Multi-Axis Tripod Locking Mechanism Final Design Report

Sponsored by

Really Right Stuff
your camera support experts

Team TLD

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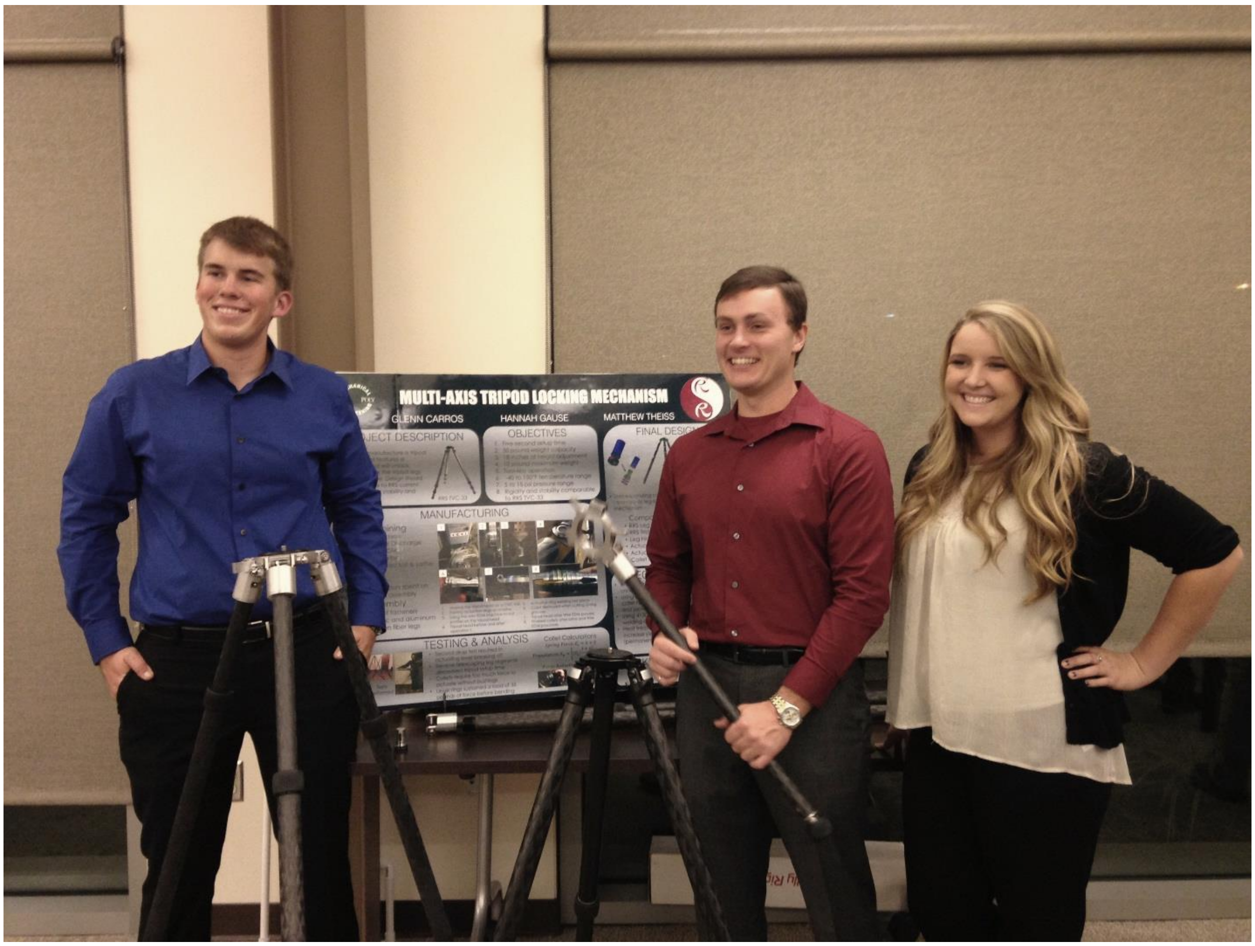

Shown above are the members of Team TLD.

From Left to Right: Glenn Carros, Matthew Theiss, and Hannah Gause

Statement of Disclaimer

Since this project is a result of a class assignment, it has been graded and accepted as fulfillment of the course requirements. Acceptance does not imply technical accuracy or reliability. Any use of information in this report is done at the risk of the user. These risks may include catastrophic failure of the device or infringement of patent or copyright laws. California Polytechnic State University at San Luis Obispo and its staff cannot be held liable for any use or misuse of the project.

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Executive Summary

Really Right Stuff, a San Luis Obispo based camera equipment manufacturer wants to produce a tripod that has the ability to unlock, extend, and lock all three tripod legs with a single user input. The project is being completed by three Mechanical Engineering students at Cal Poly, with a delivery date of December 2014.

The design created by our team is the result of extensive research into existing tripod designs, multiple concept iterations, and detailed engineering analysis. After beginning this project, each potential customer was identified and their requirements were transformed into a list of engineering specifications. These specifications were then used to create a testing plan. The purpose of the testing plan is to ensure that the mechanism designed meets all of the standards set by Really Right Stuff and their customers.

The first step in our design process involved ideation and concept selection. Each idea generated was evaluated until a final concept was chosen. After this concept was given approval by Really Right Stuff, our team completed a detailed analysis and created drawings for each part. The final design relies on a spring collet to lock and hold the tripod legs in place. The following report details our ideation and design process, as well as our plans for the manufacturing and assembly of our final prototype.

Section I - Introduction

Sponsor Background and Needs

Really Right Stuff is a San Luis Obispo based manufacturer of camera tripods, ball heads, and other camera related gear. Their products are manufactured and assembled in the greater San Luis Obispo area, and have been shipped to over 120 countries worldwide. To expand their product line, Really Right Stuff desires a tripod mechanism that can fully extend and lock all three tripod legs simultaneously with a single user input. This eliminates the need for the user to individually unlock and extend each leg segment.

Photography is either a hobby or an occupation for countless individuals all over the world. One of most useful accessories for the photographer is the tripod. Current tripods offer great adjustability, but can be time consuming to set up because they have separate locking mechanisms for each leg segment. The goal of this project is to make tripods easier to use for photographers and videographers across the globe. Our final product will make one-handed adjustment of the entire tripod possible for the user. Our goal is to design and prototype a tripod that is lightweight, easy to use, stable, and that reduces the set-up time of current tripods by 75%.

Problem Definition

The purpose of this project is to design and manufacture a working prototype of a tripod that will be able to unlock, extend and lock all of its legs at the same time. The tripod will be actuated with a single user input and be easy to use. Our design will be generated by using a process of designing, building, and testing functional prototypes; then by combining the best features into a final prototype. The final prototype will be completed by December 2014 in order to meet production requirements.

Objectives

The overall objective of team TLD is to design a tripod which is quicker and easier to set up and adjust. After discussing with Really Right Stuff their specific requirements and requests, we were able to develop a House of Quality (QFD – Quality Function Deployment) that listed customer requirements as well as engineering specifications that will be tested in our final design. The House of Quality can be found in Appendix A. Each of the customer requirements were weighted based on importance to Really Right Stuff as well as how important they are to the end users—the photographers and videographers. We then compared the customer requirements to the engineering specifications in order to determine the specific tests needed to make sure our final product fulfilled its original goals. We also compared our design specifications to those of existing similar products, discussed in **Section II** - Background, by benchmarking how well they meet our engineering requirements. Information for this

comparison was obtained from real-world experience as well as published specifications. On page one of Appendix A, the customer requirements are compared to the engineering specifications, with symbols used to indicate the relationships between them. Page two of **Appendix A** compares existing products to the customer requirements and ranks them. Page three compares the existing products to the engineering specifications and gives them target specifications. This page also ranks the existing products to the engineering specifications. The final page of **Appendix A** gives the customer requirements values of importance when compared to the various customers that we expect might interact with the tripod.

The QFD revealed that our primary requirements should be focused on making a durable design that is easy to use and has a quick setup time. Being lightweight and having a lack of maintenance were also important characteristics. When we compared our characteristics with current models we found that the Sachtler Hot Pod CF14 and Manfrotto 058B Triaut exceeded Really Right Stuff's TVC-33 in being quick to set up and having easy leg extension, but fell short when it came to being lightweight and durable. It was also helpful to find that many of our specifications have a negative correlation with tripod weight. In order to meet all of our desired specifications it may be necessary to have a primary prototype that is heavier than would be desired, but on future iterations, the tripod weight could be reduced.

The House of Quality allowed us to narrow our focus by seeing if any customer requirements were being fulfilled by multiple engineering specifications. The final specifications including tolerances, risk assessment and compliance are included in **Table 1** below. Each parameter has a corresponding requirement or target as well as a tolerance and risk factor as follows: H - High, M - Medium, and L - Low. Each engineering specification also has a compliance method label as follows: T - Testing, A - Analysis, S - Similarity to existing products, and I - Inspection.

Additional information relating to the engineering specifications is below:

- The tripod leg segments should extend under their own weight for simple setup.
- The tripod should also have the weight capacity, stability, and rigidity similar to Really Right Stuff's TVC-33.
- The mechanism designed should be able to be applied to Really Right Stuff's other tripods; however our prototype will be the size of the TVC-33.
- The design should also work in a variety of environments, being operable in extreme temperatures, extreme pressures, and even under water.
- There should be no center column so that a variety of tripod heads can be used.
- The manufacturing cost of additional components should not exceed $100.

Table 1. Tripod lock design formal engineering requirements.

Spec. #	Parameter Description	Requirement or Target	Tolerance	Risk	Compliance
1	Setup Time	5 Seconds	Maximum	H	T
2	Weight Capacity	50 Pounds	Minimum	M	A, T, S
3	Max Deployment Height	58 Inches	Minimum	L	A, T, S
4	Stored Length	26 Inches	Maximum	L	A, T, S
5	Deployed Height Adjustment	18 Inches	Minimum	M	T
6	Operating Temperature Range	-40 to 150°F	Target	M	T, S
7	Operating Pressure Range	5 to 15 PSI	Target	M	S
8	Additional Material Cost	$100	Target	H	A
9	Leg Extension From Actuation	Full Extension	Target	H	T
10	Underwater Operable	Up to 100ft	Minimum	M	A, S
11	Simple Operation	Tool-less Operation	Target	L	T
12	Durability	5 foot drop test	Minimum	M	T
13	Light Weight	10 pounds	Maximum	M	T
14	Head Acceptance Variability	No Center Column	Target	H	I
15	Standard RRS Line Capability	Uses Standard Tube Size	Target	L	I
16	Maintenance Free	5000 Actuations without Problems	Minimum	H	T
17	Rigidity and Stability	Comparable to TVC-33	Minimum	H	A, T, S

Section II - Background

Before our team was able to begin concept designs or brainstorming, we wanted to learn more about the tripods currently sold by Really Right Stuff and their competitors with features similar to the tripod we want to design.

Existing Tripod by Really Right Stuff

Really Right stuff has a carbon fiber tripod, the TVC-33, that many of our baseline specifications will be based on [5]. This tripod, shown in Figure 1, has three leg sections and can fully extend to a maximum height of 58 inches. It weighs 4.3 pounds and has a load capacity of 50 pounds. We want the rigidity, stability and load capacity of our tripod to compare to those of the TVC-33.

Figure 1. Really Right Stuff TVC – 33

Existing Tripods by Other Companies

The next tripod that we looked at was the Manfrotto 058B Triaut, **Figure 2**, a tripod that has the ability to simultaneously release of all three legs or each individual leg [4]. The claim is that within seconds the tripod legs can be extended, leveled and locked without “fiddling” with any controls. Shown in Figure 2 below, the 058B Triaut has telescoping legs and a center column with telescoping struts. After using the tripod and looking at its various components, our team determined that the tripod had multiple features that we would want to change with our tripod. The 058B Triaut was very noisy to use and made a scraping noise when extending the legs. It also had a center column that would prevent a variety of tripod heads to be used. The struts that attach the legs to the center column each have individual setscrews to lock them in position, defeating the purpose of having a simultaneous release and locking mechanism on the legs. The mechanism used also only extends and locks the first leg sections. The second sections must be unlocked and extended by hand individually. We found that it took a significant

amount of force to actuate the mechanism to release the legs, and that it would be difficult to use with one hand. This did not allow for easy adjustability of the tripod once the legs were extended. After examining the Manfrotto 058B Triaut, our team was able to better understand the scope of the requirements set.

Figure 2. Manfrotto 058B Triaut

We also researched the Manfrotto Neotec Pro Photo tripod, shown below in **Figure 3** [2]. This tripod has a mechanism that allows for quick opening and closing. To open the tripod, each leg is pulled down to the desired height and it is locked automatically without screws or knobs. To release the leg, a mechanism release button must be pushed and the leg slid back into position. The legs telescope “upside down” compared to other tripods; the largest diameter leg section is at the bottom and the other two are contained within it when collapsed. Like the Manfrotto 058B, this tripod has a center column, which reduces the variability of tripod heads you can use.

After looking at customer reviews and specs of the tripod, our team was able to understand what works well about the Neotec Pro Photo and what does not. Many customers were very satisfied with the quick speed with which they can set their tripod up and take it down. However, many complained that it was bulky and heavy when transporting. Customers were impressed with its stability, but noted that with the center column extended, much of that stability was lost. In our design, we want to use a similar mechanism to the Neotec Pro Photo,

but allow customers to extend all three legs simultaneously without needing to pull on the legs. Each leg should extend under its own weight.

Figure 3. Manfrotto Neotec Pro Photo

The final tripod that we looked at to use as reference for our design was the Sachtler Hot Pod CF 14, shown in **Figure 4** [1]. Sachtler claims the Hot Pod is "the fastest tripod in the world" and uses the position of the center column spreader to simultaneously release and lock all three tripod legs. The tripod also uses a pneumatic system to lift cameras up and down on the center column. We were able to watch a YouTube video, link included in **Appendix A**, which showed a customer using and setting up the Hot Pod [3]. To extend the legs, the user must bend down to the bottom of the center column where the spreader is located and lift the collar to unlock and release the legs. The legs do extend under their own weight and when the desired height is reached, the spreader must be pushed back down to lock it. This is inconvenient for users, especially if they need to make multiple adjustments. The continual bending down and standing up in itself is time consuming. We would avoid that by designing a tripod that has all actuation and adjustment of the tripod occurring at the top of the tripod.

From reading the few reviews that are available, the Hot Pod does work very quickly, but is geared towards videographers and therefore is a fairly bulky tripod. We would also want to design a mechanism that will work without a center column, which will allow for more variability for photographers and videographers alike.

Figure 4. Sachtler Hot Pod CF 14

Our background research allowed us to see what exists for tripod users who need quick set up time and adjustment. Through reading reviews and watching demos, we were able to determine what would help our design be ideal for all tripod users.

Patent Research

After doing patent research, our team was not able to find any patents that might impede the development of our tripod design.

Testing Research

The majority of the tests performed on the final design will be performed by team members. These tests include height, weight and setup time requirements which will not require any testing facilities. Other tests, like the temperature, rigidity and stability requirements will need to be performed using special equipment. The temperature requirement would require a testing facility with temperature capabilities from -40 to 150°F.

After further research on the stability and rigidity of tripods, Team TLD has determined that three tests could be performed to check these requirements. To test the stability of the tripod, a lever arm could be mounted to the head of the tripod and a variety weight could be applied to the lever arm at varying distances until the tripod is no longer deemed stable. The tripod would need to be tested for stability by applying a weight to the center of the tripod while at different angles. This weight would be continually increased until the legs of the tripod can no longer sufficiently support the weight applied. We would also test the tripod for torsional

stability by again attaching a lever arm to the head of the tripod and pushing on the lever arm until the tripod is forced to move because it cannot support the load torsionally.

Section III - Design Development

The method used to approach this project has followed the generic "design process" quite closely. After defining the problem, we completed our initial ideation and decided on final concept ideas. Due to the complex nature of the tripod, the project was broken up into three separate functions: the leg extension, the leg angle adjustment, and the unlocking/locking of the leg segments. Each of these critical functions was approached individually and subjected to its own design process. After evaluating each concept, we placed the top ideas in both Pugh Matrices to help generate more ideas and then decision matrices to select the final concepts.

Ideation

During the Ideation phase of the design development process, our team used brainstorming, brain writing, SCAMPER, and other methods to identify possible solutions to the problem set before us. First, we divided our task into three essential functions that the final product would have to perform. These functions were leg locking, leg extension, and leg angle adjustment. The brainstorming and brain writing exercises allowed the team to generate a great deal of ideas, building upon each other's work until we could not come up with any more. We then used SCAMPER to think about these concepts and modify them in order to come up with even more unique ideas.

Some of the ideas generated include those listed in **Figure 5**. Once we were confident that no other good ideas could be generated, we were free to move on to the concept refinement stage.

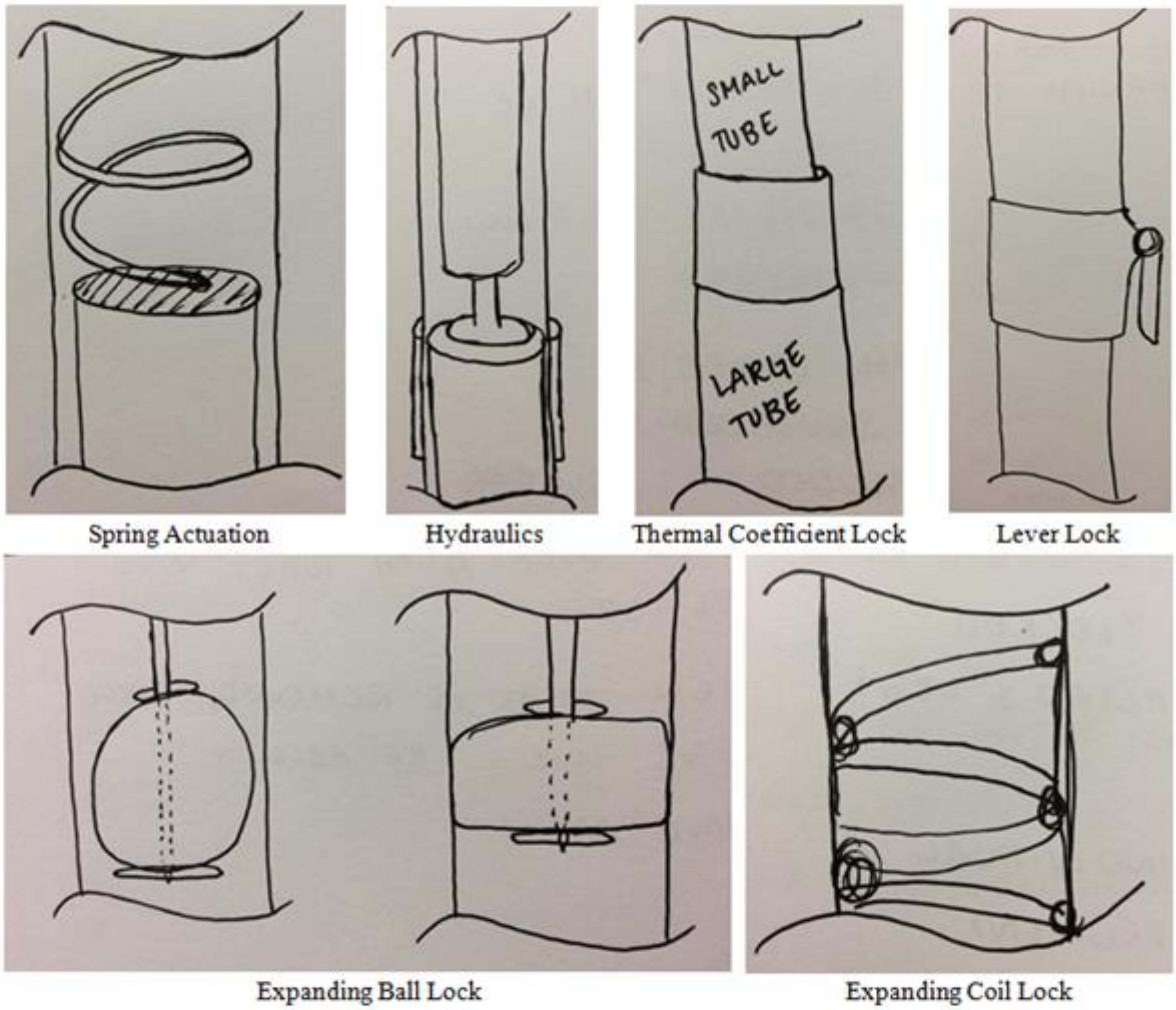


Figure 5. Concepts generated through the use of Brain writing, Brainstorming, and SCAMPER

Concept Refinement

In order to transform the many concepts generated during the ideation phase into a few superior designs, we first threw out all designs that were prohibitively expensive or dangerous to operate. This action left only a few concepts in each category to move forward with.

The next step in the concept refinement stage was to develop a Pugh Matrix for each function. The purpose of these matrices is to rate each design as better (+), worse (-), or the same (s) as a datum. These point out the shortcomings in each design and force us to think about how we can improve them. For instance, using gravity as a leg extension mechanism could be problematic because any friction in the system would make it less reliable. We corrected this potential problem by either increasing the weight of the falling leg segment or using low friction materials. All Pugh matrices can be found in **Appendix A**.

After analyzing the results of the Pugh matrices, we were able to remove designs that could not be improved to a satisfactory level, and add some new designs that we had not thought of before. These final designs were then ready to be analyzed with a decision matrix.

