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I. Project Overview

The objective of this project is to design a reusable device for the new lunar lander module that will dissipate the impact energy in such a way that it does not damage the vessel or occupants.

1. Problem Statement

The following statement was provided to the design team by the project sponsor:

> *"For the nation's first woman and next man to land on the moon in 2024, new mechanical component designs are need for the human lander. The Apollo class lander used crushable shock absorbers in their landing legs for simplicity and because of it being a low mass option. For the next generation lander, we plan to have the ability to "hop" or land multiple times with the same landing legs. So we will need to come up with a new generation of shock absorbers for these new manned lunar missions. We would like to work with the senior mechanical design students to research, design, and analyze new alternatives for landing leg shock absorbers to handle the rough dusty conditions and extreme temperatures of the lunar surface and still perform as desired. Then work together to create a scaled down version of the shock absorbers to prototype and test. This will provide the Human Lander Program additional understanding of the state of the art and potential new solutions."*

2. Project Scope

Early in the project we determined our scope based off the problem statement. After the first semester, we refined the scope of the project based off the first semester of working on the project.

A. Initial

A shock absorbing leg system compatible with lunar conditions and can be reused.

B. Refined

A reusable shock absorber, compatible with lunar conditions, that could be incorporated into a larger leg system.

3. Customer Needs

The fundamental needs of this project have been interpreted as the design of a lightweight product that is reusable in space and can repeatedly withstand initial impact velocity of 10ft/s. We determined 12 interpreted needs based off our interviews with our sponsor and technical advisors are NASA.

The product must be able to be used indefinitely, be able to make repeated trips to/from gateway and the moon without returning to Earth in between trips. To minimize trips, it must also require minimal maintenance in addition to being able to use the same tool for multiple components. It must be lightweight yet able to support 25,000kg. The dynamic qualities of the spring must not change or diminish after impact and must be able to handle an impact speed of 10 ft/s while landing at up to 10 degrees offset from the z-axis. Finally, the product would need to have a shock absorber per leg, which each must be able to support the lander under Earth's gravity.

4. Functional Decomposition

We created a list of basic functions that the design must accomplish and then grouped the basic functions into systems that accomplish a related function. We determined that our project has three main systems: support, impact reduction, and reusability.

The design will ensure a safe landing on the moon through reusable shock absorbers with the ability to absorb impact energy, withstand shock, and support the weight of the human lander and its cargo. The design will be able to transform energy, dampen vibrations, dissipate energy, and store energy allowing for the safest landing possible.

5. Targets and Metrics

We determined 11 total targets and metrics that correspond to the 11 functions. Each function is achieved through the metric to achieve a target value. There are five critical targets and metrics, given that there are five critical functions.

The first target is to absorb approximately 145 kJ of kinetic energy from impact into the system, bringing the structure to rest. The design absorbs structural shock by remaining elastically ductile while enduring less than a target of three g's of impact acceleration. The design uses materials and geometry that can support a target mass of approximately 25,000kg. Another target is that the design returns to its original state within 10 hours, through dissipation of stored energy, which is the function the unlocking mechanism. To indicate reusability, the design proves that it has returned 100% to its original state. Sensors monitor the parameter values over time and notify the user once parameters return to its initial value.

The remaining targets and metrics were a second priority. The design should limit excessive rebound to less than 0.5m, have 0kJ of final kinetic energy, should settle in two seconds, dissipate all energy in 10 hours, and must have the capacity to store 145 kJ of energy.

II. Solution Overview

This section gives an overview of the designs we considered, the design we chose to pursue, and the design changes that were made during the project.

1. Design Alternatives

The design team generated 100 possible concepts. Concept selection tools were used to select our best ideas. This section contains a brief description of the top design alternatives to give a sense of why certain design decisions were made.

A. Spider Legs

The spider legs design concept involved the use of multi-segmented lander legs. Rotational frictional dampers at the leg joints would dampen the rotation of the legs and springs would be used to define a 'normal' position of the legs. A sketch of the concept is shown in Figure 1.

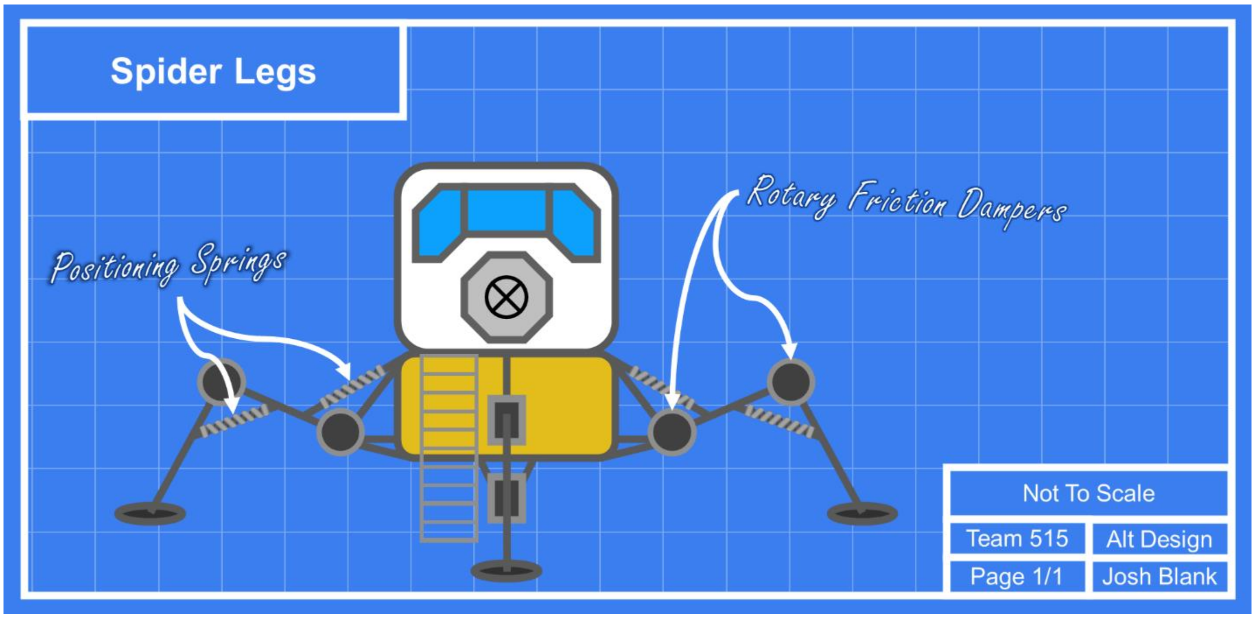


Figure 1: A sketch of the spider legs concept.

i. Pros

The design was purely mechanical, which was attractive because it would work in the event of a power failure or other kind of landing emergency. The wide landing stance of the space craft in the 'normal' position also suggested that it would be very stable and capable of landing on less-than-ideal surfaces. The rotational mechanical dampers could also be made dry, which would preclude any special equipment needed for fluid damping.

ii. Cons

The main drawback to the spider legs design was that each leg would require multiple rotational friction dampers positioning springs. It was thought that the spider legs would be much heavier than the selected design and was not seriously investigated.

B. Leaf Springs

The leaf springs concept involved the use of leaf springs, similar to the rear suspension in heavy machinery and older style carriages. A sketch of this concept is shown in Figure 2.

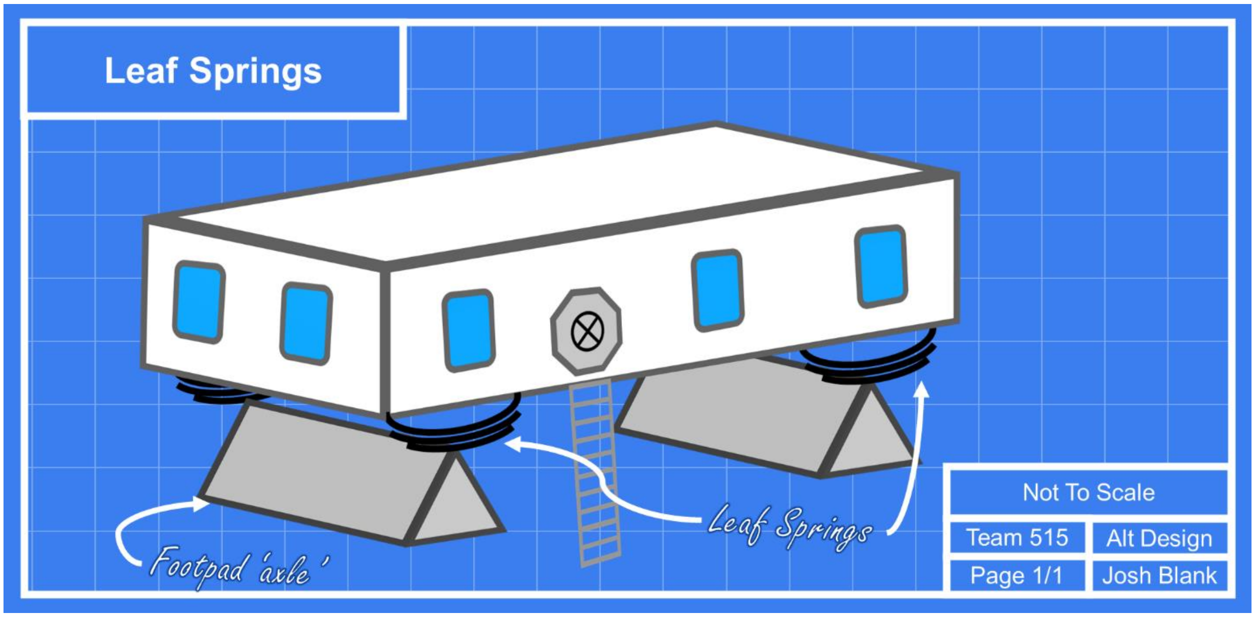


Figure 2: A sketch of the leaf springs concept.

i. Pros

This design was also purely mechanical. The leaf springs are self-damping through friction. Leaf springs have also been used for thousands of years, which gave us a lot of material to work with in designing them. They are also very simple and very robust.

ii. Cons

The major drawback to this design was the required geometry of the landing craft. If the craft was assembled in space, it may be more feasible, but our rough calculations showed no way to fit this concept into a rocket. The design was not investigated further.

C. Weighted Springs

The weighted spring design used a series of springs in conjunction with an actively controlled weight to damp out the force of impact, like how noise cancelling headphones work. A very rough sketch of this concept is shown in Figure 3

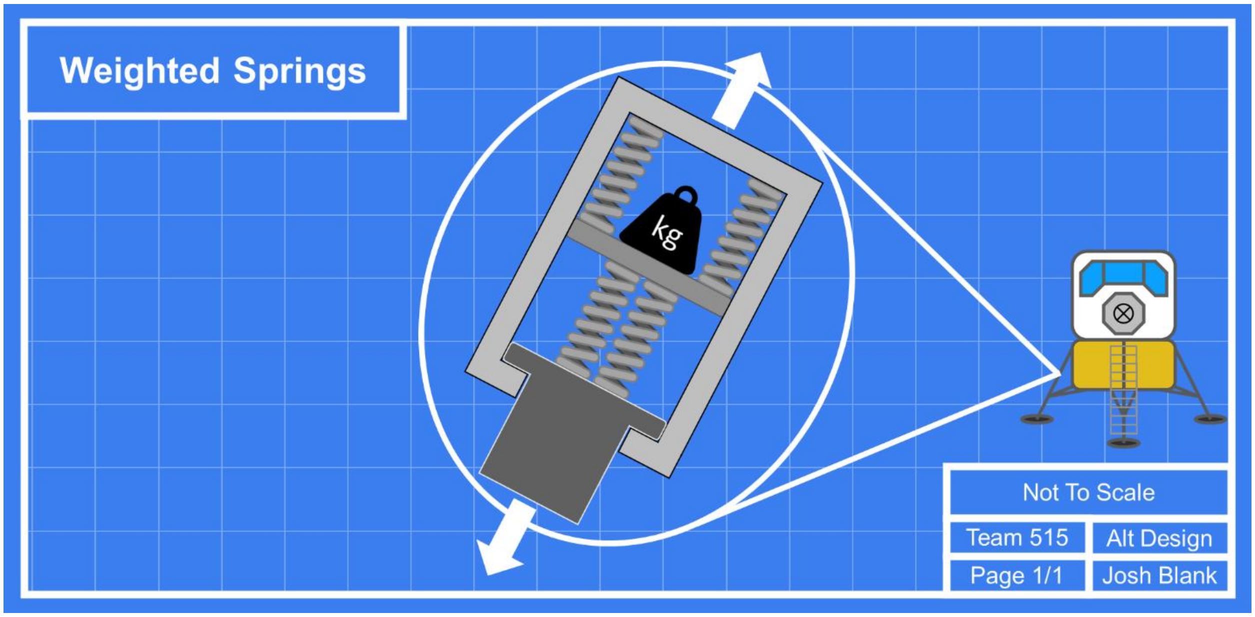


Figure 3: A sketch of the weighted springs concept.

i. Pros

The most attractive aspect of this design is that if done properly there would be no force of impact felt on the rest of the space craft.

ii. Cons

The major drawbacks to this design were the excessive mass and it was not purely mechanical. The design team also did not have a very good understanding of how to make this concept work.

2. Selected Design: Locking Springs

This design centered around the idea of locking a spring at its maximum compression during landing. The basic idea was that when a spring is at its maximum compression, all the impact energy has been absorbed and if the spring is mechanically locked at that maximum compression, then all the shock will have been absorbed. The spring could then be unlocked later to release the stored energy, possibly in conjunction with liftoff to reduce the amount of fuel needed to leave the lunar surface. A rough sketch and the original hand drawing is shown in Figure 4.

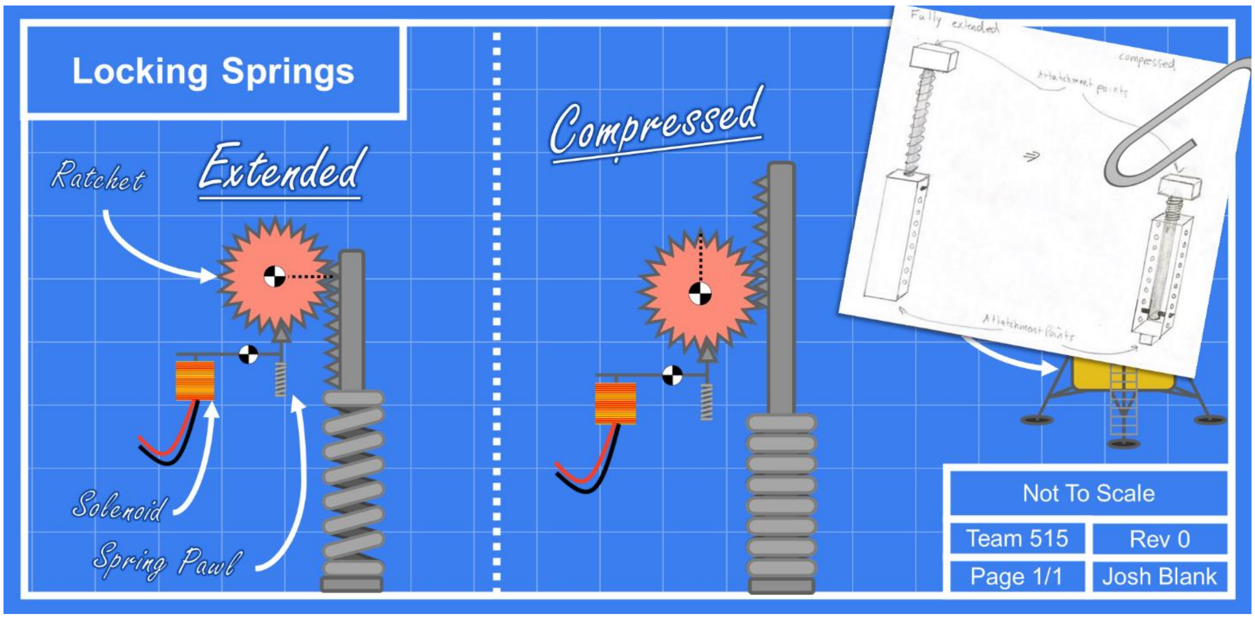


Figure 4: A sketch of the locking springs concept.

D. Pros

This design bypassed the need to dissipate the force of impact by instead storing the impact energy in the elastic deformation of the spring. This design would also be purely mechanical during the landing phase. From our rough calculations the design appeared to have the least amount of mass per leg compared to the other design alternatives.

E. Cons

The design must use some kind of energy to unlock, making the design not purely mechanical. The design also does not account for less-than-ideal landing scenarios.

3. Design Iterations

This section details the evolution of the design and explains why certain design decisions were made.

A. Simple Lever with Solenoid Actuator

Our first design iteration employed a linear ratchet with a simple lever pawl arm, shown in Figure 5. The principles of operation are as follows:

1) Upon impact, the linear ratchet would move into the main cylinder and compress the main spring.
2) As the linear ratchet moved inward, the pawl arms would be pushed outward and rotate about their pivot point.
3) When the main spring reached its maximum compression, the extension springs would hold the pawls together and keep the linear ratchet locked in place.
4) When the spring was to be unlocked, the solenoids would be activated and pull the ferromagnetic core towards the main cylinder. This would cause the pawls to rotate about their pivot points and unlock the linear ratchet.

However, it was not geometrically possible to use extension springs to generate enough force to keep the pawls shut.

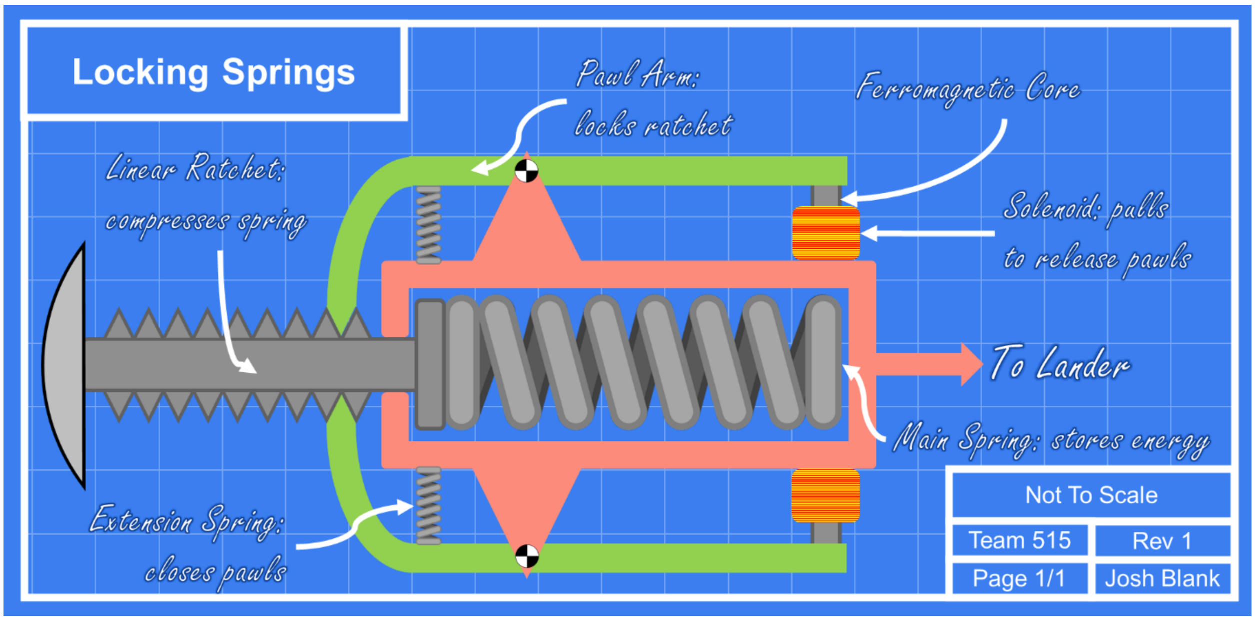


Figure 5: A sketch of the original locking springs design.

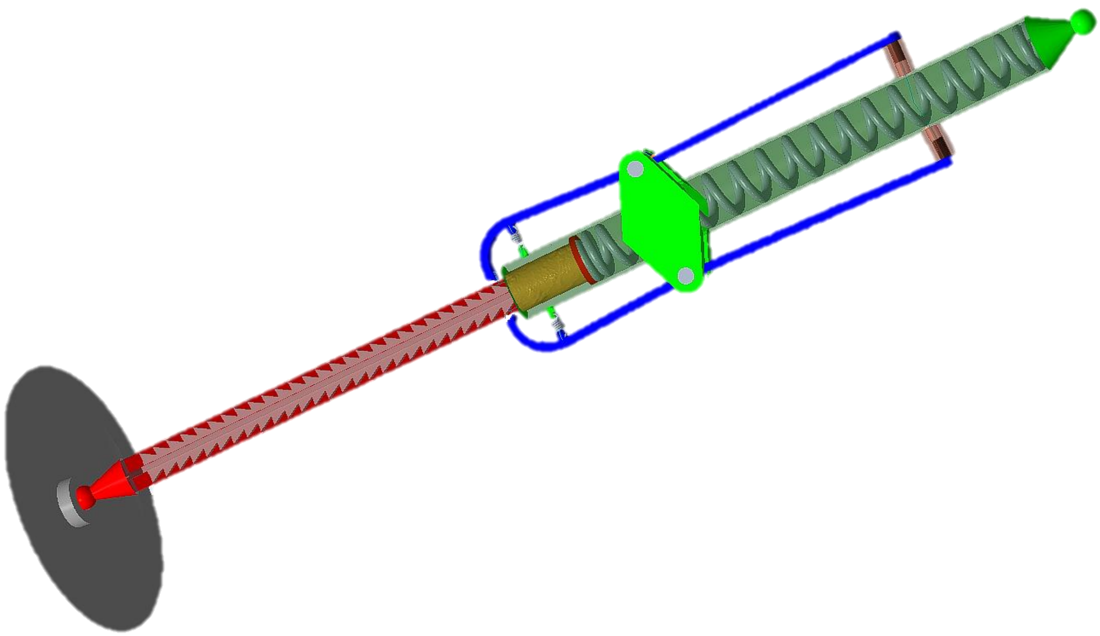


Figure 6: A CAD rendering of the first design iteration.

B. 4-Bar linkage

The next design iteration focused around using a 4-bar linkage to increase the mechanical advantage of the extension springs, shown in Figure 7. This design focused around locking the ratchet in place and the design was abandoned before an unlocking mechanism was developed. The shear force developed at the pins required the use of extreme geometry that was counterproductive to the goal of increasing mechanical advantage.

