. When the foot release is actuated the two counterweights will fall, and in turn, pull the safety bars upwards to catch the barbell. By using the force of gravity, this system would provide a reliable upward force to the bar. Since there are two counterweights, this presents the issue of the falling weights being out of sync, or only one of the weights falling and therefore flipping the barbell to one side.

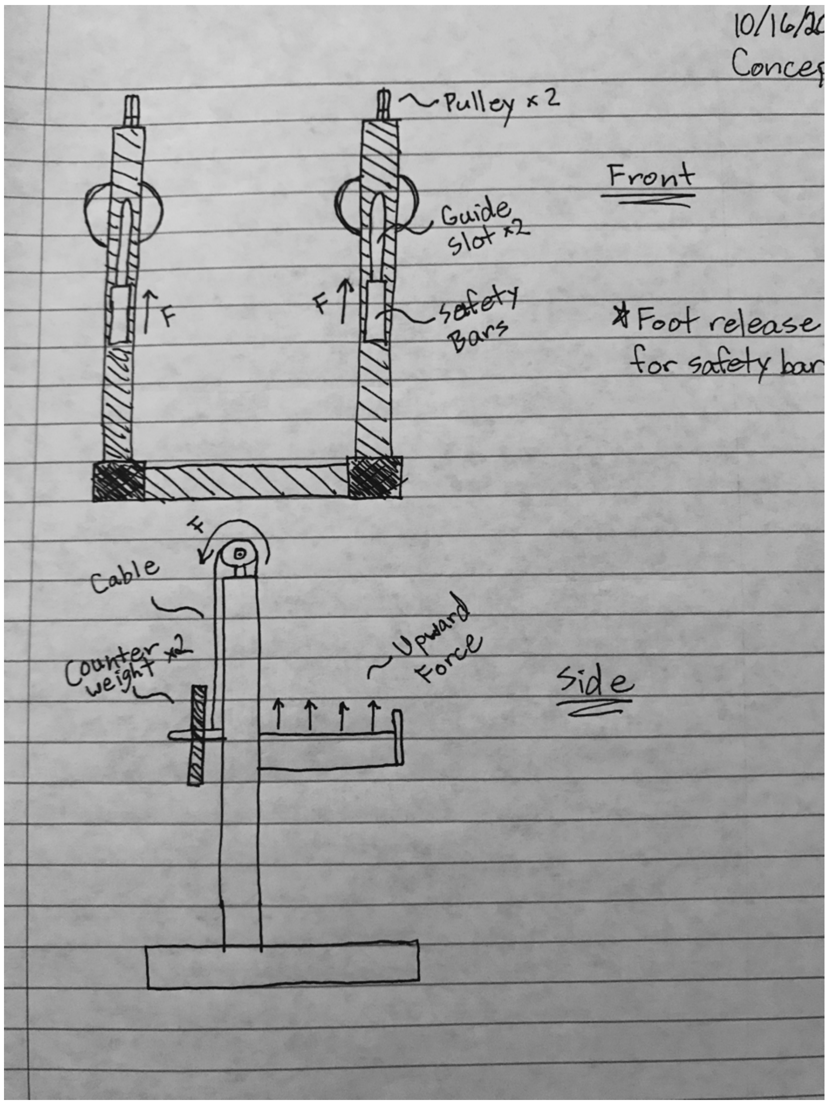


Figure 2. Design Concept 2

Concept 3 utilizes a similar counterweight system as Concept 2, except this design only uses one counterweight which is placed directly behind the lifter in between the two pillars (Figure 3). This counterweight is loaded onto a collar slider which is mounter on a vertical steel post. Two cables would be attached to the two ends on the barbell, and then be run through pulleys over the top of the two posts and attach to the counterweight slider. When the foot release is activated, the counterweight falls and therefore pulls upwards on the bar through the cables.

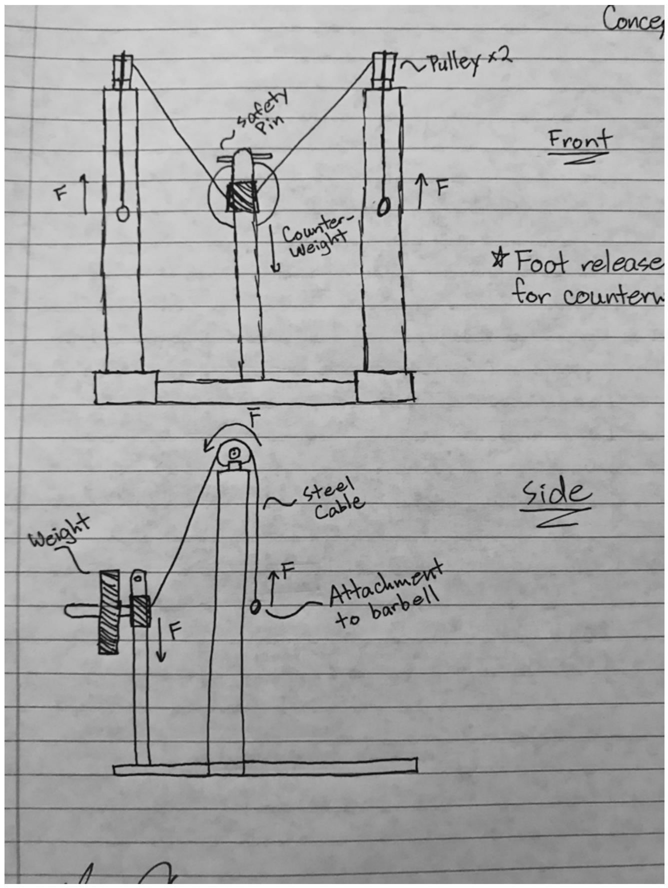


Figure 3. Design Concept 3

Ultimately, Concept 3 was selected as the best design due to its high reliability resulting from the use of a falling counterweight. This design also uses simple and easily accessible components which fulfills and meets the needs of the identified end user. The upward force will be equivalent on both sides of the barbell since it is attached to a single counterweight, which makes it the safest option for ensuring that the lifter can successfully return the barbell to the racked position in a controlled manner.

