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Bike Lock Combining Strength and Flexibility

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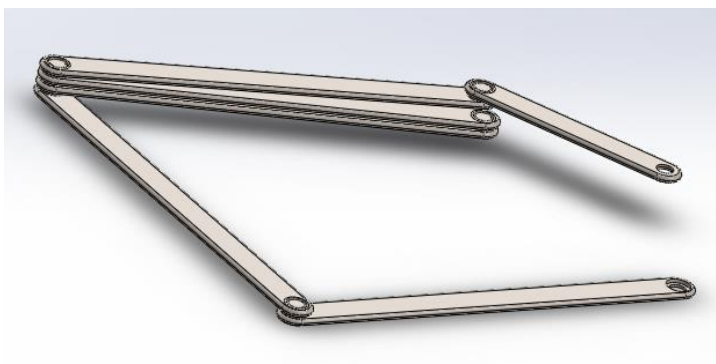

By

Zachary Uhrich

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1: INTRODUCTION

1a: Motivation:

This project was motivated by a need for a device that would allow a bicycle owner to securely lock their bike to atypical items in an urban setting, besides specifically designed bike racks.

1b: Function Statement:

The bike lock will provide the strength and security of a rigid U-lock while providing the length of flexibility of a chain lock, which allows the lock to stretch around the frame, the front tire, and any reasonable size of pole or tree available.

1c: Requirements:

Thus, a device is required that would:

- Weigh less than 10 pounds, total.
- Stretch at least 60 inches from end to end.
- Fold down to fit in a 3 inch x 3 inch x 18 inch volume (Not including the locking mechanism.
- Be comprised of no less than 4 and no more than 10 individual links.
- Have a total manufacturing cost of less than $250.
- Have a total testing cost of less than $150.
- Each link must have a material hardness of at least 65 on the Rockwell B scale.
- Each link must be able to withstand the cutting force of a pair of 42 inch bolt cutters, with 50 pounds of force applied to the handles (85,610 pounds of cutting force).
- The joints must be able to withstand the force applied from a 48 inch pry bar (27,600 pounds of force).

1d. Engineering Merit:

One of the most important aspects of this project is the selection of the correct material. This will be done by using a static force analysis on various cutting tools, such as wire or bolt cutters, to determine the necessary strength required by a material. Another aspect of the material is determining the necessary hardness to resist cutting from other cutting tools, such as saws or files.

A separate static analysis must be also be done on the selected rivets that will be used at the joints. The rivets must be analyzed to determine the amount of force required to break them, and whether or not this amount of force can be applied with readily available tools, for example pry bars.

1e. Scope of Effort

The entirety of this project will be completed by myself individually. In order to cut down on time, and due to restrictions on resources, some parts, like the links, may need to be ordered custom from other commercial retailers, cost permitting.

1f. Success Criteria:

The device can be considered successful if it meets all of the above requirements, as well as takes longer than six hours to cut or break through with a non-motorized cutting tool. Bike locks are generally rated on a 10-point scale, with ratings given based on the amount of time it takes to break them with a hand held tool. The following table is one example of this rating system. This table comes from Kryptonite Locks, one of the global leaders in bike security.

	Quick Stop	Couple of Hours	All Day	Overnight
Major Metropolitan Area	9-10 Ultimate Security	9-10 Ultimate Security	9-10 Ultimate Security	9-10 Ultimate Security
Metropolitan Area	4-6 Moderate Security	7-8 High Security	7-8 High Security	9-10 Ultimate Security
Suburbs	4-6 Moderate Security	4-6 Moderate Security	7-8 High Security	7-8 High Security
Rural Area	1-3 Secondary Security	4-6 Moderate Security	4-6 Moderate Security	4-6 Moderate Security
On the Trails	1-3 Secondary Security	4-6 Moderate Security	7-8 High Security	7-8 High Security
In/On the Trailer On the Road	4-6 Moderate Security	7-8 High Security	7-8 High Security	9-10 Ultimate Security

This table shows the two factors in determining the security of a bike lock are where the bike is locked up, and how long it is locked up for. For this bike lock to be considered a success it must rate as a 9 or 10 on this scale. This will be verified by a tester using various tools to attempt to break this lock. If the lock cannot be broken in six hours, or overnight, the lock can be considered a success.

DESIGN & ANALYSIS

2a. Approach: Proposed Solution:

The solution to this problem, needed a strong and universal bike lock, can be solved by creating a strong chain of flat plates, made of hardened steel.

Related Terms:

Link: Each individual piece of metal comprising the entire chain.

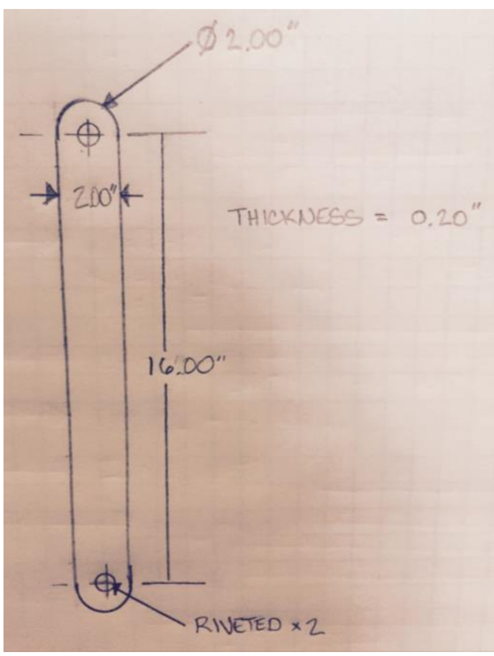
Locking Mechanism: A commercially purchased deadbolt connecting the two links on either end of the chain.

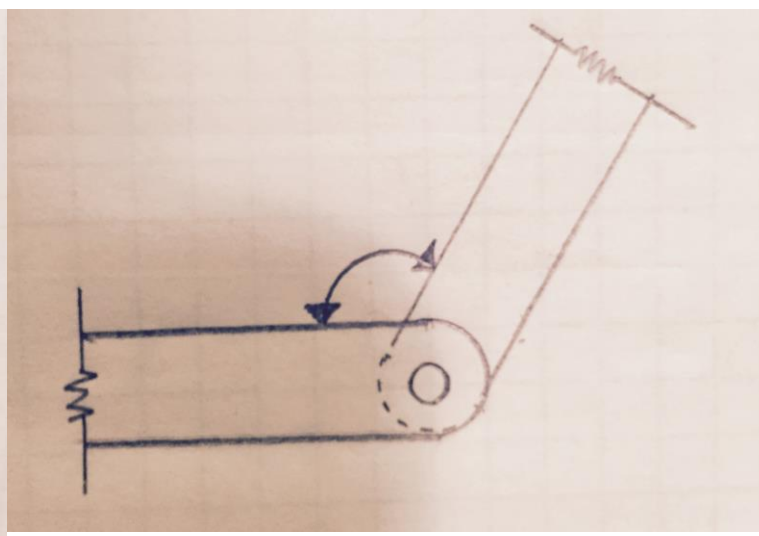
Rivet Housing: This is the term used to describe the steel parts that hold the rivets, and pin the links against each other.

2b. Description:

The links are connected at each end and free to rotate relative to each other to allow the entire lock to create a long and flexible chain that maintains the resistance, to various cutters, of hardened steel.

The following sketches illustrate the shape and size of each link (a) as well as the way they will be connected and the axis they will be free to rotate about (b).

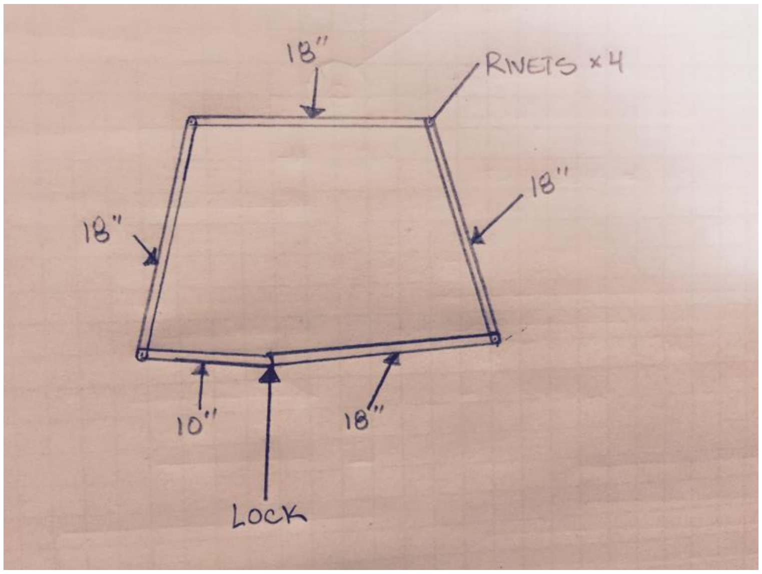




(b)

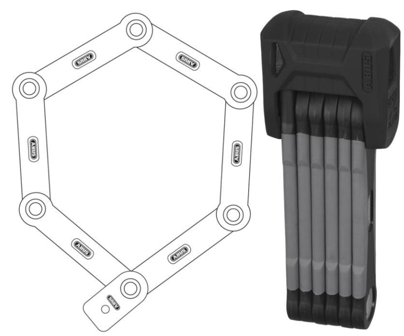
(a)

This sketch shows the entire assembly of links. The chain as a whole contains 5 links, four of which have an overall length of 18 inches, with the final link being only 10 inches.



2c: Benchmark:

The design of this bike lock will be similar to the Bordo Granit X Plus 6500 bike lock made by the German company Abus. However the major difference will be in the length of the lock, as the Bordo Granit X, at about thirty-three inches, is designed only for use with standard bike racks, and so it cannot be used when a bike rack, or other thin pole, is not readily available. The second major difference is that the Bordo Granit X uses a locking mechanism that is completely attached the links of the lock. This new lock will have a removable padlock to allow for increased flexibility, and the change the locking mechanism should it be become damaged. Images of the ABUS Bordo Granit X Plus can be found in Appendix A, Figure A-1. The image to the right shows the Abus Bordo Granit X Plus 6500 both unwrapped (left) and in the folded and locked position (right).



2d: Performance Predictions:

When attempting to predict the performance of a bicycle lock, it is important to understand the various tools which may be used to try to break it. During regular use a bike lock is not under any extreme conditions, and no excessive force is being applied. However various hand held tools may be used to try dismantle the lock. These tools include, but are not limited to:

- Screwdrivers
- Wire cutters
- Bolt Cutters
- Pry bar
- Hacksaw
- Hammer and Chisel
- Grinders

Each of these methods of theft must be taken into account in the design of a bicycle lock, however it is important to note that while there are ways to deter thieves, there is no such thing as an impenetrable bike lock. Bicycle locks are generally rated on a ten-point scale, which the judgement being made based on the length of time required to break the lock. Once it is understood that the goal is not make an unbreakable lock, but only to make it take as long as possible to break it, the task becomes much simpler.

Also, because there is no such thing as an impenetrable lock, it is important take certain methods of theft out of the question. For example, a battery powered grinder will be able to cut through virtually any lock, even one made of hardened steel. The way to defend a bike against a theft with that sort of tool is in the method and location that the lock is used. Because that is the case, the lock cannot be considered a failure due to a grinder being able to destroy it.

2e: Description of Analysis:

The first step in the analysis of this bike lock is the determination of the material required to successfully create the device. Each tool used by a bike thief is used on a specific part of the lock. The tools used to compromise each link in the chain would be wire cutters, bolt cutters, or a hacksaw. Because bolt cutters would produce much more force than wire cutters, the assumption can be made that if the material is strong enough to withstand the bolt cutters, it is also strong enough to withstand the wire cutters. Therefore, the wire cutters do not need to be taken into account for the analysis.

In order to begin the analysis, a determination must be made for the amount of shear force that can be applied with bolt cutters. This is completed using a static analysis of standard bolt cutters, with an applied force at the grips of 50 pounds. Then, a factor of safety of 1.5 is applied to that force to ensure that all special cases for the strength of a thief is included in the analysis. Finally, this force is used to determine whether or not a shearing failure would occur when that force is applied.

Once a few materials are found that will withstand the force of the bolt cutters, each material needs to be analyzed to determine if it can withstand a hacksaw. This is done by finding the hardness of each possible material, and comparing that to the hardness necessary to resist the blade of a hacksaw.

The next tools used by thieves to examine are screwdrivers and pry bars. These tools would be used to break apart the links of the chain at the rivet. This would be done by sticking the tool between two links and using the lever to pry them apart. One method to keep this from happening is to be sure the rivets are an adequate size to prevent failure due to shear or bending stress, or that there is not enough space between each link for a pry bar or screwdriver to be placed inside. The area the lever would be placed into allows for the fulcrum of the lever to exist at less than one inch from the rivet. This analysis can be seen in section 2g.

The final tools to plan against are hammer and chisel, and again a screwdriver. However, these tools can also be used to attempt to destroy the pins on the inside of the locking mechanism. A hammer can also be used to damage the outside of the lock in order damage it to the point of failure. Because this lock will require a commercially sold locking mechanism, this analysis will have already been completed by the manufacturer, and the important this will be selecting the correct lock to meet the necessary requirements.

2f: Scope of Testing and Analysis:

The most important requirement is that the strength of the bike lock hold up to tampering, however after that the priorities are the weight, length, and folded volume. Each of these values should be minimized as much as possible, without sacrificing strength and security. One last major requirement is minimizing the cost. The cost should be as low as possible, as long as that does not mean increasing weight, length, or folded volume; or sacrificing security.

Requirement	**Units**	**Testing Method or Equipment**	**Allowable Value**
Weight	pounds	Scale	<10
Overall Length	inches	Tape Measure	<60
Folded Volume	Square inches	Tape Measure	<162
Total number of links		Counting	4-10
Total Cost	dollars		$250

2g: Analysis:

i: Design Issue: Material selection of the links based on allowable stress.

The first analysis completed is a static analysis on a set of bolt cutters.

This is begun with an assumed applied force 50 pounds at the end of the handles. A 42 inch set of bolt cutters is used for the analysis, as this is the largest standard bolt cutters commercially available, and therefor able to apply the greatest force at the cutting edge. The static force analysis requires the separation of each part of the bolt cutters. From Figure A-2 it is found that by separating the parts, it is determined that Part C is a two force member. This means that only vertical forces are acting on pin d. Due to the fact that the cutting force at the blade is also a vertical force, it is found from the free body diagram that all the forces are in the vertical direction only, and no forces act horizontally on the bolt cutters. By eliminating all the horizontal forces, the remaining free body diagram is simplified. By solving each of the equations for each part, the cutting force applied at the cutting edge is found to be 57,073 pounds. Finally, a factor of safety of 1.5 is applied and so the force is then multiplied again. This brings the total cutting force to 85,610 pounds. These calculations and the relevant drawings can be found in Appendix A, figures A-2 and A-2a. Next this value for force is applied to the direct shear stress formula with approximate cross sectional dimensions selected (1.5 x 0.25 inches).With these assumed dimensions the shear stress through the part would be 228,293 psi.

From this value for the required shear resistance a list of possible materials can begin to be compiled. The preliminary list, including properties, for various series' of steel, can be seen below.

Material	Density	Ultimate Tensile Strength	Yield Tensile Strength	Ultimate Shear Strength	Ultimate Shear Strength2	Ultimate Shear Strength3	Ultimate Shear Strength4
Units	lb/in^3	MPa	MPa	MPa	Psi	MPa	psi
AISI 1000 Series Steel (average values)	0.284	646	453	484.5	70270.91	262.74	38107.28
AISI 4000 Series Steel (average values)	0.284	977	747	732.75	106276.60	433.26	62839.16

AISI 5000 Series Steel (average values)	0.284	992	824	744	107908.27	477.92	69316.56
AISI 6000 Series Steel (average values)	0.284	992	824	744	107908.27	477.92	69316.56
AISI 8000 Series Steel (average values)	0.284	968	756	726	105297.59	438.48	63596.26
AISI 9000 Series Steel (average values)	0.284	1060	799	795	115305.21	115.42	67213.51
High Carbon Steel (average values)	0.270	996	800	747	108343.39	464	67297.63
Medium Carbon Steel (average values)	0.284	987	685	740.25	107364.38	397.3	57623.60
Low Carbon Steel (average values)	0.284	766	572	574.5	83324.33	331.76	48117.81
Stainless Steel (average values)	0.282	862	591	646.5	93767.07	342.78	49716.13
1000 Series Aluminum	0.098	111	68.9	83.25	12074.41	39.962	5796.01

From this list, certain options can be eliminated right away, the Aluminum, Stainless Steel, Low Carbon Steel, and 1000 Series Steel, all have yield shear strength values which are too low for this application. Each of the remaining materials still appears to have a shear resistance lower than what is required, however these are just average values for each series of steel. The actual properties of each individual steel must be compared individually.

Robert L. Mott's book, *Machine Elements in Mechanical Design,* contains a more complete list of materials from which the remaining options can be compared. From this information the most appropriate options for this application would be SAE 4140, SAE 4140, SAE 4340, SAE 5150, SAE 5160, SAE 6150, and SAE 9255. All of these materials are oil quenched and tempered at 400 degrees Fahrenheit.

