Development of 3D Compression Molded Composite Primary Structure

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Black Gold

"A carbon fiber process more valuable than gold"

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Statement of Disclaimer

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Abstract

The work accomplished by the Black Gold team improved upon the carbon fiber compression molding research and information available on the Cal Poly San Luis Obispo campus. The team used the rear suspension rocker arm off a Ventana Alpino mountain bike as a design goal for this project. This research and body of work includes the methods used to design a compression molded part for complex part loading and shape. This extends to the process of choosing an appropriate layup process, in addition to benefits and drawbacks of the use of chopped fibers in compression molding. The research includes the process and information required to build aluminum molds for compression molded parts of complex shape; manufacturing techniques, and suggestions for the use of compression molding carbon fiber. Finally, data is presented which compares the final compression molding results under ultimate and relative stiffness testing to a comparable part made from aluminum. Ultimately, the team found that compression molding proved to be a potential manufacturing alternative. The rocker arms produced by the team were able to withstand a load of up to 800lbs; meeting the teams initial design criteria before experiencing localized fractures. With future iteration, and more focus on design for loading, the process could yield parts which could carry much higher loads. In addition, the use of chopped fiber around the bearings regions was a success, ultimately showing that a combination of chopped and cloth fiber was a useful load carrying combination. Further research in these processes would definitively improve upon the results obtained by the team, and as information regarding compression molding increases the team expects its use to become more popular.

Introduction

This Final Design Report contains the work accomplished by the Black Gold team as they worked in conjunction with Professor Mello and Sherwood Gibson of Ventana Bikes USA to research and develop the process of compression molding carbon fiber. Sherwood Gibson is the founder and owner of Ventana Bikes USA. Ventana Bikes USA wanted to research the possibility of replacing their current aluminum rocker arm with that of a carbon fiber equivalent. Black Gold worked on building upon the compression molding carbon fiber techniques developed and used by past Cal Poly researchers. The team expanded upon previous compression molding carbon fiber results to create a more complicated 3D part to meet the design requirements of Ventana Bikes USA. The design criteria for the part was to manufacture a compression molded redesigned rear rocker-arm of a Ventana Alpino. This bike featured both front and rear suspension, and is designed for all-mountain biking use. Figure 1 below shows the frame of the Ventana Alpino, and a closer view of the rocker arm component. The rocker arm presented both a dimensionally and functionally difficult design challenge. A part of this complexity, created through compression molding, had yet to have been created with the compression molding research completed on campus thus far. Sherwood Gibson hoped to benefit from this research by allowing him and his company to consider the manufacturing costs and design requirements of using carbon fiber. In addition, Dr. Mello used this project as a method to further expand upon his research regarding the use of compression molding carbon fiber. This research aided in the development of future Cal Poly composites curriculum material, in addition to providing valuable carbon manufacturing information to many of the club projects on campus.

Figure 1. Ventana Mountain Bikes USA Alpino bicycle frame, and aluminum rocker arm.[1]

Objectives

Complex part features and three-dimensional geometry will be required to create a compatible part, and documentation will be made regarding the processes and steps required to produce these features with carbon fiber compression molding. Research and testing will be done regarding the use of a combination of chopped fiber and unidirectional pre-impregnated fiber. The use of unidirectional fibers allows for the scrap pieces to be reused as chopped fibers. This reduction in waste is one of the key benefits of compression molding carbon fiber. Black Gold will experiment with the use of long fibers where loading is simple and high, and chopped fiber in areas under complex loading with less stress. This combination will be used to experiment with the structural benefits of combining long fibers throughout a chopped fiber piece. The compression molded carbon fiber part will be compared against the current aluminum rocker arm used by Ventana Bikes. They will be compared in the areas of strength, overall geometry compatibility, stiffness, and manufacturing costs. The strength and stiffness comparisons will be obtained using the on-campus Instron, model 1331. This machine allows for the parts to be loaded such that measurements can be taken in terms of deflection, loading, and strength.

Background

Compression molding carbon fiber is a manufacturing method with a small amount of current marketplace exposure. Compression molding carbon fiber can be distinguished from other carbon fiber processes in that it has a unique curing method. For the resin to cure, composite layers are placed within a metal mold with mating halves, this is seen in Figure 2 below, where the upper and lower mold halves are labeled. The molding materials for compression molding vary, metal molds, and even inserts of rubber are sometimes used. Black Gold used an aluminum mold, and one benefit of using metal molds in this process is the ability to apply increased compressive force on the carbon fiber layers[2]. In Figure 2 below, an example of a compression molding setup is shown, where two mold halves are used to shape a charge of material into the finished product. In this figure, the charge represents the unformed prepreg carbon fiber which molds to the desired part shape during the compression, heating, and curing process. The compression forces are amplified as the part is placed in a press. During the compression molding process, the molds are heated to increase the flow of the resin between fiber layers, in addition to causing the resin to cure.

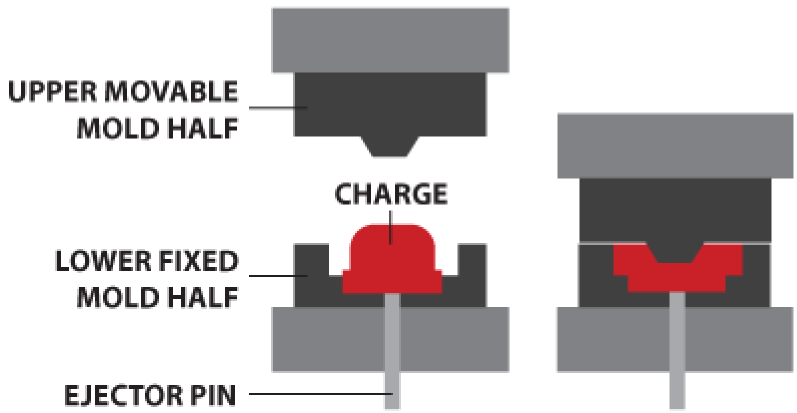

Figure 2. Compression Molding Process[2]

Traditional Manufacture of Composites

Compression molding varies from typical carbon fiber processes, which involve vacuum bagging and large autoclaves to pressurize and heat the carbon fiber parts. As composites continue to find more widespread use in products, the need for faster, more complex part production is a must[2]. This is where compression molding carbon fiber becomes an advantageous composite manufacturing method.

Almost all carbon fiber fabrication processes require that there is some sort of mold for the carbon fiber to take shape. In general, thermoset composites, composites which require high temperatures for curing, are placed in a layup. A layup is made up of the layers of fabric carbon plies in various weaves and directions depending on the loading characteristics or designed strength. The layup fundamentally determines the strength of the part, as carbon fiber is unique in the sense that it is not an isotropic material. Carbon strands have the greatest strength in tension, so when the fibers are woven in a cloth the weave of the carbon fiber cloth determines the strength characteristics of the cloth. The part designer can arrange the fibers in directions advantage for loading or design characteristics[3].

Once the carbon layup is complete, the layup needs to cure so that it can rigidly take the shape of the mold it is trying to replicate. Simple curing can be done at room temperatures until all the resin has cured. To speed up this process heat and pressure are applied to the layup, this is generally done in an autoclave. The autoclave is one of the costliest components of carbon fiber part manufacturing. This is where the compression molding process is advantageous. Compression molding mimics the pressure and temperatures of the autoclave with a heated press and mold. This alternate manufacturing method altogether replaces the need for an autoclave. The largest downside to compression molding is the expensive cost required to manufacture the metal dies used for the part shaping. Once the mold has been produced though, the molds have been known to complete thousands of parts prior to needing mold replacement. [4]

Dr. Mello, a mechanical engineering professor at Cal Poly, has been working with engineering students to further research the use of compression molding as a carbon fiber manufacturing process[2]. There has been a sequence of projects, including a master's thesis and senior project, building upon each other to develop a knowledge base for the design and process of compression molding carbon fiber parts. Dr. Mello has been able to use the information obtained from these projects as additional experiments and course content for his composite teachings and lab[5].

Corinne Warnock's thesis "Process Development for Compression Molding of Hybrid Continuous and Chopped Carbon Fiber Prepreg for Production of Functionally Graded Composite Structures" studied the use of compression molding carbon fiber for ASTM tensile testing specimens. An image of composite testing specimens can be seen below in Figure 3. These compression molded parts were tested for their structural and mechanical properties[2]. The information in this thesis was used throughout Black Gold's research as a baseline for compression molding techniques. Corinne's thesis offers a great deal of information regarding the procedure of compression molding, in addition to offering data for comparable tensile strengths of the samples created with these processes.

Figure 3. Example of initial tensile specimens created by Corinne Warnock during her research[6]

Additional research was completed after Corinne Warnock's thesis by Cal Poly students through a Cal Poly senior project team named Comp^3. This team worked on improving upon the compression molding research completed by Corinne, their primary efforts focused towards the manufacturing of more complicated compression molded parts. Comp^3 choose to use compression molding to create a sunglass case. The case was chosen as a test bed for a more complicated compression molded part. The team felt that the case offered more complexity than the tensile pieces created by Corinne, but also posed to further increase university knowledge regarding compression molding manufacturing and procedural knowledge.

Project Scope

The Black Gold team was tasked with continuing campus research on compression molding carbon fiber. The team designed and manufactured a rocker arm, a mountain bike rear suspension component, in hopes to replace a currently used machined aluminum arm as seen in Figure 4. Black Gold reverse engineered the current aluminum rocker arm design utilized by Ventana Bikes. Iterations of this rocker arm design were used to investigate a manufacturing methodology of compression molding for complex parts. In addition, this method's viability to provide comparable structural integrity to the aluminum rocker arm was tested. By converting the part to carbon fiber, the team and sponsor hoped to see a decreased weight of the part, in addition to greater stiffness, all at a reasonable cost difference. The known challenges and complexities presented in this part were its load carrying characteristics, tolerance requirements, thin features and complex shape. Compression molding a part of this complexity has been new territory for the composites research on campus thus far. This project has yielded research to determine whether compression molding is a viable option to traditional machined aluminum parts, and traditional carbon fiber manufacturing methods.

Figure 4. CNC machined aluminum rocker arms on a Ventana USA bicycle[7]

Problems with Traditional Carbon Fiber Manufacturing Method

From our interviews with Professor Mello we have learned that the industry standard procedures for creating tailored carbon fiber composite parts can be very wasteful. Common manufacturing practice includes the use of unidirectional carbon fiber sheets pre-impregnated with a resin binder matrix (unidirectional prepreg). The carbon sheets are then cut into shapes or topographic layers and laid up on top of each other in specific orientations to build the shape of a three-dimensional part. This "cookie cutting" of unidirectional prepreg, as seen in Figure 5, leaves upwards of 50% of the original sheets thrown away as scraps. A major goal of Professor Mello's research is to reduce waste by utilizing the cut away portions of the unidirectional prepreg as building material for carbon fiber parts[5].

Figure 5. An example of "cookie cutting" a pattern into a sheet of carbon fiber. In this instance, more than half of the area will be thrown away[8].

Many tailor-made carbon fiber polymer matrix composites (PMC) are currently created using autoclaves[9]. The PMC is laid up inside a disposable vacuum bag, the air is pumped out of the bag, and the assembly is placed in an autoclave for curing. The combination of low pressure inside the vacuum bag and high pressure in the autoclave forces gasses out of the PMC and helps ensure layers of prepreg bond together in a single monolithic part with a continuous polymer matrix. These parts are tailor made in that the successive layers of unidirectional prepreg are oriented in pre-calculated directions to give a composite part the greatest strength in predicted loading paradigms [9].

This contrasts the methods used during the manufacturing of compression molded composites, wherein chopped carbon fibers are generally used as a bulk molding compound (BMC) or sheet molding compound (SMC) consisting of short lengths of carbon fiber under 2 inches. The chopped fiber orientation is dispersed randomly in the mold cavity and allowed to flow into the shape of the mold. The autoclave method adds an extra level of waste in disposable vacuum bags, and autoclaves have a very high upfront cost that increases exponentially with size[9].

Professor Mello believes much of the waste in traditional carbon manufacturing processes can be avoided by hybridizing parts with unidirectional prepreg and chopped composite in a compression molded process[5]. The compression molding process replaces the vacuum bag and autoclave pressure differential with a hydraulic or mechanical press. The press is heated to activate the matrix curing, and the part is compressed between press halves to allow matrix and fibers to flow into a steady state arrangement. Part volumes with simple loading or virtual two force members can be built up with directionally oriented unidirectional prepreg sections cut from a larger sheet. Bulk volumes and areas with complex loading can be filled in with randomly or intentionally oriented chopped fiber left over from the "cookie cutting" of unidirectional prepreg sheets[2].

In a well-designed part this can mitigate waste to almost nothing, and allow complex, strong parts to be manufactured for relatively little upfront cost. There are geometric limitations to a compression molded part due to the opening and closing axis of motion of the mold; however, parts of high levels of complexity are possible with imaginative mold design. A parallel to the complexity of parts accomplished with compression molding can been seen in the injection molding industry[10]. This is evident through the wide variety of injection molded parts you see across the market today. One example of a component made with compression molding is the sunglass case made by the Comp^3 senior project team. This case can be seen below, in Figure 6. Black Gold showed that the use of compression molding allows for the creation of a part with the complex external surfaces seen in the Ventana Alpino rocker arm.

Figure 6. Compression molded sunglass case made by Comp^3[11]

Corinne Warnock's Thesis

Corrine Warnock, a former Cal Poly mechanical engineering graduate student, developed a thesis regarding the process for the compression molding of hybrid continuous and chopped carbon fiber prepreg to produce functionally graded composite structures. Her work offered research into the methods required when working with compression molding carbon fiber, in addition to the capability of the manufacturing method as an alternative to traditional carbon fiber manufacturing methods. Of particular interest in her thesis are her details around the mold design, releasing parts from the mold, and calculations for the final shape of a molded part[2].

Corinne utilized Cal Poly's composites lab in Engineering IV for her thesis work. The on-campus composites lab contains a Carver Model C heated laboratory press, seen in Figure 7, which provides a six-inch by six-inch area to fit a mold for compression molding. There is also an Instron Model 1331 tensile testing machine in the lab used to quantify carbon fiber sample strengths. The equipment in this lab was used in her research for both manufacturing and testing purposes. Black Gold has used the same equipment to manufacture the carbon fiber rocker.

Figure 7. The Carver Model C heated laboratory press located in the composites lab of Engineering IV.

Corinne Warnock's Manufacturing Methods

Warnock's mold is designed with a parting line along the top edge of a tensile specimen, and a 1° draft angle on the vertical faces to assist in removing of the part from the mold[2]. Karlos Guzman's paper "Manufacturing Methods for Composites: Compression Molding Research" contains more details regarding mold design and some of the manufacturing techniques used in Ms. Warnock's thesis. While Karlos Guzman recommends a 3-5° draft angle for larger vertical faces, Warnock's tensile specimen is only 0.201 inches tall at its largest face, which is the reason for the smaller draft angle.[7].

Warnock's mold was cut from a solid block of 6061 aluminum, and initially faced on both top and bottom surfaces using a 1.5-inch face mill. The mold cavity was designed for a scaling factor of .99991 in the fiber direction, 1.0027 in the transverse in plane direction, and 0.9 in the out of plane direction based on an assumption of using AS4/3501-6 uni prepreg sheets[7]. It is unknown if published scaling values are available for either the P35/Z03 or M46J/TC250 uni prepreg sheets that were used in Ms. Warnock's thesis. The mold was cut on a Haas VF3 vertical machining center using G-code compiled from HSMWorks and a SolidWorks solid model[2].

After machining Ms. Warnock seasoned the mold using Mavcoat 527 ML, Frekote 200 NC, and Axel F-57NC in a process developed by Quatro Composites to seal the pores in the aluminum. Alignment pins were added to the mold, and mold release sprayed on the mold prior to processing. Ms. Warnock found that mold release was not sufficient in removing the parts made of M46J/TC250 unidirectional prepeg, and later added ejection pins to assist in part removal.[2]

Ms. Warnock developed several calculations for cured ply thickness of a laminate. These calculations would estimate the final thickness of each layer of unidirectional prepreg post curing, and assist in determining the final geometry of a part made from a known number of layers of unidirectional prepreg[2]. The M46J/TC250 unidirectional prepreg was used for Ms. Warnock's thesis research, as it is specifically formulated for out of autoclave curing. The compression molding process works well with resin matrix materials that have a viscosity an order of magnitude larger than materials intended for autoclaving (close to 100 Pa*s). This promotes the fibers to flow along with the matrix during compression and curing, instead of the matrix flowing around the fibers. Compression molding unidirectional prepregs also have a higher matrix to fiber ratio, which allows some resin matrix to flow out of the mold as flashing, and helps to fill in the entire mold volume[12].

In addition to her tensile testing, Ms. Warnock performed response surface methodology calculations to determine the effects of different factors on the curing process. Her main factors were temperature, time, number of plies, and the responses were flexural strength, tangent modulus, and short beam strength. She found that none of the main factors had a statistically significant effect on the mechanical properties of the specimens; however, "...285 °F cure for 70 minutes would produce the strongest M46J/TC250 specimens of the tested cure cycles"[2].

Part and Mold Design Guidelines

A resource used by Black Gold titled, “Part and Mold Design Guidelines for the High Volume Compression Molding of Carbon Fiber Reinforced Epoxy” by Donald Lasell also proved to be a valuable asset for information regarding mold design. Mr. Lasell divides molds into two categories. A flash type compression mold, as seen in Figure 8, consists of a landed area around the perimeter of the mold cavity. The landed area allows excess resin to flow out of the cavity until the plug contacts the cavity land, at which point all the compressive pressure will be carried by the land. The second style is the sheet molding compound (SMC) design. The SMC design incorporates a “telescoping shear edge” as part of a vertical parting line, as seen in Figure 9. We believe this “telescoping shear edge” allows the full pressure of the mold to remain on the SMC, and the mold halves never make metal to metal contact. Interestingly this mold design calls for very high pressures compared to those seen in both Ms. Warnock’s thesis and the Comp^3 team’s process recipe. Per Mr. Lasell, “Molding pressures in a typical SMC pressing operation can be expected to be above 1000 psi and regularly are 2000 psi (1 ton per square inch)”. Ultimately Mr. Lasell recommends utilizing features from both flash and “telescoping shear edge” molds[13].

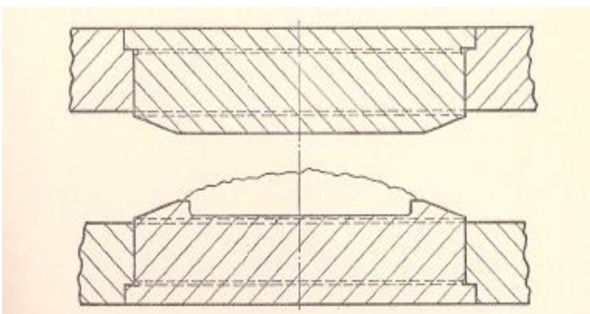

Figure 8. Cross section of a flash type mold with a landed area surrounding the mold cavity[13]

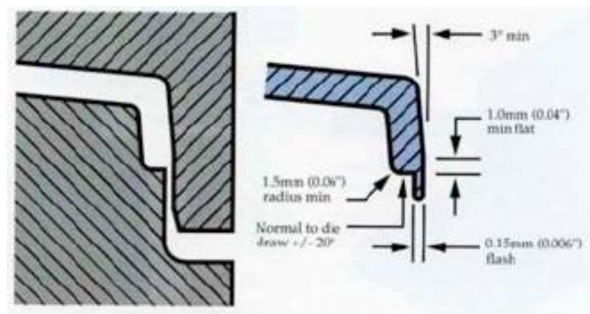

Figure 9. Close up cross section of a “telescoping shear edge” or SMC type mold on left, with the cross section of a resulting part on right[13].

The question of pressure distribution across the part and mold is one that will be modified and tested during experimentation and iteration. Ms. Warnock did run into an issue with mold interference taking up a portion of the closing pressure that was meant for the tensile specimen. This came about as a result of the solid model mold design not considering the actual tooling involved in the machining operation[2]. The bottom half of the mold had 90° external corners that mated with 90° internal corners on the top half of the mold. The mold was cut with a ball nose end mill resulting in the top half possessing a fillet instead of a 90° internal corner. A design such as the “telescoping shear edge” mold would mitigate that risk[13]

Hybrid Continuous and Chopped Fiber Patent

The idea of mixing chopped fiber with unidirectional or “continuous” fiber does have some precedent. General Electric Company filed for a patent in 2014 titled “Hybrid Continuous Fiber Chopped Fiber Polymer Composite Structure” in which they describe hybrid fiber monolithic parts for aerodynamic sections of airplane turbine engines. In this patent application, the continuous fiber portion creates the structural portion of the part, while an embedded chopped fiber section builds up the volume and shape of the part for an aerodynamic net shape[14] as seen in Figure 10.

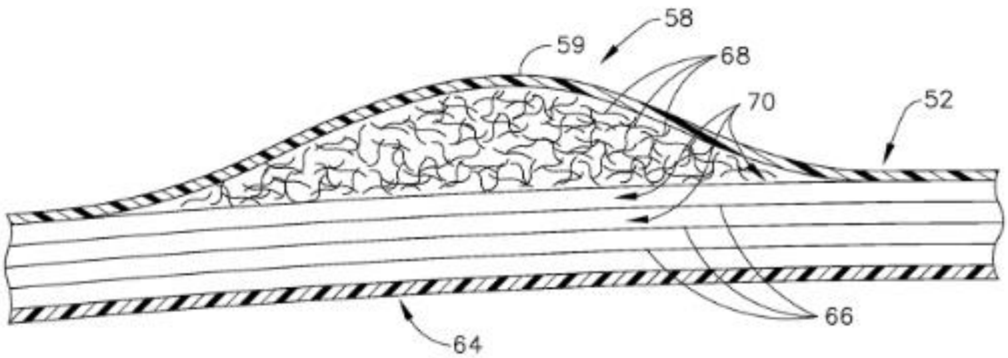

Figure 10. Hybrid continuous fiber and chopped fiber composite structure presented in patent application US2014/0186166 A1. Callouts relevant to the discussion include 66, continuous fibers, 68, chopped fibers, and 70, thermoplastic resin. All other callouts refer to the geometry of the part[13].

Bicycle Load Calculations

In a research project previously completed by Eric R. Graham, a former Cal Poly student, a Ventana bicycle was setup with load sensors and a Data Acquisition System. In this paper titled “Mountain Bike Load Data Acquisition System”, by Eric R. Graham, research is obtained by riding a full suspension mountain bike down a mountain bike trail. The main premise of this paper resides on measuring the loads experienced by the front fork and rear suspension during the bicycle’s use on the trail. Several riders are chosen for the data set, all of whom represent different skill levels, and bike loading scenarios[12]. The data obtained in this experiment regarding the loading of the rear suspension was applied to Black Gold’s project. The loading data obtained in Graham’s trials had a maximum loading cycle value of 400lbs. Most loading cycle values obtained were in the 200lb region[12]. One of the outputs of this testing can be seen below in Figure 11. This figure illustrates the forces experienced by both the front and rear wheel during a 60 second test interval. Using this 400lb load as an estimation for max loading, Black Gold used this research to help determine the forces for their final bike loading calculations.

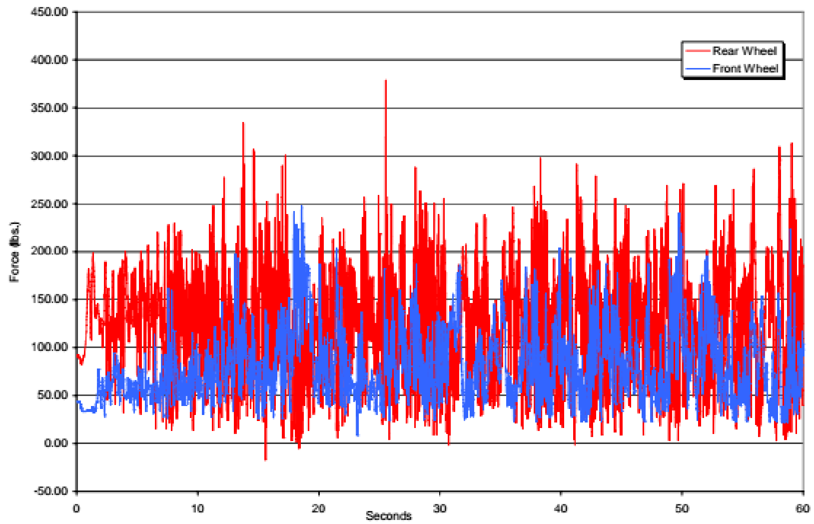

Figure 11. Plot of load versus time for 60 seconds of bike loading.

Additional testing by Graham concerned jumping the bike off a 3-foot ramp, and landing flat onto the ground. The highest force measured by the rear suspension for this impact was 550lbs[12]. This type of high impact loading indicates that as larger features are attempted on the bike the forces experienced by the bike increase greatly.

With the guidance of Dr. Mello, a value of 1600lbs was chosen for the greatest load experienced by the whole bike. This value is representative of a 200lb weight of the rider and bike at 8 gravitational forces. By dividing this 1600lb load evenly across both the front and rear of the bike results in an 800lb max loading situation which was used in the design of the carbon fiber rocker arm. This is an ultimate design load the bike would be subject to, and would be a “rare” or “uncommon” loading situation. This value was chosen as an extreme maximum loading case, as it is greater than any of the forces experienced in the data obtained from Graham’s research.

To help understand the change in geometry that occurs in a Ventana Alpino during loading, the two images in Figure 12 below show the two extreme rear suspension locations. On the Alpino, as the rear wheel experiences loading, the forces are transmitted through the upper rear triangle, known as the seat stay, and into the rocker. The rocker then pivots around the lower bearing on the rocker connected to the seat tube, and transmits the force to the shock shown in red.

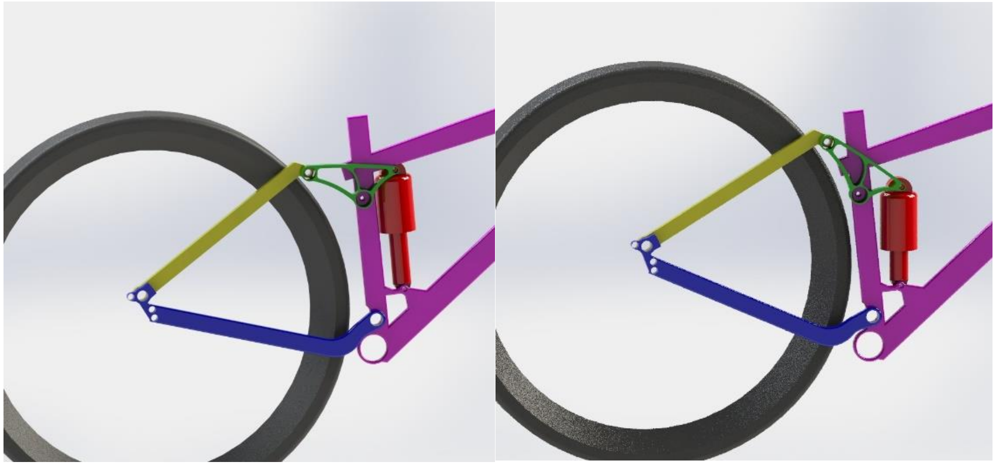

Figure 12. Left image shows the completely unloaded Ventana Alpino bike. Right image shows a fully loaded (bottomed out) Ventana Alpino bike.

An analysis was then completed on the rear triangle of the bike using the forces determined previously with our meeting with Dr. Mello. The 800lb force was to be applied to the center of the rear wheel acting upward. The assembly was then assumed to act like a system of static members, and analyzed accordingly. The analysis is shown in Figure 13 below, where the forces for each member can be seen. By calculating the forces in each of the components during this loading the team allowed the analysis of the stresses that the rocker arm experiences in a fully loaded situation. As the bike travels through its suspension under load, the leverage ratio of the forces applied to rear wheel and the forces experienced by the components of the rear triangle change.[15] To account for this, the team has calculated the expected stresses at the two extremes of the cycle, the fully extended geometry and the fully compressed geometry states of the rear suspension. Stresses were calculated using geometries from both the unloaded and fully compressed situations.

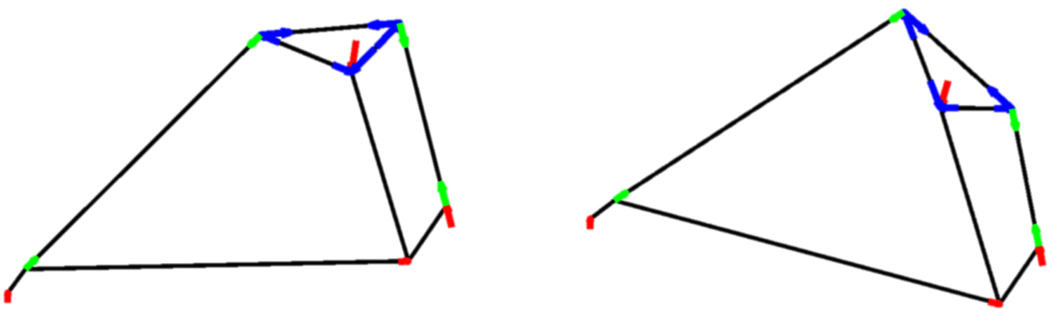

Figure 13. MATLAB reactionary force calculations. Left is unloaded geometry, Right is loaded geometry.

The forces calculated for all the components in the rear end of the bike were calculated in a MATLAB script, which allowed for their relative positions to be entered, and then the resulting forces obtained (Appendix A. Appendix A. Static Analysis MATLAB script). The output of this calculation shows where the reactionary forces of each member represented by the vectors at each of the bearing locations. The red arrows show the input force on the left and the three reaction forces on the bike frame on the right, the green arrows show the internal forces on the two force members connecting to the rocker arm, and the blue arrows show the internal forces on the rocker arm itself. In these images the direction of the vector shows the direction of the reactionary force, and the length of the vector illustrates its comparative magnitude.

The Figure 14 below shows the actual magnitude of the reaction forces experienced by the rear triangle and rocker arm. This analysis then allowed the team to use the method of joints analysis to determine the internal forces and stresses within the rocker arm.

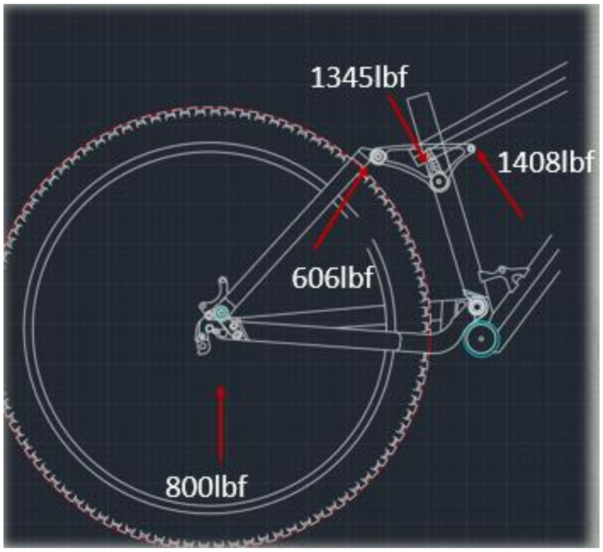

Figure 14. Magnitude of reaction forces for members on the rear triangle of the Ventana Alpino

The internal forces for the rocker were calculated in the static analysis in MATLAB, where the results of the internal forces can be seen by the MATLAB plots below. Interestingly the member of the rocker under the greatest internal forces changes as the rocker travels during its motion. In an unloaded position, the top member of the rocker, known as EF in Figure 15, has the greatest internal force, while in a fully compressed position, member DE has the greatest internal force.

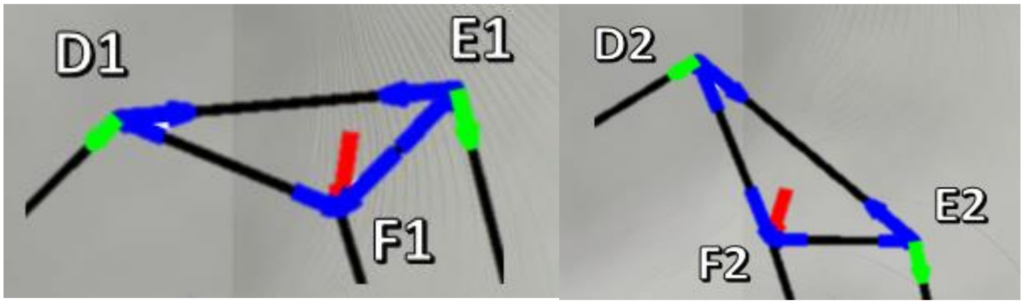

Figure 15. Internal Forces in Rocker Arm. Left-Unloaded position of rocker. Right- Loaded position of rocker.

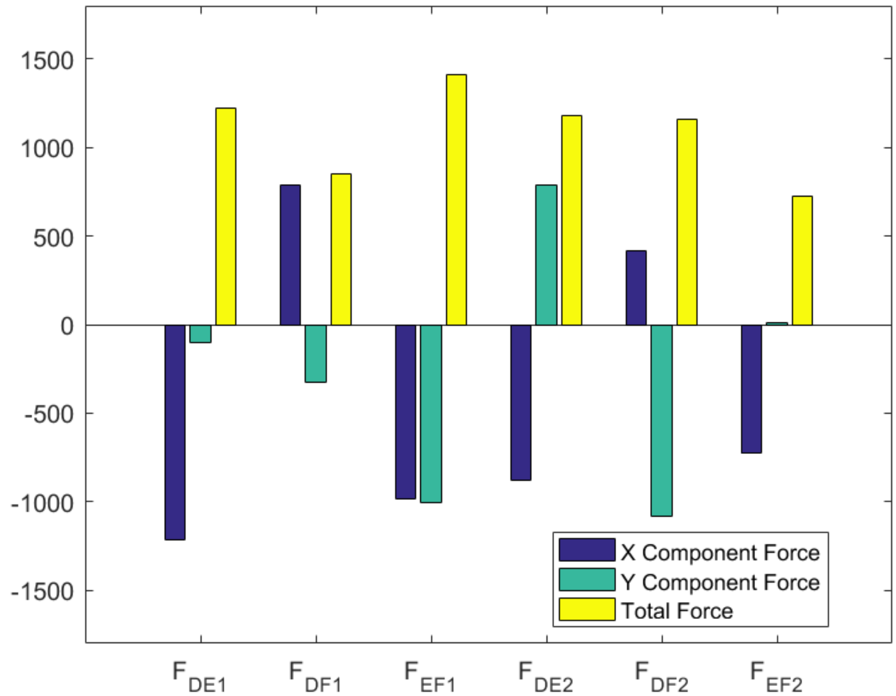

Figure 16. Internal forces in rocker in parts of the rocker. The number 1 indicates an unloaded position, while a number two indicates a fully loaded position.

Figure 16 above shows the internal forces in each member of the rocker arm experienced in the two different loading geometries as mentioned previously. This includes the fully extended, unloaded position, and the fully compressed geometry. The labels on the bottom of the horizontal axis here indicate which part of the member the force resides in, and these can be verified by looking at Figure 15. The force values on the "y" axis here are in pound force, and a negative value represents a state in which the component force vector points in the negative direction. The sign convention places the force at the vector formed by the letter combination, so F_{DE} is a force originating at point E on the DE member. Both figures above helped the team determine that the primary loads were carried by members EF and DE, and these were to be areas to focus carbon fiber layup directions on in the carbon fiber rocker design.

To estimate the internal stress that our rocker arm would experience, we discussed some loose strategies with Professor Peter Schuster. Our rocker arm design, due to manufacturing considerations, consists of a monolithic triangular shape. This complicates our analysis since there are in fact no two-force members present in the rocker arm geometry. A portion of the cross section between two bearings would be under load, and a neutral axis would exist dividing the compressive and tensile loads between different bearings. We decided on an estimation of one fourth to three fifths of the cross-sectional area between bearings that could be estimated as a purely compressive or tensile section to give us an idea of the stresses that would be present. We estimated cross sectional areas of 0.10 in^2, 0.11 in^2, and 0.17 in^2 for members DE, DF, and EF respectively. This would give us a maximum internal stress of 12.2 ksi in compression for member DE in the unloaded position, and 10.6 ksi in tension for member DF in the fully loaded position.

Chopped Fiber Material Properties

An attempt was made to quantify the material properties of the chopped fiber that was used to fill in bearing areas. A calculation for the properties known as the “Modified Rule of Mixtures” was found in “Mechanical Properties of Random Discontinuous Fiber Composites Manufactured from Wetlay Process” by Lu Yunkai[16]. The calculation, attributed to Curtis et al, takes fiber properties and matrix properties as well as chopped fiber length to diameter ratio and orientation to estimate the quasi-isentropic properties of a cured chopped fiber. Unfortunately, all of the inputs for this calculation were not able to be found, particularly the resin matrix properties for the TC275-1 epoxy made by TenCate. Material properties for a cured carbon fiber and epoxy matrix are available from TenCate, however this publishes the properties of the TC275-1 resin with a different carbon fiber from the prepreg we have available, and no properties are published of the resin by itself.

Ideation

Ideation Process

Black Gold's ideation methods focused on design elements including mold design, layup design and rocker arm design. In addition, the team also implemented a QFD ideation process in the initial design and project ideation. This process involves the listing of the customer requirements and comparing them to engineering specifications. This ultimately allows the designer to make a correlation between the customer requirements and their respective important engineering specifications. This process is performed to help define plans to produce products that meet the customer's specific needs. Our results from this process can be seen in Appendix B.

One of the most beneficial ideation sessions was that of the rocker arm design. The results from several Pugh matrices and ideation sessions for cosmetic design can be seen. In **Error! Reference source not found.**7, a Pugh matrix was utilized to compare the benefits of varying types of rocker arm cosmetic and shape designs. A Pugh matrix functions by allowing a set of criteria to be defined and analyzed, a datum is declared in order to compare the benefits of alternative design options. In our case, the datum was the aluminum rocker currently being used by Ventana. The aluminum rocker was then used in two Pugh matrices to compare the aluminum rocker in terms of manufacturability, compatibility, strength and several other aspects. This type of analysis allowed the team to see which of the cosmetic designs was most viable as a design solution. In addition to presenting the most viable design solution, the process also allowed the team to determine which engineering requirements were of key importance in the final design.

Concept / Criteria	1	2	3	4	5	6
Material Usage	Datum	-	-	+	-	S
Cost	Datum	-	-	-	S	+
Manufacturability	Datum	+	+	-	+	-
Mold Complexity	Datum	+	+	-	+	-
Aesthetics	Datum	-	S	+	-	+
Bike Compatibility	Datum	S	S	S	S	-
Size	Datum	S	S	S	+	S
Weight	Datum	-	-	+	-	+
Σ +		2	2	3	3	3
Σ -		4	3	3	3	3
Σ S		2	3	2	2	2

Figure 17. Pugh matrix for stiffness function.

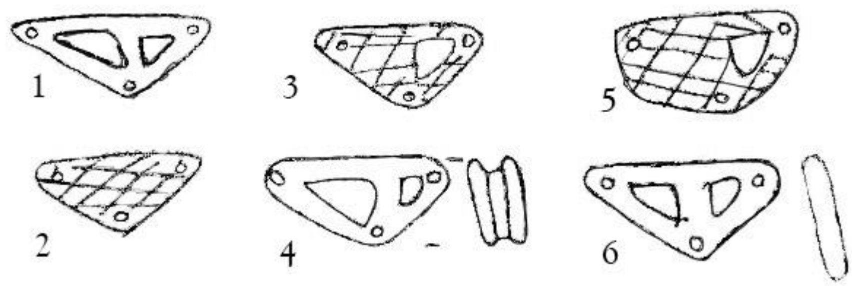

Figure 18. Stiffness function concepts used in the stiffness Pugh matrix.

Both **Error! Reference source not found.**17 and **Error! Reference source not found.**18 correlate to each other, **Error! Reference source not found.**18 contains the rocker arm shapes being used and analyzed in the Pugh matrix presented in **Error! Reference source not found.**17. Ultimately after this analysis it was found that the shape and design seen in the rocker labeled “3” in **Error! Reference source not found.**18, was the best potential design for the criteria analyzed. This proved to also align with the team’s intuition as a shape to pursue.

In Figure 19. Pugh matrix for force transmission function. and Figure 20 below, additional Pugh matrices regarding rocker arm shape are shown. This Pugh matrix primarily focuses on the manufacturing difficulties and strength offered by these designs. Once again, despite containing a different set of rocker arm designs, the results of the Pugh matrix coincided with the results found in the previous Pugh matrix of **Error! Reference source not found.**8.

Concept / Criteria	1	2	3	4	5	6	7	8	9
Manufacturability	Datum	+	+	+	S	-	+	+	+
Weight	Datum	+	+	+	+	+	+	+	+
Strength/Stiffness	Datum	-	-	-	S	S	S	S	S
Style	Datum	-	-	S	-	-	+	+	S
Manufacturing Cost	Datum	+	+	+	+	S	+	+	+
Σ + Σ - Σ S		3 2 0	3 2 0	3 1 1	2 1 2	1 2 2	4 0 1	4 0 1	3 0 2

Figure 19. Pugh matrix for force transmission function.

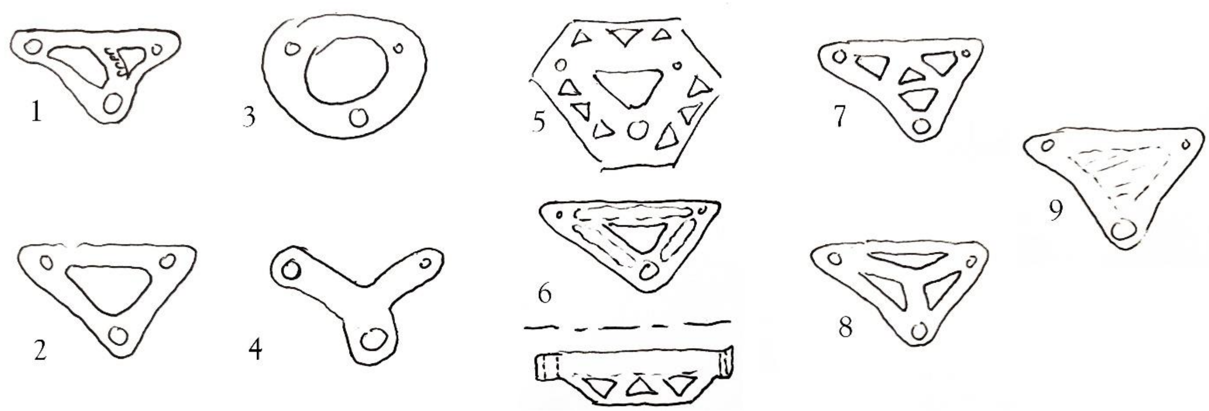

Figure 20. Force transmission function concepts used in the force transmission Pugh matrix.

In addition to differing cross sectional shapes, cosmetic three-dimensional ideation sessions were also held, where mock renderings of the rocker were created and a near-final design was chosen. This component of the design process was significant, because our sponsor Ventana Bikes USA wanted a rocker arm which had similar styling and appeal as seen in the aluminum version. The resulting renderings of several of these mock-rocker arms can be seen in Figure 21.

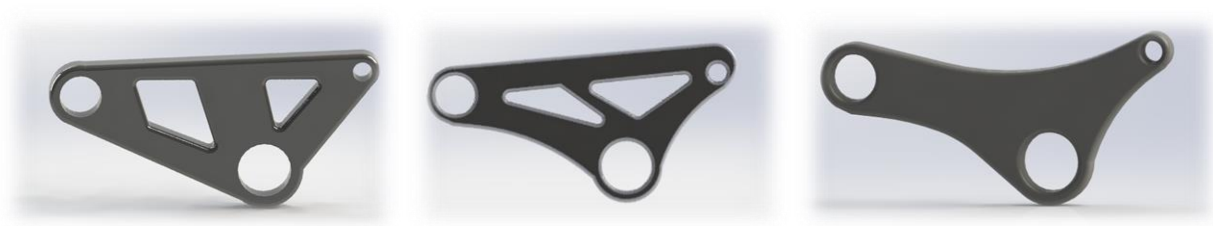

Figure 21. Three rendering iterations of the rocker arm.

After the completion of two Pugh matrices regarding the cosmetic shape and design of the rocker arm the team decided that they wanted to pursue a triangular-shaped rocker, similar in size to that of the original rocker. The difference in the new design though would be that it would only have one cavity, compared to the two seen in the aluminum rocker.