DRAWINGS

The design concept uses wooden 2x4s and 4x4s to make up the frame for the bench press. It also calls for four pulleys in total; two for the counterweight system and two for the foot release. The counterweight collar assembly is held up by two bolts which rest on a perpendicular press fit pin at the top of the post (refer to Figure 21). When the collar is rotated on the post, the two bolts unhook from the perpendicular pin and the counterweight begins to fall downwards. The foot release consists of a cable which attaches to a peg on the counterweight slider, and wraps around the outside of the pillar and attaches to the user's foot. When the user needs an upward spotting force, he or she simply pushes their foot forward and the counterweight twists on the post and releases, falling downward and causing the cables to pull upward on the barbell.

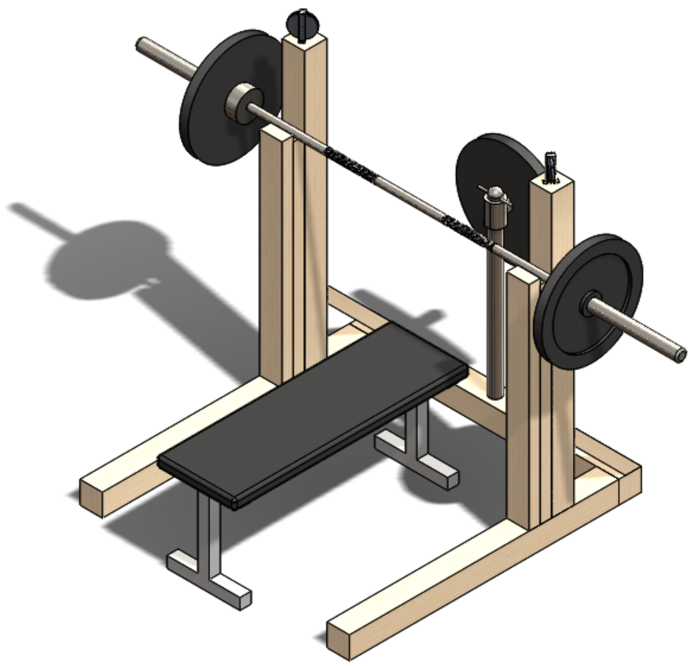


Figure 4. Solid Assembly Isometric View
(For addition views of the 3D model refer to Appendix A)

10' WOOD 4x4	2
10' WOOD 2x4	2
PULLEY	4
3' STEEL TUBE	1
COLLAR ASSY	1
STEEL CABLE	2
SCREWS	75
3/8 BOLT 6"	3

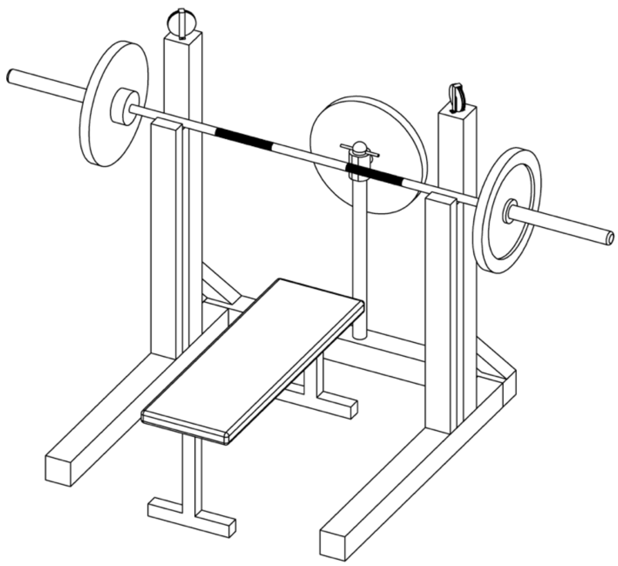


Figure 5. Manufacture Drawing Assembly

Standard 2x4s and 4x4s are cut to the specified dimensions to assemble the frame for the bench press. The 50" 4x4s create the pillars upon which the pulleys are mounted, and the 2x4s create the rack for the barbell.

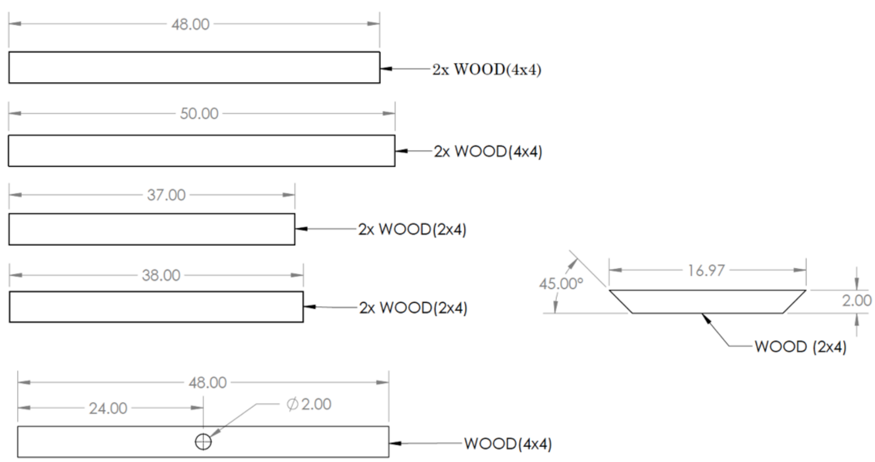


Figure 6. Manufacturing Drawing Components (1)

The open pulleys are to be mounted along with a piece of sheet metal bent over the top of the pulley track. This serves the purpose of keeping the cables on the pulley at all times. The steel collar assembly must have a thru-hole which is able to slide along the outside diameter of the post, and have a peg of sufficient length to mount standard weights.