Due to availability and price the selected material for this application is SAE 4140 steel, OQT 400.

ii: Design Issue: Determining maximum possible force applied with a pry bar.

The pry bar selected for this analysis is 42 inches in length. This is selected because it is the largest commercially available common pry bar. From Figure A-3 we see the forces acting on the pry bar during use are the force applied at the handle, the force of the pivot at the fulcrum, and the prying force. This analysis is as simple as a single equilibrium equation. By solving for the sum of the moments about the fulcrum we create an equation directly relating the applied force to the prying force. The equation is *Applied force x 92 = Prying Force.* The applied force is again assumed to be 75 pounds, which means the prying force is 13,800 pounds. The factor of safety for this analysis is 2.0, once that is applied to total force for this analysis is found to be 17,600 pounds of force. This complete analysis is found in Appendix A, Figure A-3.

This Force was then applied to the head of a counterbore rivet in order to calculate the appropriate size to avoid rivet failure. This analysis can be found in Appendix A, Figure A-4. The area triangular cross section was calculated to find the area that the shear stress would be acting on, and equation was formed using the terms *A* and *h* for the diameter of the rivet head and the height of the rivet head respectively. This formula was then inputted into the bending stress equation to form the formula below:

$$\sigma_b = \frac{2760}{\left[2\left(\frac{A}{h}\right)\sin(60)\right]h^3/24}$$

This equation was entered into a data table to calcite for the stress of each of the readily available standard rivet sizes. Figure A-5 in Appendix A shows these standard rivet sizes. The following table shows the stress on the head of the rivet for each of these available rivet sizes.

A (inches)	H (inches)	Stress (psi)
0.114	0.027	563,602,545.97
0.1695	0.04	172,709,266.91
0.226	0.053	73,781,103.70
0.2825	0.066	38,062,648.35
0.3385	0.079	22,171,366.97
0.3985	0.094	13,302,133.22
0.453	0.106	9,202,278.94
0.5095	0.119	6,491,831.14
0.5675	0.133	4,665,908.07
0.624	0.146	3,521,397.28
0.68	0.159	2,724,596.31
0.7365	0.172	2,149,689.23
0.794	0.186	1,705,135.65

The data table shows that even the largest standard size, which is a shank diameter of 7/16 inches, would allow for too great of a stress. 1,705 ksi is greater than the ultimate tensile strength of the stainless steel the rivets are made of. . Rather than find larger rivet sizes which would be able to withstand the stress, the diameter of the washer between the links will be increased in order to prevent a thief from fitting a prybar between the links, negating the need for this amount of stress resistance in the rivet head.

Although the bending stress in the rivet head can be ignored, the diameter of the rivet shank must still be long enough to resist bending between the links. The analysis to determine this bending stress can be found in Appendix A, Figure A-6. Solving for the sum of the moments about the rivet, the force in the rivets is found to be 1650 pound-inches. Then a factor of safety of 1.5 is applied to find the moment is equal to 2,475 pound-inches. Next, in Appendix A – Figure A-7, this moment is applied to the shank of the rivets to determine the necessary diameter of the rivet to resist bending failure. This leads to the following formula:

$$\sigma_b = \frac{3300}{\pi\left(\frac{D}{2}\right)^2}$$

Each of the standard diameter sizes (Shown in Figure A-5), is plugged into this formula to determine the necessary size to resist failure. The results of these calculations are shown in the following table.

D	Bending Stress in Shank (psi)
0.0615	208293.20
0.093	91087.64

0.124	51236.80
0.155	32791.55
0.1865	22649.97
0.2175	16653.55
0.2485	12757.70
0.279	10120.85
0.31	8197.89
0.342	6735.55
0.3725	5677.70
0.4035	4838.81
0.4355	4153.83

From this data table it can be determined that any size diameter over 1/8th inch is adequate to resist failure. Because the density of the rivets is not significantly different than the density of the links, there is no benefit to minimizing the size of the rivets. Due to this, we will select the largest standard sized rivet in order to maximize strength of the rivets. This means a rivet with a nominal shank diameter of 7/16^{ths} oh an inch will be used.

iii. Design Issue: Dimensions come out to be too heavy.

With the currently calculated dimensions, the overall weight will come to 12.5 pounds, which exceeds the maximum 10-pound requirement. In order to reduce the weight of the chain assembly the selected material must be reanalyzed. By returning to the list of acceptable materials, a material will a higher ultimate tensile strength can be selected. According to the material properties listed in Mott's book, *Machine Elements in Mechanical Design*, the optimum material to select is SAE 5160 OQT 400. SAE 5160 steel with these conditions, has an ultimate tensile strength of 322,000 psi. This new ultimate tensile strength can be applied to the shear stress equation to determine the necessary dimensions for the chain links. The minimum thickness of the links is determined to be 0.236 inches. In order to use a standard size plate, a thickness of 0.25 inches is selected. This analysis can be found in Appendix A, Figure A-8.

iv. Design issue: Changing Dimensions.

Now that the height of the links has been changed, the 7/16th inch rivets will no longer fit. In order to again calculate the minimum dimensions of the rivets, the stress on the rivet housing must be calculated. The compression stress and shear stress are both calculated. These calculations are shown in Appendix A, Figures A-10 and A-11. The minimum area necessary to prevent failure on the face of the rivet housing is 0.114 inches squared, and the minimum thickness is determined to be 0.054 inches. These were both solved for an applied force of 3,300 pounds of force, as determined in Figure A-6. As these calculations have shown that failure of the rivet housing will not be a problem (because these dimensions are so small), the selection of the rivets can again be enlarged as much as possible for increased strength. The only limitations are the thickness of the link, in which the head of the rivet should not extend above the top face of the link.

Figure A-9 shows the determination of the new rivet sizes. In order to minimize the height of the head of the rivet, the style of rivet is switched to be a flat head rivet. After comparison of the dimensions of each rivet option, the 11/32nd inch diameter rivets are selected as the optimal option.

2g: Device: Parts, Shapes, and Conformation:

The end of each link will be rounded with a radius of 0.75 inches, concentric with the center hole holding the rivets. The purpose of this is two-fold, for both aesthetic appeal and to remove as many sharp corners as possible in order to avoid any damage from the links to the bike.

2h: Device Assembly and Attachments:

The device is made up of five different links. The links are fastened to each other with counter bored rivets. Drawing B-4 shows an assembly of two links. Each link has a rivet housing piece inserted into the hole. The rivet housing can be seen in Drawing B-3. This piece is about 0.005 inches smaller in diameter than the hole in links, this allows the links to rotate freely around the hinge created by the rivets. On the other side of the link a 0.100 inch thick washer is inserted onto the other end of the housing. This washer creates a gap between the two links, in order to prevent wear due to rubbing. Drawing B-5 shows this assembly at the shoulder. The ability for the links to freely rotate around the shoulder allows for the chain to be folded up in to a cube, or spread out to an overall length of 85 inches.

Drawing B-7 shows an exploded view of each shoulder to see how the housing is assembled. Drawings B-5 and B-6 show the entire assembly, both in the folded and completely unfolded positions respectively.

2i: Tolerances, Kinematics, Ergonomics, etc.:

The tolerances can be found on the drawings in Appendix B.

All tolerances for this assembly are ± 0.005 unless otherwise stated. The tolerances are different for the diameter of the holes in each end of the link. This holes can only be +0.005 inches of the given dimension, in order to insure that the hole stays larger than the outside diameter of the rivet housing. Similarly, the outside diameter of the rivet housing must be within 0.005 inches less than specified dimension.

The inside diameter of the washer must also remain larger than outside diameter of the rivet assembly, however these two parts do not need to be as tight together as the link and the rivet assembly. So the tolerance for the inside diameter of the washer remains bilateral, at ±0.005 inches.

2j: Technical Risk Analysis, Failure Mode Analysis, Safety Factors, Operation Limits:

One major technical risk to the success of this project, is keeping the total assembly under the necessary weight limit. In order to maintain the necessary minimum dimensions calculated the entire assembly nearly reaches the maximum allowable weight. This weight does not yet include the weight of commercial lock which will need to be purchased. In order to cut weight without sacrificing security, a new design must be employed. As typical commercial bolt cutters are rated for use with hardened materials up to only a quarter inch, raised edges, higher than one quarter inch, can be added, so the thickness of the link can be minimized without fear of the use of bolt cutters. Therefor the weight can still be minimized, while failure due to bolt cutters can still be avoided.

Once again each possible mode of failure for this bike lock should be identified. These include: shear failure of the links due to bolt cutters, cutting failure of the links due to a hack saw, combined stress causing failure in the entire shoulder assembly (which includes the rivet and rivet housing), and failure of the locking mechanism by bolt cutters or screw driver.

The failure in the links, is avoided through proper dimensioning of the links and correct material strength and hardness. The failure in the rivets is avoided by use of the correct size of standard rivet, as is the failure in the rivet housing avoided by proper dimensioning. Finally, the failure of the locking mechanism is avoided by selecting a lock with an adequate security rating.

METHODS AND CONSTRUCTION

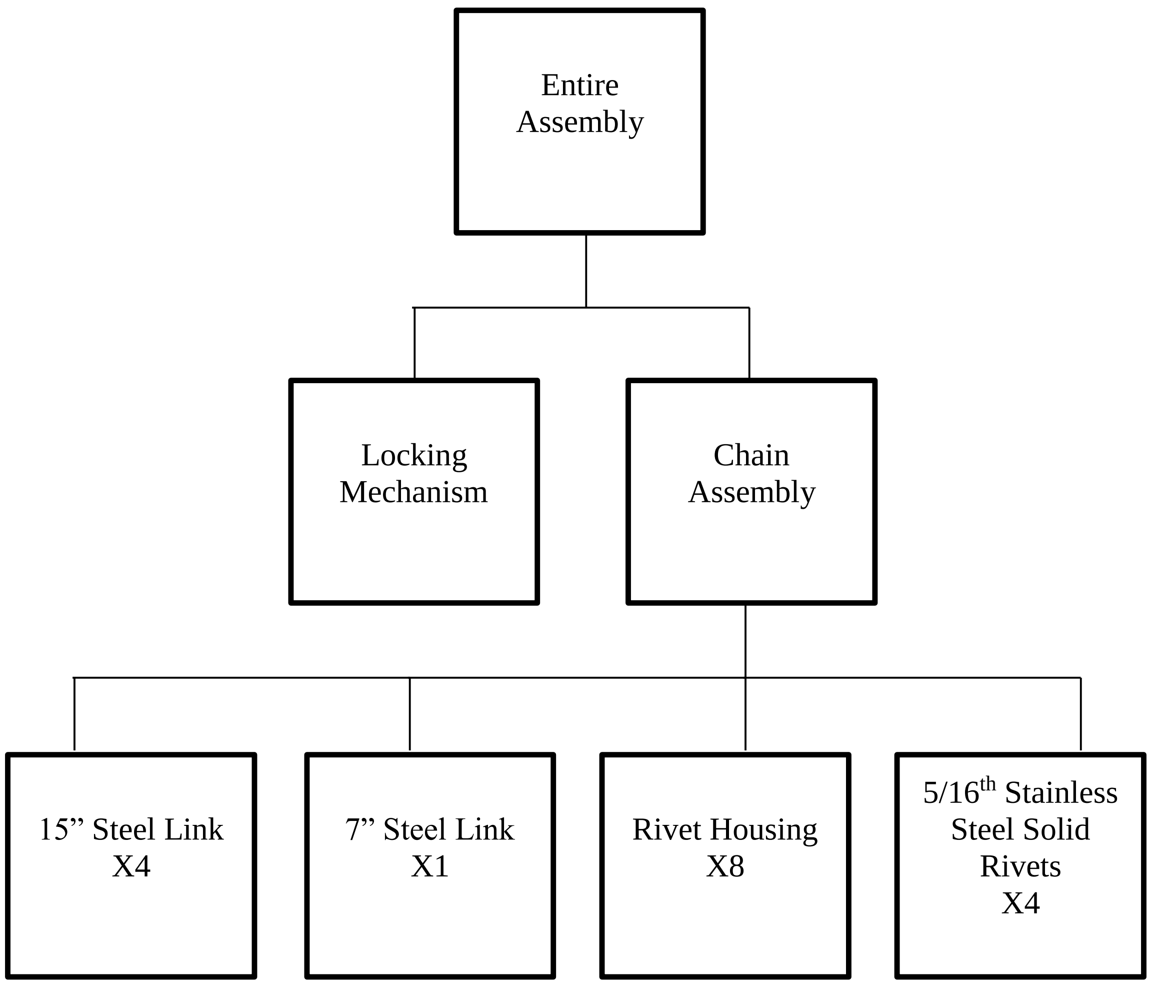
3a. Construction:

Each of the parts of this assembly will be machined in the Central Washington University machining lab, with the exception of the rivets.

Description:

a. The links will be purchased as 0.250 inch thick sheets with a width and length of 1.250 and 15 inches respectively. The rivet housing will be turned down on a manual lathe, from 1.25 inch diameter stock supplied by the Central Washington University Machine Shop. The same round bar stock will be used to turn down the washers to size.

Drawing Tree:



Parts List:

Part Name	Part #	Quantity Purchased	Purchased From	Dimensions	Cost	Shipping	Total Cost

15 inch Link	01	1	Speedymetal s.com	1/4” x 1.25” x 240” plate	$30.04	$8.00	$38.04
7 inch Link	02	0		1/4” x 1.25” x 240” plate			$0.00
Rivet Housing	03	1	Supplied by CWU	Dia. = 1” Len.=24"			$0.00
Washer	04	0	Supplied By CWU	Dia. = 1” Len.=24"			$0.00
Rivets	05	100	Rivetsonline. com	11/32th inch dia.	$22.42		$22.42
Locking Mechanism	06	1	Amazon.com Master Lock		$11.60		$11.60
Fixture Plate	07	1	Supplied by CWU	1.5” x 1.0” x 15”			
Rivet Tool	A	1	Grainger.com				
Corner Rounding Edge mill	B	1	Amazon.com Amazon	0.125" radius	$12.96	$5.32	$18.28
Shoulder Bolts	C	2	Fastenal	5/8 x 5/8 shoulder. 1.25 OAL	$20.54		$20.54
Bolt Cutters	D	1	Sears	42"	$59.00		$59.00
Pry Bar	E	1	Home Depot	48"	$35.99		$35.99
Totals					**$192.55**	**$13.32**	**$205.87**

Manufacturing Issues and Solutions

1. The first manufacturing issue come across, was the limited supply and prohibitive cost of 5160 steel. In order to fix this, the link material was changed to T1 Structural Steel. This was ordered from speedymetals.com.
2. It was determined that the rounded edges on the links could be manufactured with enough repeatability to turn out an acceptable product. Because of this, the original plan to machine the links on a manual mill was changed to include the use of a CNC mill. This added several new tasks to complete. Before the part could be machined, traveler’s had to be created and a program had to be written and tested. This was all completed with the help of Professor Ted Bramble and using Milltronics CNC Mills.
3. Another issue that came about during manufacturing was the fact that the counterbore in the rivet housing could not be cut on a lathe, as the tailstock chuck’s could only fit a cutter up to 0.500 in diameter, and a 0.750” cutter was needed. In order to complete this task, the parts were moved to a vertical mill and placed in a three-jaw chuck. Then a ¾ inch end mill was used to add the counterbore.
4. The original design included use of 11/32nd inch diameter blind, Stainless Steel, rivets. The cost of these rivets proved to be too

prohibitive, and so a change was made to solid rivets. Previous analysis (which can be found in Section 2g.ii), shows that the minimum acceptable rivet diameter is 1/8th of an inch. This allows some freedom to find the correct rivet size to optimize strength and cost. The rivets selected were flat top rivets, made of stainless steel, with a diameter of 5/16th inches and a length of 5/8ths of an inch. These rivets could be ordered and delivered from Grainger's online store.

5. After changing the type of rivet from blind to solid, it was not taken into account that much more force must be applied to set solid rivets. For this project the rivets were fastened using and anvil and a ball peen hammer. The rivet housing parts had not been designed to withstand this amount of force, which caused them to deform as the rivets were hammered in. The weakened rivet housing parts could then be completely broken easily enough to detach the links from each other. As this is not acceptable, a new design must be found which can withstand the force of the hammer, as well as lock the links into place. This new design includes a countersink instead of a counterbore, in order to increase the area of the part being subjected to the shearing forces. A new analysis was then completed, in order to determine the minimum acceptable size of this cross-section.
6. During Operation 2, of the links, the fillet was added around the entire outside of the parts. In order to complete this operation, the workpiece must be clamped from the center, not on the edges. In order to simplify this operation, and allow the fillet to be added in one complete pass, rather than multiple cuts, a workplate fixture was designed and fabricated. This workplate was fabricated in the CNC mill in order to ensure the precise distance between the two locating and clamping holes. The dimensions of the workplate fixture can be found in Drawing B-9.
7. The workplate fixture was combined with precision shoulder bolts in order to locate the workpiece. The necessary shoulder bolts were purchased from Fastenal in Ellensburg, WA. When the links were placed on the fixture and clamped down with the shoulder bolts, it was discovered that the head of the shoulder bolts was too large in diameter, and would interfere with the cutting of the corner rounding end mill. In order to fix this issue, the head of the bolts had to be turned down to a dimension which allowed clearance between the bolt and the end mill, but also was still large enough to provide the necessary clamping force. This dimension was selected to be a radius of 0.475 inches, as this was the largest possible value that would not interfere with the fillet.