The tool used to select the best designs for each essential function was a decision matrix. This chart assigned each customer requirement a percentage value. The more important requirements like speed and reliability were assigned a greater percentage (20%), while requirements deemed to be less significant like material cost and reparability were assigned a lower percentage value. The final concepts were then judged on how well they met each design requirement and assigned a grade from 0-100. This grade was then multiplied by the weighting factor of the requirement and then added together with the other scores to generate a total score for each design. This score can be seen on the right hand side of the matrices. The designs with the highest scores were deemed worthy to pursue further. All decision matrices can be found in **Appendix A**.

After analyzing the decision matrices for the various functions, it is clear the dominant mechanism for adjusting the leg angle is a manual release. Its simplicity and reliability earned it a high score of 91. Gravity turned out to be the preferred leg extension mechanism because of its simplicity and low cost. Finally, two locking mechanisms scored similarly to each other. The ball compression lock uses a deforming rubber ball that expands inside the tube to lock the tube in place. The one-way lock uses friction and statics to lock the tubes from retracting, but still allows them to expand from either unlocking the mechanism or pulling on the lower leg segment. Upon further examination, we can see that each of the ideas selected has a good chance of fulfilling the engineering requirements outlined in **Table 1.**

Top Concepts

The concept chosen for the extension of the legs is a gravity-driven extension system. This is not only the most cost effective and lightest method of deployment, but it also does not wear out and can be applied to other sizes of tripods due to its simplicity. When combined with our proposed methods to lock/unlock the leg sections, there will be no force acting against gravity when in the unlocked position, allowing the legs to fully extend under their own weight. Even when the legs are deployed at an angle, they still deploy due to the force of gravity alone. This was tested experimentally using leg sections provided by Really Right Stuff.

When evaluating the various methods for spreading the legs of the tripod it was determined that, the best method is to simply adjust the leg angle manually. Again, this is the lightest and most cost effective solution, as it has no added components. While this process is slightly slower than the other methods, the other methods add restrictions to the types of tripod heads that can be used, are not as reliable, and/or add complexity to the system that does not outweigh the benefit.

The main component of the tripod design is the locking/unlocking mechanism for the leg segments. Using our decision matrix, there were two designs that came out on top. A one-way locking mechanism, **Figure 6** below, and a compression ball system, **Figure 7** below. Note that the two figures are to convey general design, and not specific details of the concept. From this point forward, the one-way mechanism will be our primary design, but if it is found to be undesirable for a final prototype, our secondary design of a compression ball system will be utilized.

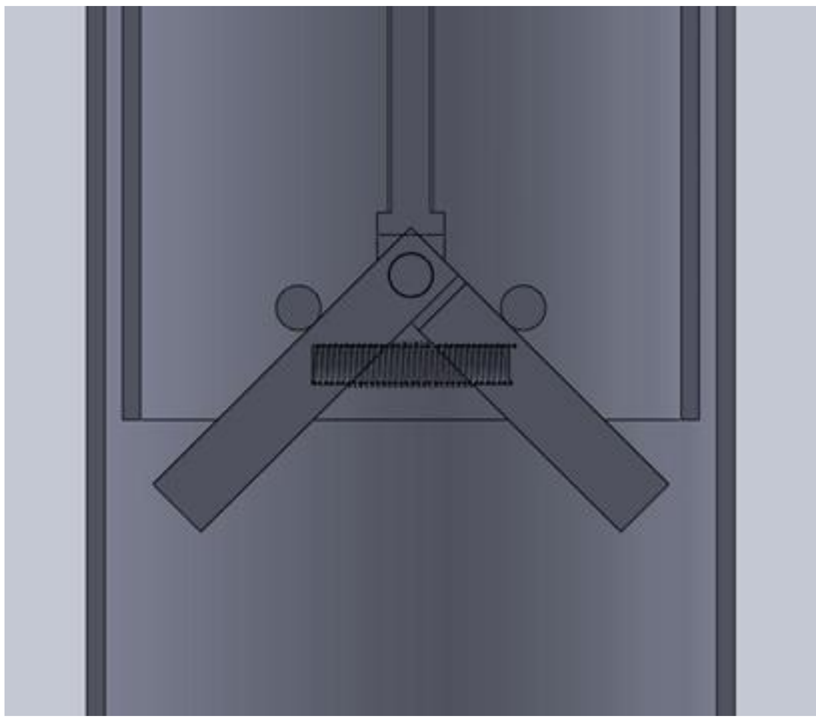


Figure 6. One-Way Mechanism Sectioned Model

The one way mechanism will either have a compression spring (as shown in **Figure 6**) or a torsion spring that will hold the locking mechanism open against the inside of the tripod tube, preventing the tripod from being collapsed. While the legs would not extend due to gravity in the locked position, they would be able to be manually pulled out and could not be collapsed unless the mechanism is released. In **Figure 6**, the one-way lock mechanism is in the unlocked or released position. When the release is actuated up near the head of the tripod, the linkage is pulled, forcing the locking mechanism and spring to compress, allowing motion of the leg segment in either direction as well as leg extension under gravity. In order to check that this method is feasible we wanted to check to see if springs were available for our design. The spring needs to supply enough force on the locking mechanism to hold up a maximum of two leg segments. Using the approximate weights of current leg segments of the Really Right Stuff TVC-33 and a factor of safety, the modeled maximum load seen would be 1.3 lbs. We used a coefficient of static friction for rubber against metal because rubber against carbon fiber could

not be found. A calculated 1.875 in-lb would be required from a 270 degree torsional spring, or 3.714 in-lb if using a compression spring at a half inch of deflection. Both these spring requirements, and stronger are easily found at McMaster-Carr. **Appendix B** shows these calculations, with a recommended spring for each method.

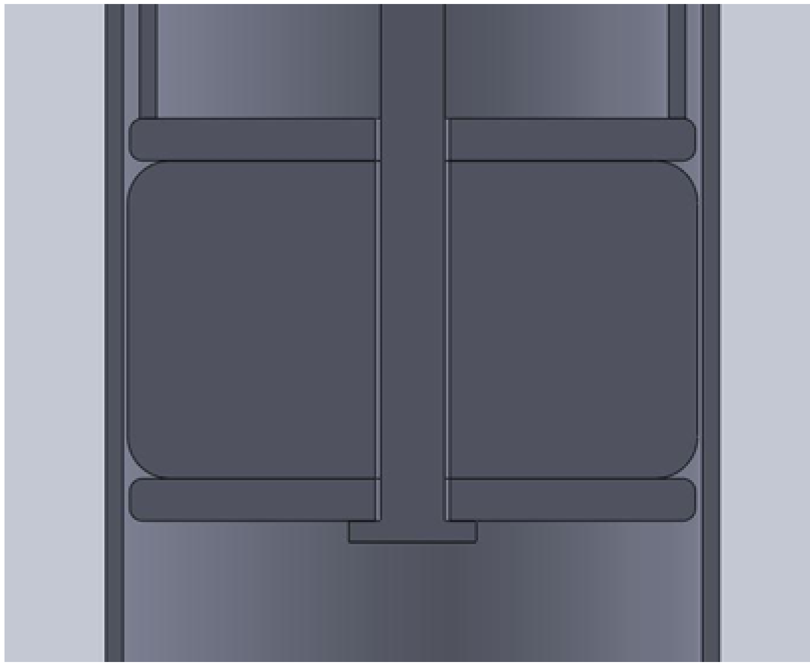


Figure 7. Compression Ball Sectioned Model

For the compression ball method of locking the tripod legs, there would be a pliable rubber ball, or cylinder (for added surface area between the cylinder and leg section) sandwiched between two compression plates. While in the unlocked position, as shown in **Figure 7** above, the rubber cylinder is not compressed and has space so that it can move freely up and down inside of the leg segment. This method has more potential for unwanted contact and friction between the locking mechanism and the inside of the leg segment wall, one of the reasons the one-way lock is the primary design. When in the locked position, the cylinder deforms and compresses, forming a friction hold against the inside of the leg segment.

Reiteration of Concept Design

After presenting our top concepts to Really Right Stuff, a few potential concerns were raised about the top two leg locking concepts. The principals liked the one-way mechanism, but were concerned about its joint stability when forces are applied perpendicular to its locking arms. The ball compression mechanism was better suited to handle forces in any direction, but the soft material was deemed to be too unpredictable to continue. It was decided to go back and redesign the mechanism. The idea of a spring collet was suggested as a compromise between

the two designs. After some discussion and preliminary calculations, we decided that this concept was worth pursuing.

Another concern raised during the meeting was that the idea of using a reverse stacking leg arrangement would drastically reduce the stability of the tripod because of the smaller moment arm at the tripod head. Reverse stacking means that the smaller tripod leg section is at the top, and larger segments extend down from it. After leaving the meeting, our team performed deflection calculations, found in **Appendix B**, to determine the difference in deflection of different sized tubes. We found that in smaller lengths, the deflection and the deflection angle of the tubes does not vary much between the different sizes. After doing these preliminary calculations, we took the tripod and leg segments provided by Really Right Stuff and performed bending tests on them. The results of these tests can be found in **Appendix B**.

Both the calculations and the tests showed that there was a slight decrease in the rigidity of a leg segment when reverse-stacked, but it was not enough to significantly affect the tripod's stability. By taking the results of these tests to Really Right Stuff, we were able to get approval to use a reverse telescoping mechanism. During the same meeting, Really Right Stuff also narrowed the project scope and told us to concentrate on only releasing the upper leg segment and generating a plan to expand the mechanism to lower leg segments in the future.

Section IV - Final Design

This section will explain the details of our final design and why we chose to include them. There were many changes made during the design process in order to create the best tripod possible. The final design includes a spring collet locking mechanism that expands to lock two tube segments together and a custom tripod head that allows one-handed operation of the locking mechanisms. The overall tripod will be similar in size and shape to the TVC – 33.

Leg Locking Mechanism

After meeting with Really Right Stuff and receiving the suggestion of using a spring collet type locking mechanism, our team returned to the design phase and came up with several designs for this piece. The final iteration of our spring collet locking system has five main features: the cutout design, the compression angle, the rubber gripping surface, the cup, and the supporting bearings. Each of these features can be seen in **Figure 8**.

The first feature of the spring collet that makes it ideal for this application is the teardrop cutout shape. This type of cutout is beneficial for two reasons. First, the shape of the cutout allows the collet to expand more than a standard collet. The bulge reduces the cross sectional area of each tine, which makes the end of the collet much easier to compress. Second, the smooth profile reduces any stress concentrations that would occur if the cutout had any sharp edges. The design chosen will make the collet have a longer fatigue life.

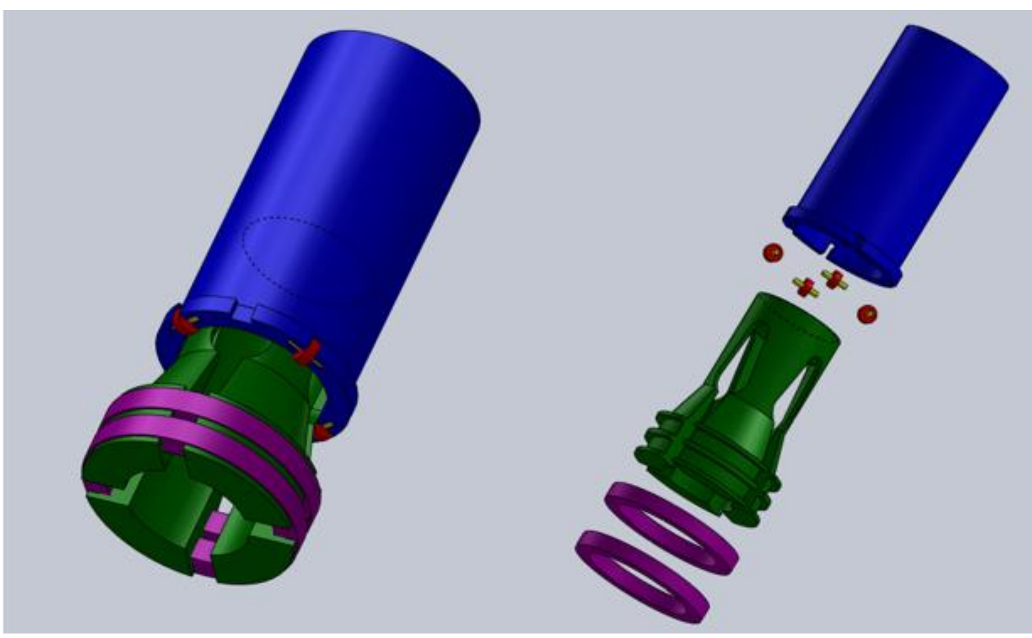


Figure 8. Collet assembly

The second set of features include the collet compression angle, the rubber gripping surfaces, the cup, and the supporting bearings. Each one of these features was designed to precisely

control how the collet compresses and limit how much force is required to compress the collet. The compression angle is set at 17 degrees in order to provide the best balance between the force required to actuate the collet and the length of pull required to fully compress the collet. The rubber gripping surfaces increase the amount of friction applied by the collet so that it can support more weight. Finally, the cup and bearings are both designed to guide the collet during its compression and reduce the amount of friction the user must overcome to actuate the mechanism and unlock the tripod.

Figure 9. Detailed locking assembly showing internal mechanism

Figure 9 shows the collet assembly in detail. When the rod is pulled up, it draws the collet into the cup and the bearings roll against the compression angle. This decreases the diameter of the rubber gripping surfaces and unlocks the tripod leg, allowing the leg height to be freely adjusted. All force calculations can be found in **Appendix B.**

Head Design

Overall Concept

The second largest design component of our tripod is the head assembly, which can be seen in **Figure 10**. The goal of the tripod head is to convert the linear motion required to unlock the collet into a rotating motion that is accessible to the user. The tripod head also needs to actuate all three legs at once. The hardest part about this design is the fact that the tripod legs are going to be used in many different positions, and the unlocking mechanism needs to work

in all possible situations. This means that the actuation motion cannot be linear and must be about the hinge axis of the tripod leg. If the motion is not along the axis of the hinge then it will only work at certain angles. The next part of the tripod head design is the ability to work with many different head plates. In order to comply with the variety of camera holders that Really Right Stuff and other companies make, the design of the head was modeled after the current TVC – 33 head. The prototype head (shown in green in **Figure 10**) was made slightly taller in order to accommodate our actuation ring (blue). Finally, we wanted to make our design it comfortable to use for left handed or right handed photographers. In order to accomplish this goal, some of the parts can be mounted in the opposite orientation to make the locking mechanism easier to use with your left hand.

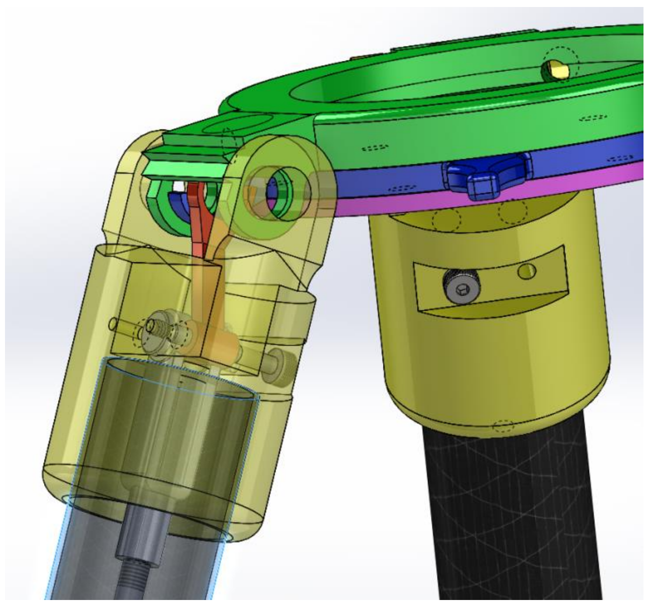


Figure 10. Detailed head assembly showing internal mechanism

Actuation Ring Design

The actuation ring is the component of the tripod that the user will actually touch, and transfers the users input motion into the linear pull required to unlock the collet. The ring itself (blue) has three levers spaced between the hinges of the tripod which can be actuated by the user, depending on which side of the tripod they are on. These levers are also ergonomically designed to be comfortably actuated in either the clockwise or count-clockwise direction. The actuation ring also has three semi-circular actuators which have a radius slightly larger than that of the hinge pin. These parts sit in cutouts between where the leg attaches. The actuation ring rotates about the head of the tripod, mounted from the bottom. It is secured using a retainer plate (purple in color) which screws directly onto the head.

Actuation Lever Design

The actuation lever (red in color) is the piece that takes the user's rotational input and translates it into the linear pull the collet requires. It also has a semicircular shape on the top which sits around the hinge pin. The actuation lever is a triangular component, so when the actuation ring pushes against the top, it rotates around one of its bottom corners and pulls up on the rod end, rod, and ultimately the collet. The actuation lever will be mounted on the tripod leg hinge, so that it can rotate freely with the leg. There are two locations for the lever to be installed so that either right hand or left hand users can easily actuate the tripod. The dimensions of the lever are very important and help to reduce the force required to actuate the locking mechanism. The ratio of the lengths of each lever arm (pivot to rod vs. pivot to hinge) is what reduces the force. Calculations for force required can be found in **Appendix B**.

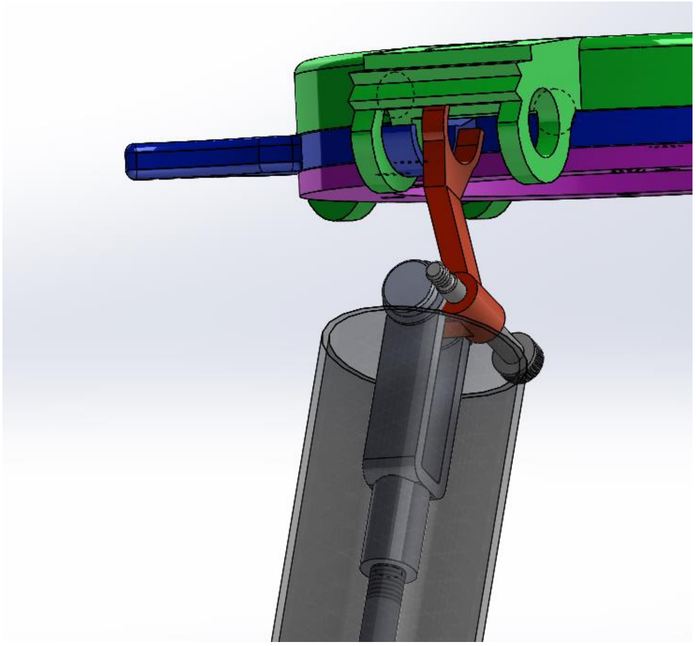


Figure 11. Close up on actuator ring and lever

Final Design Addendum

Our final prototype differed from our original design in a few different areas. One of the biggest differences was the actuation ring. In our original designs the thumb levers were small so that it could be made out of a single piece of aluminum. Concerns were raised about the comfort of this design, so to make it more comfortable for the end user we made the thumb levers larger and specified that they should be welded onto the ring. The original design also had a three sided U-shaped interface with the flipper mechanism, but in order to increase the strength of the activation ring it was changed to be an oval-shaped interface. Because the oval shaped interfaces interfered with the original Tripod Head design, new pockets were machined out of the head to accommodate for the ring's motion. A detailed view of this redesigned mechanism is included in **Figure 12**.

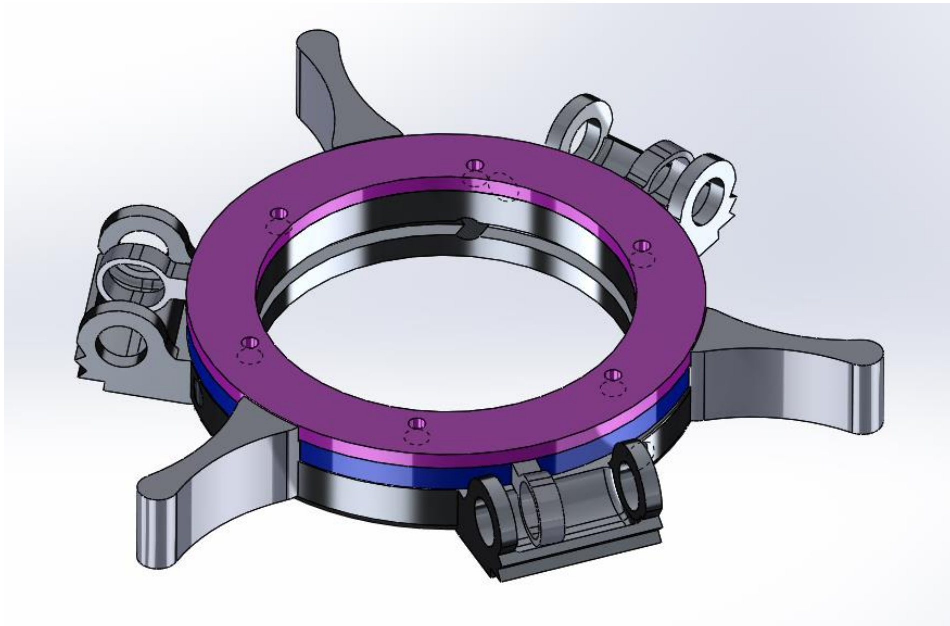


Figure 12. Redesigned tripod head mechanism

After completing manufacturing and assembly of the final tripod and locking mechanism, the tripod's collet holder required a redesign. When operating the tripod as originally designed, the bushings that were used to aid in the operation of the collet would fall out and bind the locking mechanism. This occurred because the mechanism was able to travel further than intended and therefore no longer captured the bushings. In order to correct this issue, the collet holder was redesigned so that the bushings could be fully captured against the collet. The new design calls for the bushings to be mounted on a ring that will snap into a groove cut along the inside surface of the collet holder. The redesigned collet holder is shown below in **Figure 13**, however it was unable to be manufactured due to constraints on time and material.