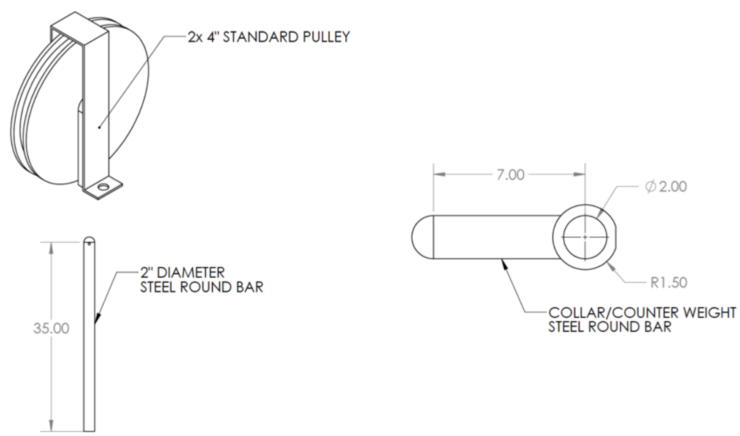
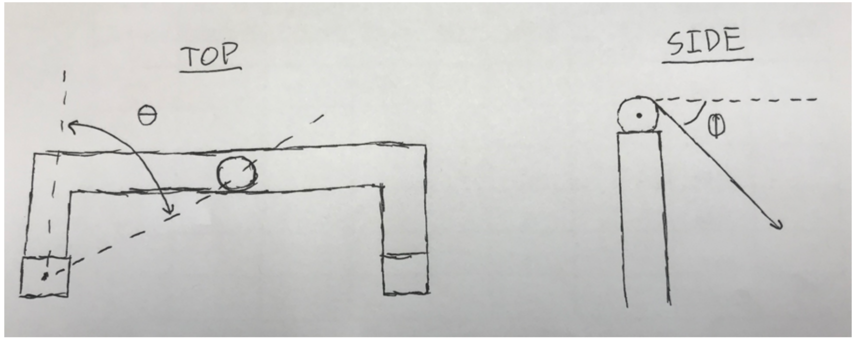


Figure 7. Manufacturing Drawing Components (2)

LOADING CONDITIONS

An equation was derived to determine the tension in the cable which would be created by the counterweight. The independent variables used in this derivation were the mass of the counterweight (m), and the two angles of the cable, theta (θ) and phi (ϕ). Once the tension was determined, the resultant force perpendicular to the pillar was also determined. Using this resultant force, the moment at the base of the pillar was found, and using the moment of inertia and the distance from the neutral axis, the bending stress on the pillar was determined $\left[\delta = \frac{My}{I}\right]$. The same process was then used on the post using the resultant force from the cable tension. The shear force also needed to be estimated using the cross-sectional area of the bolt head, washer, and the weld compound directly above the press-fitted pin (Figure 16). Figure 10 shows these hand calculations and the results using a 45lb counterweight:



Theta = 61.4°   *Phi = 57.7°*   *m = 45 lb.*

Cable Tension:

$$T = \frac{mg}{2\cos(90-\phi)} = 26.62\ lb$$

Max Force On Each Pillar:

$$F_R = \sqrt{(Tsin\theta)^2 + (Tcos\theta)^2 - (Tsin\phi + T)^2} = 14.22\ lbf$$

Force On Post:

$$P = 2Tcos\theta = 25.48\ lbf$$

Estimated Shear Force of Pins:

$$P = \frac{F}{A} = 127\ psi \sim 0.875\ MPa$$

Maximum Bar Weight:

$$400\ lbs$$

Figure 8. Hand Calculations

The equations from Figure 8 were plugged in to an Excel spreadsheet (Figure 9), where the mass of the counterweight and cable angles could be adjusted to change the results. The bending stress could also be calculated as the dimensions of the pillars and the post were adjusted. The bending stress calculations are based on a 2" outside diameter pipe with 3/16" walls for the post, and a 4" x 4" piece of wood for each pillar.

INPUT	
Cable Angle (phi)	57.7
Cable Angle (theta)	61.4
Mass Couter-Weight (lb)	45
POST (Hand Calculation)	
Tension (lbf)	26.62
Max Force on Post (lbf)	25.48
Moment (lbf*in)	815.51
Stress/Post (psi)	1038.33
Static Safety Factor (4)	**4153.34**
PILLAR (Hand Calculation)	
Resultant Force/Pillar (lbf)	14.22
Moment (lbf*in)	768.09
Stress/Pillar (psi)	18.00
Impact Safety Factor (12)	**216.03**

Table 3. Hand Calculation Results

Two different safety factors were used in this design. For the two pillars, a safety factor of 12 was used to account for the impact force from the falling counterweight. When the weight falls, it has potential to drop for a few inches before the cable becomes taut. Once it reaches this point, the two pillars will experience an impact force coming from the applied tension. Therefore, a safety factor of 12 should account for the impact applied to the two pillars. For the post, a safety factor of 4 was selected to account for the repeated loading. This part of the system never experiences a direct impact like the two pillars do, and it has free range of motion in the vertical direction. But the post does experience the repeated force of the weight trying to swing inwards toward the two pillars and the lifter. A safety factor of 4 should be sufficient to hold up to the repeated tension force from the counterweight.