3b. Links

The links are manufactured from individual plates of steel. Each plate will begin at 15" by 1.25" with a thickness of 0.25". The thickness will not need to be altered, as it will be delivered with an allowable tolerance. Each end of the link will then need to be rounded off, and fillets will be milled on each edge of the link. Finally, the counterbores on each end need to be applied. These steps will be repeated 4 times with a length of 15 inches, and then once with a length of 7 inches.

The final step, in this three operation process, is to add the fillets around the outside of each link. This will be done on a CNC mill. The correct dimensions and tolerances for these parts can be found in Appendix B, Drawings B-1 and B-4.

The final step of manufacturing the links is the heat treatment. The heat treating will be completed at *Pacific Metallurgical Inc.*, located in Kent, Washington.

3c. Rivet Housing and Washers

The rivet housing is manufactured from a one inch diameter bar of A36 steel. The bar will be turned down to 0.850 inches, and then the smaller outside (step) diameter is turned down to 0.625 inches. Next the smallest inside diameter is drilled out and reamed with an 5/16th inch reamer. The last step of machining is to use an end mill to form the inside ¾ inch inside diameter required. This will be repeated 8 times. The correct dimensions and tolerances for these parts can be found in Appendix B, Drawings B-3.

The washers will be formed from the same bar stock as the rivet housing. The washers will simply be measured to ensure the outside diameter is within the acceptable range, and then an11/32nd inch hole will be drilled through the center. Finally the end will be faced off at 0.100 inches. This will be repeated 5 times. The correct dimensions and tolerances for these parts can be found in Appendix B, Drawings B-2.

3d. Assembly

In Appendix B, Drawing B-7, an exploded view of each rivet assembly can be seen. Each of these shoulder joints are joined together by an 11/32nd inch rivet. This drawing shows that one side of the rivet housing is inserted in opposite holes in the chain links, with a washer between the two links, as a spacer. Next a rivet is inserted through both rivet housing pieces, and then fastened with a pop rivet gun. This must be repeated 5 ties for each joint. The entire assembly can be seen in both Drawing B-5 and Drawing B-6.

3e. Workplate fixture

In Appendix B, Drawing B-9, the required dimensions for the workplate fixture can be found. The overall length and width of the fixture were determined based on the available materials from the CWU machine shop. Next, a program had to be written in order to CNC mill the part. The fixture is a simple part containing three separate holes, one on the far left end, and then the two holes are in the same horizontal plane, 5.75 inches and 13.75 inches away respectively. Each hole consists of a 0.419 inch through hole, with a 0.625 inch counterbore, at a depth of 0.750 inches, and a ½ - 13 threads applied to the through hole.

TESTING METHODS

4a. Introduction

The success of this project is primarily determined by the chains ability to resist failure when the tools listed above are applied to it. It is important to reiterate that there is no such thing an unbreakable lock, and so for a bike lock to be successful, it must withstand breaking for as long as possible. In general a lock is considered superior, if it can withstand tampering from hand held tools for more than eight hours. However, it is also accepted that, with many tools if, no damage has been done to the chain, after an adequate attempt than likely no more damage will be done with more time. For example, if a Hacksaw is unable to damage or weaken the lock or chain after an hour, it is unlikely that seven more hours will yield and better results.

4b. Testing Procedure

Each of the individual tools listed in the introduction of this report must be tested on the final product in order to determine success of the project.

i. Bolt Cutters
    1. 42 inch bolt cutters will be applied to the links of the lock, with a maximum force applied in an attempt to cut through the chain. It will also be used to attempt to cut the locking mechanism.

ii. Hack Saw
    1. A hack saw will be applied to each aspect of the bike lock again to try to cut through the chain. The hacksaw will be used on the chain links, the rivets, the rivet housing, and the locking mechanism; wherever it can be applied.

iii. Pry bar
    1. The pry bar will be used to attempt to pry the links apart at the rivet housing.

iv. Screw Driver
    1. A screwdriver will be used to try to disengage the locking mechanism, by damaging the pins in the lock.

Each of these tools will be used to try to destroy the lock for at least and hour. At which point the damage done will be evaluated to determine if any damage is being done. If at that point it can be determined that the tool has been ineffective that specific testing will end. However, if any amount of damage has been done the testing will continue for another seven hours, or until the bike lock has been broken.

4c. Deliverables:

Results will need to be collected for each of the requirements listed in section 1c.

The entire bike lock assembly will need to be weighed in order to be sure it is under the 10 pound weight limit. It will also need to be measured in both it’s folded up position, as well as completely extended position.

Each of the testing methods listed above, will be filmed, in order to have the failure attempt on record. The weight and length measurements will simply be recorded

BUDGET/SCHEDULE/PROJECT MANAGEMENT

5a. Proposed Budget

The original budget listed for this project is divided into two groups of funds for both fabrication and testing.

i. The part list for this project can be found in section 3a of this document.

ii. The stock metal stock needed for the fabrication of the part is 1 plate of quarter inch thick SAE 5160 steel, with a width of 1.25 inches and a length of 240 inches (divided by 3 for shipping). This material will be enough to fabricate each of the links, as well as extras for use in testing. The cost of this steel is $68.61 plus $42.83 for shipping, from Admiral Steel.

iii. The metal stock needed for the rivet housing is a 1 inch diameter rod of A36 Steel, with a length of two feet. This will be purchased from Metals Depot for $7.20 plus 15.58 shipping.

iv. The rivets will be purchased from rivetsonline.com. They come in a box of 100 11/32nd inch diameter rivets, for $22.42 including shipping.

v. The locking mechanism is a Stanley Hardware 828145 2-inch hardened steel security lock. It is available on Amazon for $18.76.

Other equipment that needs to be purchased for the fabrication includes the tools necessary for production. These are listed here.

i. A rivet gun is necessary for installment of the rivets. A manual rivet gun is available from Grainger, produced by Stanley, for $21.38 and $11.26 for shipping.

ii. In order to add fillet's to each of the edges on the links a corner rounding end mill in required. This tool is purchased from Harvey Tool for $38.30.

iii. The remainder of the necessary tools are available for use in the Central Washington University machine shop.

The total projected budget for the production of this project will be $246.34.

i. The required tools for the testing of this project can be found in section 4b of this document.

ii. A 42 inch set of bolt cutters must be acquired. This will be purchased from Sears. A Neiko brand bolt cutter will cost $59.00 to buy.

iii. A 48 inch pry bar will need to be purchased from overstock.com for $ 35.99.

iv. The remainder of the tools required for testing have already been acquired.

The total projected budget for the testing of this project will be $94.99
This information can all be found in table format in Appendix D.

5b. Proposed Schedule

The schedule for this project can be found in the Gantt Chart in Appendix E.
The specific time projected for each task in production can be found in Appendix E.

5c. Project Management

Resources:

There are many other resources necessary to complete this project. These include both human and physical resources. The human resources include each of the professors in the Engineering Department at Central Washington University. These professors include but are not limited to Dr Craig Johnson, Professor Roger Beardsley, Professor Charles Pringle, Professor Ted Bramble, and the rest of the staff in the CWU machining lab. These professors will be invaluable in gaining advice throughout the planning and manufacturing of the bike lock chain.

The physical resources for the project include the entirety of Central Washington University machine shop. The most necessary equipment from the machine shop will be access to the lathes and the mills in the shop. These are both required in order to fabricate the necessary parts. Another need for the fabrication of these parts is an oven for use in heat treatment of the parts. c

There are no external financial resources for this project, as everything will be paid for independently by Zach Uhrich.

DISCUSSION

6a. Design Evolution:

At the start of this project, the goal was simply to create a bike lock that was just as secure as a Ulock, while still being able to lock a bike to something besides a standard bike rack. Originally, the design included telescoping legs, which would allow it to fold up into a very small space, and be lightweight. However, quickly found it was discovered that the design ideas would likely not be strong enough to withstand a pair of bolt cutters. This led through several other ideas including swiveling joints, and several different types of chains. Some other ideas included both beams and hardened chains, however eventually the idea of using only flat plates was settled on.

After the style of chain was decided it was a difficult decision to determine how long of a chain was actually necessary. This decision was very difficult because adding length, improves the versatility of the chain, however it also increases the weight of the entire chain. Eventually it was decided that five total links should be used. This will keep the chain from getting too long, which would get in the way in the case that a regulation bike rack was being used, but still remain long enough to wrap around an 18-inch tree trunk.

The remainder of the evolution of this design was recorded through the analysis section of this document. Several iterations were completed of the analysis, in order to determine the correct dimensions of each part.

CONCLUSIONS

This device has been conceived and designed to be an extremely strong bike lock, which maintains the versatility of a chain lock, without sacrificing the security that most small chains lose. ULocks are the strongest style of lock available, however the rigidity of these locks is very inhibitive in terms of what fixed device they can be used with. The most important aspect of this bicycle lock is that it combines the security of a ULock with the flexibility of a chain lock.

This idea was founded out of a love for bicycles, and the paranoia that comes with growing up in a large urban area in which bicycle theft was very common. This project fits within all the parameters of the resources allotted to a student at Central Washington University. And the design of the chain was very intensive, involving a strong understanding of both strengths of materials, material sciences, and mechanical design.

This lock will be able to withstand tampering from the most common tools for a bike thief (bolt cutter, hack saw, prybar, and screw driver). The force calculations have been completed in order to ensure an adequate material selection, as well as adequate dimensions to ensure the necessary security required for a bicycle lock.

This lock will collapse to a volume of 1.25” x 1.55” x 15.00”, which allows it to be easily transported, while it is in the completely folded position. When it is completely extended it will span 62 inches, enough to lock a bike to a tree 1 foot in diameter, while still wrapping around the frame and front tire. It will also achieve a security rating of 9/10 on the bicycle lock security rating system set up by Kryptonite Locks.

ACKNOWLEDGEMENTS

This project could not be completed without the help of the faculty at Central Washington University. The help of professors has been invaluable in the design and analysis phases of this project, and will remain equally important as the manufacturing stage begins.

Another great help in this project was the help provided by Megan Little and Stefanie Uhrich in the creation of this idea to begin with. These two assisted in early brainstorming ideas for possible senior project ideas, as well as possible solutions for the problem as it was presented.

This project could not have been completed without the extreme help of Ted Bramble and Matt Burvee, from the CWU machine shop. They supplied expertise and assistance in the planning, fabricating, and testing phases of this project. Their help was invaluable.

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Appendix A – Analysis

Figure A-1: ABUS Bordo Granit X-Plus 6500

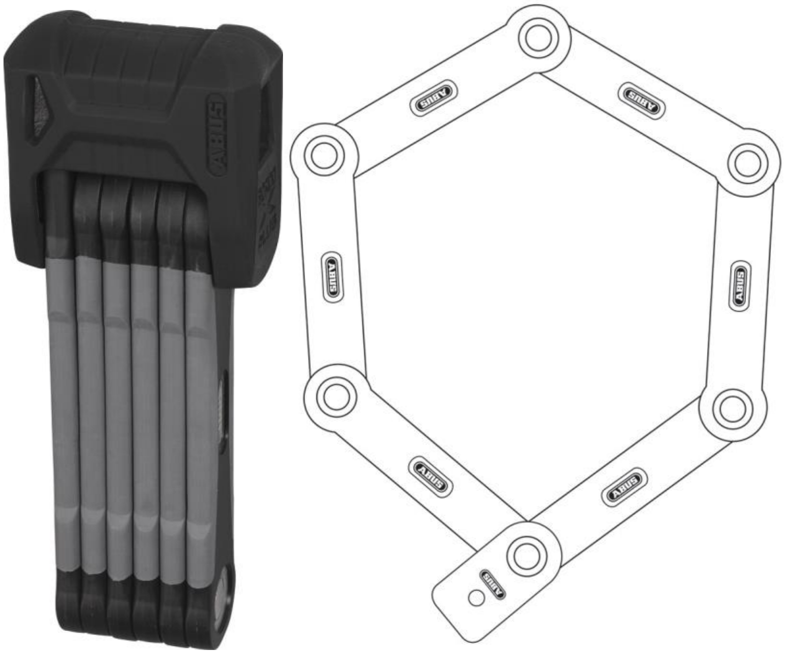


Figure A-2: Bolt Cutter Dimensions

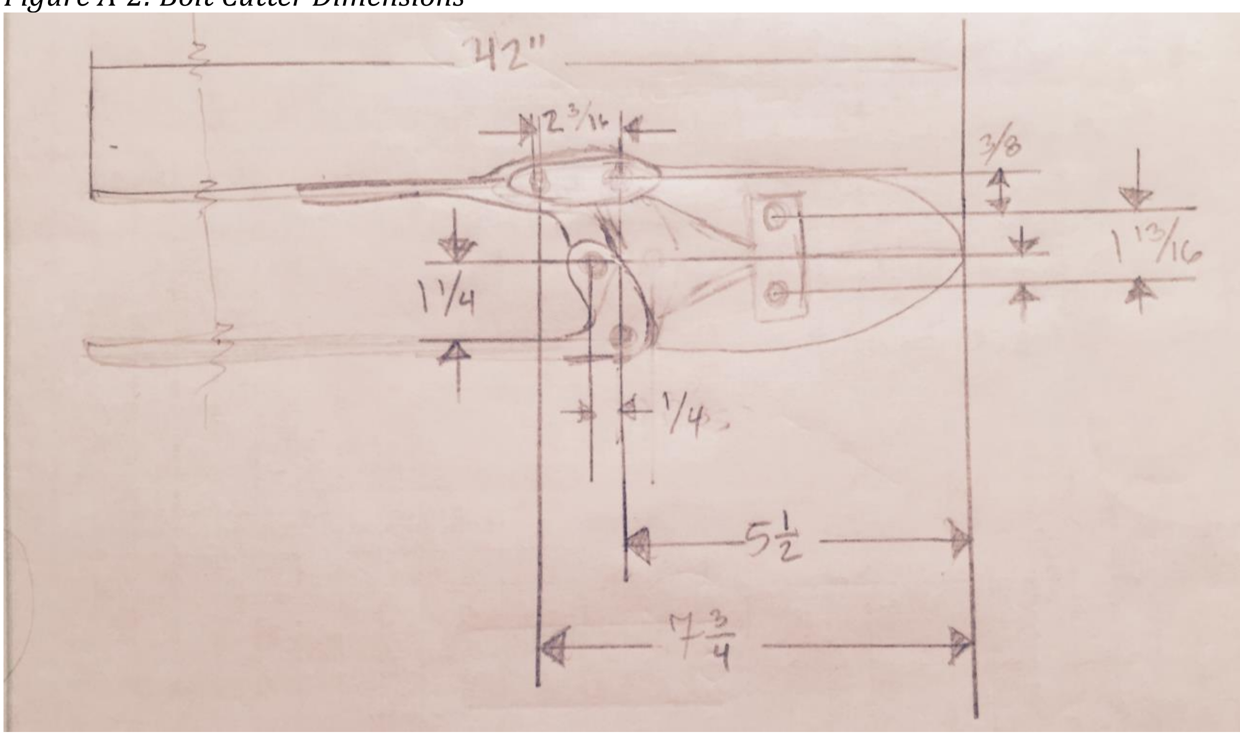


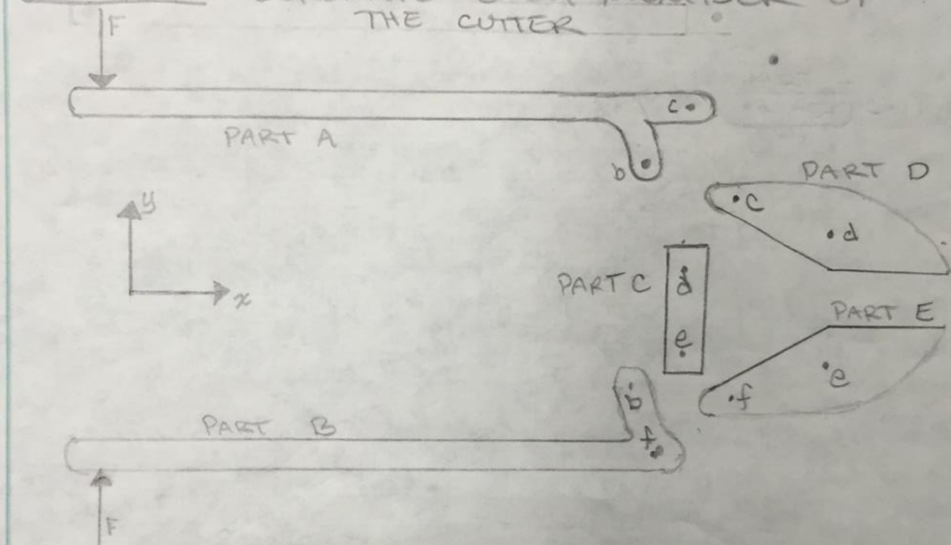
Figure A-2a: Bolt Cutter Analysis

BOLT CUTTER FORCE ANALYSIS	OCTOBER 23, 2015 Z. UHRICH	FIGURE A-2	1/2

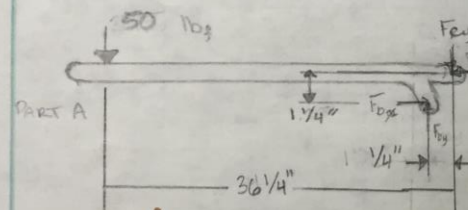
GIVEN: A BOLT CUTTER, OVERALL LENGTH, $L = 42''$
APPLIED FORCE, $F = 50/2$ lb.
SEE DRAWING A-2a FOR DISTANCES

FIND: THE CUTTING FORCE APPLIED AT THE BLADES.