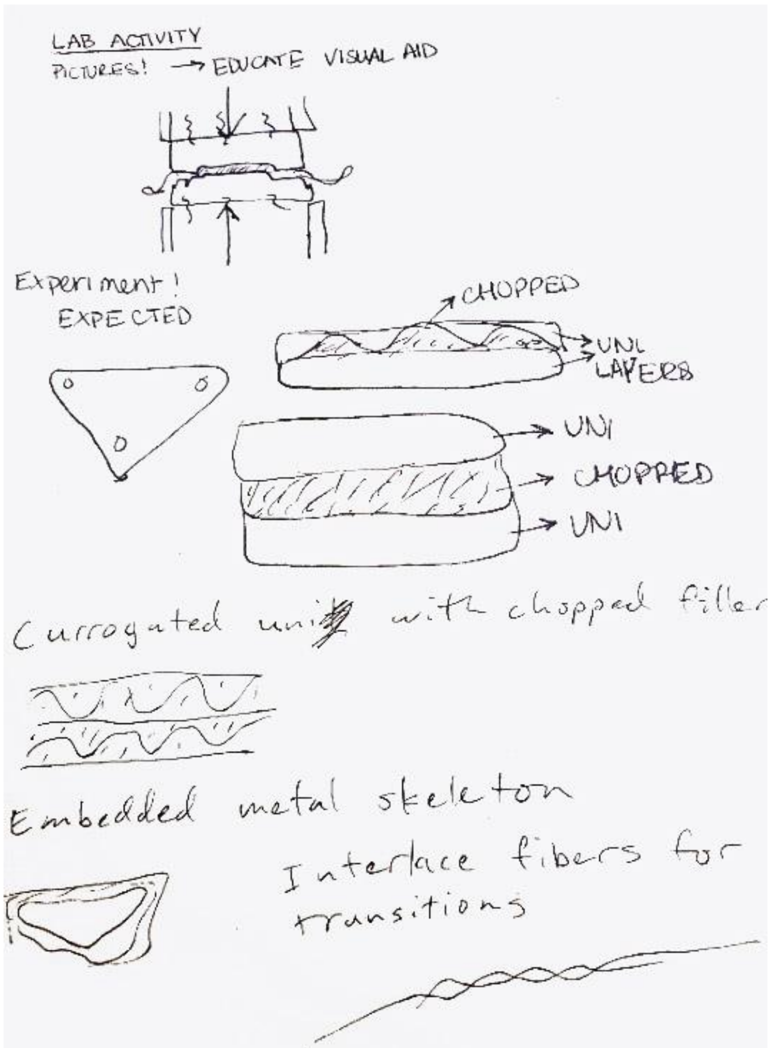

Figure 22. Chopped fiber ideation results

In addition to using Pugh matrices to help with design decisions and project ideation, Black Gold implemented brain sketching, brain-writing and the scamper method. The brain sketching method involved writing down thoughts from the ideation of each team member on individual pieces of paper. After several minutes, team members rotated papers and continued ideation based on each team member's previous thoughts. Black Gold examined ideas for integrating chopped fiber and unidirectional fiber for layups.

Chopped fibers are a random matrix of small short unidirectional fibers generally shorter than two inches, while unidirectional fibers are sheets with parallel fibers to provide strength in one primary direction. Both types of carbon fiber offer different strengths, as the chopped fiber is better for creating smaller more intricate part details or filling in bulk shapes with less strength than that of unidirectional fiber. Layering techniques such as beginning with a layer of uni-directional, building upon it with chopped fiber and then finishing it with uni-directional on top were generated. Figure 22 above shows sketches visualizing the layering technique.

A layering technique involving corrugated layers of uni combined with chopped fiber was also developed. The specific effects of these differing layering techniques and the feasibility of curing is uncertain but it would be advantageous to experiment with differing layup schedules to test the characteristics including strength and stiffness of the final composite part.

This ideation technique ultimately led the team to the idea of using partially cured chopped fiber “pucks” to ease the manufacturing process of building up material around the bearing locations of the rocker arm. This was to be done using a small mold for packing the chopped fiber and partially curing it prior to the manufacturing of the entire rocker. This would then allow the team to place the partially cured and preformed pucks in place, and not have to worry about the alignment of chopped fiber during the manufacturing of the rocker arm.

In a brain sketching session, Black Gold explored the use of different cross-sectional shapes for the rocker arm design. Concluding this ideation session, the need for a different cross-section area was established to decrease stress concentrations within the rocker arm. The change in cross-section of each side of the rocker arm part was considered. For the front face, material distribution was the largest consideration to minimize stress concentration. The dimensioning for the mounting points onto the bike remained the same for all the concepts generated. The cross-section of the side face for the part was also considered. For this cross-section, generating concepts which increased the area moment of inertia was the focus. The reasoning behind improving the area moment of inertia was to allow for a reduction of the internal stresses of the rocker arm. These cross-section concepts can be seen in Figure 23.

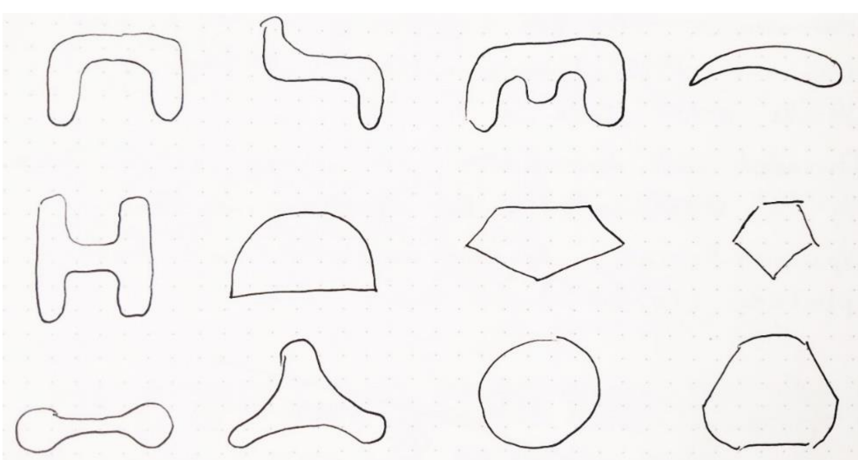

Figure 23. Carbon fiber cross section ideation sketches.

Black Gold held several ideation sessions to compare multiple cross-section concepts. Pugh matrices observed multiple criteria with regards to a function of the design. For our purposes the design was the cross-section of the rocker arm. Two functions were tested, stiffness and force transmitting. For the stiffness, the criteria included material usage, cost, manufacturability, mold complexity, aesthetics, bike compatibility, size and weight. For the design ability to transmit forces, the criteria of manufacturability, weight, strength/stiffness, style, manufacturing cost. Both Pugh matrices used the current aluminum rocker arm as a datum to compare the concepts to. The stiffness and force transmission Pugh matrices were developed simultaneously and have some overlapping design styles. The results from this ideation allowed for the team to decide on a shape that they wanted to pursue.

Ultimately, after discussion with Dr. Mello and team members, the final cross sectional shape was chosen. This shape was very similar to a "L" shape. This shaped proved to provide additional in-plane strength, thanks to the thickness added in the "L" portion. This shape was also one of the easiest to mold and manufacture. The near flat edges allowed for easier machining, and easier application of telescoping shear edges near the edges of the "L" cross section to improve molding characteristics. This cross-sectional decision was ultimately a decision made after ideation sessions, discussions with Dr. Mello, and a desire for easier part manufacturing.

Brainwriting was practiced to generate ideas. This method is like the brain sketching method where team member's thoughts were traded and further developed. This activity led the team to explore mold and cure considerations. Methods to manufacture the mold which included the use of foam to develop final mold shape was discussed. This project was not limited by mold material. There were several options regarding the composition of the molds: two metal halves, metal and rubber, two metal halves with rubber inserts. Ideas regarding cure considerations included varying compression and varying resin were developed.

The scamper method was also investigated which involved: substituting components, combining, adapting, modifying, putting to another use, eliminating and reversing of an idea. This method proved to be unsuccessful to the team's ideation. This method was difficult to develop since each section lead to a description with words as opposed to sketches which lead to underdeveloped and generic ideation.

Final Design

Part Design

The final cross section chosen by the team can be seen in Figure 24. This shape is a combination of many of the topics the team discussed in ideation sessions. This cross-sectional view of the final rocker design contains the “L” shaped cross section. It allows the team to design a mold with a telescoping shear edge, which allows for the team to change the number of layers in the layup without a need to modify the mold to some extent.

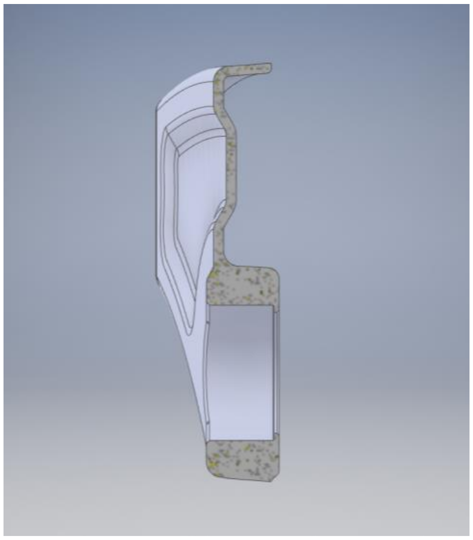

Figure 24. Cross sectional view of rocker arm, illustrating cross section at midpoint of large bottom bearing. This view illustrates the constant shell thickness throughout the part except for the bearing region.

The final rocker arm designs are shown below in Figure 25 and Figure 26. These designs implement all the main design criteria discussed in the ideation sessions and project requirements. The rocker arm utilizes a shape like that of the aluminum rocker, such that it maintains the same cosmetic appeal as that of the aluminum rocker. The part also has no cavities like that of the aluminum rocker. The team decided that it would be stronger and easier to manufacture a part with a closed interior region rather than a cavity, and the indentation was kept from the open design for style. The indented regions serve another purpose besides ease of manufacturing and style, it allows for an increased in-plane stiffness with the change in the geometry of the part-seen in this region.

Figure 25. Final rocker cosmetic shape.

Figure 26. Back side view of final rocker cosmetic shape.

A closer look at these final part designs shows that they have a “shell” shape outside of the bearing areas. This is a design feature that was chosen by the team in conjunction with deciding to use the preformed chopped fiber pucks for the bearing regions. This allowed the team to place unidirectional cloth everywhere outside of the bearing regions. With chopped fiber preformed pucks making up the bearing areas (the only three-dimensionally substantive areas), the rest of the part geometry could be made with only several layers of carbon cloth and still meet expected loading requirements.

Finite Element Analysis of "Black Aluminum"

At the suggestion of Professors Mello and Andrew Davol, a "black aluminum" finite element analysis (FEA) of stress was performed on the rocker design. The idea behind a "black aluminum" analysis is that very roughly carbon fiber composites will perform similarly to an aluminum part of the same geometry, and this analysis can be used as a first look at stresses before a more in depth anisotropic analysis. Due to the loading condition of the rocker arm, setting up this analysis proved to be more complicated than it first seemed. The FEA packages included in Solidworks, Inventor, and Fusion 360 were all unable to handle a condition where all of the input forces were known, but a degree of freedom is left open as is seen in the real-life loading condition of the rocker arm with three bearings. Ultimately a portion of the bicycle frame was needed to be included in an assembly with the mirror image rocker arms to fully define the constraints, and an analysis was able to be performed. The full assembly included the geometry between the seatpost bearings (which connects to the bicycle frame), the shock connecting pin, and the connection point between the shock and bicycle frame, as well as a pin connecting the rear frame bearings together and acting as the force input point. The extra parts were modeled as a hardened steel to minimize their effects on the displacement of the rocker arm under load. The seatpost bearing pin face, and the connection face between the shock geometry and bicycle frame were anchored in place to fully define the model, while the shock geometry was allowed to rotate with the rocker arm displacement. The full assembly can be seen in Figure below.

Figure 27. Rocker arm assembly geometry designed for FEA to remove the degree of freedom present in a single rocker arm analysis while preserving the dynamics present in the real system.

The results of the FEA analysis can be seen below in Figure 28. The input force of 1,212 lbf was taken from the MATLAB static analysis script and points in the correct direction on the tail bearing pin. The analysis was performed in the fully unloaded position, as we found our estimated maximum internal stress in that configuration. The maximum stress of 64.6 ksi was found on an internal curve near the shock pin. This stress is about 6 times larger than the estimated maximum stress, however it occurs at a stress riser of a 1/8th inch internal fillet. The stress found in the estimated cross section for member DE is between 0-30 ksi, which does correlate closely with the estimated 12.2 ksi considering that the estimated stress is an average across the approximate load bearing member area. The maximum stress area is a point of future redesign. The maximum displacement found was 0.039 inches, or about 1 mm.

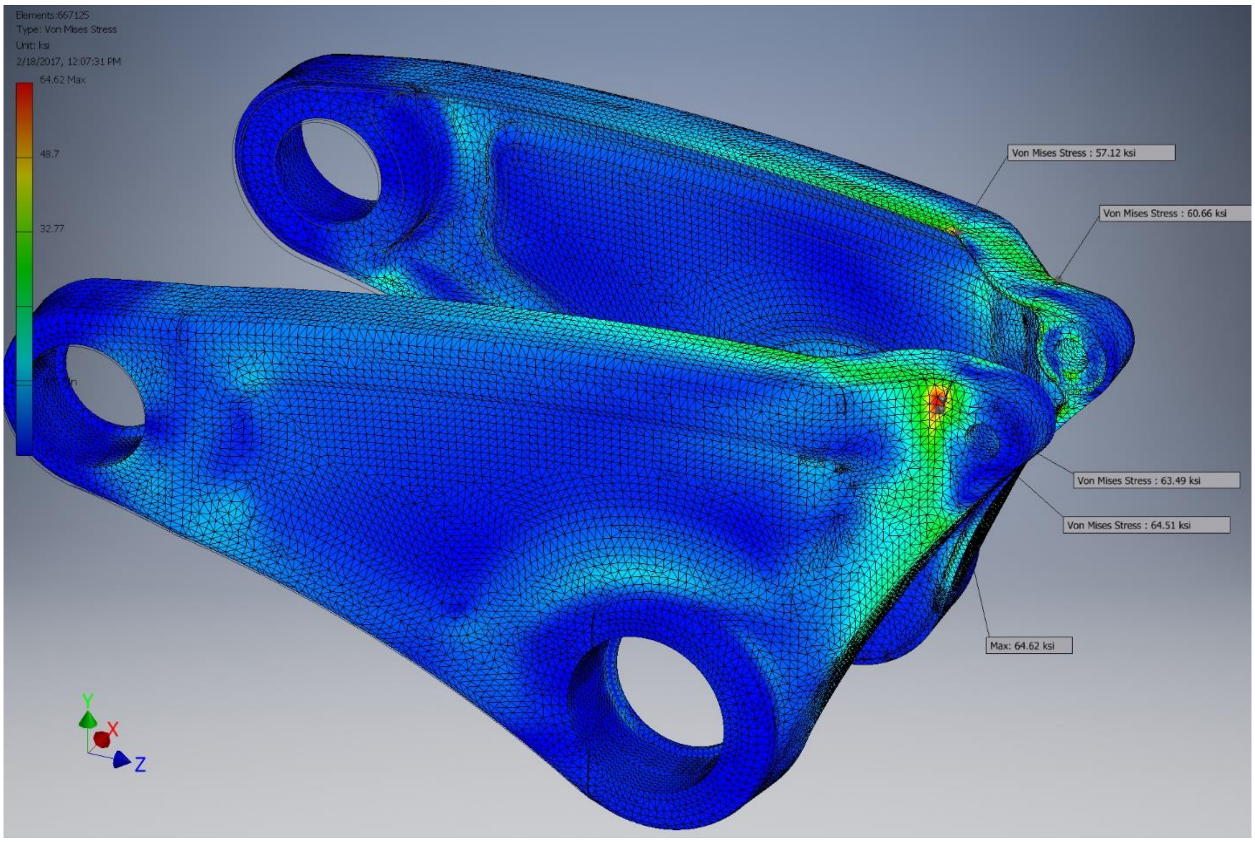

Figure 28. FEA results of "black aluminum" rocker arms. Stress points of interest and the maximum stress are labeled. Displacement can be seen near the top left bearing hole, and is on the order of 1mm.

Ply Thickness

To determine the ply thickness required for the shelled thin portions of the rocker arm a MATLAB tool created by Dr. Mello was used. This tool allowed for the analysis of a finite element of composite material. The program allowed the user to input the number of layers of composite, the orientation of the composite, and the corresponding strengths in the primary and secondary directions. This script also allowed us to apply our simulated bike loading force to the finite element. With this software, we could come up with the number of plies for our layup, in addition to the orientation of those plies. An image of the rocker arm with the cloth appearance can be seen below in Figure .

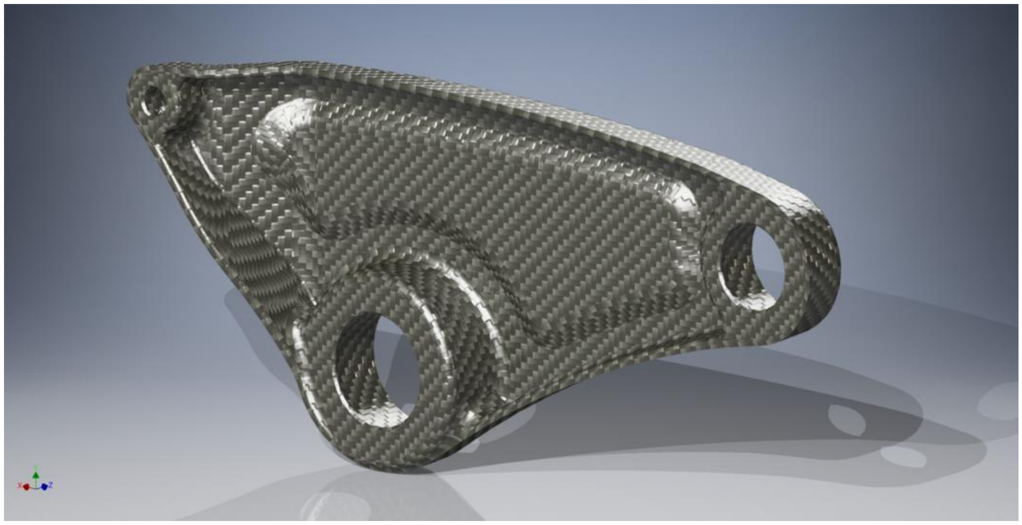

Figure 29 Rendering of backside of rocker with carbon material appearance.

The layup pattern that our team chose to use was a pattern which aligned with the main force directions of the rocker arm. This meant that the orientation of the fiber would be strongest in the directions that the forces were being applied to the rocker arm. This final pattern involved a symmetrical layout about the neutral axis, with a specific layup pattern as follows in Figure.

- Cloth
- 0°
- -27.5°
- 40.25°
- 0° -Central Axis
- 40.25 °
- -27.5°
- 0°
- Cloth

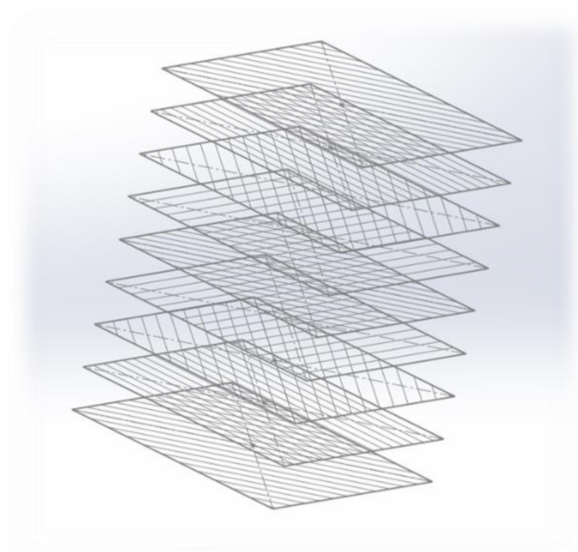

Figure 30. Carbon fiber 9-layer layup pattern.

This carbon fiber layup is 9 plies, and it’s thickness was approximated to be 0.080 inches. When the material properties for our design were assigned to the rocker design in SolidWorks, the part had an estimated weight of 0.13lbs, while the aluminum rocker was weighed by the team and found to be 0.17lbs. This meant that the team had successfully met the weight reduction requirement initially proposed in the project requirements, and the team had confidence the new part would be lighter.

The bearing volumes of the rocker arm were chosen to be made primarily out of the preformed "pucks" of chopped fibers to aid in ease of manufacturing as seen in Figure below. Chopped fiber matrices do not have the strength of unidirectional fiber, and as such, it was known to the team that these areas would need more material than the aluminum rocker bearing areas. The team and Dr. Mello concluded that a thickness that was 1.5-times that of the aluminum rocker should be sufficient in handling the bearing loads experienced by those regions. The final design has a bearing thickness 1.5-times that of the aluminum rocker.

Figure 31. Chopped fiber pucks for bearing areas

The team designed and built a test jig which utilized the rear rocker assembly provided by Ventana Bikes USA. The test jig was used in conjunction with the Instron to test the strength and stiffness of the rocker as it would be if it were being loaded on a bike. This was designed to perform with two carbon rocker arms. The details of this design can be found in the Testing section. The image shown in Figure, shows the normal operating use of both rockers with the rear shock of the bike.

Figure 32. Both rocker arms attached to rear shock of the Ventana Alpino

Mold Design

The mold for the carbon rocker was designed in two halves, a male and female half, each made out of aluminum blocks which were machined on a computer numerically controlled (CNC)**.** The molds were responsible for pressing the uncured carbon material and resin matrix under heat until the resin had cured.

The mold design of the part began after the final design version of the part was completed in January. The rocker was designed from the beginning with the intentions of being molded, so design for molding was a design requirement. One of the design aspects which helped with molding was the addition of the telescoping shear edges on the outer surfaces of the rocker arm mold. The shear edge allows for the mold to excrete excess resin out of the mold while the open area gets smaller as the mold closes. This would aid in helping to prevent harmful pinching of fiber in between the mold faces, yet still allow high internal pressure to build up which aids in the flow-ability of the fiber and matrix. This allows for a better part production; as excess resin is able to leave the matrix. In addition, this shear edge drastically improves the life of the mold as the mold halves, being made out of aluminum, can be damaged by the bottoming out of the mold against itself or the carbon. This was a problem Corinne Warnock mentioned in her thesis.

The team incorporated draft angles into the part on all its contact surfaces. These draft angles greatly aid in the ability for a part to be removed from a mold. This was one of the difficulties discussed in Warnock's thesis, where she eventually had to install removal pins to help with the removal of her tensile specimens from the mold. To illustrate the addition of all the draft angles on the rocker arm, a SolidWorks analysis was performed on the rocker model where the draft angles were analyzed. The green regions shown in *Figure* are areas with at least a three-degree draft angle.

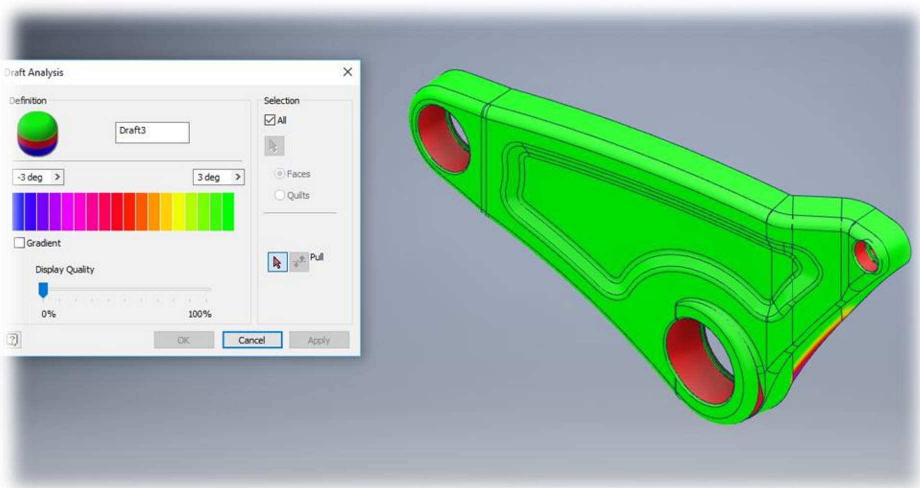

Figure 33. Draft angle analysis in SolidWorks. Red regions are areas of concern, and they will be addressed with the addition of bearing inserts.

The mold halves seen in Figure and Figure are the female and male molds respectively. These mold halves contain the intricate part geometry to create the carbon rocker, in addition to features which make for easier part manufacturing. The mold contains two guide pins near the outer surfaces of the mold to ease in the assembly and alignment of the mold prior to pressing.

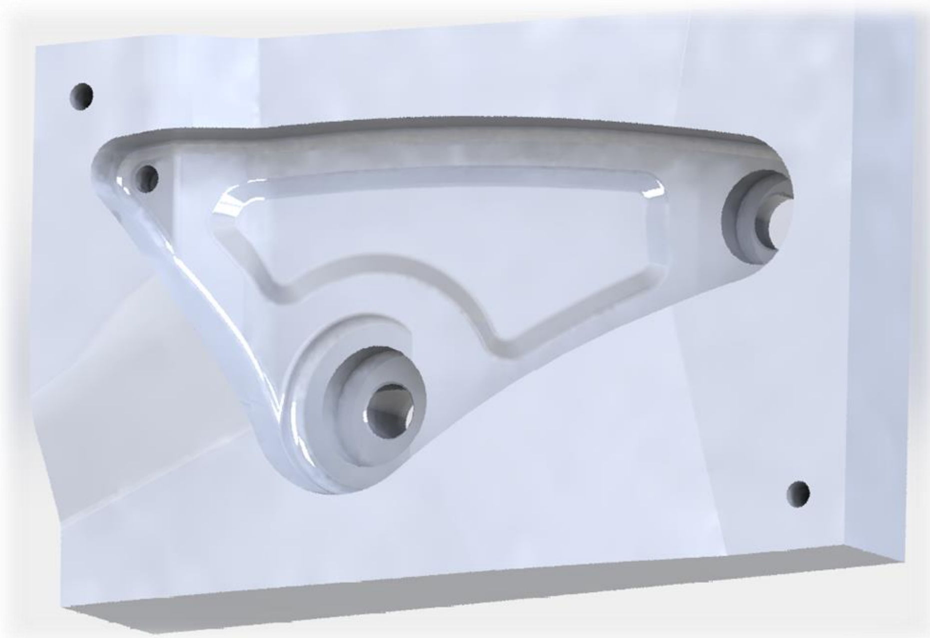

Figure 34. Female mold half for rocker arm.

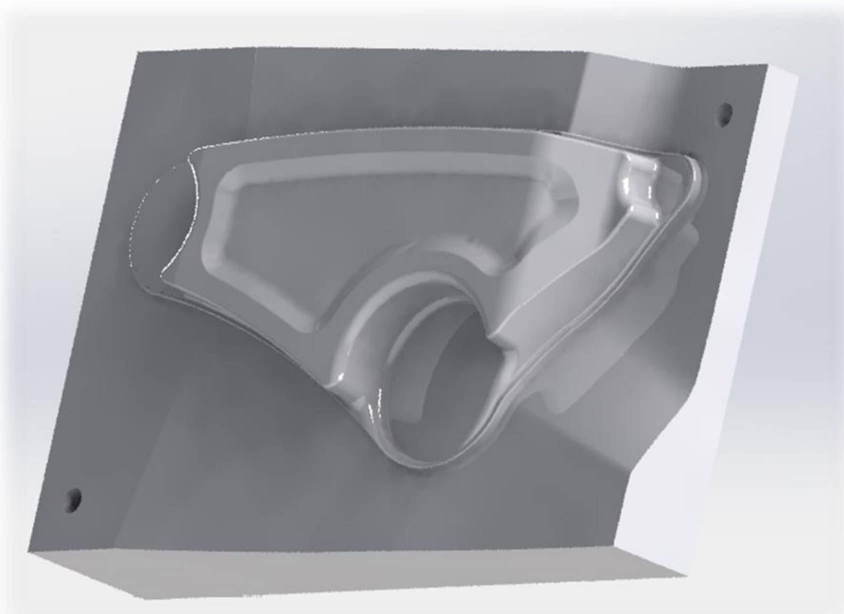

Figure 35. Male mold half for rocker arm.

In addition to the alignment pins, it was decided to use stainless steel inserts in the bearing and mounting holes. These parts were designed to be placed into the mold after mold manufacturing. The inserts create extrusions upon which to align the pucks and maintain the shape and tolerances of the holes. These features were originally going to be integrated into the mold. However, upon the design of the mold CAD, it was discovered that there would be tight radii at low depths for the mill tooling to maneuver around.

This would require a very high length to diameter ratio on the tooling and would probably result in broken tools. To accommodate for manufacturability, the bearing pins were created as a separate machining process. The insert pins were machined to tight tolerances to allow for a precise fit into the mold. The insert pins were placed into machined holes which will locate the pin placement. The insert pins designed do not have drafted angles. The stainless-steel pins have a higher coefficient of thermal expansion than the carbon fiber, and as a result will shrink more than the fiber after curing and cooling. These pins were placed during the layup process, and were made to a transition fit. Removing the pins from the final part was not a concern with the difference in shrinkage and the capability to push the pins out once the assembly is removed from the mold.

Material Selection

The final composite rocker arm part was made of TC275-1/T700SC. These are the prepreg unidirectional carbon fiber sheets used in the part. This material was provided through the composites lab. Since this material was donated, the expiration date of the carbon fiber has been reached and may have had an effect on some of the material characteristics seen. We also used chopped fiber to layup within our puck molds. The chopped fiber is ideal for the puck design since we want to fill a significant amount of the area within the curved surfaces of the rocker.

Black Gold used 6061 T6 aluminum for all of its mold halves. The team went with all aluminum molds as opposed to an aluminum and a rubber insert method because it was agreed that the aluminum mold halves will allow for better definition of complex surfaces, a nicer finish and longer life.

The team purchased rod stock for the alignment pins and the insert pins. 1/4”x 1/2" 304 tight tolerance stainless steel rods were purchased for the alignment pins. For the insert pins on both the part and puck mold, 1.25” x 6” and .75” x 6” stainless rods were purchased and then machined down to size.

Manufacturing

Mold Manufacturing

CAM (Rocker Mold Top/Bottom Left/Right, Puck Mold Top/Bottom, Puck Inserts, Rocker Inserts)
Computer Aided Manufacturing (CAM) was needed to cut the molds which would ultimately produce both the left and right rocker arms. The molds were designed with intricate surfaces, high tolerances and a high-quality surface finish. The CAM package generated tool paths and posted G-code for the Haas VF-2 Mill located in the IME Lab. The puck mold top and bottom halves, as well as both the left and right rocker arm molds, which also consist of a top and bottom half, all required CNC milling and CAM programming to achieve their intricate shapes. Inserts for both the puck mold and rocker molds used CAM software for the Haas TL-1 Lathe.

Mastercam X9 software was used for all CAM programming. The original part CAD was done using Autodesk Inventor and Solidworks, and had to be converted to a step file to be compatible with the Mastercam version because the CAD packages had newer file versions that Mastercam X9 did not recognize. Mastercam was chosen due to the complex 3D contours of the molds and its ability to optimize the work flow for parts that could potentially take hours to machine. Work coordinate systems (WCS) were established for all parts. For the rocker molds this WCS was initially placed on the bottom left corner and for the puck molds it was placed on the bottom center. The WCS was later changed to bottom center for the mirror image mold halves since the overall size of the stock is less important when measuring the mid plane. Tool path operations that were specific to the molds included Surface Dynamic Opti-Rough and Surface Constant scallop. These were used on the 3D contoured surface. The Dynamic Opti-Rough toolpath attempts to optimize tool engagement while machining out topographic layers of the surface geometry. The Constant Scallop toolpath maintains a constant spacing between parallel tool paths generally using a ball end mill. This constant spacing is maintained in three-dimensional space as the surface geometry changes slope, which leads to the ability to predict surface finish from the tool geometry and step over spacing. Feeds and speeds were established for all cutting tools used. A job routing sheet for the mill CAM parts can be found in Appendix J. The Job Routings include all manufacturing details done with the use of CNC.

We used a step over value of .0069 inches with a 1/8 inch ball end mill. These values were calculated from a transcendental equation of solving a surface finish integral for the step-over value needed to achieve a 32 micro-inch finish on a scallop geometry. The equation for the third quadrant of a circle who's bottom starts at the coordinate (0,0) is

$$y = r - \sqrt{r^2 - x^2}$$

The surface finish integral is

$$Ra = \int_{x_0}^{x_1} \frac{|y|}{x_1} dx, \text{ where } x_0 = 0, \text{and } x_1 = \frac{s}{2}$$

The combined and integrated equation is

$$Ra = -\frac{1}{s}\left[\frac{s}{2}\left(\sqrt{r^2 - \frac{1}{4}s^2} - 2r\right) + r^2 \sin^{-1}\left(\frac{s}{2|r|}\right)\right]$$

This equation was solved for step over (s) using Excel's goal seek function using the tool's radius (r) and the desired surface finish value (Ra).

Manufacture Rocker Mold Top/Bottom Right

Refer to Appendix J. This appendix shows the setup to machine the rocker mold top and bottom. The setup sheet includes operations from cutting the stock to length to the milling operations. This sheet references the feeds and speeds used for all cutting tools used to manufacture the rocker molds. A picture of the final stock setup just before machining can be seen and shows the location of our part home, G54.

For the manufacturing of these molds, the original aluminum stock piece (2.5" x 5" x 36") was cut to length (2.5" x 5" x 8") using a horizontal band saw. The sides were not completely parallel to each other after this operation was performed. All 6 sides for the molds were faced to assure that the final stock to be machined was square and had a high-quality surface finish. For the sides cut with the horizontal band saw, squaring within the vise prior to machining was done using a square after the other four sides had been faced. The faced stock dimensions were measured with an optical comparator in the IME metrology lab, and the final stock dimensions were fed back into the CAM package to ensure all tool rapid movements would miss the stock. The updated CAM file was used to post G-code for the mill, and the programs were ran with a final milling time of approximately 1.5 hours per mold half.

Figure 36. Corresponding top and bottom mold halves.

Manufacture Puck Mold Top/Bottom

Refer to Appendix J. Appendix J is the setup sheet for the rocker mold top and bottom. This used the same tooling as the puck molds so it was used as the setup sheets for the puck molds. The tools used on the puck molds as well as the feeds and speeds are the same as the ones used on the rocker molds.

The stock for the puck molds was cut to length (1” x 3” x 6”) from the original stock length of (1” x 3” x 24”) using the horizontal band saw. Again, all 6 sides for both halves were first faced to size prior to machining. However, when the code for the top mold half was ran, the end mill crashed into the surface of the machine vise and mold. The vise and tool holder had minor damage while the mold being machined was scrapped. Left over material was used to complete this process but it was only faced on the top and bottom of the mold surface. It was later discovered that a home location offset was overlooked in the CAM program file, which caused the mill to run its code under the assumption that the part was about 2 inches lower than it actually was. This was a good reminder of the importance of attention to detail.

Manufacture Puck Inserts

The puck inserts which were placed in the puck molds were created using the Haas TL-1 Lathes in the ME Machine Shops. The 3 different inserts were created using the same tools. Aluminum round stock of (1.5” x 10”) was used for these inserts. This stock was not cut to length because they were able to be parted off in the machine. The stock in the TL-1 was faced and turned before tool offsets were done. This was done to ensure that the stock was concentric with the lathe and that the measurements of the faced and turned stock were not affected by uneven surfaces. During the manufacturing of these parts, it was noted that the finishing tool would rub against the faced stock at the point of parting. To prevent this in further manufacturing, the lead out for the finishing tool was shortened to less than that of the roughing tool.

Manufacture Rocker Mold Inserts

Rocker mold inserts were originally planned to be manufactured out of stainless steel. CAM code was made for these parts for Haas TL-1 Lathes. At the time of manufacturing, the pins were difficult to machine using the CNC lathes. Surface finish of the stainless materials were inconsistent, and tolerances were unable to be met. Due to these difficulties, the inserts were made from aluminum. The inserts were finally made using a rotary table and vertical mill after it was found that the lathe would not be available again in time to make a rocker for the senior project expo. This had the added benefit that two of the inserts required that holes be drilled and tapped off the central axis and this step needed to be done on a mill. An internal and external radius could not be accomplished on the mill with the tooling on hand, and the radii were approximated with chamfers.

Manufacture Rocker Mold Top/Bottom Left

The solid models being referenced in the rocker mold CAM file were mirrored for the left sided molds. Some chain geometry needed to have the side reference flipped after mirroring in order to maintain the proper tool path orientation for contour toolpath geometries. The same job routing and setup sheet used to manufacture the right mold halves were used to manufacture the left. It was found after running the right rocker molds that the tolerance and feed rate specified in the CAM file created a situation where the mill was attempting to read G-code faster than it was capable. The tolerance specification determines how long of a path segment is used to approximate the solid model geometry for a tool path. Every line of G-code with an interpolation or circular interpolation command represents one path segment. The tolerance was originally set to .0004 inches. This tolerance combined with the feed rate for the 1/8 inch ball end mill meant that 11,000 lines of G-code needed to be read per second. The Haas mills are only capable of reading 1,000 lines of code per second. This caused the mill to continuously linger as the controller attempted to catch up in reading code, which resulted in a jerky motion of the mill and un-neccesary cutting time. The tolerance value was lowered to .005 inches in order to bring the code reading below 1,000 lines per second. The left hand molds had a shorter run time than the right mold halves due to this change. There was a slight reduction in the uniformity of the surface finish, which had no effect on the final carbon part.

Composites Manufacturing

Season All Molds

After manufacturing of mold tooling, the molds were all wet sanded starting with 300 grit up to 1000 grit sand paper. This needed to be done to maintain smooth surface to allow an easy removal of the composite part. Once the molds were sanded they were cleaned with acetone to remove any debris and residues. The molds were sealed with Fibrelease. This differed from the original seasoning plan. The team was advised by graduate student Eli Rogers to use this release agent since it allowed for fast application. Five coats of Fibrelease were applied to all molds. The process for applying the mold release was followed directly from the application instructions on the FibRelease bottle seen below in Figure 37. This release agent did not need to be heated in between coats and coats could be applied within five minutes of each other. The molds were seasoned prior to each layup.

Figure 37 FibRelease used as the release agent for the mold

Pucks

It was originally planned to partially cure chopped fiber pucks to compose the bearing areas which required added thickness. The chopped fiber was to be pressed into these molds, and cured for approximately 20% of the total curing time. Chopped cloth fibers were used in the large areas of the puck molds. The outer surface and puck inserts were wrapped with strips of cloth fiber. The smaller pin was too small for chopped fiber so the entire pin was wrapped. These pucks were cured on the press at a temperature of 275 °F for 20 minutes. There was no difficulty in separating the halves. Attempts to remove the pucks were done after the molds had completely cooled. Prior to removal the pucks had already appeared to be fully cured which is not what was expected. The insert pins were removed but the pucks were not able to be removed from the molds. The chopped fiber did not compact enough to become a solid piece and was in turn porous, as can be seen in Figure 38. In efforts to remove the pucks the molds were reheated and the team attempted to remove the pucks while the mold was warm using the protective equipment in the composites lab. This still did not remove the pucks so the team moved forward with a layup of the rocker arm without the pucks, by manually packing the bearing regions with chopped fibers.

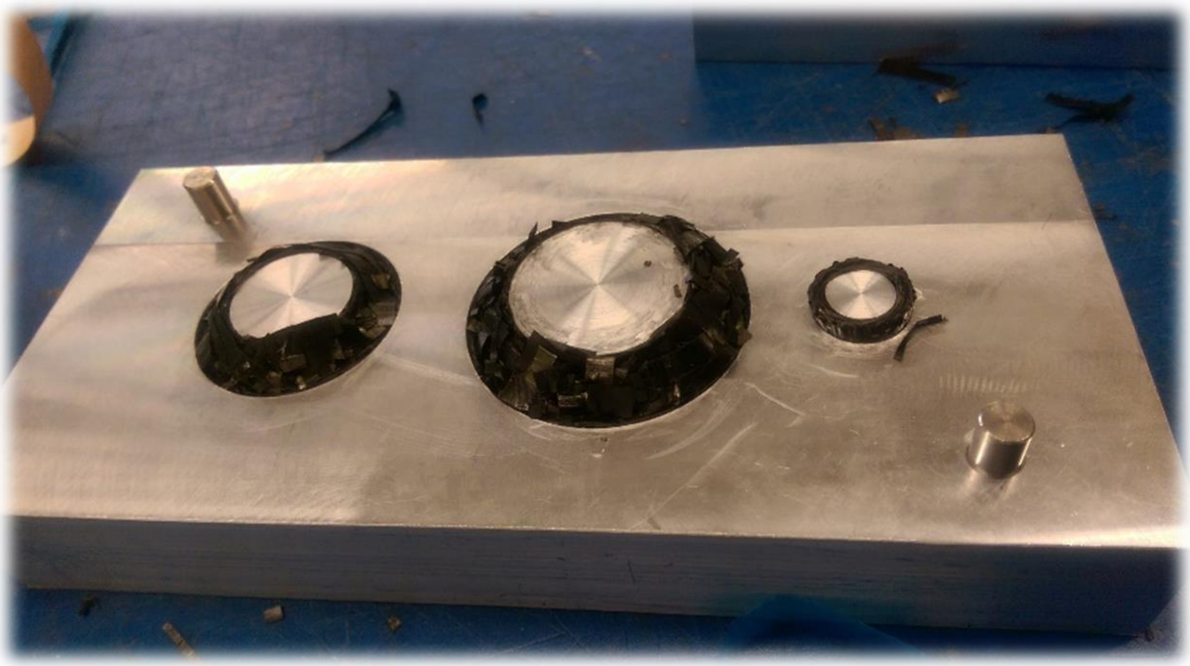

Figure 38. Puck mold showing fully cured chopped fibers stuck in mold

Left Rocker Arm

The right rocker arm was originally planned to be manufactured first. On the day of the layup it was realized that the smaller ¼” insert for the rocker arm mold did not fit the right mold. The left rocker arm could fit this insert, and was chosen to be used instead. A template of the material needed to create the outer shell of the part was created on SolidWorks. The surfaces tab was used to first create a surface of the outer counters and then to flatten this surface on a parallel plane. This template was converted into a dxf file so that a laser cut acrylic cutout template could be made. This template was used to cut all plies of material.

The teams chosen layup schedule was double checked and it was discovered that the initial angles chosen to have the fibers running were slightly different. The team decided to go with angles of 45° and - 20°. Prior to the layup, tensile specimens were made which followed the original layup schedule. The tensile specimen showed that the layup schedule was thinner than what the team had expected. Plies were added to the layup because of this, and an estimate of 0.006 inch thickness for the unidirectional plies and 0.015 inch for the cloth material was used. Since there was room to add more plies the team balanced the chosen orientation. This was done in efforts to prevent any possible warping of the part. The final layup was [cloth/0/-20/20/45/-45°/0°]S. The plies were pressed into the molds without the insert pins first. Once all the plies were placed, the inserts were wrapped with cloth strips like what was done with the puck inserts. At this point in the process it was realized that the pucks would not have worked properly due to them not being shaped correctly for the areas in which they were to occupy. This is because the pucks were designed to be concentric and did not account for the thickness surrounding half of the rocker insert. Future experimentation is needed to confirm whether preforming chopped fiber is a beneficial carbon manufacturing process.

This part was cured on the press at a temperature of 300°F for an hour and a half. Immediately after the cure was finished the halves were separated while the molds were still warm with a rubber chisel. The part was also removed while the mold was still warm. Hammering of the insert pins was required to remove the part, and it is recommended that this is done while the mold is still hot such that it's still thermally expanded. The part did stick to the mold and took many blows with a chisel and hammer on the insert pins. The insert pins needed to be hammered from the back to get the part to release. The inner bearing finish came out with a smooth finish and fit the bearings without post processing of those areas. The outer surfaces of the bearings did have porous regions, indicating areas with insufficient carbon and pressure. Areas of the part also had snagged areas due to the mating of the molds. Both aspects were targets of improvement for future iterations. The first mold iteration can be seen below in Figure 39.

Figure 39. First rocker produced, showing signs of low compression, not enough fiber, and low resin content.

Left Rocker Arm Rev 2

For the next iteration of the left rocker arm, the surfaces were cleaned and a release agent was reapplied to the surfaces. The smaller pin of ¼" was not able to be removed from the mold so the layup was done with the pin already in place. The outer surface was placed in a manner similar to before except excess fiber on the edges were left to be removed as flashing. The insert pins were again wrapped with cloth. In this iteration, chopped fiber was used to fill the bearing regions more completely, and the regions were filled excessively to avoid creating porous bearing regions. The chopped fiber was made from excess cloth material and was compacted into the bearing corners. Once the chopped fiber had been placed, a cloth layer was placed over this region. This part was cured at a temperature of 275°F for an hour and half. Like the last part fabrication, the mold halves were separated while the molds were still warm. The insert pins were again hammered from the back but required less effort to remove for this iteration. This is likely due to the flashing that was left on the mold edges. The bearings fit nicely into the surface and the outer surface was no longer porous. This part still had some snagged edges and was dry in many areas. This part required that the flashing be removed. To do this the team used a Dremel to remove the majority of the excess fiber and was wet sanded to create a smooth surface finish. The second iteration of the rocker can be seen below in Figure 40, the large differences in part quality can be seen when compared to Figure 39.

Figure 40. Second iteration of the left rocker arm, outer side showing improved finish and shape over first iteration.

Figure 41. Back side of second iteration of second rocker arm showing improved bearing areas where additional chopped fiber was used. Mold still appeared dry, and needing more resin content.

Right Rocker Arm

The right rocker arm was the third and final part to be manufactured. This was put off until the end since a new ¼" insert pin needed to be manufactured to fit the mold. Aside from the smaller pin, the same insert pins were used on the right molds. These were recoated with FibRelease. The outer surface was placed the same as before. However, to aid the dry sections an epoxy film was added after the first cloth sections. The pins were again wrapped in cloth, however fewer layers were used this time. Chopped fiber was packed into the bearing areas, making special note to add extra chopped fiber to problem areas seen in the second mold layup. Similar to the left rocker iteration a cloth layer was placed on top of the bearing sections. This part was cured at a temperature of 275°F for an hour and a half. The film layer helped to eliminate nearly all the dry areas on the part. The film did leave the rocker with pink coloring since the epoxy layer itself was pink. The snagged areas were also eliminated on the part. This was because less carbon strips were used and more chopped fiber was used in the bearing areas. This part was also post processed through grinding and sanding to remove the flashing. The third iteration of the manufactured rocker showed drastic improvement in finish and shape and the process became easier with practice.