DESIGN ANALYSIS

After performing these hand calculations, it was important to verify the results using computer software. Solidworks was used to perform finite element analysis on both the pillars and the post. Using the cable tension with a 45lb weight, a 26.6lb tension force was applied to the pillar in the direction of the cable and the same force was applied to the post in the direction of the cable. The results were then multiplied by 12 and 4 to account for the safety factors which were previously determined. Figures 9 and 10 show the results of the Solidworks tests:

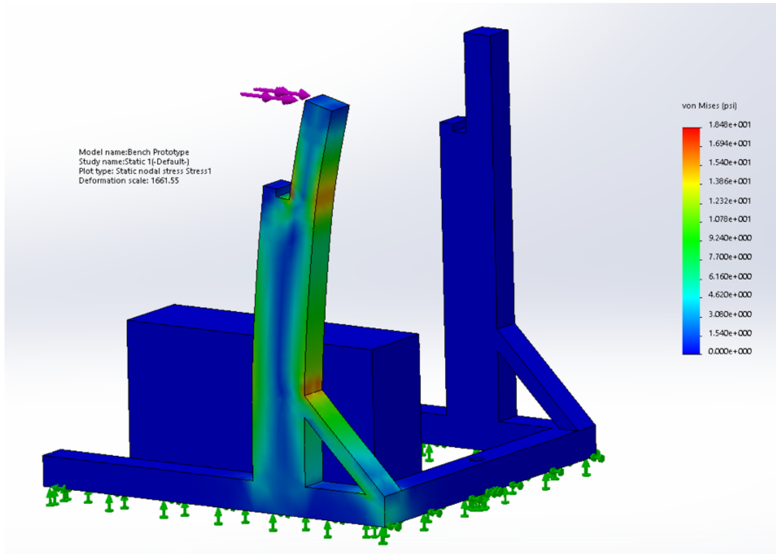


Figure 9. Finite Element Analysis (1)

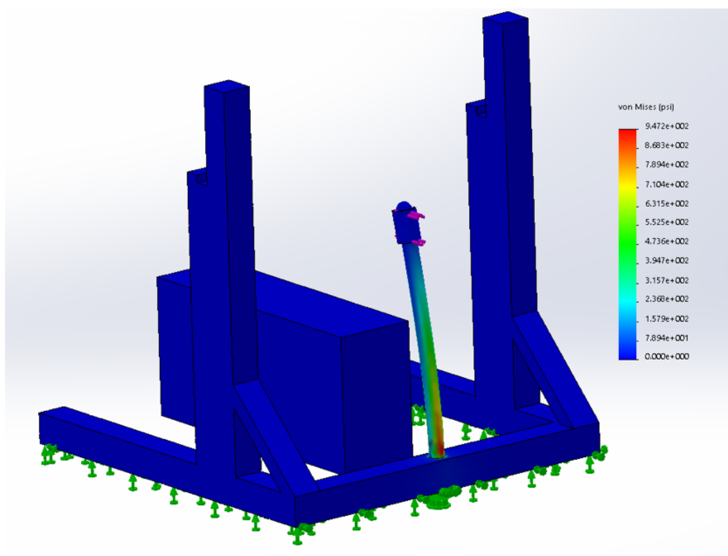


Figure 10. Finite Element Analysis (2)

Comparing the results from the hand calculations to the Solidworks results, the predicted stress values were very similar. This provided verification and presented final values which could be used in the final materials selection. The pillars each must to be able to withstand roughly 220 psi of bending stress, and the post must to be able to withstand roughly 4,200 psi of bending stress. The final material selected for the pillar was pine wood which has a maximum bending stress of approximately 1438 psi, and the post was made of carbon steel which has an estimated bending stress of 7125 psi.

INPUT				
Cable Angle (phi)	57.7		Post Height (in)	32
Cable Angle (theta)	61.4		Diameter (in)	2
Mass Couter-Weight (lb)	45			
POST (Hand Calculation)			**POST (Solidworks)**	
Tension (lbf)	26.62			
Max Force on Post (lbf)	25.48			
Moment (lbf*in)	815.51			
Stress/Post (psi)	1038.33		Stress/Post (psi)	947.22
Static Safety Factor (4)	**4153.34**		**Safety Factor (4)**	**3788.88**
PILLAR (Hand Calculation)			**PILLAR (Solidworks)**	
Resultant Force/Pillar (lbf)	14.22			
Moment (lbf*in)	768.09			
Stress/Pillar (psi)	18.00		Stress/Pillar (psi)	18.48
Impact Safety Factor (12)	**216.03**		**Safety Factor (12)**	**221.76**

Table 4. FEA Verification

COMPONENT SELECTION

The first selected component was a cast iron floor flange for a 2" pipe. This offered four bolt holes which could be used to mount to the frame of the bench press. The component would be used to hold the post vertically for the counterweight-slider assembly.

Figure 11. Floor Flange

The next components selected were the pulleys. Two 3” diameter pulleys were used on the tops of the two pillars for the cables attached to the counterweight. These two pulleys would also be mounted with a bent piece of sheet metal over the top of the track in order to keep the pulley cables in place. The two smaller 1.5” diameter pulleys would be used for the foot release system. They would be mounted to the outside of the pillar, and the foot release cable would run through both pulleys to attach the users foot to the end of the peg on the counterweight.