SOLUTION SEPERATE EACH MEMBER OF THE CUTTER

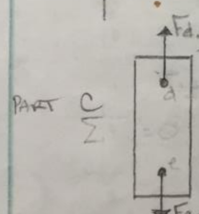


SOLVE FOR EQUILIBRIUM EQUATIONS OF PARTS A, C & D

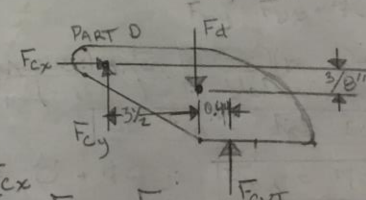


(Eq1) $\sum F_x = 0 \rightarrow F_{cx} = F_{bx}$
(Eq2) $\sum F_y = 0 \rightarrow 0 = F_{by} - F_{cy} - 75$
(Eq3) $\sum M_c = 0 \rightarrow -50\ (36.25) - F_{bx}(1.25) + F_{by}(1/4)$

$F_{bx}(1.25) - F_{by}(1/4) = 1812.5$
$F_{by} = F_{cy} + 75$



NOTE: PART C IS A 2-FORCE MEMBER
$F_{dx} = \emptyset = F_{ex}$



$\sum F_x = \emptyset = F_{cx}$
(Eq4) $\sum F_y = \emptyset : F_{cy} + F_{cut} - F_{dy}$
(Eq5) $\sum M_d = \emptyset : F_{dy}(3.5) - F_{cut}(0.44) = \emptyset$

Figure A-2b: Bolt Cutter Analysis Continued

APPLICATION OF EQUATIONS

Eq 1: $F_{cx} = F_{bx} = \emptyset$ lbs

Eq 3: $-50(36.25) - F_{bx}(1\frac{1}{4}) + F_{by}(1/4) = \emptyset$

$-1812.5 - \emptyset + F_{by}(1/4) = \emptyset$

$F_{by}(1/4) = 1812.5$

$F_{by} = 17{,}250$ lb ↑

Eq 2: $F_{by} - F_{cy} - 75 = \emptyset$

$7250 - F_{cy} - 75 = \emptyset$

$F_{cy} = 7175$ lb ↓

Eq 5: $F_{cy}(3.5) - F_{CUT}(0.44) = \emptyset$

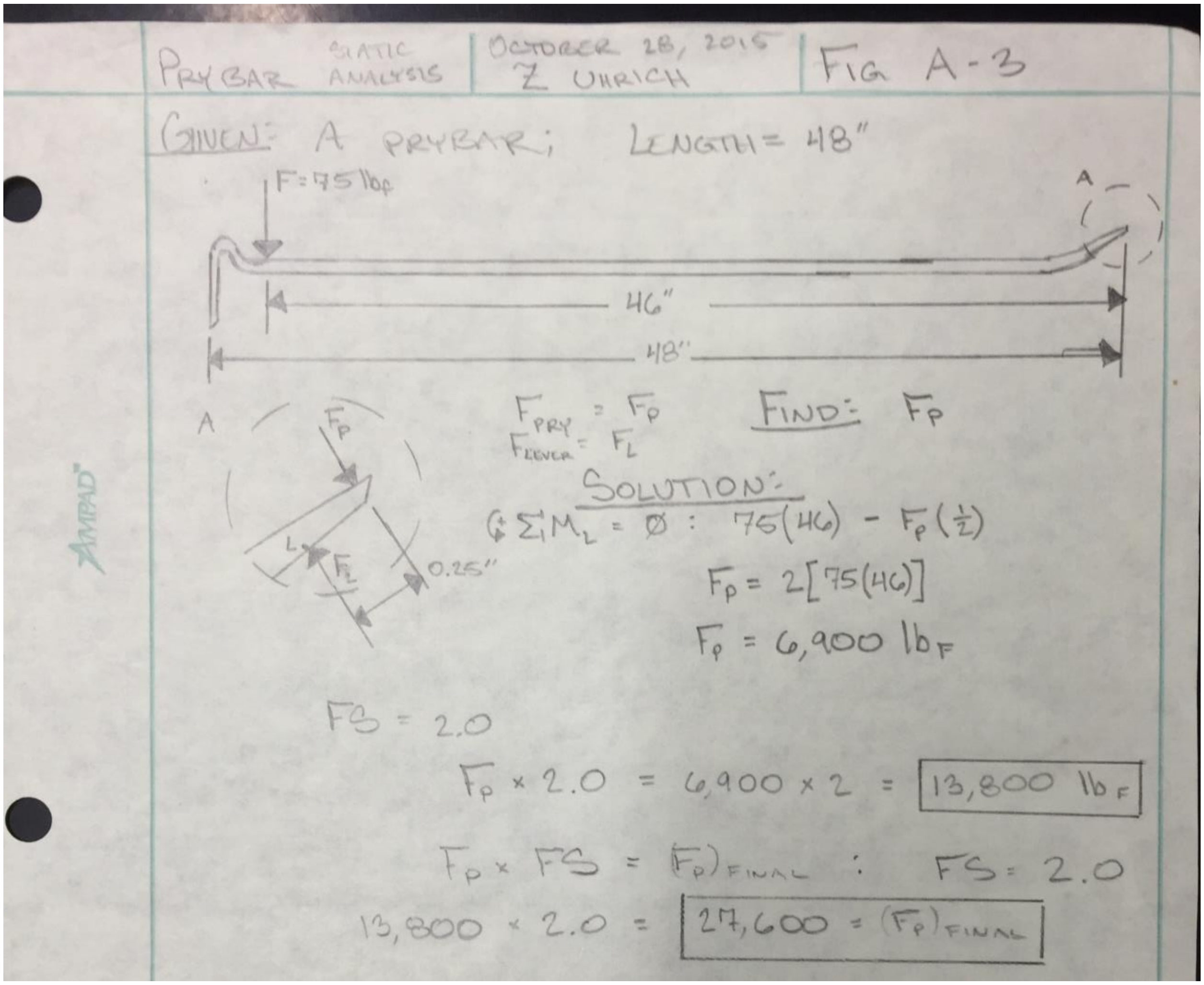
$(3.5)17{,}175 - F_{CUT}(0.44) = \emptyset$

$$\boxed{F_{CUT} = 57{,}073 \text{ lb}}$$

$85{,}909 \times FS = 57{,}073 \times 1.5$

$$\boxed{F_{TOTAL} = 85{,}610 \text{ lbs}}$$

Figure A-3, Static Force Analysis of a Pry Bar.



PRY BAR STATIC ANALYSIS | OCTOBER 28, 2015 Z UHRICH | FIG A-3

GIVEN: A PRYBAR; LENGTH = 48"

F = 75 lbf

46"

48"

A

$F_{PRY} = F_P$

$F_{LEVER} = F_L$

FIND: F_P

L

F_L

0.25"

SOLUTION:

$\sum M_L = 0 : 75(46) - F_P(\frac{1}{2})$

$F_P = 2[75(46)]$

$F_P = 6{,}900 \text{ lb}_F$

FS = 2.0

$F_P \times 2.0 = 6{,}900 \times 2 = \boxed{13{,}800 \text{ lb}_F}$

$F_P \times FS = (F_P)_{FINAL} \;:\; FS = 2.0$

$13{,}800 \times 2.0 = \boxed{27{,}600 = (F_P)_{FINAL}}$

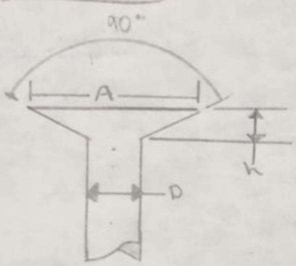
Figure A-4 – Analysis of Shear Stress of Rivet Heads

Z UHRICH | RIVET ANALYSIS | FIG A-4

GIVEN: A PRYING FORCE FROM A PRY BAR: $F = 27{,}600$ lb

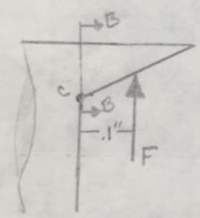
FIND: THE MINIMUM REQUIRED DIMENSIONS OF THE RIVETS TO PREVENT FAILURE.

SOLUTION:

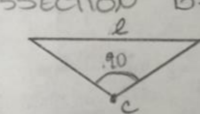


ASSUME: THE GAP BETWEEN PLATES BEING 0.1".
- MATERIAL IS 18-8 STAINLESS STEEL

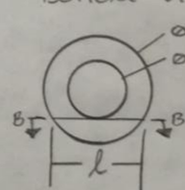
UTS =



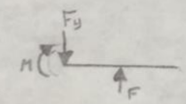
CROSSECTION B-B



BOTTOM VIEW

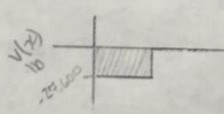


$$\boxed{l = 2\left(\frac{A}{2}\right)\sin\left(\frac{120°}{2}\right)}$$



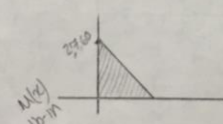
$\sum F_y = \emptyset: \quad F = F_y = 27{,}600$ lb

$\sum M = \emptyset: \quad M = 27{,}600\,(0.1); \quad M = 2{,}760$ lb·in



POINT OF MAXIMUM STRESS = C

$$\sigma_b = \frac{M}{S} \qquad M = 2{,}760 \text{ lb-in} \quad S = lh^2/24 \text{ in}^3$$



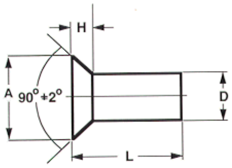
$$\sigma_b = \frac{2760}{\left[2\left(\frac{A}{h}\right)\sin(45)\right]h^2/24}$$

STANDARD SIZES FOR A & h ARE PLUGGED IN TO THE EQUATION AND STRESS IS CHECKED.

Figure A-5 – Standard Rivet Sizes – as available at www.rivetsonline.com

<u>Countersunk Head</u>

Rivet Specifications



Normal Size or Basic Shank Diameter		D		A		H
		Shank Diameter		Head Diameter		Head Height
		Max	Min	Max	Min	Ref
1/16	0.062	0.064	0.059	0.118	0.110	0.027
3/32	0.094	0.096	0.090	0.176	0.163	0.040
1/8	0.125	0.127	0.121	0.235	0.217	0.053
5/32	0.156	0.158	0.152	0.293	0.272	0.066
3/16	0.188	0.191	0.182	0.351	0.326	0.079
7/32	0.219	0.222	0.213	0.413	0.384	0.094
1/4	0.250	0.253	0.244	0.469	0.437	0.106
9/32	0.281	0.285	0.273	0.528	0.491	0.119
5/16	0.312	0.316	0.304	0.588	0.547	0.133
3/8	0.375	0.380	0.365	0.704	0.656	0.159
7/16	0.438	0.443	0.428	0.823	0.765	0.186

Figure A-6 – Bending Force Applied through the Links

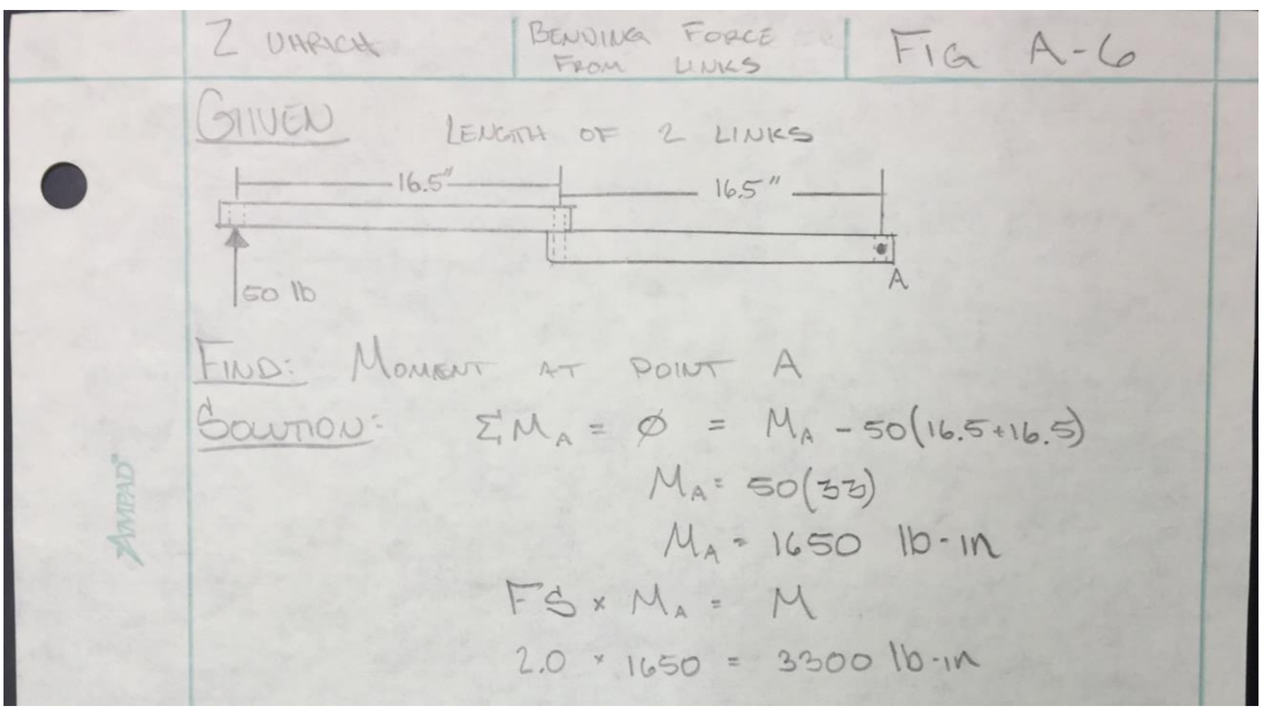
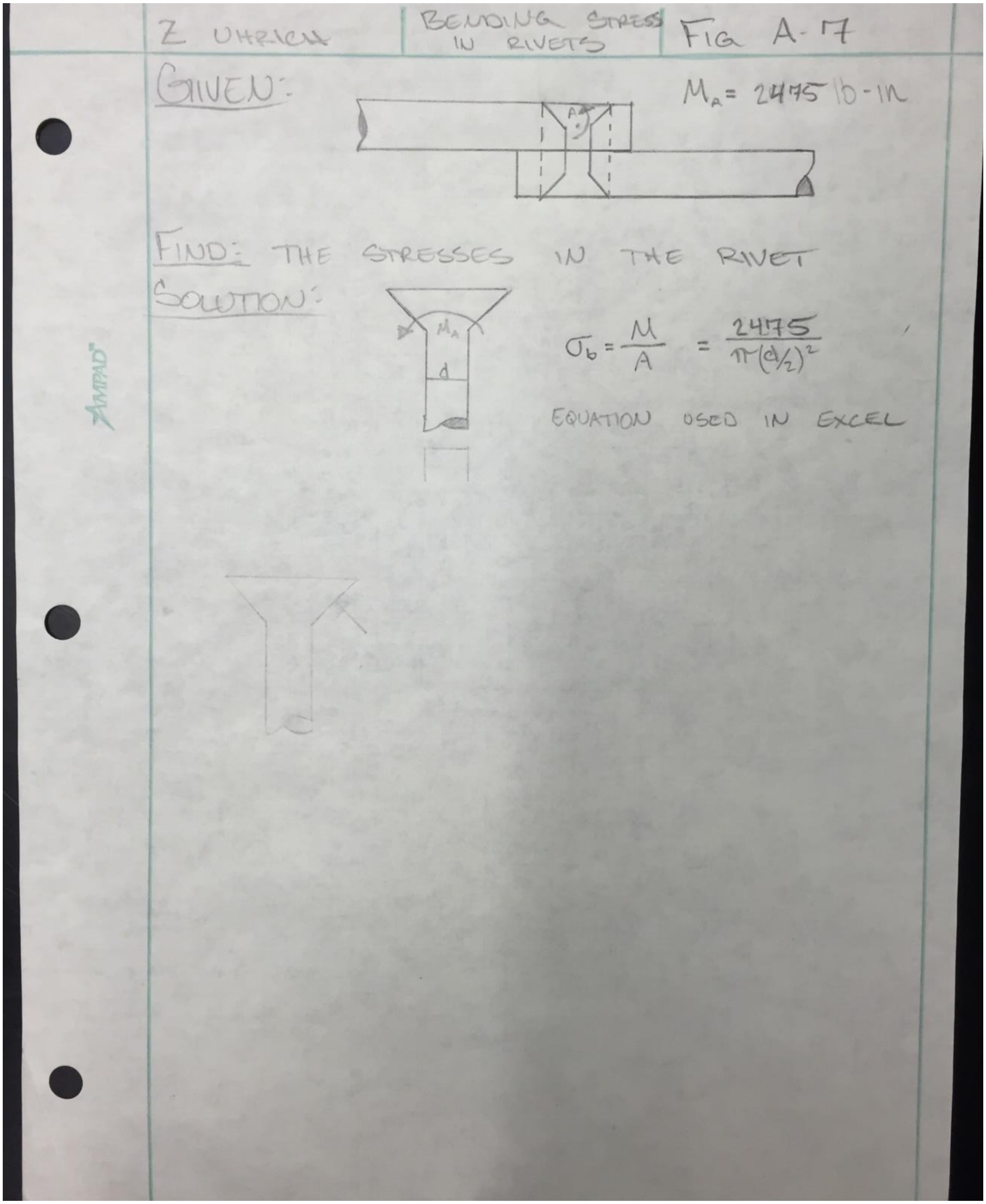