Figure 13. Redesigned collet holder

Overall Tripod Functionality

We have designed our tripod and tripod locking mechanism to be used in conjunction with stock leg sizes from Really Right Stuff. Below, in **Figure 14**, is a layout of the legs, labeled with numbered squares detailed below:

1	Standard Really Right Stuff leg segments
2	Female Twist Lock
3	Leg sleeves
4	Male Twist Lock
5	Foot adapter
6	Foot for tripod leg
7	Clevis Rod End
8	Rod
9	Collet

Figure 14. Leg components

Cost Analysis

The following is a list of all materials needed to build a prototype and their respective costs. Each part on the list has a corresponding part number that is used to identify the part drawings found in

Appendix D. The bill of materials is split up into two sections: the materials that will be requested from Really Right Stuff, and materials that will be purchased and manufactured by the team.

Really Right Stuff Materials

We are asking Really Right Stuff to provide our team with the following materials in order to complete the final prototype (**Table 2**). When designing the tripod, our team tried to use as many standard TVC – 33 parts as possible. The purpose of this method was to keep manufacturing costs as low as possible and simplify the overall design. Because we are being provided with these parts, we do not know their actual costs. Because we are able to use these parts from Really Right Stuff, we will be able to create a more cost effective prototype.

Table 2. Materials requested from Really Right Stuff

Part Number	Quantity	Description	Source	Prototype Price	Mass Production Price
TA-3-FB	3	Series 2 and 3 Foot	Standard Part	$8.00	Proprietary Information
L.Lg.306	3	TVC-33 Upper Leg Segment	Standard Part	Proprietary Information	Proprietary Information
L.Lg.206	3	TVC-33 Middle Leg Segment	Standard Part	Proprietary Information	Proprietary Information
L.Lg.106	3	TVC-33 Lower Leg Segment	Standard Part	Proprietary Information	Proprietary Information
Unknown	3	TVC-33 Upper Leg Lock	Standard Part	Proprietary Information	Proprietary Information
Unknown	3	TVC-33 Lower Leg Lock	Standard Part	Proprietary Information	Proprietary Information
Unknown	3	Tripod Leg Hinge Pin	Standard Part	Proprietary Information	Proprietary Information
Unknown	6	Tripod Leg Hinge Washers	Standard Part	Proprietary Information	Proprietary Information
Unknown	6	Tripod Leg Hinge Bushings	Standard Part	Proprietary Information	Proprietary Information
Unknown	1	Spirit Level	Standard Part	Proprietary Information	Proprietary Information
SureGrip™ Apex Lock Components					
Unknown	*1*	*Ring*	*Standard Part*	*Proprietary Information*	*Proprietary Information*
Unknown	*1*	*Pin*	*Standard Part*	*Proprietary Information*	*Proprietary Information*
Unknown	*3*	*Set Screws*	*RRS Standard Part*	*Proprietary Information*	*Proprietary Information*

Materials Purchased by Team

The following items are needed in order to complete the prototype tripod (**Table 3**). In order to accurately price the material needed, we looked at numerous sources and chose the store that had the supplies in stock and that could ship the material to us the fastest. During mass production of this tripod, we would be able to reduce these costs significantly by ordering the material in bulk and reducing waste. We believe that the $250.70 mass production price can be reduced significantly by utilizing these bulk material purchases. Sources like McMaster Carr are much more expensive than stores that sell bulk raw material, however McMaster Carr provides precisely the amount of material needed for the production of one or two prototypes.

Table 3. Materials to be purchased by the team

Part Number	Quantity	Description	Source	Prototype Price	Mass Production Price
C-001 (8364T23)	3	Stainless Steel Collet	McMaster Carr	$98.08	$49.04
4061T236	6	Rubber O-Ring	McMaster Carr	$7.99	$0.96
C-002 (9038K18)	3	Aluminum Collet Cup	McMaster Carr	$31.33	$15.67
R0	12	Miniature Ball Bearing	ISC Miniature Ball Bearings	$24.00	$24
8908K48	12	Ball Bearing Shaft	McMaster Carr	$12.00	$0.03
8974K21	3	Aluminum Rod	McMaster Carr	$5.19	$5.19
90480A195	6	10-32 Locking Nut Zinc Coated Steel	McMaster Carr	$1.71	$0.10
2449K11	3	Rod End (Clevis Type)	McMaster Carr	$3.25	$3.25
C-003 (9038K21)	3	Tripod Foot Adapter	McMaster Carr	$43.30	$3.61
C-004 (9038K22)	3	Tripod Leg Hinge	McMaster Carr	$55.62	$41.72
97345A106	6	Tripod Leg Hinge Screws	McMaster Carr	$47.88	$47.88
90107A003	27	Tripod Leg Hinge Screw Washers	McMaster Carr	$2.64	$0.72
C-005 (8975K574)	1	Tripod Head	McMaster Carr	$92.63	$30.87
C-006 (8975K574)	1	Tripod Head Ring	McMaster Carr	$0.00 (RRS)	$18.56
C-007 (8975K574)	1	Tripod Head Plate	McMaster Carr	$0.00 (RRS)	$4.63
90666A004	6	Tripod Head Screws	McMaster Carr	$7.46	$4.48
Total Cost				$433.18	$250.70

Machining Costs

The following is an analysis of the total cost of machining the tripod prototypes (**Table 4**). In order to accurately price these costs, the amount of time taken to machine each part was considered as well as the quantity of that part to be machined. The cost per hour was estimated based on our knowledge of average rates for various machinists based on their skill level and what machine they are using. These could then be used to find the estimate cost for a complete tripod to be manufactured. These estimated prototype machining costs were absorbed by the team and are not charged to Really Right Stuff.

Table 4. Estimated cost for a complete tripod to be manufactured.

Part	Machine Type	Machine Time (min)	Quantity	Cost Per Hour ($)	Total Cost ($)
Foot	CNC Lathe	7	6	$60.00	$42.00
	Manual Mill	10	6	$30.00	$30.00
	Hand Tap	2	6	$20.00	$4.00
Collet Holder	CNC Lathe	10	6	$60.00	$60.00
	CNC Mill	3	6	$60.00	$18.00
Collet	CNC Lathe	17	6	$60.00	$102.00
	Manual Lathe	10	6	$30.00	$30.00
	Wire EDM	30	4	$100.00	$200.00
Bushings	Manual Lathe	3	24	$30.00	$36.00
Hinge	CNC Mill	12	6	$60.00	$72.00
	Drill Press	2.5	6	$20.00	$5.00
Flipper	CNC Mill	12	6	$60.00	$72.00
Apex (Head)	CNC Mill	50	3	$60.00	$150.00
	Manual Lathe	10	3	$30.00	$15.00
	Wire EDM	60	3	$100.00	$300.00
Securing Plate	CNC Mill	10	1	$60.00	$10.00
	Manual Lathe	15	2	$30.00	$15.00
Actuation Ring	CNC Mill	10	1	$60.00	$10.00
	Manual Lathe	15	2	$30.00	$15.00
	Wire EDM	40	1	$100.00	$66.67
	TIG Welding	30	2	$80.00	$80.00
Shoulder Bolt	CNC Lathe	3	6	$60.00	$18.00
Total Cost					**$1,350.67**

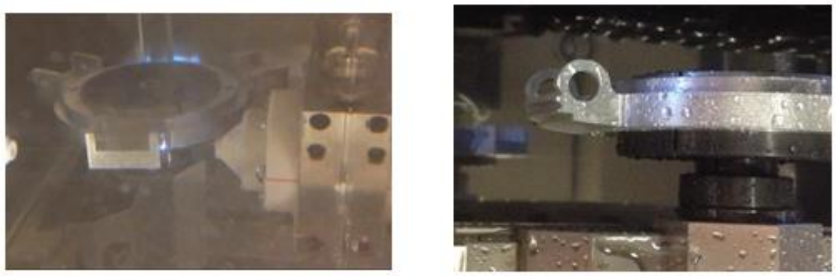
Section V - Product Realization

Manufacturing

The manufacturing process for our prototype took a total of seven weeks. We utilized a variety of different tools present in the ME Student Shops, the IME Advanced Technologies shop, and at a local business. These tools ranged from simple drills and sanders to CNC Lathes, Mills, and Wire EDM Machines. The simplest part we made was the foot holder, which was turned down on a lathe, drilled, and then milled with a 4th axis. The rolling bushings used in the Collet Holder Assembly were made by drilling a hole through the middle and then cutting them to length, but they were so small that even these two processes were difficult. Some of our more complex pieces had up to four different operations, with the majority requiring the use of CNC machines. The most notable piece that we machined was the tripod head. It not only required a complex CNC Milling program (**Figure 15**), but we also had to make a special tool to hold the head in the Wire EDM machine, shown in **Figure 16**. In order to make this tool, we ordered an expanding collet, but because it did not come in the exact size we needed, we procured a larger size and turned down its diameter on a lathe. We also machined a pair of soft jaws to hold the six inch round stock used to make the tripod heads, actuation rings, and securing plates.

Cutting the 6” Round Stock | Tripod head before and after milling operation | Machining the tripod head in a HAAS CNC Mill

Figure 15. Various processes used to machine the tripod head



Tripod head on custom fixture

Tripod head after being cut in the Wire EDM during wire EDM process

Figure 16. Machining the tripod head in the Wire EDM using custom fixture

The last part of complex manufacturing was using the CNC Lathe to create custom parts like the collets, collet holders, and hinge bolts from round stock. Some of these processes are documented in **Figure 17.** To complete the rest of our parts we used other mill and lathe processes (both CNC and manual), a drill press, a wire EDM machine, horizontal band saws, a bench grinder, bench sander and various hand tools. One of our components required welding, but due to its small size, complex geometry, and aluminum composition, we asked Kevin Williams, the welding professor at Cal Poly, to TIG weld it for us (**Figure 18**). Despite each component's tight tolerances and complex geometry, we were able to make every part needed for our final prototypes with the resources available to us.

CNC machined Collet profile

Parting Actuation Rings on manual lathe

Creating clearance grooves on hinge bolts with CNC lathe

Figure 17. Using CNC and manual lathes to create custom parts

Actuation Ring parts ready to weld

Welded Actuation Ring

Figure 18. Actuation Ring processes

If another prototype was to be manufactured, we would recommend several changes to the design and manufacturing processes. First, we would have each aluminum component anodized for strength and durability. The hard layer of aluminum oxide would help the hinges and actuation ring interface slide past each other without gouging. It would also protect the soft aluminum from premature wear. The second improvement we would recommend is to make the actuation ring out of steel in order to improve its strength and weldability. The aluminum pieces proved to be too hard for even a skilled welder to assemble properly, however steel pieces would allow even an inexperienced welder to successfully attach them. Another change would be to manufacture the collet holders according to the new specifications with the internal groove. This change was necessary in order to prevent the roller bushings from falling out of their grooves due to excess actuation movement. Finally, the collets should either undergo a heat treating process or be made out of a different material to avoid plastic deformation. Our analysis suggested that the current material would not have any problems with this type of deformation, however the recommended changes would eliminate this problem in future generation collets.

Assembly

After completing the manufacturing process, two prototype tripods were assembled. One to test the complete functionality of our system, and the second as a mock-up of a complete tripod with the original twist locks in place. Unfortunately, the roller bushings in the collet holder assembly fell out of their grooves and jammed the locking mechanism. After observing

this phenomenon, we used various short term retention methods such as epoxy and epoxy putty to hold the bushings in place. None of these methods were successful for very long, and the bushings came out of the collet holder after 1-3 actuations every time. In order to correct this problem, we redesigned the collet holder but due to lack of material and time the new components were not able to be manufactured and installed.

We used standard twist locks in the mock-up tripod so that we could test the function of the actuation mechanism without the collet locks installed. In order to put the proper tension on the mechanism, springs were installed where the collets would usually be. The mock-up tripod allowed us to show how the reverse telescoping leg design facilitated the easy setup and adjustment of the tripod, as well as how the actuation system would work on a complete prototype. The second tripod was partially disassembled to show how the internal components of our collet locking mechanism would function if it was complete. With these two models we were able to complete many of our tests and demonstrate the inner workings of the tripod to faculty and the public at the project expo.

Section VI - Design Verification Plan

The following is a discussion of the design verification plan, a detailed set of testing designed to verify the tripod mechanism's performance. These experiments are designed to see how well the final tripod meets the original design specifications listed in **Table 1**. The DVP&R, found in **Appendix A**, summarizes the tests to be carried out by the team.

Comparison Tests

Because Really Right Stuff based many of its requirements on the TVC–33, many of the tests will directly compare our tripod to the TVC – 33. These tests are as follows:

1. Measurement – The team will measure the stored height, where all three legs are collapsed, the maximum height, when all three legs are extended fully, and the range of adjustment using the locking mechanisms.
2. Stability & Rigidity – The stability and rigidity of the TVC – 33 will need to be found using preliminary tests and then the same tests will be carried out on our prototype tripod to ensure that they are comparable.
3. Weight – The tripod will be weighed and compared to the TVC – 33 to ensure that the prototype is less than 150% of its weight.

General Operation Tests

Some of the tests to be carried out are used to ensure that the mechanism will hold up to everyday use and is simple to use. These tests are as follows:

1. Weight Capacity – The tripod will be set up and the team will ensure the tripod can hold a weight of at least 50 pounds. After surpassing 50 pounds, the team will continue adding weight to the tripod until the locking mechanism fails. This will provide a maximum load rating for the new tripod.
2. Longevity – The tripod will be sent through the set up and teardown process at least 5000 cycles and the weight capacity will be tested after every 200 cycles.
3. Timing – The team will have at least 20 different people set up both the TVC – 33 and the prototype tripod five times and average the times. The prototype will pass if it is able to be set up three times as fast as the TVC – 33.
4. Drop Test – The team will drop the tripod from a height of 5 feet in various orientations and ensure that the tripod is still operable after each drop.

Temperature Test

One of the specifications of the tripod is to have it operate at very hot and very cold temperatures. All of the parts have the ability to withstand these temperatures, however without having a working tripod, the usability of the mechanism at the temperature cannot be verified. The team does not believe that the materials used have a large enough thermal expansion rate to be affected by extreme temperatures.

Underwater Test

We have ensured that the tripod and the mechanism are manufactured out of materials that can be operated underwater. However, we cannot test the tripod at a depth of 100 feet and will not be completing this test.

Results

In order to thoroughly test our prototype, we conducted a series of tests and measurements as planned in the Design Verification Plan and Results (DVP&R). This document is included in **Appendix A** for reference. The most basic tests included measuring the weight as well as both the collapsed and extended dimensions of the tripod and comparing them to those of the TVC-33 provided by Really Right Stuff. The next tests measured torsional rigidity and stability by using a cantilevered arm to exaggerate the forces required to twist the tripod in place or tip it over. The test fixture used in these tests is depicted below in **Figure 19**. Because our tripod locking mechanism was not functional for testing, the longevity, underwater, setup time, leg extension, and drop tests were conducted in order to test the validity of the actuation mechanism and reverse telescoping leg designs only. Our prototype passed these tests with ease. The maximum weight capacity, high temperature and low temperature tests were designed to test the locking mechanism itself, so these tests were deemed unnecessary.

Figure 19. Test fixture used to test the torsional rigidity and stability of tripod

Overall, our tripod performed similarly to the TVC-33 in all size and weight tests, meeting our original goals in these categories. In addition, the reverse telescoping leg design did not affect the torsional or vertical rigidity of the tripod, and the stability of our tripod was equal to that of the TVC-33 in all aspects. More importantly, while the locking mechanism failed to function, the other design improvements reduced tripod set up time by 40% among the users we tested. While this is not as fast as the original goal, it still represents a significant improvement over the current standard.

Section VII - Project Management Plan

In order to complete this project within the allotted time period, the various responsibilities needed to be divided up between team members. Hannah Gause is our team Communications Officer. She will be in charge of all communication with Really Right Stuff and the Cal Poly senior project advisor. Matthew Theiss is the team treasurer. He will be responsible acquiring the materials for the prototype and managing team expenses. In addition, he will be responsible for the team calendar, which will keep track of all important dates and deadlines. Some of the important dates are shown below. Glenn Carros is the team Machine Shop Tech, and is responsible for all prototype manufacturing and our database of SolidWorks models.

There are certain milestones that we had planned for the team to accomplish throughout the course of this project. These milestones are tasks that are associated with involvement of the sponsor. The list of these milestones and their corresponding due dates can be seen in **Table 5**. Once the design had been approved, the project moved into the production stage, which involved the construction of a prototype. The Design Expo was on November 20th, where the project was presented to school faculty and the public. A final report including a detailed process summary of the project was submitted to Really Right Stuff on December 5th.

Table 5. Summary of timeline milestones throughout project

Milestones	Due Dates
Conceptual Design Report & Review	03/04/14
Critical Design Report & Review	04/29/14
Senior Project Design Expo	11/20/14
Final Design Report	12/05/14

For the duration of the last quarter in the project, steps certain steps were taken to begin ordering parts for the motor. Some parts, such as the O-rings, nuts, and bolts, were simply ordered through distributor catalogues like McMaster-Carr. Others like the head of the tripod, the collet, and collet holders, were machined. A lot of base parts were also ordered from Really Right Stuff for the body of the tripod. Once all the parts, both stock and custom-made, had been obtained and machined, the tripod was assembled and tested here at Cal Poly in San Luis Obispo. A Gantt chart, which shows a detailed description of the timeline for the tripod locking mechanism project, can be viewed in **Appendix E**.

Section VIII - Conclusions and Recommendations

This project is the gateway to high rewards and a new line of products for Really Right Stuff. While the first iteration of this design did not result in a tripod that could be fully deployed in about five seconds, it did prove our concepts, and lead to some component changes. Through the manufacturing of our prototype and testing, we were able to show that a reverse stacking method for the legs provides sufficient strength and rigidity to the tripod. The reverse stacking method used with the twist locks proved to be an easier and quicker method of setup since the users hand never has to leave the lock. The prototype also proved our design for the head and lock release. The main challenge with this part was getting the actuation to move through the axis of the leg to avoid leg angles where the force required would change or the mechanism wouldn't work. Our final design tested on our prototype proved to work through all angles.

Through the prototyping and testing process, we came across a couple of changes for future iterations. The main alteration was a redesign to the collet holder. Due to an increased actuation range from our original design, the bushings did not stay retained in the slots through the entire range of motion of the collet. The collet holder was redesigned to have an internal groove to retain the bushings on a shared snap ring that would fit into the groove. We are confident that this redesign would be sufficient in fixing this issue and allowing the tripod locking mechanism to move freely within the tripod. Further recommendations for improving the durability of this tripod would be to anodize all of the aluminum components which would prevent material loss on the metal to metal contact surfaces. We would also recommend using 4130 steel for the actuation ring, which would aid in ease of manufacturing for welding the components of the ring together. A jig should also be developed to hold the parts during the welding process. The last thing we found a need to change was the collet itself. Despite our calculations we experienced plastic (permanent) deformation, and to eliminate this, the collet could be made of a different material, or heat treated after manufacturing.

While in the end we did not have a single completed prototype which worked how we originally designed and had in mind, it was very beneficial to have the prototype portions we did have. They allowed our team to prove concepts and designs, as well as see where our design could use improvements. If we had the time and materials to take this project to a second iteration, the changes recommended above would, in our opinion, yield a prototype which not only drastically reduced the setup time, but one which would last through many cycles of use and stand the test of time. A user manual for how the tripod is intended to be used is included in **Appendix F.**

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Really Right Stuff
1146 Farmhouse Lane
San Luis Obispo, CA 93401

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Appendices

Appendix A: House of Quality, Pugh Matrices, Decision Matrices, DVP&R – Test Plan, & DFMEA

Appendix B: Calculations & Preliminary Tests

Appendix C: List of Parts & Vendor Specifications

Appendix D: Parts Designed by Team

Appendix E: Gantt Chart

Appendix F: User Manual

Appendix A

House of Quality

Below is the entire House of Quality, and it is broken up on the following paegs.