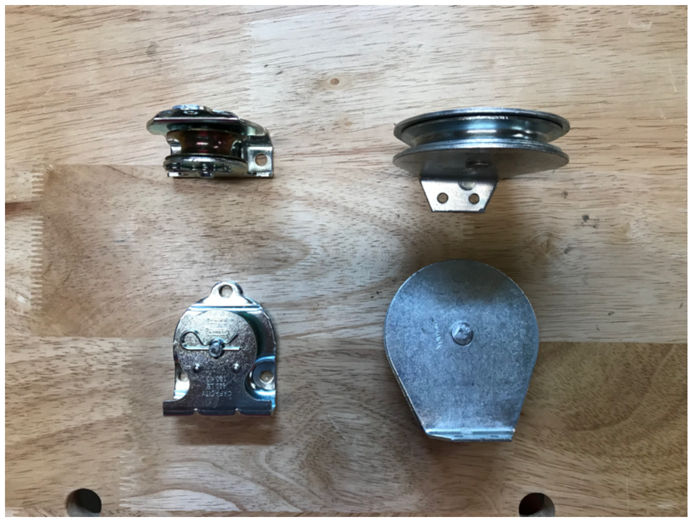


Figure 12. Pulleys

Two 6’ steel cables were selected to be attached between the counterweight and the barbell. Each one has a maximum force rating of 800lbs, which is more than sufficient for this application. The length of the cables and the height of the pillars were determined by the required drop height of the counterweight (refer to Appendix B).

Figure 13. Cables

The 2” diameter post was made from a cast steel pipe which was cut to 36” in length. A 6” 3/8 bolt was press fit through the top of the post to serve as a shelf to hook the collar assembly on to.

Figure 14. Counterweight Post

The collar assembly was created using a reducing tee fitting (Figure 15). The diameter of the main section is ¼” larger than the outside diameter of the pipe, and the threads on the inside of the fitting were filled in using JB Welding compound. Once the compound was sanded and smoothed down, the fitting was able to easily slide up and down on the cast steel pipe. The reducer was used to attach a 6” long 1-1/2” diameter nipple which could be used to mount the counterweight. This nipple is referred to as the peg in this system.

Two 6” long 3/8 bolts, with ¾” washers welded to the head, were used for the hooking system. First, two divots were cut out on the sides of the tee-fitting with a grinder to provide a place for the bolts to rest. A 3/8” gap was placed between the bottom of the washers and the top surface of the reducing-tee to provide room for the assembly to hook onto the press-fit pin. JB Welding Compound was used to secure the bolts to the side of the fitting, and two nuts and two washers were placed on the ends of the bolts and secured them to the bottom surface of the reducing tee. This allows the force to be placed on to the bottom washers, and helps prevent the bolts from shearing off under extreme weights.

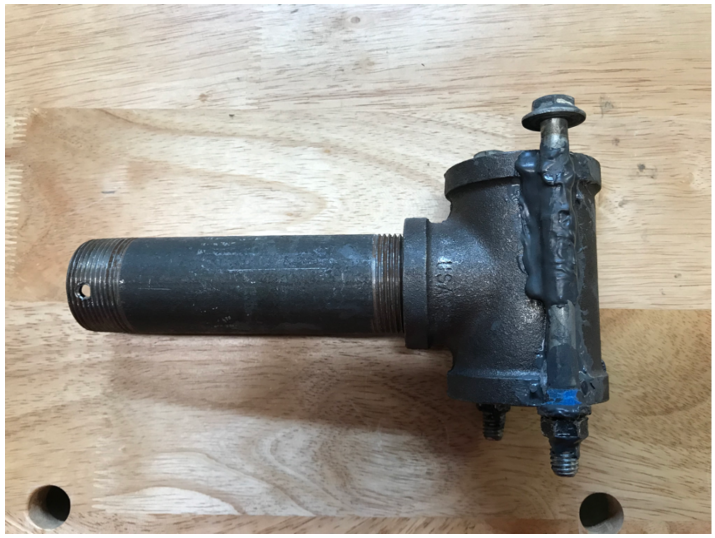


Figure 15. Collar Assembly
(For additional images, refer to Appendix C)

The following figure demonstrates how the collar assembly hooks on to the press-fit pin in the post. It is held up by two washers attached to the bolt head, and once it rotates about the post the two washers unhook from the bolt and the counterweight begins to fall. The foot release cable attaches to the end of the peg so that the assembly rotates when the cable is pulled. The shear stress shown in Figure 8 was determined to be perpendicular to the face of the washer, as the washer would be the first part to give upon failure. The cross sectional shear area is made up of the washer, bolt head, and JB Weld compound.

