Senior Project Report

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Cable Drag Test System

Sponsored by:

Specialized Bicycle Components, Inc.

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Statement of Disclaimer

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Chapter 1. Introduction

The Smooth Shifters is a team composed of Alex Powers, Brandon Roy Sadiarin, George Rodriguez, and Torey Kruisheer. We are four senior mechanical engineering students at California Polytechnic State University (Cal Poly) in San Luis Obispo, California that are working on a senior design project for Specialized Bicycle Components, Inc. located in Morgan Hill, California. We will be under the advisement of Professor Sarah T. Harding of the mechanical engineering department at Cal Poly.

Specialized, one of today's leading bicycle companies, is in need of a test setup that measures brake and shifter cable drag. High performance cyclists using time trial, triathlon, and aero bikes are constantly looking for ways to have as much aerodynamic advantage as possible, paired with a low profile look on their bicycles. To address these issues, bicycle companies have started a new trend of routing cables inside of the bicycle frames, rather than running them outside the frames. Unfortunately, routing a cable through a bicycle's frame causes additional cable drag which ultimately decreases shifting and braking performance. Specialized has requested a test setup that can be used to determine cable drag in any cable configuration prior to the fabrication of a physical prototype.

The goals of this project are:

1. To create a physical system to accurately mimic cable routing of a Specialized Tarmac bicycle frame and a comparative tool to measure the cable drag in competing systems.
2. To create a simulation environment which allows a user to build a cable system to check performance without a physical test apparatus. A database of different routing systems and components can then be built up over time for continuous use with different frames.

The purpose of the test is to save time and money, by testing and quantifying cable drag before a physical prototype is put into production. This test setup will allow for changes in frame geometry to be made, and will allow the corresponding shifter cable drag to be compared.

Chapter 2. Background

In order to understand the task at hand, we first had to research cable drag itself, its contributing factors, and why it is important to analyze. Physically, cable drag occurs when a cable is routed in such a way that the output force at the end of the cable is less than if the cable was routed in a more direct manner. This leads to less precise shifting, as well as less braking power for a given applied force. The specific causes of cable drag may be attributed to the various types of cable systems, the group set hardware they are used with, and the numerous contact points that are inherent in routing a cable both internally or externally. The following paragraphs are a summary of the key details of our research.

Cables and Related Hardware

The first stage of background research involved determining the different types of cable systems, as well as their associated hardware. This step was taken in order to familiarize ourselves with the various components that our end product will use, and to understand how each component contributes to the overall performance of the cable systems. The cable systems that our end product will test can be broken into two different types: brake cable systems and shifter cable systems. These can be differentiated through their structure, size, and housing differences.

Cable Size, Structure and Housing Differences

Brake cables are typically thicker than shifter/derailleur cables. Brake cables have diameters that range from 1.5 to 1.6 millimeters, while shifter cables have diameters that are typically 1.1 or 1.2 millimeters [1]. The differences in size can be seen in Figure 1.

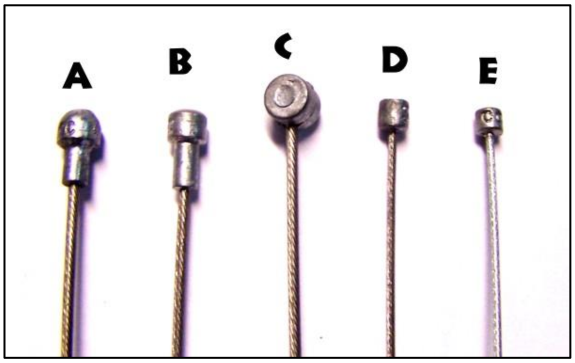

Figure 1. Various types of bicycle cable systems

In Figure 1, a typical brake cable system is labeled A, while a typical shifter cable system is labeled D. Size differences are due to the application for each type of cable system. This is related to the amount of tension needed for each type of cable system. Brake cable systems need to be stiffer and stronger in order to be able to produce more power during operation. Shifter cable systems can be more compliant, in order to have “compressionless” effects that enable riders to have crisp shifting. Differences in cable system structure can be seen in Figure 2. Due to the differences in the operation of the two types of cable systems, brake cable systems experience larger forces than shifter cable systems. This directly affects our end product, as we will have to use different benchmarks when measuring brake cable force versus measuring shifter cable force.