Figure A-7 – bending Stress Applied to the Rivets



Z UHRICH | BENDING STRESS IN RIVETS | FIG A-7

GIVEN:

$M_A = 2475$ lb-in

FIND: THE STRESSES IN THE RIVET

SOLUTION:

$$\sigma_b = \frac{M}{A} = \frac{2475}{\pi(d/2)^2}$$

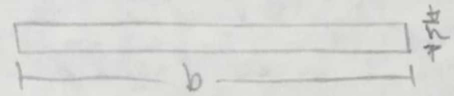
EQUATION USED IN EXCEL

Figure A-8 – Reanalyzing required thickness of the links

DETERMINING THICKNESS | Z. UHRICH | FIG A-8

GIVEN: APPLIED FORCE OF 85,610 lb

CROSS-SECTION:



$b = 1.5$

MATERIAL = 4140 STEEL

$S_u = 290$ ksi
$S_{us} = 217.5$ ksi

FIND: REQUIRED, h, to AVOID FAILURE (SHEAR)

SOLUTION:

$$\tau = \frac{F}{A}$$

$$S_{us} = \frac{F}{A} \Rightarrow 217{,}500 = \frac{85610}{1.5 \times h}$$

$h = 0.262$ inches.

minimum required height = 0.263 inches

Figure A-9 – Determination of rivet size

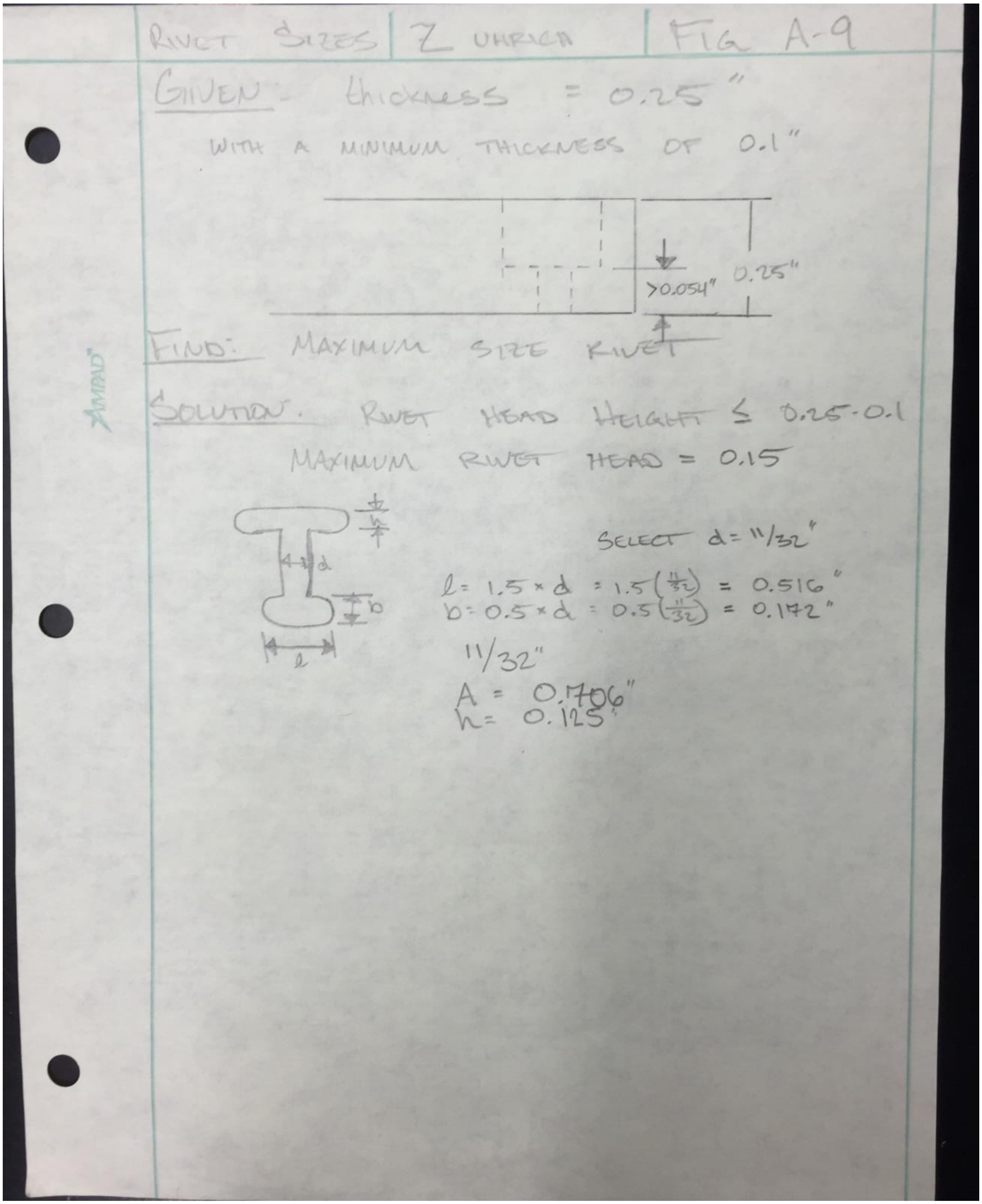
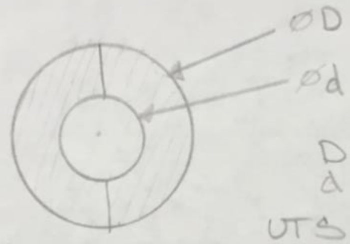


Figure A-10 – Minimum cross-sectional area of rivet housing

REQUIRED THICKNESS | Z. UHRICH | FIG A-10

GIVEN:

MATERIAL = A36 STEEL



FORCE ACTING ON THIS CROSS-SECTION IS 3300 lbs

$D \leq 1.00$ inch

d

UTS = 58,000 psi

FIND: REQUIRED DIMENSIONS

SOLUTION:

$$\text{AREA} = \pi\left(\frac{D}{2}\right)^2 - \pi\left(\frac{d}{2}\right)^2$$

$$\sigma = \frac{F}{A}$$

USE ONLY HALF AREA TO SIMULATE PRYING

$$\sigma = \frac{F}{A/2} = \frac{2F}{A}$$

$$\sigma = \frac{2(3300)}{A} = 58{,}000$$

$$A = \frac{6600}{58000} = 0.114 \text{ in}^2 \Rightarrow \text{min AREA}$$

Figure A-11 – Minimum required thickness of rivet housing

HOUSING SIZE | Z. UHRICH | FIG A-11

GIVEN: OD OF HOUSING = 0.9 inches

FORCE APPLIED = 3300 lb

FIND: MINIMUM THICKNESS OF RIVET HOUSING.

SOLUTION: AREA OF FORCE = $\left(\frac{D\pi}{2}\right)t$: t = thickness

$$S_{us} = 0.75\,S_u = 0.75 \times 58{,}000$$

$$S_{us} = 43{,}500 \text{ psi}$$

$$\sigma = \frac{F}{A} \Rightarrow 43{,}500 = \frac{3300}{\left(\frac{\pi\, 0.9}{2}\right)t}$$

$t = 0.054$ inches (MINIMUM)

Figure A-12 – Determination of total volume of folded chain

FOLDED VOLUME | Z UHRICH | FIG A-12

GIVEN: THICKNESS OF EACH LINK = 0.25"
THICKNESS OF EACH WASHER = 0.10"
WIDTH OF LINK = 1.25"

FIND: TOTAL VOLUME OF FOLDED UP BIKE LOCK.

SOLUTION: WIDTH = 1.25"
LENGTH = 18.0"
HEIGHT = $(0.25" \times 6) + (0.10 \times 5) = 2.00"$

DIMENSIONS = $1.25" \times 2.00" \times 18.00"$

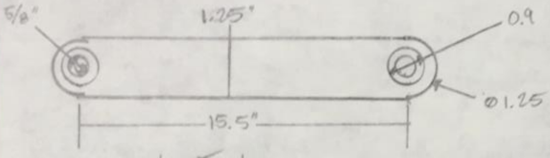
VOLUME = $45\ in^3$

Figure A-13 – Determination of total weight of chain assembly

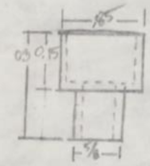
TOTAL WEIGHT | Z UHRICH | FIG A-13

GIVEN: $\rho_{5160} = 0.284\ \text{lb/in}^3$; $\rho_{A36} = 0.284$

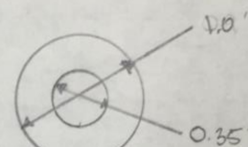
$\rho_{\text{stainless}} = 0.29\ \text{lb/in}^3$



thickness = 0.25"



thickness = 0.15"



thickness = 0.10"

FIND: TOTAL WEIGHT

LINKS:

18"

$\left(\pi\left(\frac{1.25}{2}\right)^2\right)(0.25) = 0.3068\ \text{in}^3\ +$

$(1.25 \times 15.5)(0.25) = 4.8438\ \text{in}^3\ -$

$\left(\pi\left(\frac{.9}{2}\right)^2\right)(0.1) = 0.0636\ \text{in}^3\ -$

$\left(\pi\left(\frac{5/8}{2}\right)^2\right)(0.15) = 0.0460\ \text{in}^3$

$\Big\}\ 5.26\ \text{in}^3$

10"

$(1.25 \times 7.5)(0.25) = 2.3438\ \text{in}^3\ \Big\}\ 2.54\ \text{in}^3$

RIVET HOUSING

$(\pi(0.85^2 - 0.750^2)/4)(0.15) = 0.0188\ \text{in}^3$

$(\pi(0.625^2 - 0.344^2)/4)(0.15) = 0.2139\ \text{in}^3$

$\Big\}\ 0.2327\ \text{in}^3$

WASHER

$(\pi(1.0^2 - 0.625^2)/4)(0.10) = 0.0479\ \text{in}^3\ \Big\}\ 0.0479\ \text{in}^3$

$\text{WEIGHT} = \sum V \times \rho \Rightarrow (W_{\text{LINK}})5 + (W_{\text{LINK}}) + (W_{RH})10 + (W_{\text{WASH}})5$

$\text{WEIGHT} = (5.26 \times 0.284)5 + (2.54 \times 0.284) + (0.2327 \times 0.284)10 + (0.0479 \times 0.284)5$

$\boxed{\text{TOTAL WEIGHT} = 8.919\ \text{POUNDS}}$

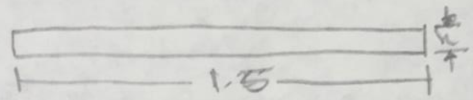
Figure A-14 – Analysis of minimum base of chain links

READJUSTING LINK WEIGHT | Z UHRICH | FIG A-14

GIVEN: DATA FROM FIG A-8

$V = 85{,}610$ lb

CHANGE MATERIAL TO SAE 5160 OQT 400



FIND: NEW MINIMUM ACCEPTABLE HEIGHT

SOLUTION:

$$\tau = \frac{V}{h \times b}$$

$S_u = 322{,}000$ psi

$S_{us} = 241{,}500$ psi

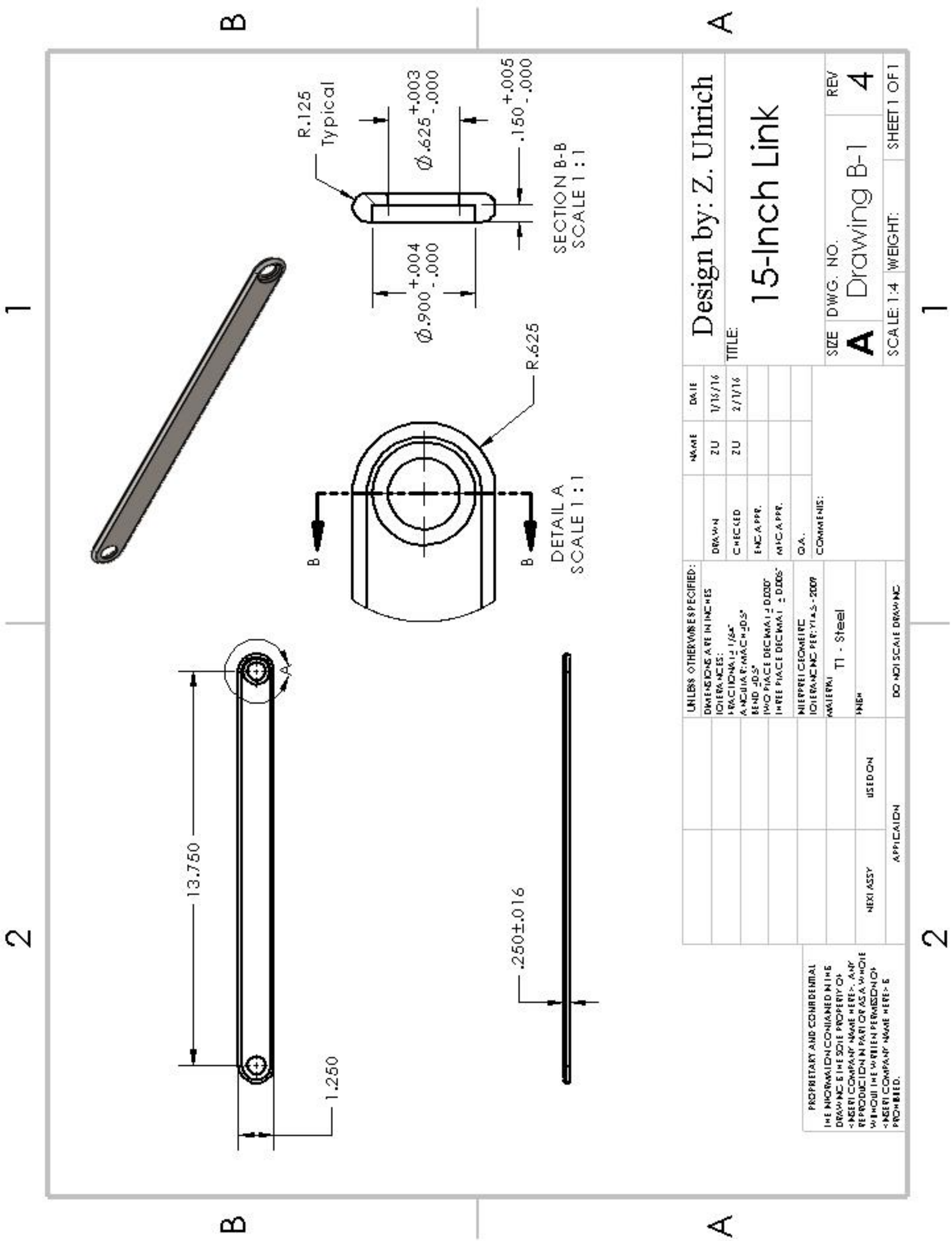
$$241{,}500 = \frac{85{,}610}{1.5 \times h}$$