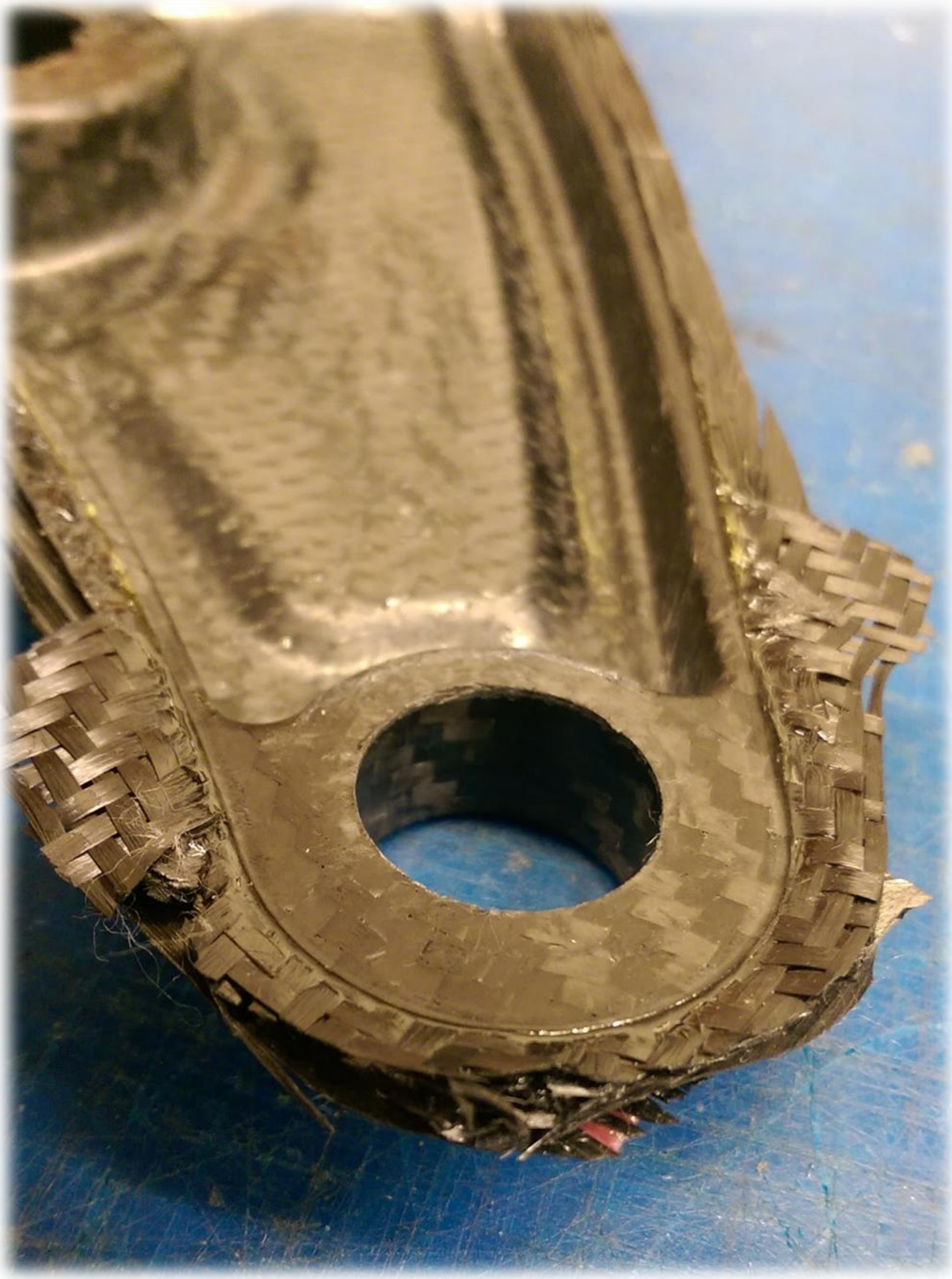

Figure 42. Post pull appearance of bearing region of third iteration of rocker. Chopped fiber fully formed around shape of bearing region, bearing rest has no need for post processing.

Figure 43. Showing successful transfer of bearing rest from inserts into carbon mold of third iteration, a point of interest which was not obtained in previous molds. In addition, pink areas are areas where adhesive film tape was flashed and filled voids within the mold.

Figure 44. Third iteration of rocker showing excess film tape flashing, but drastic improvement in surface finish and part form due to addition of layer of film tape into layup. Small voids can still be seen at the edges of the front bearing region where it is difficult to pack chopped fiber.

Figure 45. Showing all three iterations of the rocker arm. Top is the first iteration, middle is the second, and bottom is the final right-side iteration. Drastic improvement in shape, surface finish and form can be seen between these rockers.

Test Jig Manufacturing

Manufacturing of the test jig involved cutting rectangular tubing down to length. This is accomplished by following the accompanying drawings from the test jig CAD file for the design of the test jig. The cutting of the steel tubing was done with a chop saw in the Cal Poly Machine Shop. After being cut to length, the material was re-measured to ensure that the geometry was consistent with the design specifications. The tubing sections required holes to be drilled and were done with the mill utilizing the DRO to locate the hole locations. After all the holes were drilled the pieces were welded together using the MIG welders in the Cal Poly Machine Shop. The rear triangle links were welded first with their appropriate flat bar ends, this can be seen below in Figure 46. This allowed for the parts to be re-measured once more and ensured that the second flat bar end was welded on at the appropriate length. This was necessary to ensure the test jigs geometry matched that of the Ventana Alpino. Once all of the links had their respective flat bar ends the jig was assembled. Two steel rounds were manufactured using a lathe to smooth surface and drill out the inner holes. For assembly, the lower link of the rear triangle was bolted to the seat post tube, and then the seat-stay, and finally upper Instron link, the complete assembly can be seen in Figure 47. After assembly, the test jig was cycled to verify that it pivoted without substantial friction.

Figure 46. In progress manufacturing of the test jig.

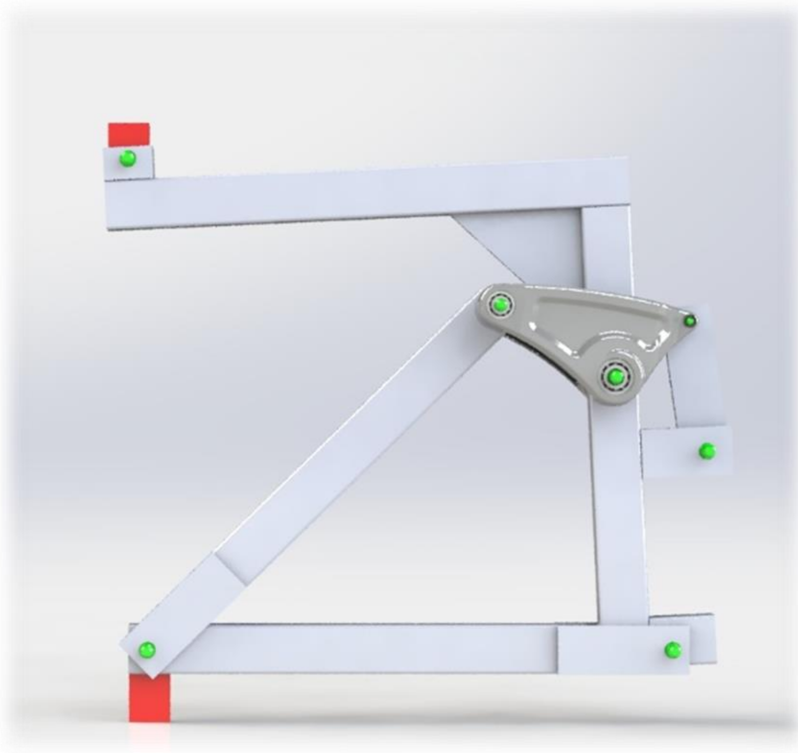

Figure 47. Test Jig Complete Model created in SolidWorks

Assembly

To assemble the carbon fiber rocker onto a Ventana Alpino, the following procedure needs to be followed:

1. First, ensure that the carbon rocker is free of any defects of manufacturing excess material which would interfere with its functionality or strength.
    a. If excess mold material is present, the part needs additional post manufacturing prior to continuing installation.
    b. If the carbon rocker appears to have defects after manufacturing that could hinder strength and performance, the part should not be used, and assembly should resume only with a properly manufactured rocker.
2. Once the rocker arm has been deemed sufficient to begin assembly, the rocker arm needs to have its bearing interfaces prepped for bearing installation. The lower large bearing interface needs to be hand sanded until it is of a transition fit to allow for tight bearing installation with epoxy.
    a. Place bearing on soft material on table
    b. Press first bearing into bearing location until it rests against locating lip.
    c. Press second bearing until its body is in contact with the first bearing. Ensure that both bearings rotate smoothly after installation. Bearing installation is shown in Figure .

Figure 48. Bearing installation into rocker arm.

3. Begin installation of rocker arm onto Ventana Alpino. Prior to attaching the rocker to the bike ensure that the rear shock is depressurized such that rocker motion can be tested prior to use.
4. Begin attachment by securing the upper shock mount to the front mounting location on the rocker. Use the provided hardware to secure the rocker arm, and torqued per Ventana's specifications
5. After the front of the rocker has been mounted, use the provided hardware to mount the large lower rocker arm bearing interface to the Ventana frame. Tighten the bolt and nut.
6. Now that the front two mating surfaces of the rocker have been mounted to the Ventana frame, attach the rear portion of the rocker to the chain stay link on the Ventana bicycle. Use the provided hardware to mount the rocker, and torque to Ventana Bikes USA's specifications.
7. Ensure that the rocker arm pivots smoothly, without friction or resistance prior to pressurizing shock and using the bike.

Verification Plan

The carbon fiber rocker arm design was tested for manufacturability and structural comparability to that of the aluminum rocker. Attached in Appendix C is the Design Verification Plan developed by Black Gold. The verification plan includes methods of testing for design specifications seen in Appendix D. the specification table created by team Black Gold outlines the engineering requirements, tolerances, and risks associated with each requirement. These goals were formed through the accumulation of requirements set forth by both Dr. Mello, and Sherwood Gibson. The Design Specifications Testing in the Design Verification Plan or DVP is separated into 3 categories: Concept Verification, Design Verification and Product and Process Verification.

Concept Verification

For our Concept Verification category, denoted by CV, Fit Press and Mold Geometry have been included.

1. Fit Press – To cure the part, the mold needed to be pressed and heated as previously discussed. To perform this stage of manufacturing, the mold needed to fit into the Hydraulic Press in the ME Composites Lab, Figure 7, which can hold a mold at a width of 6 inches. It is possible to change the orientation to accommodate a mold larger than 6 inches in width. The part mold was designed so that it does not exceed 6 inches in length for one side of the mold. CAD was checked to make sure that this length limit is met. The mold was inspected through use of dial calipers to ensure that the 6-inch limit is met.
2. Mold Geometry – Mold Geometry is a specification to describe the surface areas of the molds which the carbon fiber will be placed. There are two halves for the mold a top male half and a bottom female half. The features and edges of the mold design were inspected to ensure preform capabilities. The CAD was reviewed to make sure appropriate draft angles and fillets are included on the features of the part. This was a visual inspection of the mold CAD. A second test was performed to confirm the preform capabilities. This test was done by performing a mock layup of the carbon fiber on the mold. This ensured that carbon fiber can be maneuvered into all areas of the part.

Design Verification

The Design Verifications are denoted by DV and include tests which examine Rocker Arm Geometry, Tolerances and Press Fit Holes, Part Material, Mold Material, Stiffness, Strength and Weight.

1. Rocker Arm Geometry – The attachment of the rocker needed to satisfy the same mounting configuration and hardware as that of the current aluminum rocker. To check this criterion, CAD was checked to ensure dimensions locating part holes for the bearings and shoulder bolt are identical to that of the aluminum rocker arm. The mating of these holes to the bike was also checked upon manufacturing completion. The final part was tested by mounting it to the aluminum bike components from Ventana Bikes. We tested with the final part since the composite rocker needed to be post processed after curing.
2. Tolerances and Press Fit Holes – In the specification section, specified tolerances for press fit holes were noted. These were inspected on the final part by measuring the hole locations with respect to each other and by measuring the press fit holes. These measurements were checked against the specified tolerances to ensure that there is negligible variation in fitting.
3. Part Material – In the specifications from Sponsor, Dr. Mello, the material of the final part needed to be TC 275-1/T700SC. The part was visually inspected to ensure that it is carbon fiber and carbon fiber serials will be checked prior to layup.

4. Mold Material – Specifications decided by Black Gold included that the entire mold be machined out of aluminum. Material was visually inspected and upon ordering, material the serial numbers were checked to ensure that the aluminum is 6061-T6.
5. Stiffness – Stiffness of the composite part was tested against the stiffness of the aluminum part. To test this, a test fixture was designed. The fixture was specially designed to replicate the loads the rocker would experience on the bike. The Instron in the ME Composites Lab was used to apply loads to the rocker to develop a stress strain curve. To pass this test the composite rocker stiffness needed to be larger or equal to that of the aluminum rocker arms.
6. Strength – The strength of the composite part as compared to the aluminum was tested. This test was also conducted with the Instron and test fixture to develop a stress, strain curve. To pass this test, the composite part needed to have a strength greater or equal to that of the aluminum rocker arm.
7. Weight – One of the specifications decided upon for this part required that the composite part maintains the similar or better stiffness and strength to the part without compromising the weight of the part. Prior to manufacturing, the composite rocker arm weight was estimated using evaluating tools on the composite rocker arm CAD software. The final part was weighed and tested against the weight of the aluminum rocker arm. To pass this test the composite rocker arm weight needed to be equal to or less than that of the aluminum rocker arm.

Product and Process Verification

The Product Process Verification is denoted by PV in the DVP chart. Items included in the PV category include Documentation of the Process, Total Research Costs and Manufacturing Costs.

1. Documentation of Process – The main goals of this project was to provide a detailed manufacturing guide which will allow others to perform and evolve carbon fiber compression molding. Full documentation of the manufacturing process from mold design, manufacturing, prep and carbon fiber layup, cure, post process was developed.
2. Total Research Costs – Thorough records of all purchases made in regards to the project were kept. The final cost of the total project was checked frequently to ensure that the project total stays at $500 or below.
3. Manufacturing Costs – Thorough records of all manufacturing purchases was kept. Total manufacturing costs must be equal to or less than that of the aluminum.

Testing

Testing Design

To test the strength of the rockers, a test jig was designed and built to test the aluminum and the carbon rockers built by Black Gold. It was determined by the team that the test jig would mimic the geometry of the rear triangle of the Ventana Alpino bike. This meant that the rockers would be loaded in a geometry that was identical to their loading situations while in use on a bike. The team decided that they wanted to test both rockers, left and right, at the same time, to further mimic the loading of the rockers while in use. This test jig was also designed such that it would be able to fit within the Instron Model 1331 within the composites lab on campus. The team planned to obtain two sets of data from this test jig, the first being a determination of the stiffness of the aluminum and carbon rockers so that the two could be compared, in addition to testing the ultimate strength of the aluminum and carbon rockers. The ultimate strength would be determined by testing each respective pair of rockers until failure. With this data, the team would be able to determine whether the compression molded rockers were a viable option for Ventana Bikes USA by satisfying initial project requirements of producing a stiffer and stronger part.

The finalized test jig is shown below in Figure 49 first as a SolidWorks CAD model, and then the final product. The test jig was built out of 1” x 1.5” rectangular steel tubing, and .25” x 1.5” steel flat bar. This construction allowed for easy manufacture, and the sizing of the material was determined through loading calculations expected by the team. A copy of the analysis for the test jig can be seen in Appendix J.

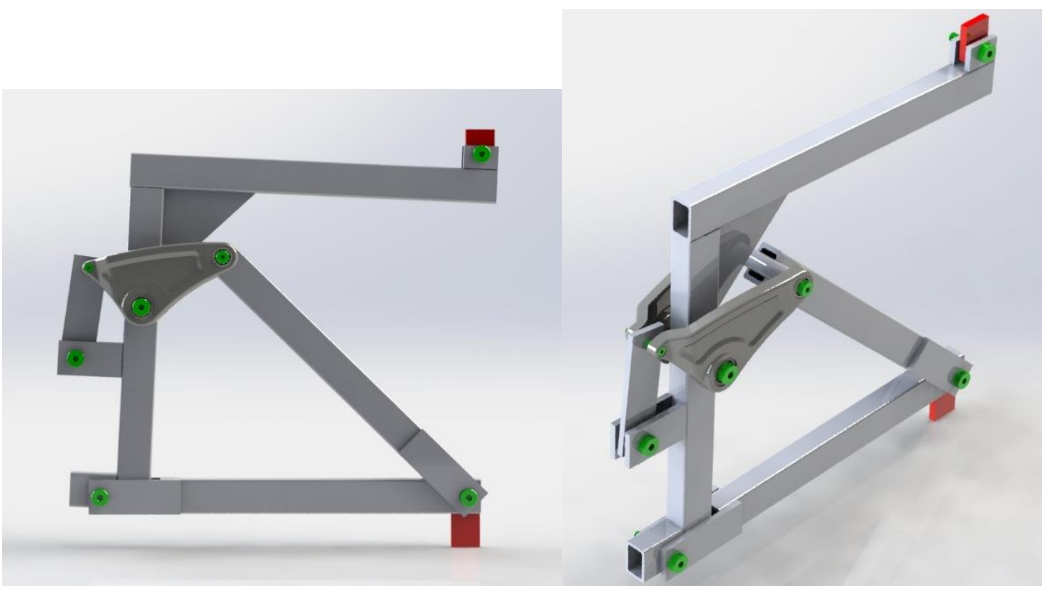

Figure 49. SolidWorks renderings of the finalized test jig design.

In Figure 49 above, the red parts indicate the surfaces in which the Instron grips the test fixture. The green components are the selected shoulder bolts to be used throughout the design as pivots for the various pieces of the test jig linkage. The test jig holds the rocker in a fixed position, as if the shock were a solid link. This allows for all the load to be transferred through the rocker without changing the rear geometry through loading. The manufactured test jig is shown below in Figure 50. It was determined after manufacturing that the test grips needed to be rotated 90 degrees for the entire test fixture to fit within the

Instron. The team then altered the assembly, re-welding both metal grip tabs such that the fixture would fit within the machine properly.

Figure 50. Test jig after grip rotation, being installed into the Instron for testing.

Testing Process

Testing was planned such that the rockers would first be subject to a small loading under the Instron and test jig such that the relative stiffness of each rocker could be compared. Rather than measuring the actual displacement at the rocker during the stiffness testing, the team would apply a constant displacement load test to the test jig. This allowed the team to determine the displacement of the entire test jig under loading, and since the deflection of the test jig would be the same across similar loading situations, the relative stiffness of each pair of rockers could be compared. After the stiffness of both rockers was determined, the team would load the rockers again, but this time to failure. This would ultimately allow the team to determine the ultimate failing load for both the aluminum and carbon rockers. Since the test jig was not initially designed for testing to failure, the team decided to reinforce the weakest portion of the test fixture by welding an additional 1.5” x 1” piece of rectangular tubing on top of the top loading member, which can be seen in the Figure 51 below.

Figure 51. Test jig with welded support on upper load bearing member.

Due to timing constraints, the team initially tested the single carbon rocker with the other side as an aluminum rocker to determine the relative stiffness of the carbon rocker, and to verify that it did in fact hold a load. Both the carbon-aluminum rocker and the aluminum-aluminum rocker were tested to 400lbf wheel force, which is equivalent to half of the max loading value determined by the team.

Figure 52. Showing both the carbon and aluminum rocker mounted to the test jig for manufacturing.

In addition to determining the structural properties of the carbon rocker, the carbon rocker was weighed and compared to the aluminum rocker. Weighing of rocker was done with a gram scale and all the bearings required in the assembly of one of the rocker sides. This was done such that the weight difference could be a relative difference between the rocker assemblies for each side.

Testing Results

Weight Comparison

The weights of both the carbon rocker iterations and aluminum rockers were compared. The results from this testing can be seen below in Table 1. A depiction of the weighing setup can be seen below in Figure 53 where each individual rocker is weighed with the bearings required for its assembly.

*Figure 53. 1st Iteration carbon rocker weighing in at 103.2g (**Left)** Aluminum rocker weighing in at 130.4g (**Right)***

Rocker	**Weight[g]**
Aluminum	130.4
Carbon (1st Iteration)	103.2
Carbon (2nd Iteration)	110.5
Carbon (3rd Iteration)	116.8

Table 1. Weight comparison data of carbon and aluminum rockers

Stiffness Comparison

The force and normalized displacement for the aluminum and carbon rockers loaded to 800 lbs are plotted in Figure 54. The data of the rockers is convoluted with that of the test jig, therefore only a relative comparison between the entire assembly with either the aluminum rockers or the carbon rockers can be analyzed. The assembly stiffness (slope of the curve of force vs displacement) with the aluminum rockers can be seen to increase slightly in stiffness between 0.2 in and 0.4 in of displacement, and then gradually roll off in stiffness as the rocker and/or test fixture starts to yield. The assembly with the carbon rockers on the other hand maintains almost a perfect linear relationship up to around 640 lbs of force, where a fiber failure occurred. The fiber failures can be easily seen on the plot where the force suddenly drops off and then resumes increasing. There were three fiber failures that occurred before the test jig yielding prevented further increase in force, which is seen at the top of the plot where the curve becomes nearly flat. Upon visual inspection it appears that there is slight yielding in the aluminum rocker due to the change in slope that occurs at a lower force in the aluminum assembly than that of the carbon assembly. The aluminum assembly begins to lose stiffness at around 500lbs of force, while the carbon assembly appears to maintain constant stiffness until around 700lbs of force. The drop in force that occurs in both assemblies just before 0.2 in of displacement appears to be a settling of some portion of the assembly and is not a part failure.

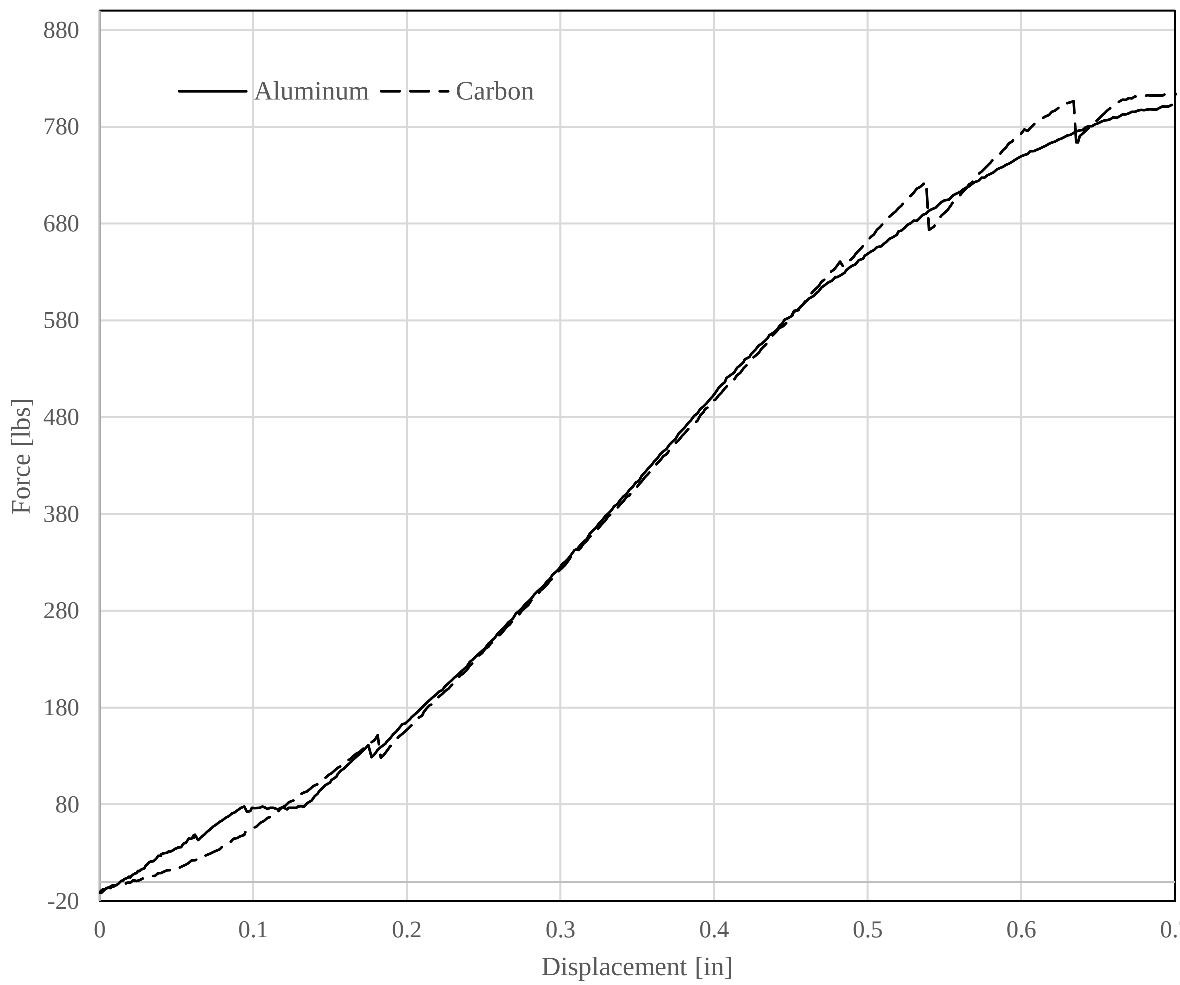

Figure 54. Aluminum vs Carbon Force vs. Displacement comparison.

In order to compare the stiffness of the two assemblies, a linear trend line for each assembly was added to the plot, seen in Figure 56. The trend line spans the majority of the linear relationships in both assemblies without including any of the fiber failures. We found the assembly with the carbon rocker to have a stiffness of 1716.5 lb/in and that of the aluminum assembly to be 1693.7 lb/in. This is a percent difference of 1.3 %. This difference is probably within statistical variation, which makes the result inconclusive.

It is interesting to point out the progressive failure mechanism that is observed in the carbon rockers in Figure 55. Our assumption was that the carbon rocker would fail catastrophically, meaning the entire rocker would lose the ability to hold force in a single failure. In fact the rocker had a small fiber failure that redistributed forces to another location on the rocker, and continued to build up force. This is beneficial for a bicycle rider who may overload the rocker because it is unlikely to cause an injury as small fiber failures occur.

Figure 55. Localized buckling seen on both rockers during testing of rockers for maximum strength.

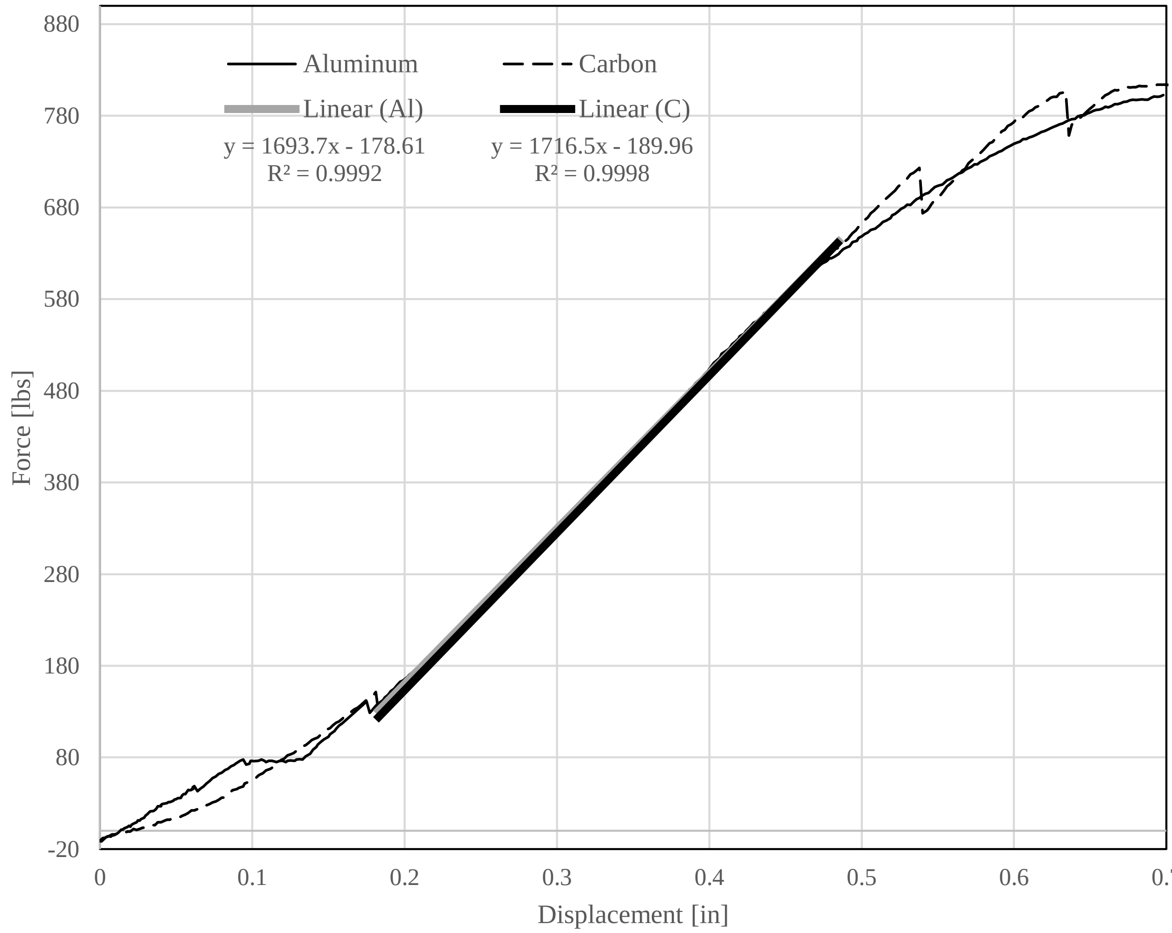

Figure 56. Linear trend line comparison of aluminum and carbon stiffness.

Ultimate Strength Comparison

We were unable to test the ultimate strength of either the carbon or aluminum rocker assemblies due to the test jig yielding before ultimate failure could be achieved. If this project were to continue, the test jig design could be iterated to increase its ability to hold forces without yielding. It is also possible that the limiting factor may turn out to be the small bolt that attaches the rockers to the shock link, which also yielded during testing.

Considerations

Safety concerns for manufacturing have been developed into two categories, mold manufacturing and part manufacturing. A hazard checklist for these safety concerns has been developed and can be referenced to in Appendix E. For mold manufacturing, standard machine shop procedures were followed. These procedures include: long pants, closed toe shoes, and protective eye wear. These procedures were enhanced depending on which machine was used. During part manufacturing, the composite lab safety procedures were followed. Protective eye wear will be worn, gloves will be used when handling composite material and release agents. Masks will be worn during the handling and application of release agents.

There are several safety considerations which need to be considered when using the rocker. The main safety concerns arise when the arm is being tested with the test jig, where users need to be aware of possible pinch points and loading situations. The pinch points on the test jig could be very harmful and dangerous, and as such the jig should not be touched by any individual during use. In terms of loading safety, the rocker should only be loaded under normal operation conditions, and all testing to failure should be done in a safe environment.

In the situation that the rocker is being used on a bike for actual testing and function, the rocker should be checked for proper attachment and condition prior to use. Any indications of part wear, improper installation, or unsafe conditions should be avoided and the rocker should not be used.

Maintenance and Repair Considerations

The rocker arm produced by Black Gold is not designed for future repair. Failure modes were considered and can be seen in Appendix F. If the part is damaged, it is unfit for use, and needs to be replaced with a properly functioning rocker.

The only maintenance items on the rocker are the bearings and mounting hardware. The bearings need to be inspected for proper operation. This refers to smooth rolling characteristics, proper lubrication, and that no visible damage or wear is evident. In the case that bearings are worn or unfit for use, they should be replaced prior to continuing operation and use of the rocker. The hardware supplied with the carbon rocker has been design for the Ventana Alpine bike. In the situation that the hardware appears worn, or deemed unfit for use; the use of the rocker should stop. Improper bearing maintenance can result in injury and damage to both the bike and user. Through the proper maintenance and repair considerations mentioned above, the carbon fiber rocker should provide years of fun on the Ventana Alpino.

Detailed Cost Analysis

The Bill of Materials which shows the cost of parts to manufacture the final rocker can be seen in Appendix G. These parts include our assembly parts to make the composite rocker arms and parts which go into the manufacturing of the molds. Our mold parts include our stock material for the molds, and rod stock for our alignment pins and insert pin fittings for our mounting holes. Ventana Bikes USA has provided 2 sets of the two different bearings to be used and the screws which will be used to mount the part. Since they are provided, the cost has not been listed in the Bill of Materials. Within our Bill of Materials are the cost of the raw stock needed to manufacture molds. The final cost to the team of parts comes out $277.91. It should be noted that this cost does not include shipping and that some of the stock will also be provided to Black Gold from Ventana Bikes.

This price also does not evaluate the total cost to the project. Items that were used but are not included in the Bill of Materials since they are not parts include: TC275-1/T700SC, MAVCoat 527 ML, Frekote 700 NC, Axel F-57NC, gloves, masks, and tooling. The items listed above will be provided to the team through on campus resources such as the composites lab and the ME machine shops. The items listed that won't be provided are special tools needed to manufacture the mold. The team will need a specific 15/64 Flat End Mill that they will be purchasing from Harvey tooling. The cost for this tool is $14.

Conclusion

The current design of the carbon fiber rocker arm has not conclusively met the goals of lighter, stronger, and stiffer than the aluminum rocker arm in use. Specifically we were not able to test ultimate strength due to the limitations of the test jig, and the stiffness result is inconclusive. The carbon rocker arm measured 1.3% stiffer than the aluminum rocker arm, which is not a large enough difference to be statistically significant. Given more time and resources we would iterate the carbon rocker design to create a larger "L" member at the failure point, and reduce the stress concentration by implementing a larger radius at the same point.

The puck pre-molding process is an avenue of considerable interest, as success in this area would reduce variation in the final material volume of a carbon fiber rocker arm, as well as increasing the ease and speed of preparing a layup. Given more time, we would like to determine the exact shape and volume required by the puck pre-molds. This shape would be determined by removing the .08 inch sheet layup shell from the solid model of the carbon rocker arm, and extrapolating a solid model of the remaining bearing volume. Mold models would then be created from the puck solid model, and machined to the same precision as the rocker molds and inserts.

Our test jig could be iterated to develop a jig capable of withstanding the extreme forces required to ultimately fail both the aluminum and carbon fiber rocker arms, as well as design for stiffness to help remove some of the convolution currently present in our jig and rocker assembly. A statistically significant sample size of rockers could be manufactured and tested to determine the mean and standard deviation of the stiffness and strength inherent in the part, which would help to determine if a result such as 1.3% stiffer could actually be significant.

Ultimately, the material presented in this project goes well beyond our initial intentions, and opens a large breadth of future composites research. We are proud of our attempt to reach such conclusions, and excited to see where this research goes in the future.

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Appendices:

A. Static Analysis MATLAB Script
B. QFD
C. Design Verification Plan
D. Design Specifications
E. Hazard Identification Checklist
F. FMEA
G. Bill of Materials
H. Gantt Chart
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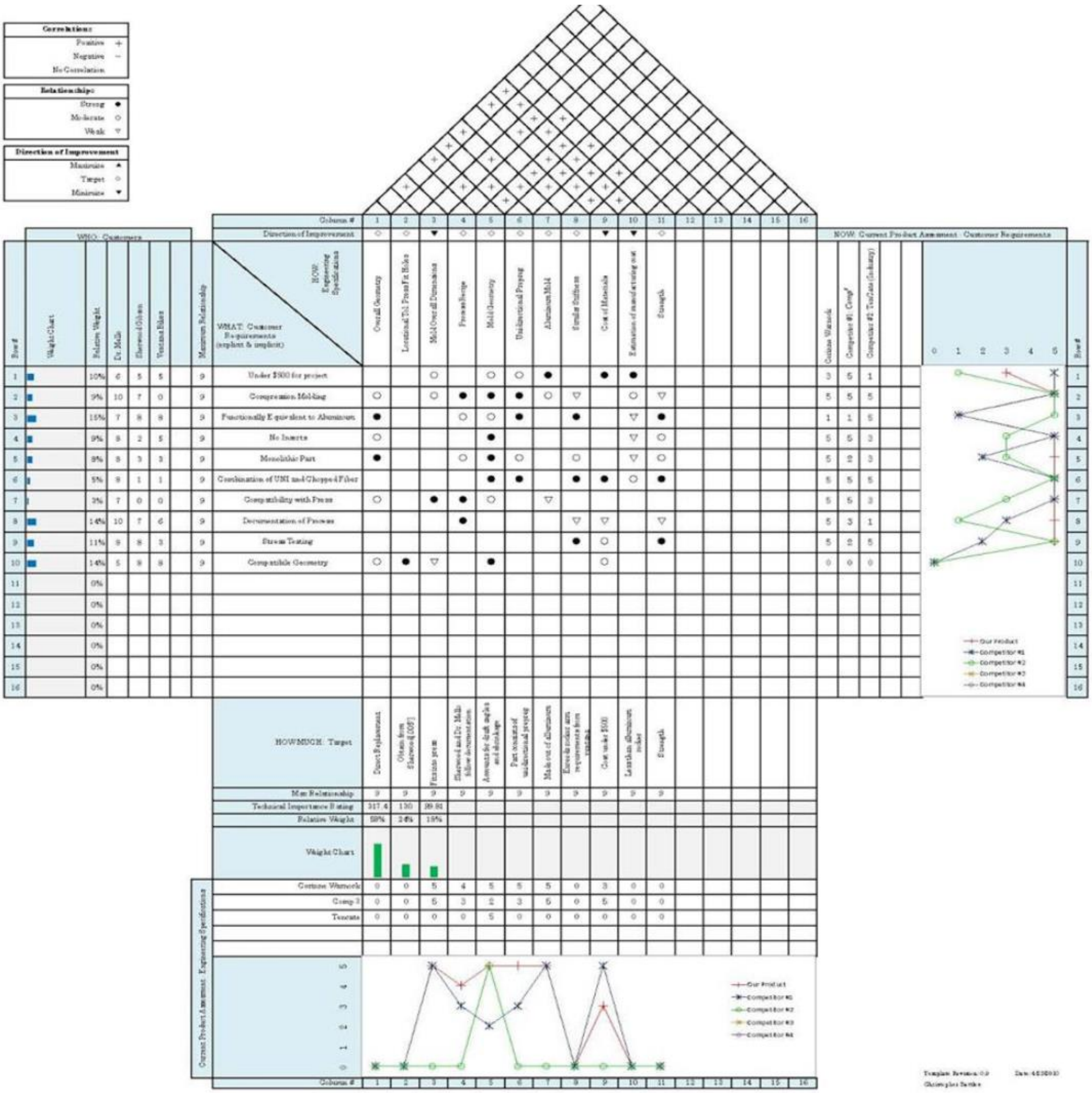
Appendix A. Static Analysis MATLAB script

```
% Sean Tischler
% 2-D Truss Analysis of Ventana USA Alpino rear suspension members

clc
clear all
close all

% Initialize variables
A = [0,0];
B1 = [-16.7579,-0.3534];    % [in]
B2 = [-16.4613,4.4134];     % [in]
C1 = [-16.0197,-0.3379];    % [in]
C2 = [-15.4900,4.1530];     % [in]
D1 = [-6.1827,9.4441];      % [in]
D2 = [-3.8560,11.7138];     % [in]
E1 = [-0.3683,9.9394];      % [in]
E2 = [0.4985,7.8293];       % [in]
F = [-2.3847,7.8781];       % [in]
G = [1.5813,2.3095];        % [in]
P = [0,800/2];              % Input Force [lbf]
Ra1 = [0,0];                % Reaction Force [lbf]
Ra2 = [0,0];                % Reaction Force [lbf]
Rf1 = [0,0];                % Reaction Force [lbf]
Rf2 = [0,0];                % Reaction Force [lbf]
Rg1 = [0,0];                % Reaction Force [lbf]
Rg2 = [0,0];                % Reaction Force [lbf]

% Find Reaction Forces at beginning and end of travel
coMatrix1 = [1,0,1,0,1,0;
            0,1,0,1,0,1;
            0,0,G(1),0,F(1),0;
            0,0,0,G(2),0,F(2);
            0,0,(E1(2)-G(2)),-(E1(1)-G(1)),0,0;
            B1(2),-B1(1),0,0,0,0];
rhsMatrix1 = [0;-P(2);0;-P(2)*B1(2);0;0];
rMatrix1 = linsolve(coMatrix1,rhsMatrix1)
Ra1(1) = rMatrix1(1);
Ra1(2) = rMatrix1(2);
Rg1(1) = rMatrix1(3);
Rg1(2) = rMatrix1(4);
Rf1(1) = rMatrix1(5);
Rf1(2) = rMatrix1(6);

coMatrix2 = [1,0,1,0,1,0;
            0,1,0,1,0,1;
            0,0,G(1),0,F(1),0;
            0,0,0,G(2),0,F(2);
            0,0,(E2(2)-G(2)),-(E2(1)-G(1)),0,0;
            B2(2),-B2(1),0,0,0,0];
rhsMatrix2 = [0;-P(2);0;-P(2)*B2(2);0;0];
rMatrix2 = linsolve(coMatrix2,rhsMatrix2)
Ra2(1) = rMatrix2(1);
Ra2(2) = rMatrix2(2);
Rg2(1) = rMatrix2(3);
Rg2(2) = rMatrix2(4);
Rf2(1) = rMatrix2(5);
Rf2(2) = rMatrix2(6);

%Plot Frame and forces
figure(1)
myPlot1 = plot([0,G(1)],[0,G(2)],[0,F(1)],[0,F(2)],[0,B1(1)],[0,B1(2)],...
    [C1(1),D1(1)],[C1(2),D1(2)],[D1(1),E1(1)],[D1(2),E1(2)],...
    [D1(1),F(1)],[D1(2),F(2)],[E1(1),F(1)],[E1(2),F(2)],...
    [E1(1),G(1)],[E1(2),G(2)])
set(myPlot1,'Color','black');
hold on;
myPlot1a = plot([0,Ra1(1)/200],[0,Ra1(2)/200],[G(1),G(1)+Rg1(1)/200],[G(2),G(2)+Rg1(2)/200],...
    [F(1),F(1)+Rf1(1)/200],[F(2),F(2)+Rf1(2)/200],[B1(1),B1(1)+P(1)/200],[B1(2),B1(2)+P(2)/200])
set(myPlot1a,'Color','red','LineWidth',3);
```

```
hold off;

figure(2)
myPlot2 = plot([0,G(1)],[0,G(2)],[0,F(1)],[0,F(2)],[0,B1(1)],[0,B1(2)],...
    [C1(1),D1(1)],[C1(2),D1(2)],[D1(1),E1(1)],[D1(2),E1(2)],...
    [D1(1),F(1)],[D1(2),F(2)],[E1(1),F(1)],[E1(2),F(2)],...
    [E1(1),G(1)],[E1(2),G(2)])
set(myPlot2,'Color','black');
hold on;
myPlot2a = plot([0,Ra1(1)/200],[0,Ra1(2)/200],[G(1),G(1)+Rg1(1)/200],[G(2),G(2)+Rg1(2)/200],...
    [F(1),F(1)+Rf1(1)/200],[F(2),F(2)+Rf1(2)/200],[B1(1),B1(1)-P(1)/200],[B1(2),B1(2)-P(2)/200])
set(myPlot2a,'Color','red','LineWidth',3);
hold off;
```

Appendix B. QFD



Appendix C. Design Verification Plan

BLACK GOLD DVP&R

Report Date	6/8/2017	Sponsor	Joeseph Mello	Component/Assembly	REPORTING ENGINEER:

TEST PLAN											TEST REPORT			
							SAMPLES		TIMING		TEST RESULTS			
Item No	Specification or Clause Reference	Test Description	Equipment	Acceptance Criteria	Test Responsib	Test Stage	Quantity	Type	Start date	Finish date	Test Result	Quantity Pass	Quantity Fail	NOTES
1	Rocker Arm Geometry	Inspections of the fittings on the rocker arm to the bike	Allen Key set	Functional on Bike	Jacob	2	3	B	5/30/2017	6/6/2017	Pass	3	0	Carbon Rockers fit Test jig with same mounting points as the bike
2	Tolerances and Press fit holes	Inspection of final dimensions and press fit holes	Calipers	+- .00045"	Jacob	2	3	B	5/30/2017	6/6/2017	Pass	3	0	
3	Fit Press	Inspection of the mold Dimensions will be done	Ruler/Caliper	6 inches wide	Alea	1	3	A	5/21/2017	5/21/2017	Pass	3	0	All molds fit press area
4	Documentation of Process	Tester verification. Test subjects will be given documetation and will assess repeatability	Project FDR	Repeatable by ME student	Jacob	3	1	C	4/2/2017	5/14/2017	Pass	N/A	N/A	Repeated by all three team members
5	Mold Geometry	Inspection of mold and moc preform with prototypes	Manufactured mold halves and carbon for test layups	Perform Moldability	Alea	1	3	A	5/2/2017	5/7/2017	Pass	3	0	
6	Part Material	Inspection of final part material	N/A	Carbon Fiber	Jacob	2	3	B	5/29/2017	6/6/2017	Pass	3	0	Left completed 5/29
7	Mold Material	Inspection of final mold material	N/A	A1-6061	Sean	2	3	B	4/12/2017	4/15/2017	Pass	3	0	All molds machined from Aluminum
8	Stiffness	Instrom testing, part will be placed in fixture and undergo stress and strain	Instron	≥AL	Sean	2	1	B	5/30/2017	6/7/2017	Pass	1		Carbon Rockers were 1.3% stiffer
9	Total Research Costs	Cost Report and documentation of purchases	Final Cost Sheet	$500	Alea	3	1	C	9/22/2017	6/8/2017	Pass	N/A	N/A	Total Cost $277.91
10	Manufacturing Costs	Cost Report and documentation of purchases	Final Cost Sheet	<Al	Alea	3	1	C	9/22/2017	6/8/2017	Pass	N/A	N/A	Material Cost $155.48
11	Strength	Instrom testing, part will be placed in fixture and undergo stress and strain testing	Instron	≥AL	Sean	2	3	B	5/30/2017	6/7/2017	N/A	N/A	N/A	Test could not be completed. Aluminum rockers were not taken to failure
12	Weight	Using a scale, part will be wieghed in order to compare to aluminum weight	Scale	≥130.4 g	Jacob	2	3	B	5/29/2017	6/6/2017	Pass	3	0	Left 1: 103.2 g Left 2: 110.5 g Right: 116.8 g