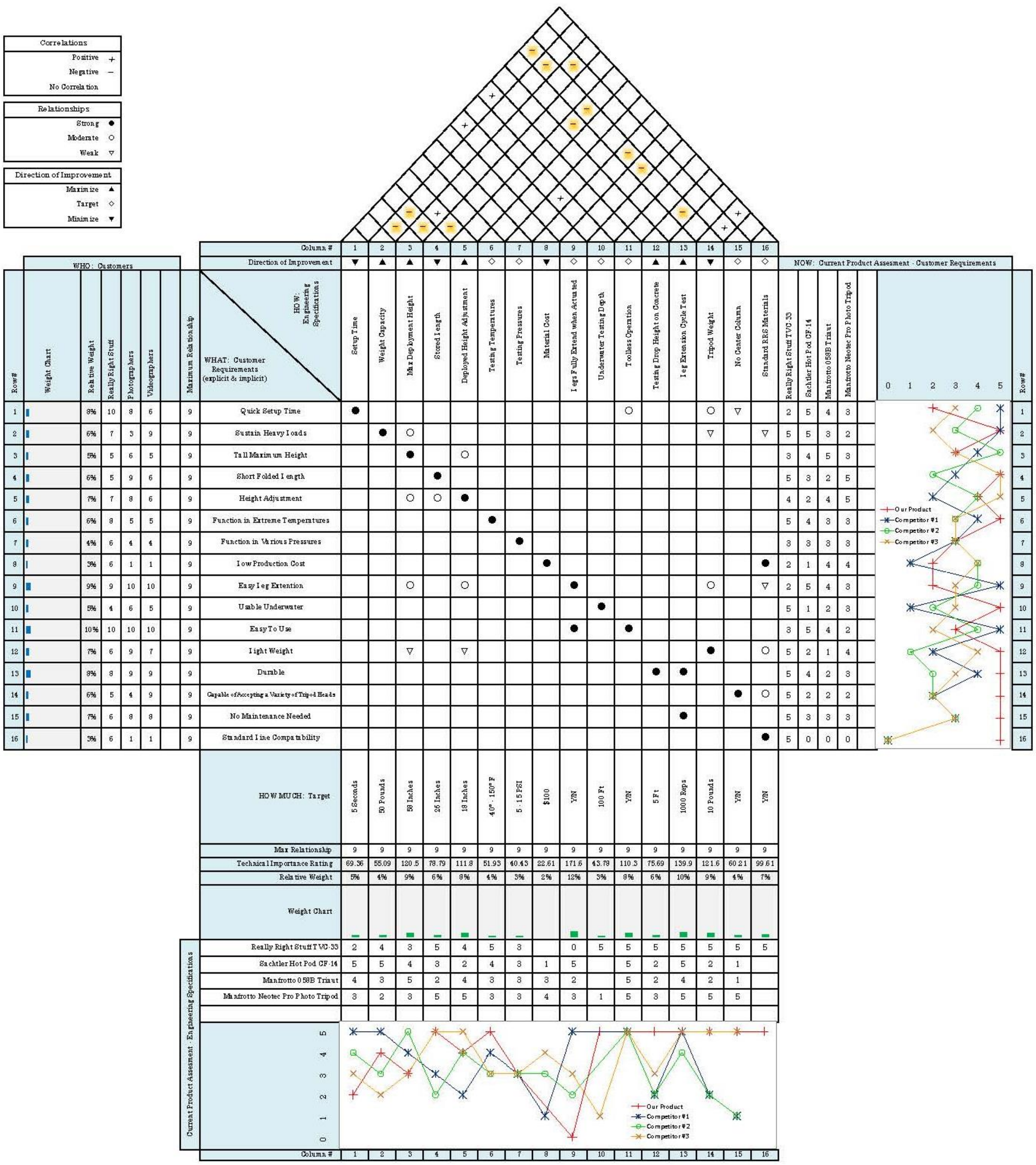


Figure A1. Overall House of Quality

Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Direction of Improvement	▼	▲	▲	▼	▲	◇	◇	▼	◇	◇	◇	▲	▲	▼	◇	◇
WHAT: Customer Requirements (explicit & implicit) / HOW: Engineering Specifications	Setup Time	Weight Capacity	Max Deployment Height	Stored Length	Deployed Height Adjustment	Testing Temperatures	Testing Pressures	Material Cost	Legs Fully Extend when Actuated	Underwater Testing Depth	Toolless Operation	Testing Drop Height on Concrete	Leg Extension Cycle Test	Tripod Weight	No Center Column	Standard RRS Materials
Quick Setup Time	●										○			○	▽	
Sustain Heavy Loads		●	○											▽		▽
Tall Maximum Height			●		○											
Short Folded Length				●												
Height Adjustment			○	○	●											
Function in Extreme Temperatures						●										
Function in Various Pressures							●									
Low Production Cost								●								●
Easy Leg Extention			○		○				●					○		▽
Usable Underwater										●						
Easy To Use									●		●					
Light Weight			▽		▽									●		○
Durable												●	●			
Accept a Variety of Tripod Heads															●	○
No Maintenance Needed													●			
Standard Line Compatability																●

Figure A2. Comparison of customer requirements and engineering specifications.

WHAT: Customer Requirements (explicit & implicit)	NOW: Current Product Assesment - Customer Requirements			
	Really Right Stuff TVC-33	Sachtler Hot Pod CF-14	Manfrotto 058B Triaut	Manfrotto Neotec Pro Photo Tripod
Quick Setup Time	2	5	4	3
Sustain Heavy Loads	5	5	3	2
Tall Maximum Height	3	4	5	3
Short Folded Length	5	3	2	5
Height Adjustment	4	2	4	5
Function in Extreme Temperatures	5	4	3	3
Function in Various Pressures	3	3	3	3
Low Production Cost	2	1	4	4
Easy Leg Extention	2	5	4	3
Usable Underwater	5	1	2	3
Easy To Use	3	5	4	2
Light Weight	5	2	1	4
Durable	5	4	2	3
Capable of Accepting a Variety of Tripod Heads	5	2	2	2
No Maintenance Needed	5	3	3	3
Standard Line Compatability	5	0	0	0

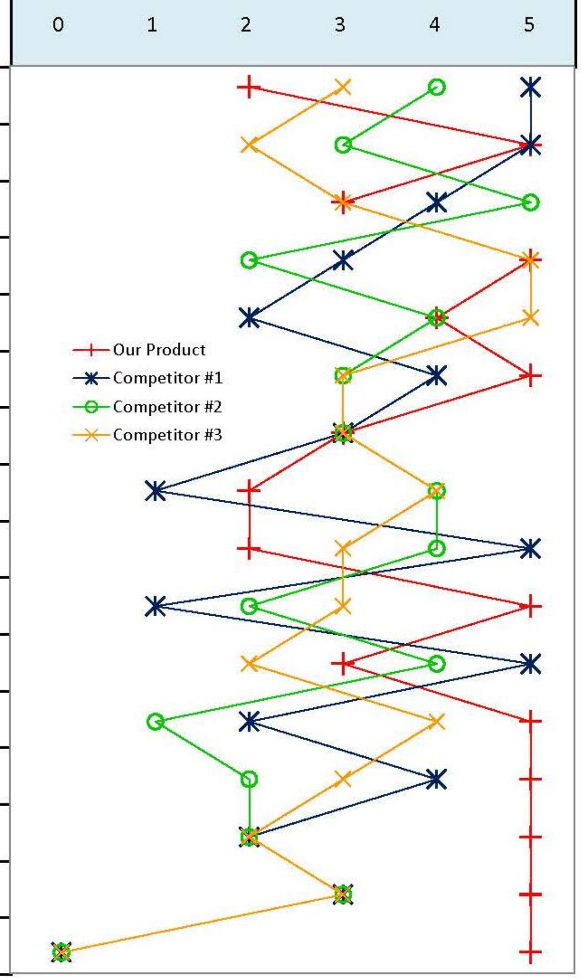


Figure A3. Comparison of customer requirements and existing products.

HOW: Engineering Specifications	Setup Time	Weight Capacity	Max Deployment Height	Stored Length	Deployed Height Adjustment	Testing Temperatures	Testing Pressures	Material Cost	Legs Fully Extend when Actuated	Underwater Testing Depth	Toolless Operation	Testing Drop Height on Concrete	Leg Extension Cycle Test	Tripod Weight	No Center Column	Standard RRS Materials
HOW MUCH: Target	5 Seconds	50 Pounds	58 Inches	26 Inches	18 Inches	-40° - 150° F	5 - 15 PSI	$100	Y/N	100 Ft	Y/N	5 Ft	1000 Reps	10 Pounds	Y/N	Y/N
Max Relationship	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
Technical Importance Rating	69.3619	55.088	120.535	78.7862	111.817	51.9252	40.429	22.6073	171.59	43.7844	110.304	75.6876	139.879	121.568	60.2096	99.6119
Relative Weight	5%	4%	9%	6%	8%	4%	3%	2%	12%	3%	8%	6%	10%	9%	4%	7%
Weight Chart	II	II	IIII	II	IIII	I	I		IIIII	I	IIII	II	IIIII	IIII	II	III
Really Right Stuff TVC-33	2	4	3	5	4	5	3		0	5	5	5	5	5	5	5
Sachtler Hot Pod CF-14	5	5	4	3	2	4	3	1	5		5	2	5	2	1	
Manfrotto 058B Triaut	4	3	5	2	4	3	3	3	2		5	2	4	2	1	
Manfrotto Neotec Pro Photo Tripod	3	2	3	5	5	3	3	4	3	1	5	3	5	5	5	

Current Product Assesment - Engineering Specifications

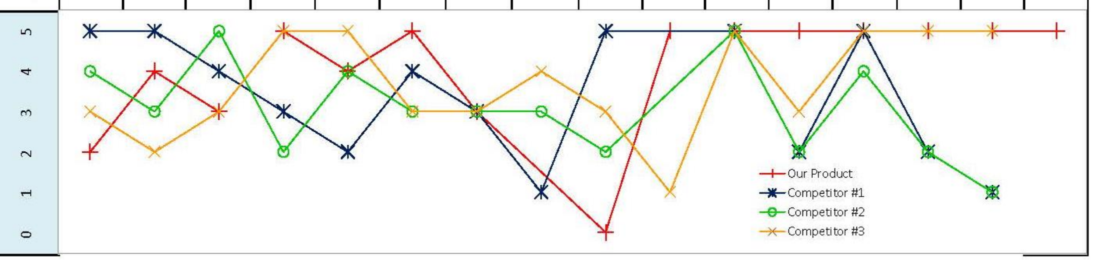
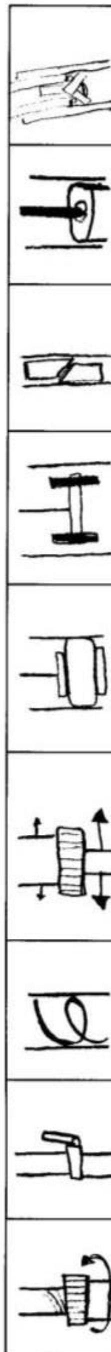


Figure A4. Comparison of engineering specifications & targets with existing products.

WHO: Customers						
Weight Chart	Relative Weight	Really Right Stuff	Photographers	Videographers	Maximum Relationship	WHAT: Customer Requirements (explicit & implicit)
III	8%	10	8	6	9	Quick Setup Time
III	6%	7	3	9	9	Sustain Heavy Loads
II	5%	5	6	5	9	Tall Maximum Height
III	6%	5	9	6	9	Short Folded Length
III	7%	7	8	6	9	Height Adjustment
II	6%	8	5	5	9	Function in Extreme Temperatures
II	4%	6	4	4	9	Function in Various Pressures
I	3%	6	1	1	9	Low Production Cost
IIII	9%	9	10	10	9	Easy Leg Extention
II	5%	4	6	5	9	Usable Underwater
IIII	10%	10	10	10	9	Easy To Use
III	7%	6	9	7	9	Light Weight
IIII	8%	8	9	9	9	Durable
II	6%	5	4	9	9	Capable of Accepting a Variety of Tripod Heads
III	7%	6	8	8	9	No Maintenance Needed
I	3%	6	1	1	9	Standard Line Compatability

Figure A5. Ranking of customer requirements when looking at specific customers.

Pugh Matrices



Criteria \ Concept	Twist Lock	Lever Lock	Expanding Coil	Thermal Coefficient	Ball Compression	Electromagnetic	Bike Head Tube	Hydraulic	1-Way Mech
Manufacturing Cost	D	S	-	-	-	-	-	-	S
Durability		-	-	-	S	-	-	-	S
Reliability	A	-	-	S	-	-	S	+	-
Repairability		S	-	-	S	-	+	-	S
Material Cost	T	+	-	-	-	-	+	-	-
Speed		S	+	-	+	+	S	S	+
Ease of Operation	U	+	+	-	+	+	+	+	+
Weight		S	-	S	S	S	S	-	+
Scalability	M	S	S	S	S	S	S	+	+
Σ +	0	2	2	0	2	2	3	3	4
Σ -	0	2	6	6	3	5	2	5	2
Σ S	0	5	1	3	4	2	4	1	3

Figure A6. Pugh matrix for leg locking mechanism.

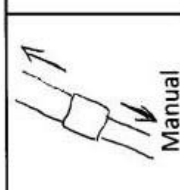
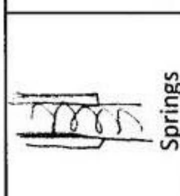
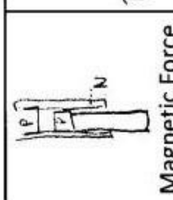
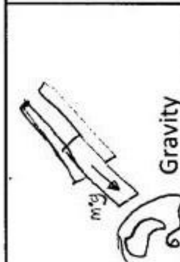
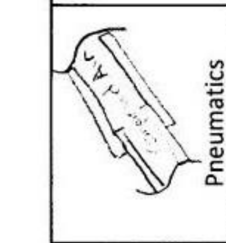
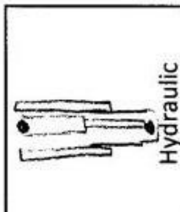
Criteria \ Concept	 Manual	 Springs	 Magnetic Force	 Gravity	 Pneumatics	 Hydraulic
Material Cost	D	-	-	S	-	-
Manufacturing Cost		S	S	S	-	-
Durability	A	-	S	+	S	S
Reliability		S	S	-	S	S
Repairability	T	S	-	S	-	-
Speed		+	+	+	+	+
Ease of Operation	U	+	+	+	+	+
Weight		-	-	-	-	-
Scalability	M	S	-	S	-	-
Σ+	0	2	2	3	2	2
Σ-	0	3	4	2	5	5
ΣS	0	4	3	4	2	2

Figure A7. Pugh matrix for leg extension mechanism.

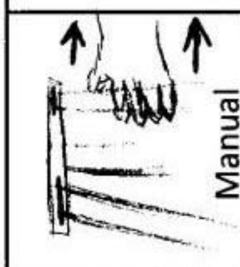
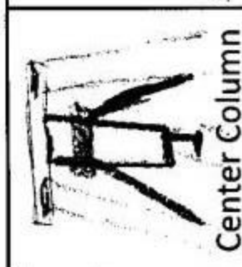
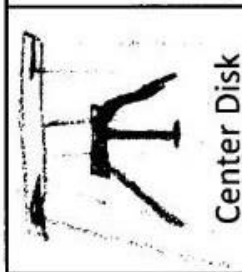
Criteria \ Concept	 Manual	 Center Column	 Center Disk	 Hydraulic/Pneumatic
Manufacturing Cost	D	-	-	-
Durability		-	-	-
Reliability	A	-	-	-
Repairability		-	-	-
Material Cost	T	-	-	-
Speed		+	+	+
Ease of Operation	U	+	+	+
Weight		-	-	-
Scalability	M	S	S	S
$\sum +$	0	2	2	2
$\sum -$	0	6	6	6
$\sum S$	0	1	1	1

Figure A8. Pugh matrix for leg angle adjustment mechanism.

Decision Matrices

Concept Name	Category Weighting %	5%	15%	20%	5%	5%	20%	10%	10%	10%	100%
	Category Name	Manufacturing Cost	Durability	Reliability	Repairability	Material Cost	Speed	Ease of Operation	Weight	Scalability	Score
	Lever Lock	75 / 3.75	90 / 13.5	90 / 18	80 / 4	90 / 4.5	40 / 8	30 / 3	90 / 9	0 / 0	63.75
	Expanding Coil	60 / 3	40 / 6	40 / 8	80 / 4	75 / 3.75	60 / 12	50 / 5	70 / 7	50 / 5	53.75
	1-Way Locking Mech	65 / 3.25	80 / 12	65 / 13	60 / 3	80 / 4	95 / 19	100 / 10	80 / 8	80 / 8	80.25
	Compression Ball	60 / 3	90 / 13.5	70 / 14	80 / 4	70 / 3.5	90 / 18	80 / 8	70 / 7	70 / 7	78
	Electromagnetic	20 / 1	50 / 7.5	60 / 12	40 / 2	10 / 0.5	100 / 20	100 / 10	40 / 4	60 / 6	63
	Reverse Twist Lock	70 / 3.5	90 / 13.5	95 / 19	50 / 2.5	90 / 4.5	30 / 6	50 / 5	90 / 9	80 / 8	71
	Bike Head Tube Lock	65 / 3.25	70 / 10.5	50 / 10	60 / 3	80 / 4	80 / 16	80 / 8	60 / 6	60 / 6	66.75

Figure A9. Decision matrix for leg locking mechanism.

Concept Name	Category Weighting %	5%	15%	20%	5%	5%	20%	10%	10%	10%	100%
	Category Name	Manufacturing Cost	Durability	Reliability	Repairability	Material Cost	Speed	Ease of Operation	Weight	Scalability	Score
	Springs	20 / 1	75 / 11.25	80 / 16	50 / 2.5	75 / 3.75	100 / 20	100 / 10	60 / 6	60 / 6	76.5
	Magnetic Force	20 / 1	75 / 11.25	80 / 16	75 / 3.75	50 / 2.5	80 / 16	80 / 8	60 / 6	80 / 8	72.5
	Gravity	100 / 5	100 / 15	70 / 14	100 / 5	100 / 5	60 / 12	70 / 7	80 / 8	100 / 10	81

Figure A10. Decision matrix for leg extension mechanism.

	Category Weighting %	5%	15%	20%	5%	5%	20%	10%	10%	10%	100%
	Category Name	Manufacturing Cost	Durability	Reliability	Repairability	Material Cost	Speed	Ease of Operation	Weight	Scalability	Score
Concept Name	Center Column	75 / 3.75	80 / 12	85 / 17	80 / 4	85 / 4.25	85 / 17	85 / 8.5	80 / 8	90 / 9	83.5
	Center Disc	85 / 4.25	80 / 12	85 / 17	85 / 4.25	90 / 4.5	80 / 16	80 / 8	85 / 8.5	90 / 9	83.5
	Hydraulic/Pneumatic	70 / 3.5	65 / 9.75	75 / 15	75 / 3.75	60 / 3	90 / 18	90 / 9	60 / 6	70 / 7	75
	Manual	100 / 5	95 / 14.25	95 / 19	95 / 4.75	100 / 5	70 / 14	90 / 9	100 / 10	100 / 10	91

Figure A11. Decision matrix for leg angle adjustment mechanism.

DVP&R – Test Plan

Report Date: 3/13/2014			Sponsor: Really Right Stuff	Component/Assembly: Prototype Assembly						Reporting Engineer: Matt Theiss			
TEST PLAN										**TEST REPORT**			
Item No	Specification or Clause Reference	Test Description	Acceptance Criteria	Test Responsibility	Test Stage	SAMPLES TESTED		TIMING		TEST RESULTS			NOTES
						Quantity	Type	Start date	Finish date	Test Result	Quantity Pass	Quantity Fail	
1	Maximum Weight Capacity	Add weight until failure of locking mechanism	Greater than 50 lbs	Team TLD	DV	1	Prototype 3	10/21/2014	10/21/2014	Incomplete			Unable to test complete tripod, one locking mechanism was able to support 13.4 pounds.
2	Longevity	At least 1000 Cycles of Operation, test of weight capacity after each 200 cycles	Tripod successfully deploys and supports target weight capacity after tests	Team TLD	DV	1	Prototype 2	10/20/2014	10/24/2014	Partially Complete			Actuation Mechanism: Pass Locking Mechanism: Unable to Test
3	High Temperature Operation	Operate Tripod for 3 hours at 150°F	Tripod successfully deploys and supports target weight capacity during tests	Team TLD	DV	1	Prototype 2	10/14/2014	10/16/2014	Unable to Test			
4	Low Temperature Operation	Operate Tripod for 3 Hours at -40°F	Tripod successfully deploys and supports target weight capacity during tests	Team TLD	DV	1	Prototype 2	10/14/2014	10/16/2014	Unable to Test			
5	Underwater Operation	Operate Tripod for 3 hours underwater	Tripod successfully deploys and supports target weight capacity during tests	Team TLD	DV	1	Prototype 2	10/18/2014	10/18/2014	Partially Complete			Actuation Mechanism: Pass Locking Mechanism: Unable to Test
6	Rigidity	Measure deflection under rated load, compare to TVC-33	Comparable to TVC - 33	Team TLD	DV	1	Prototype 2	10/24/2014	10/24/2014	Pass			TVC-33 1/16" Team TLD 1/32"

7	Torsional Stability	Measure torsional load required until failure (legs skip across ground), measure angular deflection of head when this occurs. Compare to TVC-33	Comparable to TVC - 33	Team TLD	DV	1	Prototype 2	10/24/2014	10/24/2014	Pass			TVC-33 1.6 Lbs Team TLD 1.6 Lbs
8	Cantilever Stability	Design testing rig to measure cantilevered load to tipping point. Measure between leg segments and aligned with a leg segment. Compare to TVC-33	Comparable to TVC - 33	Team TLD	DV	1	Prototype 2	10/24/2014	10/24/2014	Pass			TVC-33 .5 Lbs Team TLD .25 Lbs
9	Setup Time	Have 20 different people set up tripod. Average the times and compare to TVC - 33	1/4 TVC - 33 time	Team TLD	DV	1	Prototype 2	10/13/2014	10/13/2014	Partially Complete			Reverse Telescoping leg mechanism reduced setup time by 40%. We were unable to test the locking mechanism.
10	Max Deployment Height	Measure, compare to TVC - 33	Comparable to TVC - 33	Team TLD	DV	1	Prototype 2	10/22/2014	10/22/2014	Pass			TVC-33 59 Inches Team TLD 59 Inches
11	Stored Length	Measure, compare to TVC - 33	Comparable to TVC - 33	Team TLD	DV	1	Prototype 2	10/22/2014	10/22/2014	Pass			TVC-33 25.75 Inches Team TLD 26.5 Inches
12	Height Adjustment Range	Measure, compare to TVC - 33	Comparable to TVC - 33	Team TLD	DV	1	Prototype 2	10/22/2014	10/22/2014	Pass			TVC-33 33.25 Inches Team TLD 32.5 Inches
15	Leg Extension from Actuation	Measure percent overall leg extension per actuation, average results	100%	Team TLD	DV	1	Prototype 2	10/22/2014	10/22/2014	Partially Complete	1	0	Tripod Legs fully extended when actuated during preliminary test. Unable to test full locking mechanism.
16	Tripod Weight	Measure final weight of tripod	< 150% weight of TVC - 33	Team TLD	DV	1	Prototype 2	10/23/2014	10/23/2014	Pass			