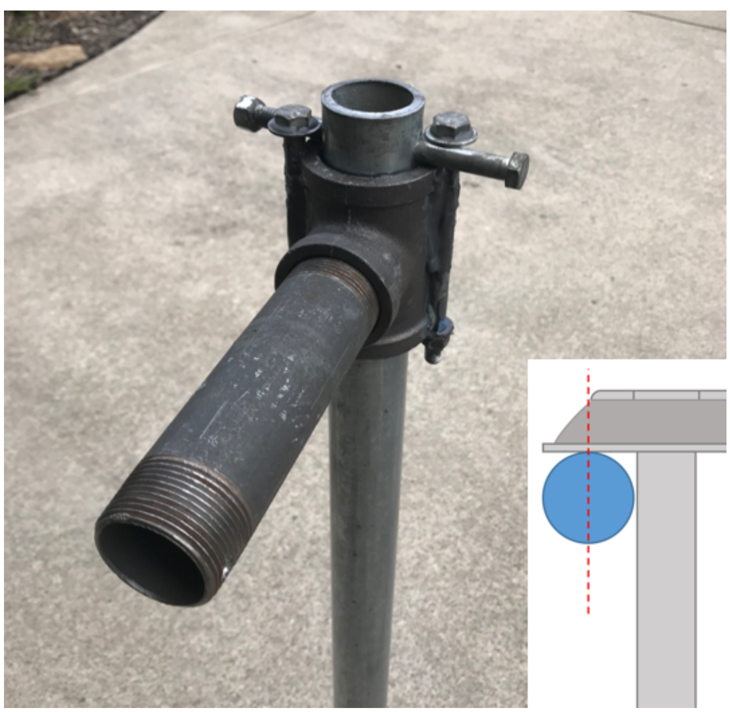


Figure 16. Collar-Post Assembly

FINAL ASSEMBLY

The final product was then assembled according to the manufacturing drawings. There was initially an issue with getting the counterweight to slide down the post when loaded with a 45lb weight, but after sanding down the post and applying bearing grease to the surface, the collar assembly was able to freely slide up and down. Additional 45 degree supports were added to the front of each pillar due to the excess material from the previously cut up 2x4s. To temporarily attach the cables to the counterweight and the ends of the barbell, industrial zip ties were used. Moving forward, the cables are to be permanently secured to the collar assembly, and the other ends will be secured to standard barbell clamps which can be easily attached and removed while also securing the weights to the barbell.

Figure 17. Final Assembly (1)

The final prototype used Para cord for the foot release, which later on is to be replaced with a rigid exercise cable attached to a standard ankle cuff. The wood was coated with outdoor paint, and all cracks and crevices were filled with caulk for aesthetics and additional protection from moisture.

Figure 18. Final Assembly (2)

Testing was performed by releasing a 45lb counterweight while the barbell was just above the chest, which is a common sticking point for most lifters. Once the foot was pushed forward only a few inches, you could feel the counterweight start to unhook from the pin and finally release all together. The release was smooth and you could immediately feel the weight of the bar lessen once the cable became taut. The cables did a good job of pulling the bar directly to the racked position, making it much easier for the lifter to complete the repetition. Resetting the counterweight was also very easy; just simply lift the counterweight and hook it on to the press-fit pin. Never once during testing was there an accidental counterweight release. The foot release required an adequate amount of force to prevent unintended activation, yet not too much force that it couldn't be activated in an emergency.

PROJECT MANAGEMENT

Budget, Bill of Materials

The project came in a $24 under budget, mostly due to using reclaimed wood to build parts of the frame. This allowed additional money to be allocated to the collar assembly, and towards paint and caulk for the final assembly. The pulleys came out to be more than expected because the initially selected pulleys were on backorder, so a more expensive pair had to be selected. The cables only came in at $6 a piece which was much less than the allocated budget. Table 6 provides a breakdown of the proposed budget verses the actual costs:

Item	Quantity	Budget	Actual Cost	Difference
Wood 2x4	3	$10.50	$0.00	$10.50
Wood 4x4	4	$30.00	$14.00	$16.00
Cable	2	$30.00	$12.00	$18.00
Post	1	$40.00	$25.00	$15.00
Pulley	2	$15.00	$35.00	($20.00)
Collar Assembly	1	$30.00	$45.00	($15.00)
Weight Release	1	$15.00	$9.00	$6.00
Screws	25	$4.50	$6.00	($1.50)
Misc		$25.00	$30.00	($5.00)
Total		**$200.00**	**$176.00**	**$24.00**

Table 5. Proposed Budget vs. Actual Budget

Schedule, proposed /actual

The actual schedule was very close to the proposed schedule, only deviating from the plan during manufacturing. Most of this delay was due to the time it took to borrow a weight set for testing, which was then in turn used to work on the aesthetics of the assembly. Testing was relatively straightforward and only took one week to complete before the Tech Expo. Figure 19 shows a comparison of the proposed schedule verse the actual schedule:

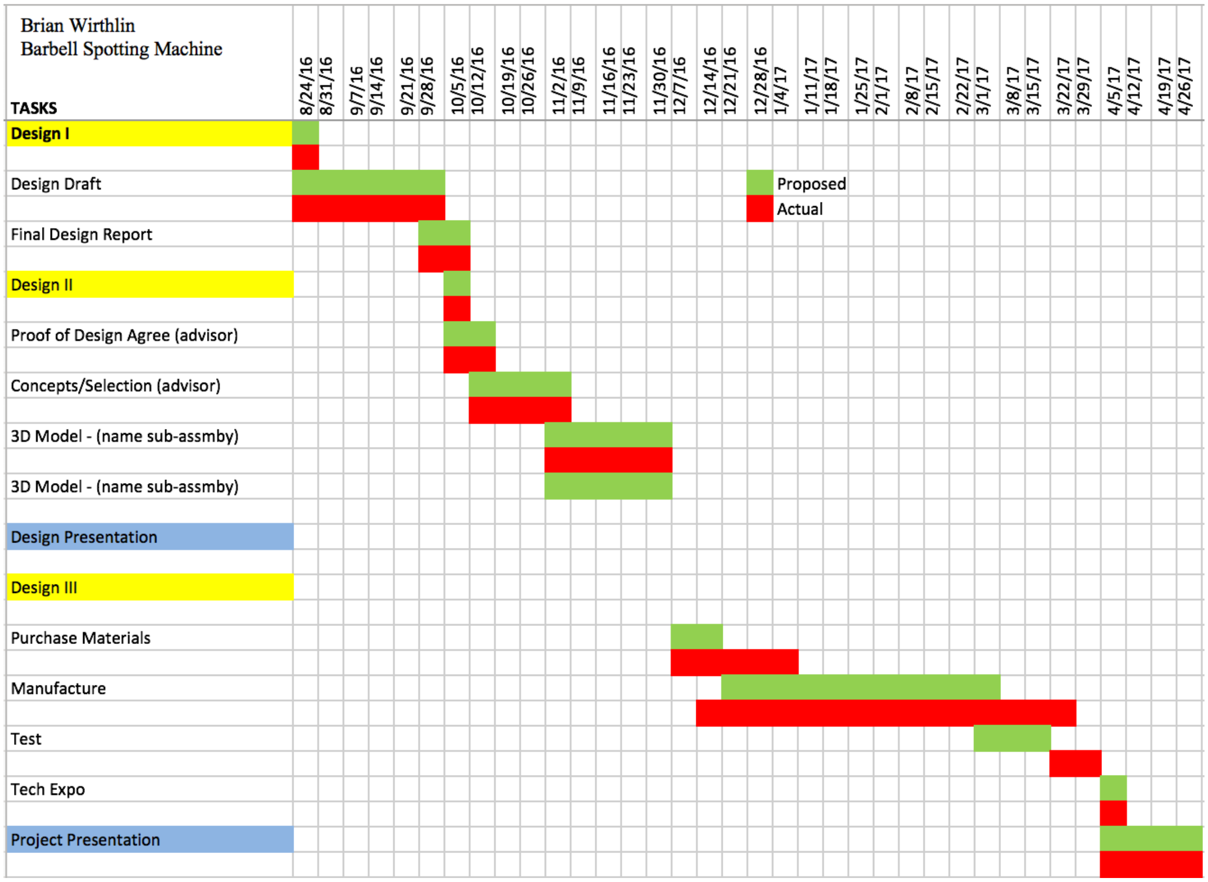


Figure 19. Proposed Schedule vs. Actual Schedule

CONCLUSION

The assisted bench press offers a counterweight system which can be activated by the user's foot at any point during his or her lift in order to provide an upward force to the barbell. The design utilizes the force of gravity to increase the reliability of the system in an emergency situation, and uses simple components which are affordable, easily accessible, and require little to no maintenance. The entire system can be assembled for $200 or less depending on how many of the components need to be purchased, as many of them may already be laying around the house. The design takes up very little space relative to smith/cable machines, and requires very few special processes for assembly. It is not meant to fully overcome the weight of the barbell, but to act as a spotter would in providing an assisting upward force to the barbell on the last repetition.

The counterweight system was tested with a 45lb weight which essentially removes 27lbs from the weight of the barbell. The system could potentially handle more than 45lbs in weight due to the significantly high safety factors of the selected materials. Before increasing the weights, it would be recommended to add a bar/pipe between the tops of the two pillars. This would provide additional stability against the impact of the counterweight, and also provide an extra layer of security for the lifter by catching the cable if it were to somehow slip from the pulley. It is also recommended to use a stiff rope/cable for the foot release to remove as much give as possible before the counterweight fully unhooks. Overall, this system meets all of the predetermined requirements- it provides an upward spotting force to a traditional barbell, it can be operated solely by the lifter, in most cases it uses existing exercise equipment, and it utilizes affordable and easily accessible materials.

WORKS CITED

1. *Traumatic Asphyxia in Weightlifters.* **Jumbelic, Mary I. M.D.** s.l. : NCJRS, 5 2007, Journal of Forensic Sciences Volume:52 Issue:3.

2. **Heffernan, Conor.** PUMPING IRON: THE HISTORY OF THE BENCH PRESS. *physicalculturestudy.com.* [Online] April 9, 2015. [Cited: September 14, 2017.] https://physicalculturestudy.com/2015/04/09/pumping-iron-the-history-of-the-bench-press/.

3. **Ketchum, Dan.** What Are the Benefits of Bench Presses? *azcentral.* [Online] [Cited: September 11, 2017.] http://healthyliving.azcentral.com/benefits-bench-presses-9139.html.

4. HIGH SCHOOL FOOTBALL PLAYER DIES BENCH PRESSING IN BASEMENT. *Scooby's Workshop.* [Online] December 5, 2010. [Cited: September 14, 2017.] http://scoobysworkshop.com/2010/12/05/high-school-football-player-dies-bench-pressing-in-basement/.

5. **Vorozilchak, Dave.** MAXX BENCH: First Ever Gravity Release Bench Press. *KICKSTARTER.* [Online] [Cited: September 11, 2017.] https://www.kickstarter.com/projects/754670088/maxx-bench-first-ever-gravity-release-bench-press.