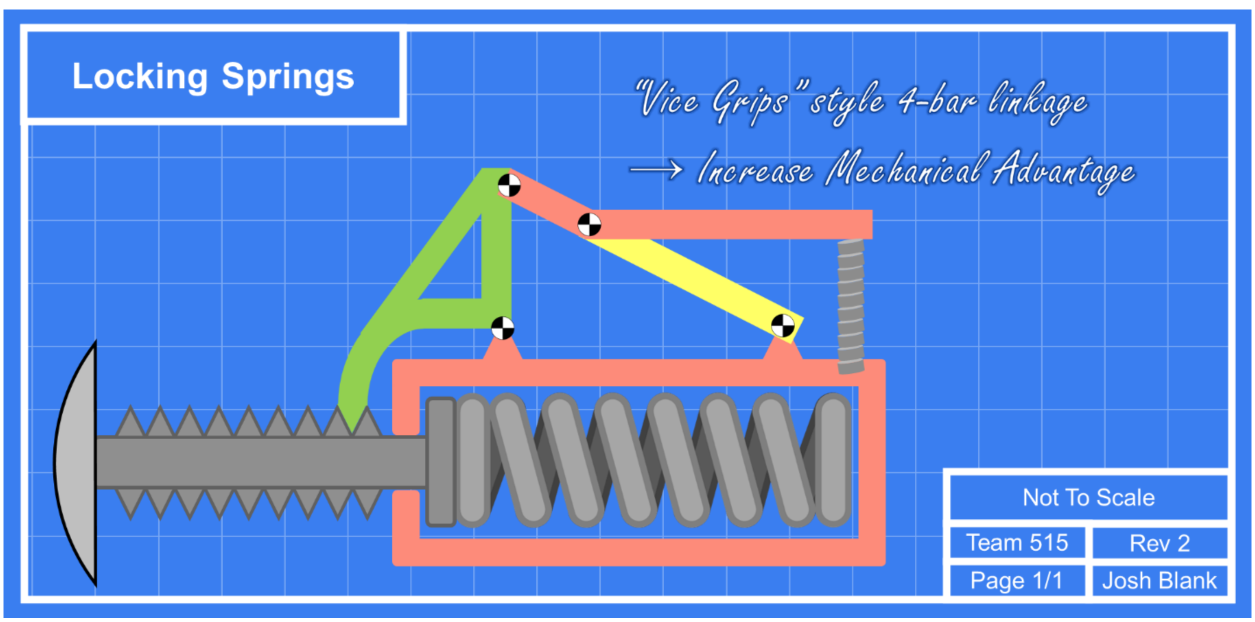


Figure 7: A sketch of the vice grips concept.

C. Ratchet Screw

The next design focused around using the elastic properties of the pawl arms as the locking mechanism; effectively turning the pawl arms into leaf springs. The ends of the pawl arms would be rigidly attached to the upper end of the main cylinder, as shown in Figure 8. The pawl arms would deflect in a similar manner to the first design iteration, but the geometry of the arms would resist the rotational moment created by the compressed main spring. This design also allowed the use more pawl arms to help distribute the load better, as shown in Figure 9.

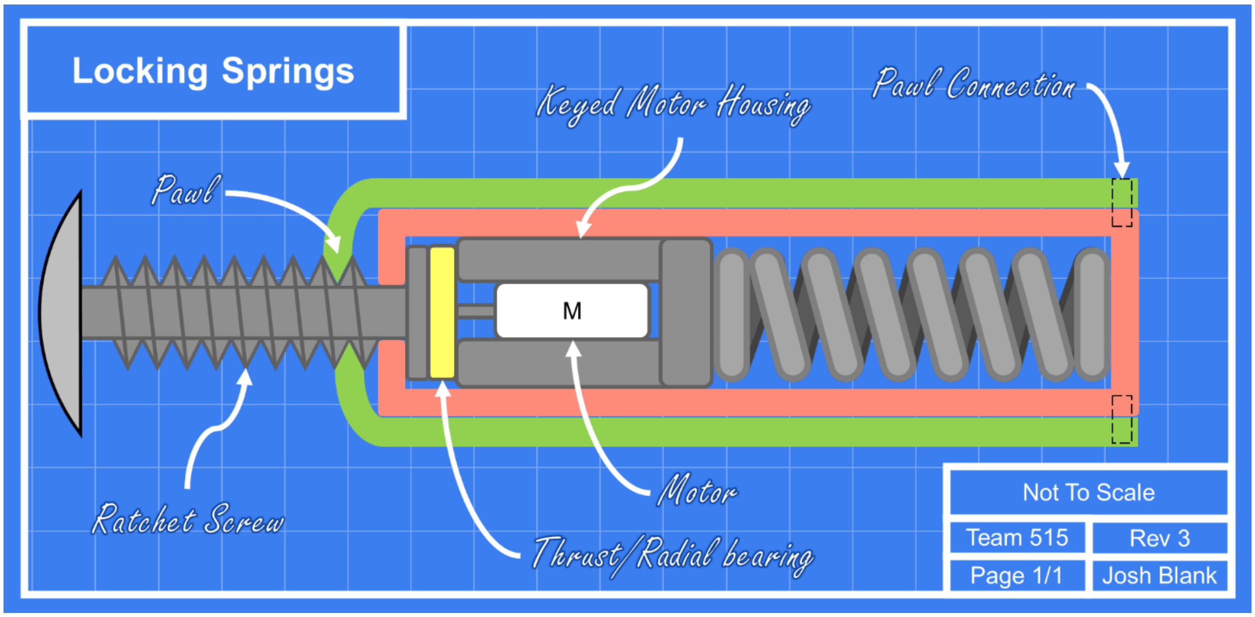


Figure 8: A sketch of the ratcheting screw concept.

The ratchet of this design would have a helix profile, like a buttress thread except the angle of the thread would be optimized for ratcheting. This screw profile would require the pawls to be staggered, and have teeth angled to match the pitch of the thread, as shown in Figure 10. To simplify the complex geometry of the pawl teeth and increase strength it was decided to use 'half nut' style pawl teeth. An internally threaded nut that matched the threading of the ratchet screw would be divided radially into equal parts, one for each arm. The partial nuts would then be attached to the pawl arms. This would allow for each pawl arm to be the same length and increase the surface area of the mating teeth, as shown in Figure 11.

A high torque motor inside of the main cylinder could be used to slowly rotate the screw outward after landing. The motor would be within a housing that protects the motor from the full axial force of landing. A thrust bearing would be used to transmit the impact energy from the ratchet screw to the motor housing, then the motor housing would transmit the energy to the main spring. The motor housing would need to be keyed in such a way to keep the motor body from rotating inside of the main cylinder. The motor housing would most likely have the male key(s), while the main cylinder would have the female keyway(s). This arrangement would be less likely to interfere with the main spring during operation.

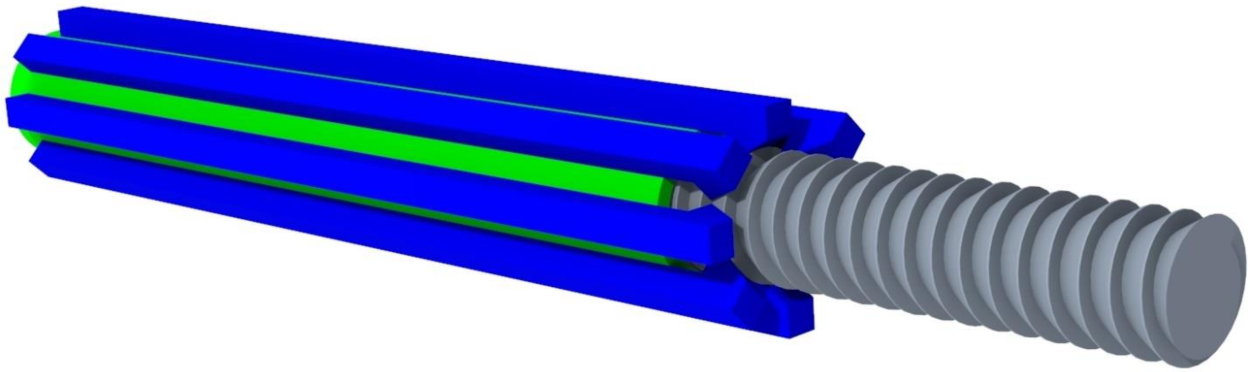


Figure 9: A CAD rendering of the ratchet screw concept.

Since the unlocking operation no longer required the opening of the pawl arms, it was now advantageous to back cut the load bearing face of the ratchet. In the first and second design iterations, when the pawls disengaged from the linear ratchet to unlock, an excessive frictional force would have been incurred if the load face of ratchet was back cut. Since the pawls of the ratchet screw remain in place during unlocking, the increased frictional force from back cutting helps ensure that the pawls remain engaged.

Since the unlocking operation is much slower in the ratchet screw design then in the previous design iterations, the unlocking phase can no longer assist in liftoff. However, the screws may be used to level the space craft after landing.

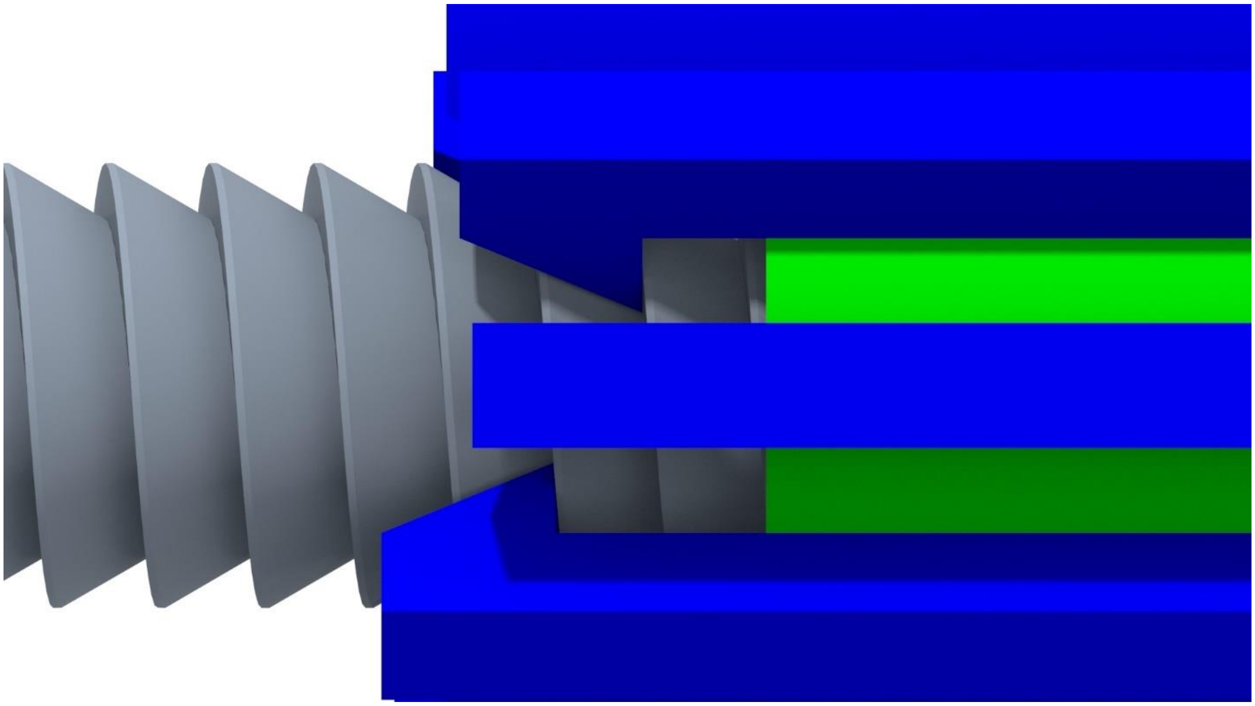


Figure 10: A CAD rendering of the ratchet screw concept. The staggered nature of the pawls and the pitch angle of the teeth are observable.

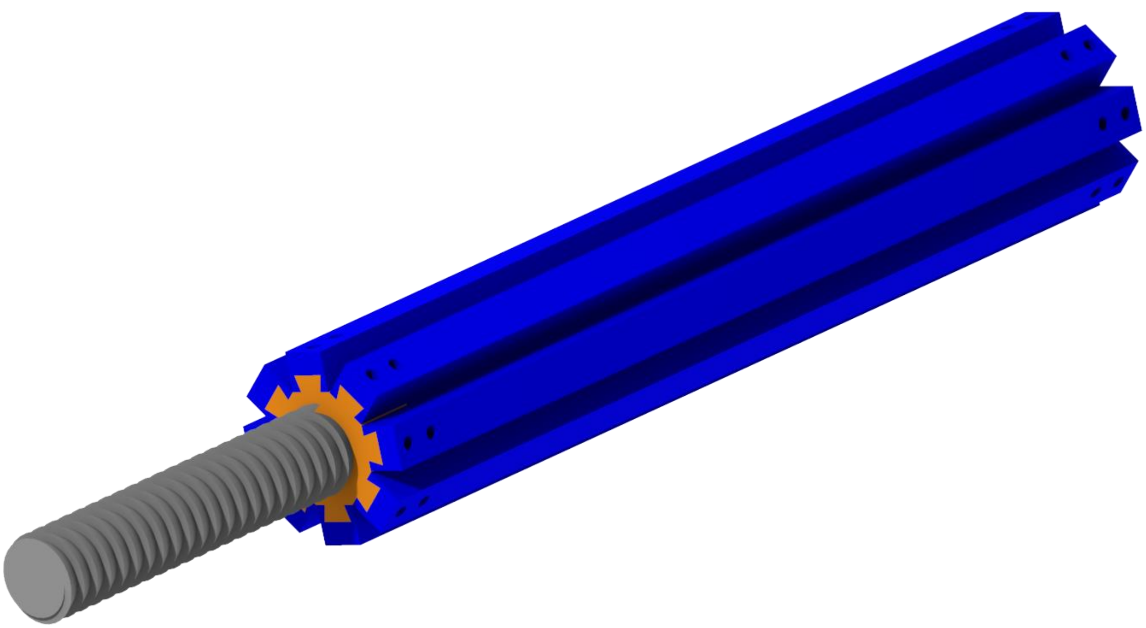


Figure 11: A CAD rendering of the ratchet screw design with eighth nuts as pawl teeth.

4. Prototype Scaling

The prototypes for this project were dynamically scaled according to *Dynamic similarity and scaling for the design of dynamical legged robots* (Miller & Clark), and the relevant scaling factors are presented in Table 1: A tabulation of relevant scaling factors and their relationship to each other.

Table 1: A tabulation of relevant scaling factors and their relationship to each other.

Parameter	Scaling Factor	Relationship
Length	α_L	α_L
Mass	α_m	α_F
Stiffness	α_k	$\alpha_F\ \alpha_L$
Touch-Down Velocity	α_v	$\alpha_L{}^{1/2}$

The prototypes were scaled around a preformed spring. The prototype spring was chosen from a catalogue and was selected because it had a similar scaling factor to the designed spring in both the radial and axial directions. The overall length scaling factor was taken as the average between the radial and axial scaling factors of the prototype spring. The stiffness scaling factor was taken as the ratio between the designed spring and the prototype spring. From there, the scaling factors for mass and velocity were found using the relationships listed in Table 1.

The scaling factors and various test parameters are listed in Table 2. The deflection was calculated in two ways. The first way was the use of the spring energy equation, listed in the table, using the scaled spring stiffness and scaled impact energy. The second was by applying the length scaling factor to the expected real spring deflection. The fact that both calculated deflections are the same proves that the dynamic scaling was performed properly.

Table 2: Various parameter values for the spring prototype.

Spring Prototype Calculations				
Stiffness Scaler	5.530E-03		180.8	
Length Scaler	0.280		3.567	
Time Scaler	0.5294651		1.889	
Force/Mass scaler	0.0015503		645.0	
Mass	38.76	kg	85.45	lbs
Drop height	0.1659265	m	0.544	ft
Impact Energy	63.088426	J		
Scaled speed	1.8042941	m/s		
Deflection calc KE = 0.5*k*x^2	0.1852268	m	0.608	ft
Deflection from scale	0.1852268	m	0.608	ft

5. General Timeline

Table 3 contains a tabulation of the major events that made up this project and when they occurred.

Table 3: A rough timeline of our project

Month	Event
September	Established contact with sponsor.
	Defined project scope and determine customer needs.
	Researched space's extreme conditions to grasp or working environment.
October	Performed a functional decomposition based on customer needs.
	Began stating targets and defining metrics.
	Brainstormed some general ideas.
November	Generated realistic possible designs.
	Analytically selected best design.
	Wrote a bill of materials for the design.
December	Generated a safety manual for low-risk operation of the design.
	Started computations for the design.
	Used CAD to make the design.
January	3D printed the design to scale.
	Developed prototypes for testing.
	Ordered parts and assembled prototypes.
February	Tested Spring prototype.
	Changed design to helical ratchet.
	Restarted computations for the design.
March	Used CAD to make and 3D print the design.
	Tested scaled 3D print for functionality.
	Started to machine helical ratchet parts.
April	Test locking mechanism prototype
	Finish website
	Senior design day

III. Components

This section contains a list, brief description, and some of the considerations for each component of our full design and the prototypes.

1. Full Scale Design

The full-scale design is for the shock absorber that we intended to be used on the lunar lander. This is the design that we will give NASA at the end of this project.

A. Main Cylinder

The main cylinder is the anchor component of the entire design. It houses the main spring and the unlocking motor, it receives the ratchet screw as the lander impacts the lunar surface, and it supports the pawls. The end of the main cylinder that is connected to the rest of the space craft is referred to as the top or upper part, and the end of the main cylinder that is towards the footpad is referred to as the bottom or lower part.

The main stress points are located where the spring interfaces with the main cylinder, and where the pawls connect to the main cylinder. The main cylinder is not susceptible to bucking because compressive loads are not placed across it.

The inside of the main cylinder is designed to prevent the motor housing from rotating. The main cylinder is designed with female keyways in the axial direction. The use of male keys was considered unfavorable because the main spring may have rubbed against them and posed a fabrication challenge.

B. End Cap

The end cap serves as the mounting component that the pawl arms are bolted to and gives the main spring a surface to contact while being compressed.

The end cap is fit to the inside diameter of the main cylinder and has two rows of mounting holes for the pawl arms to be bolted to.

C. Main Spring

The main spring absorbs the energy of impact and stores that energy in elastic deformation until spring is unlocked.

The main spring was designed to absorb the entire impact force under the worst-case scenario landing: on one leg at the maximum expected speed. The material of the spring must withstand the force of impact in the extreme lunar environment. Most of the landing craft is made from high strength aluminum alloy, which retains its material properties through the entire expected temperature range, however the low modulus of elasticity of aluminum precluded its use in spring applications. The use of carbon steels is made difficult because of the ductile to brittle transition at low temperatures. 300 series stainless steels were identified as potential materials for the main spring because of their extensive use in the cryogenic industry. All calculations were made assuming that the spring was made of 304 stainless steel. The dimensions and some parameters of the spring are listed in Table 4.

Table 4: Designed Spring Parameters

Parameter	Value	Units
Stiffness	665	kN/m
Stroke	66	cm
Wire Diameter (d)	1.25	in
Nominal Spring Diameter (D)	5	in
Spring Length (L)	72	in
Active Coils (N_a)	20	#

D. Ratchet Screw

The ratchet screw transmits the impact force from the footpad into the rest of the shock absorber and prevents the main spring from rapidly expanding after impact. During impact, the ratchet screw moves into the main cylinder and compresses the main spring. As the ratchet screw moves inward, the angled face of the threads pushes against the angled surface of the pawl teeth and deflects the pawls outward.

When the spring has reached its maximum compression the ratchet springs stops moving inward. The main spring forces the ratchet screw outwards until the load bearing surface of the pawl teeth engage with the load bearing teeth of the ratchet screw. At that point, the ratchet screw becomes locked and prevents the main spring from expanding further.

The angle of the ratcheting threads is lower (30^o) than a normal buttress thread (45^o) to direct more of the impact force outwards to better deflect the pawls. The load bearing face of the threads is back cut to help lock the pawls into the ratchet screw.

The ratchet screw is susceptible to buckling since all the force will be applied though it. The previous design iterations used a linear ratchet mounted in a circular I-beam, which greatly resisted bucking. The ratchet screw is effectively a round column with diameter equal to the minor diameter of the threads. All column calculations were done with this assumption.

The ratchet screw is susceptible to surface failure because of the ratcheting impacts of the pawls and the unscrewing under load. The material that the ratchet screw is made of will need to be very hard to resist failure. High strength steel alloys would work well, but weight considerations make this an unattractive option. High grade aluminum alloys may be hard enough to withstand surface failure, but some titanium alloys offer a compromise on both weight and hardness.

Since wet lubrication is not an option, dry film lubricants must be used. Various dry lubricants are available, and testing may need to be performed to select the best option. ETFE is a polymer like Teflon, but is much more mechanically durable, heat resistant, and used in cryogenic applications. Various molybdenum disulfide (MoS_2 / Molykote) lubricants exist for aerospace applications and appears to be the most widely used lubricant in space.

E. Pawl Arms

The pawls arms prevent outward linear motion of the ratchet screw but allow the ratchet screw to rotate outward. The pawl arms are attached near the top of the main cylinder. The long length of the pawl arms ensures they will be easily deflected with minimal bending stresses withing the beam of the pawl arms.

The pawl arms engage the ratchet screw with threaded teeth. The teeth of each pawl arm make up a portion of a nut threaded with the same profile as the ratchet screw. This concept is like a half-nut in a quick release vice except the nut is divided into eight pieces instead of two. All teeth engage the ratchet thread when the spring is locked, but only the upper most (closest to the pawl connection) thread of each pawl is involved in the ratcheting movement. The other threads will be deflected up more than the first thread and will not actually interact with the ratchet thread until the pawl returns to its fully down position.

The pawl arms are susceptible to surface failure just like the ratchet screw and must also be made from a similarly hard material. The calculations for the pawl arms were done assuming 304 stainless steel since they act like leaf springs.

The pawl arms will share the same lubricant as the ratchet screw.

F. Eighth Nuts

The eighth nuts are eight equally sized partitions of a female threaded nut that matches the helix profile of the ratchet screw. The eighth nuts allow for the ratcheting motion and hold the ratchet screw in place when the spring is at its maximum compression. The use of eight nuts instead of pawls with integrated teeth simplifies the geometry of the pawl arms, removes the need to stagger the pawl arms, and provides more thread engagement per pawl.

The eighth nuts are connected to the pawl arms via a dove tail and two mounting bolts.

The eighth nuts could be fabricated by first drilling and threading a hole into a large piece of stock. The dovetails and mounting holes could then be machined into the nut. Finally, the nut could be cut into the eight sections by use of water jet, laser, or mechanical saw. The threads would most likely be partially damaged near the fringes and would need to be cleaned up.

G. Motor Housing

The motor housing allows the motor to be located within the main cylinder between the ratchet screw and the main spring without subjecting the motor to the full axial impact force. The motor housing also provides a radially secure mount for the motor when unscrewing the ratchet screw.

The motor housing will slide axially in the main cylinder and transfer the impact energy from the ratchet screw to the main spring. The housing will be radially fixed by male keys that fit into female keyways in the main cylinder.

The motor housing must be made from a sufficiently strong material that will withstand the force of impact and withstand the shear forces imposed by the keys onto the keyways when the motor is operating. High grade aluminum alloys should work fine for this application.

The motor housing must be lubricated in two ways. The first is to lubricate the axial motion of the motor housing into the main cylinder during impact; the motor housing should be sufficiently lubricated to prevent binding from occurring if the impact force is not perfectly centered on the axis. The second way is to lubricate the axial motion of the keys in the keyways as the motor turns the ratchet screw. Although both situations may be lubricated in the same manner, it is important to note the two distinct situations that require lubrication because of how different the forces are applied. ETFE and MoS_2 are also good possible contenders for lubricants for the motor housing.