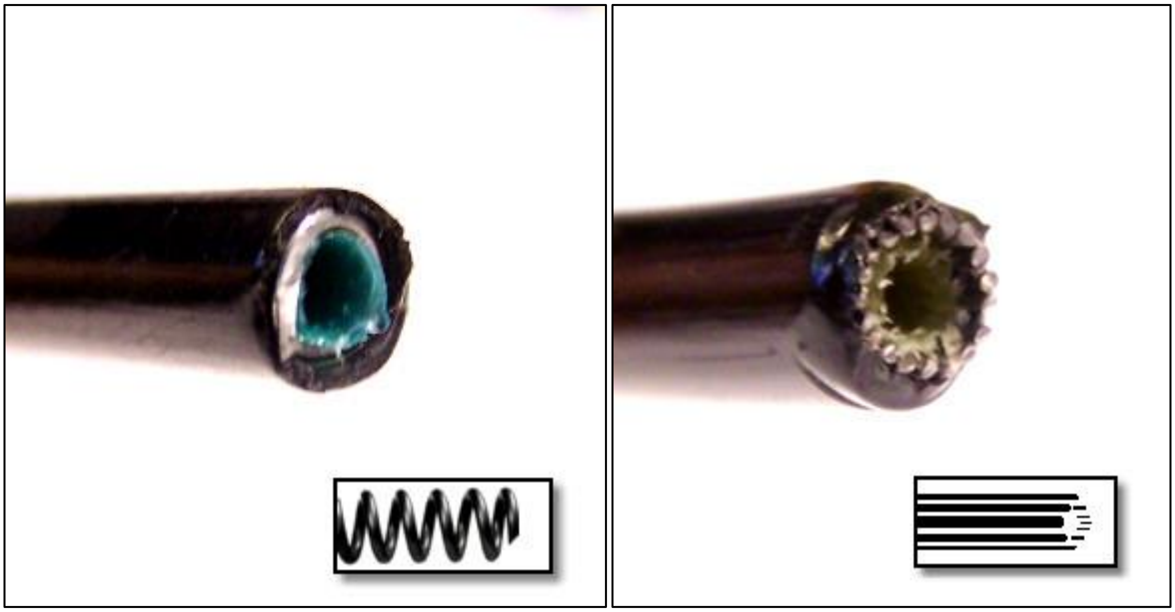

Figure 2. Internal structures of brake and shifter cable systems, respectively

Patents and Similar Existing Systems

The second stage of our background research involved patent searches of existing internally routed cable systems, as well as existing cable force measurement devices and methods. We researched patents in order to see what similar systems and solutions already exist, and to evaluate their methods of solving the problem. This is important because it allows us to have some sort of standard or base for developing ideas that will lead us towards a solution. Although we cannot directly copy the patents' assemblies and technologies, we are able to generate ideas easier from this initial patent research rather than starting from complete scratch. A patent search also shows the state of prior art to ensure our design is not infringing on any existing patents. For the purpose of this document, we will focus on existing systems that utilize at least one of the intended functions that our end product will have, such as force measurement.

Verizon Patent and Licensing, Inc.

In order to install fiber optic cables through ducts, Verizon uses a method called blow-in, or cable jetting [2]. For effective installation, the cable must meet specific requirements. Verizon has developed an apparatus that measures a bending and kink force associated with a cable when it is subject to a bend/kink. A diagram of the apparatus can be seen in Figure 3.