APPENDIX A

*Additional views of solid model assembly

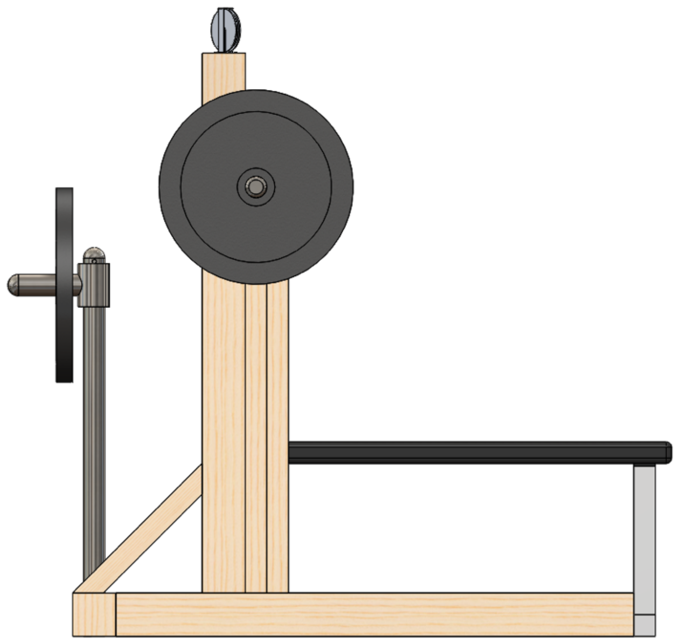


Figure 20. Solid Assembly Side View

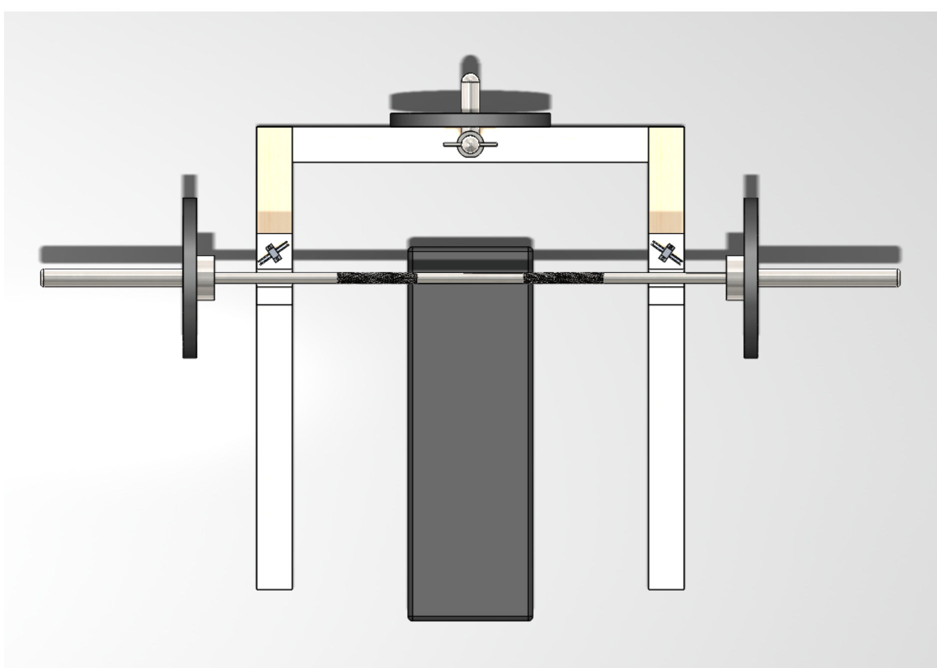


Figure 21. Solid Assembly Top View

APPENDIX B

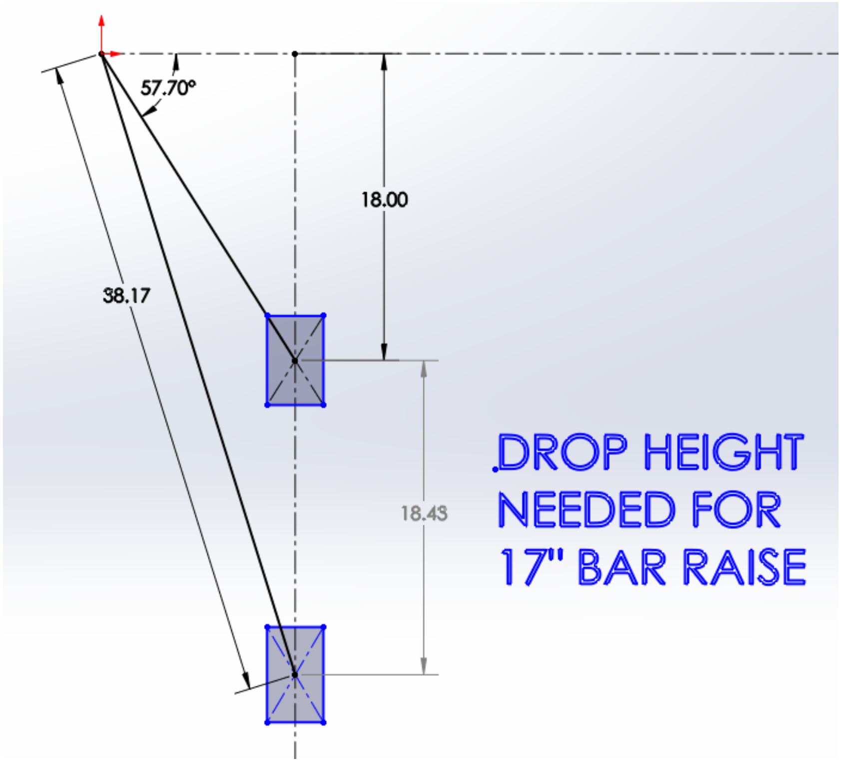


Figure 22. Counterweight Drop Distance

*Screenshot from Solidworks determining how far the counterweight needed to drop. It was estimated that the bar travels 17" from the lifter's chest to the top racked position, and given the selected cable angles and pillar height, the counterweight needed to drop approximately 18.5" to create a 17" inch lift.

APPENDIX C

*Additional close-up images of the counterweight slider assembly

Figure 23. Collar Assembly (1)

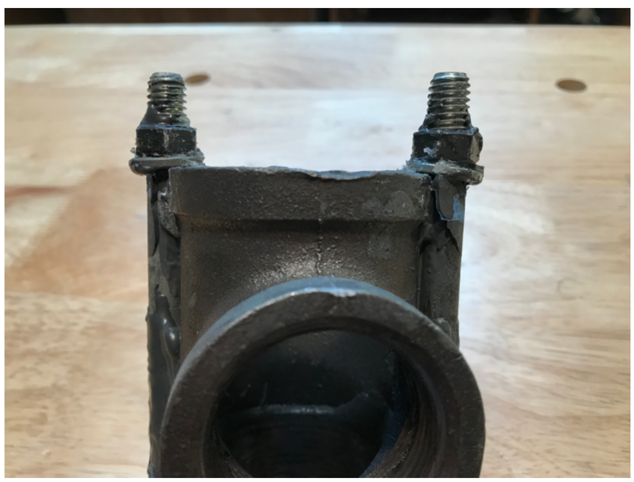


Figure 24. Collar Assembly (2)