17	Simple Operation	Operate the tripod without using any extra tools	Toolless Operation	Team TLD	DV	1	Prototype 2	10/13/2014	10/13/2014	Pass			
18	Drop Test	Drop tripod from 5 ft in various orientations, test deployment after each drop	Tripod successfully deploys	Team TLD	DV	1	Prototype 3	10/13/2014	10/13/2014	Partially Complete			Actuation Mechanism: Pass Locking Mechanism: Unable to Test

Design Failure Mode and Effects Analysis

									Action Results			
Item / Function	**Potential Failure Mode**	**Potential Effect(s) of Failure**	**Sev**	**Potential Cause(s) / Mechanism(s) of Failure**	**Occur**	**Crit**	**Recommended Action(s)**	**Responsibility & Target Completion Date**	**Actions Taken**	**Sev**	**Occur**	**Crit**
Lock Segments	Buckling	Leg segments collapse >> instability, camera falls	8	Weight Overload	1	8	Warning in Manual, Factor of Saftey	12-5-14 9-22-14	Warning in Manual, Factor of Saftey	8	1	8
	Fracturing	Decrease Load Capacity, Leg segments collapse >> instability, camera falls	8	Weight Overload	2	16	Warning in Manual, Factor of Saftey	12-5-14 9-22-14	Warning in Manual, Factor of Saftey	8	1	8
	Debonding	Decrease Load Capacity, Leg segments collapse >> instability, camera falls	8	Excess Temperature, Chemical Exposure	3	24	Warning in Manual, Proper Adhesieve Selecting	12-5-14 9-22-14	Warning in Manual, Proper Adhesieve Selecting	8	1	8
Lock Spring	Fatigue	Decrease Load Capacity, Less reliable locking function	5	Excess Use, Improper Maintenece	1	5	Proper Spring Sizing	9-22-14	Proper Spring Sizing	5	3	15
	Stretch	Decrease Load Capacity, Less reliable locking function	5	Excess Use, Improper Maintenece	1	5	Proper Spring Sizing	9-22-14	Proper Spring Sizing	5	3	15
Extension Limiting Assembly	Cracking	Leg segments separate under full extension, sharp edges exposed	6	Impact, Extended UV Exposure, Chemical Exposure	2	12	Warning in Manual	12-5-14	Warning in Manual	6	2	12
	UV Exposure	Plastic deteriorates, less aesthetic appeal, increase likelihood of cracking	5	Leaving in the Sun for Extended Periods of Time	2	10	Warning in Manual	12-5-14	Warning in Manual	5	2	10
Leg Segments	Cracking	Decreased Stability, Camera Falls	8	Excess Weight, Fatigue, Torquing System, Impact	1	8	Warning in Manual, Factor of Saftey	12-5-14 9-22-14	Warning in Manual, Factor of Saftey	8	1	8
	Fatigue	Cracking, Decreased Load Capacity	6	Torquing System,	2	12	Warning in Manual, Factor of Saftey	12-5-14 9-22-14	Warning in Manual, Factor of Saftey	6	1	6
Angle Adjustment Mechanism	Pins Fall Out	Leg Falls Off, Camera Falls	8	Improper Crimping, Impact, Improper Maintenance	2	16	Maintenance Instructions, Warning in Manual	12-5-14	Maintenance Instructions, Warning in Manual	8	1	8
	Fatigue	Leads to Cracking	6	Ecess Load, Torquing System	1	6	Warning in Manual	12-5-14	Warning in Manual	6	1	6
	Cracking	Leg Falls Off, Camera Falls	8	Torquing System, Load Exceeded, Impact	1	8	Warning in Manual	12-5-14	Warning in Manual	8	1	8
Lock Release Cable	Fray	Leads to Cable Break, Sharp Pieces	6	Pinching, Friction	2	12	Design Properly	9-22-14	Design Properly	6	1	6
	Stretch	Larger Movement Needed	6	Extreme Force Used	4	24	Warning in Manual, Factor of Saftey	12-5-14 9-22-14	Warning in Manual, Factor of Saftey	6	2	12
	Break	Leg Locked Stuck in Lock Position	8	Fraying, Pinching, Friction	1	8	Proper Sizing	9-22-14	Proper Sizing	8	1	8
Mount Plate	Fracture	No Longer Holds Camera, Camera falls	8	Impact, Extended UV Exposure, Chemical Exposure	2	16	Warning in Manual	12-5-14	Warning in Manual	8	1	8
	Warp	No Longer Holds Camera	8	Extreme Temperature	2	16	Warning in Manual	12-5-14	Warning in Manual	8	1	8

Figure A13. DFMEA for tripod usage.

Appendix B
Detailed Supporting Analysis

Spring Force Calculations

MAX LOAD MODELED AS 1.3 lb

RUBBER ON STEEL: μ_s : 0.7 - 1.0
WORST CASE SCENARIO: $\mu_s = 0.7$

REQUIRED NORMAL FORCE:

$$N = \frac{F_c}{\mu_s} = \frac{1.3\ lb}{0.7} = 1.857\ lb$$

NEED 1.857 lb FOR 270° TORSION SPRING

NEED 3.714 lb FOR COMPRESSION SPRING WITH 0.5" DEFLECTION

MCMASTER-CARR:

TORSION SPRING: SKU# 9271K541

COMPRESSION SPRING: SKU# 9657K73

NOTE: μ_s IS ESTIMATED, SHOULD BE TESTED TO DETERMINE IF LARGER SPRINGS ARE NEEDED.

Deflection Calculations

$$\delta = \frac{W\ell^3}{3EI}$$

$W \equiv$ LOAD = 20 lbs
$\ell \equiv$ LENGTH
$E \equiv$ MODULUS OF ELASTICITY = 70 GPa
$= 10.153 \times 10^6$ psi
$I \equiv$ MOMENT OF INERTIA
$$= \frac{\pi(d_o^4 - d_i^4)}{64}$$

THREE TUBES:
LARGE: $d_{oL} = 1.803$ IN
$d_{iL} = 1.503$ IN
MEDIUM: $d_{oM} = 1.283$ IN
$d_{iM} = 1.204$ IN
SMALL: $d_{oS} = 0.964$ IN
$d_{iS} = 0.880$ IN

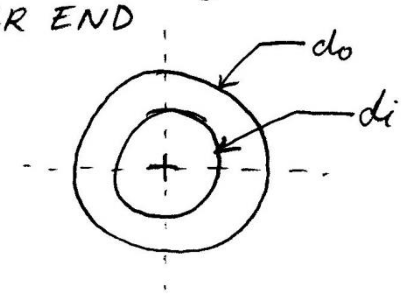
$$I_L = \frac{\pi(1.603\,\text{IN}^4 - 1.503\,\text{IN}^4)}{64} = 0.07362\ \text{IN}^4$$

$$I_M = \frac{\pi(1.283\,\text{IN}^4 - 1.204\,\text{IN}^4)}{64} = 0.02986\ \text{IN}^4$$

$$I_S = \frac{\pi(0.964\,\text{IN}^4 - 0.880\,\text{IN}^4)}{64} = 0.01295\ \text{IN}^4$$

TWO LENGTHS: $\ell_1 = 58$ IN (3 SEGMENTS)
$\ell_2 = 20$ IN (1 SEGMENT)

MODELED AS A BEAM WITH ONE FIXED END AND A POINT LOAD AT OTHER END



LARGE TUBE:

$$\delta = \frac{(20\ \text{lbs})(\ell)^3}{3(10.153\times10^6\ \text{psi})(0.07362\ \text{IN}^4)}$$

ℓ_1: $\delta_1 = 1.740$ INCHES
ℓ_2: $\delta_2 = 0.07135$ INCHES

MEDIUM TUBE:

$$\delta = \frac{(20\ lbs)(\ell)^3}{3(10.153 \times 10^6\ psi)(0.02986\ IN^4)}$$

ℓ_1: $\delta_1 = 4.291$ INCHES

ℓ_2: $\delta_2 = 0.1759$ INCHES

SMALL TUBE:

$$\delta = \frac{(20\ lbs)(\ell)^3}{3(10.153 \times 10^6\ psi)(0.01295\ IN^4)}$$

ℓ_1: $\delta_1 = 9.893$ INCHES

ℓ_2: $\delta_2 = 0.4056$ INCHES

<u>DEFLECTION ANGLE CALCULATIONS</u>

$$\theta = \frac{W\ell^2}{2EI}$$

LARGE TUBE:

$$\theta = \frac{(20\ lbs)(\ell)^2}{2(10.153 \times 10^6\ psi)(0.07362\ IN^4)}$$

ℓ_1: $\theta_1 = 2.579°$

ℓ_2: $\theta_2 = 0.307°$

MEDIUM TUBE:

$$\theta = \frac{(20\ lbs)(\ell)^2}{2(10.153 \times 10^6\ psi)(0.02986\ IN^4)}$$

ℓ_1: $\theta_1 = 6.358°$

ℓ_2: $\theta_2 = 0.756°$

SMALL TUBE:

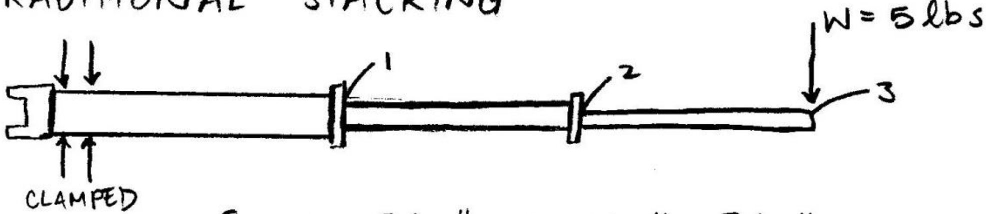
$$\theta = \frac{(20\ lbs)(\ell)^2}{2(10.153 \times 10^6\ psi)(0.01259\ IN^4)}$$

ℓ_1: $\theta_1 = 14.659°$

ℓ_2: $\theta_2 = 1.743°$

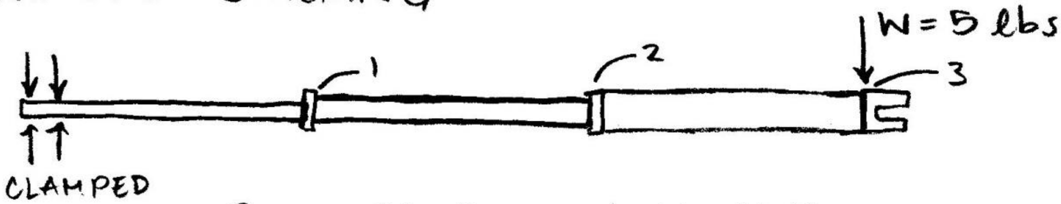
Deflection Test – Entire Leg

TRADITIONAL STACKING



$$\delta_1 = 36\,5/8'' - 36\,1/4'' = 3/8''$$
$$\delta_2 = 36'' - 34\,13/16'' = 1\,3/16''$$
$$\delta_3 = 35\,1/8'' - 33'' = 2\,1/8''$$

REVERSE STACKING



$$\delta_1 = 36\,3/16'' - 35\,11/16'' = 1/2''$$
$$\delta_2 = 35\,1/2'' - 34'' = 1\,1/2''$$
$$\delta_3 = 34\,3/4'' - 31\,7/8'' = 2\,7/8''$$

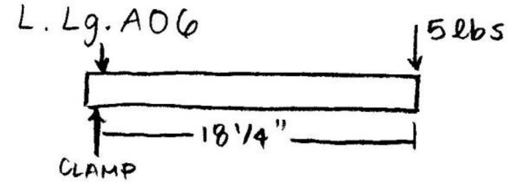
FACTOR OF $\dfrac{\text{REVERSE}}{\text{TRADITIONAL}}$:

POINT 1 : $\dfrac{1/2''}{3/8''} = 1.33$

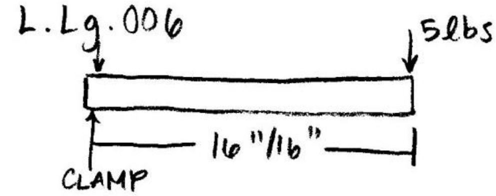
POINT 2 : $\dfrac{1\,1/2''}{1\,3/16''} = 1.26$

POINT 3 : $\dfrac{2\,7/8''}{2\,1/8''} = 1.35$

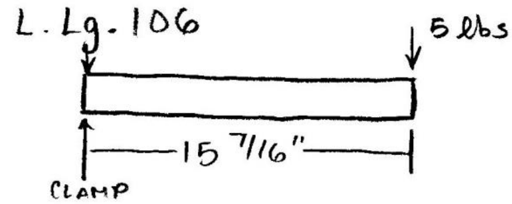
Deflection Test – Single Leg Segments



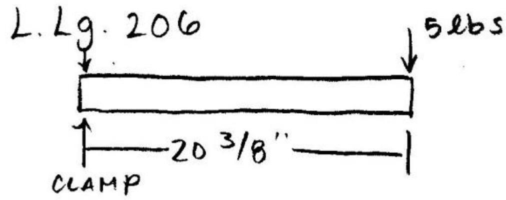
$\delta = 37\,1/4'' - 36\,1/2'' = 3/4''$



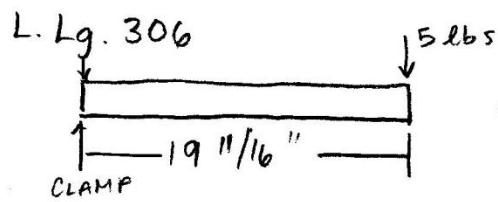
$\delta = 37\,1/4'' - 36\,15/16'' = 5/16''$



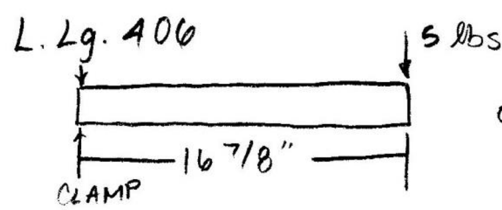
$\delta = 37\,1/4'' - 37'' = 1/4''$



$\delta = 37\,7/16'' - 36\,13/16'' = 5/8''$



$\delta = 37\,5/8'' - 37\,3/16'' = 7/16''$

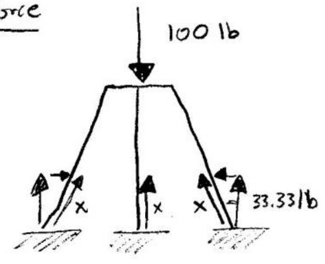


$\delta = 36\,3/4'' - 36\,5/8'' = 1/8''$

Static Force Calculations

Goal: Support 50 lb camera, Factor of Safety = 2

1) Find Normal Force



Vertical force: $33.3\bar{3}$ lbf

Force Along leg segment:

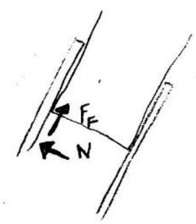
$$x = \frac{33.33}{\cos(30)} = 38.49 \text{ lbf}$$

$$F_F = x = 38.49 \text{ lbf}$$

$$F_F = \mu \cdot N$$

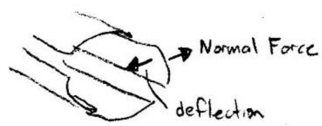
$$N = \frac{F_F}{\mu} = \frac{38.49}{.7}$$

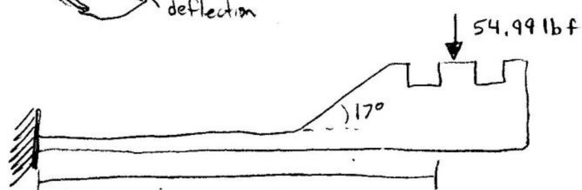
$$N = 54.99 \text{ lbf}$$



μ (rubber/solid) = .7 - 1.0

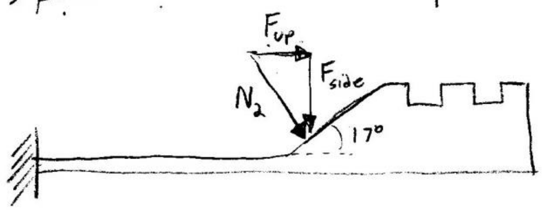
2) Collet deflection





State 1: Locked

δ = .06 in



State 2: Unlocked

δ = .075 in

Find Spring Constant

$$F = k\delta \Rightarrow k = \frac{F}{\delta} = \frac{54.99}{.06} = 916.43 \text{ lbf/inch}$$

Find Force at Unlocked Position

$$F = k\delta = 916.43(.075) = 68.7323 \text{ lbf}$$

Transform force to bearing contact point

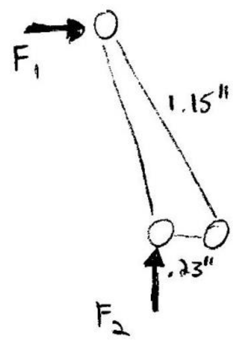
$$N_2 = (68.7323)\left(\frac{1.05+.45}{1.05}\right) / \cos(17)$$

$$N_2 = 102.68 \text{ lbf}$$

$$F_{up} = \sin(17)(102.68) = 30.02 \text{ lbf}$$

$$F_{side} = \cos(17)(102.68) = 98.19 \text{ lbf}$$

3) Find Force Reduction in Tripod head



$$F_1 = \frac{.23}{1.15} F_2$$

$$F_1 = .2 F_2$$

$$F_{rot} = .2 F_{up}$$

$$F_{rot} = .2(30.02) = 6.00 \text{ lbf}$$

4) Find total Rotation Forces

$$F_{rot\,(Total)} = 3 * F_{rot} = 18.01 \text{ lbf}$$

Total rotational Force = 18.01 lbf

Tripod Force Calculations – Expected Values

Likely								
Shoulder Angle (degrees)	5.00	10.00	15.00	17.00	20.00	25.00	30.00	35.00
Desired Spring Force (lbs)	38.49	38.49	38.49	38.49	38.49	38.49	38.49	38.49
Rubber-Solid Coeff	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Normal Force (lbs)	38.49	38.49	38.49	38.49	38.49	38.49	38.49	38.49
Initial Deflection (in)	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Release Deflection (in)	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Travel Required (in)	0.11	0.06	0.04	0.03	0.03	0.02	0.02	0.01
Spring Constant (lb/in)	641.50	641.50	641.50	641.50	641.50	641.50	641.50	641.50
New Normal Force (lb)	64.40	65.14	66.41	67.08	68.27	70.78	74.07	78.31
Aluminum-Steel Coeff	0.30	0.30	0.30	1.30	0.30	0.30	0.30	0.30
Friction Force (lb)	19.32	19.54	19.92	87.21	20.48	21.23	22.22	23.49
Friction Force Up (lb)	19.25	19.25	19.25	83.40	19.25	19.25	19.25	19.25
Force Up (lb)	5.61	11.31	17.19	19.61	23.35	29.91	37.04	44.92
Force Sideways (lb)	64.15	64.15	64.15	64.15	64.15	64.15	64.15	64.15
Total Force Up (lb)	24.86	30.56	36.43	103.01	42.59	49.16	56.28	64.16
Rotating Travel (in)	0.375	0.375	0.375	0.375	0.375	0.375	0.375	0.375
Force Reduction	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Force Rotate (lb)	4.97	6.11	7.29	20.60	8.52	9.83	11.26	12.83
Total Rotation Force (lb)	14.91	18.33	21.86	61.80	25.56	29.50	33.77	38.50
Frictionless Force Up (lb)	5.61	11.31	17.19	19.61	23.35	29.91	37.04	44.92
Frictionless Force Rotate (lb)	1.12	2.26	3.44	3.92	4.67	5.98	7.41	8.98
Frictionless Rotation Force (lb)	3.37	6.79	10.31	11.77	14.01	17.95	22.22	26.95

Tripod Force Calculations – Worst Case Values

Worst Case								
Shoulder Angle (degrees)	5.00	10.00	15.00	17.00	20.00	25.00	30.00	35.00
Desired Spring Force (lbs)	38.49	38.49	38.49	38.49	38.49	38.49	38.49	38.49
Rubber-Solid Coeff	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Normal Force (lbs)	54.99	54.99	54.99	54.99	54.99	54.99	54.99	54.99
Initial Deflection (in)	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Release Deflection (in)	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Travel Required (in)	0.17	0.09	0.06	0.05	0.04	0.03	0.03	0.02
Spring Constant (lb/in)	916.43	916.43	916.43	916.43	916.43	916.43	916.43	916.43
New Normal Force (lb)	98.56	99.70	101.65	102.68	104.49	108.34	113.38	119.87
Aluminum-Steel Coeff	0.61	0.61	0.61	1.61	0.61	0.61	0.61	0.61
Friction Force (lb)	60.12	60.82	62.01	165.31	63.74	66.09	69.16	73.12
Friction Force Up (lb)	59.90	59.90	59.90	158.08	59.90	59.90	59.90	59.90
Force Up (lb)	8.59	17.31	26.31	30.02	35.74	45.79	56.69	68.75
Force Sideways (lb)	98.19	98.19	98.19	98.19	98.19	98.19	98.19	98.19
Total Force Up (lb)	68.49	77.21	86.20	188.10	95.63	105.68	116.58	128.65
Rotating Travel (in)	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Force Reduction	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Force Rotate (lb)	13.70	15.44	17.24	37.62	19.13	21.14	23.32	25.73
Total Rotation Force (lb)	41.09	46.33	51.72	112.86	57.38	63.41	69.95	77.19
Frictionless Force Up (lb)	8.59	17.31	26.31	30.02	35.74	45.79	56.69	68.75
Frictionless Force Rotate (lb)	1.72	3.46	5.26	6.00	7.15	9.16	11.34	13.75
Frictionless Rotation Force (lb)	5.15	10.39	15.79	18.01	21.44	27.47	34.01	41.25

Appendix C
Vendor Supplied Component Specifications and Data Sheets

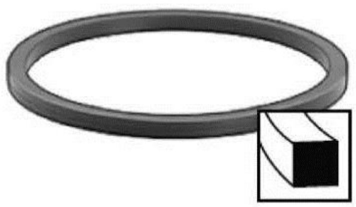
Square Buna-N O-Ring

McMASTER-CARR. OVER 555,000 PRODUCTS

(562) 692-5911
(562) 695-2323 (fax)
la.sales@mcmaster.com
Text 75930

Square Buna-N O-Ring
AS568A Dash Number 214

In stock
$7.99 per pack of 50
4061T236



AS568A Dash No.	214
Fractional Size	
ID	1"
OD	1 1/4"
Actual Inch Size	
ID	0.984"
OD	1.262"
Additional Specifications	Width: 1/8" Fractional (0.139" Actual) O-Ring Sizing Chart

The square cross section on these rings retains a seal longer than standard O-rings, especially at higher temperatures and pressures. Interchangeable with AS568A O-rings size for size. Buna-N is for use in oil applications. Temperature range is -30° to +212° F. Durometer hardness is A70. Color is black.