Appendix D. Design Specifications

Spec. #	Description	Target	Tolerance	Risk	Compliance
1	Rocker Arm Geometry	Functional on Bike	--	Medium	Inspection
2	Tolerances and Press Fit Holes	Acquiring from Ventana	± 0.005	Low	Testing
3	Fit Press	6 inches wide	MAX	Medium	Inspection
4	Documentation of Process	Can be repeatable and understood by a Mechanical Engineering student.	--	High	Trials
5	Mold Geometry	Net Shape	±0.05	Low	Testing
6	Part Material	Carbon Fiber Composite	--	Low	Inspection
7	Mold Material	Al-6061	--	Low	Inspection
8	Stiffness	≥ Al	MIN	Medium	Testing
9	Total Research Cost	$500	MAX	Low	--
10	Manufacturing Costs	< Al	MAX	Low	--
11	Strength	≥ Al	MIN	High	Testing

Appendix E. Hazard Identification Checklist

Description of Hazard	Corrective Actions to Be Taken	Planned Completion Date	Actual Completion Date
Hazardous fumes from release agent.	Use in well ventilated area.	9MAY2017	29MAY2017
Pinch Point Hazard from hydraulic press.	Keep fingers and all body parts away from press during use.	10MAY2017	31MAY2017
Carbon Fiber Splinters.	Wear PPE and avoid direct contact with skin and carbon fiber edges.	9MAY2017	29MAY2017
Possible burns when mold is heated during compression manufacturing process.	Signage to illustrate that the mold is currently heated and hot, and to keep away.	10MAY2017	10MAY2017

Appendix F. FMEA

Team Black Gold	Alea Perez, Sean Tischler, Jacob Goldstein FMEA							
Functon	**Potential Failure**	**Potential Effects**	**Severity**	**Potential Causes**	**Occurance**	**Criticality**	**Responsibility and Target Completion Date**	**Action**
Mate To Bike	Doesn't mate to bike	Does not function	7	Improper Mating Geometry	3	21	Sean Tischler - CDR	Analyze design prior to production
			7	Incorrect Part Design	4	28	Sean Tischler - CDR	Analyze design prior to production
			7	Manufacturing Warping	4	28	Sean Tischler - CDR	Defect inspection prior to installation
			7	Incorrect Tolerancing	2	14	Sean Tischler - CDR	Analyze design prior to production
		Injures rider	9	Improper Mating Geometry	3	27	Sean Tischler - CDR	Analyze design prior to production
			9	Incorrect Part Design	4	36	Sean Tischler - CDR	Analyze design prior to production
			9	Manufacturing Warping	4	36	Sean Tischler - CDR	Defect inspection prior to installation
			9	Incorrect Tolerancing	2	18	Sean Tischler - CDR	Analyze design prior to production
			9	Lack of ergonomic Design	2	18	Sean Tischler - CDR	Ergonomic design review prior to production
		Pinches Rider	8	Improper Mating Geometry	3	24	Sean Tischler - CDR	Warpage visual inspection
			8	Incorrect Part Design	4	32	Sean Tischler - CDR	Analyze design prior to production
			8	Manufacturing Warping	4	32	Sean Tischler - CDR	Defect inspection prior to installation
			8	Incorrect Tolerancing	2	16	Sean Tischler - CDR	Analyze design prior to production
			8	Lack of ergonomic Design	2	16	Sean Tischler - CDR	Ergonomic design review prior to production
		Tire Wear(Rub)	5	Improper Mating Geometry	3	15	Sean Tischler - CDR	Analyze design prior to production
			5	Incorrect Part Design	4	20	Sean Tischler - CDR	Analyze design prior to production
			5	Manufacturing Warping	4	20	Sean Tischler - CDR	Defect inspection prior to installation
			5	Incorrect Tolerancing	2	10	Sean Tischler - CDR	Analyze design prior to production
		Interferes with Frame	6	Improper Mating Geometry	3	18	Sean Tischler - CDR	Analyze design prior to production
			6	Incorrect Part Design	4	24	Sean Tischler - CDR	Analyze design prior to production
			6	Manufacturing Warping	4	24	Sean Tischler - CDR	Defect inspection prior to installation
			6	Incorrect Tolerancing	2	12	Sean Tischler - CDR	Ergonomic design review prior to production
	Under-mates to bike	Does not function	5	Improper Mating Geometry	3	15	Sean Tischler - CDR	Analyze mating geometry prior to production
			5	Incorrect Design Geometry	4	20	Sean Tischler - CDR	Analyze design prior to production
		Injures rider	9	Improper Mating Geometry	3	27	Sean Tischler - CDR	Analyze design prior to production
			9	Incorrect Design Geometry	4	36	Sean Tischler - CDR	Analyze design prior to production
			9	Lack of ergonomic Design	2	18	Sean Tischler - CDR	Ergonomic design review prior to production
		Pinches Rider	8	Improper Mating Geometry	3	24	Sean Tischler - CDR	Analyze design prior to production
			8	Incorrect Design Geometry	4	32	Sean Tischler - CDR	Analyze design prior to production
			8	Lack of ergonomic Design	2	16	Sean Tischler - CDR	Ergonomic design review prior to production
		Part Wear	4	Improper Mating Geometry	3	12	Sean Tischler - CDR	Analyze design prior to production
			4	Incorrect Design Geometry	4	16	Sean Tischler - CDR	Analyze design prior to production
		Mate Failure	7	Improper Mating Geometry	3	21	Sean Tischler - CDR	Analyze design prior to production
			7	Incorrect Design Geometry	4	28	Sean Tischler - CDR	Analyze design prior to production
		Tire Wear(Rub)	8	Improper Mating Geometry	3	24	Sean Tischler - CDR	Analyze design prior to production
			8	Incorrect Design Geometry	4	32	Sean Tischler - CDR	Defect inspection prior to installation
	Over-mates to bike	Part does not rotate	6	Incorrect Mating Geometry	3	18	Sean Tischler - CDR	Visual Mate Inspection
			6	Foreign material in bearings	5	30	Sean Tischler - CDR	Defect inspection prior to installation
			6	Connections over tightened	4	24	Sean Tischler - CDR	Verify installation procedure
			6	Incorrect installation	3	18	Sean Tischler - CDR	Verify installation procedure
		Part fails under shock loads	5	Incorrect Mating Geometry	3	15	Sean Tischler - CDR	Analyze design prior to production
			5	Foreign material in bearings	5	25	Sean Tischler - CDR	Defect inspection prior to installation
			5	Connections over tightened	4	20	Sean Tischler - CDR	Verify installation procedure
			5	Incorrect Installation	3	15	Sean Tischler - CDR	Verify installation procedure
		Frame Damage	5	Incorrect Mating Geometry	2	10	Sean Tischler - CDR	Visual Installation inspection
			5	Connections over tightened	4	20	Sean Tischler - CDR	Verify installation procedure
			5	Incorrect Installation	3	15	Sean Tischler - CDR	Verify installation procedure
		Rider Discomfort	7	Incorrect Mating Geometry	3	21	Sean Tischler - CDR	Analyze design prior to production
			7	Foreign material in bearings	5	35	Sean Tischler - CDR	Defect inspection prior to installation
			7	Connections over tightened	4	28	Sean Tischler - CDR	Verify installation procedure

			4	Incorrect installation	3	12	Sean Tischler - CDR	Verify installation procedure
	Incorrect mate to bike	Mate Failure	7	Increased stress on joints	4	28	Sean Tischler - CDR	Reevaluate bike loads
			7	correct geometry increasing stress or interferen	4	28	Sean Tischler - CDR	Analyze design prior to production
		Part wear	8	Increased stress on joints	4	32	Sean Tischler - CDR	Analyze design prior to production
			8	correct geometry increasing stress or interferen	4	32	Sean Tischler - CDR	Analyze design prior to production
			8	Under constrained frame geometry	2	16	Sean Tischler - CDR	Analyze design prior to production
		Tire Wear(Rub)	8	Increased stress on joints	4	32	Sean Tischler - CDR	Analyze mating geometry prior to production
			8	correct geometry increasing stress or interferen	4	32	Sean Tischler - CDR	Analyze design prior to production
			8	Under constrained frame geometry	2	16	Sean Tischler - CDR	Analyze design prior to production
		Pinches Rider	8	correct geometry increasing stress or interferen	4	32	Sean Tischler - CDR	Analyze design prior to production
			8	Under constrained frame geometry	2	16	Sean Tischler - CDR	Analyze design prior to production
		Injures rider	9	correct geometry increasing stress or interferen	4	36	Sean Tischler - CDR	Analyze design prior to production
			9	Under constrained frame geometry	2	18	Sean Tischler - CDR	Analyze design prior to production
		Part does not rotate	6	correct geometry increasing stress or interferen	4	24	Sean Tischler - CDR	Analyze design prior to production
			6	Over constrained frame geometry	2	12	Sean Tischler - CDR	Analyze design prior to production
Aesthetically Pleasing	Not Pleasing	Not seen as a viable alternative to al	3	Poor aesthetic design	4	12	Jacob Goldstein- CDR	Ergonomic design review prior to production
			3	Poor Surface Finish	5	15	Jacob Goldstein- CDR	Analyze design prior to production
			3	Clashing aesthetics with other parts	1	3	Jacob Goldstein- CDR	Aesthetic design review prior to production
	Somewhat-ugly compared to bike	Difficult customer appeal	2	Poor aesthetic design	4	8	Jacob Goldstein- CDR	Ergonomic design review prior to production
			2	Poor Surface Finish	5	10	Jacob Goldstein- CDR	Analyze design prior to production
			2	Clashing aesthetics with other parts	1	2	Jacob Goldstein- CDR	Aesthetic design review prior to production
Transfers Forces	Transfers forces in Different direction	Damages Frame	5	Misaligned mating geometry	4	20	Sean Tischler - CDR	Analyze mating geometry prior to production Analyze design prior to production
		Rider Discomfort	4	Part warping in manufacturing	4	16	Sean Tischler - CDR	Warpage visual inspection
		Improper/Dangerous bike handling	4	Out of tolerance mating geometry	4	16	Sean Tischler - CDR	Inspect mating tolerances after production
	Does not transfer any forces	Critical Rear Triangle Failure	6	Improper part geometry	4	24	Sean Tischler - CDR	Analyze design prior to production
		Severe handling changes	5	Over-mated part design	2	10	Sean Tischler - CDR	Analyze design prior to production
		Severe shock loading forces	5	Incorrect mating method to bike	2	10	Sean Tischler - CDR	Analyze design prior to production
	Reduces forces transferred	Rocker arm failure	6	Severe rocker arm deflection	5	30	Sean Tischler - CDR	Analyze design prior to production
		Difficult suspension tuning	4	Insufficient part stiffness	5	20	Sean Tischler - CDR	Analyze design prior to production
		Seat stay failure	5	Incorrect leverage ratio	1	5	Sean Tischler - CDR	Analyze design prior to production
	Increased force transfer	Damage to frame	5	Incorrect leverage ratio	1	5	Sean Tischler - CDR	Analyze design prior to production
		Shock Failure	6	Overly-stiff part design	3	18	Sean Tischler - CDR	Analyze design prior to production
		Rocker arm failure	6	Improper part installation	2	12	Sean Tischler - CDR	Verify installation procedure
	Doesn't Move	Rocker arm failure	6	Improper part installation	2	12	Alea Perez-Inspect After Part Manufacture	Verify installation procedure
		Bike frame damage	5	Improper mating geometry	3	15	Sean Tischler - CDR	Analyze design prior to production
		Poor bike handling	4	Over-defined mating method	2	8	Sean Tischler - CDR	Analyze design prior to production
		Damages shock	4	Incorrect leverage ratio		4	Sean Tischler - CDR	

		[illegible]	[illegible]	[illegible]	2	[illegible]	[illegible]	Analyze design prior to production
Full Range of Motion	Moves too much	Damages shock	4	Incorrect leverage ratio	1	4	Sean Tischler - CDR	Analyze design prior to production
		Damages Frame	5	Incorrect part installation	2	10	Alea Perez-Inspet After Part Manufacture	Verify installation procedure
	Incorrect motion	Shock Failure	5	Incorrect part geometry	3	15	Sean Tischler - CDR	Analyze design prior to production
		User harm	8	Incorrect installation	2	16	Alea Perez-Inspect After Part Manufacture	Verify installation procedure
		Frame Damage	5	Incorrect part design	4	20	Sean Tischler - CDR	Analyze design prior to production
	Limited range of motion	Limited bike travel	4	Overmated part design	2	8	Sean Tischler - CDR	Analyze design prior to production
		Reduced bike handling	4	Incorrect part design	4	16	Sean Tischler - CDR	Analyze design prior to production
		Increased shock loading	3	Incorrect part installation	2	6	Alea Perez-Inspect After Part Manufacture	Verify installation procedure
	Dragging Parts	Frame Damage	5	Manufacturing warping	4	20	Alea Perez-Inspect After Part Manufacture	Defect inspection prior to installation
		User Harm	8	Inproper part tolerancing	2	16	Sean Tischler - CDR	Analyze design prior to production
	Difficult to move	Reduced bike handling	4	Misaligned mating geometry	4	16	Alea Perez-Inspect After Part Manufacture	Analyze design prior to production
		Increased shock loading	3	Improper installing procedure	2	6	Alea Perez-Inspect After Part Manufacture	Verify installation procedure
	Intereferes with user	User Harm	8	Poor part ergonomic design	2	16	Jacob Goldstein- CDR	Ergonomic design review prior to production
		Reduced bike handling	4	Part design too wide	1	4	Sean Tischler - CDR	Analyze design prior to production

Appendix G. Bill of Materials

Black Gold Bill of Materials

Puck, Part Mold Materials and Final Part Assembly Material

Notes: Total Cost to the Team 2016-2017

Assembly Level	Part Number	Description: Level 0	Description: Level 1	Description: Level 2	Vendor	Qty.	Cost	Total Cost	Tax Cost
0	CR1-1-1	Composite Rocker Arm							
1	CR1-3-1/2		Puck Mold						
2	CR1-3-8			Chopped Fiber	Composites Lab	N/A	NC	NC	NC
2	CR1-3-6			Aluminum (1.25" x 3" x 13")	Ventana Bikes USA	1	NC	NC	NC
2	CR1-3-4/5			Aluminum(1.5" x 12")	IME Lab	1	NC	NC	NC
2	CR1-3-7			Steel Pins (.25" X 7/8")X5	Online Metals	1	6.96	6.96	0.5
1	CR1-2-1/2		Part Mold						
2	CR1-2-8			TC275-1/T700SC	Composites Lab	N/A	NC	NC	NC
2	CR1-2-6			Aluminum(2.5" x 5" x 36")	Ventana Bikes USA	1	NC	NC	NC
2	CR1-2-4/5			Stainless Steel (1.25" x 12")	Online Metals	1	39.93	39.93	
2	CR1-2-7			Compression Springs	Mcmaster	1	7.26	7.26	
1	CR1-1-2		Bearing		Ventana Bikes USA	2	NC	NC	NC
1	CR1-1-3		Bearing		Ventana Bikes USA	2	NC	NC	NC
1	CR1-1-4		Screw		Ventana Bikes USA	2	NC	NC	NC
1	CR1-1-5		Screw		Ventana Bikes USA	2	NC	NC	NC
1	CR1-1-6		Screw		Ventana Bikes USA	2	NC	NC	NC
1	CR1-4-1		Test Jig						
2	CR1-4-2			Steel Tube (1.5"x1" .120") Rectangular	Paso Robles Steel	1	24.14	24.14	
2	CR1-4-3			1.5" Steel Round	Paso Robles Steel	1	10.47	10.47	
2				3/8" Diameter x 4" Long shoulder, 5/16"-18 Thread	Mcmaster	1	3.17	3.17	
2				1/2" Diameter x 1" Long Shoulder, 3/8"-16 Thread Size	Mcmaster	2	2.40	4.8	
2				1/2" Diameter x 1-1/2" Long Shoulder, 3/8"-16 Thread Size	Mcmaster	2	5.00	10	
				1/2" Diameter x 3" Long Shoulder, 3/8"-16 Thread Size	Mcmaster	1	3.33	3.33	
2				1/4" Diameter x 1-1/4" Long Shoulder, 10-24 Thread Size	Mcmaster	5	5.50	27.5	
2				Alloy Steel Socket Nut	Mcmaster	1	11.68	11.68	
	Total Parts					**30**		**$ 149.24**	**$ 0.50**

Black Gold Consumable Purchases

Description	Vendor	Qty.	Cost	Total Cost	Tax Cost
15/64" End Mill	McMaster-Carr	1	19.65	19.65	1.42
3M Scissor	Costco	1	9.99	9.99	0.77
Protractor	Home Depot	1	8.97	8.97	0
50PK Carbide Utility Blades	Home Depot	1	19.97	19.97	0
Dewalt Folding Retract Utility Knife	Home Depot	2	9.97	19.94	0
Acetone Gal	Home Depot	1	12.97	12.97	0
Disposable Nitrile	Home Depot	2	4.97	9.94	0
Husky 16" Tool Box	Home Depot	1	6.97	6.97	6.1
				$ 108.40	**$ 8.29**

Black Gold Bill of Materials

Puck, Part Mold Materials and Final Part Assembly Material

Notes: Cost of Project if payed out of pocket

Assembly Level	Part Number	Description Level 0	Description Level 1	Description Level 2	Vendor	Qty.	Cost	Total Cost
0	CR1-1-1	Composite Rocker Arm						
1	CR1-3-1/2		Puck Mold					
2	CR1-3-8			Chopped Fiber	Composites Lab	N/A	NC	NC
2	CR1-3-6			Aluminum (3" x 24" x 1.25")	McMaster	1	58.61	58.61
2	CR1-3-4/5			Aluminum(1.5" x 12")	IME Lab	1	NC	NC
2	CR1-3-7			Steel Pins (1/4" X 12")	McMaster	1	4.71	4.71
1	CR1-2-1/2		Part Mold					
2	CR1-2-8			TC275-1/T700SC	Composites Lab	N/A	NC	NC
2	CR1-2-6			Aluminum(5" x 24" x 2.5")	McMaster	2	179.89	359.78
2	CR1-2-4/5			Stainless Steel (1.25" x 12")	Online Metals	1	39.93	39.93
2	CR1-2-7			Compression Springs	Mcmaster	1	7.26	7.26
1	CR1-1-2		Bearing		Ventana Bikes USA	2	NC	NC
1	CR1-1-3		Bearing		Ventana Bikes USA	2	NC	NC
1	CR1-1-4		Screw(M6)		Ventana Bikes USA	2	NC	NC
1	CR1-1-5		Screw		Ventana Bikes USA	2	NC	NC
1	CR1-1-6		Screw		Ventana Bikes USA	2	NC	NC
1	CR1-4-1		Test Jig					
2	CR1-4-2			Steel Tube(1.5"x1" .120") Rectangular	Mcmaster	6	24.14	144.84
2	CR1-4-3			.5" Hex Drive Rounded Head Screw Pack of 5	Mcmaster	1	10.47	10.47
1	CR1-4-4			.5" Steel Hex Nut Pack of 50	Mcmaster	1	7.59	7.59
2	CR1-4-2			Steel Tube (1.5"x1" .120") Rectangular	Paso Robles Steel	1	24.14	24.14
2	CR1-4-3			1.5" Steel Round	Paso Robles Steel	1	10.47	10.47
2				3/8" Diameter x 4" Long shoulder, 5/16"-18 Thread Size	Mcmaster	1	3.17	3.17
2				1/2" Diameter x 1" Long Shoulder, 3/8"-16 Thread Size	Mcmaster	2	2.40	4.8
2				1/2" Diameter x 1-1/2" Long Shoulder, 3/8"-16 Thread Size	Mcmaster	2	5.00	10
2				1/2" Diameter x 3" Long Shoulder, 3/8"-16 Thread Size	Mcmaster	1	3.33	3.33
2				1/4" Diameter x 1-1/4" Long Shoulder, 10-24 Thread Size	Mcmaster	5	5.50	27.5
2				Alloy Steel Socket Nut	Mcmaster	1	11.68	11.68
	Total Parts					**39**		**$ 1,343.41**

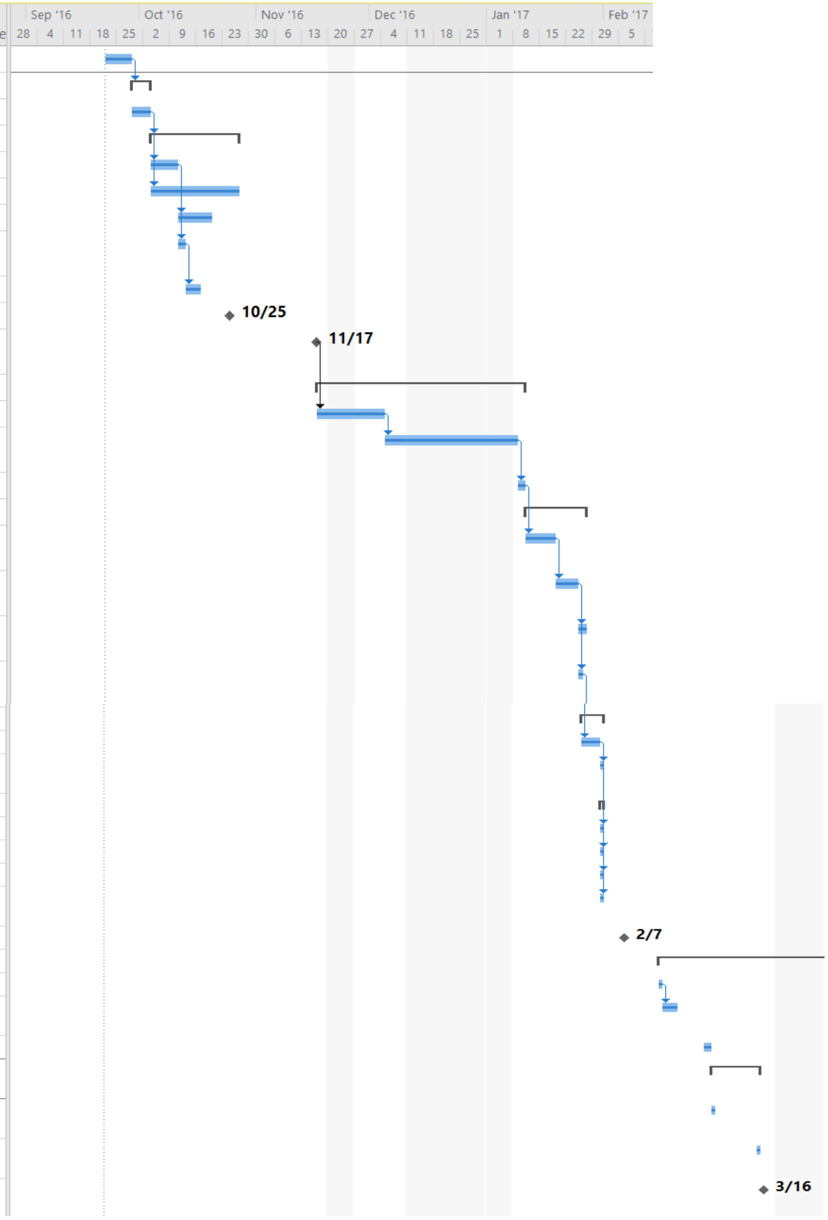
	Total Spending		Consumables	
Spent	$	155.48	$	122.43
Total	$	277.91		
Remaining	$	222.09		

Appendix H. Gantt Chart

GANTT CHART

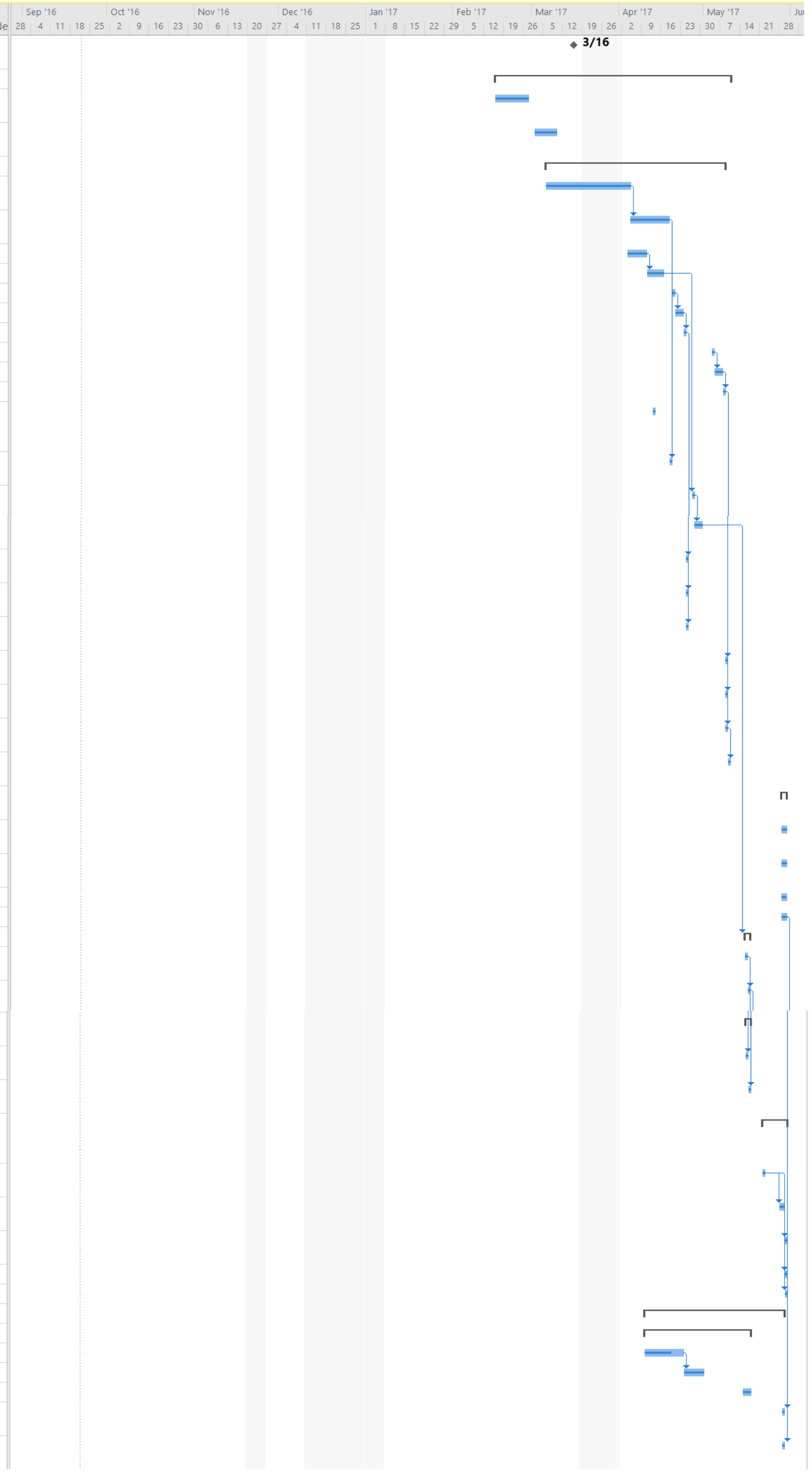
	Task Name	Duration	Start	Finish	Prede
1	Choose Project	5 days	Thu 9/22/16	Thu 9/29/16	
2	**Meet Team**	**3 days**	**Thu 9/29/16**	**Tue 10/4/16**	**1**
3	Create Team Contract	3 days	Thu 9/29/16	Tue 10/4/16	
4	**Project Introduction**	**17 days**	**Tue 10/4/16**	**Thu 10/27/16**	**3**
5	Interview Sponsor	5 days	Tue 10/4/16	Tue 10/11/16	3
6	Research Project	17 days	Tue 10/4/16	Thu 10/27/16	3
7	Define Project	7 days	Tue 10/11/16	Thu 10/20/16	5
8	Create Customer Requirements	2 days	Tue 10/11/16	Thu 10/13/16	5
9	Develop QFD	2 days	Thu 10/13/16	Mon 10/17/1€	8
10	**Project Proposal**	0 days	Tue 10/25/16	Tue 10/25/16	
11	**Preliminary Design Review**	0 days	Thu 11/17/16	Thu 11/17/16	
12	**Post PDR**	**14 days**	**Thu 11/17/16**	**Wed 1/11/17**	
13	Experiment with Fusio	7 days	Thu 11/17/16	Mon 12/5/16	11
14	Generate Ideas for Rocker Cross-Section	5 days	Mon 12/5/16	Mon 1/9/17	13
15	Select Cross-Section	2 days	Mon 1/9/17	Wed 1/11/17	14
16	**Rocker Arm Design**	**11 days**	**Wed 1/11/17**	**Fri 1/27/17**	
17	Experiment Rocker Arm Designs	5 days	Wed 1/11/17	Thu 1/19/17	15
18	Use Matlab Code to Analyze Rockers	4 days	Thu 1/19/17	Wed 1/25/17	17
19	Design Matrix for Rocker Models	2 days	Wed 1/25/17	Fri 1/27/17	18
20	Choose Rocker Arm Design	1 day	Wed 1/25/17	Thu 1/26/17	18
21	**Mold Design**	**4 days**	**Thu 1/26/17**	**Wed 2/1/17**	
22	Create CAD for Mold	3 days	Thu 1/26/17	Tue 1/31/17	20
23	Check through features	1 day	Tue 1/31/17	Wed 2/1/17	22
24	**Manufacture Plan**	**1 day**	**Tue 1/31/17**	**Wed 2/1/17**	
25	Mold Machining	1 day	Tue 1/31/17	Wed 2/1/17	22
26	Mold Prep	1 day	Tue 1/31/17	Wed 2/1/17	22
27	Composite Layup	1 day	Tue 1/31/17	Wed 2/1/17	22
28	Composite Post Processing	1 day	Tue 1/31/17	Wed 2/1/17	22
29	**Critical Design Review**	0 days	Tue 2/7/17	Tue 2/7/17	
30	**Post CDR**	**62.06 days**	**Thu 2/16/17**	**Thu 6/1/17**	
31	CTE Calcs	1 day	Thu 2/16/17	Fri 2/17/17	
32	Update Puck Parts to match CTE	1 day	Fri 2/17/17	Tue 2/21/17	31
33	Experiment Planning	2 days	Tue 2/28/17	Thu 3/2/17	
34	**Preliminary Tensile Test**	**8.83 days**	**Thu 3/2/17**	**Wed 3/15/17**	
35	Mock layup tensile specimen	1 day	Thu 3/2/17	Fri 3/3/17	
36	Post Process and Instron Test	1 day	Tue 3/14/17	Wed 3/15/17	
37	**Project Update Report**	0 days	Thu 3/16/17	Thu 3/16/17	

GANTT CHART



GANTT CHART

	Task Name	Duration	Start	Finish	Prede
37	**Project Update Report**	0 days	Thu 3/16/17	Thu 3/16/17	
38	**Mold Manufacturing**	**48.08 days**	**Thu 2/16/17**	**Thu 5/11/17**	
39	Order Materials for Mold	7 days	Thu 2/16/17	Tue 2/28/17	
40	Order Rod for pins and tooling	6 days	Thu 3/2/17	Fri 3/10/17	
41	**CAM**	**35.31 days**	**Mon 3/6/17**	**Tue 5/9/17**	
42	CAM Bottom Mold (Right)	12 days	Mon 3/6/17	Wed 4/5/17	
43	CAM Top Mold (Right)	10 days	Wed 4/5/17	Wed 4/19/17	42
44	CAM Puck Botton	5 days	Tue 4/4/17	Tue 4/11/17	
45	CAM Puck Top	4 days	Tue 4/11/17	Mon 4/17/17	44
46	CAM Insert 1	1 day	Thu 4/20/17	Fri 4/21/17	
47	CAM Insert 2	1 day	Fri 4/21/17	Mon 4/24/17	46
48	CAM Insert 3	1 day	Mon 4/24/17	Tue 4/25/17	47
49	CAM Plunge Pin 1	1 day	Thu 5/4/17	Fri 5/5/17	
50	CAM Plunge Pin 2	1 day	Fri 5/5/17	Mon 5/8/17	49
51	CAM Plunge Pin 3	1 day	Mon 5/8/17	Tue 5/9/17	50
52	Manufacture Bottom Mold (Right)	1 day	Thu 4/13/17	Fri 4/14/17	
53	Manufacture Top Mold (Right)	1 day	Wed 4/19/17	Thu 4/20/17	43
54	Manufacture Puck Bottom	1 day	Thu 4/27/17	Fri 4/28/17	45
55	Manufacture Puck Top	1 day	Fri 4/28/17	Mon 5/1/17	54
56	Manufacture Puck Insert 1	1 day	Tue 4/25/17	Wed 4/26/17	48
57	Manufacture Puck Insert 2	1 day	Tue 4/25/17	Wed 4/26/17	48
58	Manufacture Puck Insert 3	1 day	Tue 4/25/17	Wed 4/26/17	48
59	Manufacture Mold Insert 1	1 day	Tue 5/9/17	Wed 5/10/17	51
60	Manufacture Mold Insert 2	1 day	Tue 5/9/17	Wed 5/10/17	51
61	Manufacture Mold Insert 3	1 day	Tue 5/9/17	Wed 5/10/17	51
62	Prepare Molds for Layup	1 day	Wed 5/10/17	Thu 5/11/17	61
63	**Composites Manufacturing**	**1.33 days**	**Mon 5/29/17**	**Wed 5/31/17**	
64	Cut Carbon Preform	1 day	Mon 5/29/17	Wed 5/31/17	
65	Layup Carbon Fiber on Mold	1 day	Mon 5/29/17	Wed 5/31/17	
66	Cure Carbon Fiber	1 day	Mon 5/29/17	Wed 5/31/17	
67	Post Process Part	1 day	Mon 5/29/17	Wed 5/31/17	
68	**CAM 2**	**2 days**	**Tue 5/16/17**	**Thu 5/18/17**	**55**
69	CAM Bottom Mold (Left)	1 day	Tue 5/16/17	Wed 5/17/17	
70	CAM Top Mold (Left)	1 day	Wed 5/17/17	Thu 5/18/17	69
71	**Left Mold Manufacture**	**2 days**	**Wed 5/17/17**	**Fri 5/19/17**	
72	Manufacture Bottom Mold (left)	1 day	Wed 5/17/17	Thu 5/18/17	69
73	Manufacture Top Mold (left)	1 day	Thu 5/18/17	Fri 5/19/17	70
74	**Composite Manufacturing (left rev2)**	**6.25 days**	**Tue 5/23/17**	**Thu 6/1/17**	
75	Prepare Left Mold Halves	1 day	Tue 5/23/17	Wed 5/24/17	
76	Cut Carbon Preform	1 day	Mon 5/29/17	Wed 5/31/17	75
77	Layup Carbon Fiber on Mold	1 day	Wed 5/31/17	Thu 6/1/17	75
78	Cure Carbon Fiber	1 day	Wed 5/31/17	Thu 6/1/17	75
79	Post Process Part	1 day	Wed 5/31/17	Thu 6/1/17	75
80	**Testing**	**34.63 days**	**Tue 4/11/17**	**Wed 5/31/17**	
81	**Test Jig**	**27.48 days**	**Tue 4/11/17**	**Fri 5/19/17**	
82	Design Test Jig	10 days	Tue 4/11/17	Tue 4/25/17	
83	Order Materials	5 days	Tue 4/25/17	Tue 5/2/17	82
84	Build Test Jig	3 days	Tue 5/16/17	Fri 5/19/17	
85	Test Aluminum Rocker Arm	1 day	Tue 5/30/17	Wed 5/31/17	67
86	Test Composite Rocker Arm	1 day	Tue 5/30/17	Wed 5/31/17	67

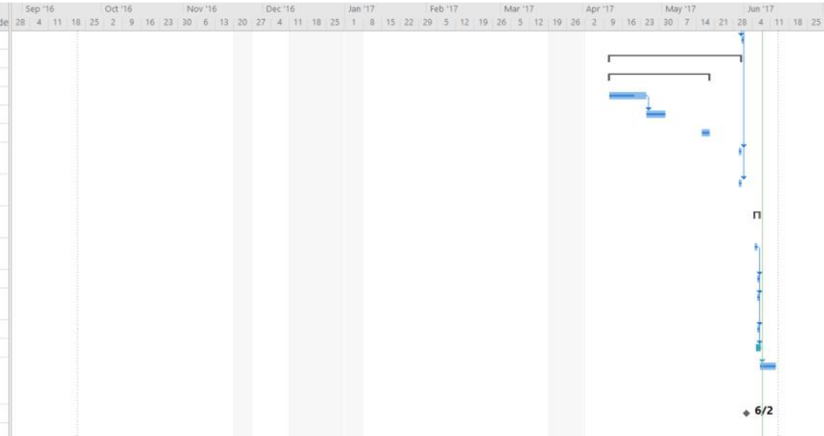


GANTT CHART

GANTT CHART

GANTT CHART

	Task Name	Duration	Start	Finish	Prede
79	Post Process Part	1 day	Wed 5/31/17	Thu 6/1/17	75
80	**Testing**	**34.63 days**	**Tue 4/11/17**	**Wed 5/31/17**	
81	**Test Jig**	**27.48 days**	**Tue 4/11/17**	**Fri 5/19/17**	
82	Design Test Jig	10 days	Tue 4/11/17	Tue 4/25/17	
83	Order Materials	5 days	Tue 4/25/17	Tue 5/2/17	82
84	Build Test Jig	3 days	Tue 5/16/17	Fri 5/19/17	
85	Test Aluminum Rocker Arm	1 day	Tue 5/30/17	Wed 5/31/17	67
86	Test Composite Rocker Arm	1 day	Tue 5/30/17	Wed 5/31/17	67
87	**Composite Manufacturing (right)**	**2 days?**	**Mon 6/5/17**	**Wed 6/7/17**	
88	Prepare mold halves	1 day	Mon 6/5/17	Tue 6/6/17	
89	Cut Carbon	1 day	Tue 6/6/17	Wed 6/7/17	88
90	Layup Carbon Fiber on Mold	1 day	Tue 6/6/17	Wed 6/7/17	88
91	Cure Carbon Fiber	1 day	Tue 6/6/17	Wed 6/7/17	88
92	Post Process Part	1 day	Tue 6/6/17	Wed 6/7/17	88
93	Document and Summarize Process and Test Results	4 days	Wed 6/7/17	Tue 6/13/17	92
94	**FDR Report**	0 days	Fri 6/2/17	Fri 6/2/17	



Appendix I. Operators Manual

Black Gold

"A carbon fiber process more valuable than gold"

Rocker Arm Operators Manual

March 9, 2017

Sponsor:

Joseph Mello

Team Members:

Sean Tischler

Alea Perez

Jacob Goldstein

Assembly:

To assemble the carbon fiber rocker onto a Ventana Alpino, the following procedure should be followed:

1. First, ensure that the carbon rocker is free of any defects due to manufacturing. Any excess material which would interfere with its functionality or strength should be removed or noted as a defect from using the part.
    a. If excess mold material is present, the part needs additional post manufacturing prior to continuing installation.
    b. If the carbon rocker appears to have defects after manufacturing that could hinder strength and performance, the part should not be used, and assembly should resume only with a properly manufactured rocker.
2. Once the rocker arm has been deemed sufficient to begin assembly, the rocker arm needs to have its bearing interfaces prepped for bearing installation. The lower large bearing interface needs to be wet sanded until it is of a transition fit to allow for tight bearing installation with epoxy.
    a. Place rocker on soft material on table
    b. Press first bearing into bearing location until it rests against locating lip.
    c. Press second bearing until it’s body is in contact with the first bearing. Ensure that both bearings rotate smoothly after installation. Bearing installation is shown in Figure 36.

Figure 36. Bearing installation into rocker arm.

3. Begin installation of rocker arm onto Ventana Alpino. Prior to attaching the rocker to the bike ensure that the rear shock is depressurized such that rocker motion can be tested prior to use.
4. Begin attachment by securing the upper shock mount to the front mounting location on the rocker. Use the provided hardware to secure the rocker arm, and torque per Ventana’s specifications
5. After the front of the rocker has been mounted, use the provided hardware to mount the large lower rocker arm bearing interface to the Ventana frame. Tighten the bolt and nut.

6. Now that the front two mating surfaces of the rocker have been mounted to the Ventana frame, attach the rear portion of the rocker to the chain stay link on the Ventana bicycle. Use the provided hardware to mount the rocker, and torque to Ventana Bikes USA's specifications.
7. Ensure that the rocker arm pivots smoothly, without friction or resistance prior to pressurizing shock and using the bike.

Use:

The carbon fiber rocker produced by Black Gold is only intended for compression molding research and use only on a Ventana Alpino mountain bike. This rocker arm can only be used on the Ventana mountain bike is not compatible with any other mountain bikes. The rocker arm is designed for normal bike usage, and abnormal or extreme riding conditions can cause part failure. If you are unsure whether on what normal riding conditions are please contact Ventana Bikes USA for more information.

Warnings:

Mountain biking is a dangerous sport and all precautions should be made to ensure the safety of the rider during the use of the Ventana Alpino. This means that the rocker and all other parts on the bike need to be inspected prior to each use.

Appendix J. Job Routing Sheets

CAL POLY
College of Engineering

Part Routing / Job Planner	
Name:	Black Gold
Part:	Rocker Mold Top/Bottom Left/Right
Drawing Rev:	A
Material:	AL 6061-T6

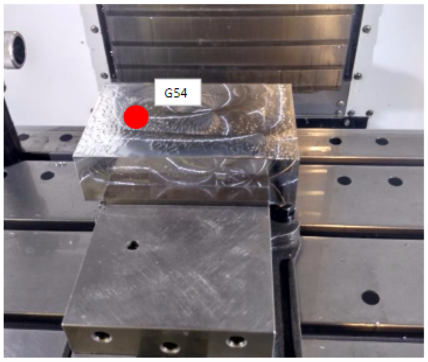
Notes: Deburr all edges after every operation.

OP #	Operation Description	Machine Tool	Tooling & Fixtures Required	OP Time (min)	Approval
10	Cut stock to length and deburr	Horizontal Band Saw	Caliper/tape measure, deburring tool or metal file	30	
20	CNC OP 1	Haas VF-2	Mill vise, 1-3/4" parallels, Haas Probe, calipers, 3" face mill, 1/2" End Mill, 1" Insert Mill, 1/4" Ball, 1/8" Ball, C Drill, 1/2" Drill, 15/64" End Mill, .249 Reamer, 3/4" Chamfer Mill	240	
30	First article inspection 1	Micro-Vu vision system	Calipers	30	
40	CNC OP 2	Haas VF-2	Mill vise, 1-5/8" parallels, Haas probe, calipers, 3" face mill, 1/2" End Mill, 1" Insert Mill, 1/4" Ball, 1/8" Ball, C Drill, 1/2" Drill, 15/64" End Mill, .249 Reamer	150	
50	First article inspection 2	Micro-Vu vision system	Calipers	30	
60					
70					

CAL POLY College of Engineering	Operation Setup Sheet			
	Name:	Black Gold	Machine Tool:	Haas VF-2
	Part:	Rocker Molds Bottom Left/Right		
	Drawing Rev:	A		
	Material:	AL 6061-T6, 2.50" x 5.00" x 8.00" Cut Stock		

Notes: Deburr all edges after every operation.
Tooling Information: Haas VF-2 Vertical Machining Center, Mill Vice, Parallels, Edge Finder, 3" Face Mill, 1/2" End Mill, 1" Insert Mill, 1/4" Ball Mill, 1/8" Ball Mill, C Drill, 1/2" Drill, 15/64 End Mill, .249" Reamer
Inspection Equipment: Caliper
Personal Protective Equipment: Safety Glasses, Long Pants, Closed Toed Shoes

OP #	Operation Description
20	CNC Operation 1: Turn on power to mill. Press reset. Press Power Up/Restart. Ensure mill vice is trammed in plane with test indicator, adjust if necesary. Place parallels in vice. Set G54 zero to parallel's left and rear edge. Place aluminum stock in vice sitting atop parallels. Align left edge of stock with vice edge. Tighten vice, and ensure no part lift has occured with soft blow mallet. Load tools into tool holders if necesary. Load tools into mill. Set tool height offsets of tools to top face of stock. Load program O00020 (CNC OP 1) into active memory from storage device. Ensure coolant valves are open. Close shroud doors and run program. Once program completes, wash chips down from all surfaces with attached hose. Remove part. Inspect major dimensions of part with calipers.