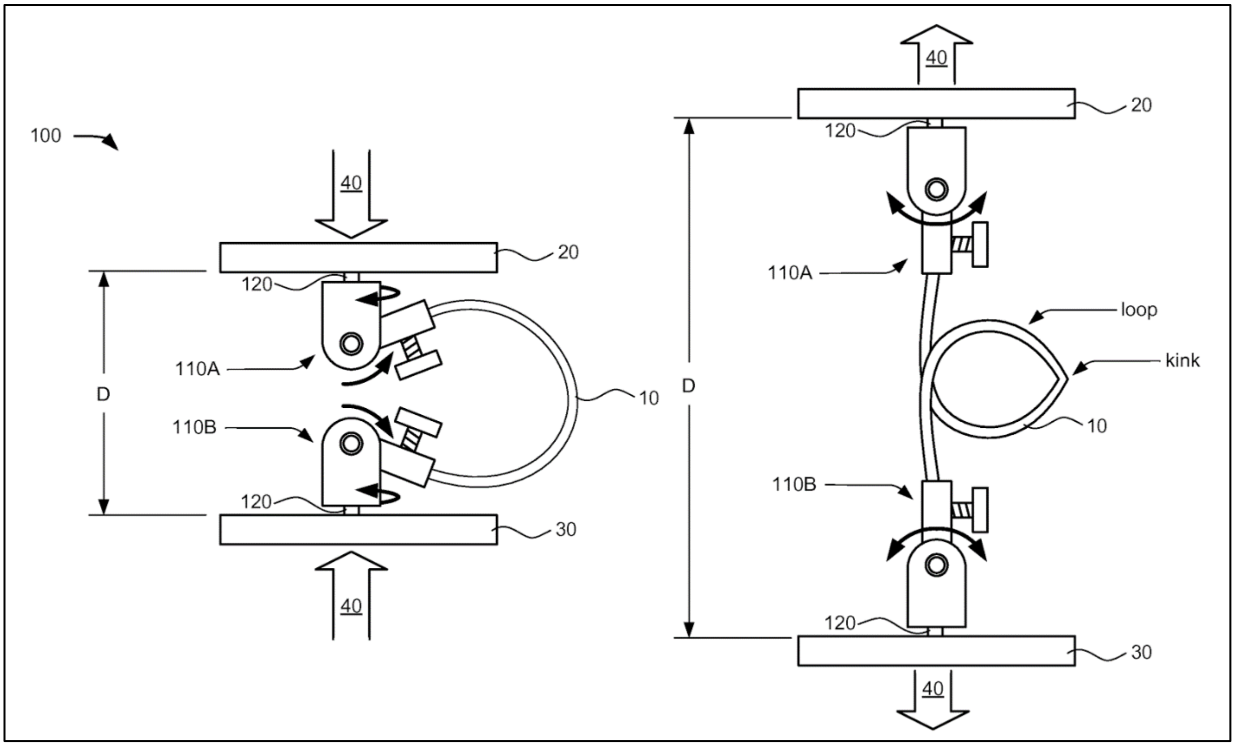

Figure 3. Test apparatus for measuring bending and kink forces in cables

We have made observations on Verizon’s patent, and have found aspects of the design that we would like to include in our design, as well as things that could be improved upon. Due to the nature of patents, we could not identify the true size of Verizon’s test apparatus; however, we noticed that the test apparatus is only capable of testing a small length of cable. Our system will need to be capable of testing a much larger test configuration.

What we did like about this test apparatus is its ability to measure a cable’s force when a bend is present. We would like to be able to expand on that ability so that our end product is able to measure forces when multiple bends exist within the test cable. We are primarily concerned with accurate simulation in our test system.

Cable Tension Tester

Another patent that we looked into describes an apparatus specifically for testing cable tension in brake cables [3].This apparatus tests cables that are subjected to various input tensions. It includes a comparator which compares the measured tensions in the test cables to reference tension values. A detailed drawing of the apparatus can be seen in Figure 4.