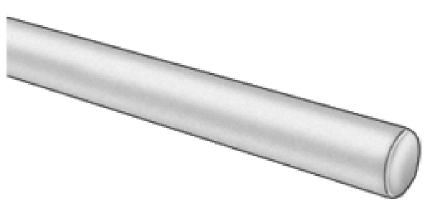
Collet Material

303 Stainless Steel Drive Shaft
1-1/4" OD, 12" Length

Shaft Dia.	Dia. Tolerance	Straightness Tolerance
¼"	0.0" to –0.0002"	0.0036" per ft.
⅜", ½"	0.0" to –0.0002"	0.0048" per ft.
⅝"-1¼"	0.0" to –0.0004"	0.0096" per ft.

Each
ADD TO ORDER

In stock
$98.08 Each
8364T23



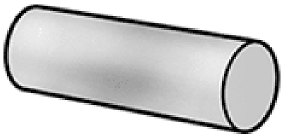
Length	12"
Additional Specifications	Type 303 Stainless Steel Shafts 1 1/4" Dia.

Type 303 Stainless Steel Shafts—Have good corrosion resistance but are not as strong as steel shafts. Rockwell hardness is B83. Ends are beveled.

Collet Cup Material

Easy-to-Machine 6020 Aluminum

Corrosion-Resistant, 1-1/4" Diameter



Length, ft.	Each
1	ADD TO ORDER
3	
6	9038K18

Diameter	1 1/4"
Diameter Tolerance	±0.003"
Yield Strength	39,000 psi
Hardness	Soft (100 Brinell)
Temper	Heat Treated (T8, except 7/8", 1 1/4", 1 3/8", and 1 1/2" Diameter rods are T9)
Additional Specifications	Rods—Unpolished

Compared to other easy-to-machine aluminum, Alloy 6020 offers the best corrosion resistance. Use it for screw machine products, valves, and hydraulic parts. This material has an excellent surface finish and responds well to anodizing. It is nonmagnetic and heat treatable. Temperature range is not rated.

View detailed performance properties and composition for aluminum.

Yield strength is approximate and may vary based on size and shape.

Length tolerance is ±1".

Ball Bearing Shaft

Stainless Steel Wire (Type 302/304)

Spring Back, .045" Diameter, 1' Length

1-ft. Lengths

Packs of 100

ADD TO ORDER

In stock
$11.91 per pack of 100
8908K48

Wire Diameter	0.045"
Additional Specifications	Spring-Back Type 304 Stainless Steel—Matte Finish 1-ft. Lengths Spring-back wire (spring temper) Meets ASTM A313 and A555

View a wire gauge conversion chart.

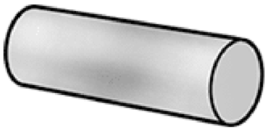
This multipurpose wire has good corrosion resistance. Diameter tolerance is ±0.001". Maximum temperature is 570° F.

Warning! Temperature is not guaranteed and is intended only as a basis for comparison.

Aluminum Rod

Multipurpose 6061 Aluminum Rod

3/16" Diameter



Length, ft.
1
2
3
6

Each

ADD TO ORDER

8974K21

Material Certification	Rods
Diameter	3/16"
Yield Strength	35,000 psi
Hardness	Soft (95 Brinell)
Temper	Heat Treated (T6511, unless noted)
Additional Specifications	Rods—Unpolished Meet ASTM B221, unless noted Temper is T6. Meet ASTM B211.

The most widely used aluminum, Alloy 6061 is a popular choice for vehicle parts and pipe fittings. It has better corrosion resistance and weldability than Alloys 2024 and 7075, but it's not as strong. It is nonmagnetic, heat treatable, and resists stress cracking. Temperature range is -320° to 300° F.

View detailed performance properties and composition for aluminum.

Yield strength is approximate and may vary based on size and shape.

Diameter tolerance for 1/8" to 1 7/8" dia. rods is ±0.006". Length tolerance for 1-ft. to 6-ft. lengths is ±1".

Zinc Hex Nut

Zinc-Plated Steel Machine Screw Hex Nut

10-32 Thread Size, 3/8" Width, 1/8" Height

Packs of 100

ADD TO ORDER

In stock
$1.71 per pack of 100
90480A195

Thread Size	10-32
Width	3/8"
Height	1/8"
Additional Specifications	Zinc-Plated Steel

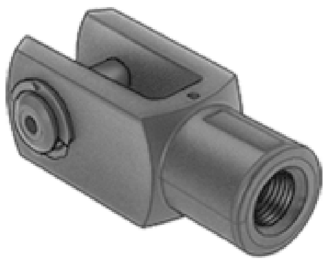
Often used on machine screws and threaded rods, and great for tight spaces. Top of nut is flat and has chamfered corners; bottom may be flat or chamfered. Nuts have a Class 2B thread fit and dimensions that meet ANSI/ASME B18.6.3.

Zinc-plated steel nuts are not rated for hardness.

Rod End

Corrosion-Resistant Plastic Clevis Rod End

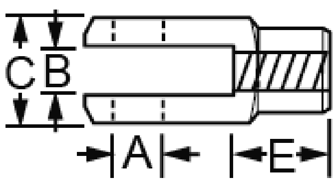
10-32 Female Thread Size, 25/32" Length

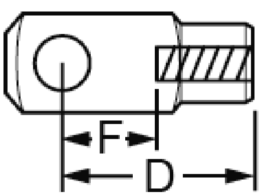


Each | ADD TO ORDER

In stock
$3.25 Each
2449K11

Shank Thread Size	10-32
ID (A)	3/16"
Jaw Width (B)	3/16"
Overall Width (C)	13/32"
Length (D)	25/32"
Thread Length (E)	5/16"
Length (F)	13/32"
Additional Specifications	Inch Sizes



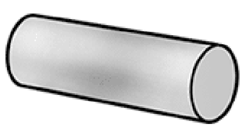


In addition to offering superior corrosion resistance, these lightweight, fiber-reinforced plastic rod ends also reduce noise and vibration. Often called yoke end linkages, they're good for making pivot points for shafts, rods, and other assemblies. All have female right-hand threads. Each comes with a clevis pin and a retaining clip.

Foot Adapter Material

Easy-to-Machine 6020 Aluminum

Corrosion-Resistant, 1-1/2" Diameter



Length, ft.
1
3
6

Each | ADD TO ORDER

9038K21

Diameter	1 1/2"
Diameter Tolerance	±0.003"
Yield Strength	39,000 psi
Hardness	Soft (100 Brinell)
Temper	Heat Treated (T8, except 7/8", 1 1/4", 1 3/8", and 1 1/2" Diameter rods are T9)
Additional Specifications	Rods—Unpolished

Compared to other easy-to-machine aluminum, Alloy 6020 offers the best corrosion resistance. Use it for screw machine products, valves, and hydraulic parts. This material has an excellent surface finish and responds well to anodizing. It is nonmagnetic and heat treatable. Temperature range is not rated.

View detailed performance properties and composition for aluminum.

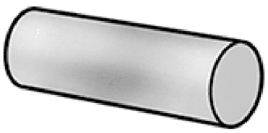
Yield strength is approximate and may vary based on size and shape.

Length tolerance is ±1".

Hinge Material

Easy-to-Machine 6020 Aluminum

Corrosion-Resistant, 1-3/4" Diameter



Length, ft.
1
3
6

Each

ADD TO ORDER

9038K22

Diameter	1 3/4"
Diameter Tolerance	±0.004"
Yield Strength	39,000 psi
Hardness	Soft (100 Brinell)
Temper	Heat Treated (T8, except 7/8", 1 1/4", 1 3/8", and 1 1/2" Diameter rods are T9)
Additional Specifications	Rods—Unpolished

Compared to other easy-to-machine aluminum, Alloy 6020 offers the best corrosion resistance. Use it for screw machine products, valves, and hydraulic parts. This material has an excellent surface finish and responds well to anodizing. It is nonmagnetic and heat treatable. Temperature range is not rated.

View detailed performance properties and composition for aluminum.

Yield strength is approximate and may vary based on size and shape.

Length tolerance is ±1".

Hinge Screw

Type 316 Stainless Steel Shoulder Screw

1/8" Diameter x 7/8" Long Shoulder, 4-40 Thread

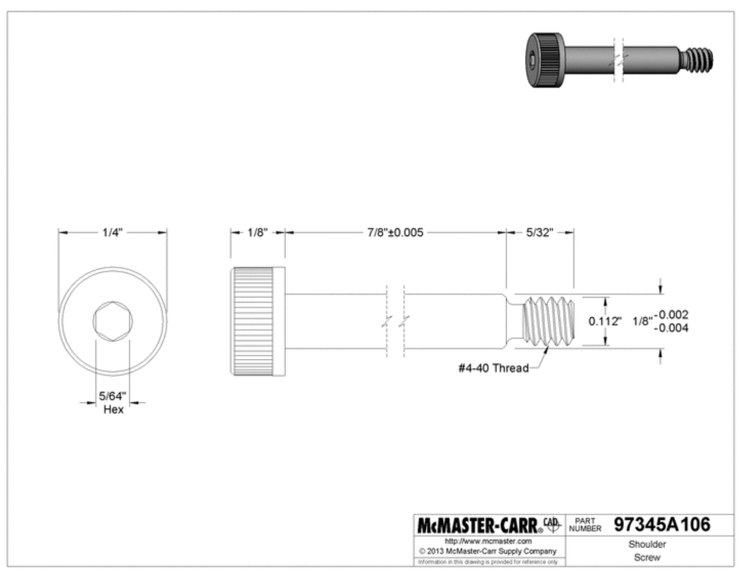
Each

ADD TO ORDER

In stock
1-4 Each $9.05
5 or more $7.98
97345A106

Material	Type 316
Shoulder Length	7/8"
Thread Size	4-40
Thread Length	5/32"
Additional Specifications	Stainless Steel 1/8" Shoulder Dia.—Head Dia.: 1/4", Head Ht.: 1/8"

Inch Sizes—Screws have a Class 3A thread fit. Shoulder diameter tolerance is –0.002" to –0.004". Shoulder length tolerance is ±0.005".



Washers

Type 316 Stainless Steel General Purpose Flat Washer

Number 2 Screw Size, 1/4" OD, .01"-.04" Thick

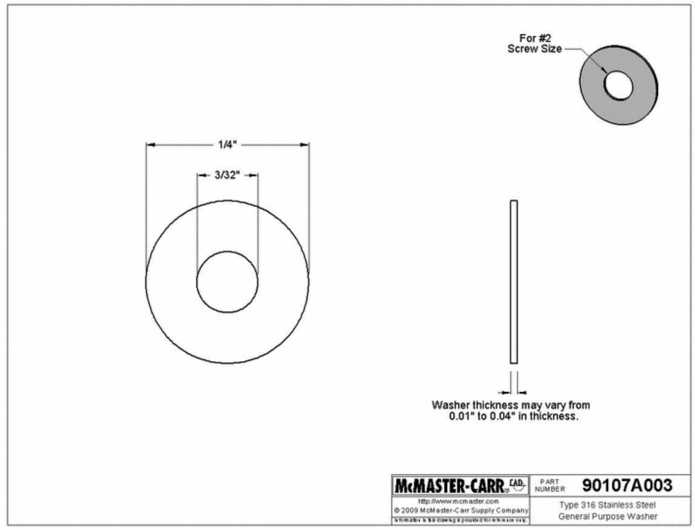
Packs of 100

ADD TO ORDER

In stock
$2.64 per pack of 100
90107A003

Screw Size	No. 2
ID	3/32"
OD	1/4"
Thickness, Minimum -Maximum	0.01"-0.04"
Additional Specifications	Type 316 Stainless Steel

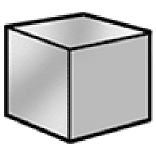
Why pay for precision you don't need? These washers are not made to USS or SAE standards, so they're economical alternatives when tight tolerances are not important. Made from stainless steel for excellent corrosion resistance, they may be mildly magnetic and are not rated for hardness.



Head, Head Ring, and Head Plate Material

Multipurpose 6061 Aluminum

5" Thick x 5" Width x 5" Length



Each

ADD TO ORDER

In stock
$92.63 Each
8975K574

sq. Size	5"
sq. Tolerance	±0.034"
Yield Strength	35,000 psi
Hardness	Soft (80 Brinell)
Temper	Heat Treated (T6511)
Additional Specifications	Cubes—Unpolished Meet ASTM B221

The most widely used aluminum, Alloy 6061 is a popular choice for vehicle parts and pipe fittings. It has better corrosion resistance and weldability than Alloys 2024 and 7075, but it's not as strong. It is nonmagnetic, heat treatable, and resists stress cracking. Temperature range is -320° to 300° F.

View detailed performance properties and composition for aluminum.

Yield strength is approximate and may vary based on size and shape.

Head Screws

Type 316 Stainless Steel Low Profile Socket Head Cap Screw
8-32 Thread, 1/4" Long

Packs of 10 | ADD TO ORDER

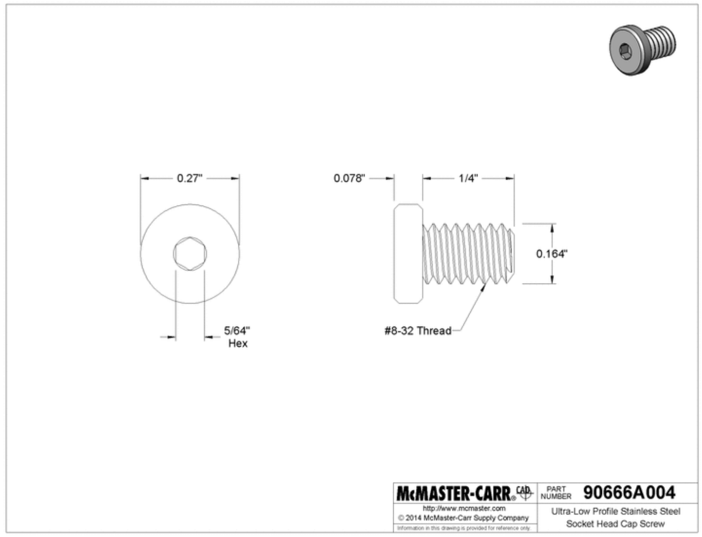
Usually ships in 1 week.
$7.46 per pack of 10
90666A004

Thread Size	8-32
Length	1/4"
Thread Length	Full
Head Height	0.078"
Additional Specifications	Low Profile Type 316 Stainless Steel

For use where space is limited, these screws have heads that are a fraction of the height of standard socket head cap screws. Not recommended for high-strength fastening, they have a minimum tensile strength of 70,000 psi.

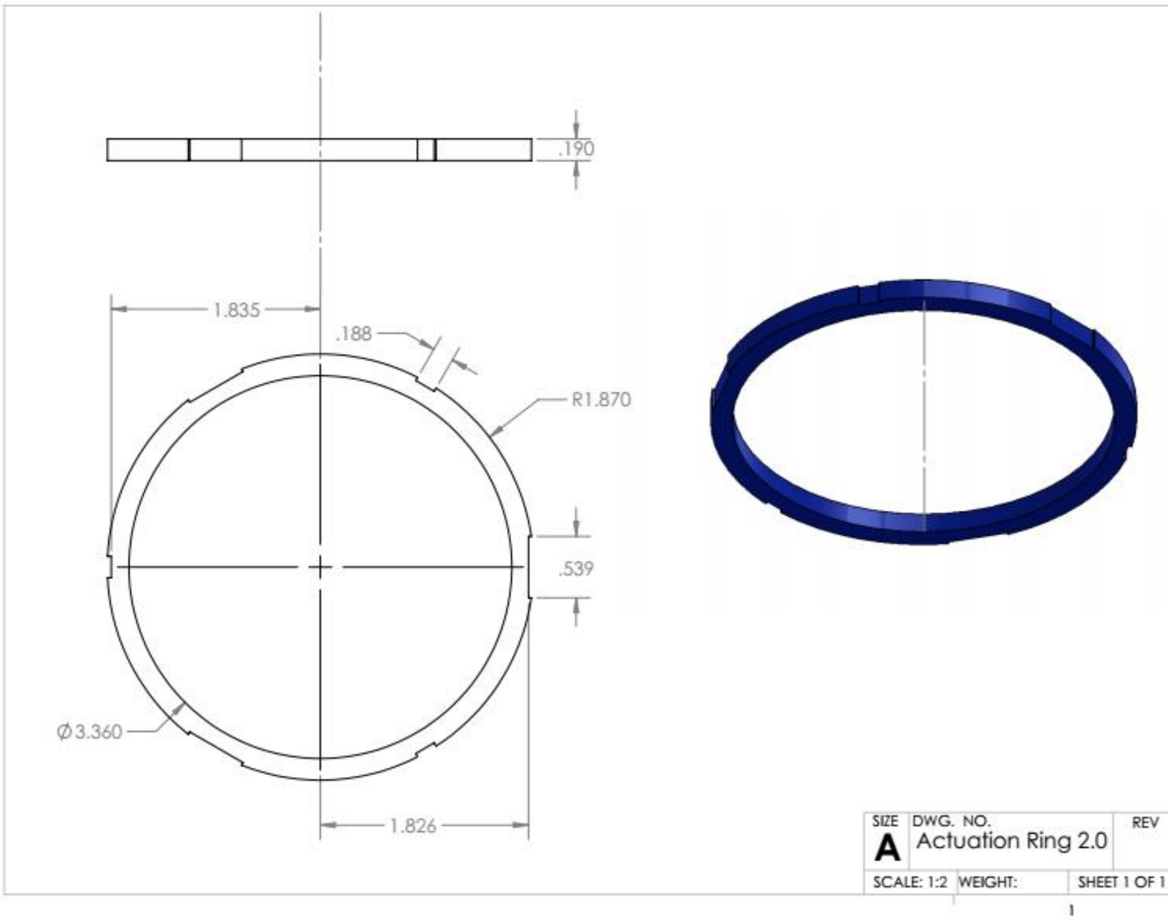
Inch screws have a minimum Rockwell hardness of B70 and a Class 3A thread fit.