Tool	Tool Description	SFM [ft/min]	RPM [rev/min]	Chip Load [in/tooth]	Feed Rate [in/min]	Setup Figure
A1	Kurt Mill Vice	-	-	-	-	
A2	Test Indicator	-	-	-	-	
A3	1-3/4" Parallels	-	-	-	-	
A4	Soft Blow Hammer	-	-	-	-	
A5	Haas Probe	-	-	-	-	
T1	3" Facing Shell Mill, Carbide Inserts, 5 teeth	2500	3100	.002	25	
T2	1/2" End Mill	750	5730	.0022	50	
T3	1" Insert Mill	2500	10000	.002	25	
T4	1/4" Ball Mill	650	10000	0.003	120	

CAL POLY
College of Engineering

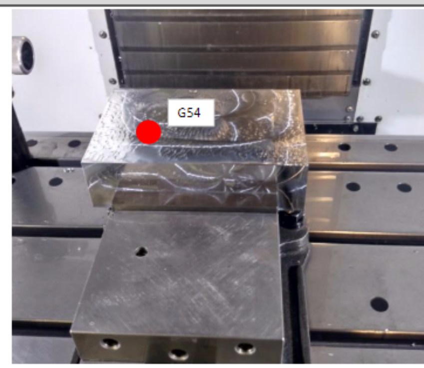
Operation Setup Sheet			
Name:	Black Gold	Machine Tool:	Haas VF-2
Part:	Rocker Molds Bottom Left/Right		
Drawing Rev:	A		
Material:	AL 6061-T6, 2.50" x 5.00" x 8.00" Cut Stock		

Notes: Deburr all edges after every operation.
Tooling Information: Haas VF-2, Mill Vice, Parallels, Edge Finder, 3" Face Mill, 1/2" End Mill, 1" Insert Mill, 1/4" Ball Mill, 1/8" Ball Mill, C Drill, 1/2" Drill, 15/64 End Mill, .249" Reamer
Inspection Equipment: Caliper
Personal Protective Equipment: Safety Glasses, Long Pants, Closed Toed Shoes

OP #	Operation Description
20	CNC Operation 1: Turn on power to mill. Press reset. Press Power Up/Restart. Ensure mill vice is trammed in plane with test indicator, adjust if necesary. Place parallels in vice. Set G54 zero to parallel's left and rear edge. Place aluminum stock in vice sitting atop parallels. Align left edge of stock with vice edge. Tighten vice, and ensure no part lift has occured with soft blow mallet. Load tools into tool holders if necesary. Load tools into mill. Set tool height offsets of tools to top face of stock. Load program O00020 (CNC OP 1) into active memory from storage device. Ensure coolant valves are open. Close shroud doors and run program. Once program completes, wash chips down from all surfaces with attached hose. Remove part. Inspect major dimensions of part with calipers.

Tool	Tool Description	SFM [ft/min]	RPM [rev/min]	Chip Load [in/tooth]	Feed Rate [in/min]
T5	1/8" Ball Mill	320	10000	0.0069	276
T6	C Drill	300	4700	0.006	55
T7	1/2" Drill	250	1900	0.002	4.6
T8	15/64" End Mill	600	10000	0.0015	60
T9	.249" Reamer	150	2200	0.002	3.8
T10	3/4" Chamfer Mill	600	2300	.002	10
B1	Calipers	-	-	-	-

Setup Figure



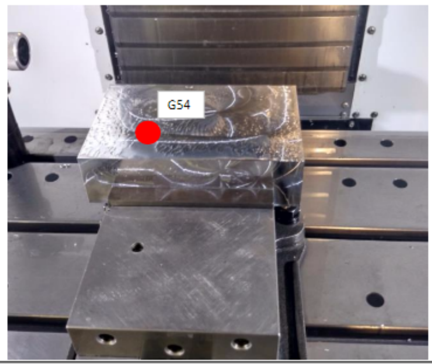
CAL POLY College of Engineering	Operation Setup Sheet			
	Name:	Black Gold	Machine Tool:	Haas VF-2
	Part:	Rocker Molds Top Left/Right		
	Drawing Rev:	A		
	Material:	AL 6061-T6, 2.50" x 5.00" x 8.00" Cut Stock		

Notes: Deburr all edges after every operation.
Tooling Information: Haas VF-2 Vertical Machining Center, Mill Vice, Parallels, Edge Finder, 3" Face Mill, 1/2" End Mill, 1" Insert Mill, 1/4" Ball Mill, 1/8" Ball Mill, C Drill, 1/2" Drill, 15/64 End Mill, .249" Reamer
Inspection Equipment: Caliper
Personal Protective Equipment: Safety Glasses, Long Pants, Closed Toed Shoes

OP #	Operation Description
40	CNC Operation 2: Turn on power to mill. Press reset. Press Power Up/Restart. Ensure mill vice is trammed in plane with test indicator, adjust if necesary. Place parallels in vice. Set G54 zero to parallel's left and rear edge. Place aluminum stock in vice sitting atop parallels. Align left edge of stock with vice edge. Tighten vice, and ensure no part lift has occured with soft blow mallet. Load tools into tool holders if necesary. Load tools into mill. Set tool height offsets of tools to top face of stock. Load program O00021 (CNC OP 2) into active memory from storage device. Ensure coolant valves are open. Close shroud doors and run program. Once program completes, wash chips down from all surfaces with attached hose. Remove part. Inspect major dimensions of part with calipers.

Tool	Tool Description	SFM [ft/min]	RPM [rev/min]	Chip Load [in/tooth]	Feed Rate [in/min]
A1	Kurt Mill Vice	-	-	-	-
A2	Test Indicator	-	-	-	-
A3	1-5/8" Parallels	-	-	-	-
A4	Soft Blow Hammer	-	-	-	-
A5	Haas Probe	-	-	-	-
T1	3" Facing Shell Mill, Carbide Inserts, 5 teeth	2500	3100	.002	25
T2	1/2" End Mill	750	5730	.0022	50
T3	1" Insert Mill	2500	10000	.002	25
T4	1/4" Ball Mill	650	10000	0.003	120

Setup Figure



CAL POLY
College of Engineering

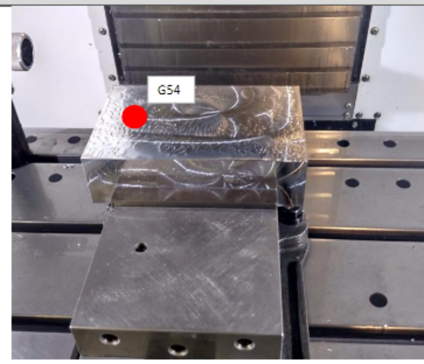
Operation Setup Sheet			
Name:	Black Gold	Machine Tool:	Haas VF-2
Part:	Rocker Molds Top Left/Right		
Drawing Rev:	A		
Material:	AL 6061-T6, 2.50" x 5.00" x 8.00" Cut Stock		

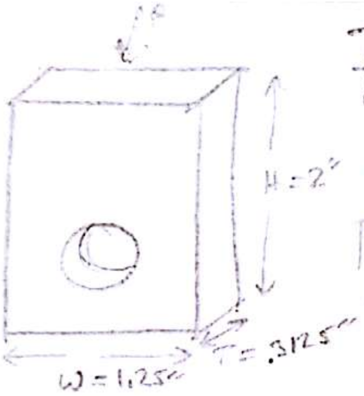
Notes: Deburr all edges after every operation.
Tooling Information: Haas VF-2 Vertical Machining Center, Mill Vice, Parallels, Edge Finder, 3" Face Mill, 1/2" End Mill, 1" Insert Mill, 1/4" Ball Mill, 1/8" Ball Mill, C Drill, 1/2" Drill, 15/64 End Mill, .249" Reamer
Inspection Equipment: Caliper
Personal Protective Equipment: Safety Glasses, Long Pants, Closed Toed Shoes

OP #	Operation Description
40	CNC Operation 2: Turn on power to mill. Press reset. Press Power Up/Restart. Ensure mill vice is trammed in plane with test indicator, adjust if necesary. Place parallels in vice. Set G54 zero to parallel's left and rear edge. Place aluminum stock in vice sitting atop parallels. Align left edge of stock with vice edge. Tighten vice, and ensure no part lift has occured with soft blow mallet. Load tools into tool holders if necesary. Load tools into mill. Set tool height offsets of tools to top face of stock. Load program O00022 (CNC OP 2) into active memory from storage device. Ensure coolant valves are open. Close shroud doors and run program. Once program completes, wash chips down from all surfaces with attached hose. Remove part. Inspect major dimensions of part with calipers.

Tool	Tool Description	SFM [ft/min]	RPM [rev/min]	Chip Load [in/tooth]	Feed Rate [in/min]
T5	1/8" Ball Mill	320	10000	0.0069	276
T6	C Drill	300	4700	0.006	55
T7	1/2" Drill	250	1900	0.002	4.6
T8	15/64" End Mill	600	10000	0.0015	60
T9	.249" Reamer	150	2200	0.002	3.8
B1	Calipers	-	-	-	-

Setup Figure





Top Instron Grip

Normal Stress:

$\sigma = P/A$

$\sigma = 800lbf / .3906 in^2$

$\sigma = 2048 psi$

app FS = 4

$\sigma_D = 8192 psi$

$P = 800lbf$

$A = T \times w$

$= .3125'' \times 1.25'' = .3906 in^2$

- Using A36 steel

$\sigma_y = 36000 psi$ - wiki

- Apply factor of safety of 4.0, per Dr. Mello's suggestions

$D = .5''$

$T = .3125''$

Bearing Stress:

$\sigma_B = P/A_p$

$\sigma_B = 800lbf / .15625 in^2$

Apply FS = 4

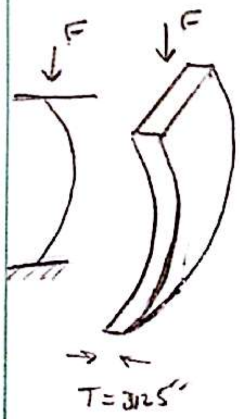
$\sigma_B = 20,480 psi$

$P = 800lbf$

$A_p = DT$

$= (.5'')(.3125'')$

$= .15625 in^2$



Buckling:

- Assume fixed both ends

$F_{allow} = \frac{n\pi^2 EI}{L^2}$

$F_{allow} = \frac{(4)(\pi^2)(29\times10^6 psi)(.2083 in^4)}{(2'')^2}$

$F_{allow} = 59.6 \times 10^6 lbf$

apply FS = 4

$F_{allow} = 14.9 \times 10^6 lbf$

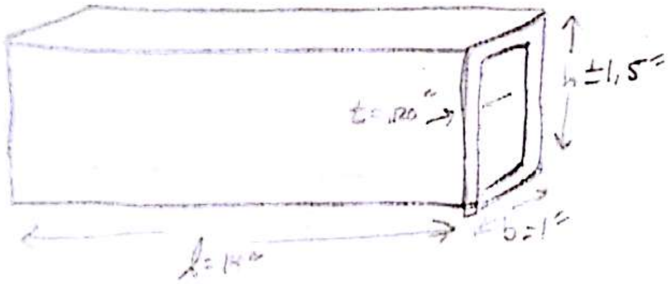
$n = 4$

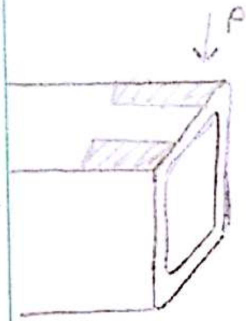
$E = 29 \times 10^6 psi$ - wiki

$I = \frac{wL^3}{12} = \frac{(.3125'')(2'')^3}{12} = .2083 in^4$

$L = 2''$

Top Instrom Beam





Shear Stress:

$\tau = V/A$

$V = 800 lbf$

A = Area of two grip pads?

Bending Stress:

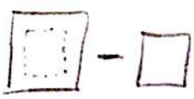
$\sigma_b = \frac{My}{I}$

$M = F \cdot D$

$= (800lbf)(14in)$

$= 11,200 \; lbf\text{-}in$

$y = 0.75 in$

$I =$  ← Outside - inside

$= \frac{BH^3}{12} - \frac{bh^3}{12}$

$= \frac{(1")(1.5")}{12} - \frac{(1"-.24")(1.5-.24")}{12}$

$= .28125 - .1267$

$= .1546 \; in^4$

$\sigma_B = \frac{(11,200 lb \cdot in)(.75in)}{.1546 in^4}$

No good → $\sigma_B = 54,333 \; psi$

Deflections at End

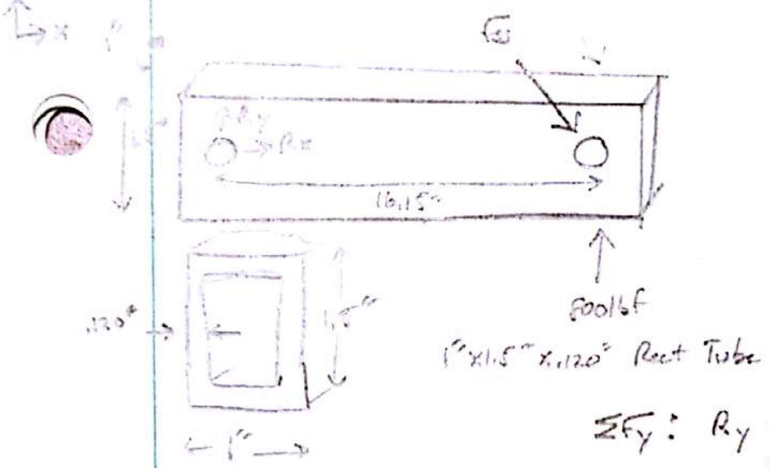
$\delta_{max} = \frac{PL^3}{3EI}$

$\delta_{max} = \frac{(800lbf)(14in)^3}{3(29 \times 10^6 psi)(.1546 in^4)}$

$\delta_{max} = 0.163"$

- reverse out load

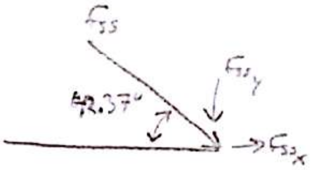
Chain Stay



F_{ss} - Force from seat stay link

R_y - Horizontal force from bearing location

R_x - Vertical force from bearing location



$\Sigma F_y: \; R_y - F_{ss_y} + 800\,lbf = 0$

$800\,lbf = F_{ss_y} - R_y$

$\Sigma F_x: \; R_x + F_{ss_x} = 0$

$R_x = -F_{ss_x}$

$\circlearrowleft \Sigma M_R: \; (800\,lbf)(16.15'') - (F_{ss_y})(16.15'') = 0$

$800\,lbf = F_{ss_y} \downarrow$

$R_y = 0$

$F_{ss} \sin(42.37°) = 800\,lbf$

$F_{ss} = \dfrac{800\,lbf}{\sin(42.37°)} = 1187.1\,lbf \searrow$

$F_{ss_x} = F_{ss} \cos(42.37°)$

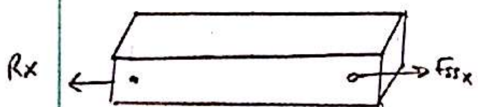
$= 1187.1 \cos(42.37°)$

$F_{ss_x} = 877.0 \rightarrow$

Plug into ΣF_x:

$R_x = -877.0\,lbf$

$R_x = 877.0\,lbf \leftarrow$



- Calc Stress Due to Tension

$\sigma = P/A$

$P = R_x + F_{ss_x}$

$P = 877 + 877$

$P = 1754\,lbf$

$A = (1.5'')(1'') - (1.5'' - .24'')(1'' - .24'')$

$A = 0.5424\,in^2$

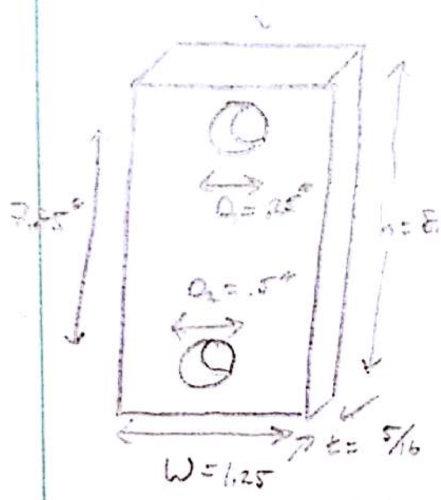
$\sigma = \dfrac{1754\,lbf}{.5424\,in^2}$

$\sigma = 3233.7\,psi$

Apply FS = 4

$\boxed{\sigma = 12{,}935\,psi}$ tension

Fixed Link for Rocker



- has two lengths; one for each rear triangle position will calc buckling at both

Top Bearing Stress:

$\sigma_B = P/A_p$

$P =$

$A_p = (D_1)(T)$

$= (\ \ ")(\ \ ")$

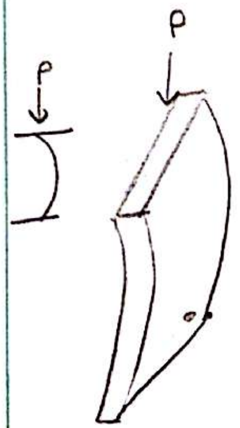
Bottom Bearing Stress:

$\sigma_B = P/A_p$

$P =$

$A_p = (D_2)(T)$

$(\ \ ")(\ \ ")$



Buckling:

$F = \frac{n\pi^2 EI}{L^2}$

$n =$ both fixed

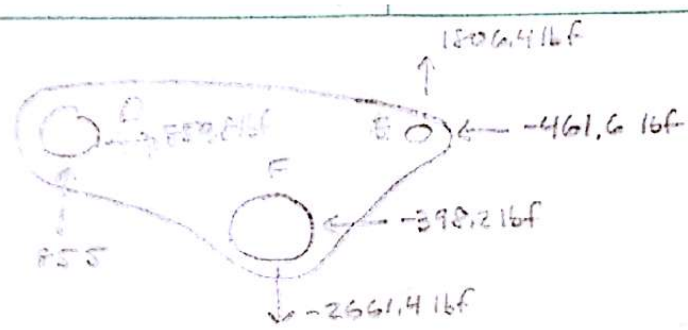
$E = 29 \times 10^6$ psi

$I = \frac{1}{12} b h^3$

$= \frac{w t^3}{12}$

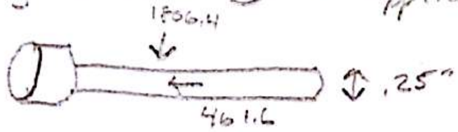
$= \frac{(\ \ ")(\ \ ")^3}{12}$

$L^2 =$



- Unloaded position max applied rocker loads

Bearing Stresses @ E applied to upper shock bolt,



McMaster Shear Strength: 84 ksi

$$\tau_{max} = \frac{4V}{3A} \qquad V = 1806.4 \text{ lbf}$$

$$A = \frac{\pi(.25'')^2}{4} = 0.049 \text{ in}^2$$

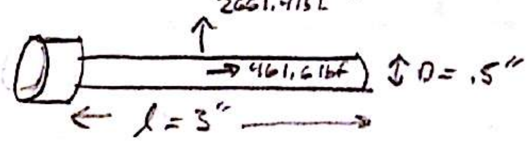
Only factors largest load

$$\tau = \frac{4(1806.4 \text{ lbf})}{3(0.049)}$$

$$\tau = 49{,}153 \text{ psi}$$

$$FS = \frac{84{,}000}{49{,}153} = \underline{1.7} \checkmark$$

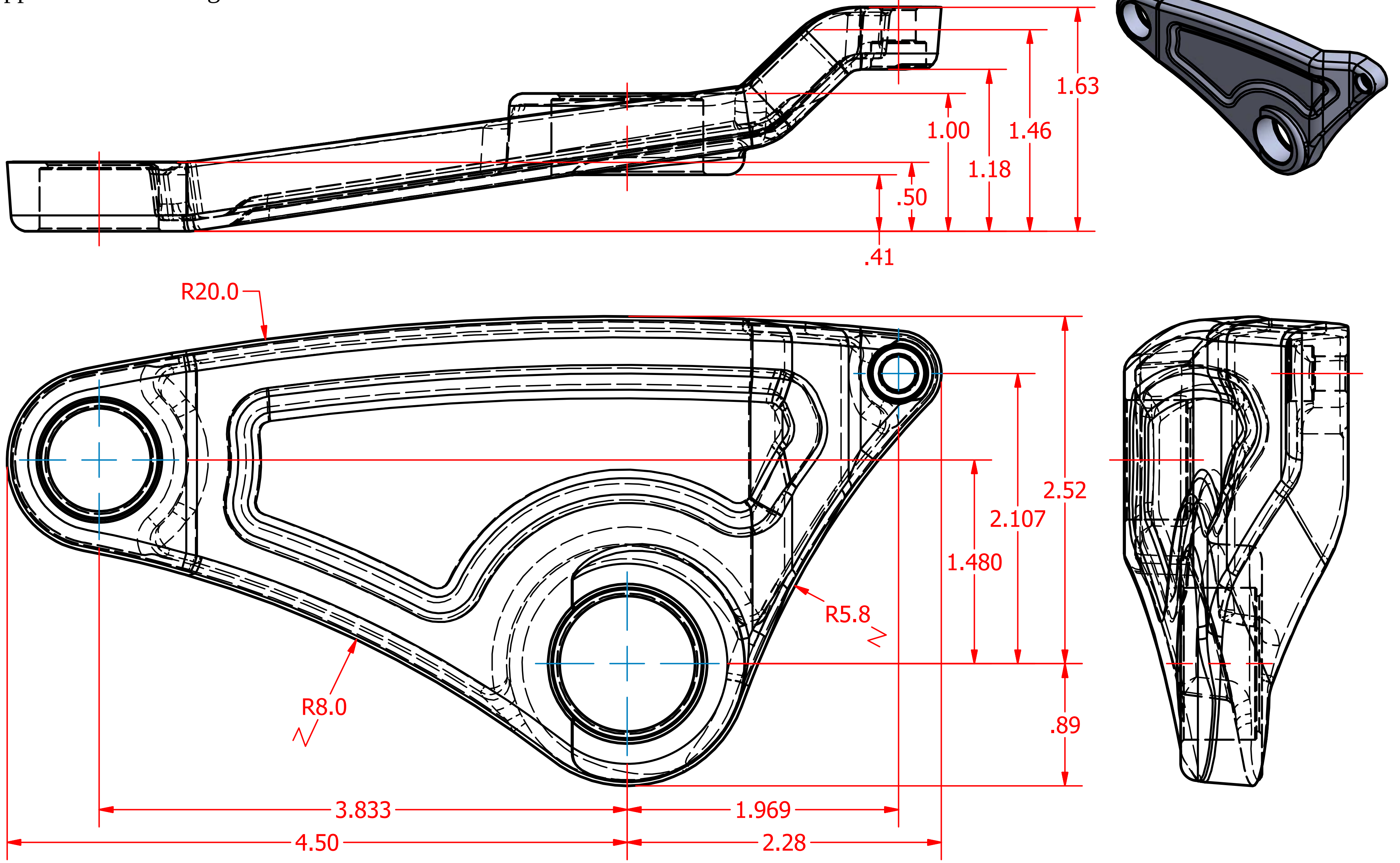
Bearing Stresses @ F applied to seat tube bolt.



Max Shear: 84 ksi

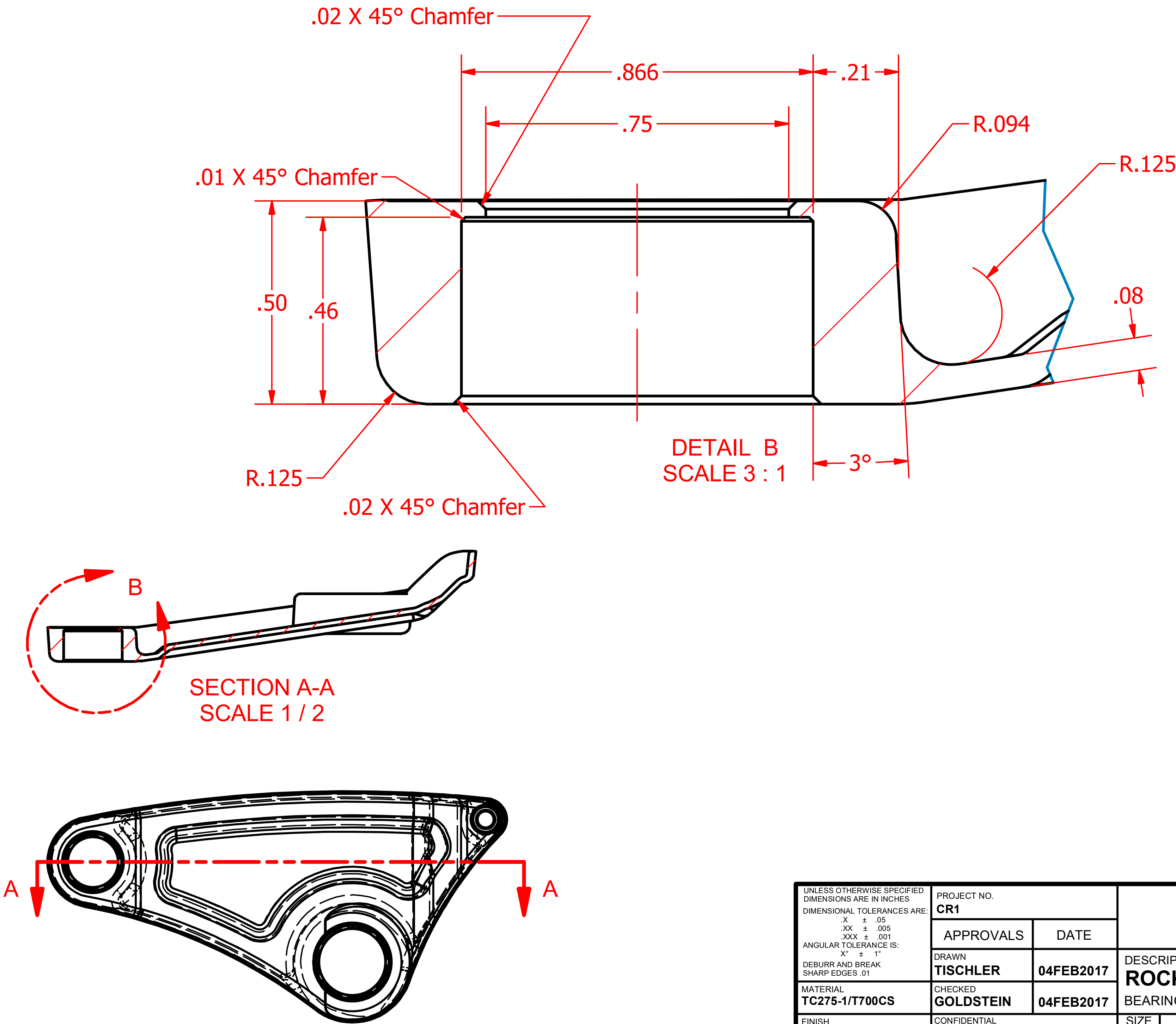
$$\tau_{max} = \frac{4V}{3A}$$

Appendix L. Drawings



NOTE: FULL PART GEOMETRY IS REPRESENTED IN SOLID MODEL CAD FILE

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DIMENSIONAL TOLERANCES ARE: .X ± .05 .XX ± .005 .XXX ± .001 ANGULAR TOLERANCE IS: X° ± 1° DEBURR AND BREAK SHARP EDGES .01	PROJECT NO. CR1 APPROVALS	DATE	CAL POLY College of Engineering Mechanical Engineering Department
	DRAWN TISCHLER	02FEB2017	DESCRIPTION ROCKER ARM
MATERIAL TC275-1/T700CS	CHECKED GOLDSTEIN	04FEB2017	TEAM BLACK GOLD SENIOR PROJECT
FINISH AS IS	CONFIDENTIAL The information contained within this drawing is proprietary to Team Black Gold and shall not be disclosed without prior written consent of Black Gold executive officers		SIZE A · DRAWING NO. CR1-1 · REV. SCALE 1:1 · SHEET 1 OF 7



NOTE: FULL PART GEOMETRY IS REPRESENTED IN SOLID MODEL CAD FILE

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
DIMENSIONAL TOLERANCES ARE:
.X ± .05
.XX ± .005
.XXX ± .001
ANGULAR TOLERANCE IS:
X° ± 1°
DEBURR AND BREAK SHARP EDGES .01

PROJECT NO.
CR1

APPROVALS	DATE
DRAWN **TISCHLER**	**04FEB2017**
CHECKED **GOLDSTEIN**	**04FEB2017**

MATERIAL
TC275-1/T700CS

FINISH
AS IS

CONFIDENTIAL
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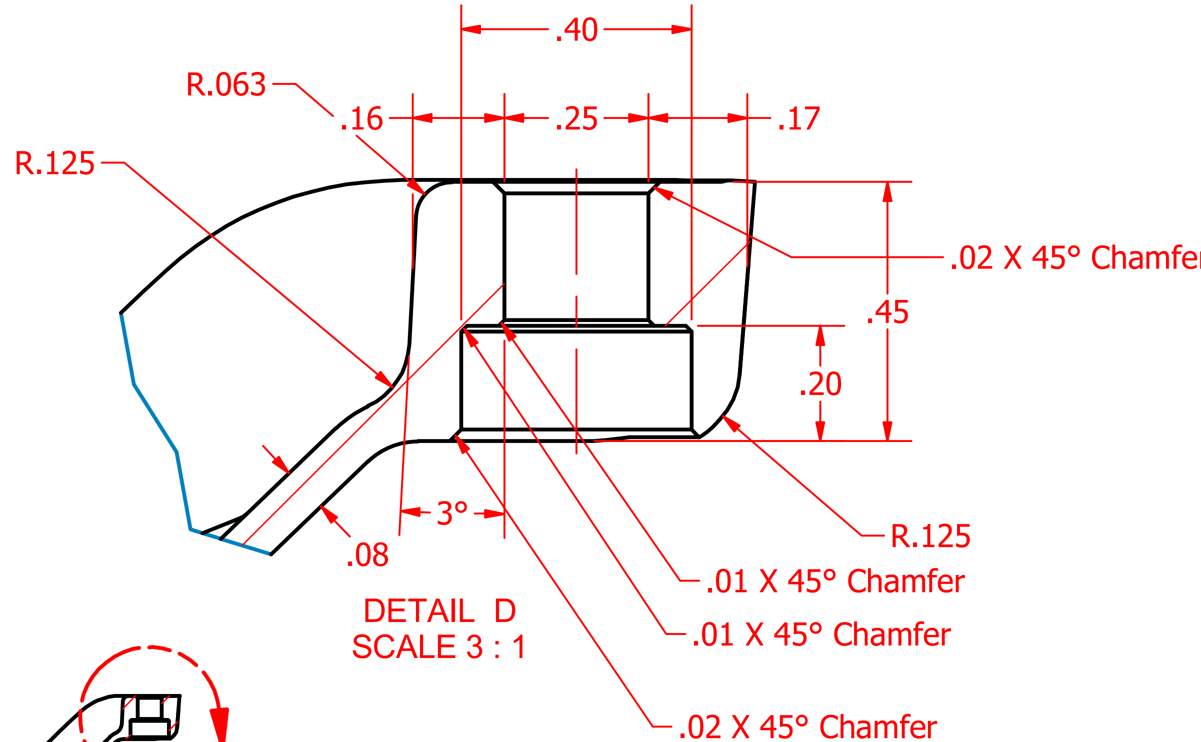
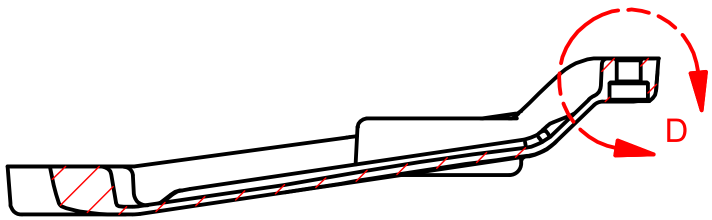
CAL POLY
College of Engineering
Mechanical Engineering Department

DESCRIPTION
ROCKER ARM RIGHT
BEARING SECTION VIEW 1

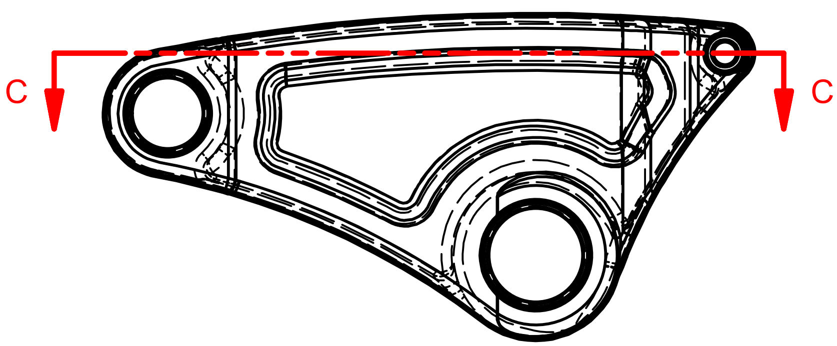
SIZE A
DRAWING NO. **CR1-1**
REV.
SCALE SHOWN
SHEET 2 OF 7



DETAIL D
SCALE 3 : 1

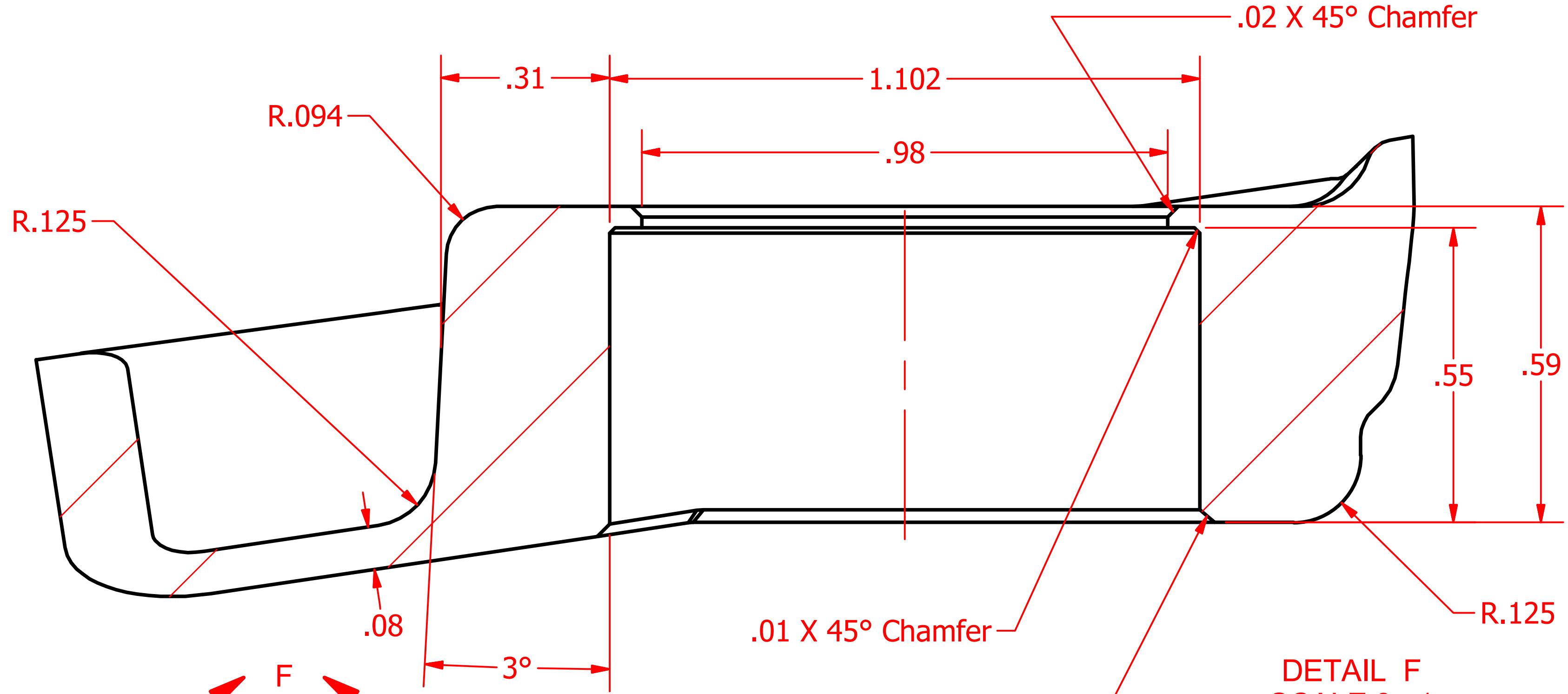


SECTION C-C
SCALE 1 / 2

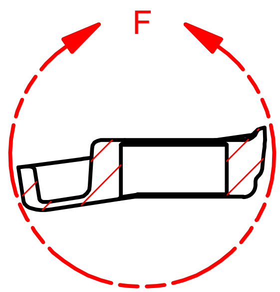


NOTE: FULL PART GEOMETRY IS REPRESENTED IN SOLID MODEL CAD FILE

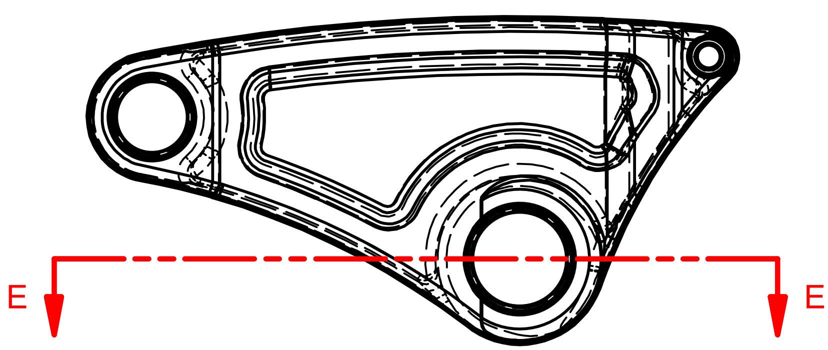
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DIMENSIONAL TOLERANCES ARE: .X ± .05 .XX ± .005 .XXX ± .001 ANGULAR TOLERANCE IS: X° ± 1° DEBURR AND BREAK SHARP EDGES .01	PROJECT NO. CR1		CAL POLY College of Engineering Mechanical Engineering Department
	APPROVALS	DATE	
	DRAWN TISCHLER	04FEB2017	DESCRIPTION ROCKER ARM RIGHT BEARING SECTION VIEW 2
MATERIAL TC275-1/T700CS	CHECKED GOLDSTEIN	04FEB2017	
FINISH AS IS	CONFIDENTIAL The information contained within this drawing is proprietary to Team Black Gold and shall not be disclosed without prior written consent of Black Gold executive officers.		SIZE A · DRAWING NO. CR1-1 · REV.
			SCALE SHOWN · SHEET 3 OF 7



DETAIL F
SCALE 3 : 1



SECTION E-E
SCALE 1 / 2



NOTE: FULL PART GEOMETRY IS REPRESENTED IN SOLID MODEL CAD FILE

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DIMENSIONAL TOLERANCES ARE: .X ± .05 .XX ± .005 .XXX ± .001 ANGULAR TOLERANCE IS: X° ± 1° DEBURR AND BREAK SHARP EDGES .01	PROJECT NO. **CR1**		CAL POLY College of Engineering Mechanical Engineering Department
	APPROVALS	DATE	
	DRAWN **TISCHLER**	**04FEB2016**	DESCRIPTION **ROCKER ARM** BEARING SECTION VIEW 3
MATERIAL **TC275-1/T700CS**	CHECKED **GOLDSTEIN**	**04FEB2017**	
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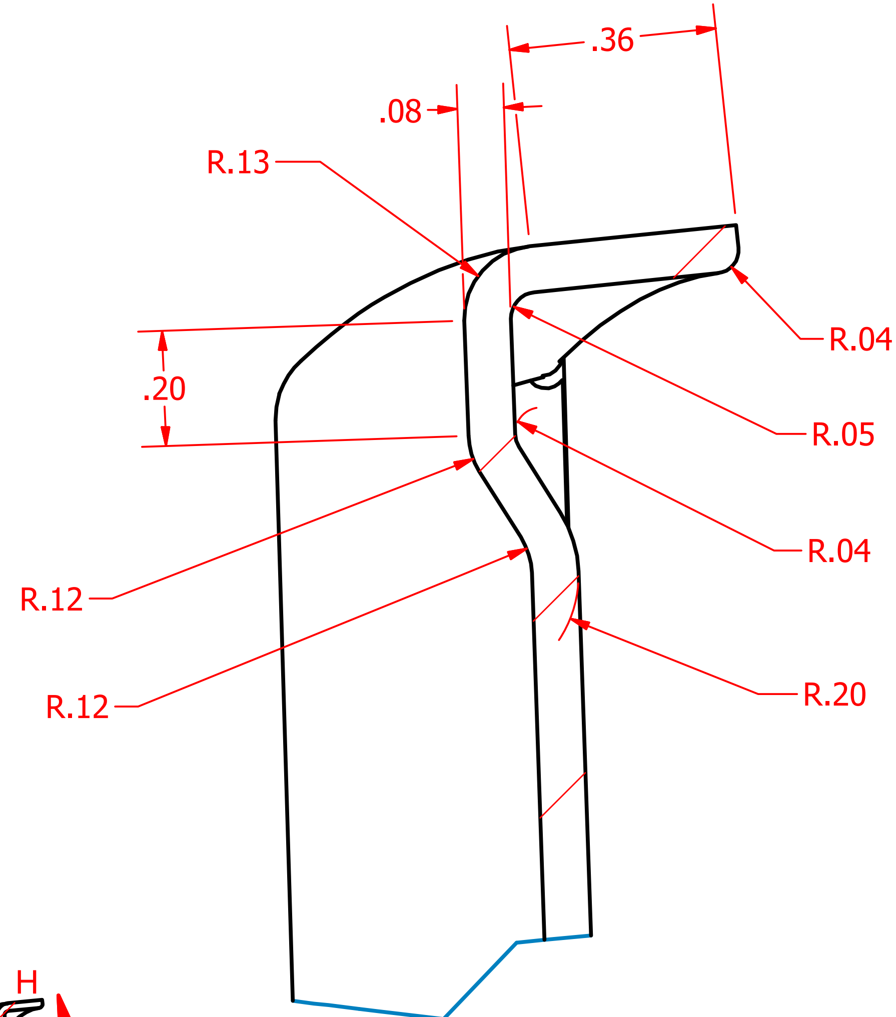
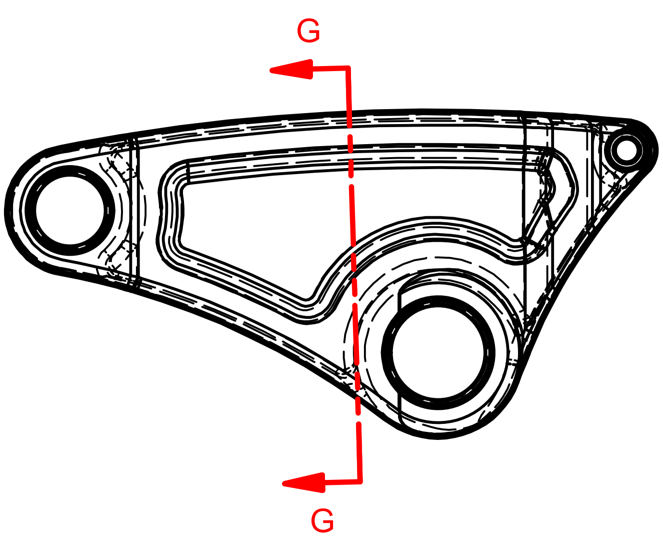
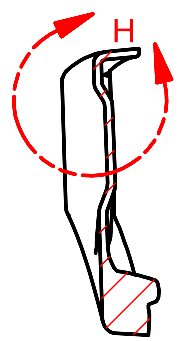