H. Motor & Gear Box

The motor and gear box, referred to collectively as just the motor, are responsible for unthreading the ratchet screw after impact to reset the shock absorber for its next landing. The motor is located inside of the main cylinder to account for the variable position of the ratchet screw, and to reduce the weight from a long motor shaft if the motor was located at the top of the main cylinder.

The power cords for the motor are run down through the center of the main spring and are held taut by a retractor. The power cords must be held taut to prevent them from being caught in the spring or by the motor housing during impact. The motor and retractor are outside of the scope of this project. The motor must be able to deliver 40 kNm of torque at maximum spring compression.

I. Thrust Bearing

The thrust bearing allows the ratchet screw to transfer the impact to the motor housing and allows the ratchet screw to rotate while the motor housing remains in radially fixed. The thrust bearing is within the scope of this project but has not yet been designed. The drawing that is included in Appendix B.1 should be taken as a rough draft. A ball bearing is expected to work for this application since it will be a very low rotational speed application.

The thrust bearing will most likely need to be lubricated with dry film lubricant like MoS_2 because treating all rubbing surfaces with a ETFE film would be difficult.

J. Controls

To ensure safety of the user, there will be a sensor integrated into the design that measures how extended/compressed the main spring is. If it is extended at all, a warning will be output to the user. It will show the user when the system is ready to be used again. The sensor design and integration are outside the scope of this project, but an infrared distance sensor could be used to measure the distance between the motor housing and the end cap.

2. Spring Prototype

The spring prototype was used to measure the deflection of the prototype spring under a dynamically scaled impact. Drawings for the spring prototype are in Appendix B.2.

A. Base Plate

The base plate provided a base for the spring pipe, stabilized the entire prototype during testing, and provided a surface for the compression spring to interact with. The spring pipe is welded to the center of the base plate. Four ¼ inch holes are located on the base plate, one near each corner, to allow for bolting the baseplate to a foundation or test containment to provide extra stability.

B. Spring Pipe

The spring pipe contains the spring and allows for observation of the deflection of the spring during testing. The spring pipe is a segment of threaded gas pipe with a ½ inch viewing slot end-milled into the side of the pipe. The viewing slot should be long enough to observe the maximum expected deflection of the spring. The expected deflection of the test was approximately 7 inches, and the viewing slot was only cut to 7 inches from the end of the pipe instead of the end of the threads. In hindsight, the viewing slot should have been cut much longer because there was no reason not to.

C. Spring

The spring was placed inside of the spring pipe and was compressed by the plunger. Various parameters of the prototype spring are listed in Table 5

Table 5: Tabulation of prototype spring parameters

Parameter	Value
Outside Diameter	1.470 in
Length	16.000 in
Wire Diameter	0.187 in
Stiffness	21.00 lbs./in
Max Load	151.8 lbs.
Max Deflection	7.23 in
Pitch	0.397 in

D. Plunger

The plunger transfers the force of impact from the strike plate to the spring. The plunger connects the strike plate to the spring and interferes with the cap to prevent the plunger from shooting back out after compression.

The plunger is a machined circular rod with two different diameters. The smaller diameter is connected to the strike plate and extends out through the cap. The larger diameter rests on top of the spring and acts as a cylindrical sliding surface that rubs against the inside of the pipe wall. The larger diameter does not pass through the hole it the cap and prevents the plunger from leaving the pipe.

The plunger diameter that rubbed against the pipe was machined smaller than it probably should have been. The reason that it was machined so small was to minimize frictional forces, however the smaller diameter allowed for greater axial misalignment between the plunger and pipe which resulted in binding when the load was dropped off center.

E. Pipe Cap

The pipe cap is a standard, internally threaded gas pipe cap with a hole cut in the center to allow the smaller diameter of the plunger to pass through but not the larger diameter. The cap also acts as a hard stop against the bottom of the strike plate to prevent over compression of the spring. The cap is threaded onto the pipe after the plunger is in place.

F. Strike Plate

The strike plate provides a large surface to drop a weight onto. The strike plate transfers the force of impact to the plunger, which in turn transfers the force of impact to the compression spring.

The strike plate is a piece of plate steel with a center cut hole that allows a bolt to pass through and thread into the plunger.

3. Locking Mechanism Prototype

The locking mechanism prototype tests two aspects of the design: the inward ratcheting motion of the ratchet screw and the ability of the pawl arms to lock the ratchet screw in place under load. The locking mechanism prototype was designed to test these features without the use of the prototype spring, for safety concerns.

A. Base Plate

The base plate provides a surface for the main cylinder to connect to, stabilizes the prototype during the inward motion tests, and provides a mounting surface for the prototype during the locking mechanism test.

The base plate is a piece of plate steel with a center cut hole the same size as the main cylinder inside diameter. The base plate has four smaller holes located around the edges to attach the base plate to another surface for stability and mounting purposes. The base plate is welded to the main cylinder, with the center cut hole axially aligned with the main cylinder.

B. Main Cylinder

The main cylinder provides a mounting location for the pawl arms and provides a cylindrical sliding surface for the slider block. The main cylinder receives the slider block and ratchet screw as they both move inward during the inward motion test.

The main cylinder is a gas pipe with mounting holes for the pawl arms to connect to.

C. Pawl Arms

The locking mechanism prototype was designed to have quarter nuts similar to the full-scale design eighth nuts, but fabrication challenges at the local machine shop required use of the previous pawl arms with angled teeth design. The pawl arms deflect upward and out of the way during inward motion and hold the ratchet screw in place under load.

The pawl arms are made of bar stock and are connected to the main cylinder by nuts and bolts.

D. Slider Block

The slider block provides a sliding surface to interact with the main cylinder during inward motion and acts as a hard stop to prevent the ratchet screw from pulling out of the main cylinder completely if the pawl arms cannot lock the ratchet screw under load.

The slider block is machined from a piece of round stock to have the same outer diameter as the main cylinder inside diameter, which should minimize the chance of binding during the inward motion test. The slider block is a larger diameter than the ratchet screw, and thus prevents the slider block from passing through the pawl teeth. This prevents the ratchet screw from completely leaving the main cylinder if the pawl arms cannot lock the ratchet screw.

E. Ratchet Screw

The ratchet screw deflects the pawl arms outward during inward motion and is locked in place by the pawl teeth under load.

The upper end of the ratchet screw is secured to the slider block with a 3/8-16 bolt. The lower end is attached to either an eyebolt or strike plate with a 1/4-20 threaded fastener. The reasons for the two different bolt sizes are reuse of spring prototype components and selective failure. The strike plate from the spring prototype was desired to be used in the locking prototype, which was designed to be used with a 1/4-20 bolt. It is entirely possible that either bolt may shear off the ratchet screw, and it was decided that it would be easier to extract the broken bolt from the lower end than the upper end, because the ratchet screw will probably be partially threaded into the pawl arms.

F. Slider Block

The slider block provides a sliding surface that connects the ratchet screw to the main cylinder and prevents the ratchet screw from fully disengaging from the pawl teeth.

The slider block is made from machined round stock is bolted co-axially to the ratchet screw. The slider block has a larger diameter than the ratchet screw to interfere with the pawl teeth and prevent ratchet screw disengagement. The slider block is designed to minimize the chance of binding during the inward motion test and freely slide within the main cylinder.

G. End Attachments

There are two end attachments that serve two separate purposes.

i. Strike plate

A strike plate is connected to the end of the ratchet screw for the inward motion test. This plate will provide a larger area to apply the force to move the ratchet screw inward.

The strike plate for the locking mechanism prototype is fundamentally the same as the strike plate for the spring prototype.

ii. Eyebolt

An eyebolt is connected to the end of the ratchet screw for the locking mechanism test. The weight will be connected the eyebolt to simulate the maximum force that the spring would create at maximum compression.

They eyebolt is a preformed component and should be able to support at least 150 lbs.

4. Unlocking Mechanism Prototype

The unlocking mechanism prototype has not been fully designed at the time of writing. The purpose of the unlocking mechanism prototype is to test that the ratchet screw can be unthreaded from the pawl arms under load. The unlocking prototype would have essentially the same components and appearance of the Locking Prototype with the following additions:

A. Motor

The motor is used to unscrew the ratchet screw from the pawl teeth on the pawl arms. The motor is rigidly mounted inside the motor housing and the motor shaft is connected to the ratchet screw.

The motor should be able to produce at least 16 Nm of torque. The design of the motor is outside the scope of this project and a prebuilt motor should be used.

B. Motor Housing

The motor housing radially fixes the position of the motor, which allows the motor to create a rotational force between the ratchet screw and the main cylinder. The motor housing of the real design also transfers the impact energy from the ratchet screw to the main spring, but that function is not required on this prototype.

The motor housing remains radially fixed by use of keys and keyways on the inside surface of the main cylinder. The motor housing is attached to the thrust bearing, which allows the ratchet screw to rotate.

C. Thrust Bearing

The thrust bearing allows the ratchet screw to rotate while the motor housing remains radially fixed. In the real design the thrust bearing is used to transfer the force of impact to the motor housing, but that function is not required on this prototype.

The thrust bearing outer race is connected to the motor housing and remains radially fixed. The thrust bearing inner race is connected to the ratchet screw and motor shaft and can rotate relative to the motor housing.

D. Main Cylinder

The main cylinder is largely unchanged from the locking prototype design, but the inside surface is keyed in such a way to keep the motor housing from rotating within the main cylinder.

E. Ratchet Screw

The ratchet screw is largely unchanged from the locking prototype design, but the upper end of the ratchet screw is machined in such a way that it can be pressed into the thrust bearing. The real design ratchet screw would need to have a collar to prevent the ratchet screw from pushing through the inner race of the thrust bearing, but that function is not required in this prototype.

IV. Principles of Operation

This section explains how the full-scale design and each of the prototypes is operated.

1. Full Scale Design

The full-scale design operation is purely hypothetical and not all applicable prototype tests have been performed at the time of writing. The following procedure is a sequential list of expected interactions between the various components and any steps that need to be taken by the user.

1) The ratchet screw is impacted by a force.
2) The impact force is transferred from the ratchet screw to the thrust bearing, which transfers the force to the motor housing, which transfers the force to the main spring.
3) The main spring is compressed as the ratchet screw moves inward.
4) A sensor delivers information to the user that the spring has compressed.
5) The angled surface of the ratchet screw helix profile encounters the angled surface of the pawl teeth.
6) The ratchet screw deflects the end of the pawls outward as the ratchet screw moves inward.
7) The pawl tooth eventually slides over the top of the ratchet tooth that it was in contact with and falls down into the cavity created behind the ratchet tooth.
8) Steps 4-6 repeat until all the impact energy has been absorbed by the main spring and the inward movement of the ratchet screw stops.
9) The main spring attempts to expand, which pushes the motor housing, thrust bearing, and ratchet screw out of the main cylinder.
10) The ratchet screw moves outward until the load bearing face of the helix profile interacts with the load bearing surface of the pawl tooth. The force of the main spring, acting through the motor housing, thrust bearing, and ratchet screw, is now held completely by the pawl arms.
11) The sensor notifies the user that the spring is fully compressed.
12) At this point all the impact energy is stored in the main spring. The system can remain in this state indefinitely. The rest of the procedure must be performed before the shock absorber is ready to be used again.
13) To unload the main spring the user must activate the motor.
14) The motor creates a twisting force between the main cylinder and the thrust bearing, which turns rotates the ratchet screw.
15) The ratchet screw is unthreaded from the pawl teeth until the main spring is completely decompressed.
16) The user deactivates the motor, the sensor shows that the spring is not compressed, and the system is ready for use again.

2. Spring Prototype

The spring prototype is designed to test the main spring component of the design. The spring should not fail under the load resulting from an impact force or compress far enough that the strike plate bottoms out. The following procedure is a sequential list of expected interactions between the various components and any steps that need to be taken by the user.

1) The base plate is fastened to a surface to provide stability. A 55-gallon steel drum provides stability and prevents the weights from sliding off the strike plate after the drop.
2) A displacement measurement system is established. Paper rulers can be taped near the viewing slot on the spring pipe. Slow motion video capture can be used to analyze each drop test afterwards.
3) The strike plate is impacted by a 90lb weight that is dropped from a fixed height of 6 inches. This produces the dynamically scaled impact energy expected during a worst-case scenario lunar landing. The scaled impact energy is 63 Joules.
4) The stroke length is recorded, preferably with slow motion video capture. The stroke length is the max distance the plunger travels before reversing direction from the spring's opposing force.
5) Multiple weight drops should be performed to collect a list of data.
6) The spring will be determined fit or unfit for the design based on the stroke length.

3. Locking Mechanism Prototype

The locking mechanism prototype is tested in two ways. The first is a ratcheting motion test, which tests that the ratchet screw deflects the pawls outward as designed. The second is a locking mechanism test, which tests whether the locking mechanism will be able to hold the spring/ratchet helix in place when it has all the energy stored from the landing.

A. Ratcheting Motion Test

1) The eyebolt is removed from the ratchet screw and the strike plate is inserted.
2) The locking mechanism prototype is mounted in such a way that the strike plate can be impacted.
3) The ratchet screw is positioned such that most or all of the ratchet screw is extended out through the pawl arms.
4) Impact the strike plate by dropping 90lbs. from a height of 6 inches onto

B. Locking Mechanism Test

1) The strike plate is removed from the ratchet screw and the eye bolt is inserted.
2) The locking mechanism prototype is mounted in such a way that the weight, 144 lbs., can safely be hung from the eyebolt.
3) The ratchet screw is positioned such that at least half of the ratchet screw is inside of the main cylinder.
4) The weight is hung from the eyebolt and any movements are noted. The weight should be hung for enough time to note any slow changes or deformations. The ratchet screw may slowly unscrew under load. If this occurs the speed of the rotation should be noted, and calculations should be performed to determine if the rotation would pose a threat to the safety of the landing craft on the full-size design.
5) Remove the weight from the eyebolt.

4. Unlocking Mechanism Prototype

The unlocking mechanism prototype is designed to test the ability of the ratchet screw to unthread under maximum loading.

1) The prototype is mounted in such a way that the proper amount of weight, 144lbs, can be hung from the eyebolt on the ratchet screw.
2) The ratchet screw is positioned in the pawl teeth such that half of the ratchet screw is within the main cylinder.
3) The weight is attached to the eyebolt.
4) The motor is activated to unthread the ratchet screw through the pawl teeth.
5) When the screw is fully unthreaded and the slider block is interfering with the pawl teeth, turn off the motor and remove the weight from the eyebolt.

V. Appendix A: Problem Supplements

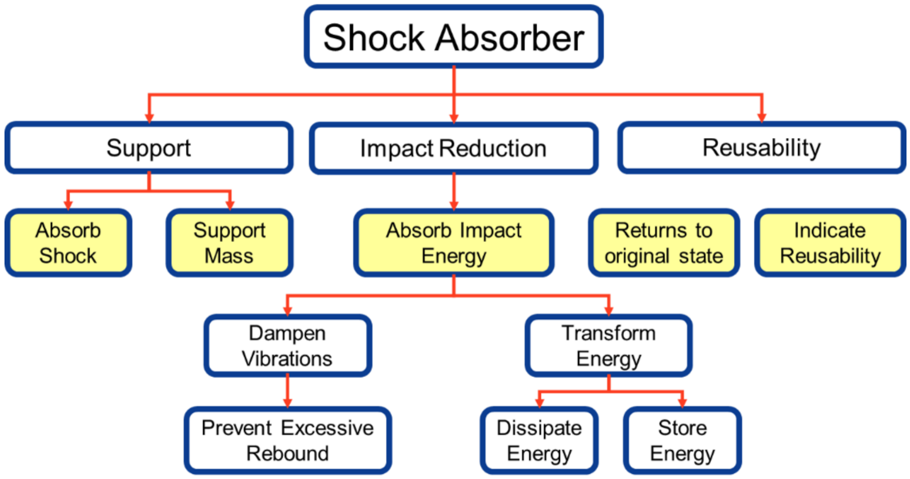
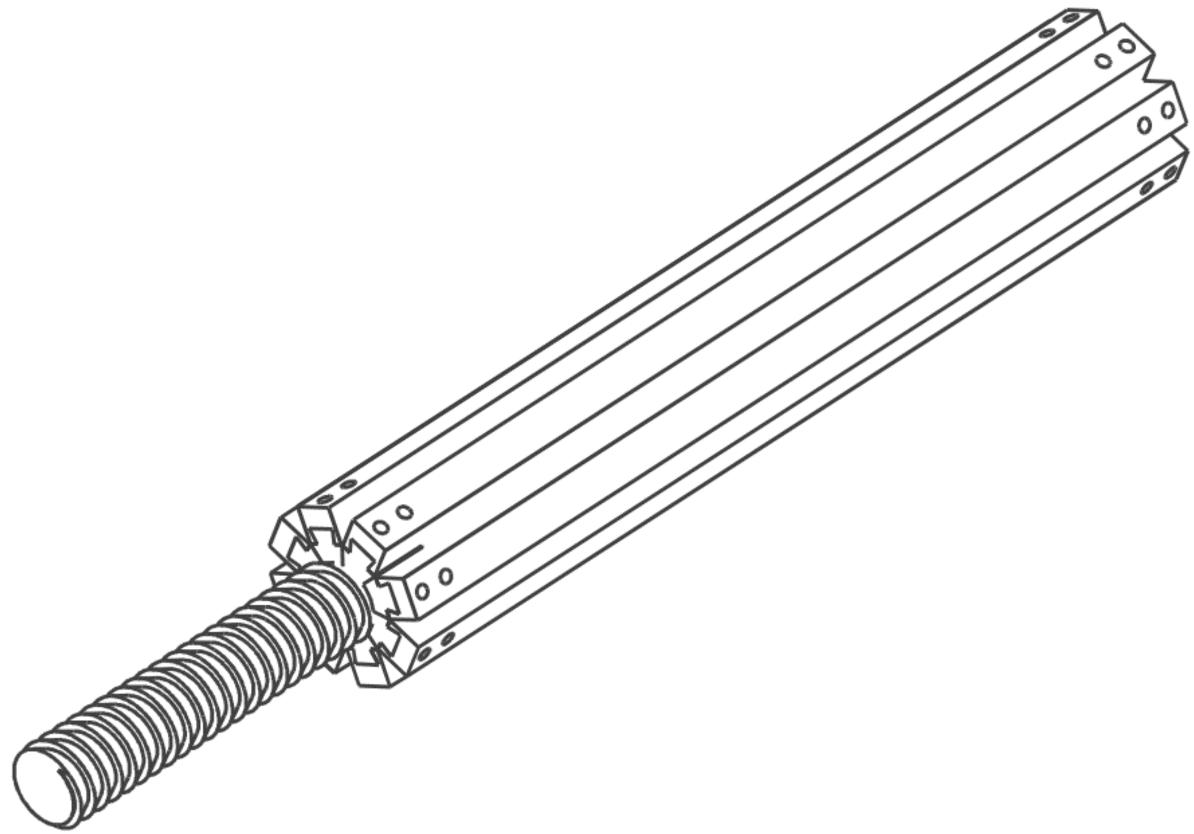


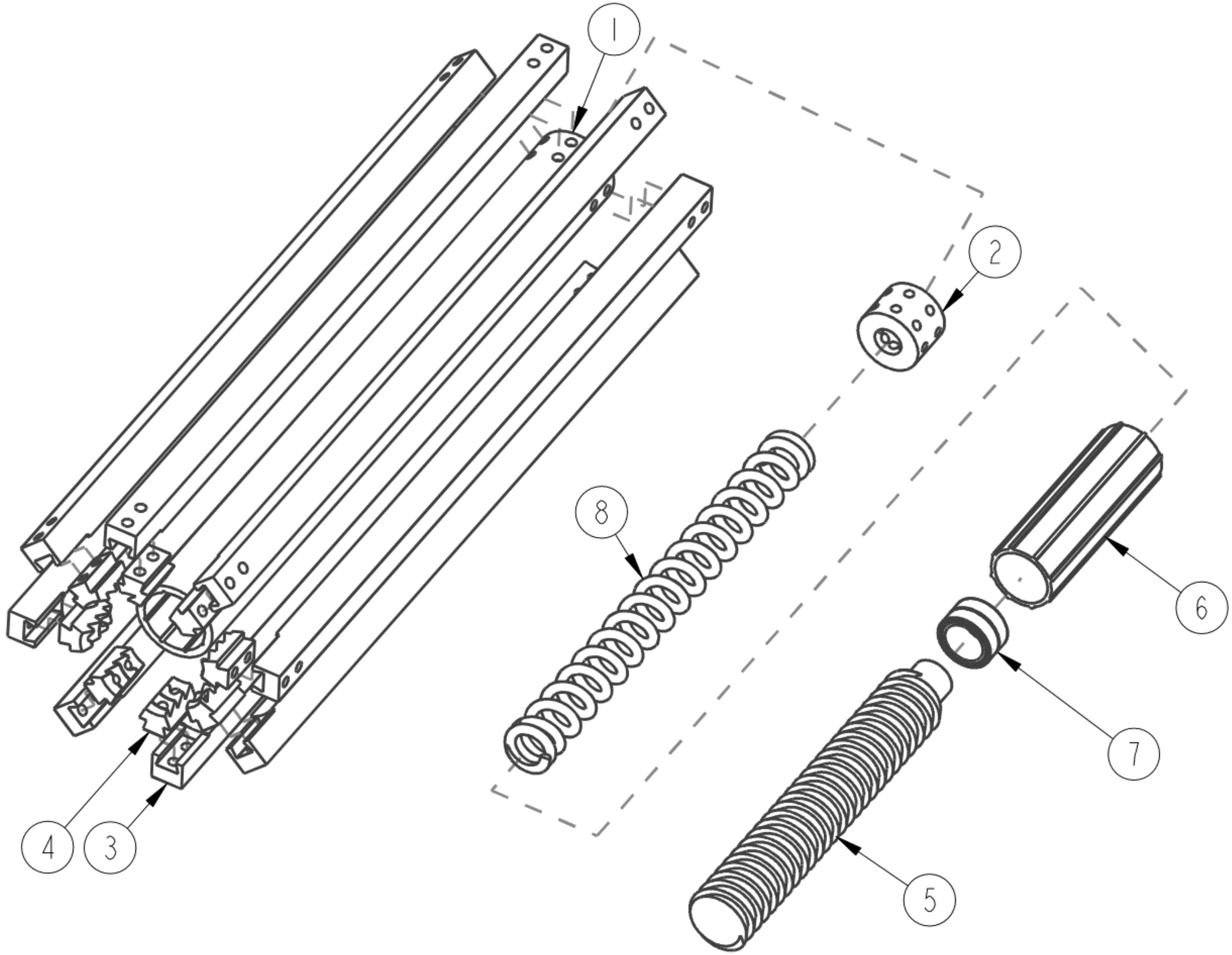
Figure A-1: The functional decomposition with critical functions highlighted in yellow.

VI. Appendix B: Drawings

This appendix contains the drawings of the full-scale design, the spring prototype, and the locking mechanism prototype. The unlocking mechanism prototype has not been designed yet at the time of writing.



UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES	PART NAME: ASSEMBLY			PROJECT NAME: SHOCK ABSORBER	
TOLERANCES: X.X ± 0.1 X.XX ± 0.01 X.XXX ± 0.003 ANGLES ± 0.5°	DRAWN BY: JOSH BLANK		DATE: 3/18/21	SIZE: A	MATERIAL: VARIOUS
	SCALE: 0.060	REV: 0	SHEET NUMBER: 1 OF 3	PART NUMBER: SA-21-009	



UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES	PART NAME: ASSEMBLY				PROJECT NAME: SHOCK ABSORBER	
TOLERANCES: X.X ± 0.1 X.XX ± 0.01 X.XXX ± 0.003 ANGLES ± 0.5°	DRAWN BY: JOSH BLANK		DATE: 3/18/21		SIZE: A	MATERIAL: VARIOUS
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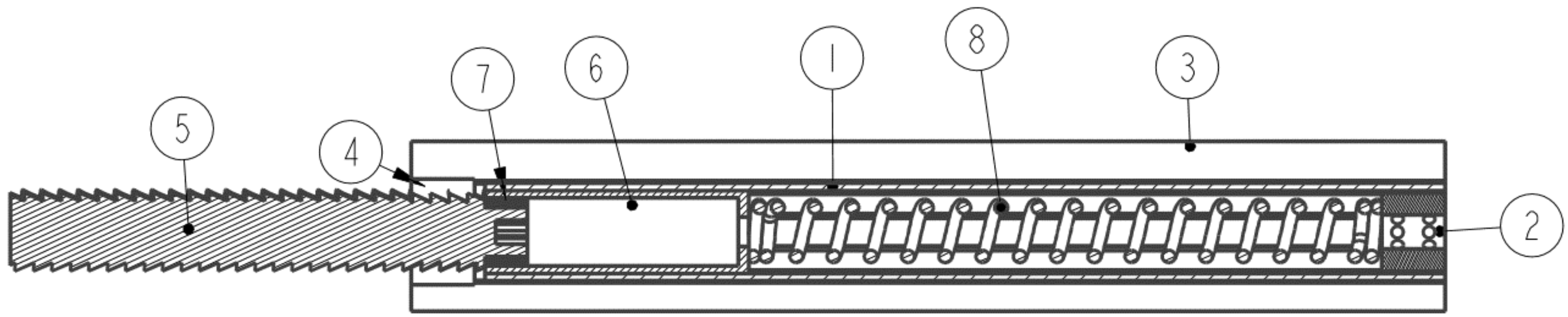
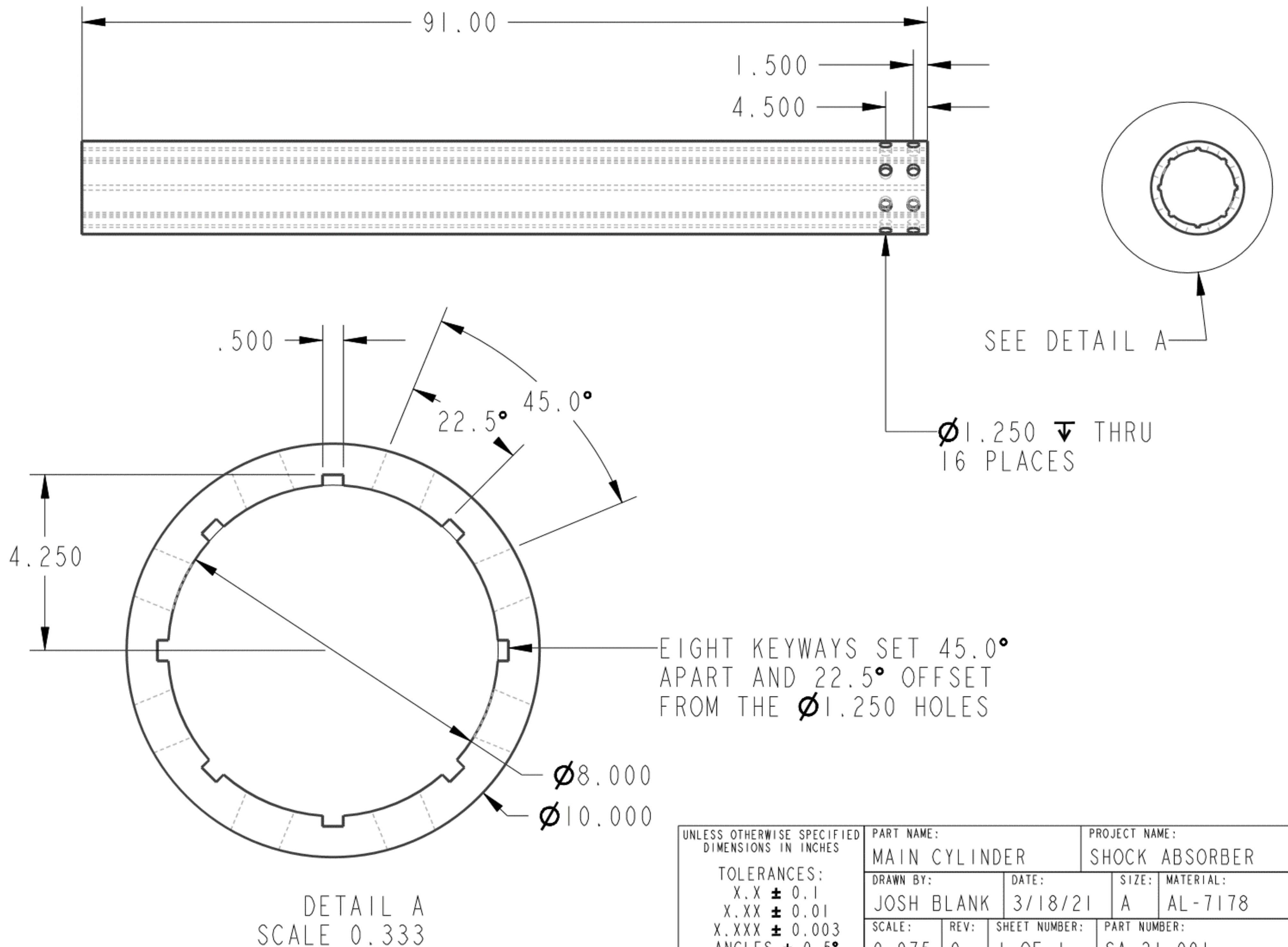


#	PART NAME	QTY	MATERIAL
1	MAIN CYLINDER	1	AL-7178
2	END CAP	1	AL-7178
3	PAWL ARM	8	304 SS
4	EIGTH NUT	8	304 SS
5	RATCHET SCREW	1	304 SS
6	MOTOR HOUSING	1	AL-7178
7	THRUST BEARING	1	304 SS
8	MAIN SPRING	1	304 SS

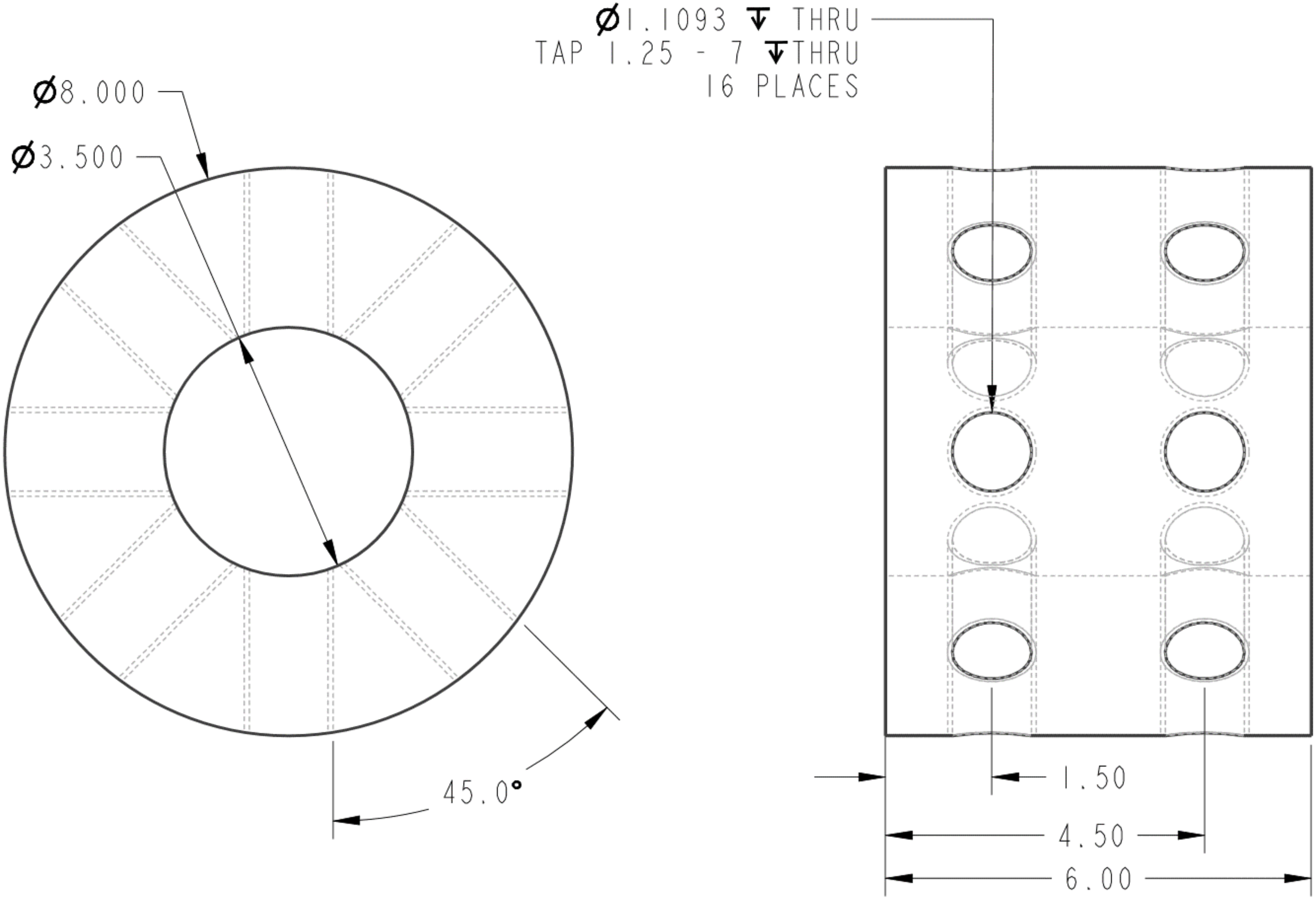
UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES

TOLERANCES:
X.X ± 0.1
X.XX ± 0.01
X.XXX ± 0.003
ANGLES ± 0.5°

PART NAME:			PROJECT NAME:	
ASSEMBLY			SHOCK ABSORBER	
DRAWN BY: JOSH BLANK		DATE: 3/18/21	SIZE: A	MATERIAL: VARIOUS
SCALE: 0.060	REV: 0	SHEET NUMBER: 3 OF 3	PART NUMBER: SA-21-009	

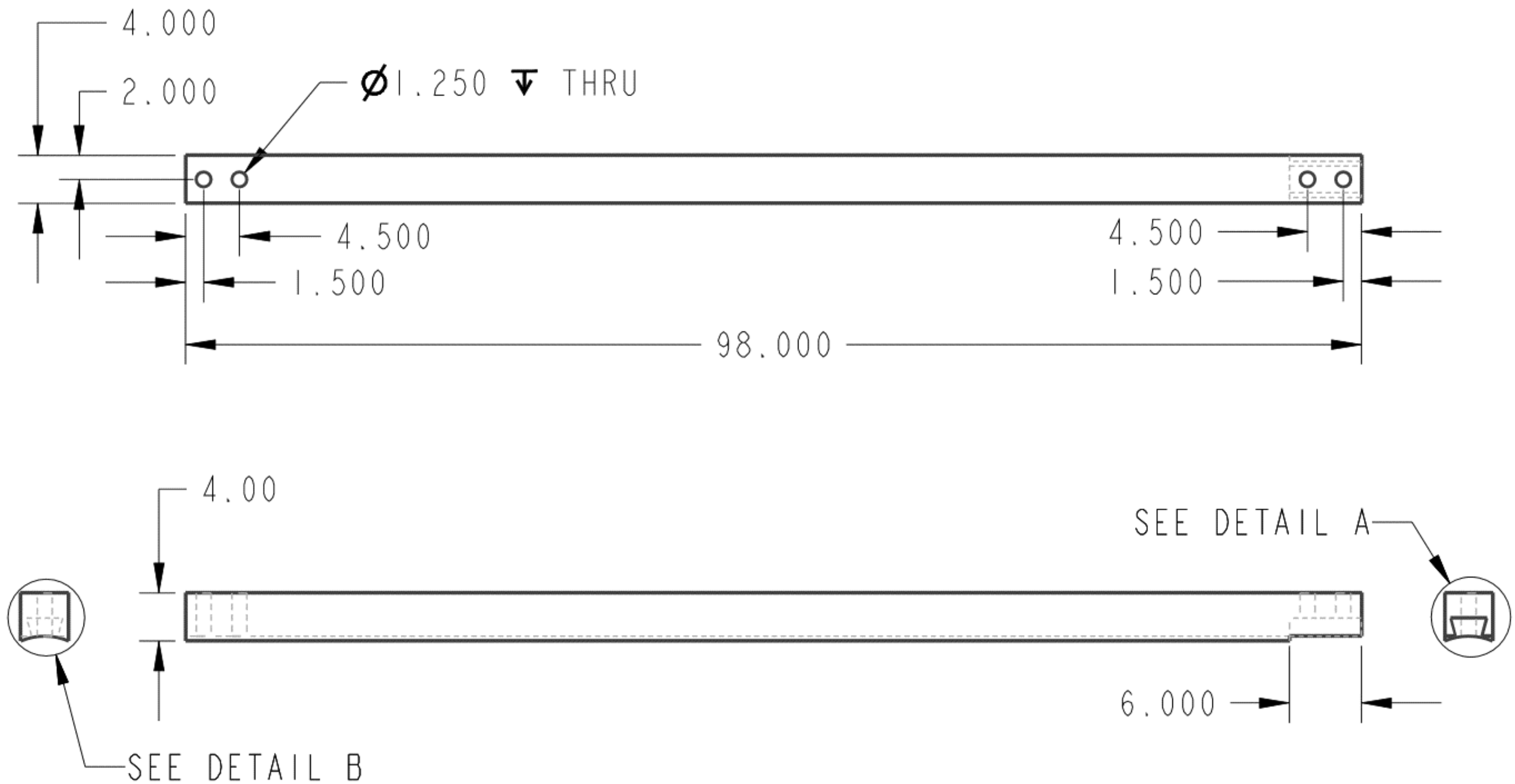


UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES	PART NAME: MAIN CYLINDER			PROJECT NAME: SHOCK ABSORBER		
TOLERANCES: X.X ± 0.1 X.XX ± 0.01 X.XXX ± 0.003 ANGLES ± 0.5°	DRAWN BY: JOSH BLANK		DATE: 3/18/21	SIZE: A	MATERIAL: AL-7178	
	SCALE: 0.075	REV: 0	SHEET NUMBER: 1 OF 1		PART NUMBER: SA-21-001	



TWO ROWS OF 8 1.25-7 TAPPED HOLES SET 45° APART

UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES TOLERANCES: X.X ± 0.1 X.XX ± 0.01 X.XXX ± 0.003 ANGLES ± 0.5°	PART NAME: END CAP			PROJECT NAME: SHOCK ABSORBER	
	DRAWN BY: JOSH BLANK		DATE: 3/18/21	SIZE: A	MATERIAL: AL-7178
	SCALE: 0.500	REV: 0	SHEET NUMBER: 1 OF 1	PART NUMBER: SA-21-002	

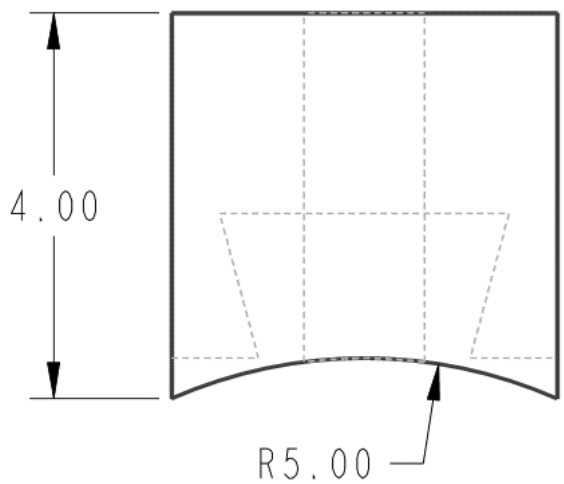


UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES

TOLERANCES:
X.X ± 0.1
X.XX ± 0.01
X.XXX ± 0.003
ANGLES ± 0.5°

PART NAME: PAWL ARM		PROJECT NAME: SHOCK ABSORBER	
DRAWN BY: JOSH BLANK	DATE: 3/18/21	SIZE: A	MATERIAL: 304 SS
SCALE: 0.075	REV: 0	SHEET NUMBER: 1 OF 1	PART NUMBER: SA-21-003

DETAIL B
SCALE 0.500



DETAIL A
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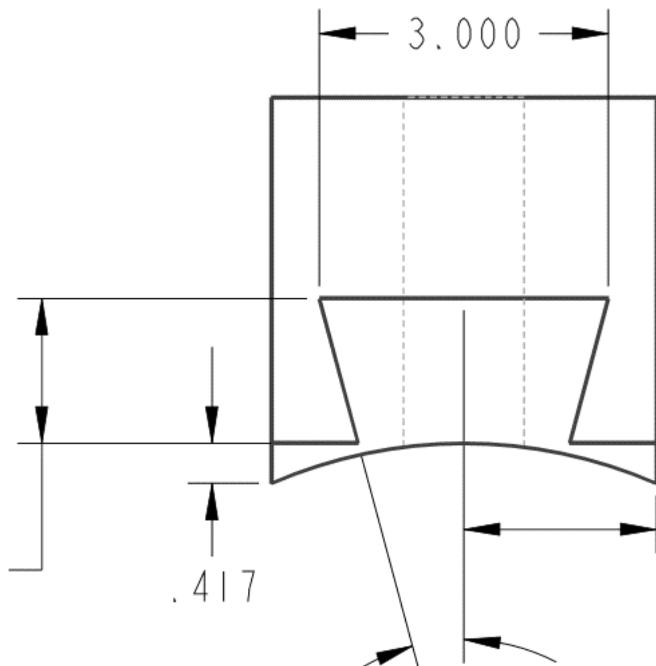
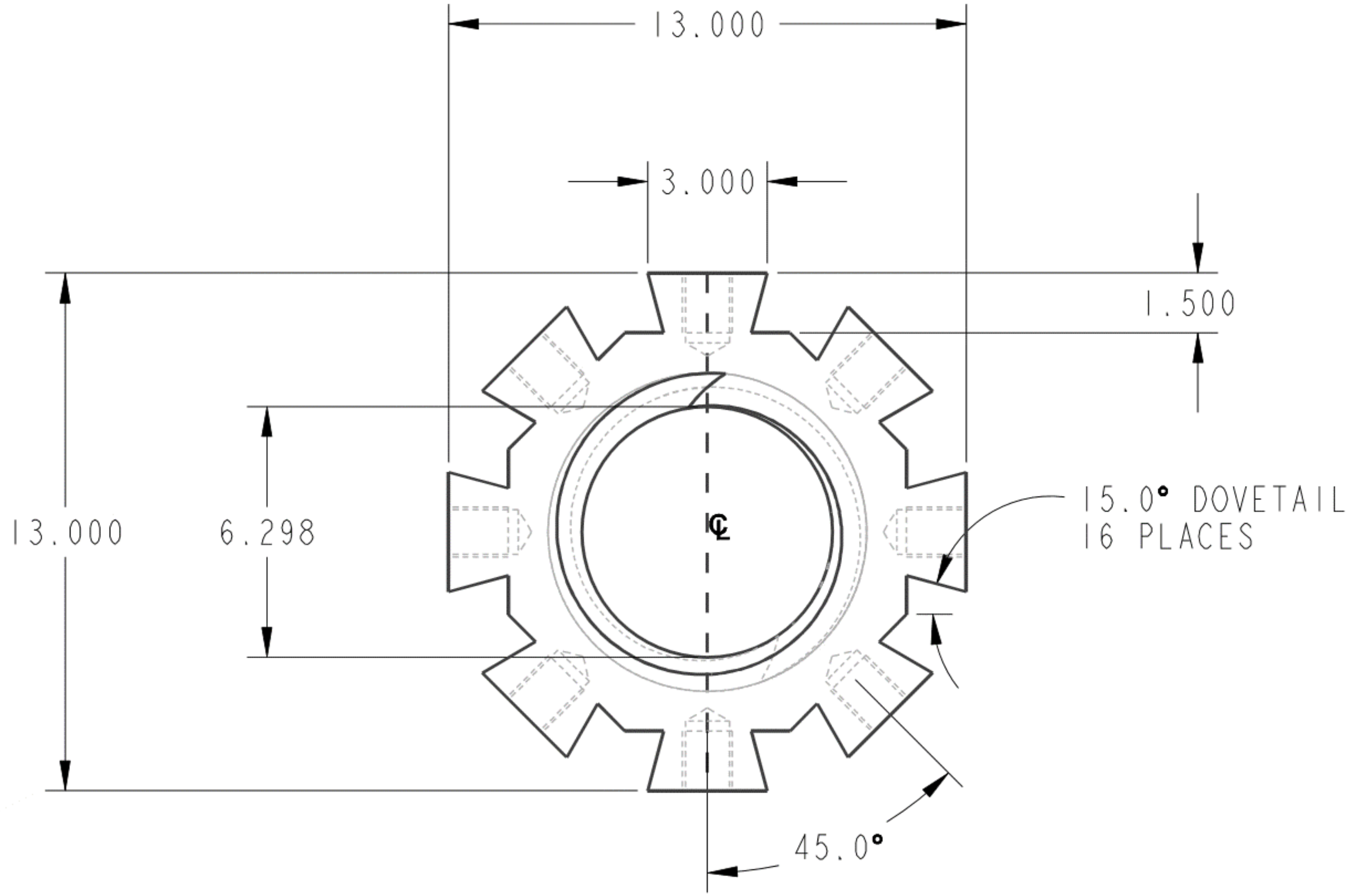