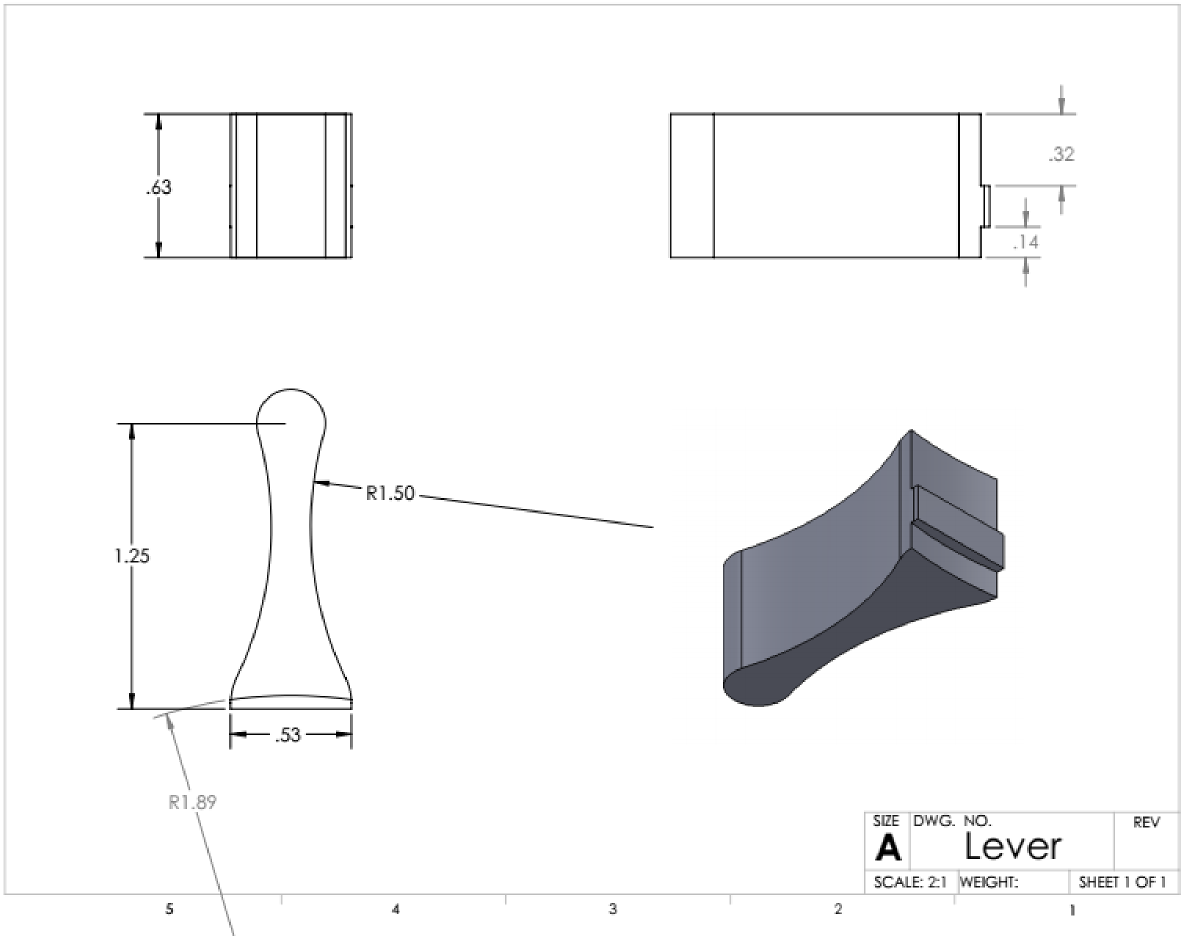
Low Profile—Have a head that's about half the height of standard socket head screws. Length is measured from under the head.

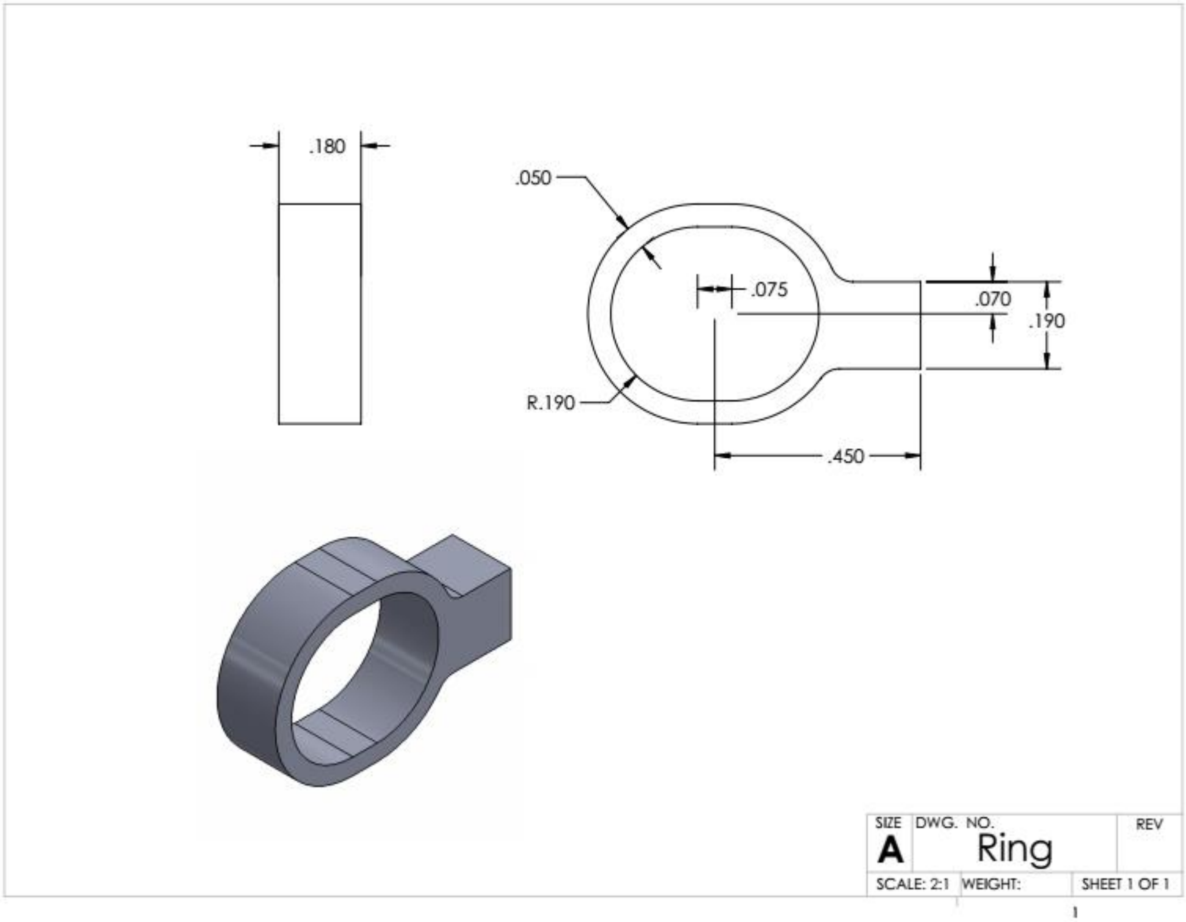


Appendix D
Designed Parts for Tripod

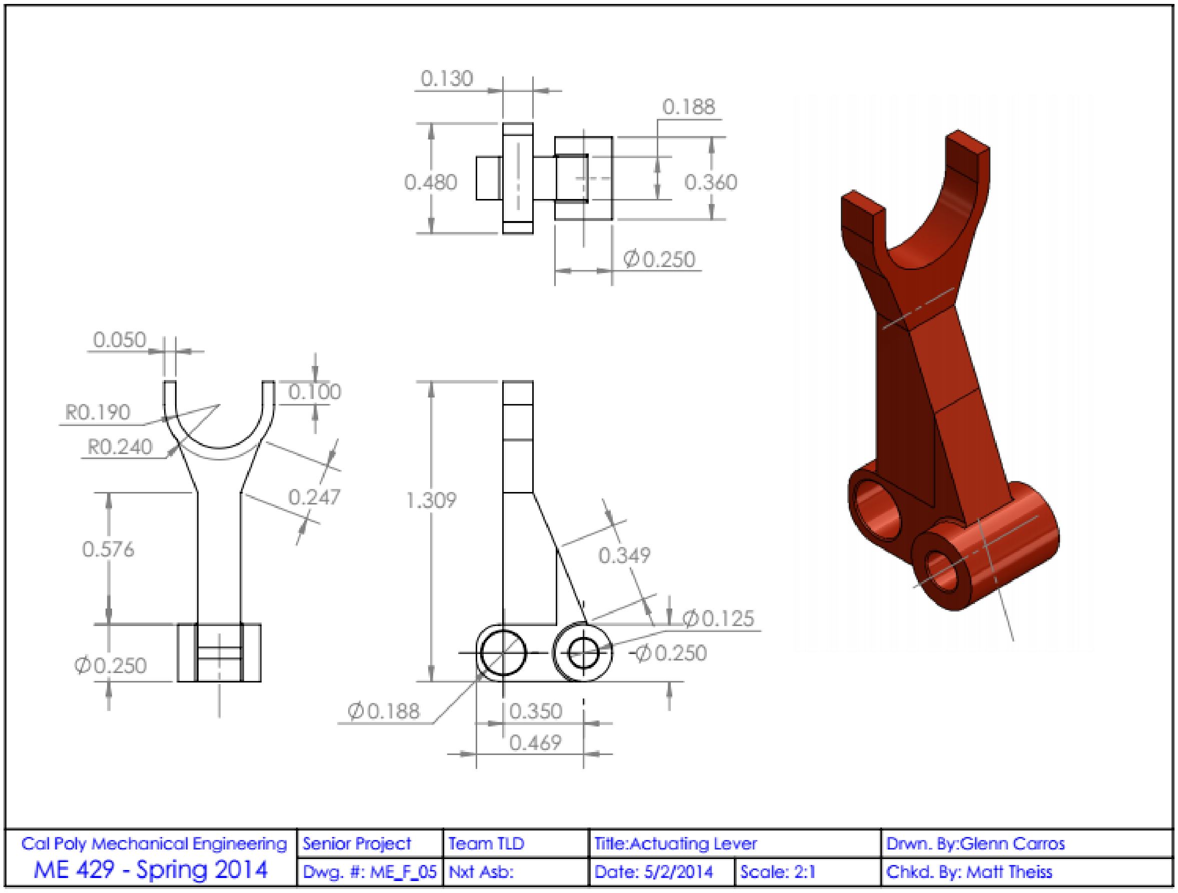
Tripod Actuation Ring Engineering Drawings



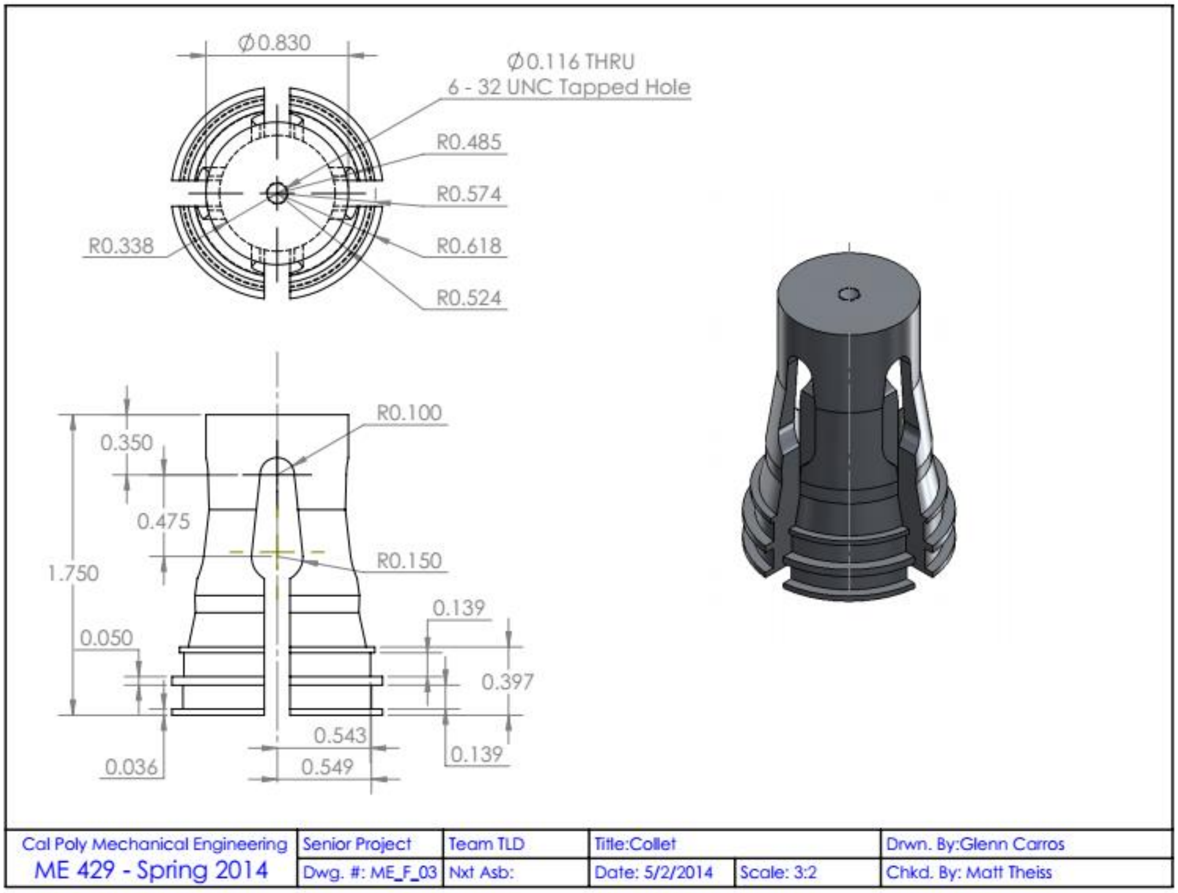

.63
.32
.14
R1.50
1.25
.53
R1.89
SIZE
A
DWG. NO.
Lever
REV
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1
5
4
3
2
1


.180
.050
.075
.070
.190
R.190
.450
SIZE
A
DWG. NO.
Ring
REV
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1

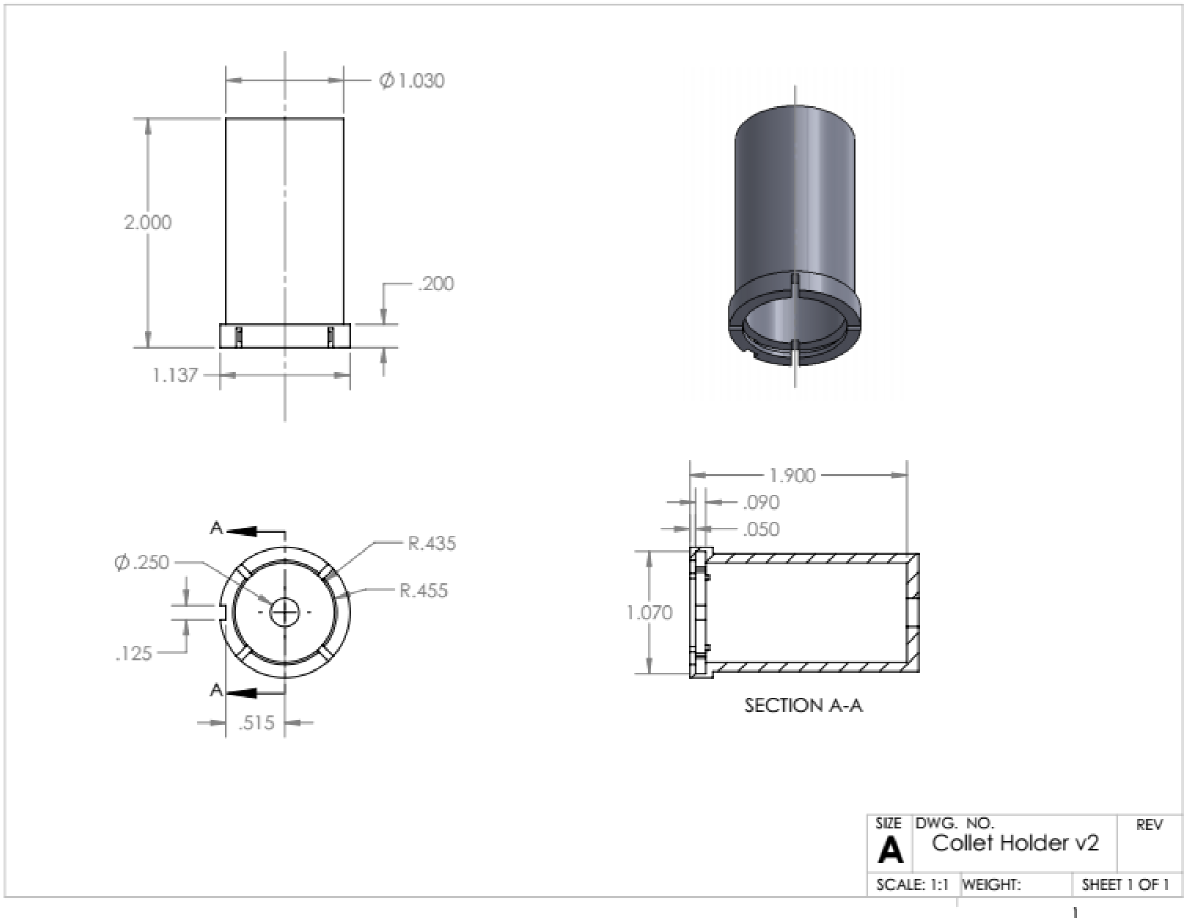
Tripod Actuation Lever Engineering Drawing



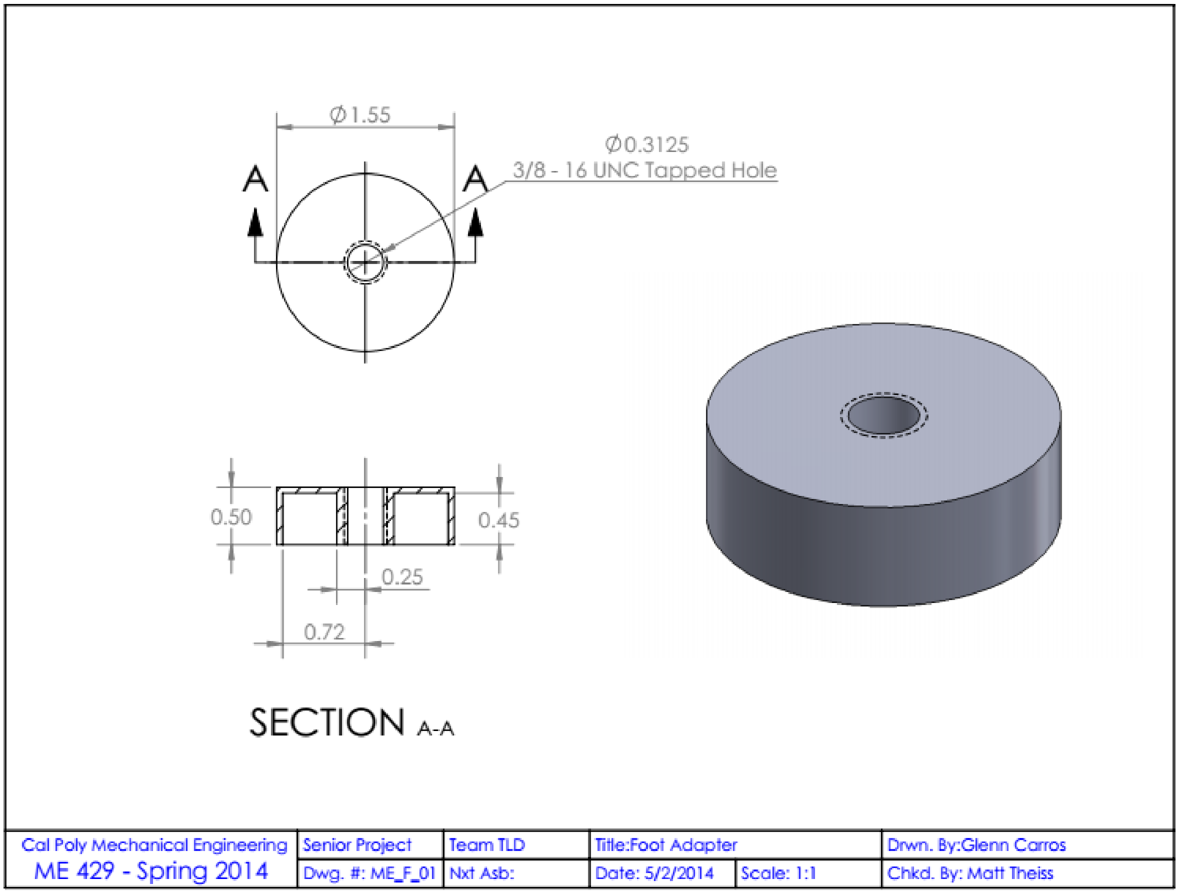
Tripod Collet Engineering Drawing



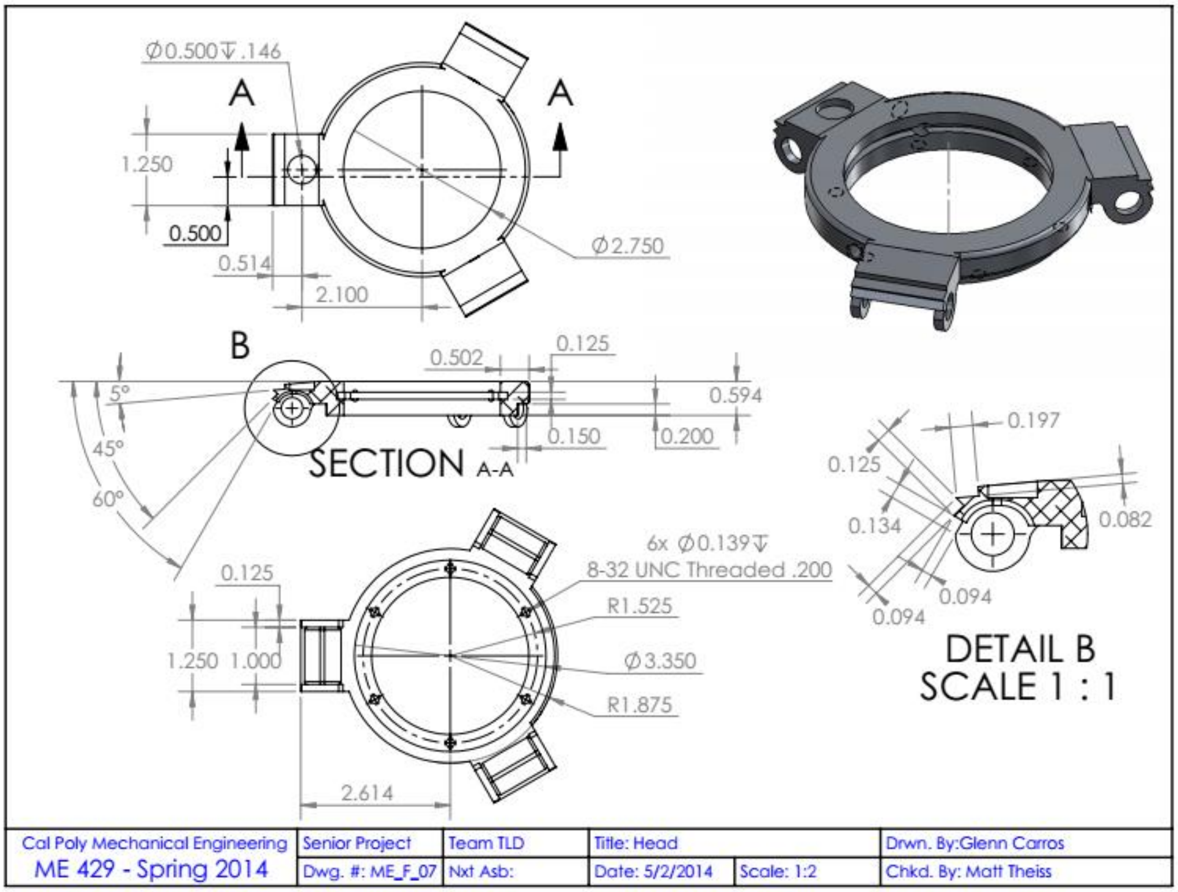
Tripod Collet Holder Engineering Drawing