DETAIL H
SCALE 3 : 1

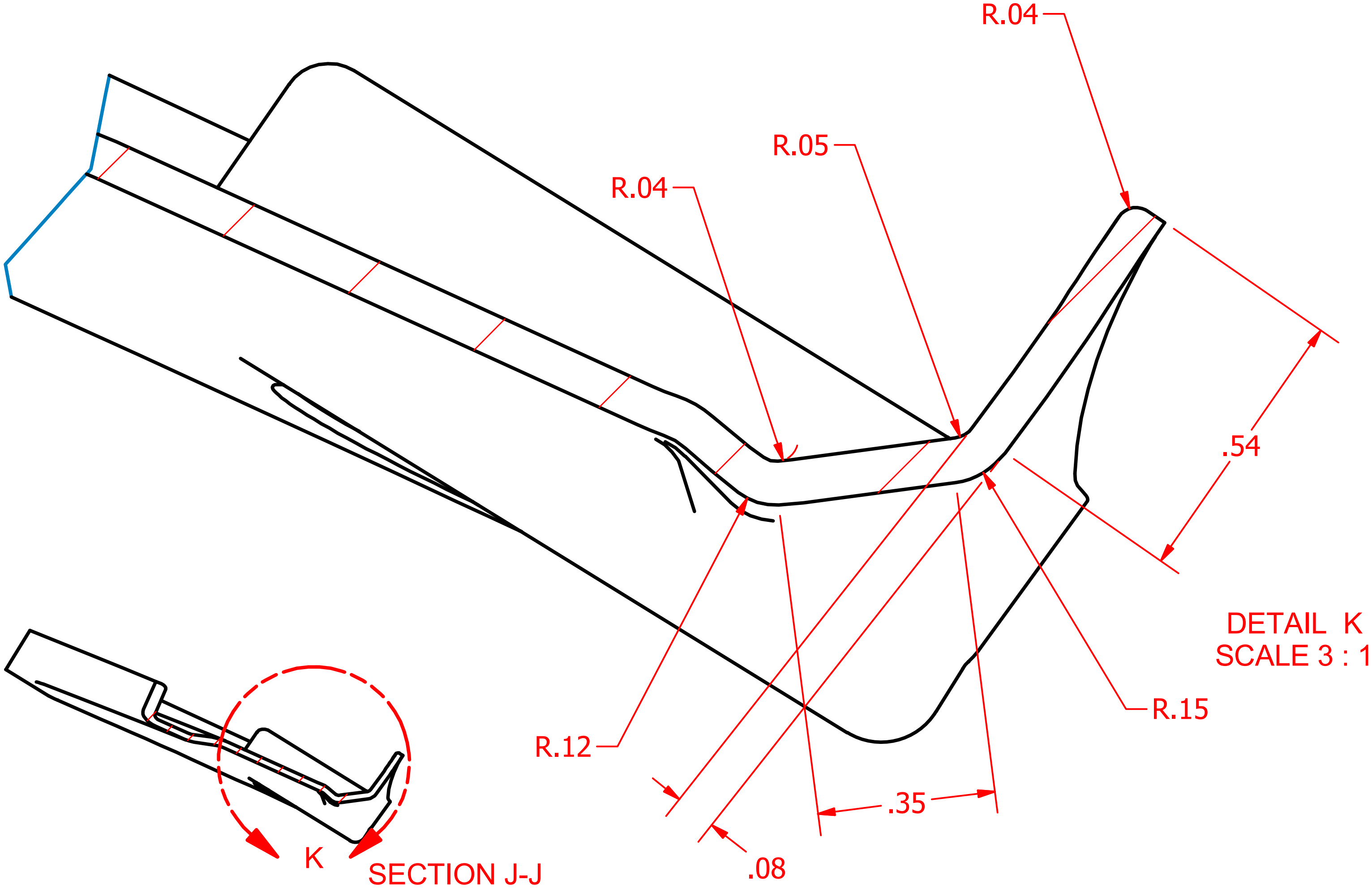




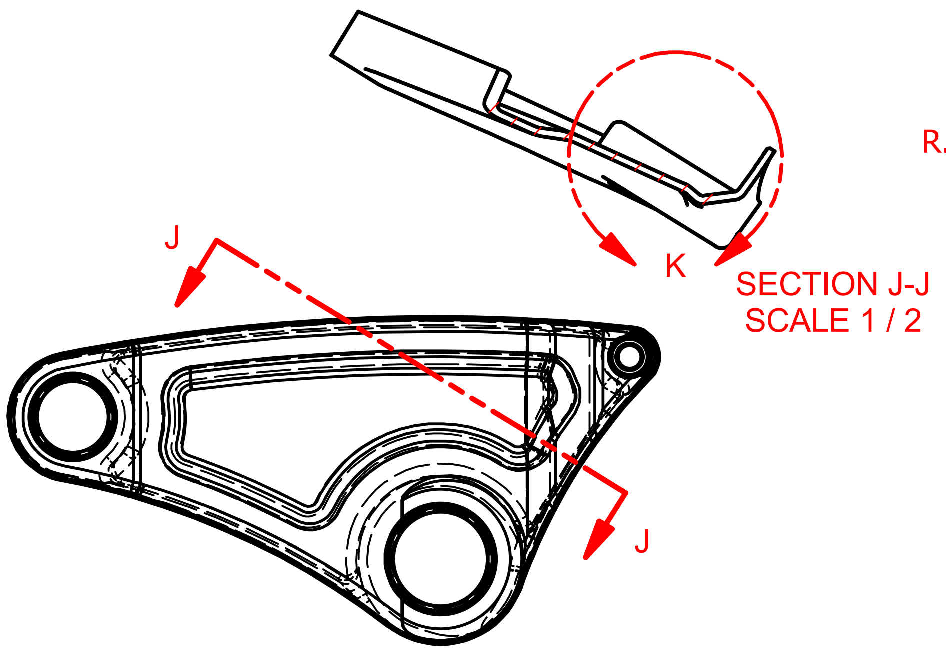
SECTION G-G
SCALE 1 / 2

NOTE: FULL PART GEOMETRY IS REPRESENTED IN SOLID MODEL CAD FILE

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DIMENSIONAL TOLERANCES ARE: .X ± .05 .XX ± .005 .XXX ± .001 ANGULAR TOLERANCE IS: X° ± 1° DEBURR AND BREAK SHARP EDGES .01	PROJECT NO. CR1		CAL POLY College of Engineering Mechanical Engineering Department
	APPROVALS	DATE	
	DRAWN TISCHLER	04FEB2017	DESCRIPTION **ROCKER ARM** WEB SECTION VIEW 1
MATERIAL TC275-1/T700CS	CHECKED GOLDSTEIN	04FEB2017	
FINISH AS IS	CONFIDENTIAL The information contained within this drawing is proprietary to Team Black Gold and shall not be disclosed without prior written consent of Black Gold executive officers.		SIZE: A DRAWING NO.: CR1-1 REV.: SCALE: SHOWN SHEET 5 OF 7



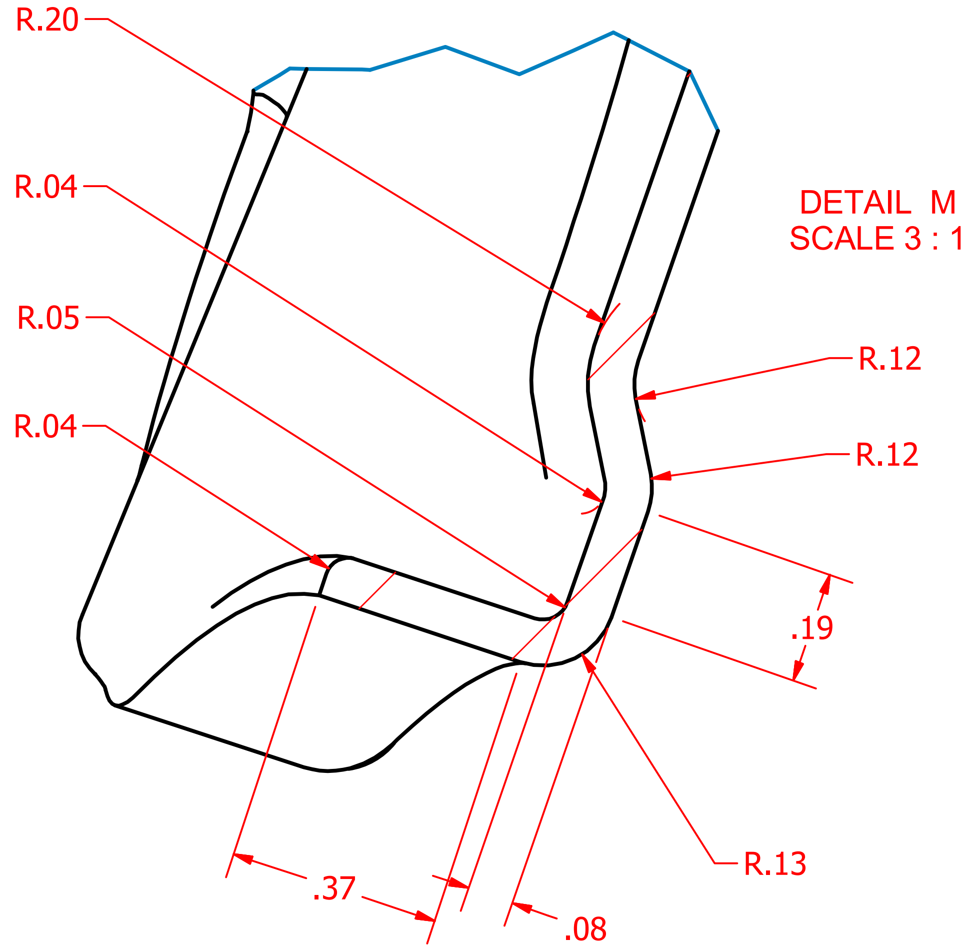
DETAIL K
SCALE 3 : 1

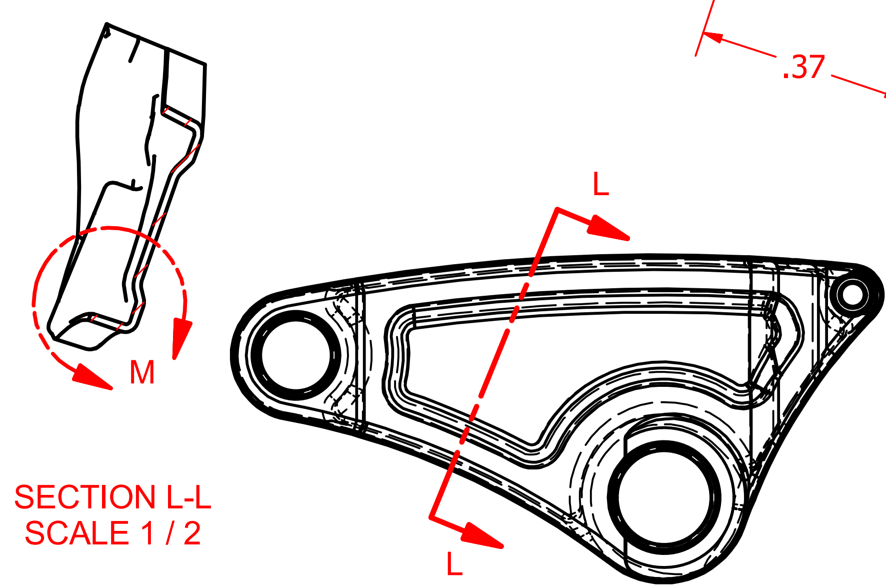


SECTION J-J
SCALE 1 / 2

NOTE: FULL PART GEOMETRY IS REPRESENTED IN SOLID MODEL CAD FILE

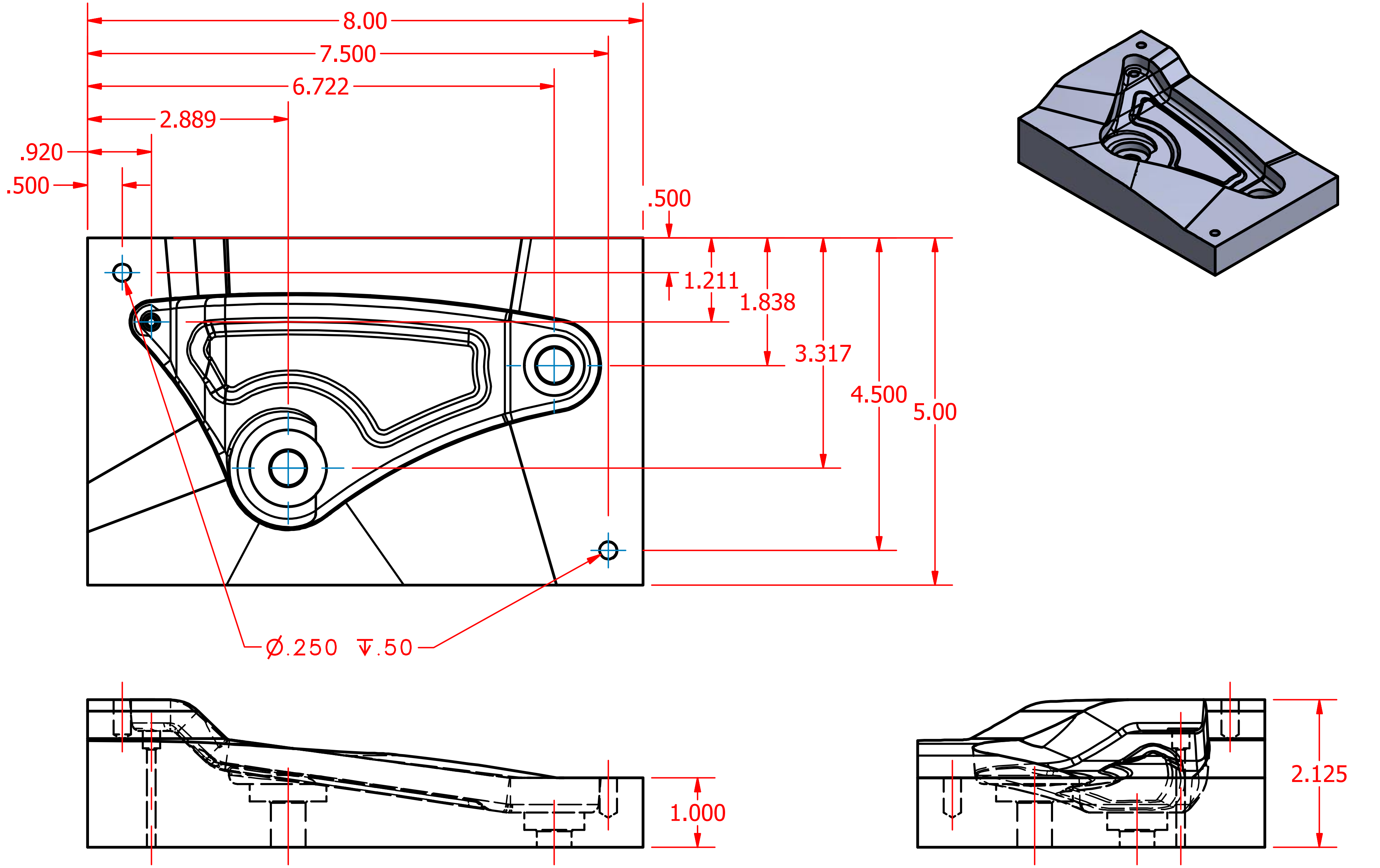
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DIMENSIONAL TOLERANCES ARE: .X ± .05 .XX ± .005 .XXX ± .001 ANGULAR TOLERANCE IS: X° ± 1° DEBURR AND BREAK SHARP EDGES .01	PROJECT NO. **CR1** APPROVALS / DATE DRAWN **TISCHLER** **04FEB2017**	CAL POLY College of Engineering Mechanical Engineering Department	
MATERIAL **TC275-1/T700CS**	CHECKED **GOLDSTEIN** **04FEB2017**	DESCRIPTION **ROCKER ARM** WEB SECTION VIEW 2	
FINISH **AS IS**	CONFIDENTIAL The information contained within this drawing is proprietary to Team Black Gold and shall not be disclosed without prior written consent of Black Gold executive officers	SIZE A DRAWING NO. **CR1-1** REV. SCALE SHOWN	SHEET 6 OF 7





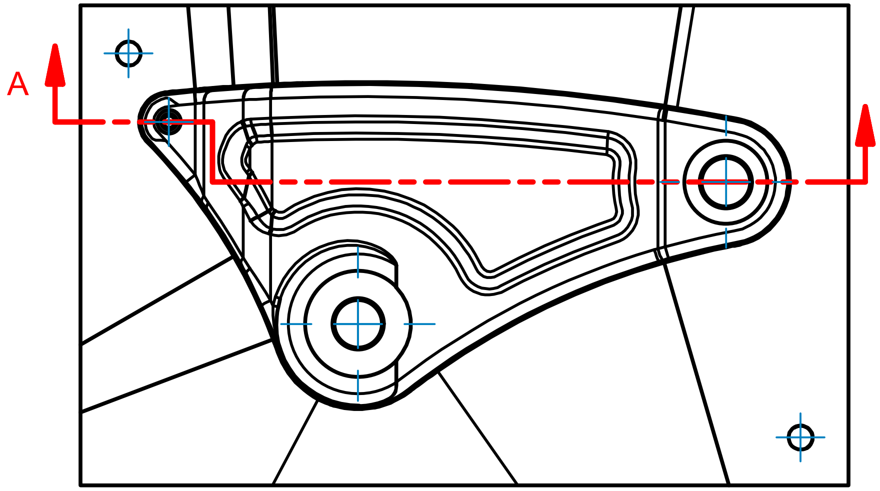
NOTE: FULL PART GEOMETRY IS REPRESENTED IN SOLID MODEL CAD FILE

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DIMENSIONAL TOLERANCES ARE: .X ± .05 .XX ± .005 .XXX ± .001 ANGULAR TOLERANCE IS: X° ± 1° DEBURR AND BREAK SHARP EDGES .01	PROJECT NO. CR1		CAL POLY College of Engineering Mechanical Engineering Department
	APPROVALS	DATE	
	DRAWN TISCHLER	04FEB2017	DESCRIPTION ROCKER ARM WEB SECTION VIEW 3
MATERIAL TC275-1/T700CS	CHECKED GOLDSTEIN	04FEB2017	
FINISH AS IS	CONFIDENTIAL The information contained within this drawing is proprietary to Team Black Gold and shall not be disclosed without prior written consent of Black Gold executive officers.		SIZE A / DRAWING NO. CR1-1 / REV. SCALE SHOWN / SHEET 7 OF 7

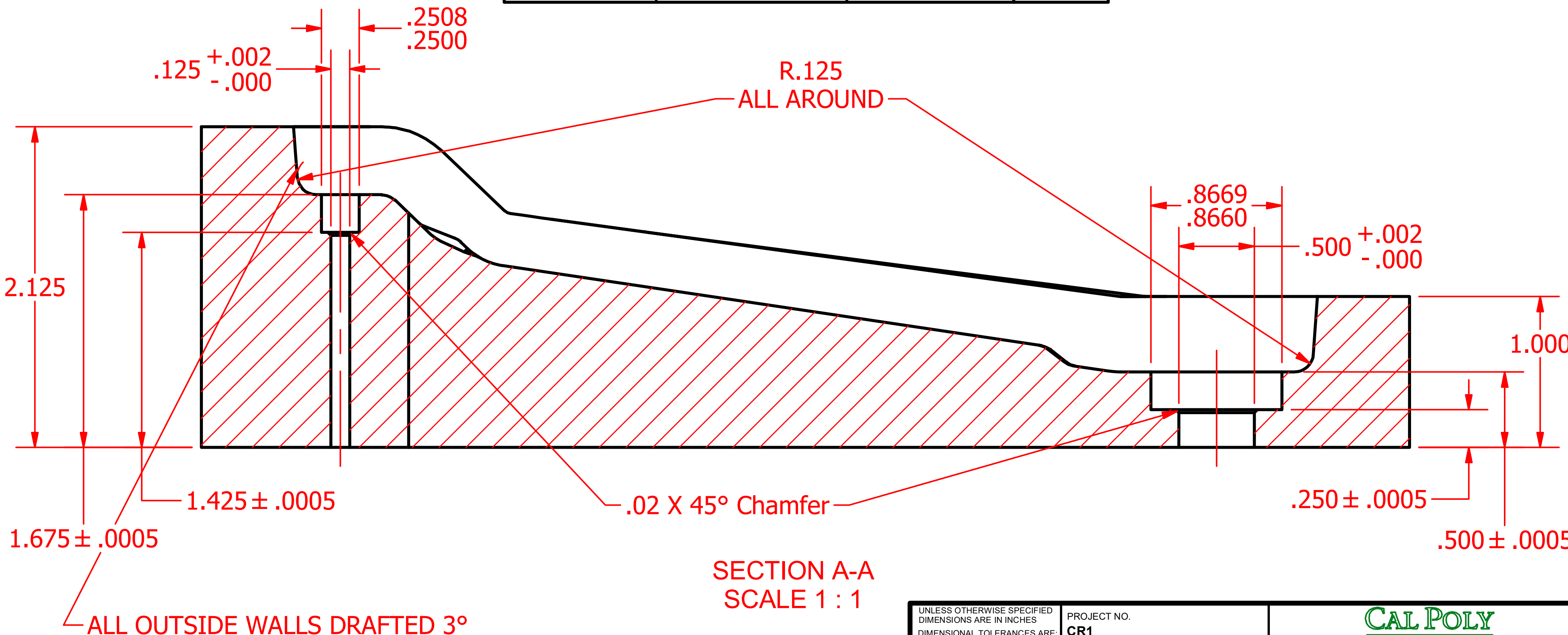


NOTE: FULL PART GEOMETRY IS REPRESENTED IN SOLID MODEL CAD FILE

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DIMENSIONAL TOLERANCES ARE: .X ± .05 .XX ± .005 .XXX ± .0005 ANGULAR TOLERANCE IS: X° ± 1° DEBURR AND BREAK SHARP EDGES .01	PROJECT NO. **CR1**		CAL POLY College of Engineering Mechanical Engineering Department
	APPROVALS	DATE	
	DRAWN **TISCHLER**	**05FEB2017**	DESCRIPTION **ROCKER MOLD BOTTOM** 3-VIEW
MATERIAL **AL 6061 T6**	CHECKED **GOLDSTEIN**	**05FEB2017**	
FINISH **MOLD SEALANT**	CONFIDENTIAL The information contained within this drawing is proprietary to Team Black Gold and shall not be disclosed without prior written consent of Black Gold executive officers.		SIZE A · DRAWING NO. **CR1-2-1** · REV. SCALE 1:2 · SHEET 1 OF 3



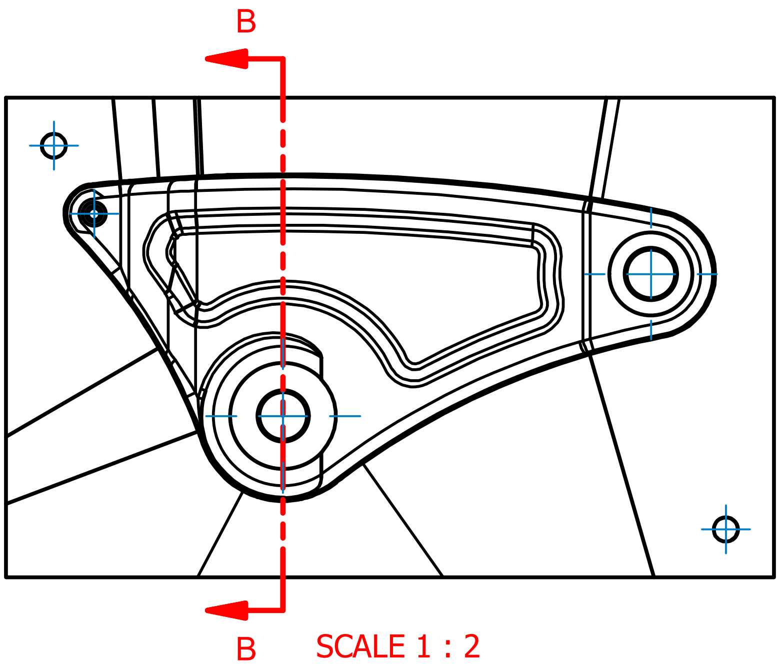
SCALE 1 : 2



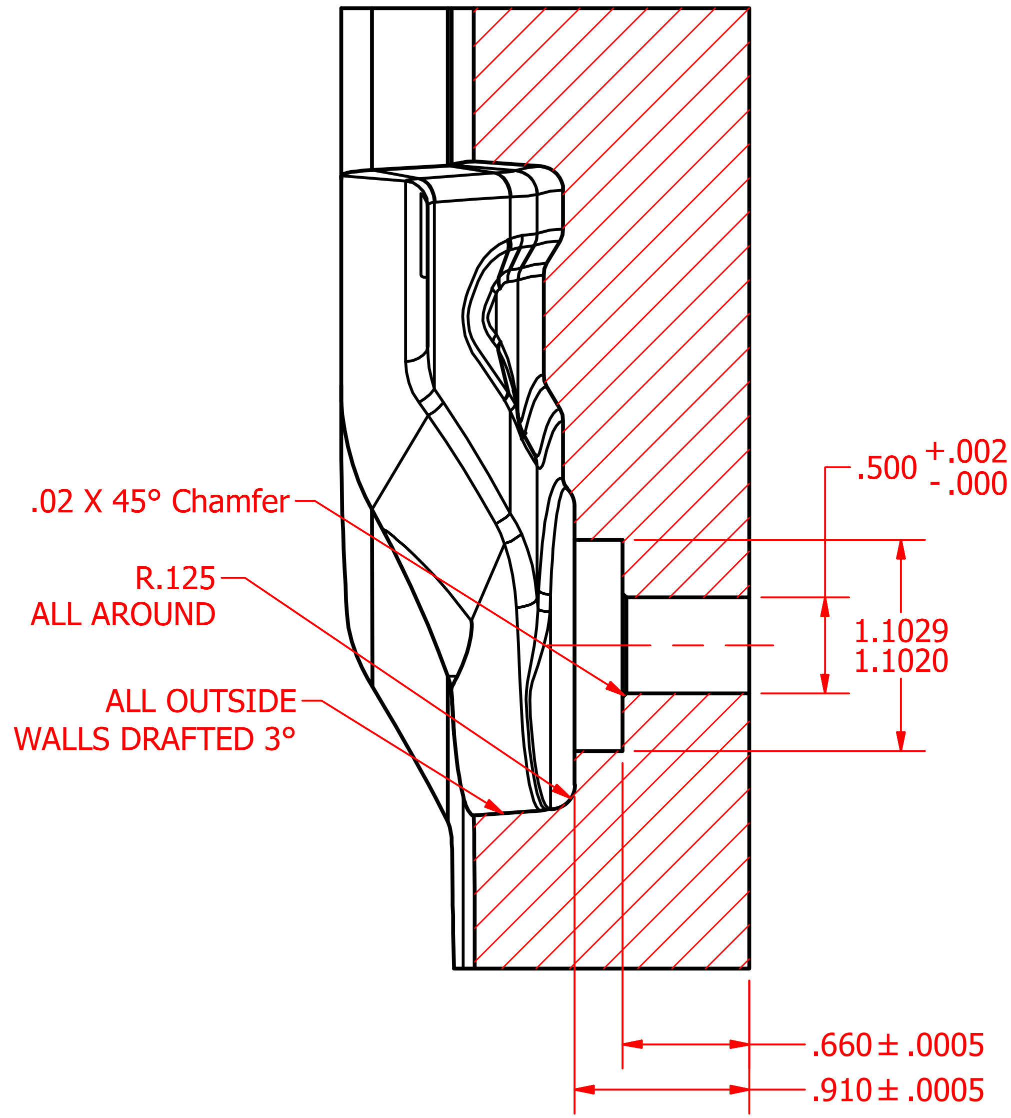
SECTION A-A
SCALE 1 : 1

NOTE: FULL PART GEOMETRY IS REPRESENTED IN SOLID MODEL CAD FILE

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DIMENSIONAL TOLERANCES ARE: .X ± .05 .XX ± .005 .XXX ± .0005 ANGULAR TOLERANCE IS: X° ± 1° DEBURR AND BREAK SHARP EDGES .01	PROJECT NO. **CR1**		CAL POLY College of Engineering Mechanical Engineering Department
	APPROVALS	DATE	
	DRAWN **TISCHLER**	**05FEB2017**	DESCRIPTION **ROCKER MOLD BOTTOM** SECTION VIEW 1
MATERIAL **AL 6061 T6**	CHECKED **GOLDSTEIN**	**05FEB2017**	
FINISH **MOLD SEALANT**	CONFIDENTIAL The information contained within this drawing is proprietary to Team Black Gold and shall not be disclosed without prior written consent of Black Gold executive officers		SIZE A · DRAWING NO. **CR1-2-1** · REV. SCALE SHOWN · SHEET 2 OF 3



SCALE 1 : 2



SECTION B-B
SCALE 1 : 1

NOTE: FULL PART GEOMETRY IS REPRESENTED IN SOLID MODEL CAD FILE

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
DIMENSIONAL TOLERANCES ARE:
.X ± .05
.XX ± .005
.XXX ± .0005
ANGULAR TOLERANCE IS:
X° ± 1°
DEBURR AND BREAK
SHARP EDGES .01

MATERIAL
AL 6061-T6

FINISH
MOLD SEALANT

PROJECT NO.
CR1

APPROVALS	DATE
DRAWN **TISCHLER**	**05FEB2016**
CHECKED **GOLDSTEIN**	**05FEB2017**

CONFIDENTIAL
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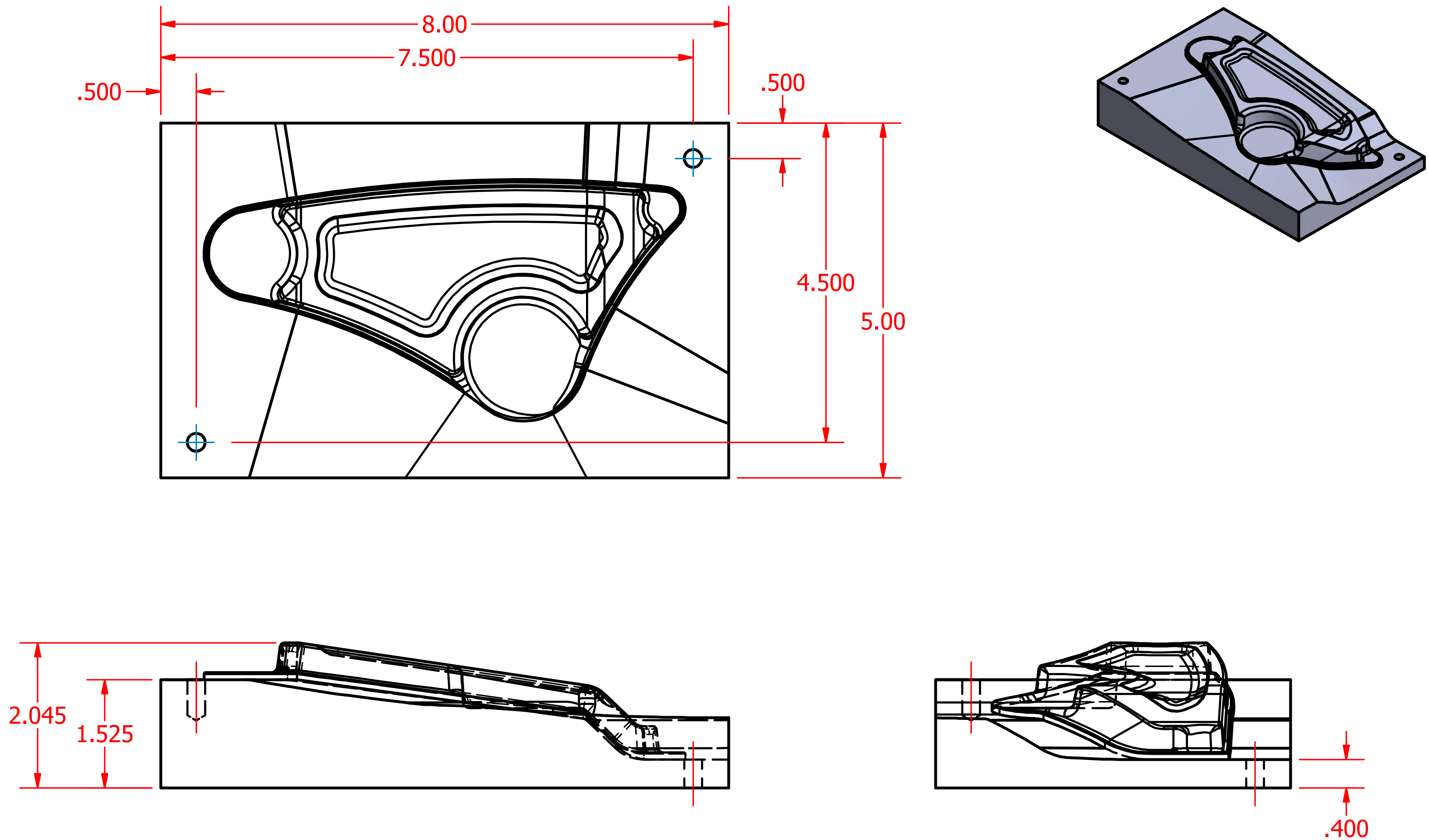
CAL POLY
College of Engineering
Mechanical Engineering Department

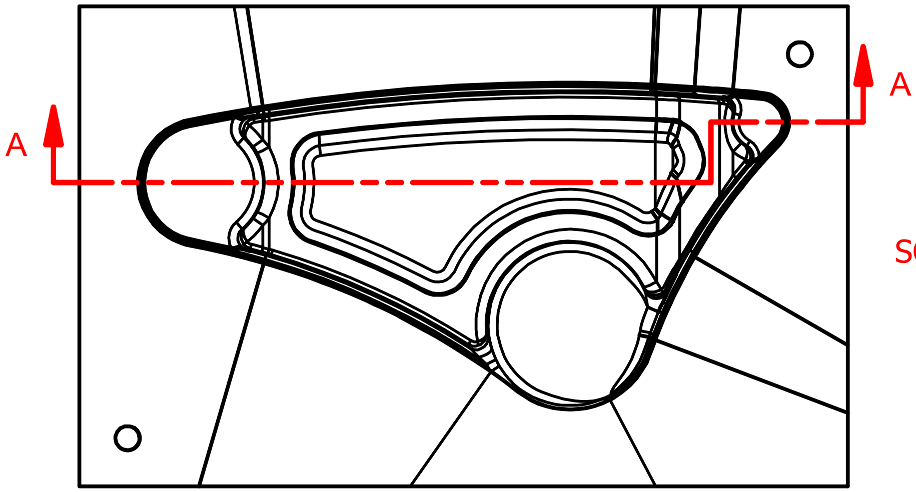
DESCRIPTION
ROCKER MOLD BOTTOM
SECTION VIEW 2

SIZE A
DRAWING NO. **CR1-2-1**
REV.
SCALE SHOWN
SHEET 3 OF 3

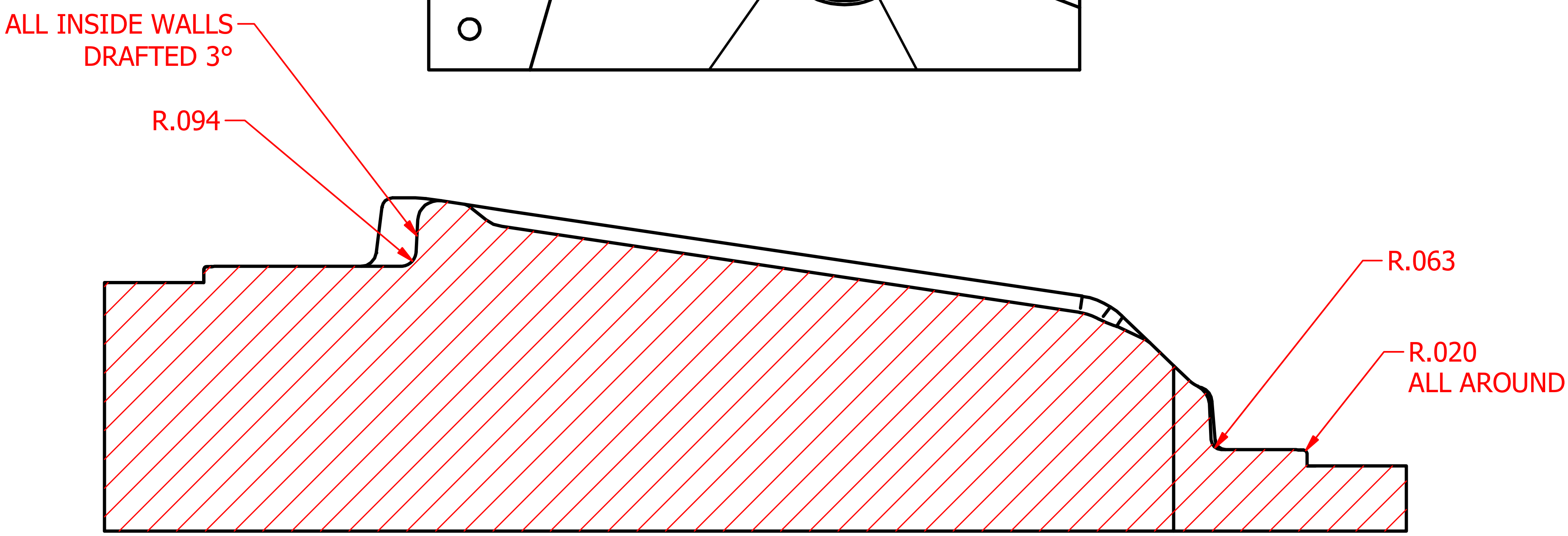


NOTE: FULL PART GEOMETRY IS REPRESENTED IN SOLID MODEL CAD FILE

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DIMENSIONAL TOLERANCES ARE: .X ± .05 .XX ± .005 .XXX ± .0005 ANGULAR TOLERANCE IS: X° ± 1° DEBURR AND BREAK SHARP EDGES .01	PROJECT NO. **CR1**		CAL POLY College of Engineering Mechanical Engineering Department
	APPROVALS	DATE	
	DRAWN **TISCHLER**	**05FEB2017**	DESCRIPTION **ROCKER MOLD TOP** 3-VIEW
MATERIAL **AL 6061-T6**	CHECKED **GOLDSTEIN**	**05FEB2017**	
FINISH **MOLD SEALANT**	CONFIDENTIAL The information contained within this drawing is proprietary to Team Black Gold and shall not be disclosed without prior written consent of Black Gold executive officers		SIZE A · DRAWING NO. **CR1-2-2** · REV. SCALE 1:2 · SHEET 1 OF 3



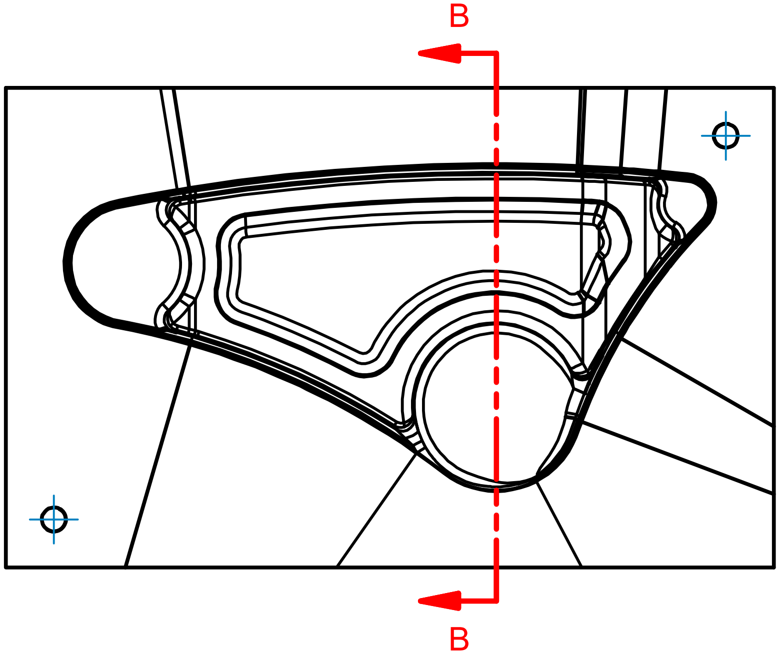
SCALE 1 : 2



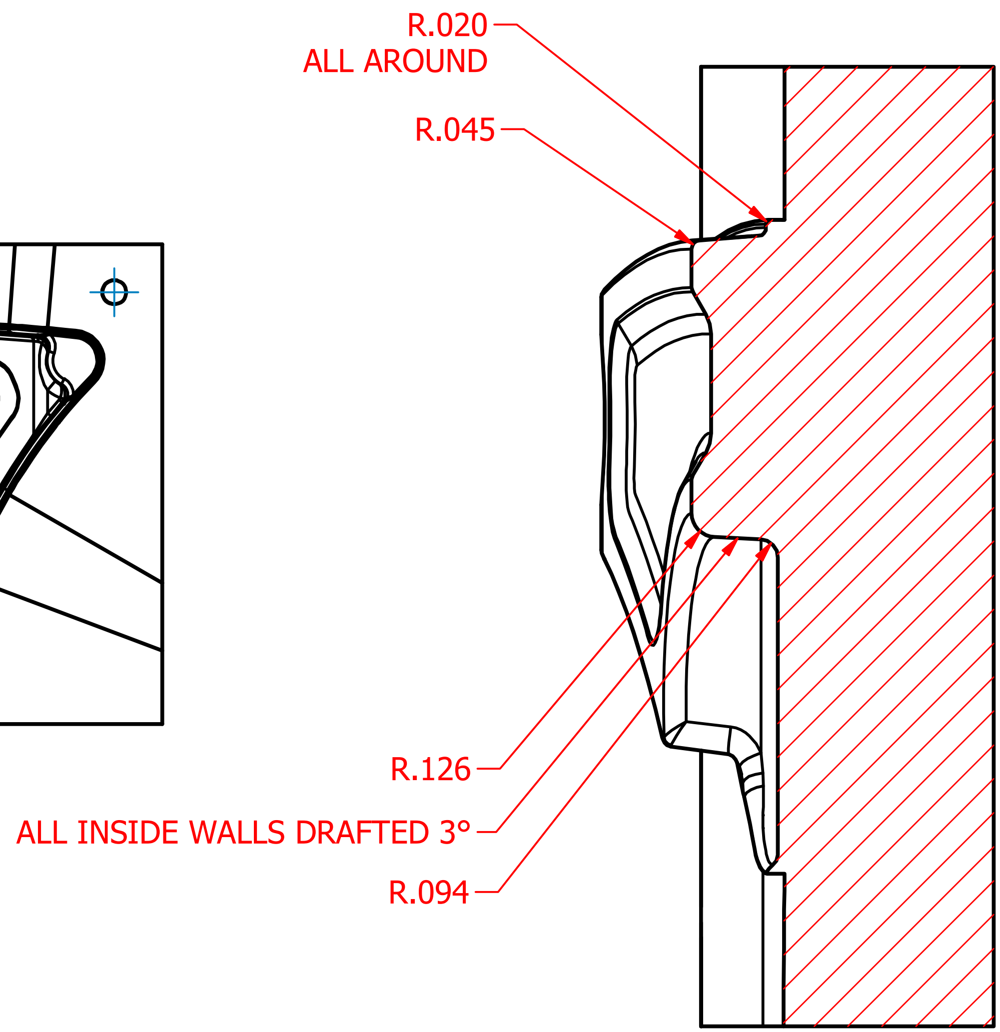
SECTION A-A
SCALE 1 : 1

NOTE: FULL PART GEOMETRY IS REPRESENTED IN SOLID MODEL CAD FILE

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DIMENSIONAL TOLERANCES ARE: .X ± .05 .XX ± .005 .XXX ± .0005 ANGULAR TOLERANCE IS: X° ± 1° DEBURR AND BREAK SHARP EDGES .01	PROJECT NO. **CR1**		CAL POLY College of Engineering Mechanical Engineering Department
	APPROVALS	DATE	
	DRAWN **TISCHLER**	**05FEB2017**	DESCRIPTION **ROCKER MOLD TOP** SECTION VIEW 1
MATERIAL **AL 6061-T6**	CHECKED **GOLDSTEIN**	**05FEB2017**	
FINISH **MOLD SEALANT**	CONFIDENTIAL The information contained within this drawing is proprietary to Team Black Gold and shall not be disclosed without prior written consent of Black Gold executive officers.		SIZE A · DRAWING NO. **CR1-2-2** · REV. SCALE SHOWN · SHEET 2 OF 3



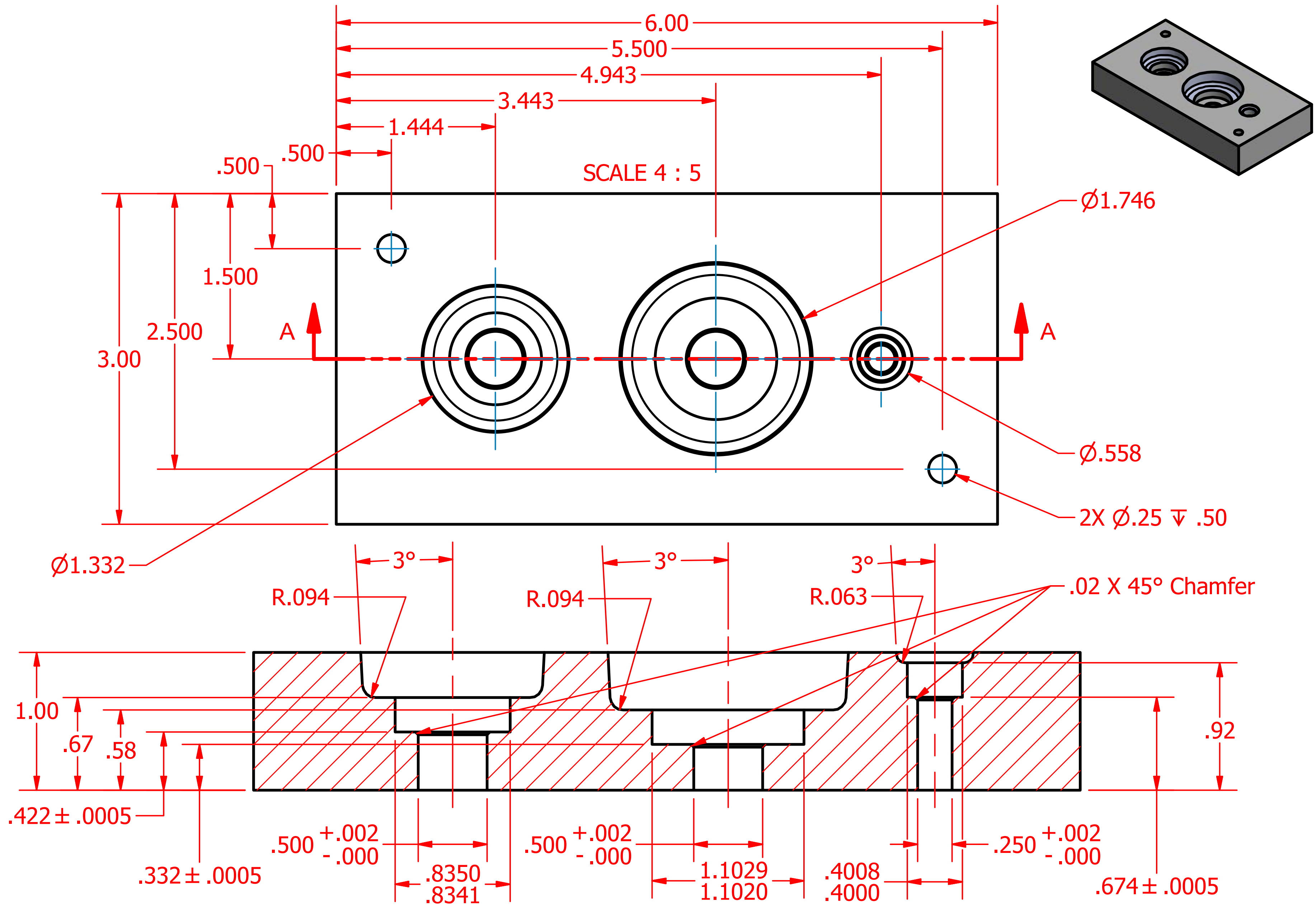
SCALE 1 : 2



SECTION B-B
SCALE 1 : 1

NOTE: FULL PART GEOMETRY IS REPRESENTED IN SOLID MODEL CAD FILE

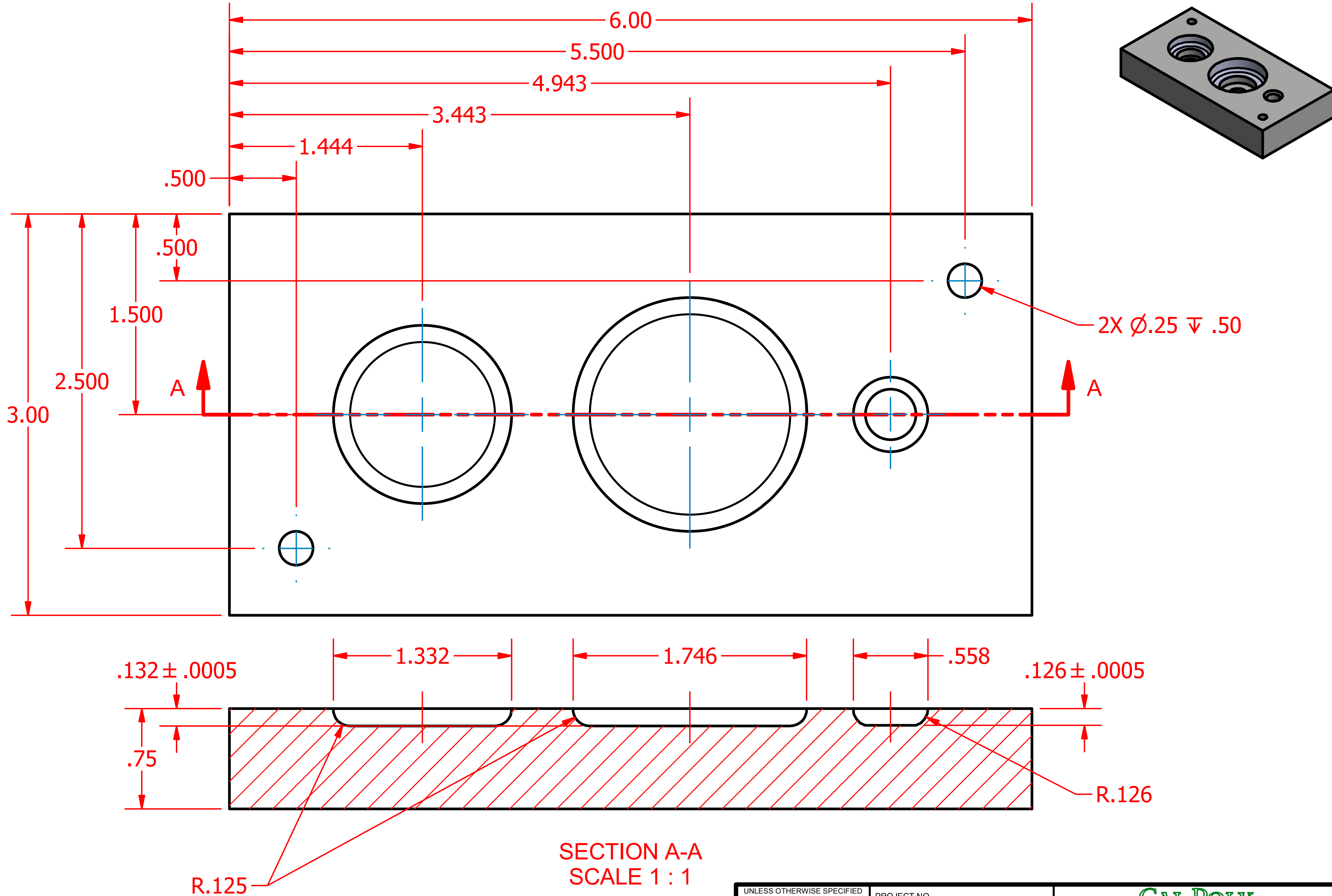
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DIMENSIONAL TOLERANCES ARE: .X ± .05 .XX ± .005 .XXX ± .0005 ANGULAR TOLERANCE IS: X° ± 1° DEBURR AND BREAK SHARP EDGES .01	PROJECT NO. **CR1**		CAL POLY College of Engineering Mechanical Engineering Department
	APPROVALS	DATE	
	DRAWN **TISCHLER**	**05FEB2017**	DESCRIPTION **ROCKER MOLD TOP** SECTION VIEW 2
MATERIAL **AL 6061-T6**	CHECKED **GOLDSTEIN**	**05FEB2017**	
FINISH **MOLD SEALANT**	CONFIDENTIAL The information contained within this drawing is proprietary to Team Black Gold and shall not be disclosed without prior written consent of Black Gold executive officers.		SIZE A · DRAWING NO. **CR1-2-2** · REV. SCALE SHOWN · SHEET 3 OF 3