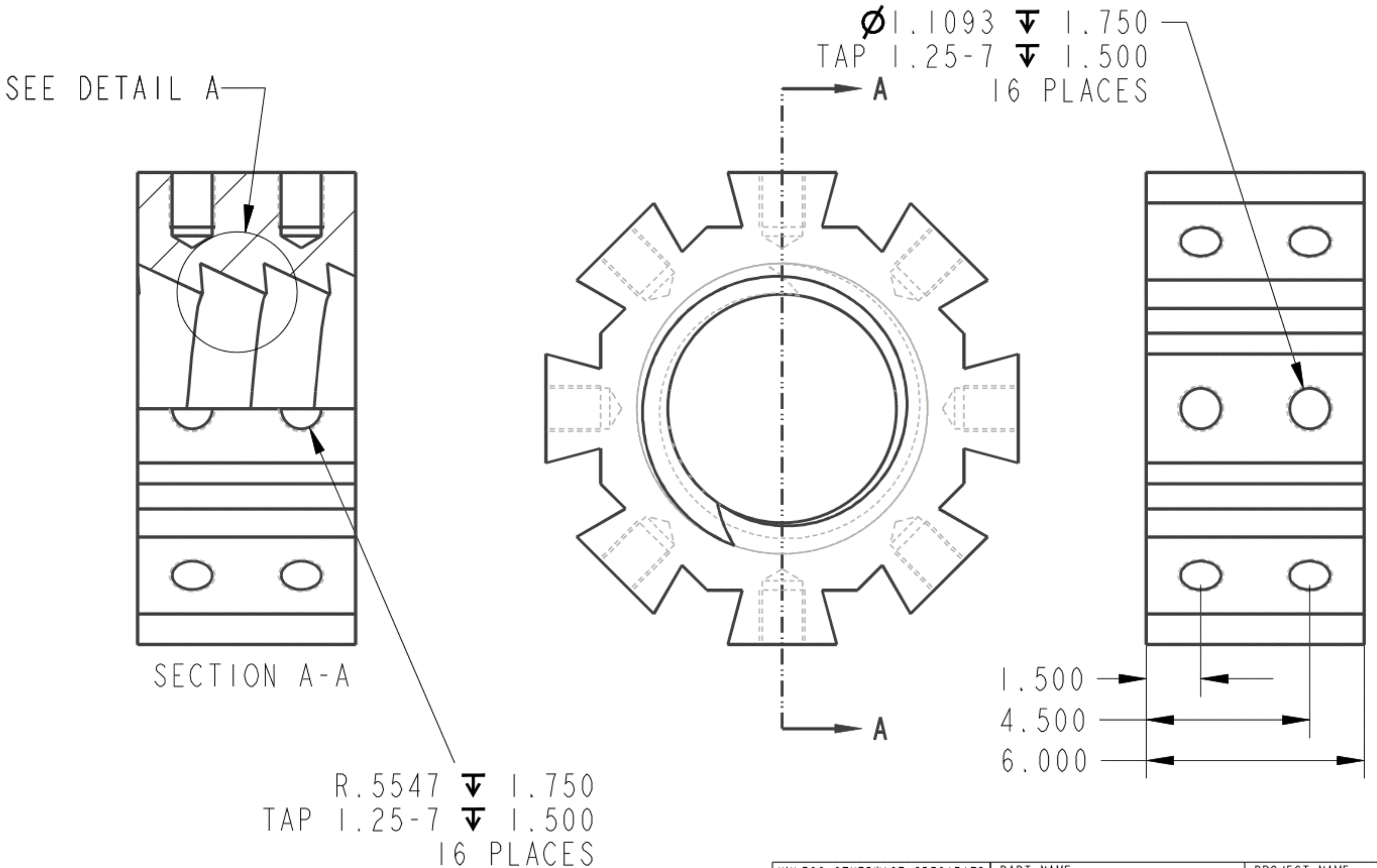
UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES

TOLERANCES:
X.X ± 0.1
X.XX ± 0.01
X.XXX ± 0.003
ANGLES ± 0.5°

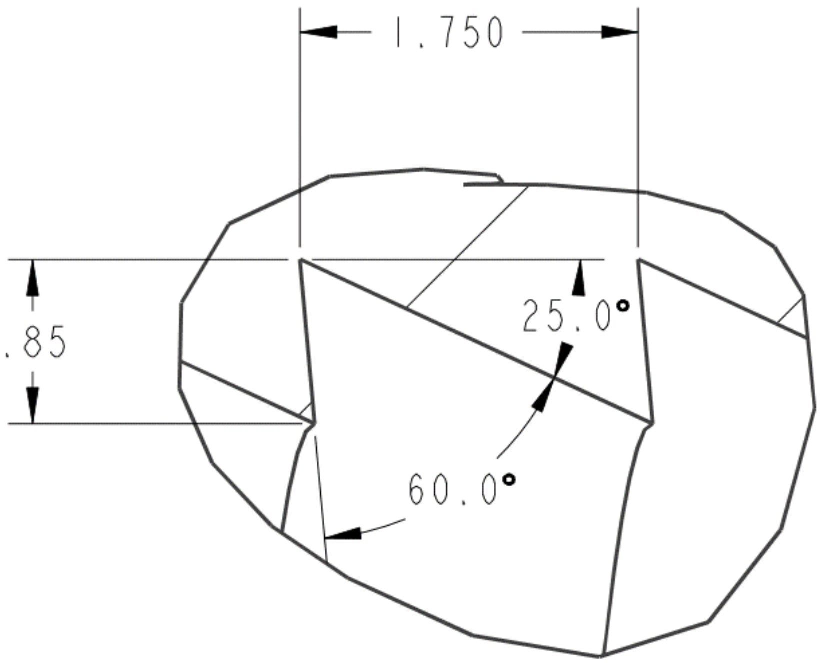
PART NAME: PAWL ARM		PROJECT NAME: SHOCK ABSORBER	
DRAWN BY: JOSH BLANK	DATE: 3/18/21	SIZE: A	MATERIAL: 304 SS
SCALE: 0.075	REV: 0	SHEET NUMBER: 1 OF 1	PART NUMBER: SA-21-003



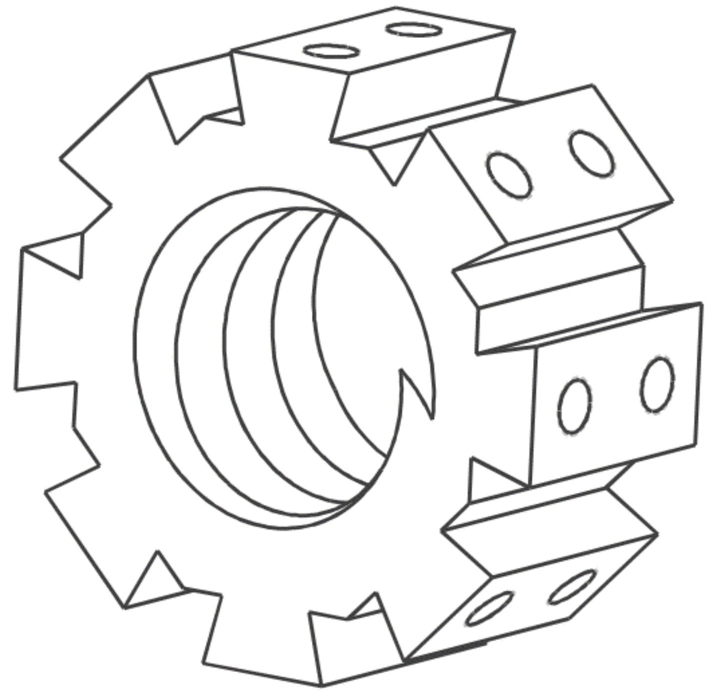
UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES TOLERANCES: X.X ± 0.1 X.XX ± 0.01 X.XXX ± 0.003 ANGLES ± 0.5°	PART NAME: EIGHTH NUTS			PROJECT NAME: SHOCK ABSORBER	
	DRAWN BY: JOSH BLANK		DATE: 3/18/21	SIZE: A	MATERIAL: 304 SS
	SCALE: 0.250	REV: 0	SHEET NUMBER: 1 OF 4	PART NUMBER: SA-21-004	



UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES	PART NAME: EIGHTH NUTS			PROJECT NAME: SHOCK ABSORBER	
TOLERANCES: X.X ± 0.1 X.XX ± 0.01 X.XXX ± 0.003 ANGLES ± 0.5°	DRAWN BY: JOSH BLANK		DATE: 3/18/21	SIZE: A	MATERIAL: 304 SS
	SCALE: 0.250	REV: 0	SHEET NUMBER: 2 OF 4	PART NUMBER: SA-21-004	



DETAIL A
SCALE 1.000



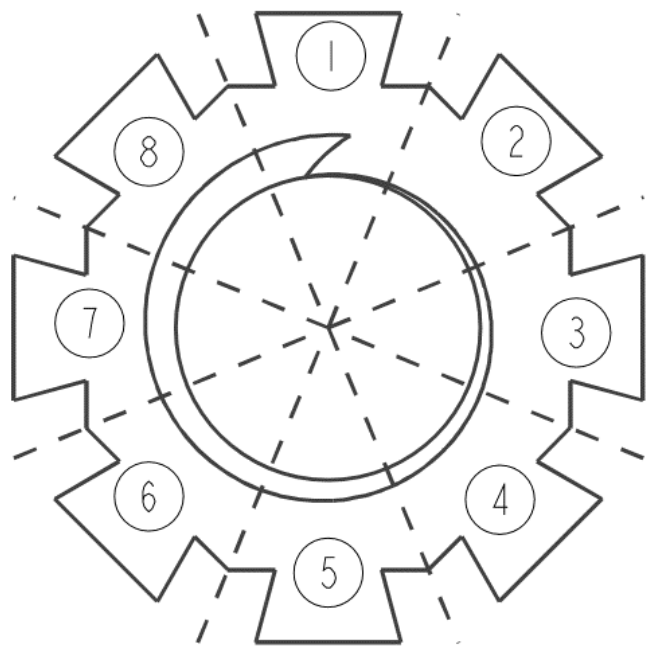
CONCEPTUAL VIEW

SCREW INFOMATION	
MINOR ID	6.298
MAJOR ID	8.00
PITCH	1.750
DEPTH	.851

UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES

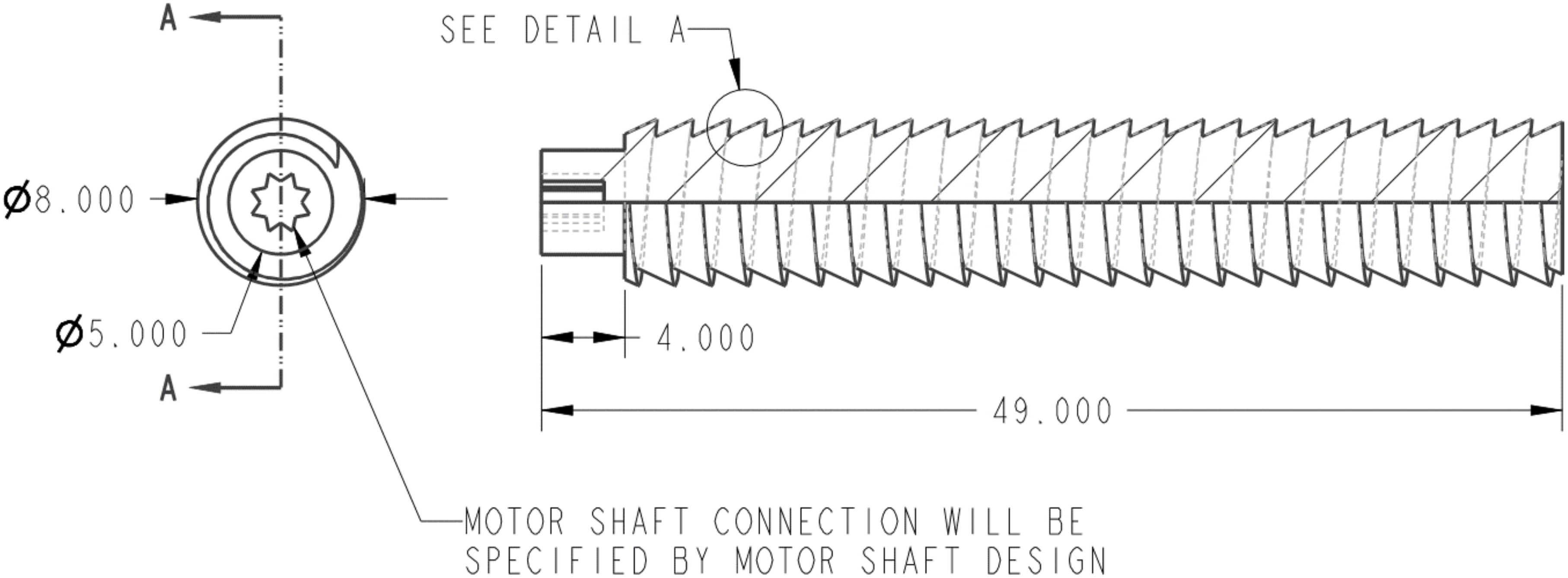
TOLERANCES:
X.X ± 0.1
X.XX ± 0.01
X.XXX ± 0.003
ANGLES ± 0.5°

PART NAME:				PROJECT NAME:	
EIGHTH NUTS				SHOCK ABSORBER	
DRAWN BY:		DATE:		SIZE:	MATERIAL:
JOSH BLANK		3/18/21		A	304 SS
SCALE:	REV:	SHEET NUMBER:		PART NUMBER:	
0.250	0	3 OF 4		SA-21-004	

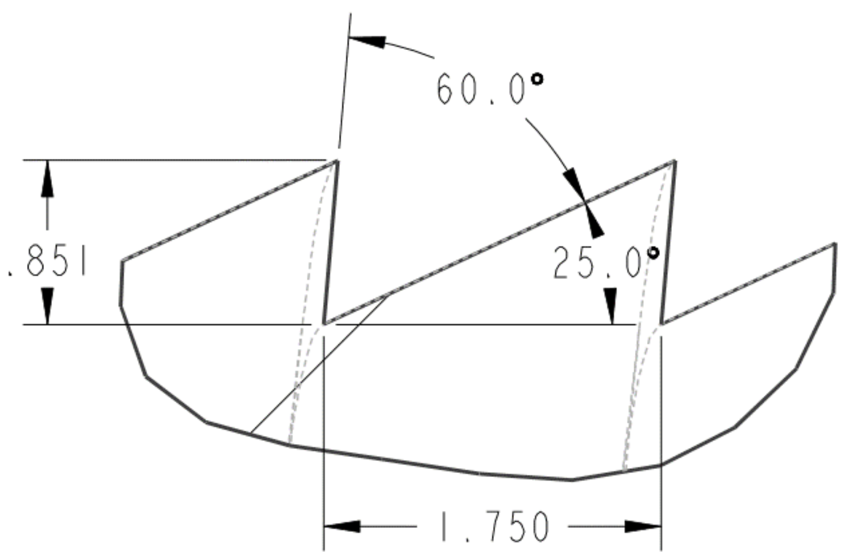


AFTER FABRICATION, CUT NUT INTO EIGHT SECTIONS ALONG DASHED LINES
MARK EACH SECTION 1-8 CLOCKWISE AS NOTED BY BALLOONS

UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES	PART NAME: EIGHTH NUTS		PROJECT NAME: SHOCK ABSORBER	
TOLERANCES: X.X ± 0.1, X.XX ± 0.01, X.XXX ± 0.003, ANGLES ± 0.5°	DRAWN BY: JOSH BLANK	DATE: 3/18/21	SIZE: A	MATERIAL: 304 SS
	SCALE: 0.250	REV: 0	SHEET NUMBER: 4 OF 4	PART NUMBER: SA-21-004

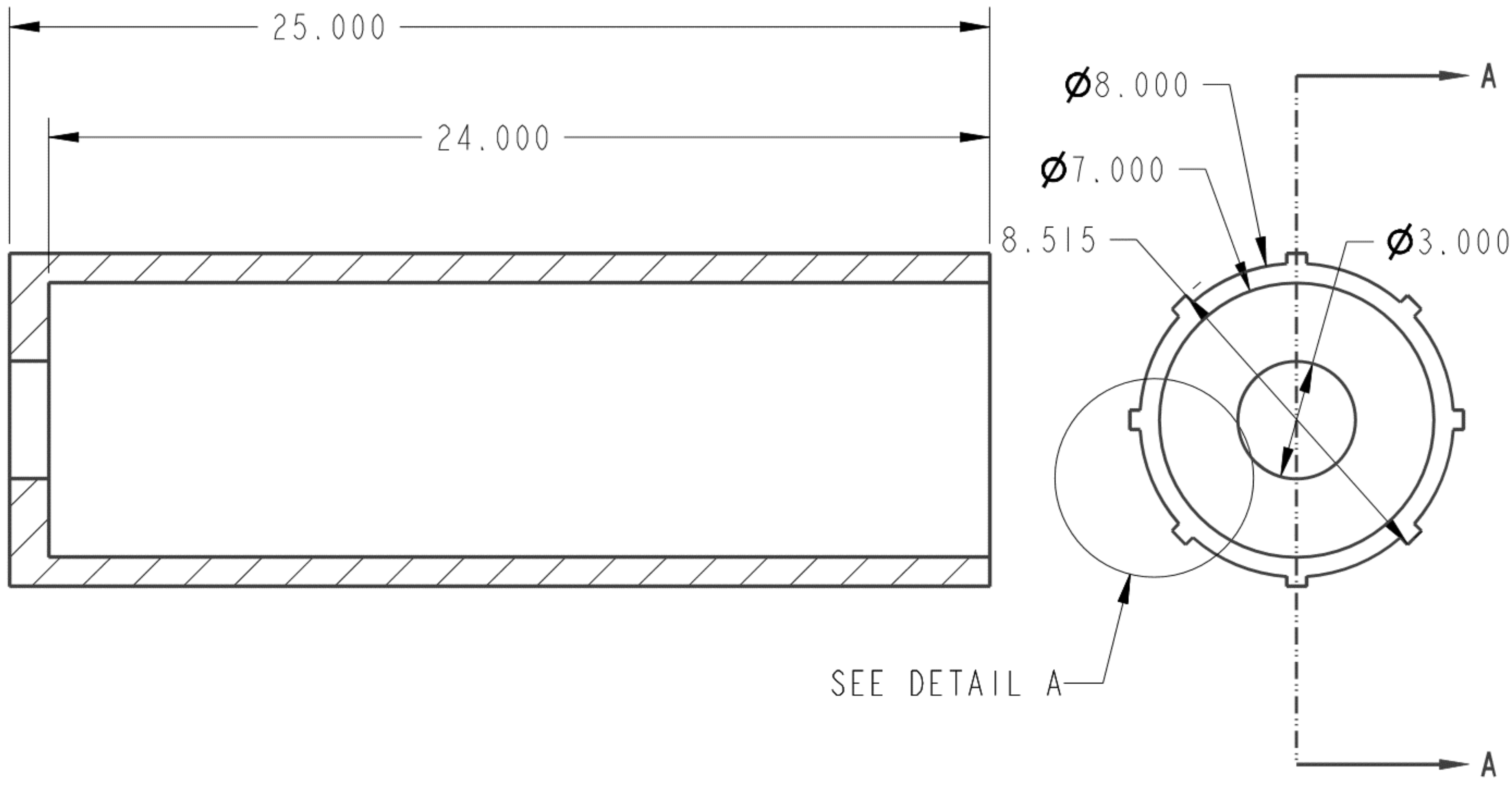


SCREW INFORMATION	
MAJOR OD	8.000
MINOR OD	6.30
PITCH	1.750
DEPTH	.851

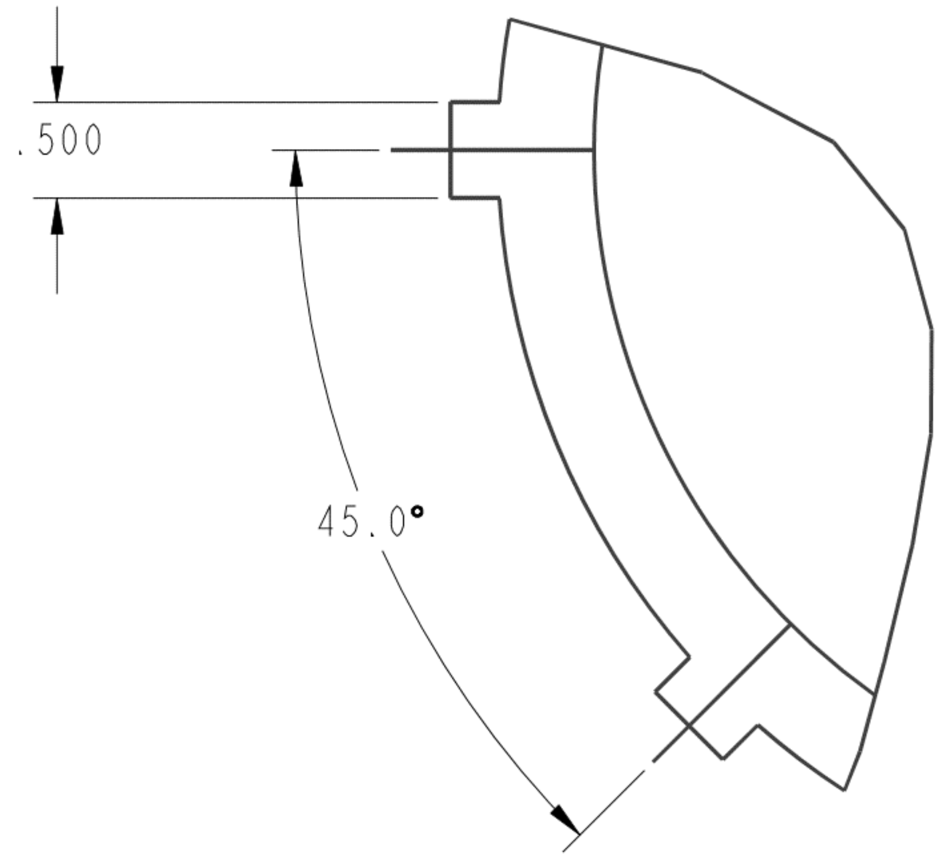


DETAIL A
SCALE 1.000

UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES TOLERANCES: X.X ± 0.1 X.XX ± 0.01 X.XXX ± 0.003 ANGLES ± 0.5°	PART NAME: RATCHET SCREW			PROJECT NAME: SHOCK ABSORBER	
	DRAWN BY: JOSH BLANK		DATE: 3/18/21	SIZE: A	MATERIAL: 304 SS
	SCALE: 1.000	REV: 0	SHEET NUMBER: 1 OF 1	PART NUMBER: SA-21-005	