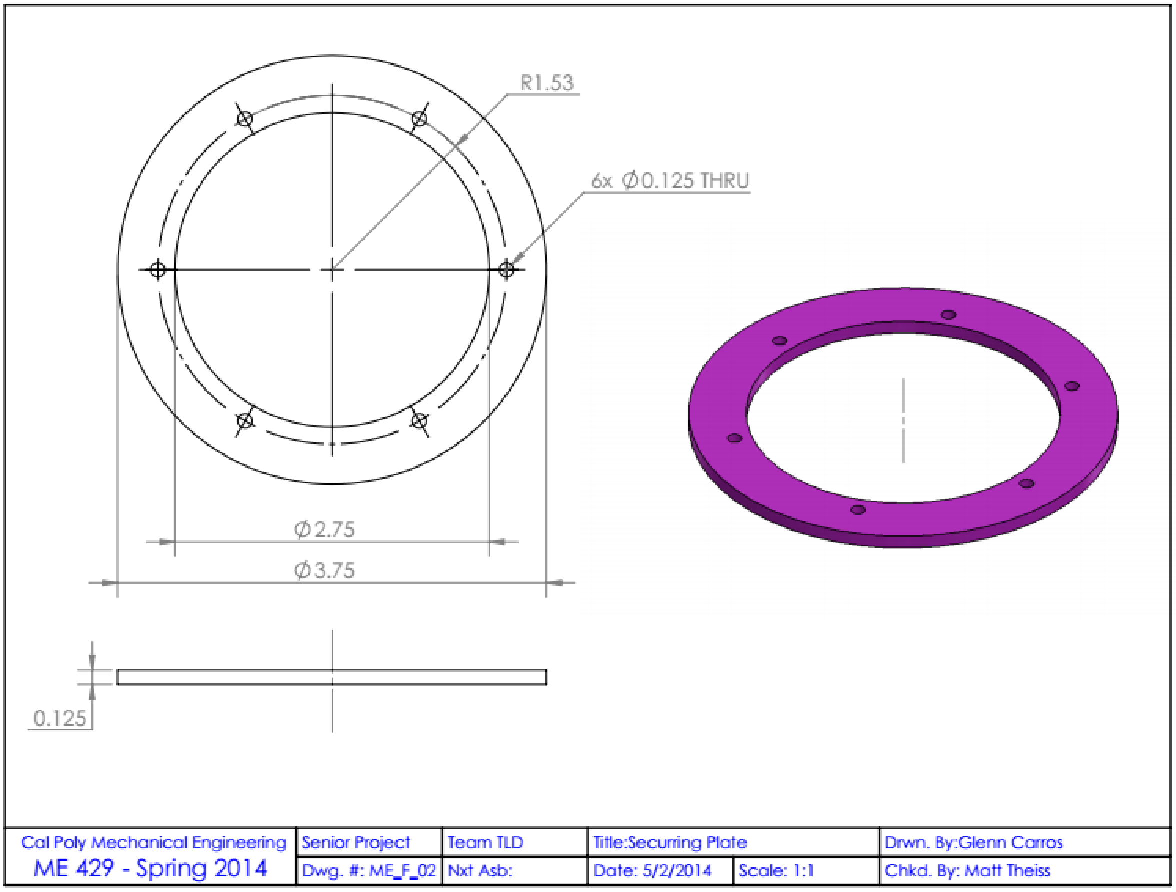
Tripod Foot Adapter Engineering Drawing



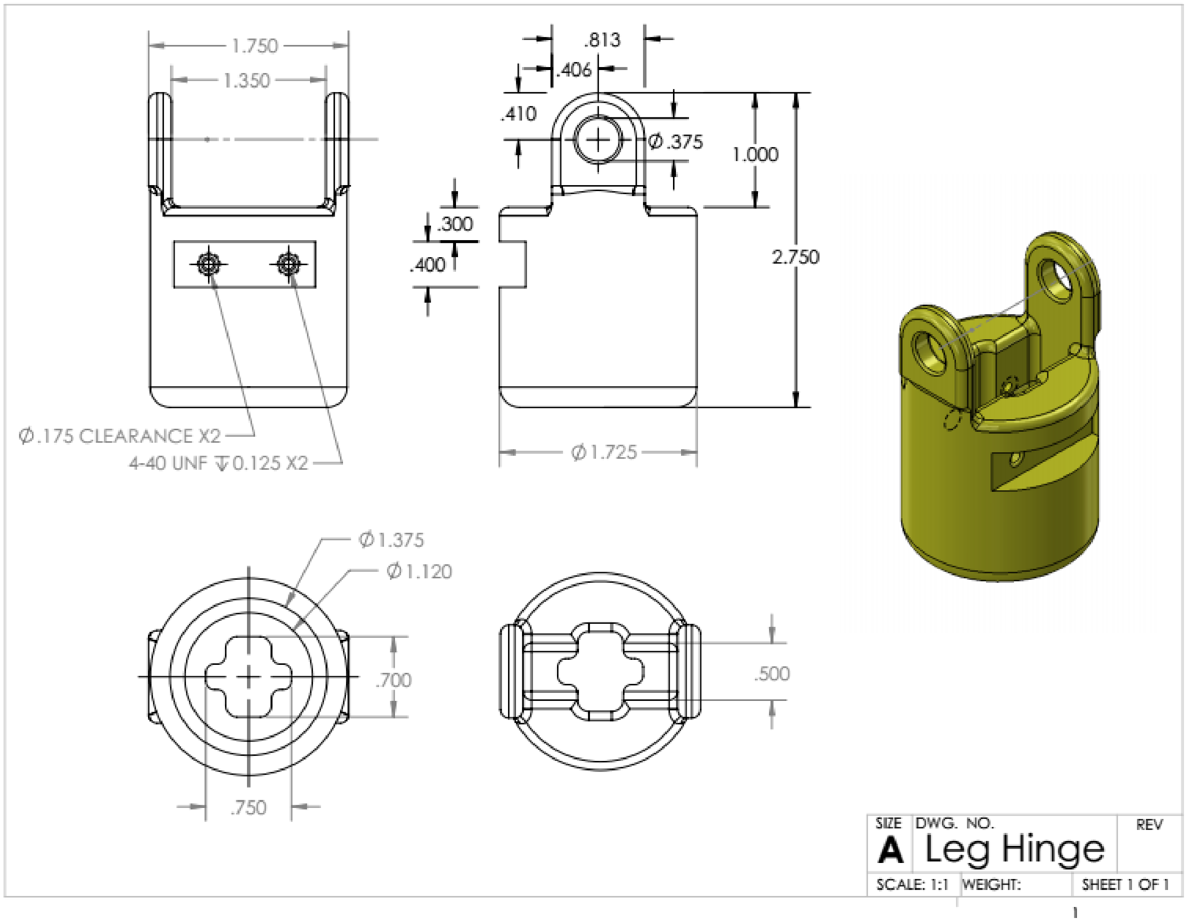
Tripod Head Engineering Drawing



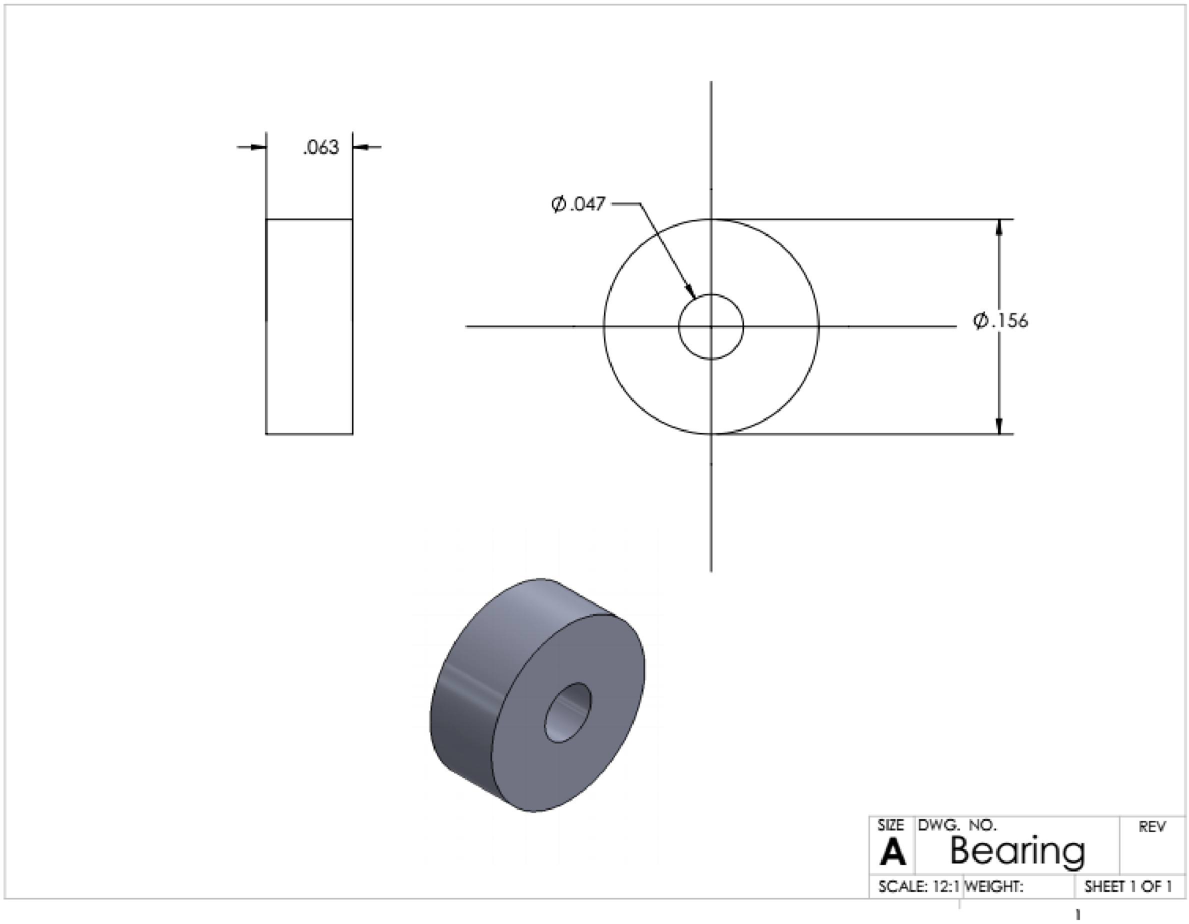
Tripod Securing Plate Engineering Drawing



Tripod Leg Hinge Engineering Drawing



Tripod Bushing Engineering Drawing



Appendix E
Gantt Chart

Attached you will find the definitive schedule for the project up to this point and through the end of the project.

ID		Task Mode	Task Name	Duration	Start	Finish
1			**Choose Project**	**3 days**	**Mon 1/6/14**	**Wed 1/8/14**
2			Project Presentations	1 day	Tue 1/7/14	Tue 1/7/14
3			Turn in Project Preference Form	0 days	Wed 1/8/14	Wed 1/8/14
4			**Introduction to Sponsor**	**7 days**	**Thu 1/9/14**	**Fri 1/17/14**
5			Send Intro Letter	0 days	Tue 1/14/14	Tue 1/14/14
6			Turn in Travel Paperwork	2 days	Wed 1/15/14	Thu 1/16/14
7			Meet Sponsor	0 days	Fri 1/17/14	Fri 1/17/14
8			**Project Proposal**	**11 days**	**Tue 1/21/14**	**Tue 2/4/14**
9			Project Definition	3 days	Tue 1/21/14	Thu 1/23/14
10			Existing Product Research	3 days	Fri 1/17/14	Tue 1/21/14
11			Patent Research	1 day	Tue 1/21/14	Tue 1/21/14
12			House of Quality	3 days	Tue 1/28/14	Thu 1/30/14
13			Submit Project Proposal	0 days	Tue 2/4/14	Tue 2/4/14
14			**Conceptual Design Stage**	**28 days**	**Tue 2/4/14**	**Thu 3/13/14**
15			Ideation	7 days	Tue 2/4/14	Wed 2/12/14
16			Team Evaluation 1	1 day	Thu 2/6/14	Thu 2/6/14
17			Concept Modeling	1 day	Tue 2/11/14	Tue 2/11/14
18			**Idea Evaluation**	**9 days**	**Thu 2/13/14**	**Tue 2/25/14**
19			Pugh Matricies	4 days	Mon 2/17/14	Thu 2/20/14
20			Decision Matricies	4 days	Thu 2/20/14	Tue 2/25/14
21			Budgeting	3 days	Tue 2/25/14	Thu 2/27/14
22			Project Planning	3 days	Tue 2/25/14	Thu 2/27/14
23			Gantt Chart	1 day	Tue 2/25/14	Tue 2/25/14
24			Turn in Concept Design Report	0 days	Tue 3/4/14	Tue 3/4/14
25			Concept Design Review (In Class)	0 days	Thu 3/6/14	Thu 3/6/14
26			Concept Design Review (With Sponsor)	0 days	Thu 3/13/14	Thu 3/13/14
27			**Final Design Stage**	**66 days**	**Fri 2/7/14**	**Fri 5/9/14**
28			Design FMEA	3 days	Tue 3/11/14	Thu 3/13/14
29			Design DVP	3 days	Tue 3/11/14	Thu 3/13/14
30			Team Evaluation 2	1 day	Thu 3/13/14	Thu 3/13/14
31			Reflection 2	1 day	Sun 3/16/14	Sun 3/16/14

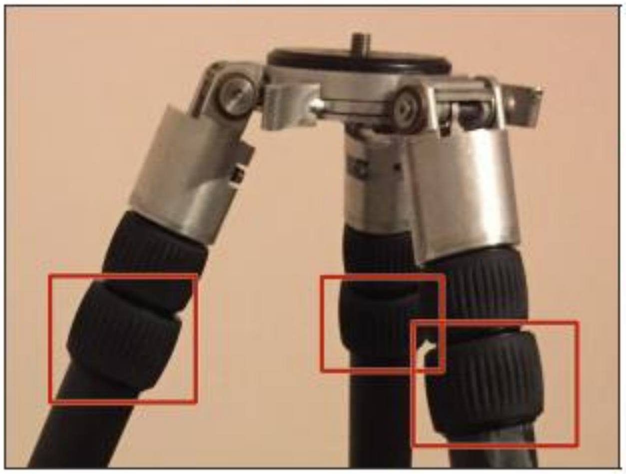
ID		Task Mode	Task Name	Duration	Start	Finish
32			Desing Work	12 days	Fri 3/14/14	Mon 3/31/14
33			DFM	3 days	Tue 4/1/14	Thu 4/3/14
34			DFA	3 days	Tue 4/1/14	Thu 4/3/14
35			Design Analysis	9 days	Thu 4/3/14	Tue 4/15/14
36			BOM	4 days	Thu 4/17/14	Tue 4/22/14
37			CAD Models	8 days	Tue 4/22/14	Thu 5/1/14
38			Prepare Design Report and Presentation	6 days	Thu 4/24/14	Thu 5/1/14
39			In Class CDR	0 days	Thu 5/1/14	Thu 5/1/14
40			Turn in Design Report	0 days	Fri 5/2/14	Fri 5/2/14
41			Team Evaluation 3	1 day	Tue 5/6/14	Tue 5/6/14
42			Reflection 3	1 day	Thu 5/8/14	Thu 5/8/14
43			Sponsor CDR	0 days	Fri 5/9/14	Fri 5/9/14
44			**Ethics Case Study**	**13 days**	**Tue 5/6/14**	**Thu 5/22/14**
45			Ethics Training	1 day	Tue 5/6/14	Tue 5/6/14
46			Ethics Memo Due	1 day	Tue 5/13/14	Tue 5/13/14
47			Case Study Presentation	1 day	Thu 5/22/14	Thu 5/22/14
48			**Prototype Construction**	**110 days**	**Tue 5/13/14**	**Mon 10/13/14**
49			Part Ordering	9 days	Tue 5/13/14	Fri 5/23/14
50			Manufacturing Prototype Components	102 days	Tue 5/20/14	Wed 10/8/14
51			Team Evaluation & Reflection 4	1 day	Thu 6/5/14	Thu 6/5/14
52			Project Update to Sponsor	0 days	Fri 10/3/14	Fri 10/3/14
53			Assemble Prototype	6 days	Mon 10/6/14	Mon 10/13/14
54			Complete Prototype	0 days	Mon 10/13/14	Mon 10/13/14
55			**Project Testing**	**16 days**	**Mon 10/13/14**	**Mon 11/3/14**
56			Drop Test	1 day	Mon 10/13/14	Mon 10/13/14
57			Timed Setup/Takedown	1 day	Mon 10/13/14	Mon 10/13/14
58			Thermal Test	3 days	Tue 10/14/14	Thu 10/16/14
59			Underwater Test	1 day	Sat 10/18/14	Sat 10/18/14
60			Durability (1000 Cycles)	5 days	Mon 10/20/14	Fri 10/24/14
61			Weight Capacity	1 day	Tue 10/21/14	Tue 10/21/14
62			Height Inspection	1 day	Wed 10/22/14	Wed 10/22/14
63			Weigh	1 day	Thu 10/23/14	Thu 10/23/14
64			Rigidity and Stability	1 day	Fri 10/24/14	Fri 10/24/14

ID	ℹ	Task Mode	Task Name	Duration	Start	Finish
65			Project Hardware Demo	1 day	Fri 10/24/14	Fri 10/24/14
66			Team Evaluation & Reflection 5	1 day	Fri 10/31/14	Fri 10/31/14
67			**Senior Project Exit Exam**	**1 day**	**Fri 10/31/14**	**Fri 10/31/14**
68			**Prepare For Expo**	**9 days**	**Mon 11/10/14**	**Thu 11/20/14**
69			Clean Prototype	1 day	Tue 11/11/14	Tue 11/11/14
70			Make Posters	5 days	Tue 11/11/14	Mon 11/17/14
71			Senior Expo	0 days	Thu 11/20/14	Thu 11/20/14
72			**Prepare Final Report**	**11 days**	**Fri 11/21/14**	**Fri 12/5/14**
73			Work on Report	11 days	Fri 11/21/14	Fri 12/5/14
74			Team Evaluation & Reflection 6	1 day	Fri 12/5/14	Fri 12/5/14
75			Turn In Final Report	0 days	Fri 12/5/14	Fri 12/5/14

Appendix F

Really Right Stuff Quick Adjust Tripod Manual

Step 1 — Extending the Lower Leg Segments



- This step only needs to be completed to achieve a height greater than 42.5"
- Twist locks counter-clockwise to unlock
- Extend leg to desired height
- Twist locks clockwise to lock

Step 2 — Using the Upper Quick Set Leg Locks

- Using thumb, apply pressure to lever until legs drop
- If full height is not desired, push legs against ground to shorten
- Release lever to lock legs in place

Step 3 — Setting the Base

- Spread all three legs to desired angles

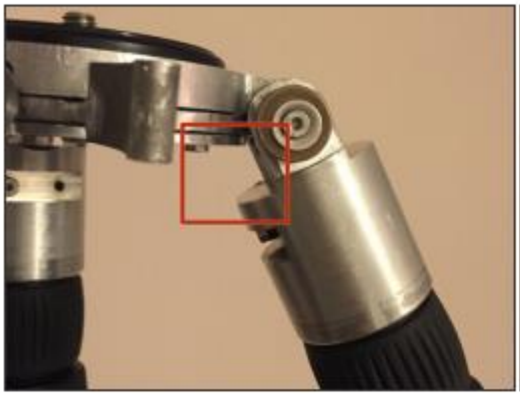
Step 4 — Making Quick Adjustments

- Press on thumb lever to release upper leg locks
- Move tripod head to desired location (adjusting height of the legs)
- Release thumb lever to lock legs into place

Step 5 — Collapsing Tripod for Storage

- Bring all legs to their center position
- Actuate thumb lever and press legs against ground to fully collapse legs
- Release lever so legs lock into collapsed position
- Twist lower lock counter-clockwise to unlock leg
- Bring leg up to fully collapsed position
- Twist lower lock clockwise to secure leg into collapsed position

Step 6 — Warnings



- Pinch point located between the leg and the apex (head)

- Pinch point located above the twist lock at fully collapsed position