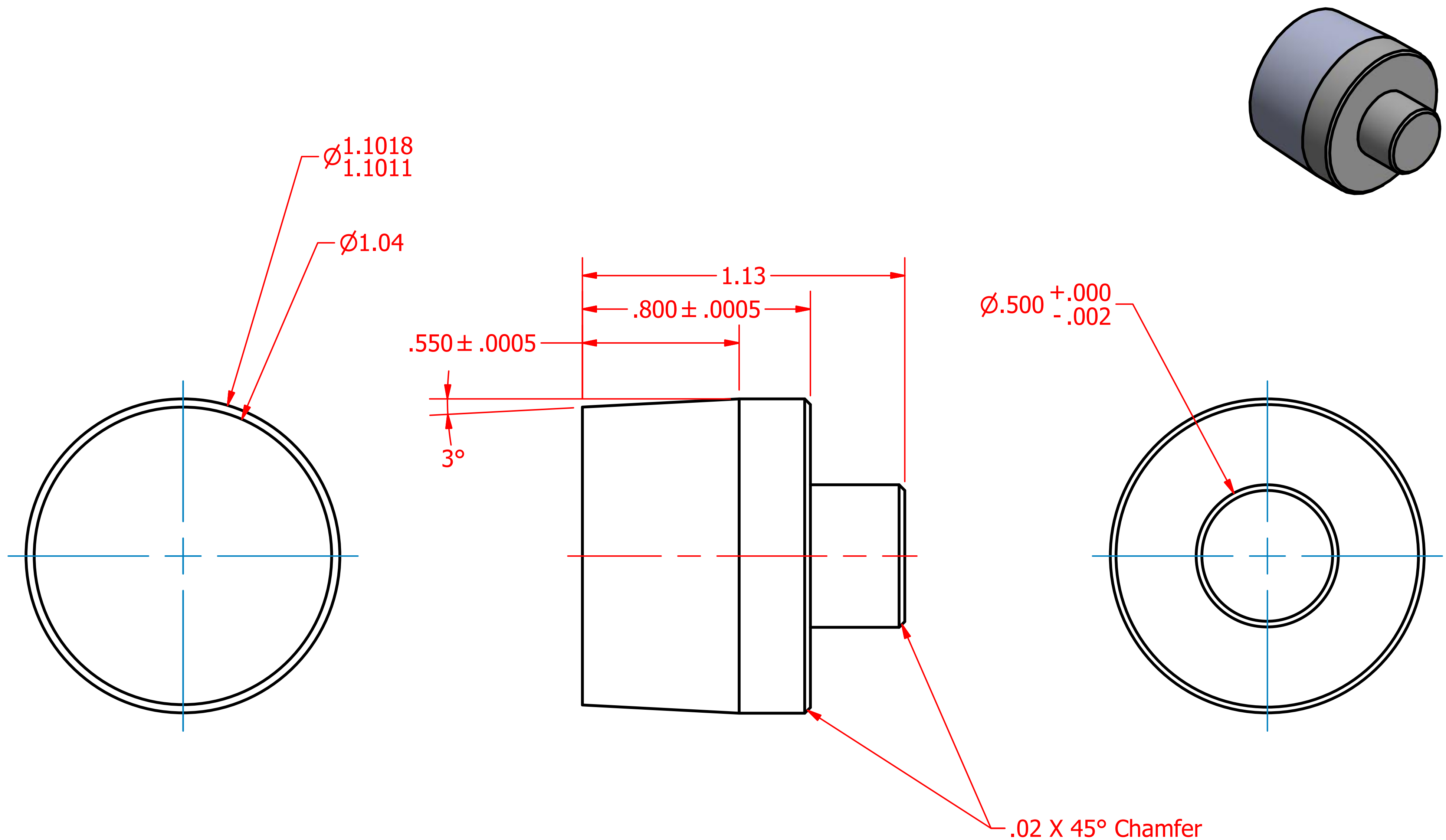
SECTION A-A
SCALE 1 : 1

NOTE: FULL PART GEOMETRY IS REPRESENTED IN SOLID MODEL CAD FILE

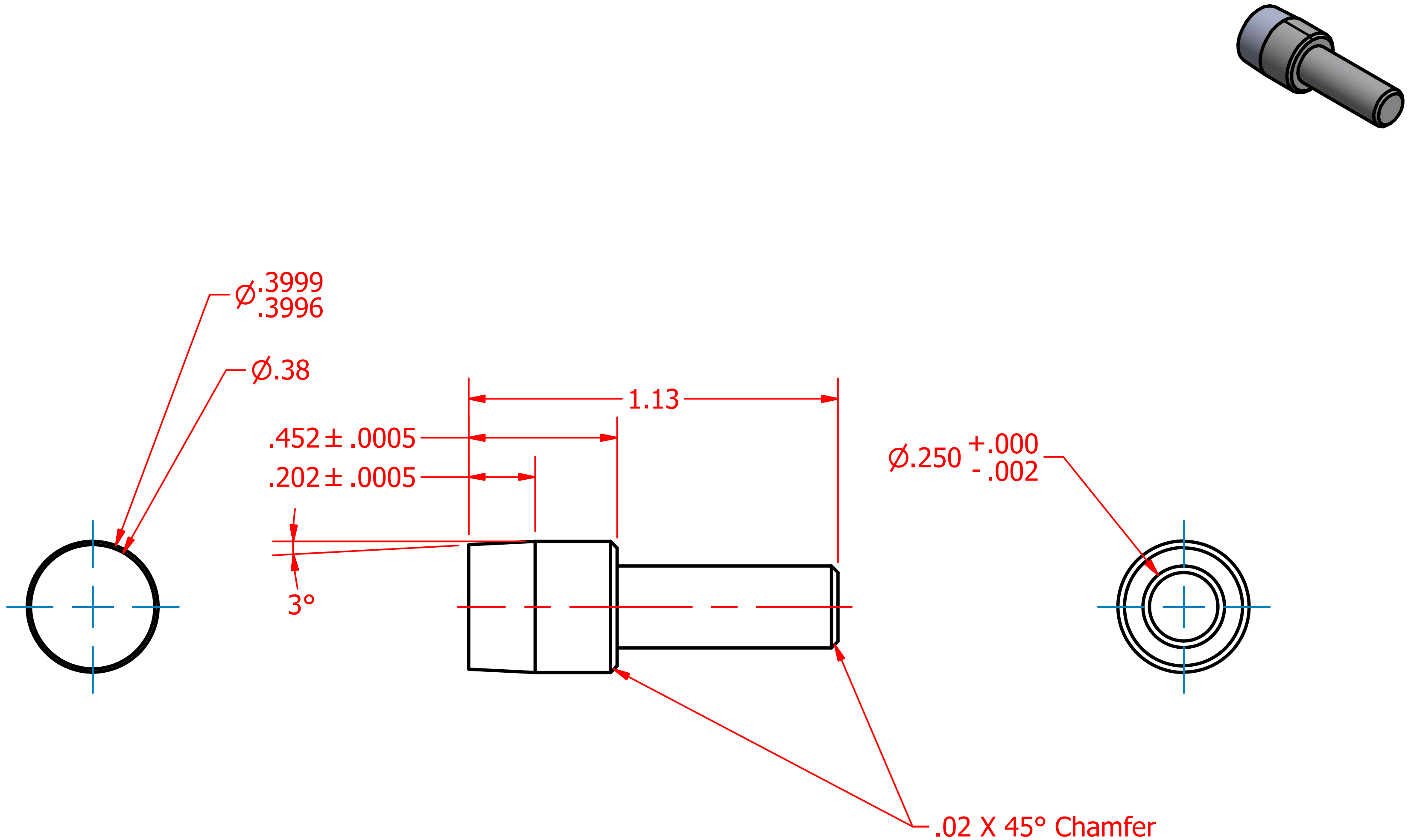
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DIMENSIONAL TOLERANCES ARE: .X ± .05 .XX ± .005 .XXX ± .0005 ANGULAR TOLERANCE IS: X° ± 1° DEBURR AND BREAK SHARP EDGES .01	PROJECT NO. CR1		CAL POLY College of Engineering Mechanical Engineering Department
	APPROVALS	DATE	
	DRAWN **TISCHLER**	**05FEB2017**	DESCRIPTION **PUCK MOLD BASE** SECTION VIEW
MATERIAL **AL 6061-T6**	CHECKED **GOLDSTEIN**	**05FEB2017**	
FINISH **MOLD SEALANT**	CONFIDENTIAL The information contained within this drawing is proprietary to Team Black Gold and shall not be disclosed without prior written consent of Black Gold executive officers		SIZE: A DRAWING NO.: **CR1-3-1** REV.: SCALE: SHOWN SHEET 1 OF 1



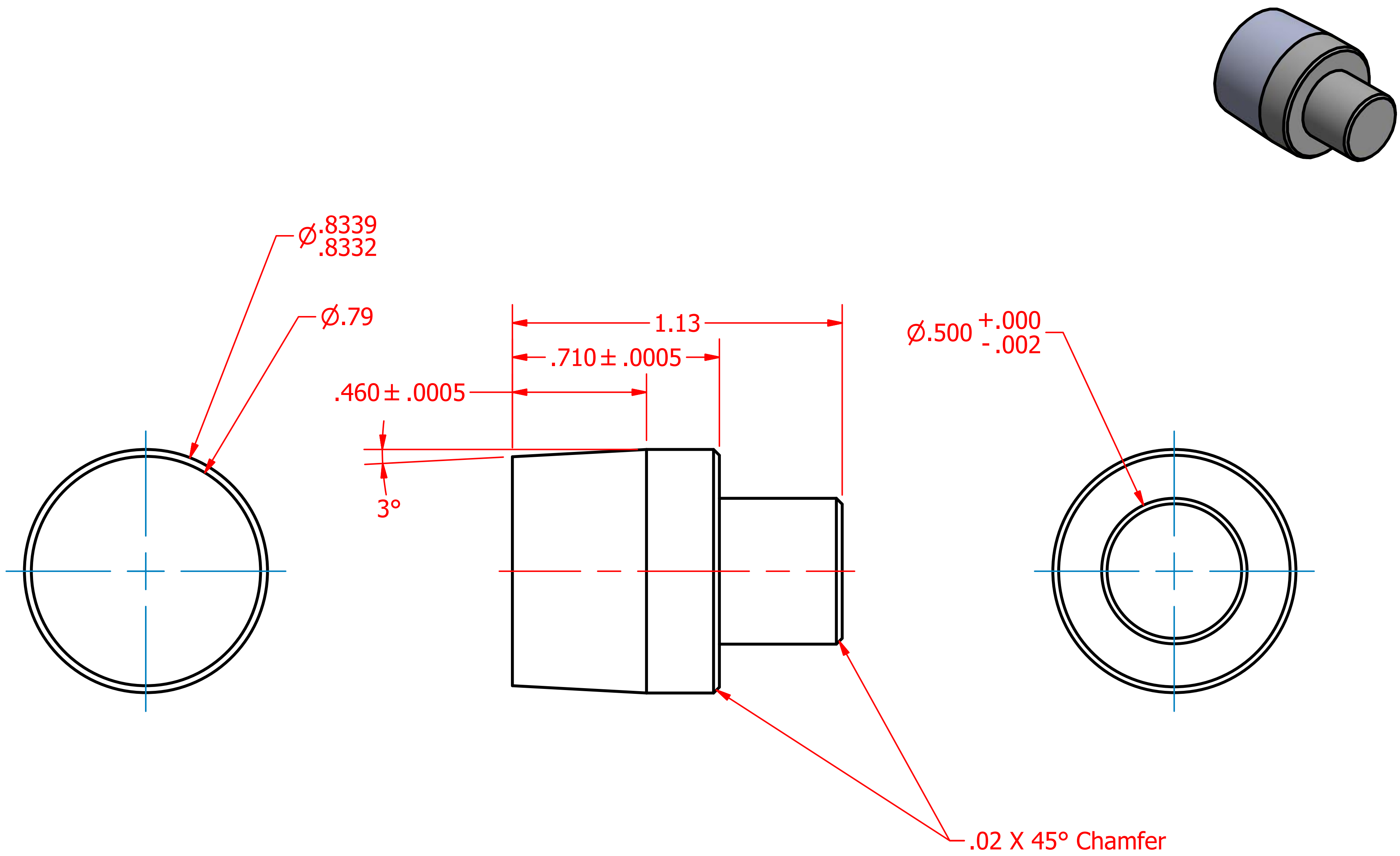
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DIMENSIONAL TOLERANCES ARE: .X ± .05 .XX ± .005 .XXX ± .0005 ANGULAR TOLERANCE IS: X° ± 1° DEBURR AND BREAK SHARP EDGES .01	PROJECT NO. **CR1**		CAL POLY College of Engineering Mechanical Engineering Department	
	APPROVALS	DATE		
	DRAWN **TISCHLER**	**05FEB2016**	DESCRIPTION **PUCK MOLD TOP** SECTION VIEW	
MATERIAL **AL 6061-T6**	CHECKED **GOLDSTEIN**	**05FEB2017**		
FINISH **MOLD SEALANT**	CONFIDENTIAL The information contained within this drawing is proprietary to Team Black Gold and shall not be disclosed without prior written consent of Black Gold executive officers		SIZE A DRAWING NO. **CR1-3-2**	REV.
			SCALE SHOWN	SHEET 1 OF 1



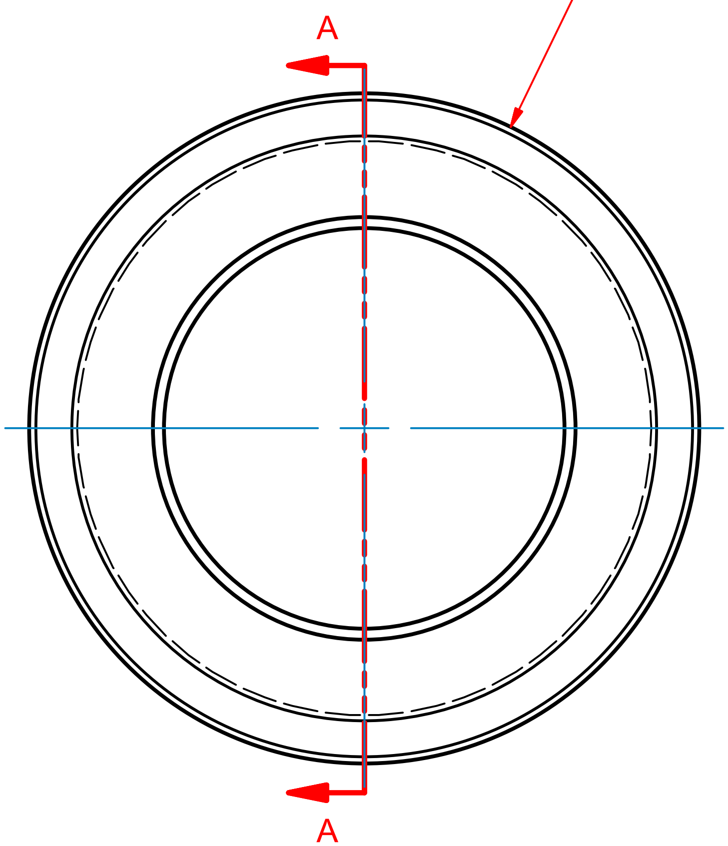
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DIMENSIONAL TOLERANCES ARE: .X ± .05 .XX ± .005 .XXX ± .0005 ANGULAR TOLERANCE IS: X° ± 1° DEBURR AND BREAK SHARP EDGES .01	PROJECT NO. **CR1**		CAL POLY College of Engineering *Mechanical Engineering Department*
	APPROVALS	DATE	
	DRAWN **TISCHLER**	**05FEB2017**	DESCRIPTION **SEATPOST PUCK PIN** PUCK MOLD BOTTOM PIN INSERT
MATERIAL **SS-304**	CHECKED **GOLDSTEIN**	**05FEB2017**	
FINISH	CONFIDENTIAL The information contained within this drawing is proprietary to Team Black Gold and shall not be disclosed without prior written consent of Black Gold executive officers.		SIZE A · DRAWING NO. **CR1-3-4** · REV. SCALE 2:1 · SHEET 1 OF 1

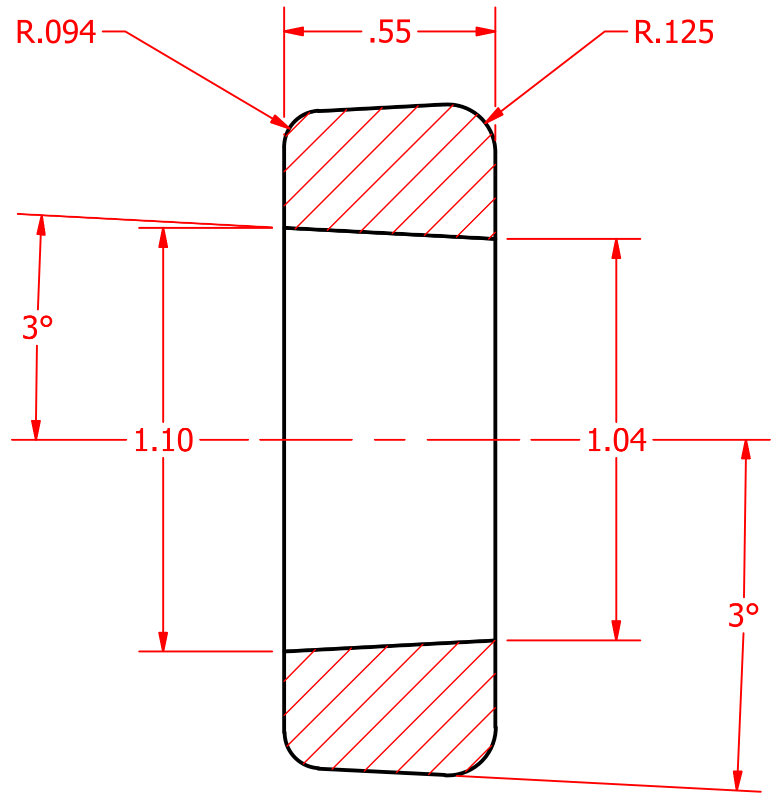


UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DIMENSIONAL TOLERANCES ARE: .X ± .05 .XX ± .005 .XXX ± .0005 ANGULAR TOLERANCE IS: X° ± 1° DEBURR AND BREAK SHARP EDGES .01	PROJECT NO. **CR1**		CAL POLY College of Engineering Mechanical Engineering Department	
	APPROVALS	DATE		
	DRAWN **TISCHLER**	**05FEB2017**	DESCRIPTION **SHOCK PUCK PIN**	
MATERIAL **SS-304**	CHECKED **GOLDSTEIN**	**05FEB2017**	PUCK MOLD BOTTOM PIN INSERT	
FINISH	CONFIDENTIAL The information contained within this drawing is proprietary to Team Black Gold and shall not be disclosed without prior written consent of Black Gold executive officers.		SIZE A / DRAWING NO. **CR1-3-3**	REV.
			SCALE 2:1	SHEET 1 OF 1

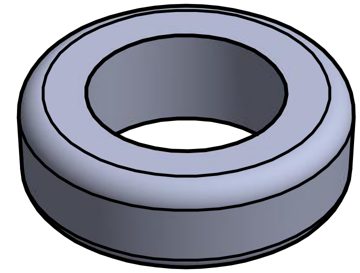


UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DIMENSIONAL TOLERANCES ARE: .X ± .05 .XX ± .005 .XXX ± .0005 ANGULAR TOLERANCE IS: X° ± 1° DEBURR AND BREAK SHARP EDGES .01	PROJECT NO. **CR1** APPROVALS | DATE DRAWN **TISCHLER** | **05FEB2017**	CAL POLY College of Engineering Mechanical Engineering Department	
MATERIAL **SS-304**	CHECKED **GOLDSTEIN** | **05FEB2017**	DESCRIPTION **TAIL PUCK PIN** PUCK MOLD BOTTOM PIN INSERT	
FINISH	CONFIDENTIAL The information contained within this drawing is proprietary to Team Black Gold and shall not be disclosed without prior written consent of Black Gold executive officers.	SIZE A | DRAWING NO. **CR1-3-5** SCALE 2:1 | SHEET 1 OF 1	REV.



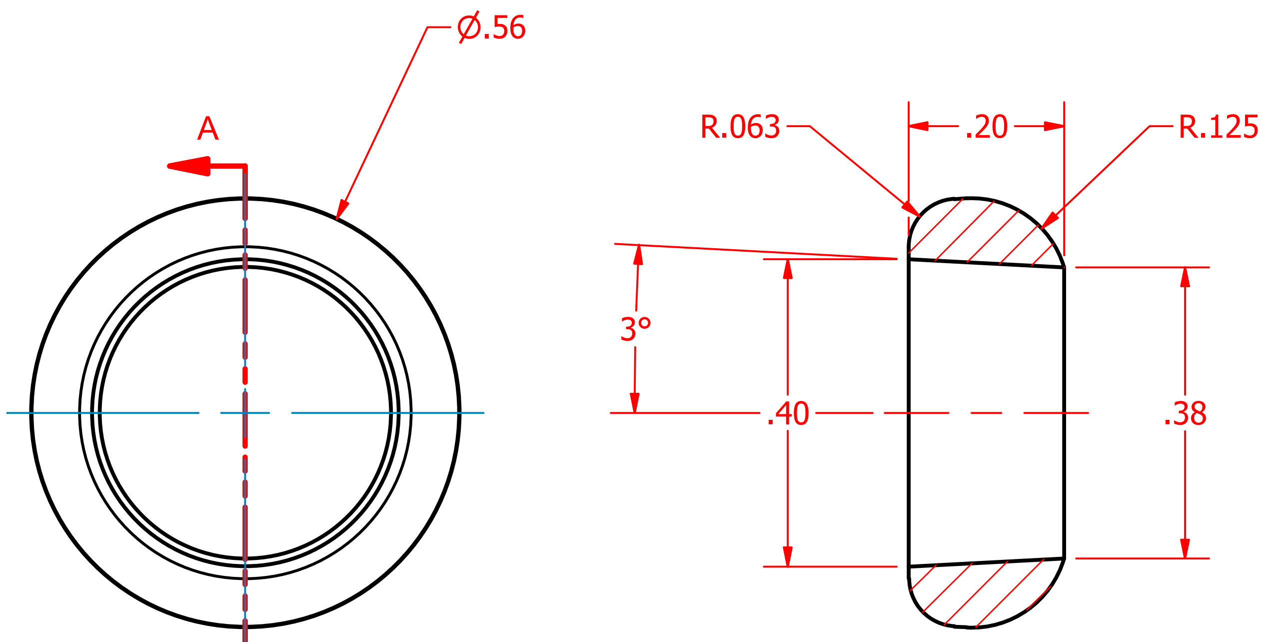


SECTION A-A
SCALE 2 : 1

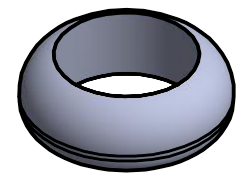


NOTE: FULL PART GEOMETRY IS REPRESENTED IN SOLID MODEL CAD FILE

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DIMENSIONAL TOLERANCES ARE: .X ± .05 .XX ± .005 .XXX ± .0005 ANGULAR TOLERANCE IS: X° ± 1° DEBURR AND BREAK SHARP EDGES .01	PROJECT NO. **CR1**		CAL POLY College of Engineering Mechanical Engineering Department
	APPROVALS	DATE	
	DRAWN **TISCHLER**	**05FEB2017**	DESCRIPTION **SEATPOST PUCK** MOLD PRE-INSERT
MATERIAL **TC275-1/T700SC**	CHECKED **GOLDSTEIN**	**05FEB2017**	
FINISH **AS IS**	CONFIDENTIAL The information contained within this drawing is proprietary to Team Black Gold and shall not be disclosed without prior written consent of Black Gold executive officers		SIZE: A DRAWING NO.: **CR1-1-2** REV.: SCALE: 2:1 SHEET 1 OF 1



SECTION A-A
SCALE 4 : 1



NOTE: FULL PART GEOMETRY IS REPRESENTED IN SOLID MODEL CAD FILE

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
DIMENSIONAL TOLERANCES ARE:
.X ± .05
.XX ± .005
.XXX ± .0005
ANGULAR TOLERANCE IS:
X° ± 1°
DEBURR AND BREAK SHARP EDGES .01

MATERIAL
TC275-1/T700SC

FINISH
AS IS

PROJECT NO.
CR1

APPROVALS	DATE
DRAWN **TISCHLER**	**05FEB2017**
CHECKED **GOLDSTEIN**	**05FEB2017**

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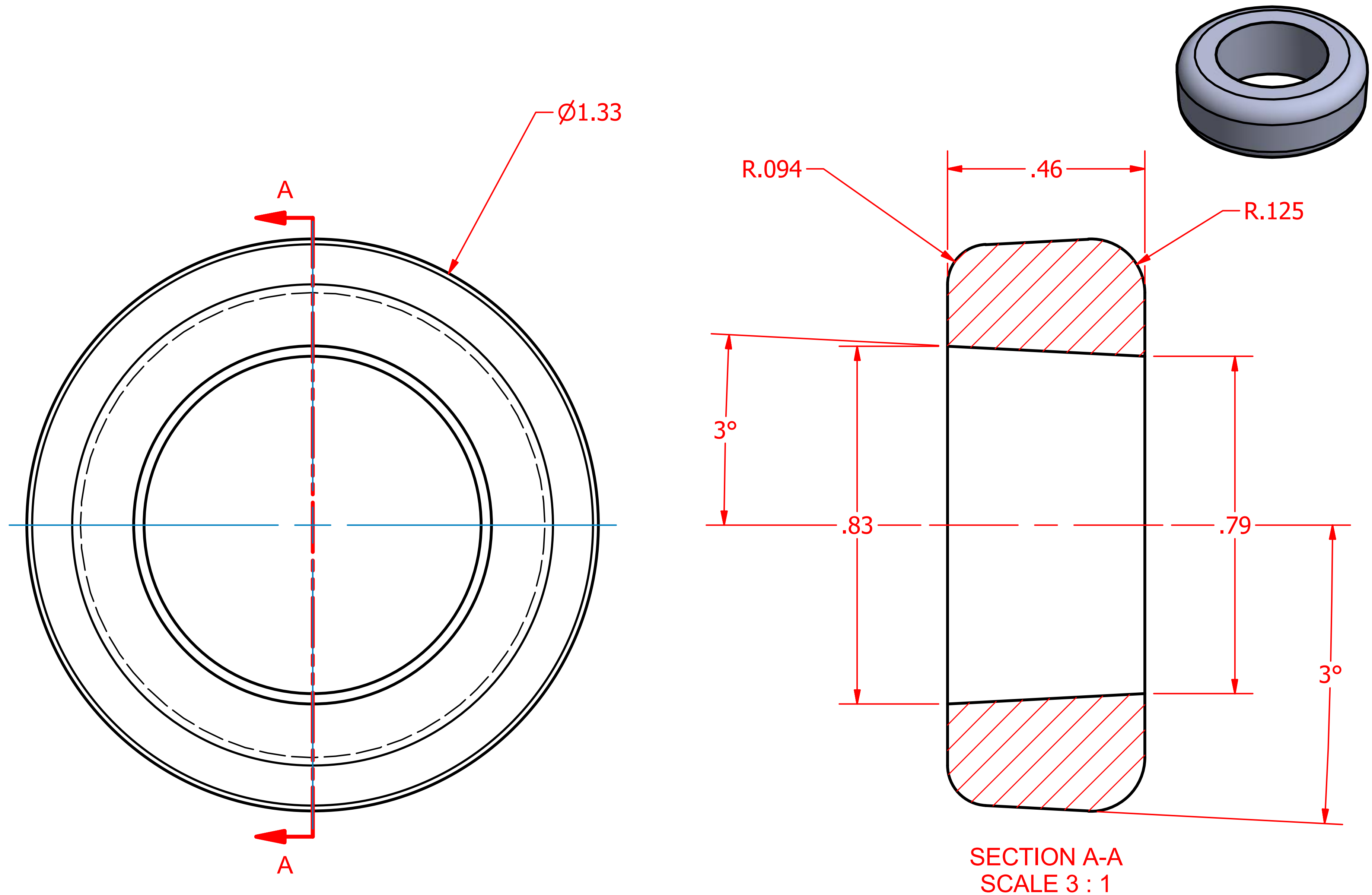
CAL POLY
College of Engineering
Mechanical Engineering Department

DESCRIPTION
SHOCK PUCK
MOLD PRE-INSERT

SIZE A
DRAWING NO. **CR1-1-1**
REV.
SCALE 4:1
SHEET 1 OF 1



NOTE: FULL PART GEOMETRY IS REPRESENTED IN SOLID MODEL CAD FILE

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
DIMENSIONAL TOLERANCES ARE:
.X ± .05
.XX ± .005
.XXX ± .0005
ANGULAR TOLERANCE IS:
X° ± 1°
DEBURR AND BREAK
SHARP EDGES .01

MATERIAL
TC275-1/T700SC

FINISH
AS IS

PROJECT NO.
CR1

APPROVALS	DATE
DRAWN **TISCHLER**	**05FEB2017**
CHECKED **GOLDSTEIN**	**05FEB2017**

CONFIDENTIAL
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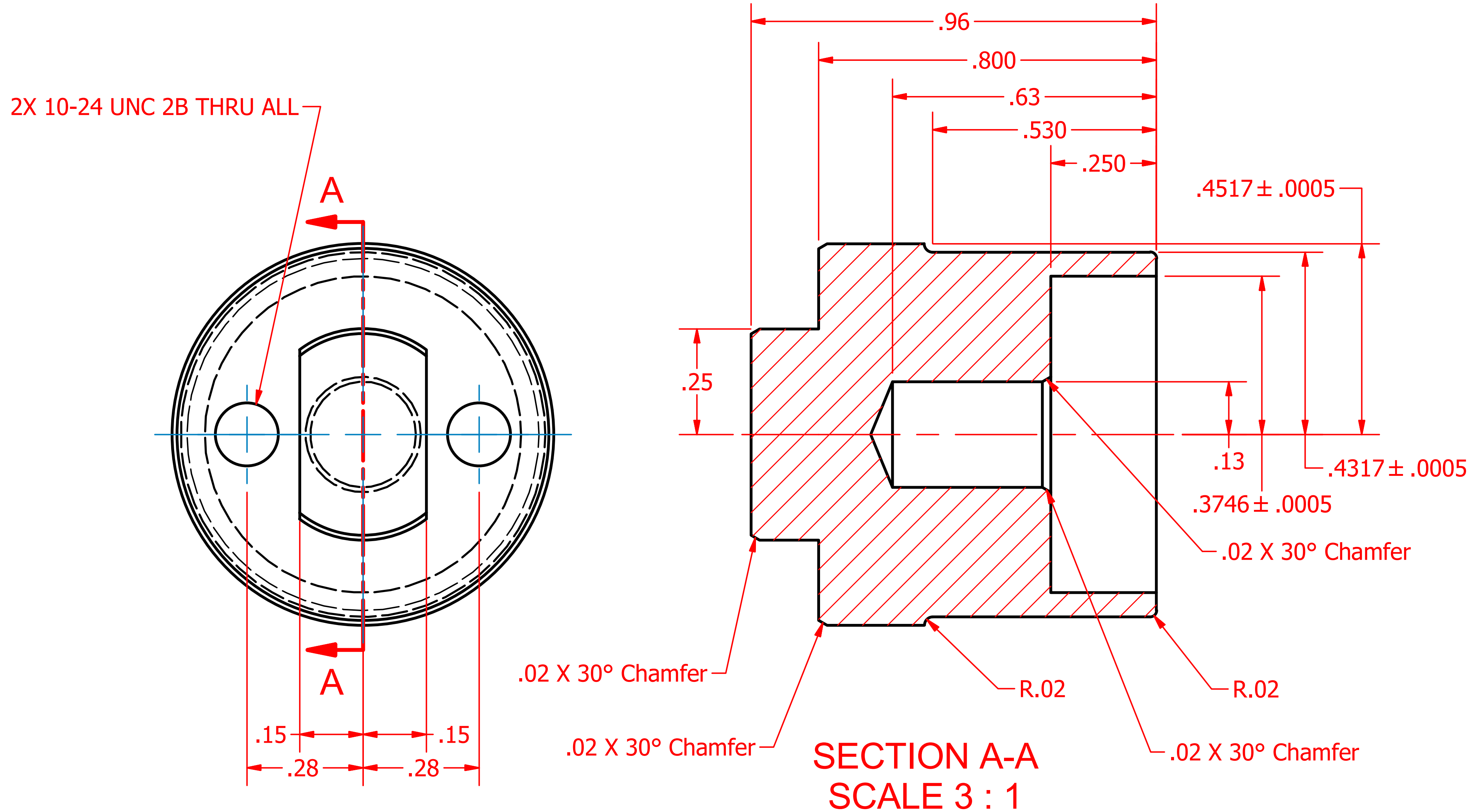
CAL POLY
College of Engineering
Mechanical Engineering Department

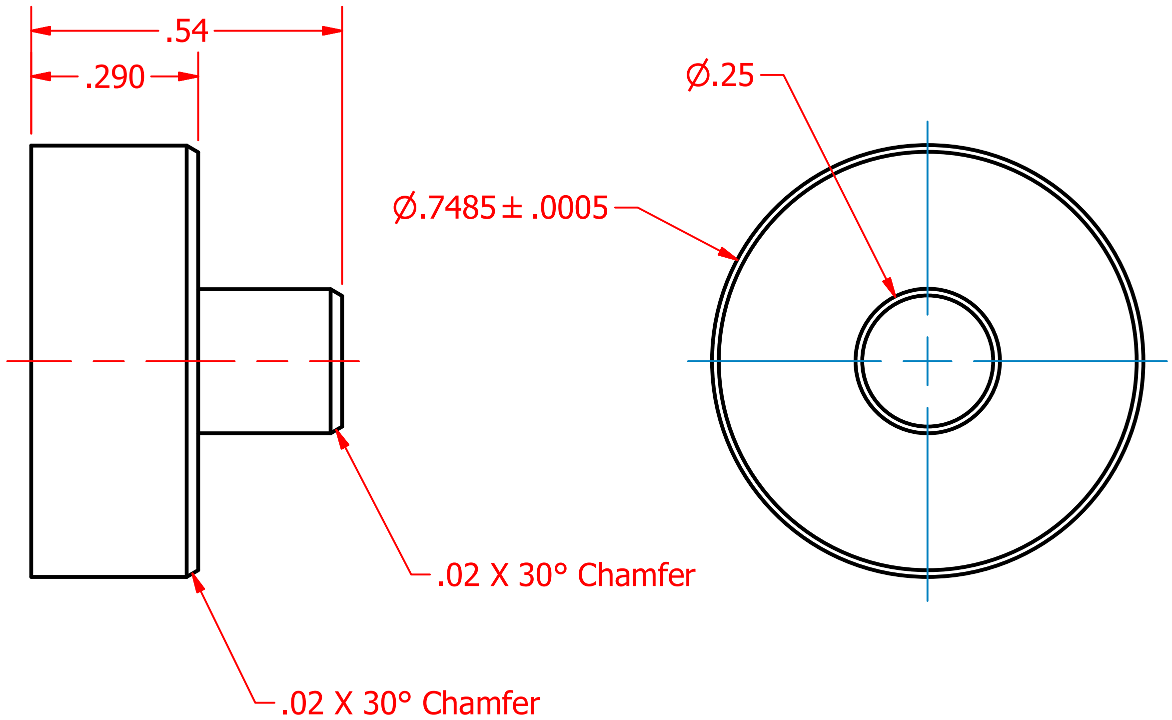
DESCRIPTION
TAIL PUCK
MOLD PRE-INSERT

SIZE	DRAWING NO.	REV.
A	**CR1-1-3**	

SCALE	3:1	SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DIMENSIONAL TOLERANCES ARE: .X ± .05 .XX ± .005 .XXX ± .0005 ANGULAR TOLERANCE IS: X° ± 1° DEBURR AND BREAK SHARP EDGES .01	PROJECT NO. APPROVALS	DATE	CAL POLY College of Engineering Mechanical Engineering Department
	DRAWN **TISCHLER**	**9JUN2017**	DESCRIPTION **TAIL PIN**
MATERIAL **AL 6061**	CHECKED **GOLDSTEIN**	**9JUN2017**	
FINISH	CONFIDENTIAL The information contained within this drawing is proprietary to Team Black Gold and shall not be disclosed without prior written consent of Black Gold executive officers.		SIZE: A DRAWING NO.: **CR1-2-C-1** REV. SCALE: 3:1 SHEET 1 OF 5



UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
DIMENSIONAL TOLERANCES ARE:
.X ± .05
.XX ± .005
.XXX ± .0005
ANGULAR TOLERANCE IS:
X° ± 1°
DEBURR AND BREAK
SHARP EDGES .01

MATERIAL
AL 6061

FINISH

PROJECT NO.

APPROVALS	DATE
DRAWN **TISCHLER**	**9JUN2017**
CHECKED **GOLDSTEIN**	**9JUN2017**

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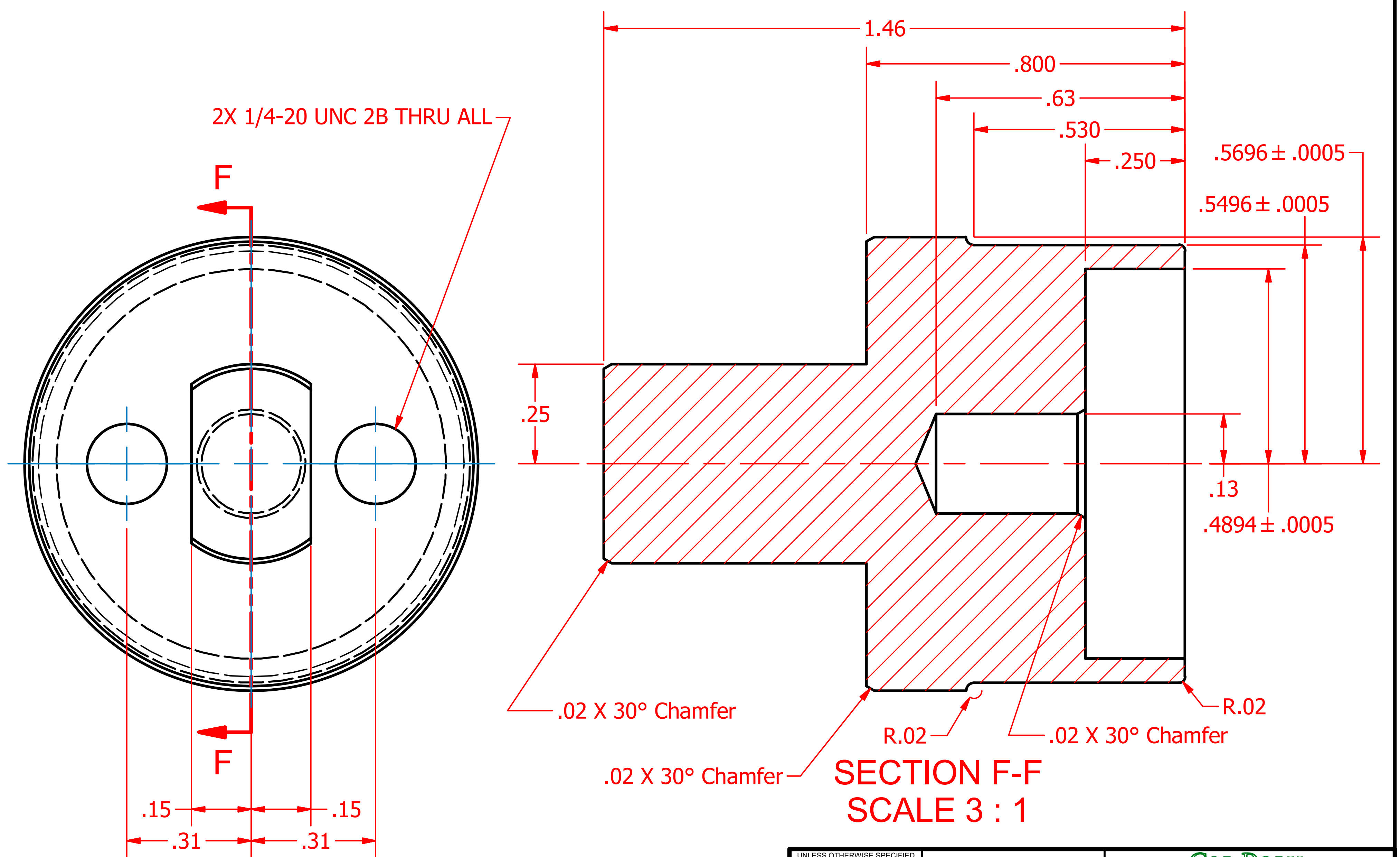
CAL POLY
College of Engineering
Mechanical Engineering Department

DESCRIPTION
TAIL PIN INSERT

SIZE A | DRAWING NO. **CR1-2-C-2** | REV.

SCALE 3:1 | SHEET 1 OF 5



UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
DIMENSIONAL TOLERANCES ARE:
.X ± .05
.XX ± .005
.XXX ± .0005
ANGULAR TOLERANCE IS:
X° ± 1°
DEBURR AND BREAK SHARP EDGES .01

MATERIAL
AL 6061

FINISH

PROJECT NO.