$h = 0.236$ INCHES

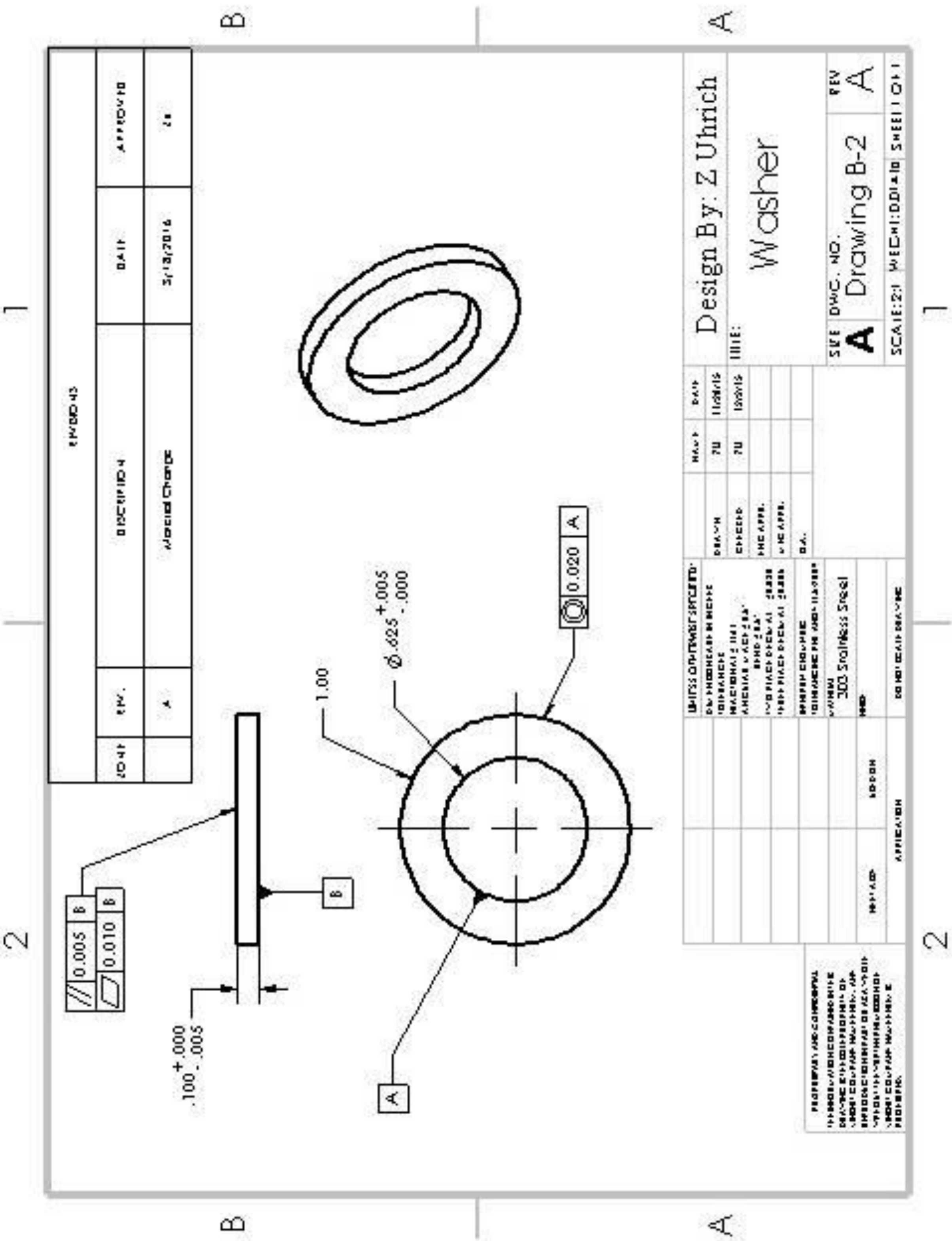
MINIMUM HEIGHT IS 0.236 inches

APPENDIX B – Part Drawings

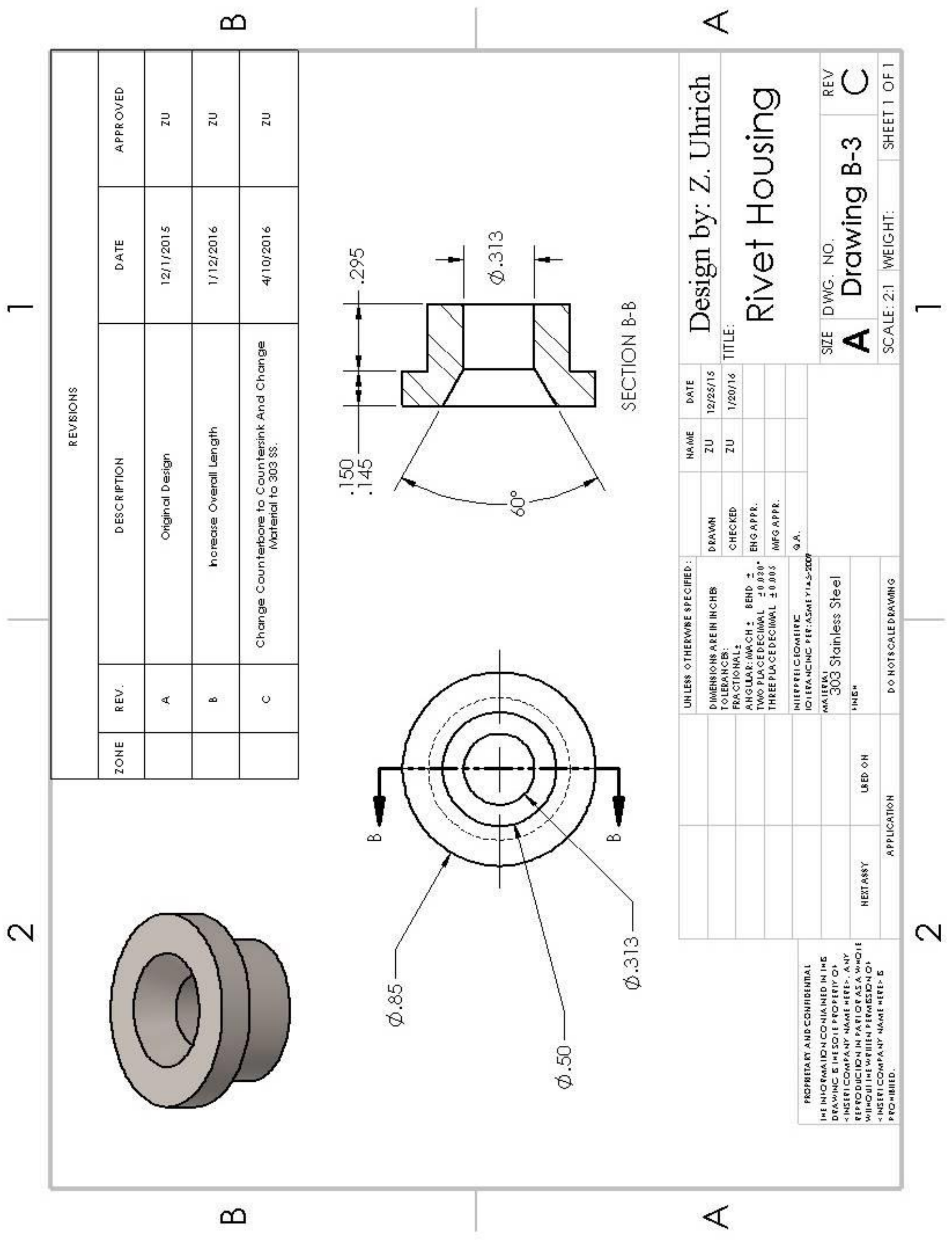
Drawing B-1 – 15 inch Link



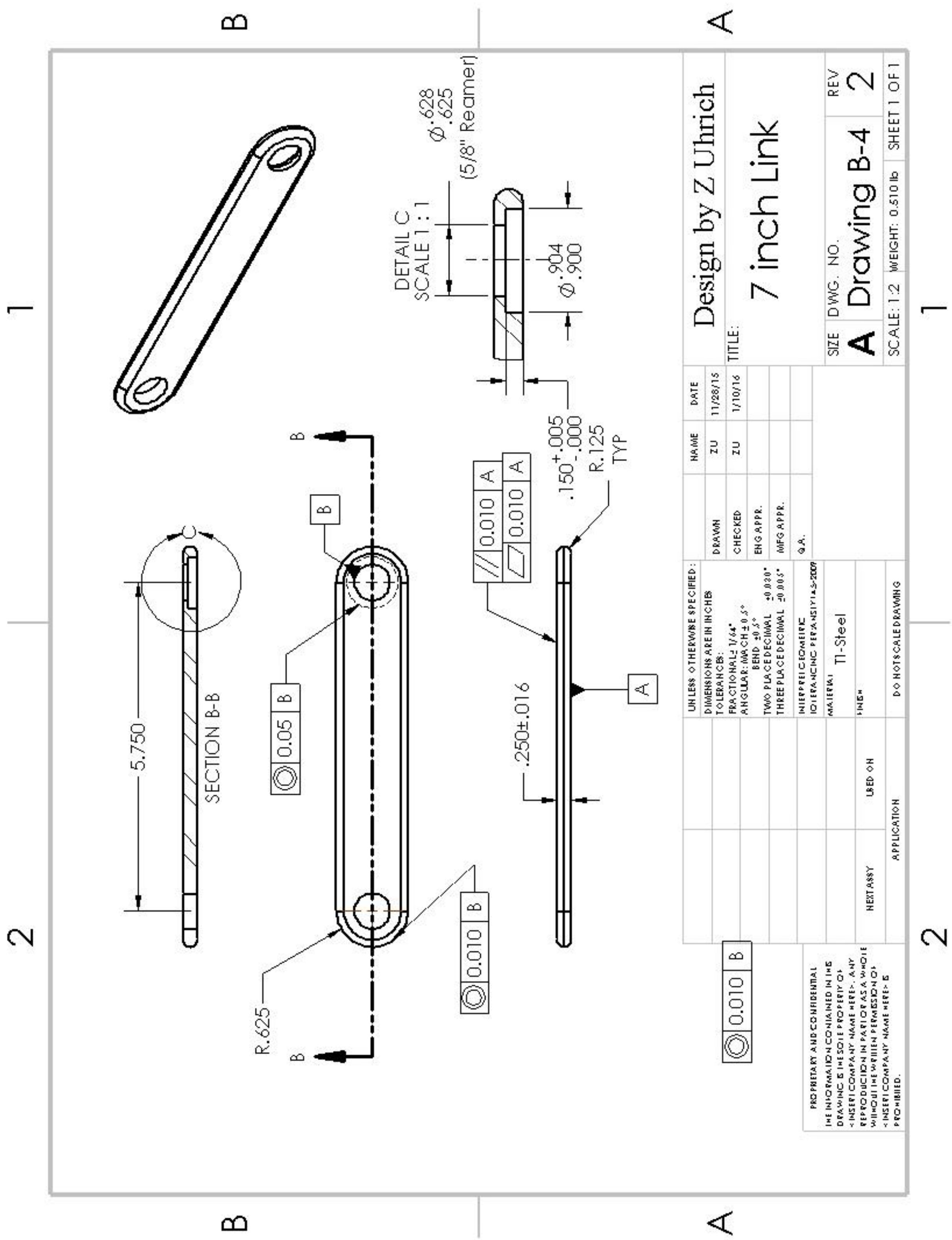
Drawing B-2 – Washer



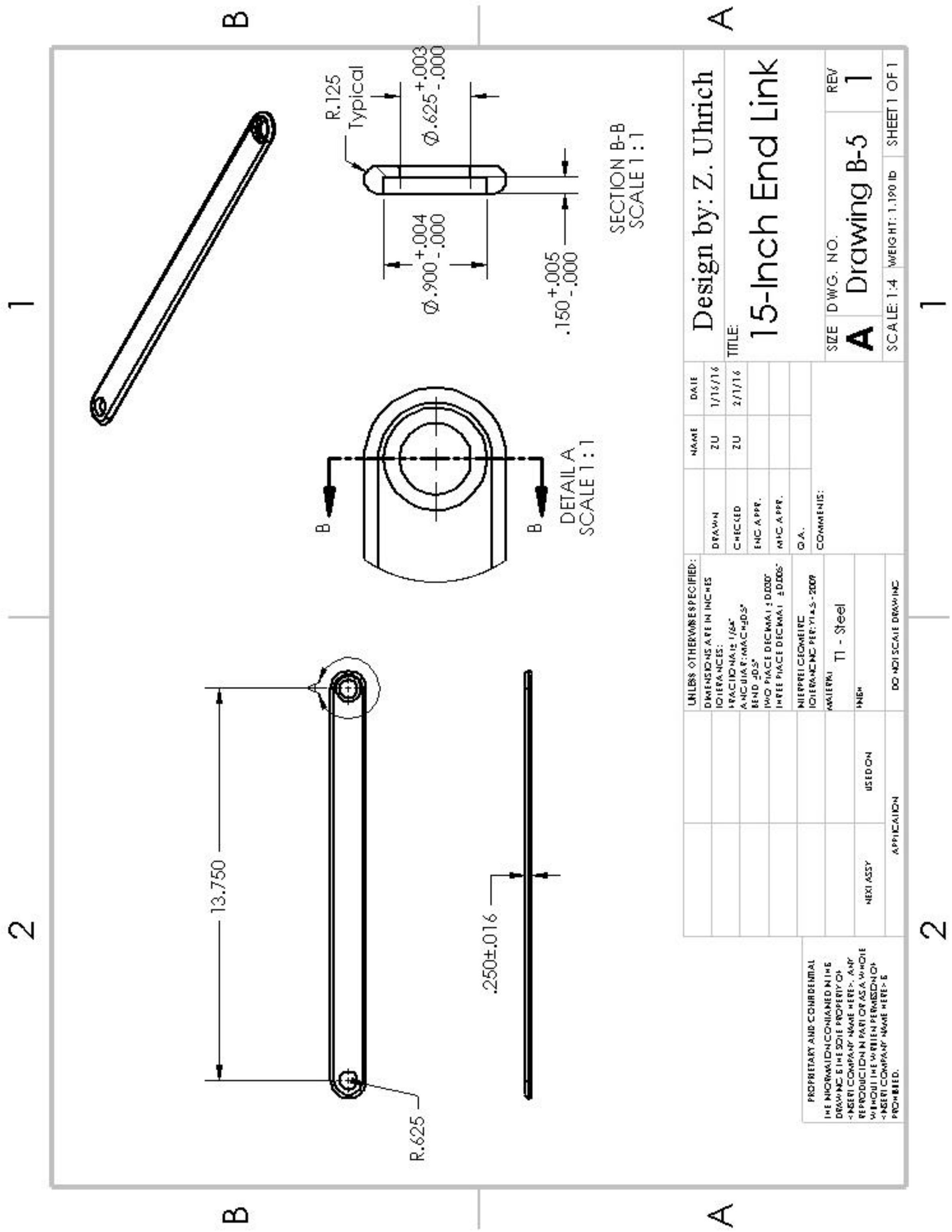
Drawing B-3 – Rivet Housing



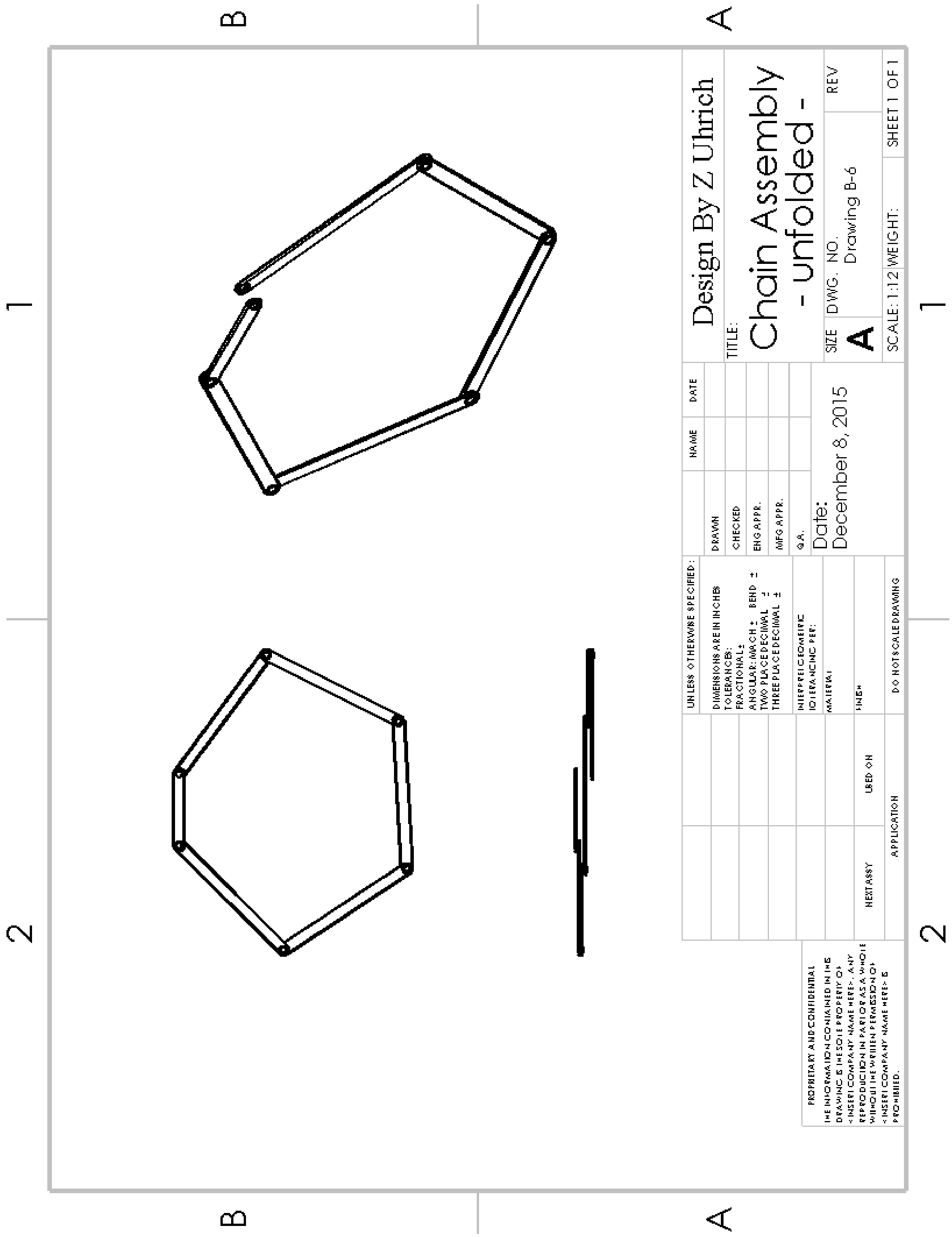
Drawing B-4 – 7 inch Link



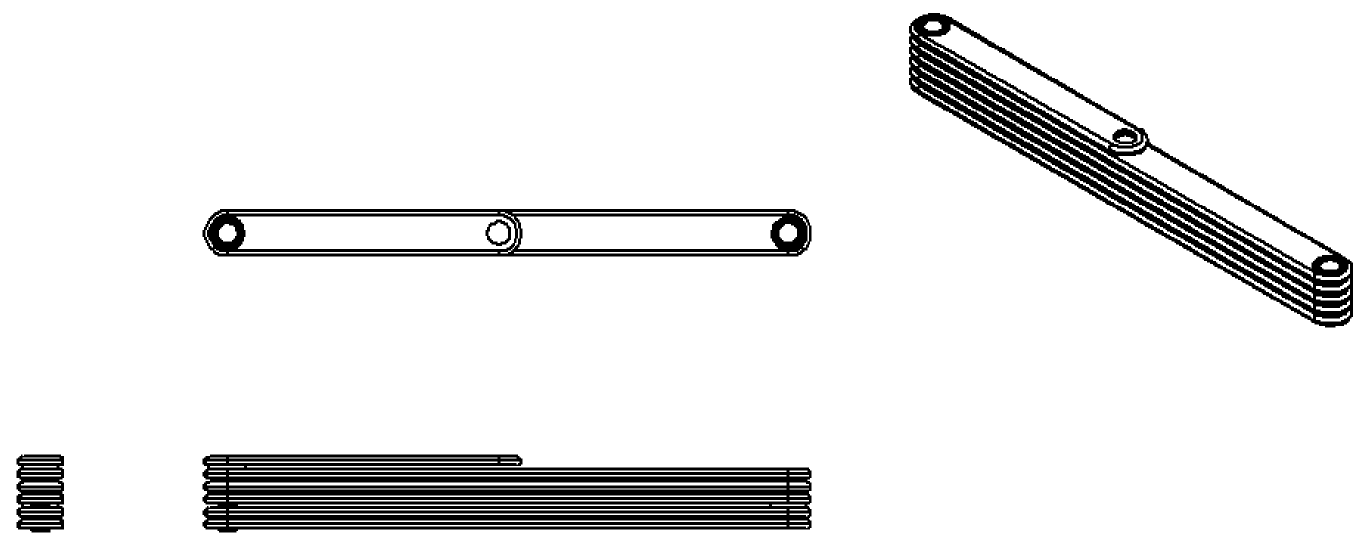
Drawing B-5 – 15 inch End Link



Drawing B-6 – Chain Assembly unfolded



Drawing B-7 – Chain Assembly folded



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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

Weight: 7.65 pounds

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

Date:
December 5, 2015

Design By Z Uhrich

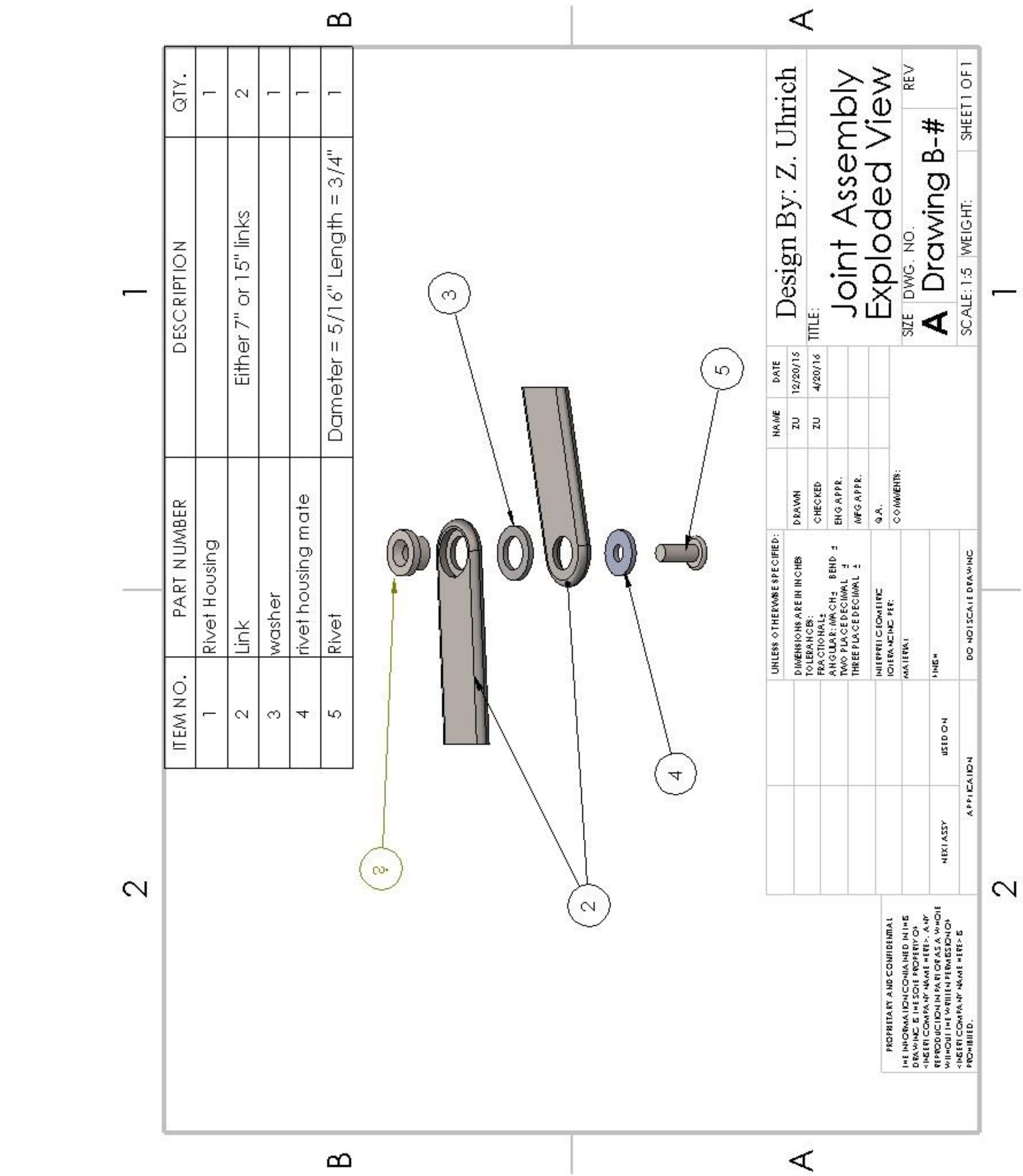
TITLE:

Entire Chain Assembly - Folded

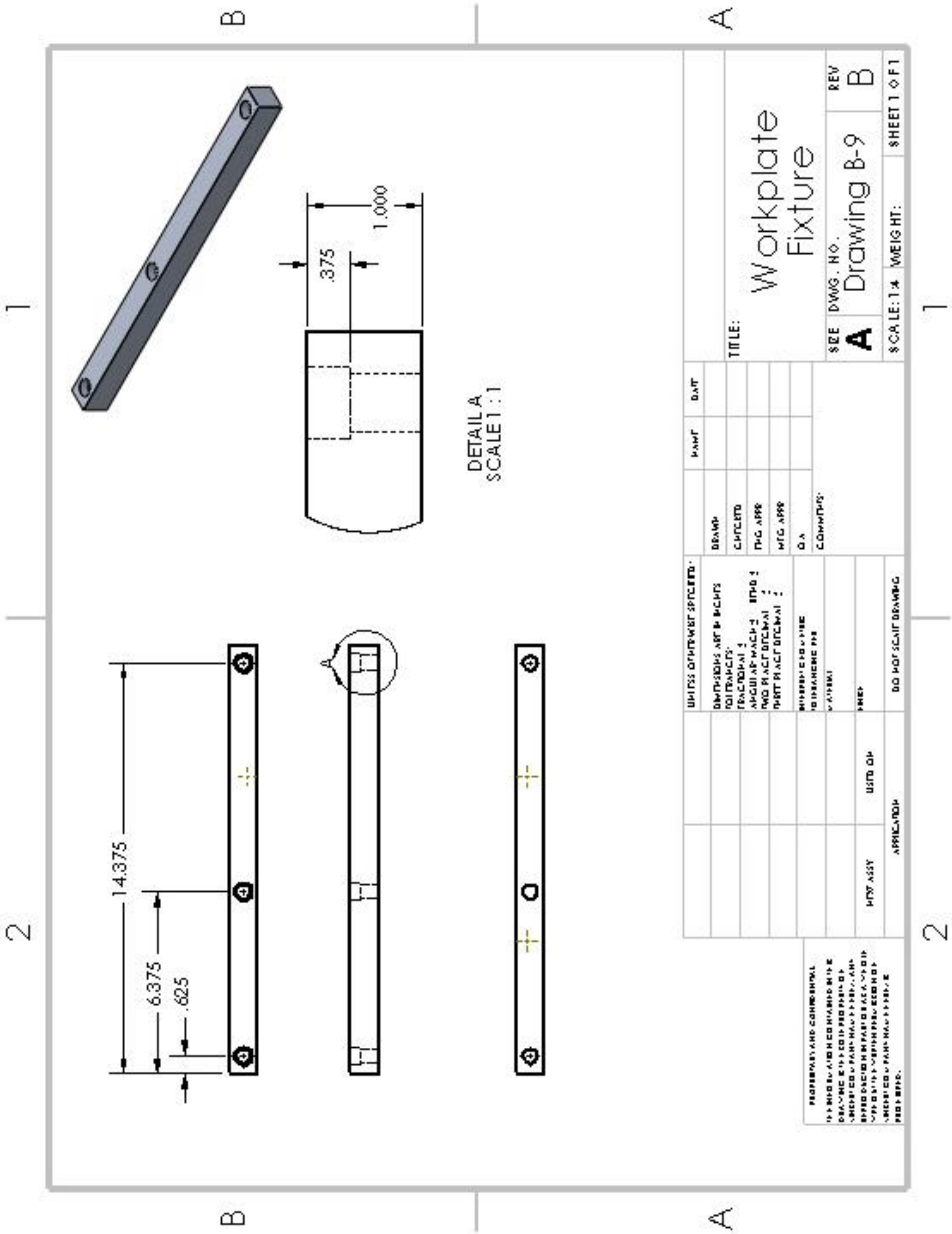
SIZE	DWG. NO.	REV
A	Drawing B - 6	

SCALE: 1:4 WEIGHT: SHEET 1 OF 1

Drawing B-8 Single Joint Assembly



Drawing B-9 Workplate Fixture



APPENDIX C – PART LIST AND BUDGET

Part Name	Quantity Purchased	Purchased From	Unit Dimensions	Cost	Shipping	Total Cost
15 inch Link	1	Speedymetals.com	1/4” x 1.25” x 240” plate	$30.04	$8.00	$38.04
7 inch Link	0		1/4” x 1.25” x 240” plate			$0.00
Rivet Housing	1	Supplied by CWU	Dia. = 1” Len.=12"			$0.00
Rivet Housing Modifications	1		Dia. = 1” Len.=24"	$16.12	$7.45	$23.57
Washer	0	Supplied By CWU	Dia. = 1” Len.=9"			$0.00
Rivets	25	Grainger	5/16 diameter (5/8" length)	$12.43	$9.99	$22.42
Rivets Modifications	25	Grainger	5/16 diameter (3/4" length)	$21.13	$13.00	$34.13
Locking Mechanism	1	Amazon.com		$11.60		$11.60
Fixture Plate	1	Supplied by	1.5” x 1.0” x 15”			$0.00
Corner Rounding Edge mill	1	Amazon.com	0.125" radius	$12.96	$5.32	$18.28
60 degree Countersink Bit	1	Grainger	1/2"	$21.85	$13.06	$34.91
HSS turning tool blanks	3	CWU Bookstore	1/4"	$6.50		$6.50
Flat end mill	1	CWU Bookstore	1/2"	$4.95		$4.95
Shoulder Bolts	2	Fastenal	5/8 x 5/8 shoulder. 1.25 OAL	$20.54		$20.54
Shoulder Bolts	2	Fastenal	5/8 x 5/8 shoulder. 1.75" OAL	$21.58		$21.58
Bolt Cutters	1	Amazon	24"	$34.86		$34.86
Pry Bar	1	Amazon	36"	$14.95		$14.95
Hacksaw	1	Amazon		$24.00		$24.00
Hacksaw Blades	2	Amazon		$3.21		$3.21
Totals				**$256.72**	**$56.82**	**$313.54**

APPENDIX D – Schedule