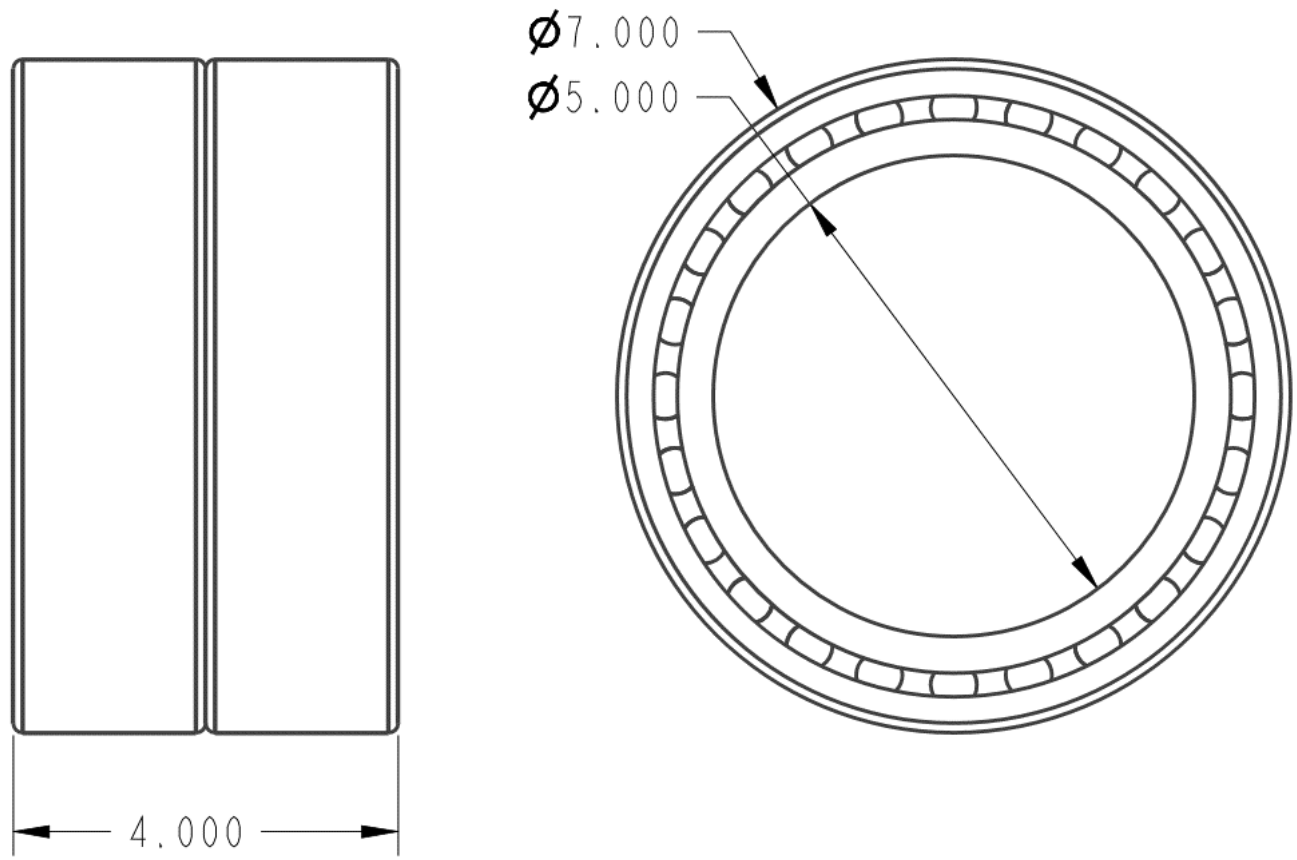
UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES TOLERANCES: X.X ± 0.1 X.XX ± 0.01 X.XXX ± 0.003 ANGLES ± 0.5°	PART NAME: MOTOR HOUSING			PROJECT NAME: SHOCK ABSORBER	
	DRAWN BY: JOSH BLANK		DATE: 3/18/21	SIZE: A	MATERIAL: AL-7178
	SCALE: 0.250	REV: 0	SHEET NUMBER: 1 OF 2	PART NUMBER: SA-21-006	



DETAIL A
SCALE 1.000

UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES	PART NAME: MOTOR HOUSING			PROJECT NAME: SHOCK ABSORBER	
TOLERANCES: X.X ± 0.1, X.XX ± 0.01, X.XXX ± 0.003, ANGLES ± 0.5°	DRAWN BY: JOSH BLANK		DATE: 3/18/21	SIZE: A	MATERIAL: AL-7178
	SCALE: 0.250	REV: 0	SHEET NUMBER: 2 OF 2	PART NUMBER: SA-21-006	

THE THUST BEARING HAS NOT BEEN DESIGNED YET
THE LISTED OD, ID AND LENGTH ARE WORKING VALUES



UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES	PART NAME: THRUST BEARING			PROJECT NAME: SHOCK ABSORBER	
TOLERANCES: X.X ± 0.1 X.XX ± 0.01 X.XXX ± 0.003 ANGLES ± 0.5°	DRAWN BY: JOSH BLANK		DATE: 3/18/21	SIZE: A	MATERIAL: 304 SS
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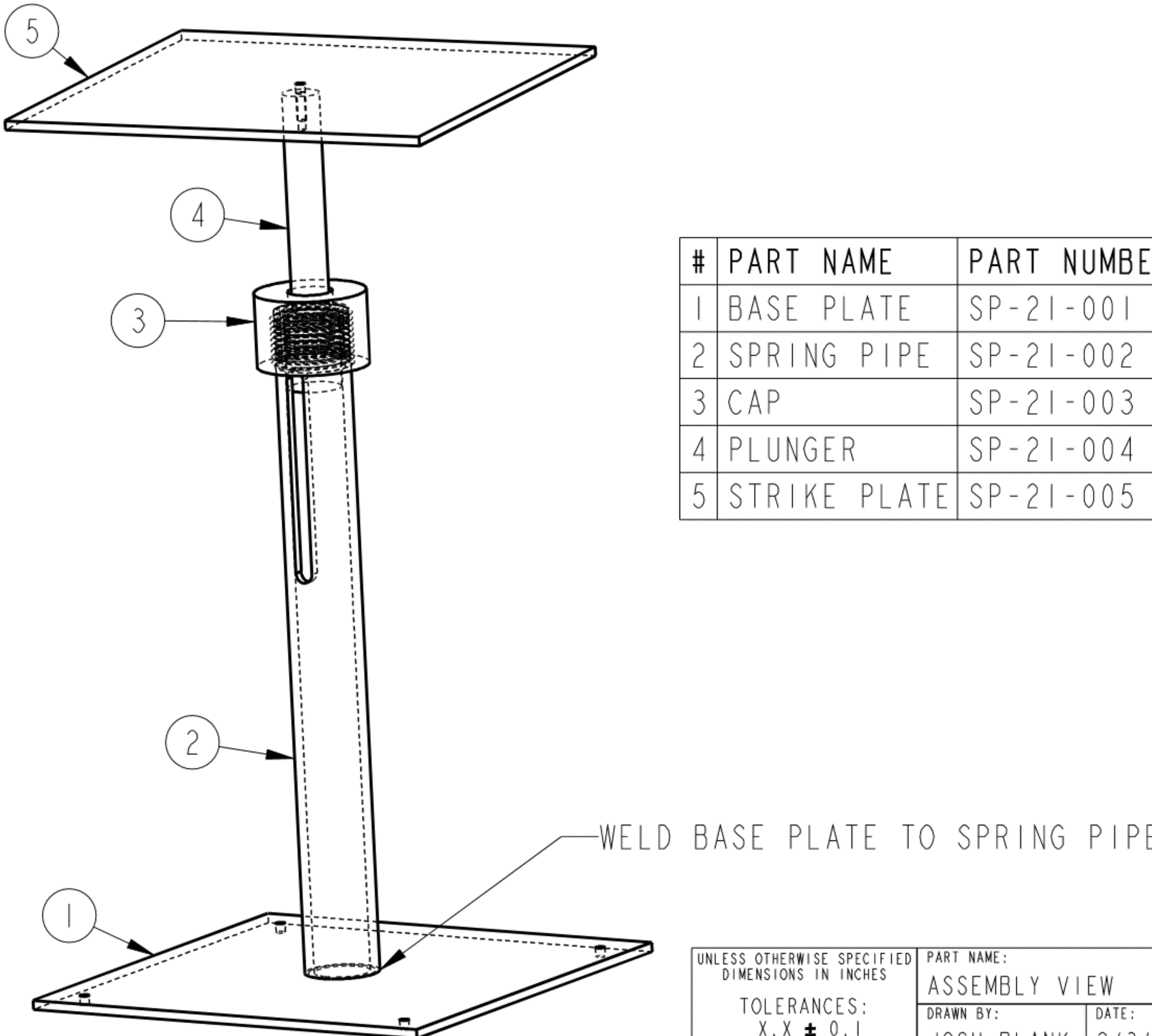
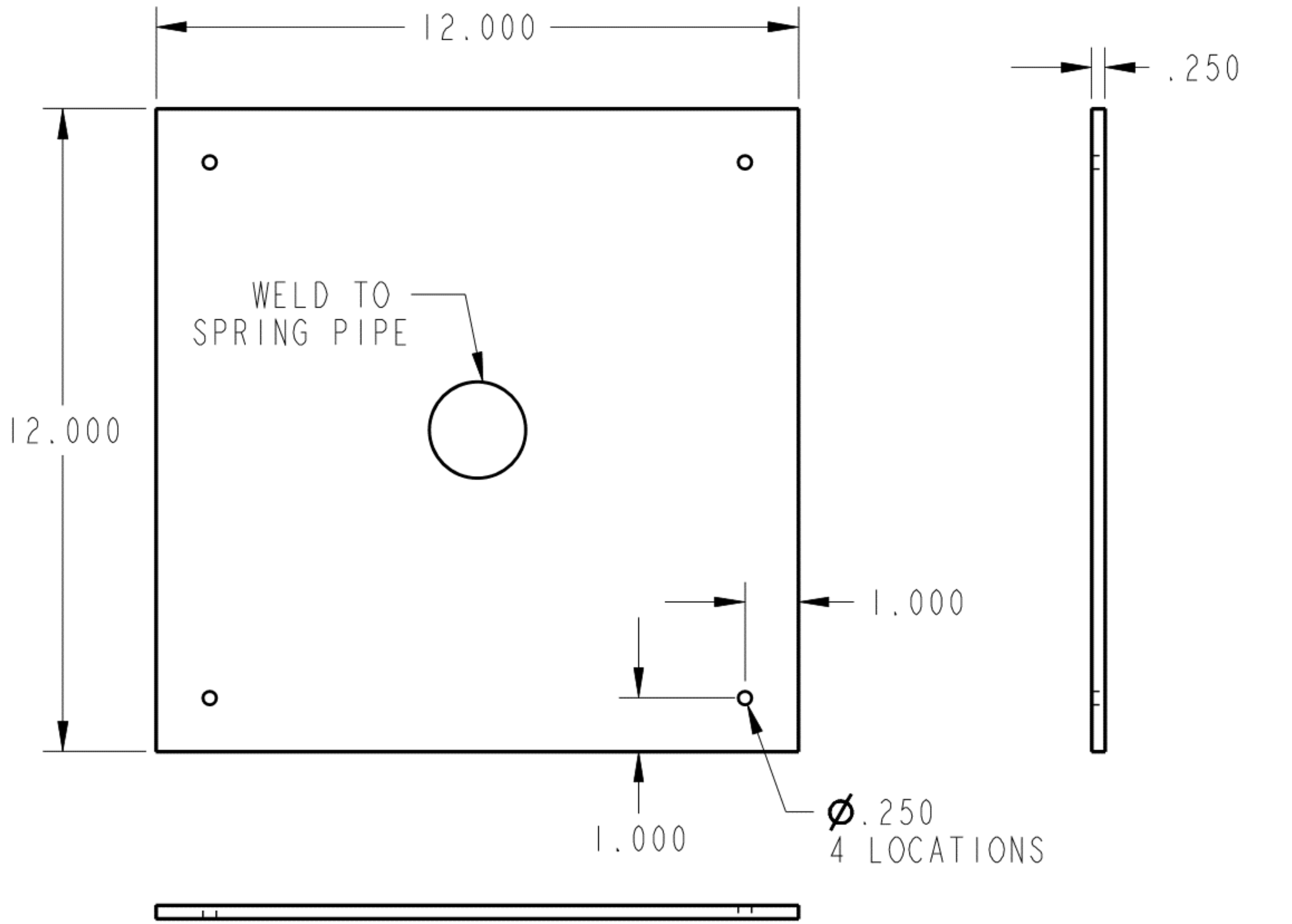


#	PART NAME	PART NUMBER
1	BASE PLATE	SP-21-001
2	SPRING PIPE	SP-21-002
3	CAP	SP-21-003
4	PLUNGER	SP-21-004
5	STRIKE PLATE	SP-21-005

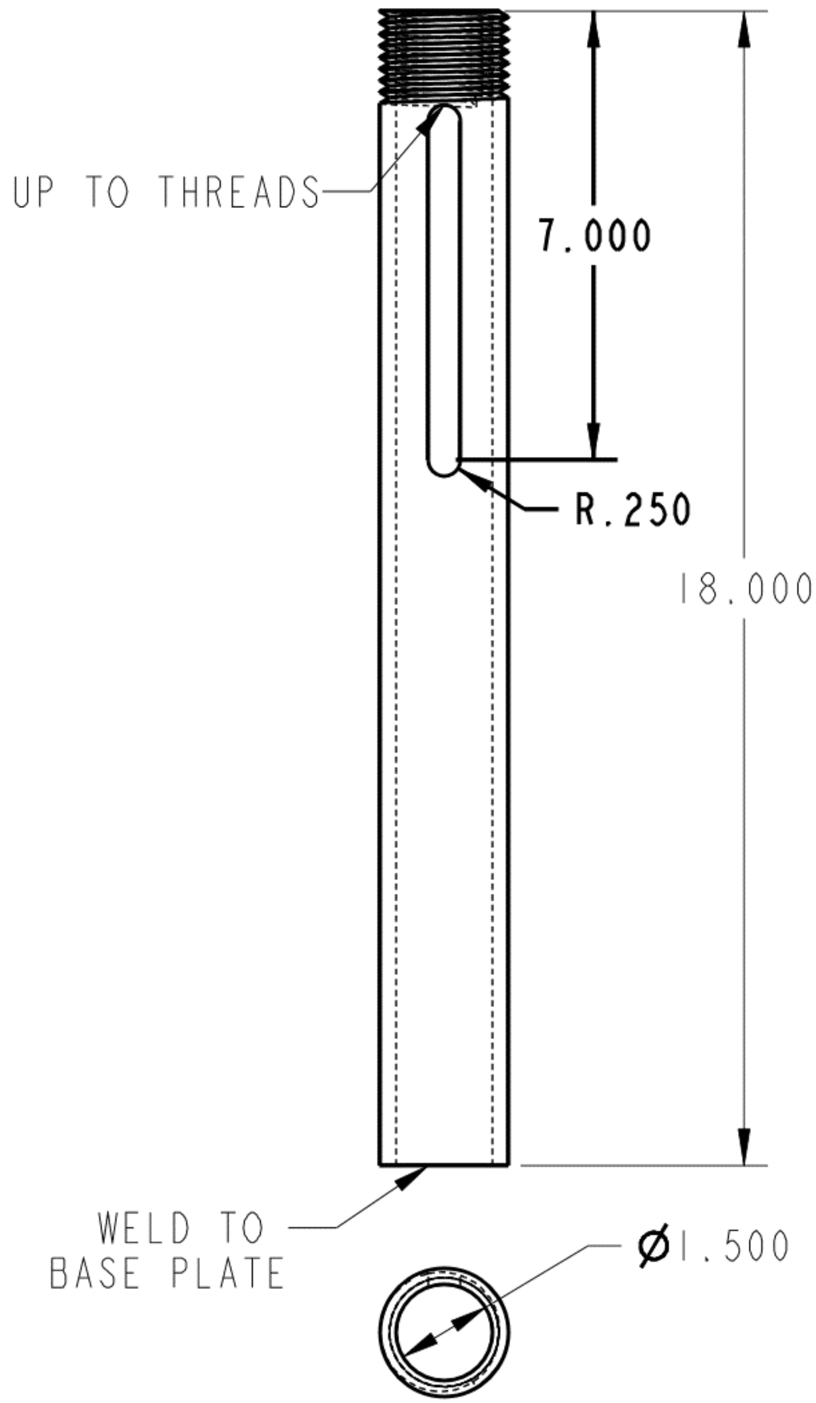
UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES

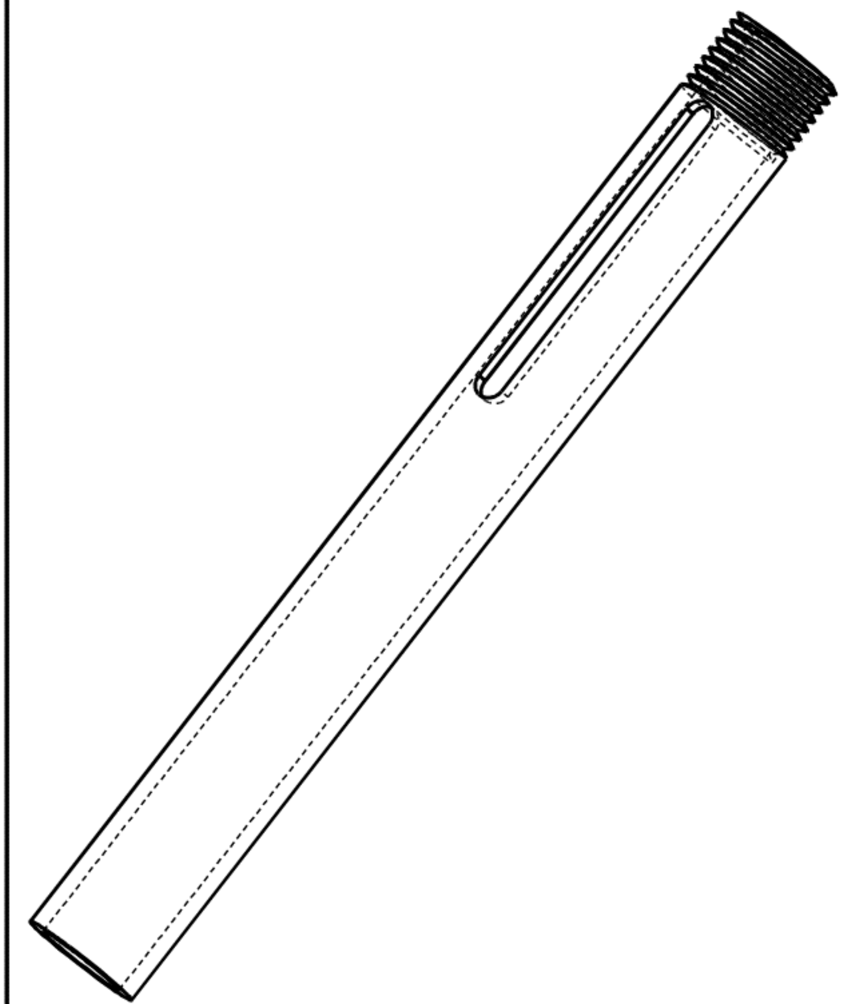
TOLERANCES:
X.X ± 0.1
X.XX ± 0.01
X.XXX ± 0.003
ANGLES ± 0.5°

PART NAME: ASSEMBLY VIEW		PROJECT NAME: SPRING PROTOTYPE	
DRAWN BY: JOSH BLANK	DATE: 2/3/21	SIZE: A	MATERIAL: VARIOUS
SCALE: 0.500	REV: 0	SHEET NUMBER: 1 OF 1	PART NUMBER: SP-21-006



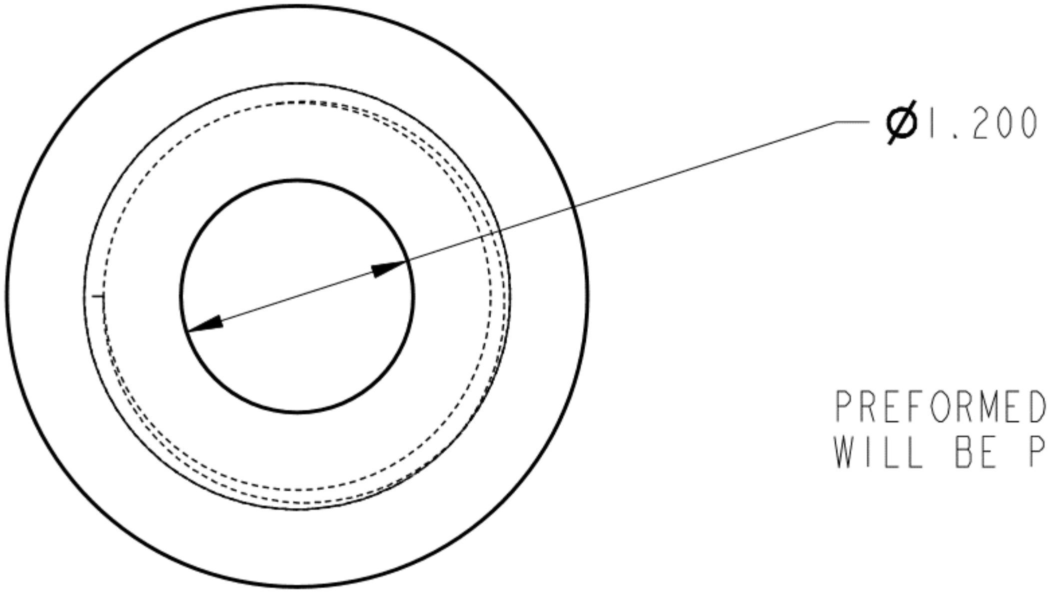
UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES TOLERANCES: X.X ± 0.1 X.XX ± 0.01 X.XXX ± 0.003 ANGLES ± 0.5°	PART NAME: BASE PLATE			PROJECT NAME: SPRING PROTOTYPE	
	DRAWN BY: JOSH BLANK		DATE: 2/3/21	SIZE: A	MATERIAL: STEEL PLATE
	SCALE: 0.333	REV: 0	SHEET NUMBER: 1 OF 1	PART NUMBER: SP-21-001	