APPROVALS	DATE
DRAWN **TISCHLER**	**9JUN2017**
CHECKED **GOLDSTEIN**	**9JUN2017**

CONFIDENTIAL

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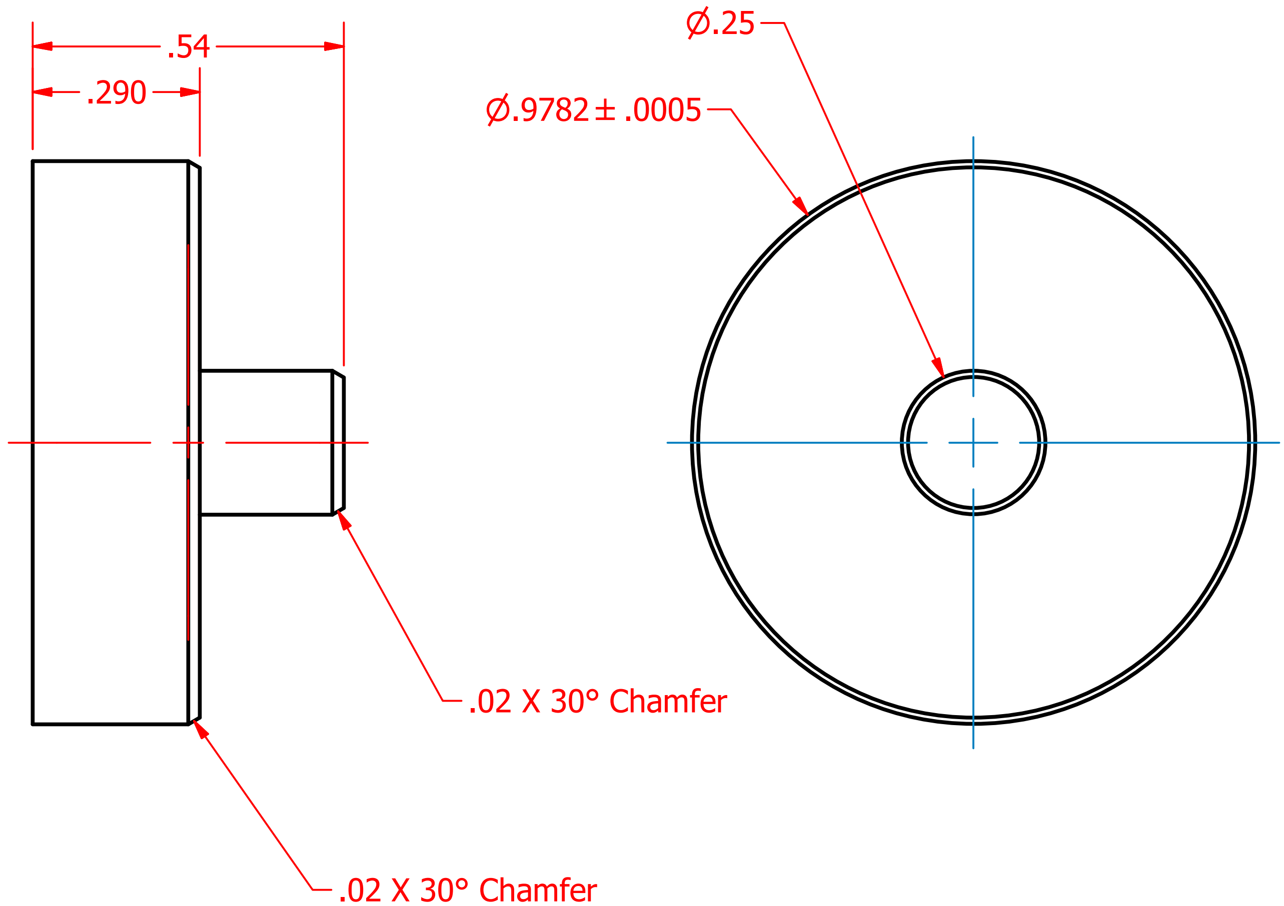
CAL POLY
College of Engineering
Mechanical Engineering Department

DESCRIPTION
SEATPOST PIN

SIZE	DRAWING NO.	REV.
A	**CR1-2-C-3**	

SCALE 3:1 — SHEET 3 OF 5



UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
DIMENSIONAL TOLERANCES ARE:
.X ± .05
.XX ± .005
.XXX ± .0005
ANGULAR TOLERANCE IS:
X° ± 1°
DEBURR AND BREAK
SHARP EDGES .01

MATERIAL
AL 6061

FINISH

PROJECT NO.

APPROVALS	DATE
DRAWN **TISCHLER**	**9JUN2017**
CHECKED **GOLDSTEIN**	**9JUN2017**

CONFIDENTIAL

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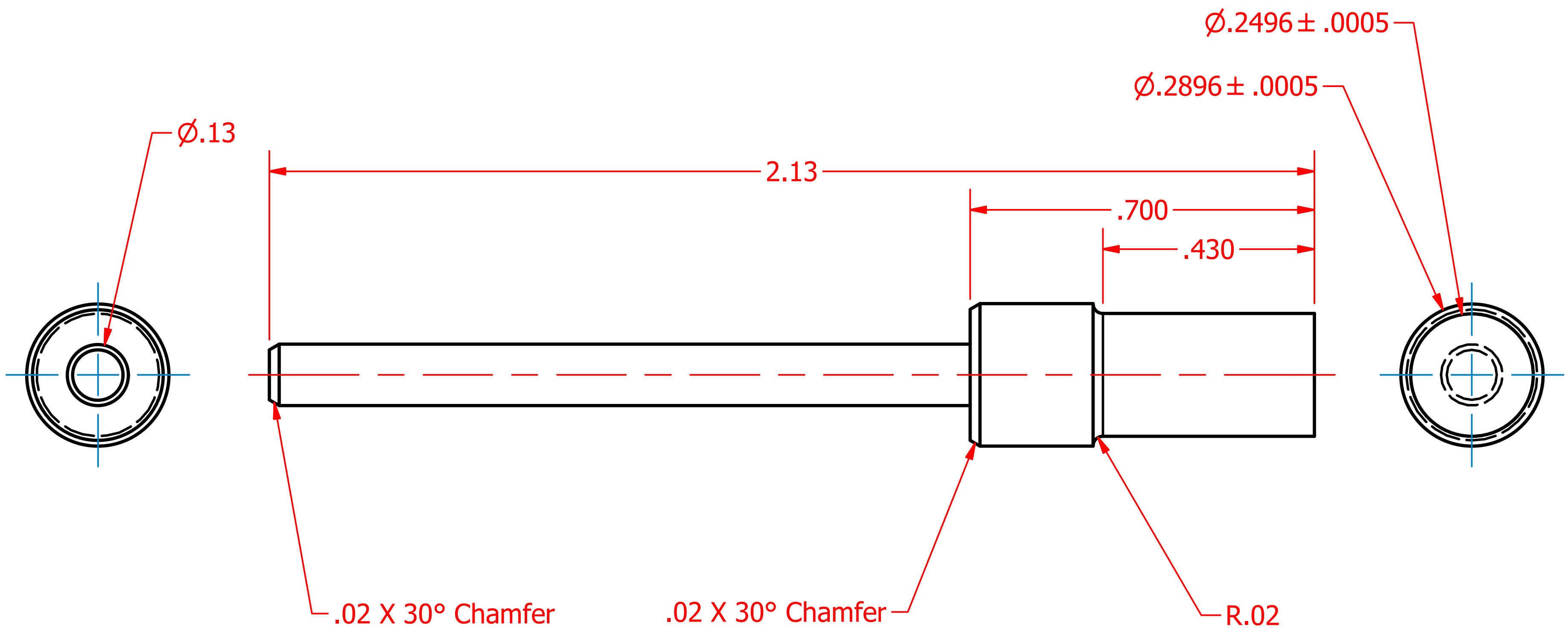
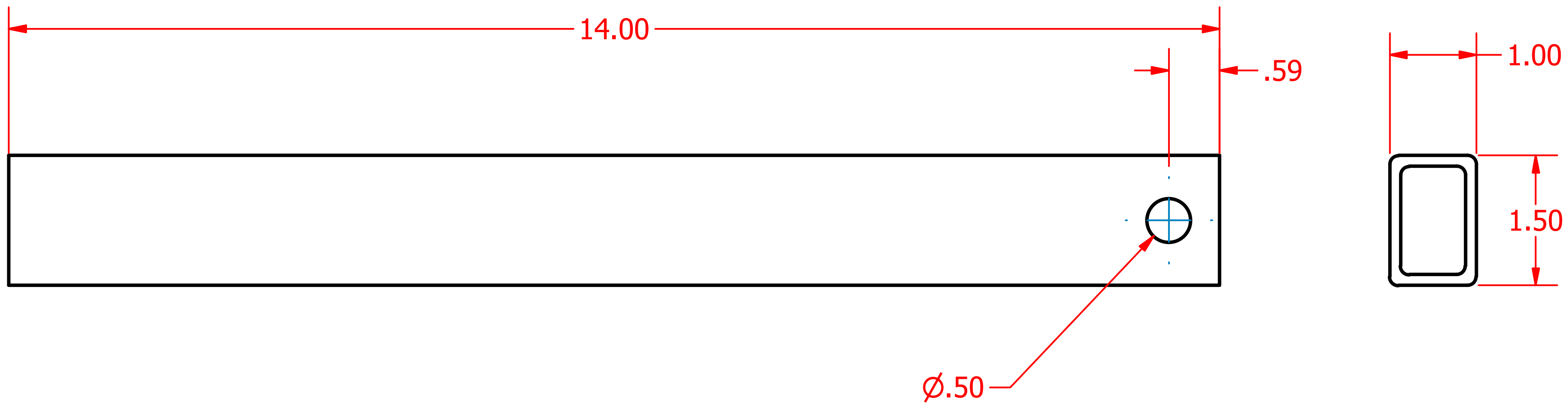
CAL POLY
College of Engineering
Mechanical Engineering Department

DESCRIPTION
SEATPOST PIN INSERT

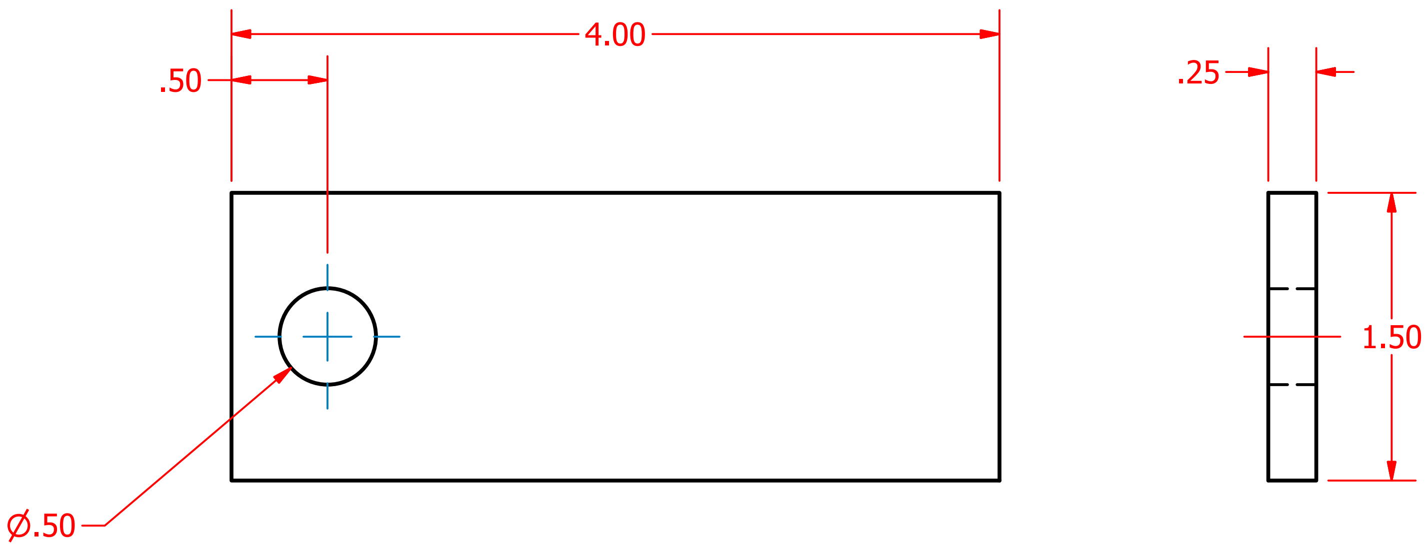
SIZE	DRAWING NO.	REV.
A	**CR1-2-C-4**	
SCALE 3:1	SHEET 4 OF 5	



UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DIMENSIONAL TOLERANCES ARE: .X ± .05 .XX ± .005 .XXX ± .0005 ANGULAR TOLERANCE IS: X° ± 1° DEBURR AND BREAK SHARP EDGES .01	PROJECT NO.		CAL POLY College of Engineering Mechanical Engineering Department
	APPROVALS	DATE	
	DRAWN **TISCHLER**	**9JUN2017**	DESCRIPTION **SHOCK PIN**
MATERIAL **AL 6061**	CHECKED **GOLDSTEIN**	**9JUN2017**	
FINISH	CONFIDENTIAL The information contained within this drawing is proprietary to Team Black Gold and shall not be disclosed without prior written consent of Black Gold executive officers		SIZE: A · DRAWING NO.: **CR1-2-C-5** · REV. SCALE 3:1 · SHEET 5 OF 5



UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DIMENSIONAL TOLERANCES ARE: .X ± .05 .XX ± .005 .XXX ± .0005 ANGULAR TOLERANCE IS: X° ± 1° DEBURR AND BREAK SHARP EDGES .01	PROJECT NO. APPROVALS	DATE	CAL POLY College of Engineering Mechanical Engineering Department
	DRAWN TISCHLER	9JUN2017	DESCRIPTION **CHAIN STAY TUBE**
MATERIAL **STEEL**	CHECKED GOLDSTEIN	9JUN2017	
FINISH	CONFIDENTIAL The information contained within this drawing is proprietary to Team Black Gold and shall not be disclosed without prior written consent of Black Gold executive officers.		SIZE A DRAWING NO. **TJ-01** REV. SCALE 1:2 SHEET 1 OF 14



UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
DIMENSIONAL TOLERANCES ARE:
.X ± .05
.XX ± .005
.XXX ± .0005
ANGULAR TOLERANCE IS:
X° ± 1°
DEBURR AND BREAK
SHARP EDGES .01

MATERIAL
STEEL

FINISH

PROJECT NO.

APPROVALS	DATE
DRAWN **TISCHLER**	**9JUN2017**
CHECKED **GOLDSTEIN**	**9JUN2017**

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CAL POLY
College of Engineering
Mechanical Engineering Department

DESCRIPTION
WELD LINK
CHAIN STAY

SIZE	DRAWING NO.	REV.
A	**TJ-02**	

SCALE 1:1 SHEET 2 OF 14

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
DIMENSIONAL TOLERANCES ARE:
.X ± .05
.XX ± .005
.XXX ± .0005
ANGULAR TOLERANCE IS:
X° ± 1°
DEBURR AND BREAK
SHARP EDGES .01

PROJECT NO.

CAL POLY
College of Engineering
Mechanical Engineering Department

APPROVALS	DATE
DRAWN **TISCHLER**	**9JUN2017**
CHECKED **GOLDSTEIN**	**9JUN2017**

MATERIAL
STEEL

FINISH

DESCRIPTION
INSTRON GRIP

CONFIDENTIAL
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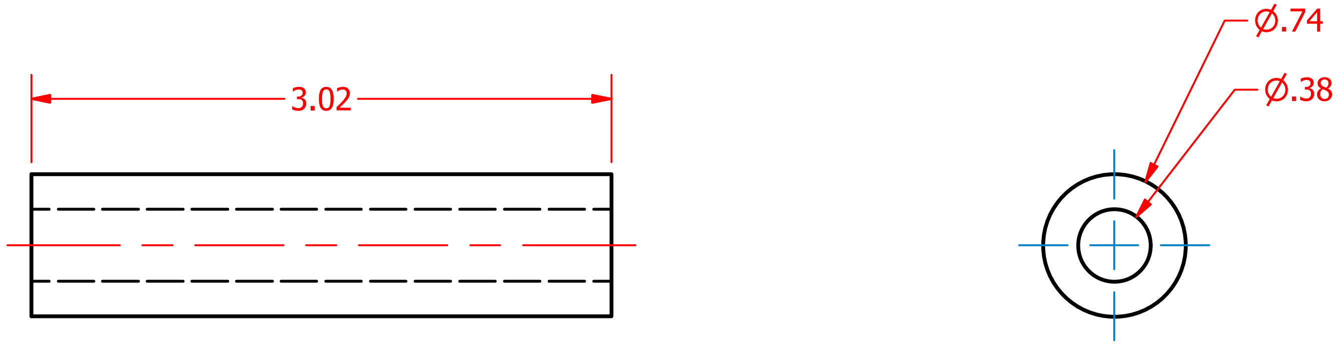
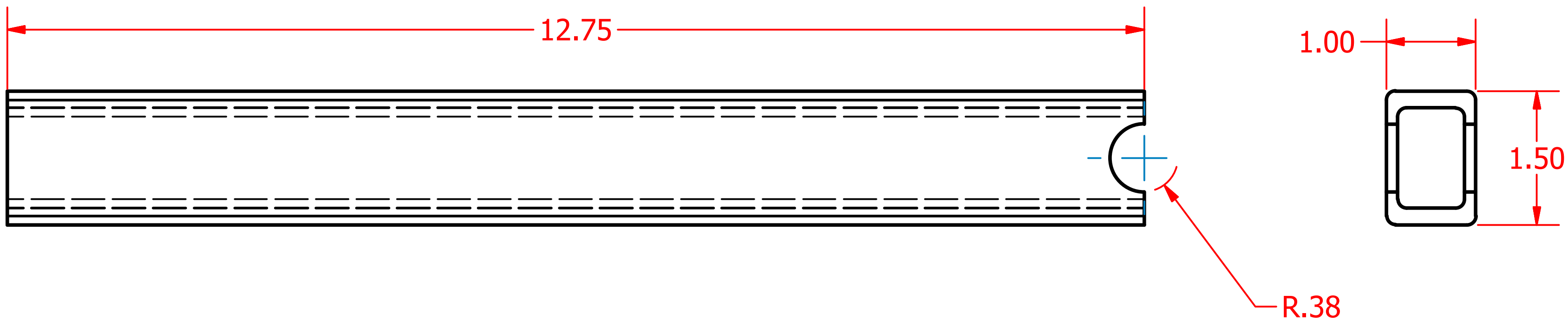
SIZE	DRAWING NO.	REV.
A	**TJ-03**	

SCALE 1:1

SHEET 3 OF 14



UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DIMENSIONAL TOLERANCES ARE: .X ± .05 .XX ± .005 .XXX ± .0005 ANGULAR TOLERANCE IS: X° ± 1° DEBURR AND BREAK SHARP EDGES .01	PROJECT NO.		CAL POLY College of Engineering Mechanical Engineering Department
	APPROVALS	DATE	
	DRAWN **TISCHLER**	**9JUN2017**	DESCRIPTION **DOWEL** SEAT STAY ROCKER
MATERIAL **STEEL**	CHECKED **GOLDSTEIN**	**9JUN2017**	
FINISH	CONFIDENTIAL The information contained within this drawing is proprietary to Team Black Gold and shall not be disclosed without prior written consent of Black Gold executive officers.		SIZE: A — DRAWING NO.: **TJ-04** — REV.:
			SCALE 1:1 — SHEET 4 OF 14



UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
DIMENSIONAL TOLERANCES ARE:
.X ± .05
.XX ± .005
.XXX ± .0005
ANGULAR TOLERANCE IS:
X° ± 1°
DEBURR AND BREAK
SHARP EDGES .01

MATERIAL
STEEL

FINISH

PROJECT NO.

APPROVALS	DATE
DRAWN **TISCHLER**	**9JUN2017**
CHECKED **GOLDSTEIN**	**9JUN2017**

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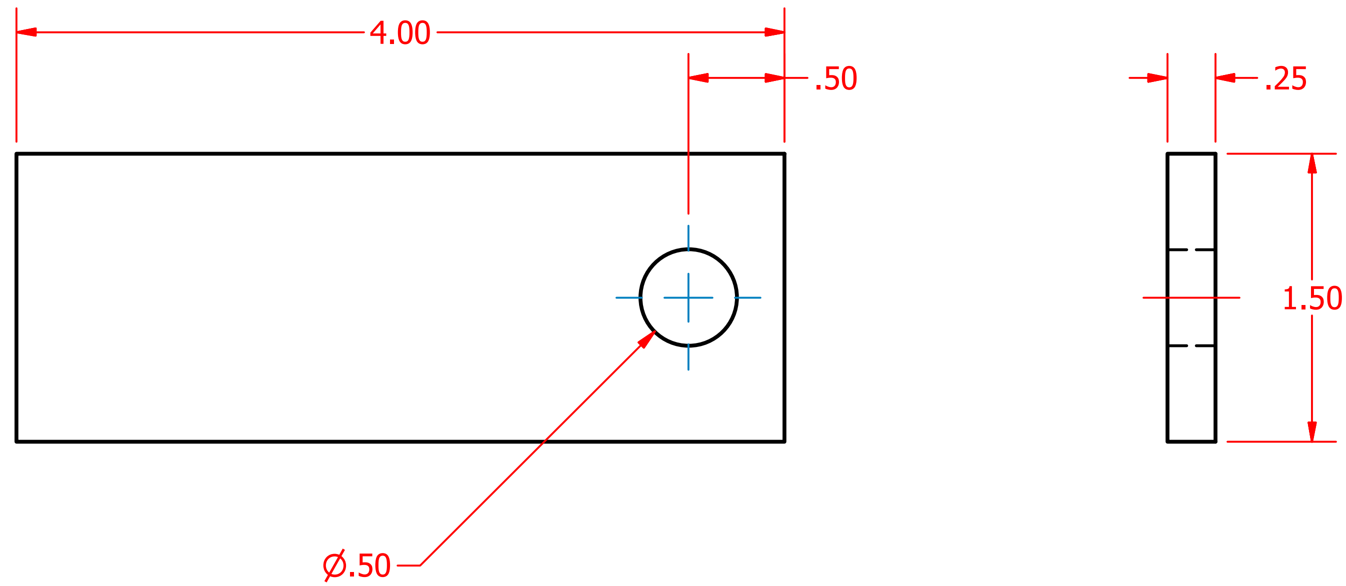
CAL POLY
College of Engineering
Mechanical Engineering Department

DESCRIPTION
SEAT STAY TUBE

SIZE: A
DRAWING NO.: **TJ-05**
REV.
SCALE 1:2
SHEET 5 OF 14



UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
DIMENSIONAL TOLERANCES ARE:
.X ± .05
.XX ± .005
.XXX ± .0005
ANGULAR TOLERANCE IS:
X° ± 1°
DEBURR AND BREAK
SHARP EDGES .01

MATERIAL
STEEL

FINISH

PROJECT NO.

APPROVALS	DATE
DRAWN **TISCHLER**	**9JUN2017**
CHECKED **GOLDSTEIN**	**9JUN2017**

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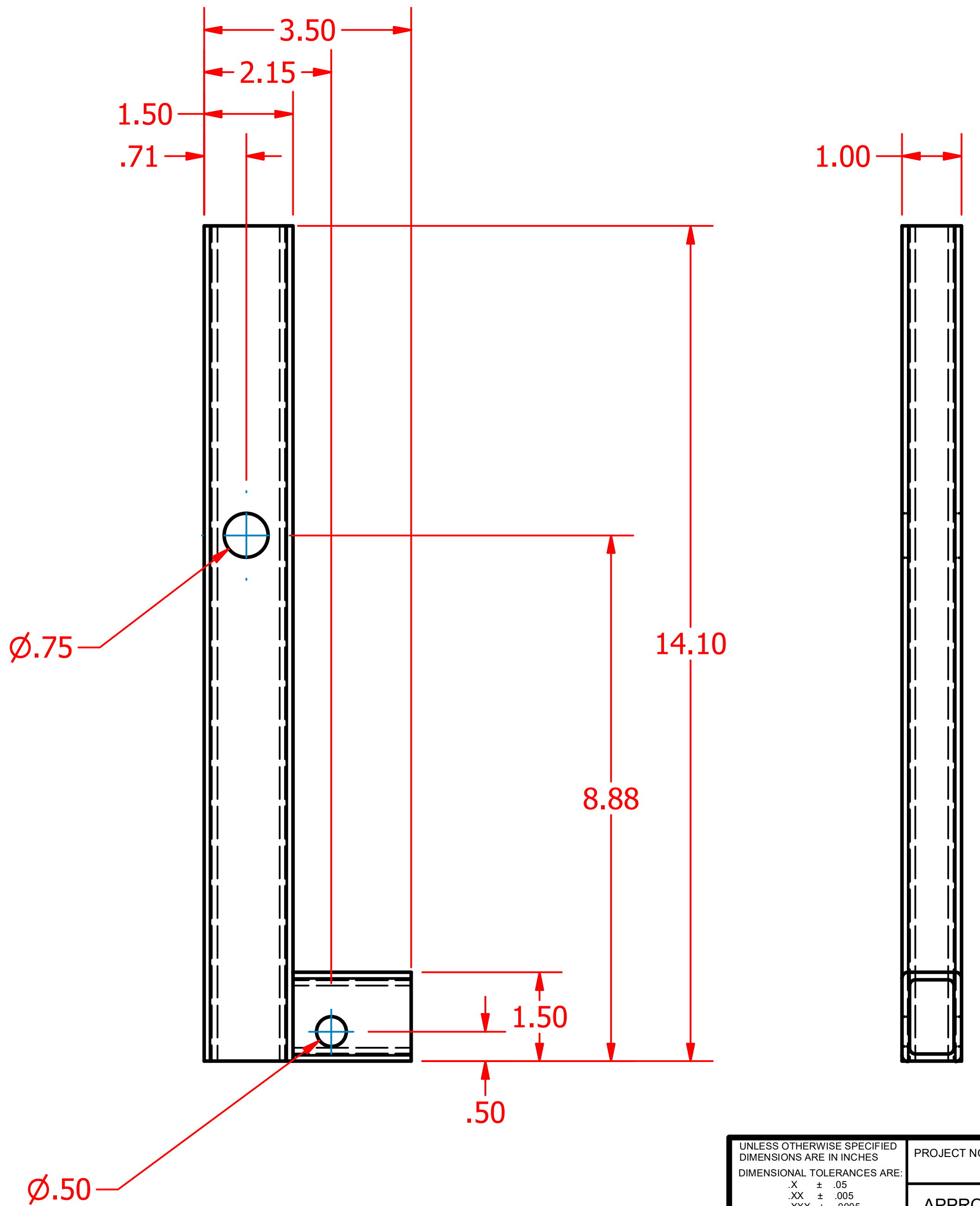
CAL POLY
College of Engineering
Mechanical Engineering Department

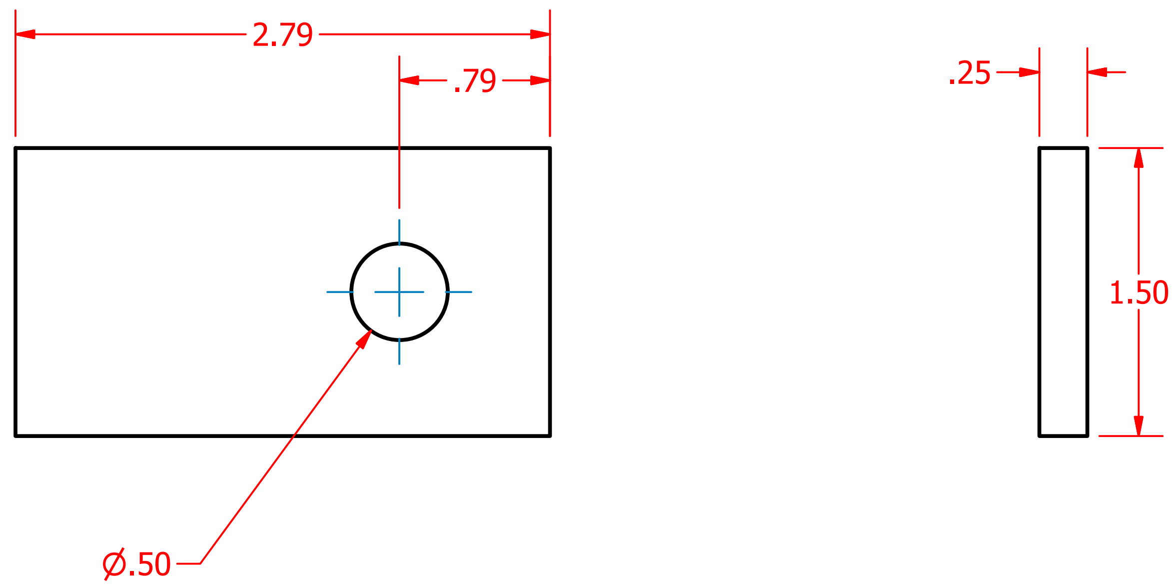
DESCRIPTION
WELD LINK
SEAT STAY

SIZE	DRAWING NO.	REV.
A	**TJ-06**	

SCALE 1:1 SHEET 6 OF 14



UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DIMENSIONAL TOLERANCES ARE: .X ± .05 .XX ± .005 .XXX ± .0005 ANGULAR TOLERANCE IS: X° ± 1° DEBURR AND BREAK SHARP EDGES .01	PROJECT NO.		CAL POLY College of Engineering Mechanical Engineering Department
	APPROVALS	DATE	
	DRAWN **TISCHLER**	**9JUN2017**	DESCRIPTION **SEAT TUBE**
MATERIAL **STEEL**	CHECKED **GOLDSTEIN**	**9JUN2017**	
FINISH	CONFIDENTIAL The information contained within this drawing is proprietary to Team Black Gold and shall not be disclosed without prior written consent of Black Gold executive officers.		SIZE: A — DRAWING NO.: **TJ-07** — REV.: SCALE 1:3 — SHEET 7 OF 14



UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DIMENSIONAL TOLERANCES ARE: .X ± .05 .XX ± .005 .XXX ± .0005 ANGULAR TOLERANCE IS: X° ± 1° DEBURR AND BREAK SHARP EDGES .01	PROJECT NO.		CAL POLY College of Engineering Mechanical Engineering Department
	APPROVALS	DATE	
	DRAWN **TISCHLER**	**9JUN2017**	DESCRIPTION **MOUNT TAB** SHOCK LOWER
MATERIAL **STEEL**	CHECKED **GOLDSTEIN**	**9JUN2017**	
FINISH	CONFIDENTIAL The information contained within this drawing is proprietary to Team Black Gold and shall not be disclosed without prior written consent of Black Gold executive officers.		SIZE: A — DRAWING NO.: **TJ-08** — REV. SCALE 1:1 — SHEET 8 OF 14

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DIMENSIONS ARE IN INCHES
DIMENSIONAL TOLERANCES ARE:
.X ± .05
.XX ± .005
.XXX ± .0005
ANGULAR TOLERANCE IS:
X° ± 1°
DEBURR AND BREAK
SHARP EDGES .01

MATERIAL
STEEL

FINISH

PROJECT NO.

APPROVALS	DATE
DRAWN TISCHLER	9JUN2017
CHECKED GOLDSTEIN	9JUN2017

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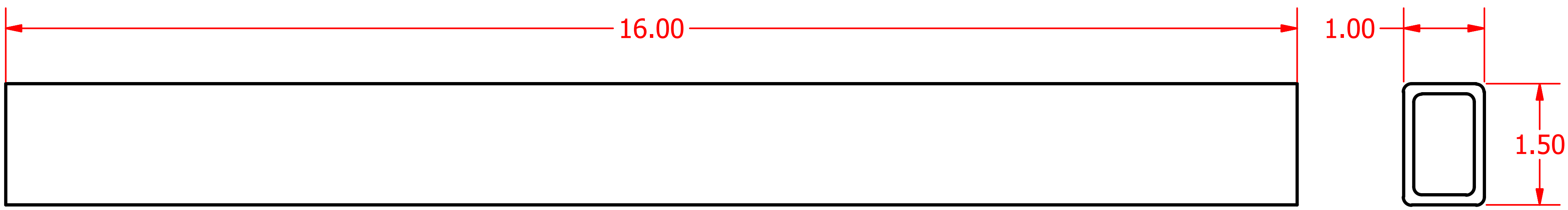
CAL POLY
College of Engineering
Mechanical Engineering Department

DESCRIPTION
DOWEL
ROCKER PIVOT

SIZE A
DRAWING NO. **TJ-09**
REV.
SCALE 1:1
SHEET 9 OF 14



UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
DIMENSIONAL TOLERANCES ARE:
.X ± .05
.XX ± .005
.XXX ± .0005
ANGULAR TOLERANCE IS:
X° ± 1°
DEBURR AND BREAK
SHARP EDGES .01

PROJECT NO.

CAL POLY
College of Engineering
Mechanical Engineering Department

APPROVALS	DATE
DRAWN **TISCHLER**	**9JUN2017**
CHECKED **GOLDSTEIN**	**9JUN2017**

MATERIAL
STEEL

FINISH

DESCRIPTION
TOP CONNECT TUBE

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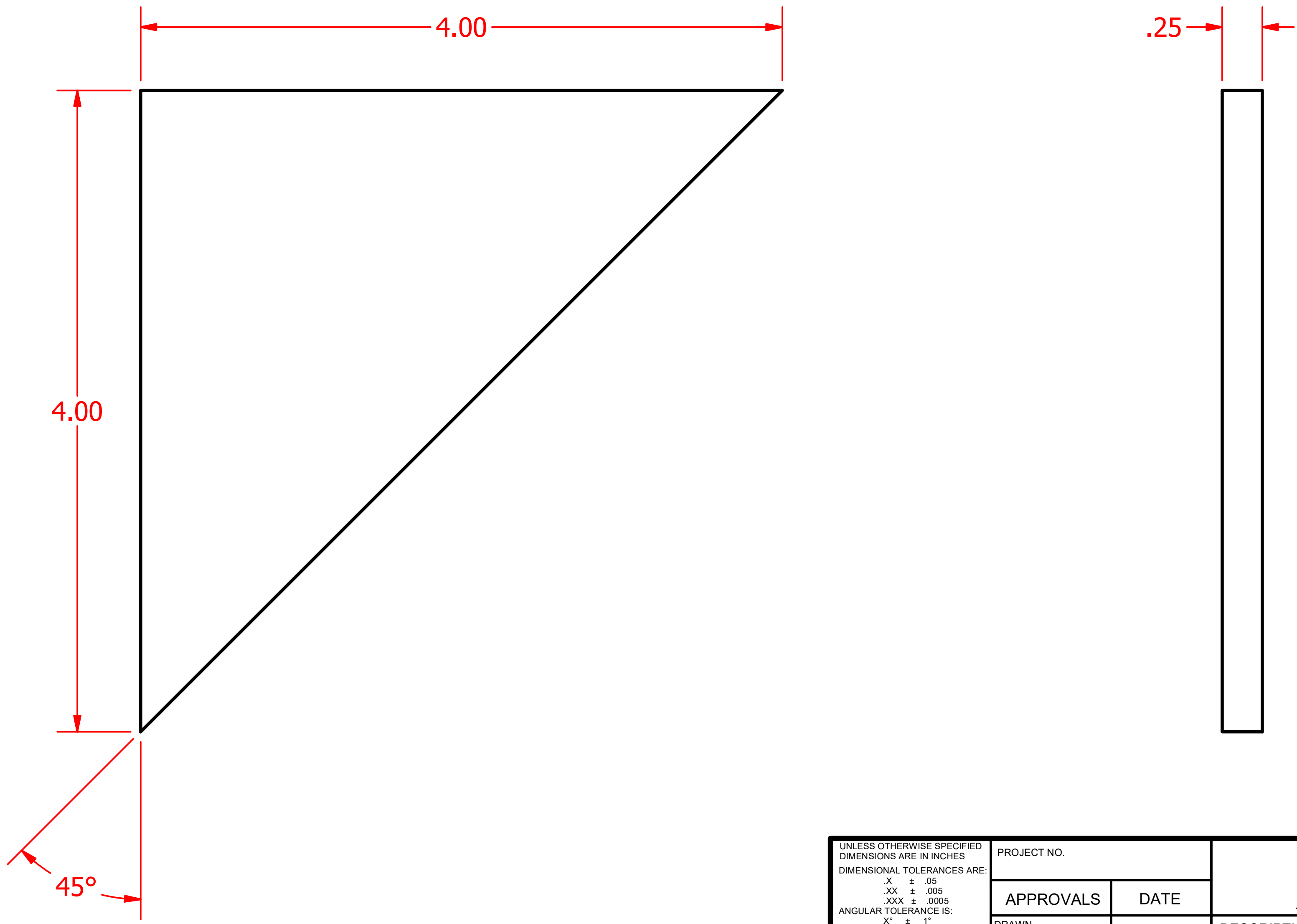
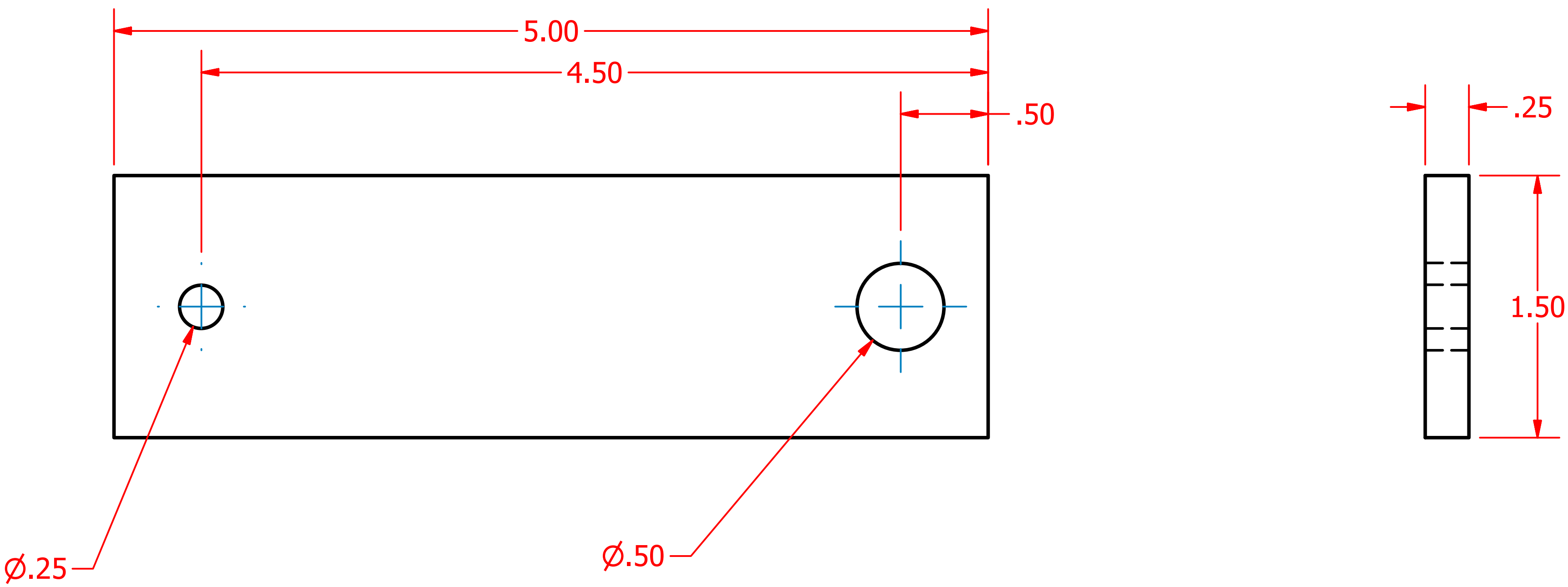
SIZE	DRAWING NO.	REV.
A	**TJ-10**	

SCALE 1:2

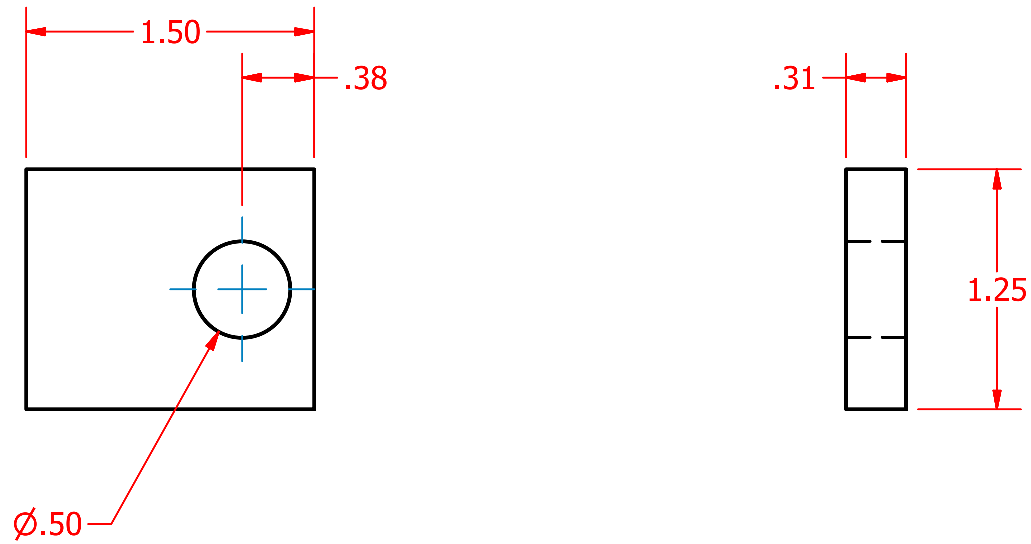
SHEET 10 OF 14



UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DIMENSIONAL TOLERANCES ARE: .X ± .05 .XX ± .005 .XXX ± .0005 ANGULAR TOLERANCE IS: X° ± 1° DEBURR AND BREAK SHARP EDGES .01	PROJECT NO.		CAL POLY College of Engineering Mechanical Engineering Department
	APPROVALS	DATE	
	DRAWN **TISCHLER**	**9JUN2017**	DESCRIPTION **TRIANGLE GUSSET**
MATERIAL **STEEL**	CHECKED **GOLDSTEIN**	**9JUN2017**	
FINISH	CONFIDENTIAL The information contained within this drawing is proprietary to Team Black Gold and shall not be disclosed without prior written consent of Black Gold executive officers.		SIZE: A	DRAWING NO.: **TJ-11**	REV.: SCALE: 1:1	SHEET 11 OF 14



UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DIMENSIONAL TOLERANCES ARE: .X ± .05 .XX ± .005 .XXX ± .0005 ANGULAR TOLERANCE IS: X° ± 1° DEBURR AND BREAK SHARP EDGES .01	PROJECT NO.		CAL POLY College of Engineering Mechanical Engineering Department	
	APPROVALS	DATE		
	DRAWN **TISCHLER**	**9JUN2017**	DESCRIPTION **SHOCK LINK**	
MATERIAL **STEEL**	CHECKED **GOLDSTEIN**	**9JUN2017**		
FINISH	CONFIDENTIAL The information contained within this drawing is proprietary to Team Black Gold and shall not be disclosed without prior written consent of Black Gold executive officers.		SIZE A | DRAWING NO. **TJ-12**	REV.
			SCALE 1:1	SHEET 12 OF 14



UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
DIMENSIONAL TOLERANCES ARE:
.X ± .05
.XX ± .005
.XXX ± .0005
ANGULAR TOLERANCE IS:
X° ± 1°
DEBURR AND BREAK
SHARP EDGES .01

PROJECT NO.

CAL POLY
College of Engineering
Mechanical Engineering Department

APPROVALS	DATE
DRAWN **TISCHLER**	**9JUN2017**
CHECKED **GOLDSTEIN**	**9JUN2017**

MATERIAL
STEEL

FINISH

DESCRIPTION
UPPER INSTRON GRIP

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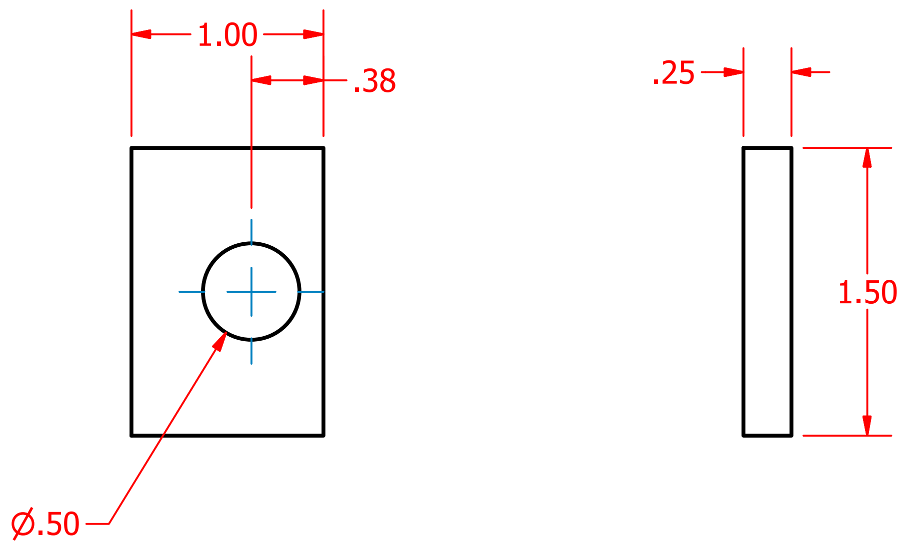
SIZE	DRAWING NO.	REV.
A	**TJ-13**	

SCALE 1:1
SHEET 13 OF 14



UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DIMENSIONAL TOLERANCES ARE: .X ± .05 .XX ± .005 .XXX ± .0005 ANGULAR TOLERANCE IS: X° ± 1° DEBURR AND BREAK SHARP EDGES .01	PROJECT NO.		CAL POLY College of Engineering Mechanical Engineering Department
	APPROVALS	DATE	
	DRAWN **TISCHLER**	**9JUN2017**	DESCRIPTION **INSTRON MOUNT** UPPER PIVOT
MATERIAL **STEEL**	CHECKED **GOLDSTEIN**	**9JUN2017**	
FINISH	CONFIDENTIAL The information contained within this drawing is proprietary to Team Black Gold and shall not be disclosed without prior written consent of Black Gold executive officers.		SIZE A · DRAWING NO. **TJ-14** · REV. SCALE 1:1 · SHEET 14 OF 14