Bike Lock

Period Highlight: 1 | Plan | Actual | % Complete | Actual (beyond plan) | % Complete (beyond plan)

	SECTION	ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Fall Quarter	Introduction	Motivation	1	1	1	1	100%
		Funtion Statement	1	1	1	1	100%
		Requirements	1	1	1	1	100%
		Engineering merit	2	2	2	2	100%
		Scope of Effort	2	2	2	2	100%
		Success Criteria	2	2	2	2	100%
	Design and Analysis	Approach	3	2	3	3	100%
		Description	3	2	3	3	100%
		Benchmark	3	2	3	3	100%
		Performance Predictions	3	2	3	3	100%
		Description of Analyses	4	2	4	4	100%
		Scope of Testing and Evaluation	4	2	4	3	100%
		Analysis	6	3	6	5	75%
		Device: Parts, Shapes, Conformations	8	1	8	1	100%
		Device Assembly, Attachments	8	1	8	1	100%
		Tolerances, Kinematics, Ergonomics	8	1	8	1	100%
		Technical Risk Analysis	8	1	8	1	100%
	Methods and Contstruction	Links	9	1			0%
		Rivets Housing	9	1			0%
		Assembly	9	1			0%
	Testing Methods	Modes of Failure	9	2			0%
	Budget/Schedule/ Project Management	Proposed Budget	10	1			0%
		Proposed Schedule	10	1			0%
		Project Management	10	1			0%
	Discussion	Design Evolution	10	2			0%
		Project Risk Analysis	10	1			0%
		Success	10	1			0%
	Conclusion	Conclusion	10	1			0%
	Acknowledgements	Acknowledgements	11	1			0%
	References	References	11	1			0%
Winter Quarter	Collection of Materials	Links	13	3			0%
		Rivet Housing/washer	13	3			0%
		Rivets	13	3			0%
		Rivet Gun	13	3			0%
		Locking Mechanism	15	2			0%
	Fabrication	Links - milling	16	3			0%
		Links - heat treatment	18	2			0%
		Rivet Housing - turning	17	3			0%
		Rivet Housing - heat treatment	19	2			0%
	Assembly	Assemble bike lock	20	2			0%
	Collection of Testing Tools	Collect necessary equipment	24	2			0%
	Modes of failure	Bolt Cutters	26	2			0%
		Hack Saw	27	2			0%
		Screw Driver	28	2			0%
		Pry Bar	29	2			0%

Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Week	28-Sep-15	5-Oct-15	12-Oct-15	19-Oct-15	26-Oct-15	2-Nov-15	9-Nov-15	16-Nov-15	23-Nov-15	30-Nov-15	7-Dec-15	14-Dec-15	21-Dec-15	28-Dec-15	4-Jan-16	11-Jan-16	18-Jan-16	25-Jan-16	1-Feb-16	8-Feb-16

Period	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Week	15-Feb-16	22-Feb-16	29-Feb-16	7-Mar-16	14-Mar-16	21-Mar-16	28-Mar-16	4-Apr-16	11-Apr-16	18-Apr-16	25-Apr-16	2-May-16	9-May-16	16-May-16	23-May-16	30-May-16	6-Jun-16	13-Jun-16	20-Jun-16	27-Jun-16