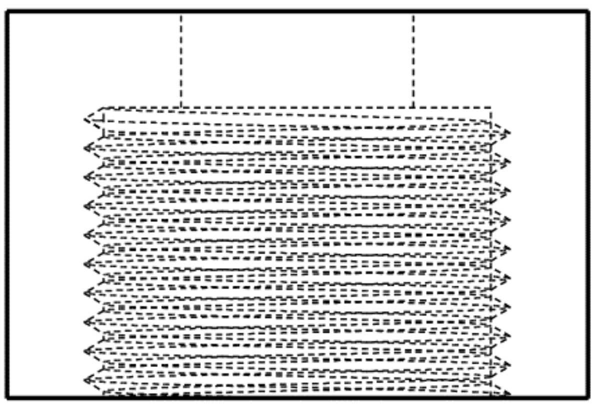


PERSPECTIVE VIEW FOR VISUALIZATION

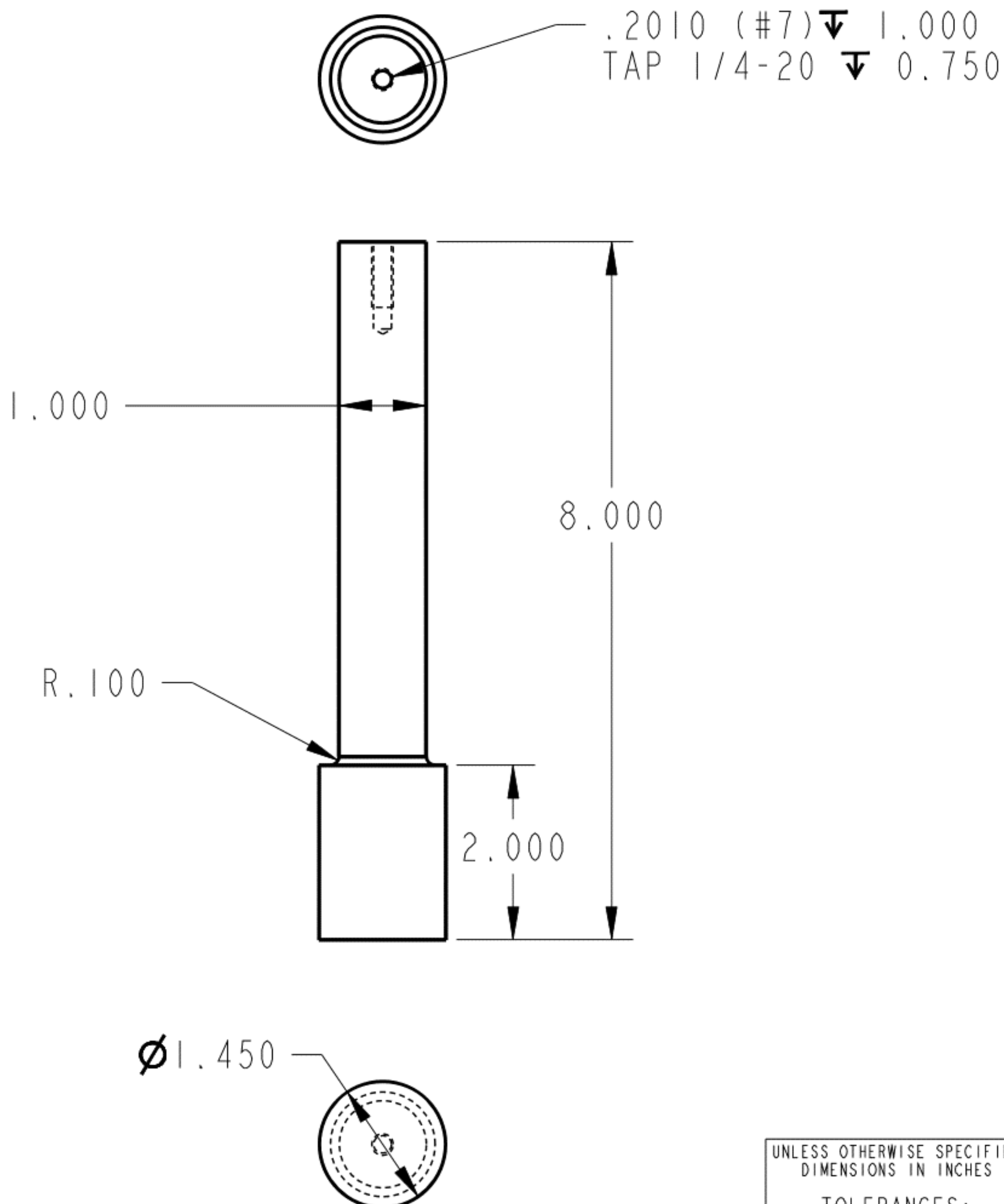
UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES TOLERANCES: X.X ± 0.1 X.XX ± 0.01 X.XXX ± 0.003 ANGLES ± 0.5°	PART NAME: SPRING PIPE		PROJECT NAME: SPRING PROTOTYPE	
	DRAWN BY: JOSH BLANK	DATE: 2/3/21	SIZE: A	MATERIAL: BLACK PIPE
	SCALE: 0.333	REV: 0	SHEET NUMBER: 1 OF 1	PART NUMBER: SP-21-002



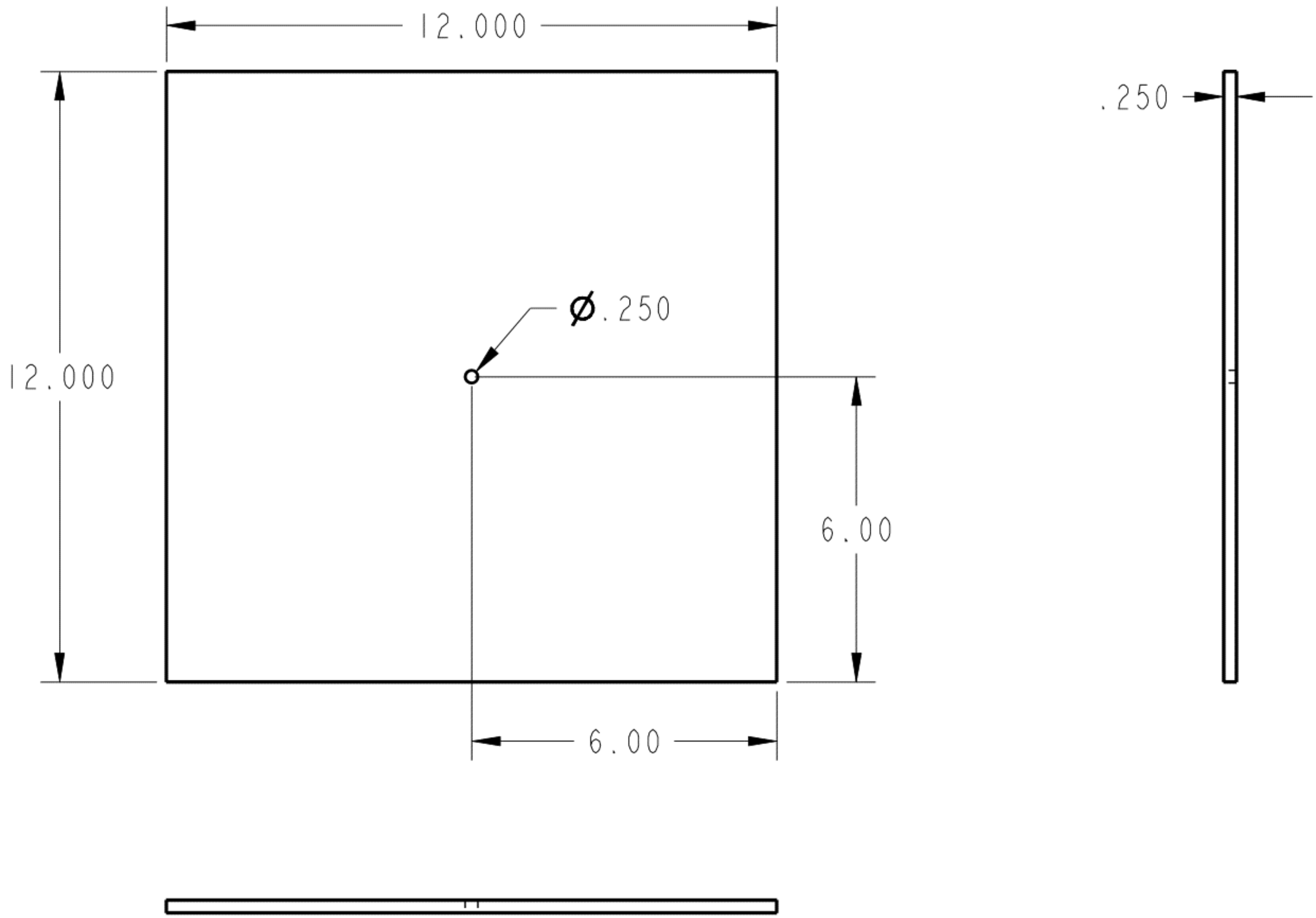
PREFORMED PIPE CAP WITH FNPT
WILL BE PROVIDED



UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES TOLERANCES: X.X ± 0.1 X.XX ± 0.01 X.XXX ± 0.003 ANGLES ± 0.5°	PART NAME: CAP			PROJECT NAME: SPRING PROTOTYPE		
	DRAWN BY: JOSH BLANK		DATE: 2/3/21		SIZE: A	MATERIAL: STEEL CAP
	SCALE: 1.000	REV: 0	SHEET NUMBER: 1 OF 1	PART NUMBER: SP-21-003		



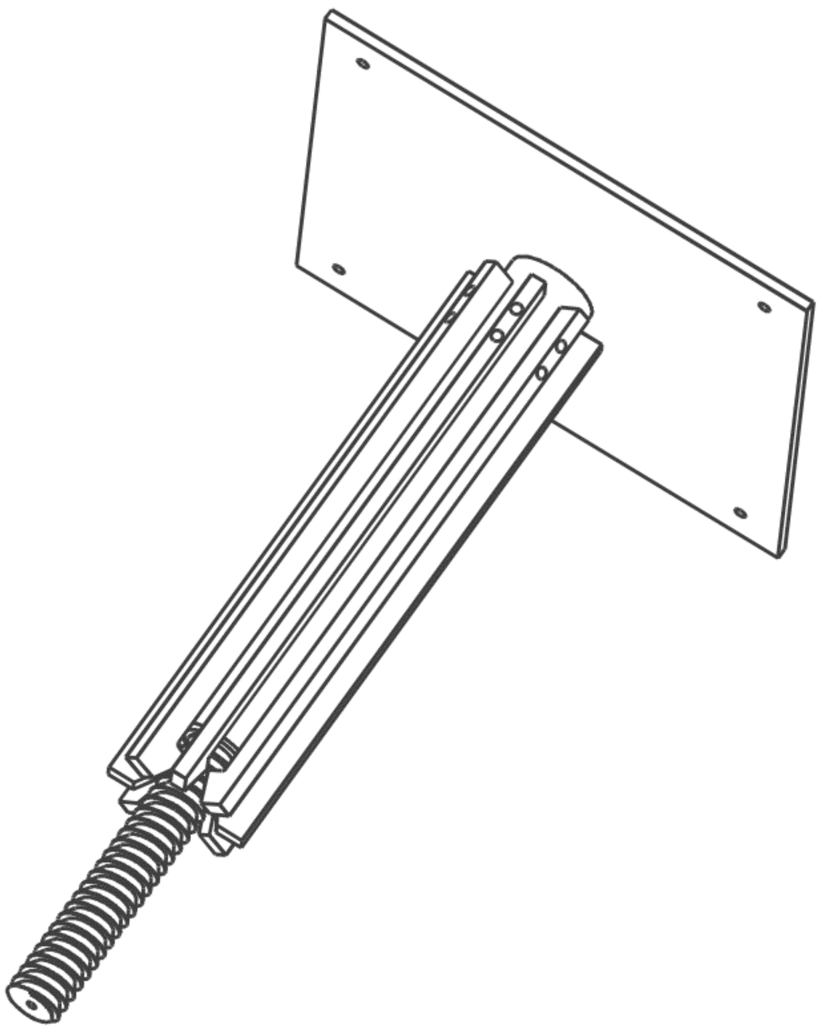
UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES TOLERANCES: X.X ± 0.1 X.XX ± 0.01 X.XXX ± 0.003 ANGLES ± 0.5°	PART NAME: PLUNGER			PROJECT NAME: SPRING PROTOTYPE	
	DRAWN BY: JOSH BLANK		DATE: 2/3/21	SIZE: A	MATERIAL: STEEL ROD
	SCALE: 0.500	REV: 0	SHEET NUMBER: 1 OF 1	PART NUMBER: SP-21-004	



UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES

TOLERANCES:
X.X ± 0.1
X.XX ± 0.01
X.XXX ± 0.003
ANGLES ± 0.5°

PART NAME: STRIKE PLATE			PROJECT NAME: SPRING PROTOTYPE	
DRAWN BY: JOSH BLANK	DATE: 2/3/21		SIZE: A	MATERIAL: STEEL PLATE
SCALE: 0.333	REV: 0	SHEET NUMBER: 1 OF 1	PART NUMBER: SP-21-005	

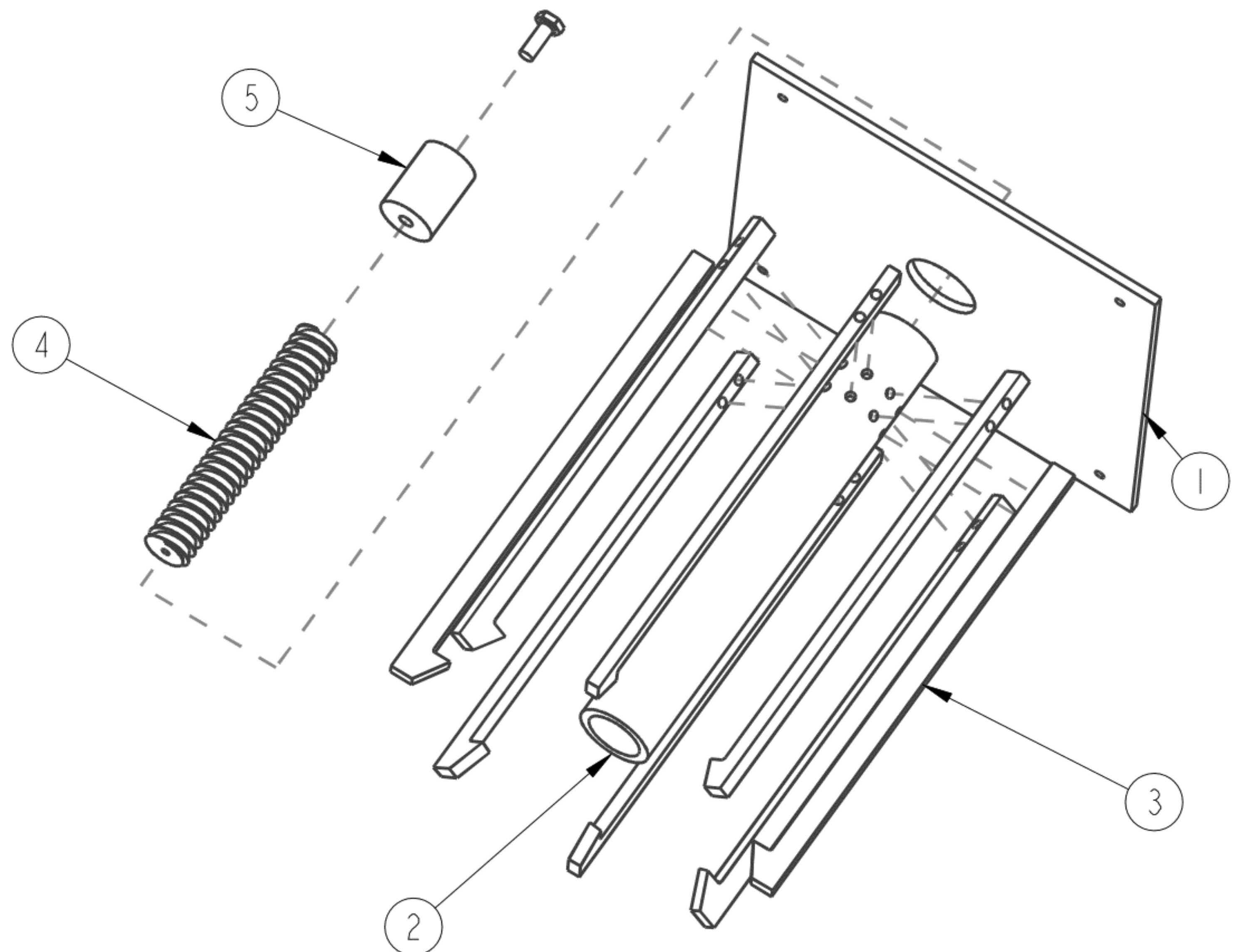


PART #	PART NAME	QTY	MATERIAL
1	BACK PLATE	1	STEEL
2	MAIN CYLINDER	1	STEEL
3	PAWL ARM	8	STEEL
4	SCREW	1	STEEL
5	SLIDER BLOCK	1	STEEL
	3/8-16 x 1.5 BOLT	1	
	1/4-20 x 1.25 BOLT	17	
	1/4-20 NUT	17	

UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES

TOLERANCES:
X.X ± 0.1
X.XX ± 0.01
X.XXX ± 0.003
ANGLES ± 0.5°

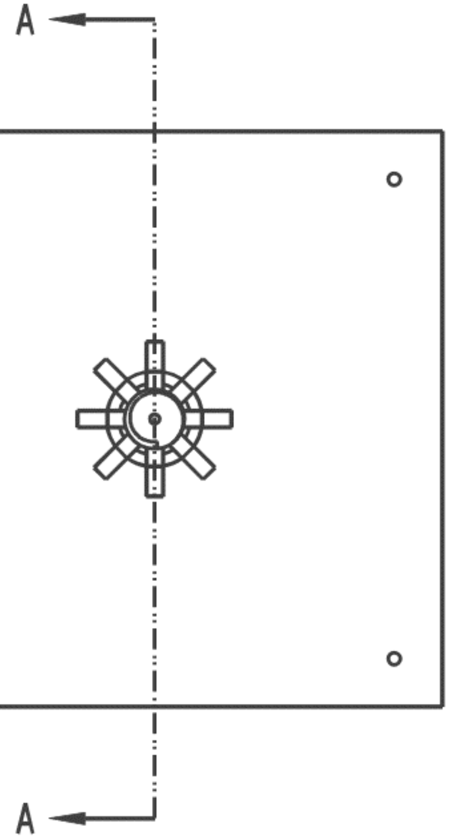
PART NAME: ASSEMBLY	PROJECT NAME: LOCKING PROTOTYPE
DRAWN BY: JOSH BLANK	DATE: 3/3/21
SIZE: A	MATERIAL: STEEL
SCALE: 0.250	REV: 0
SHEET NUMBER: 1 OF 3	PART NUMBER: LP-21-006

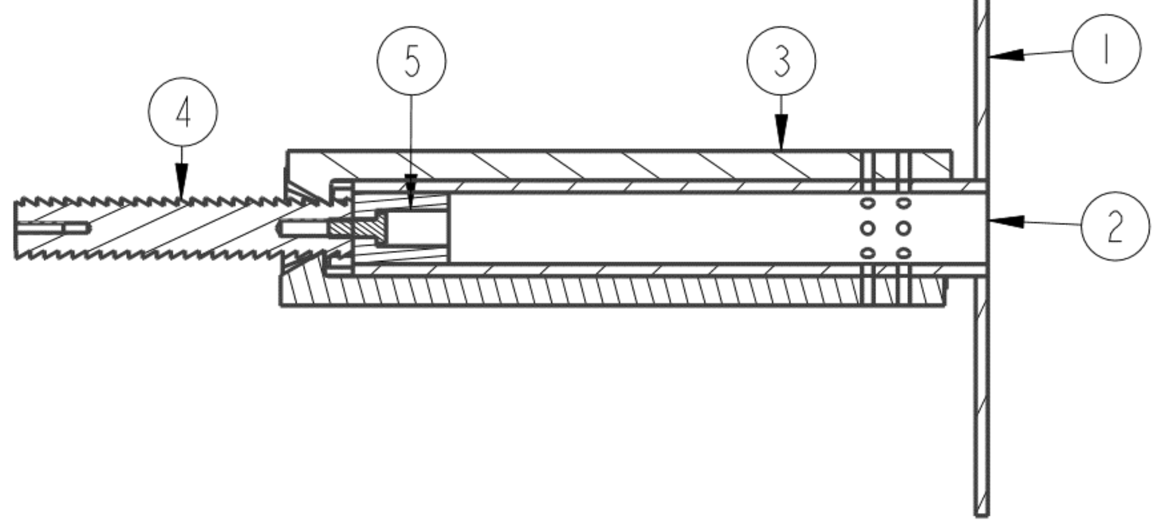


UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES

TOLERANCES:
X.X ± 0.1
X.XX ± 0.01
X.XXX ± 0.003
ANGLES ± 0.5°

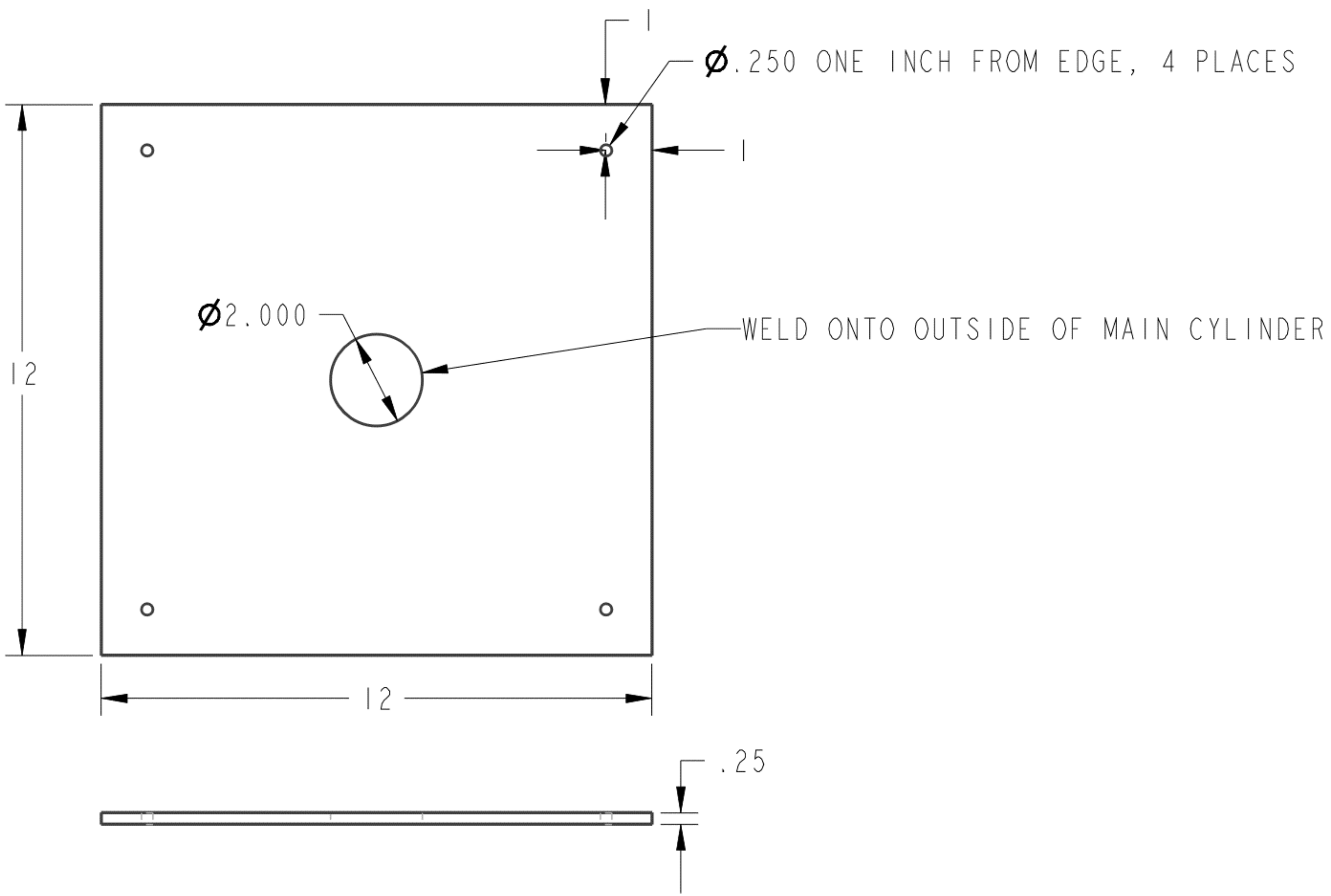
PART NAME: ASSEMBLY				PROJECT NAME: LOCKING PROTOTYPE
DRAWN BY: JOSH BLANK		DATE: 3/3/21	SIZE: A	MATERIAL: STEEL
SCALE: 0.250	REV: 0	SHEET NUMBER: 2 OF 3		PART NUMBER: LP-21-006