Winter Quarter – Fabrication – 2016

Task Number	Category	Task name	Projected Hours (Hours)	Projected Hours (Total)	Actual Hours (Each)	Actual Hours (Total)
010	**Collection of Materials**	Links	1.00	1.00	1.50	1.50
020		Rivet Housing/washer	1.00	1.00	1.50	1.50
030		Rivets	1.00	1.00	4.00	4.00
040		Rivet Tool	1.00	1.00	0.25	0.25
050		Locking Mechanism	0.50	0.50	1.00	1.00
060		Work Plate	0.50	0.50	0.25	0.25
070		5/8 Shoulder Bolts	0.50	0.50	1.00	1.00
080	**Traveler's**	Rivet Housing	1.00	1.00	3.00	3.00
090		Washers	1.00	1.00	1.00	1.00
100		Links	1.00	2.00	2.50	5.00
110		Work Plate	1.00	1.00	1.00	1.00
120	**Fabrication**	Rivet Housing - Operation 1	0.17	1.67	0.50	5.00
121		Rivet Housing - Dimension Checks	0.10	1.00	0.10	1.00
123		Rivet Housing - Operation 1 Adjustments	0.25	2.00	0.50	2.50
124		Rivet Housing - Operation 2	0.10	1.00	0.25	2.50
130		Work Plate CNC program	1.50	1.50	4.00	4.00
131		Work Plate Fabrication.	2.00	2.00	3.00	3.00
140		Program for CNC Milling - 15in Op 1	2.00	2.00	3.00	3.00
141		Program for CNC Milling - 7in Op 1	0.25	0.25	0.25	0.25
142		Program for CNC Milling - 15in Op 2	3.00	3.00	2.50	2.50
143		Program for CNC Milling - 7in Op 2	0.25	0.25	0.25	0.25
144		15 inch Links - CNC Operation 1	1.50	12.00	2.50	20.00
145		7 inch Links - CNC Operation 1	0.50	1.00	0.75	1.50
146		15 inch Links - CNC Operation 2	1.00	8.00	1.25	10.00
147		7 inch Links - CNC Operation 2	0.50	1.00	0.50	1.00
148		15 inch Links - Drill Press Operation 3	0.17	1.33	0.17	1.33
149		7 inch Links - Drill Press Operation 3	0.17	0.33	0.17	0.33
150		Links - heat treatment	3.00	30.00	4.00	40.00
160	**Assembly**	Assemble bike lock (Joints)	0.25	1.00	0.50	2.00
		Totals		79.8367		119.667

APPENDIX E – EVALUATION SHEET

REQUIREMENT	VALUE	MEASURING TOOL	ACTUAL VALUE
Maximum weight	10 pounds	Scale	6.2
Minimum Length	60 inches	Tape Measure	62
Minimum Diameter of closed loop	12 inches	Tape Measure	15
Minimum Rockwell Hardness	65	Hardness Tester	66.5

APPENDIX F - Testing Results:

Introduction:

- Requirements:
  - Weigh less than 10 pounds.
  - Fold down to fit in a 3 inch x 3 inch x 18 inch volume (Not including the locking mechanism.
  - Be comprised of no less than 4 and no more than 10 individual links.
  - Each link must have a material hardness of at least 65 on the Rockwell C scale.
  - Each link must be able to withstand the cutting force of a pair of 42 inch bolt cutters, with 50 pounds of force applied to the handles (85,610 pounds of cutting force).
  - The joints must be able to withstand the force applied from a 48 inch pry bar (27,600 pounds of force).
- Parameters of interest:
  - The most important aspect of this bike lock is the security it provides. Therefor the most important thing to test is the resistance of the bike lock chain against common bike theft tools. This lock must be able to withstand bolt cutters, hacksaws, pry bars, and screw drivers for at least eight hours. The testing for each of these four tools will be considered *failure testing* in this report.
- Predicted performance:
  - The analysis completed before the design of this bike lock chain, will ensure that the bolt cutters are unable to cut through the link. It will also ensure that a hacksaw will become dull before it is able to do any serious damage to the links. The Design of the joints may not offer the necessary resistance required to prevent failure from a large pry bar, however the design of the joints will prevent a pry bar from being able to fit between the links. And, a small screw driver may be able to fit between the links, but will not be able to apply enough force to cause failure of the joint.
- Results:
  - The results of the hacksaw and bolt cutter testing will be a time and depth of cut, which allows for the calculations of total time to failure.
  - The results of the pry bar and screwdriver tests will be either observations of the success and failure of the part, or the time required to cause failure.
- Schedule:
  - The Gantt Chart for this testing can be found in the appendix.

Method/Approach:

- Resources required:
  - Hardness Testing

        - A hardness testing machine
        - A standard block with known hardness
        - Two different testing specimens
    - Hack Saw Testing
        - A hack saw with blade (for metal)
        - A rigid table clamp
        - One testing specimen
        - A timer
    - Bolt Cutter Testing
        - 24 inch bolt cutters (42 inch bolt cutters may be needed as well)
        - A rigid table clamp
        - One testing specimen
        - A timer
    - Pry Bar and Screwdriver testing
        - A 48 inch pry bar.
        - A large flat head screwdriver.
        - One testing specimen (comprised of two links and one joint)
        - A timer
- Data Capture:
    - The Hardness testing will result in acquired values which can be compared to the requirements to determine success.
    - The failure tests will require observations to be noted throughout the tests, then this combined with the values recorded will be used to determine the success or failure of each test.
- Operational limitations:
    - For the failure testing a certain amount of human strength is required to ensure the validity of the results. This amount of strength is not quantified in this testing and so the tester must be able to determine if they are unable to adequately use these tools. If this is the case, a second tester should be asked for assistance to ensure excessive force is use.
- Precision and accuracy discussion
    - The depth of cut values for the failure testing should be taken multiple times, with a resolution of 0.001 of an inch to ensure results are accurate.
    - The stopwatch used for the failure testing has to be started immediately before the testing begins, and stopped immediately after, in order to determine precise times.
- Data Analysis;
    - The collected data must be analyzed for the failure testing. This analysis involves using the found time and depth of cut to calculate the required time to cut through the entire part. The following formula will be used:

$$Time_{total} = (Depth\ of\ Cut/Length\ of\ cut\ required) \times Time_{cut}$$

Where: $Time_{cut}$ is equal to the time spent cutting

And length of Cut required is the total thickness that is being cut.

- The hardness testing data will be gathered using the Rockwell Hardness A scale, and then will be converted using the conversation table with the machine.

Test Procedure:

- Hardness Testing
  - Duration:
    - Setup: 10 minutes
    - Testing: 10 minutes
  - Location:
    - Central Washington University Metallurgy Lab
  - Procedure: (Supplied by CWU Engineering Department) conforms with ASTM E8
    - Calibration Procedure
      - Select appropriate calibration block for Rockwell C scale
      - Follow testing procedure to collect three calibration values
      - Follow ASTM E8 to obtain a correction value
    - Test Procedure
      - Crank the platen post down so the indenter slot is exposed
      - Insert a flat platen
      - Insert an indenter
      - Place your specimen on the platen
      - Raise the platen until it touches the indenter
      - Slowly raise the platen and watch the dial
        - Very slowly raise it until the small pointer is on the dot
      - Rotate the outer knurled dial edge to line up “zero”
      - Gently push the top right silver knob to activate the test
      - Watch the dial and count the revolutions
      - When at rest, pull back the top right silver handle and count revolutions
      - Check that the total dial rotation is less than one
        - If not less than one, you much change scales
      - Record the hardness
      - Slowly lower the platen until the indenter is clear
      - Select the next location and repeat or unload it.
      - Repeat testing until five values of hardness have been obtained
      - Get the second testing specimen and repeat the test.
    - Post Test Procedure
      - Secure the specimens and data
      - Lower the platen to its initial height

            - Remove and store the platen in the correct holder
  - Risk, Safety, Evaluation readiness:
    - Use the five hardness values to find an average value and compare that to the required hardness of 65 on the Rockwell C scale. This is the only data needed to determine the success of this specific criterion.
- Hack saw resistance testing
  - Duration:
    - Setup: 5 minutes
    - Testing: 30 minutes
  - Location:
    - Central Washington University Machine Shop
  - Procedure:
    - Insert testing specimen into strong fixed table clamp
      - Ensure between three and four inches extend past the edge of the clamp
    - Set a timer for ten minutes.
    - Begin sawing on the specimen
    - When timer ends write down observations on the condition of both the part and the hacksaw blades
      - If the testing specimen is being cut, measure and record the depth of the cut
    - Reset the time for ten minutes and repeat the previous step
    - Continue repeating three times
      - Be sure to record observations every ten minutes
      - Depth of cut should be measured as precisely as possibly
      - Stop testing and record time if cut makes it through entire part
    - After completion of testing, use depth of cut to determine length of time required to cut through entire testing specimen.
    - Slide the link so that it hangs three to four inches past the edge of the clamp, and repeat the test a second time.
  - Risk, Safety, Evaluation readiness:
    - Safety goggles must be worn during the entirety of this testing
    - Care must be taken to ensure proper handling of hacksaw
    - If at any point the testing specimen becomes weak enough to break by hand, the time should be noted, however the part should continue to be cut until it is broken entirely with the hacksaw.
- Bolt cutter resistance testing
  - Duration:
    - Setup: 5 minutes
    - Testing: 15 minutes
  - Location:
    - Central Washington University Machine Shop
  - Procedure:
    - Insert testing specimen into strong fixed table clamp

            - Allow about a third of the link to hang out the side of the clamp
        - Start a stopwatch at the point you are ready to begin cutting.
        - Use the 24 inch bolt cutters to attempt the cut the link.
            - After the first attempt record any observations about the deformation caused to the link, and any deformation caused to the bolt cutter blades.
            - If the link is cut completely record the time taken to cut it.
        - If the bolt cutters could not be closed completely with the link in the clamp, then remove the link from the clamp and instead place the link in the jaws of the bolt cutter, and pin one arm of the bolt cutters against the ground.
            - This will allow the tester to place their body weight behind the cut and apply additional force.
            - If the link is cut completely record the time taken to cut it.
            - Continue adding more force until the bolt cutter is completely closed.
            - Record the time taken to close the bolt cutters
            - Record any observations about the deformation caused to the link, and any deformation caused to the bolt cutter blades.
        - If the testing was unsuccessful but jaws of the bolt cutters are not damaged beyond use, then the testing must be repeated with 42 inch bolt cutters.
    - Risk, Safety, Evaluation readiness:
        - Be sure only the link is in the jaws of the bolt cutter before attempting to cut.
        - Safety glasses and close toed shoes must be warn at all times.
        - If the bolt cutters close all the way without cutting the link, there will be a large amount of potential energy stored in the bolt cutter arms. It is important that this energy is released cautiously in order to avoid injury.
- Pry bar and screw driver testing
    - Duration:
        - Setup: 5 minutes
        - Testing: 15 minutes
    - Location:
        - Central Washington University Machine Shop
    - Procedure:
        - Acquire one set of two links joined together with the rivet and rivet housing.
        - Place one link into a rigid table clamp allowing the joint to hang out one end
        - Attempt to fit the pry bar into any space between the links, at the joint.
            - A mallet can be used, if necessary, to force the pry bar into the joint once it has been started.

            - If the pry bar is able to fit into the joint, use the leverage applied by the pry bar to attempt to break the joint apart.
            - If the pry bar is unable to fit into the joint, record that data.
        - Repeat the previous step with two other joints.
        - Repeat the previous two steps using a screw driver instead of a pry bar.
    - Risk, Safety, Evaluation readiness:
        - A large amount of space is required while using the pry bar, to ensure that that there is adequate room in the case that the joint does fail.
        - Safety glasses and closed toed shoes must be warn at all times.
- Size and weight measurements
    - Duration:
        - Testing: 15 minutes
    - Location:
        - Central Washington University Machine Shop
    - Procedure:
        - Place the entire chain link (with the lock) on a scale and record the weight
        - Use as precise equipment as available to record the overall length of the chain unfolded.
        - Fold the chain up completely and remove the locking mechanism.
            - Record the height, width, and length of the folded chain. Record this data.

Deliverables:

- Hardness testing:

  The data table for the hardness testing can be found in the appendix. The average value found from these test was 66.5 on the Rockwell C scale. This is above the requirement of 65, therefor this test was successful.

- Hacksaw resistance testing:

  The results table for this testing can be found in the appendix. The hacksaw testing was continued for only ten minutes, at which point it was determined that the hacksaw blade had become completely unusable. The teeth on the blade were either worn down or broken off to the point that the cutting edge was now a smooth surface. After ten minutes of cutting, the depth of cut into the link was 0.026 inches.

Due to the hardness of the link, it was nearly impossible to get the cut started without something to locate the cut. This was accomplished by lining the hacksaw blade against the edge of the table clamp, in order to prevent it from sliding out of place. This is important to note, as it would be much more difficult to replicate those conditions while the bike is in use. This fact would make it even more difficult to get a cut started using a hacksaw blade.

The formula for total time to cut was used to determine how long it would take to cut all the way through the part, and assuming a person could continue cutting at that same speed for the entirety of the time, it would take 8.01 hours to cut through the cross-section. This is also assuming that the thief is able to use a new hacksaw blade each time the previous one becomes dull, which would require 49 different hacksaw blades to complete the task. Considering this information, this test is considered to be successful.

- Bolt cutter resistance testing:

    The results table for this testing can be found in the appendix. During the bolt cutter testing, only a 24 inch bolt cutter was used. At 4 minutes and 30 seconds into the testing, the bolt cutters closed completely around the link, so that no further force could be applied. At this point the jaws of the bolt cutter had deformed enough to allow the link to rest between them without deforming at all. This one cut rendered the – previously unused – bolt cutters completely useless. There was no visible damage done to the link itself. This testing was completely successful.

- Pry bar and screwdriver testing:

    The pry bar testing was considered successful as the pry bar could not be fit between the links in order to attempt to deform the joints. This means that even if enough force could be applied using this tool, it is still not usable due to the design of the joints. Although, this requirement was originally to withstand the force applied by the bar, it is considered equally adequate to simply negate any use of the bar instead.

    The screw driver was able to squeeze slowly into a gap between the link and the washer, however when force was applied only the screwdriver deformed and not any part of the joint. The screwdriver shaft quickly bent into an unusable position. This testing was also considered successful.

- Conclusion:
    - All testing for this project was considered very successful. The bike chain lock met all requirements for resistance to the necessary bike theft tools. After testing, it is clear that the chain is able to easily withstand the force of a hacksaw, bolt cutters, pry bars, and screwdrivers.

Report Appendix:

- Hardness Testing

Part	Test Number	A scale results	C scale results
A	1	82	61
A	2	88	73
A	3	84	64
A	4	86	69
A	5	86	69
B	1	84	65
B	2	86	69
B	3	82	61
B	4	84	65
B	5	86	69
		Average:	66.5

- Hacksaw Testing

Time	Depth of Cut	Observations of Cutting Tool	Observations of Link
10 minutes	0.026 inches	The teeth are broken off the blade. The blade is now nearly smooth, making the hacksaw useless.	A small cut has been made in the link. The surface of the link is extremely scuffed and scratched from the blade.
20 minutes	N/A	N/A	N/A
30 minutes	N/A	N/A	N/A

- Hacksaw Testing

Time	Depth of Cut	Observations of Cutting Tool	Observations of Link
4:30	none	At 4 minutes 30 seconds into the test the bolt cutter blades closed completely. The jaws deformed enough to allow the link to fit between them even while fully closed.	The link had only small scuff marks on it, the bolt cutters caused no real deformation.

APPENDIX G – Resume

Zachary M. Uhrich

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EDUCATION

Masters of Science in Mechanical Engineering Technology Expected June 2017
Central Washington University, Ellensburg, WA
Bachelor of Science in Mechanical Engineering Technology Expected June 2016
Central Washington University, Ellensburg, WA
Western Washington University, Bellingham, WA 2010-2014
Relevant Coursework
Polymer and Composite Technology, Circuit Analysis, Manufacturing Processes, Machining Processes, Metallurgy, Computer Aided Design, Finite Element Analysis
Activities / Certifications
Member of ASME and SME 2014-Present
Certified in use of Solidworks software
CWU Deans List Summer 2014 - Present

EXPERIENCE

Teachers Assistant| Western Washington University Spring 2014
Bellingham, WA | Statics and Strengths of Materials | Professor Jill Davishahl

- Led labs involving Finite Element Analysis using CATIA software
- Graded and Assisted with homework assignments

Assistant Facilities Manager | Animal Critical Care & Emergency Services 2012-2015
Seasonal
Seattle, WA

- Assisted in creating and maintaining a label system for all hospital inventory.
- Maintained the building and surrounding lot through repairs, painting, cleaning, and setting up hardware

Vehicle Technician| Jiffy Lube 2008-2010
Seattle, WA

- Worked with a team to complete basic fluid exchanges and small engine part replacements.
- Worked as customer service representative as both sales representative and cashier

SKILLS

- Skilled with use of CATIA software for three dimensional modeling, as well as Finite Element Analysis
- Skilled and certified with use of Solidworks software for three dimensional modeling
- Experienced with MSC Patran software for Finite Element Analysis