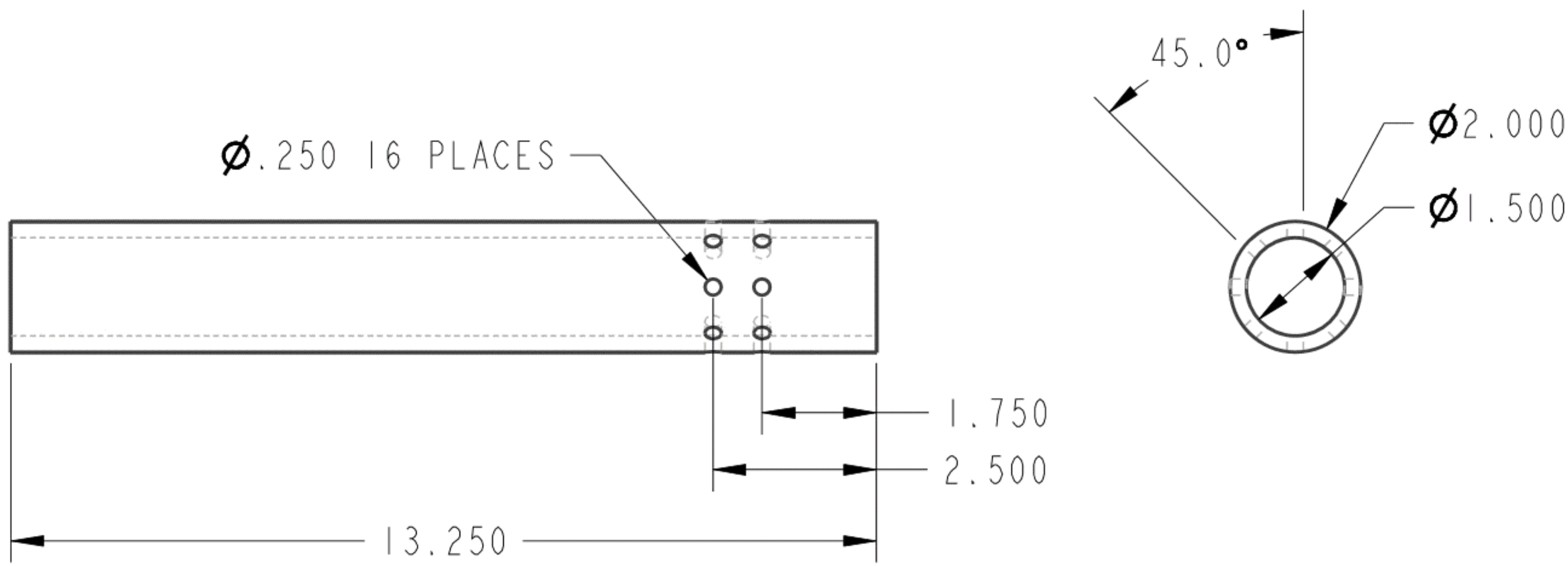
SECTION A-A
SCALE 0.250

UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES	PART NAME: ASSEMBLY				PROJECT NAME: LOCKING PROTOTYPE	
TOLERANCES: X.X ± 0.1, X.XX ± 0.01, X.XXX ± 0.003, ANGLES ± 0.5°	DRAWN BY: JOSH BLANK		DATE: 3/3/21		SIZE: A	MATERIAL: STEEL
	SCALE: 0.250	REV: 0	SHEET NUMBER: 3 OF 3		PART NUMBER: LP-21-006	

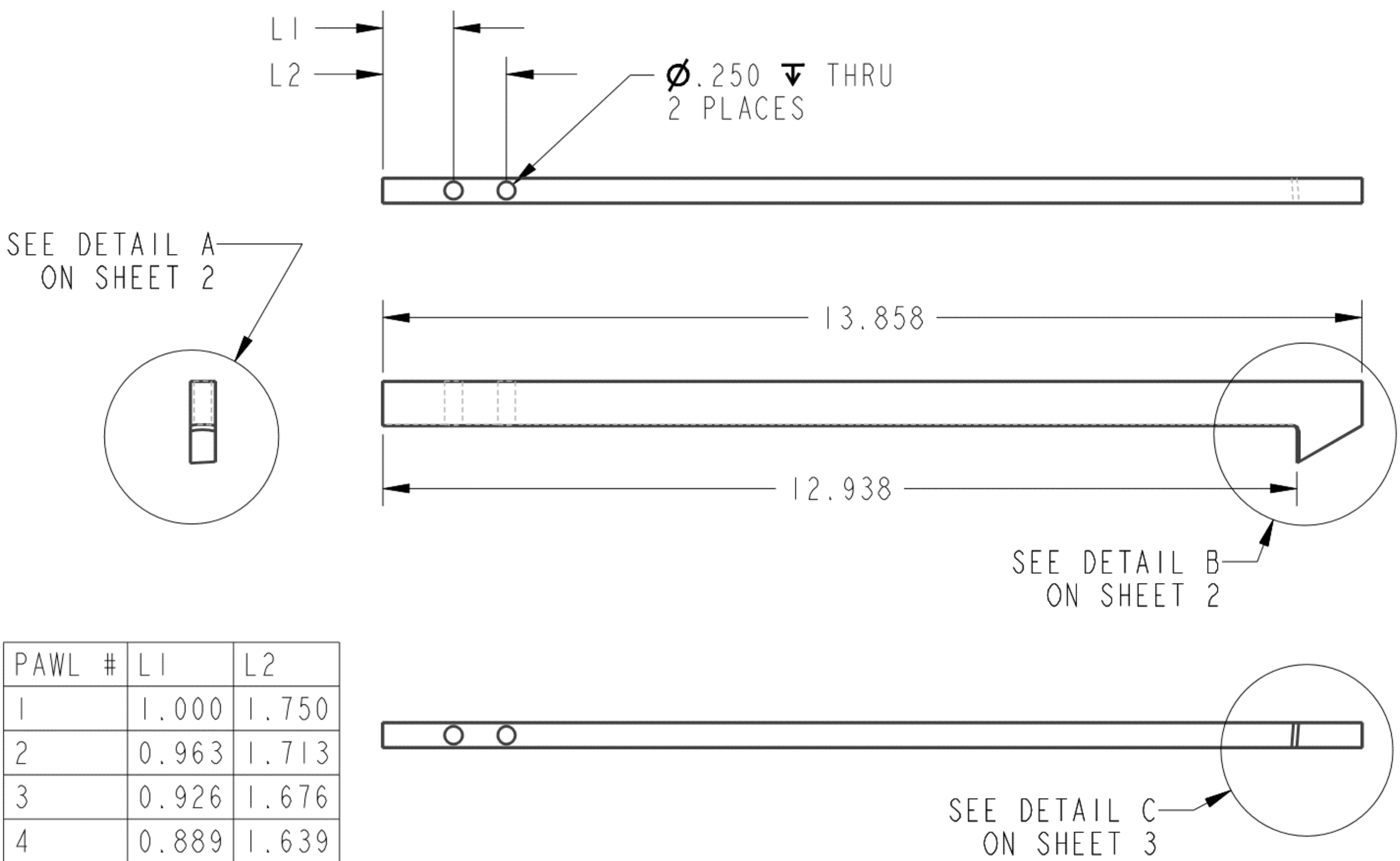


UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES	PART NAME: BACK PLATE			PROJECT NAME: LOCKING PROTOTYPE	
TOLERANCES: X.X ± 0.1, X.XX ± 0.01, X.XXX ± 0.003, ANGLES ± 0.5°	DRAWN BY: JOSH BLANK		DATE: 3/3/21	SIZE: A	MATERIAL: STEEL PLATE
	SCALE: 0.333	REV: 0	SHEET NUMBER: 1 OF 1	PART NUMBER: LP-21-001	

CLYINDER HAS 2 ROWS OF Ø.250 HOLES, AT 45° FROM EACH OTHER FOR A TOTAL OF 16 HOLES



UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES TOLERANCES: X.X ± 0.1 X.XX ± 0.01 X.XXX ± 0.003 ANGLES ± 0.5°	PART NAME: MAIN CYLINDER		PROJECT NAME: LOCKING PROTOTYPE	
	DRAWN BY: JOSH BLANK	DATE: 3/3/21	SIZE: A	MATERIAL: STEEL
	SCALE: 0.375	REV: 0	SHEET NUMBER: 1 OF 1	PART NUMBER: LP-21-002



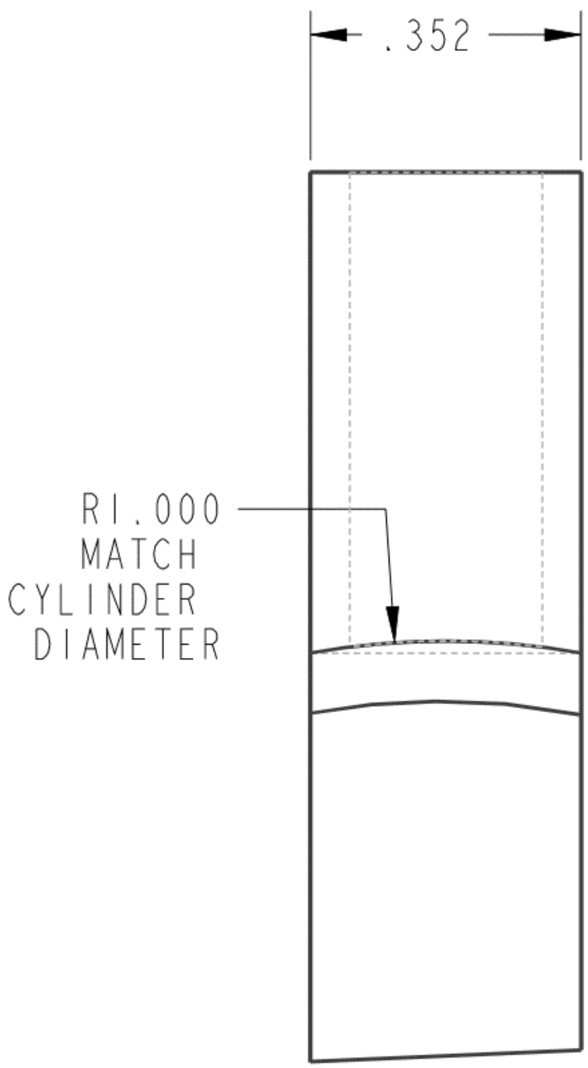
PAWL #	L1	L2
1	1.000	1.750
2	0.963	1.713
3	0.926	1.676
4	0.889	1.639
5	0.852	1.602
6	0.815	1.565
7	0.778	1.528
8	0.741	1.491

FABRICATE EIGHT PAWL ARMS WITH STAGGARED MOUNTING HOLES ACCORDING TO TABLE

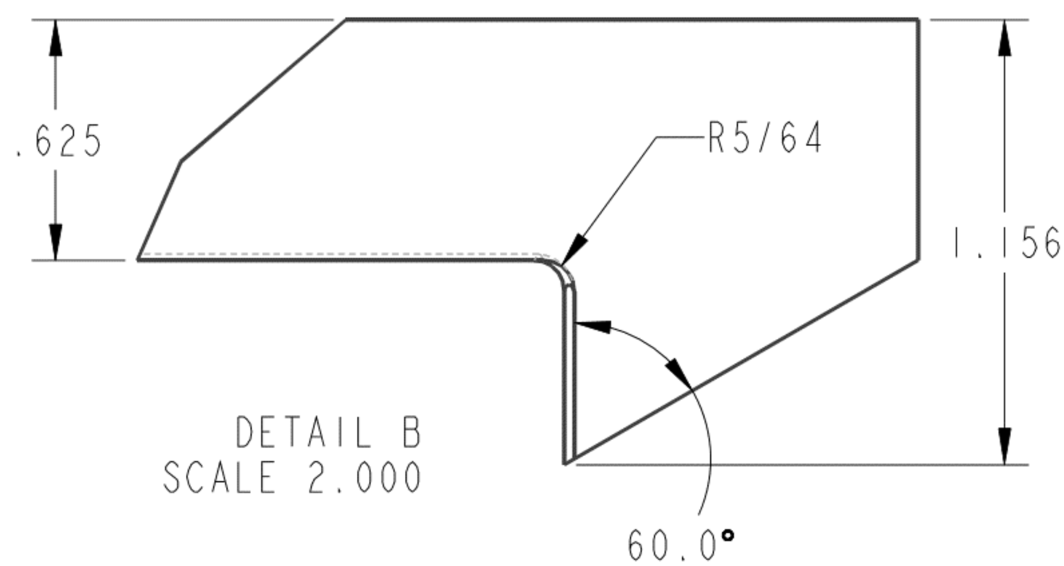
UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES

TOLERANCES:
X.X ± 0.1
X.XX ± 0.01
X.XXX ± 0.003
ANGLES ± 0.5°

PART NAME: PAWL ARM				PROJECT NAME: LOCKING PROTOTYPE	
DRAWN BY: JOSH BLANK		DATE: 3/3/21		SIZE: A	MATERIAL: STEEL
SCALE: 0.500	REV: 0	SHEET NUMBER: 1 OF 3		PART NUMBER: LP-21-003	



DETAIL A
SCALE 4.000

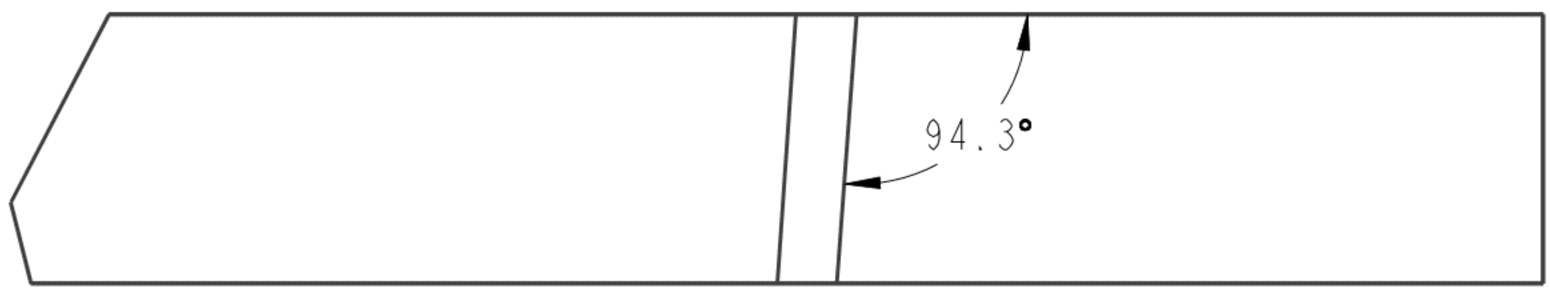


DETAIL B
SCALE 2.000

UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES

TOLERANCES:
X.X ± 0.1
X.XX ± 0.01
X.XXX ± 0.003
ANGLES ± 0.5°

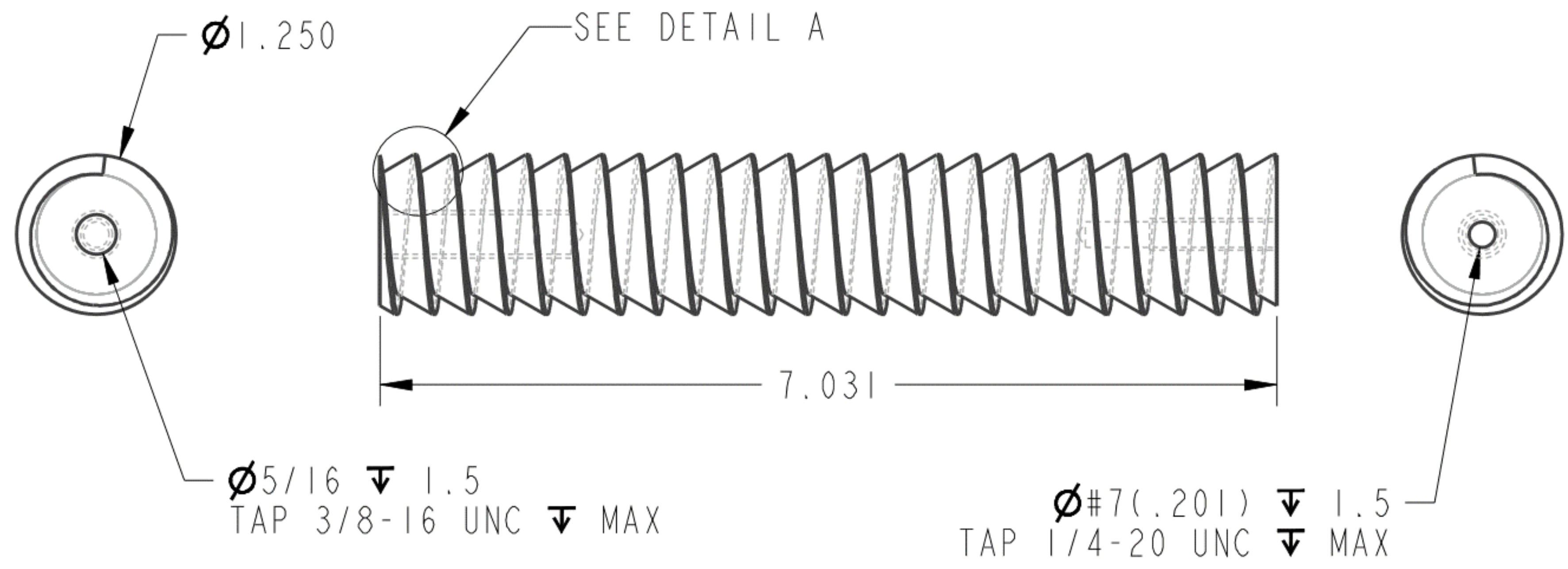
PART NAME: PAWL ARM		PROJECT NAME: LOCKING PROTOTYPE	
DRAWN BY: JOSH BLANK	DATE: 3/3/21	SIZE: A	MATERIAL: STEEL
SCALE: 0.500	REV: 0	SHEET NUMBER: 2 OF 3	PART NUMBER: LP-21-003

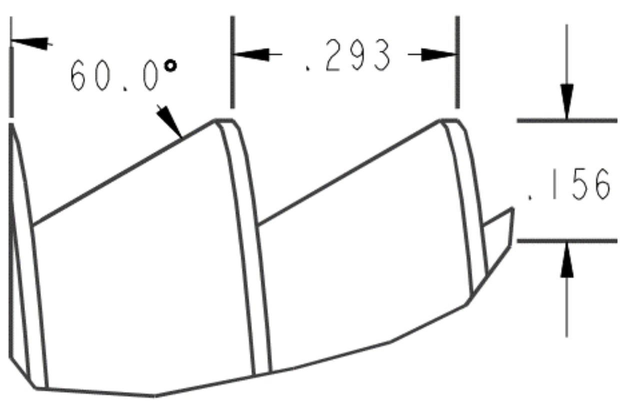


DETAIL C
SCALE 4.000

TOOTH FLAT ON PAWL ARM IS ANGLED TO MATCH THE PITCH OF THE SCREW

UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES TOLERANCES: X.X ± 0.1 X.XX ± 0.01 X.XXX ± 0.003 ANGLES ± 0.5°	PART NAME: PAWL ARM			PROJECT NAME: LOCKING PROTOTYPE	
	DRAWN BY: JOSH BLANK		DATE: 3/3/21	SIZE: A	MATERIAL: STEEL
	SCALE: 0.500	REV: 0	SHEET NUMBER: 3 OF 3	PART NUMBER: LP-21-003	

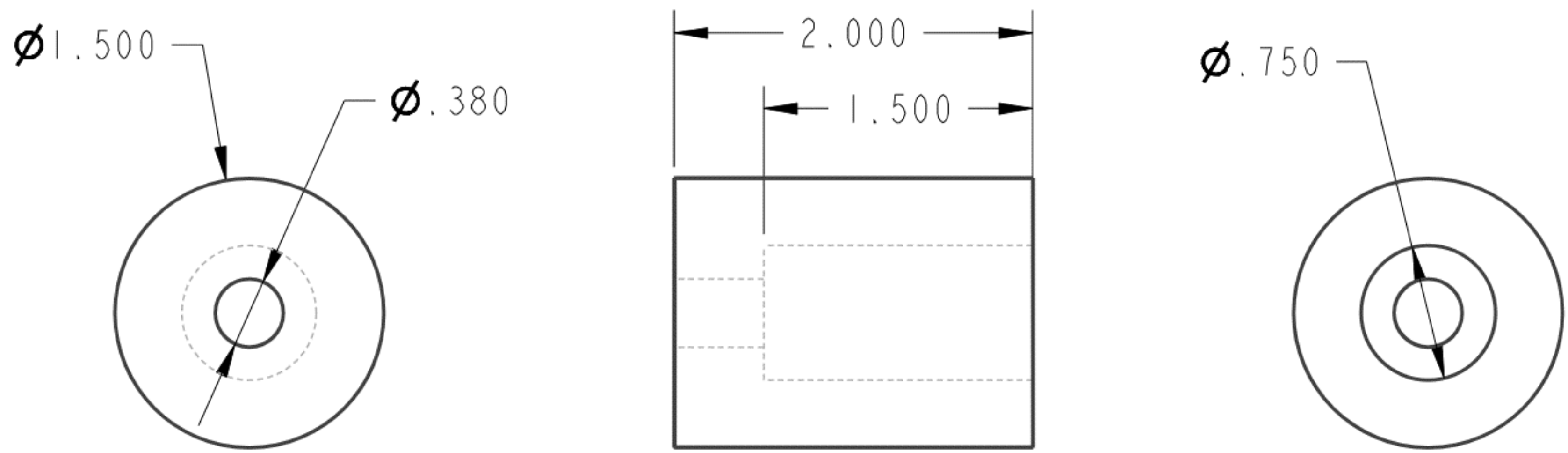




DETAIL A
SCALE 4.000

SCREW HAS A RIGHT TRIANGULAR PROFILE,
A PITCH OF 0.293 AND A DEPTH OF 0.156

UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES	PART NAME: SCREW				PROJECT NAME: LOCKING PROTOTYPE	
TOLERANCES: X.X ± 0.1 X.XX ± 0.01 X.XXX ± 0.003 ANGLES ± 0.5°	DRAWN BY: JOSH BLANK		DATE: 3/3/21		SIZE: A	MATERIAL: STEEL
	SCALE: 0.750	REV: 0	SHEET NUMBER: 1 OF 1		PART NUMBER: LP-21-004	



UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES	PART NAME: SLIDER BLOCK			PROJECT NAME: LOCKING PROTOTYPE	
TOLERANCES: X.X ± 0.1 X.XX ± 0.01 X.XXX ± 0.003 ANGLES ± 0.5°	DRAWN BY: JOSH BLANK		DATE: 3/3/21	SIZE: A	MATERIAL: STEEL
	SCALE: 1.000	REV: 0	SHEET NUMBER: 1 OF 1	PART NUMBER: LP-21-005	

VII. Bibliography

Miller, B. D., & Clark, J. E. (n.d.). Dynamic similarity and scaling for the design of dynamical legged robots. Tallahassee, FL, USA: Department of Mechanical Engineering, Florida State University.