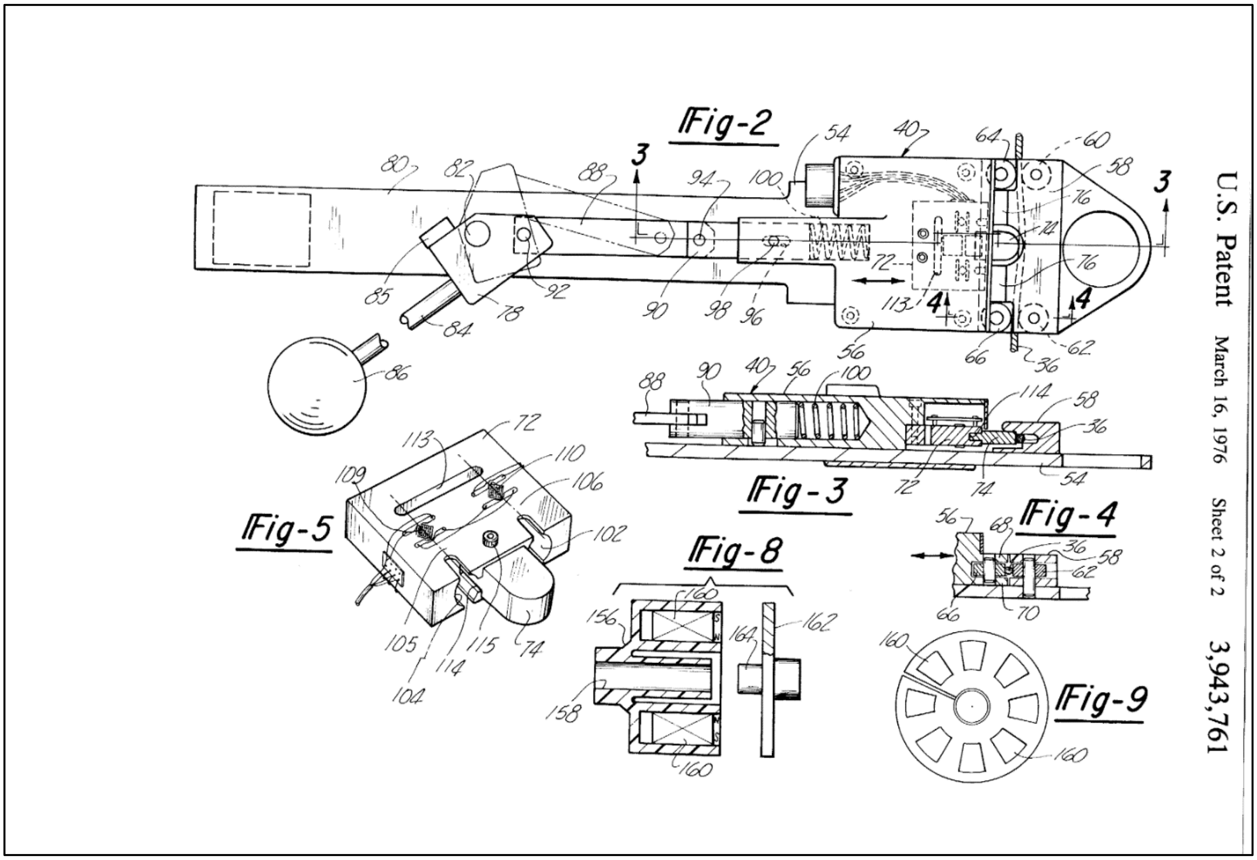

Figure 4. Representation of a cable tension tester

The ability to input various tension forces in this design directly correlates with the need for our end product to be modular and reconfigurable. However, this cable tension tester only operates with lateral displacement and does not take into account displacement in three dimensions. Our end product needs to be able to have measurements in all three dimensions, and account for both linear and radial movements.

Cable-Conduit System Model

A paper published in the Institute of Electrical and Electronic Engineers' Transactions on Robotics provides a detailed model of cable-conduit interactions based on cable curvature, tension, and nonlinear friction [4]. The mathematical model developed in this paper is given by a set of partial differential equations that can be solved to determine the precise motion and tension transmission in a cable-conduit system. This is directly applicable to the simulation portion of this project. The mathematical models developed by Agrawal, Peine, and Yao are a possible method of force analysis, which could be used for input into the computer simulation.

The model was verified by experimental results from a test set up that is not all that different from a routing configuration on a bicycle. The experiment included a tensioned cable, a conduit, and cable curvature; all of which are key factors in realistically modeling cable routing configurations seen on a bicycle.

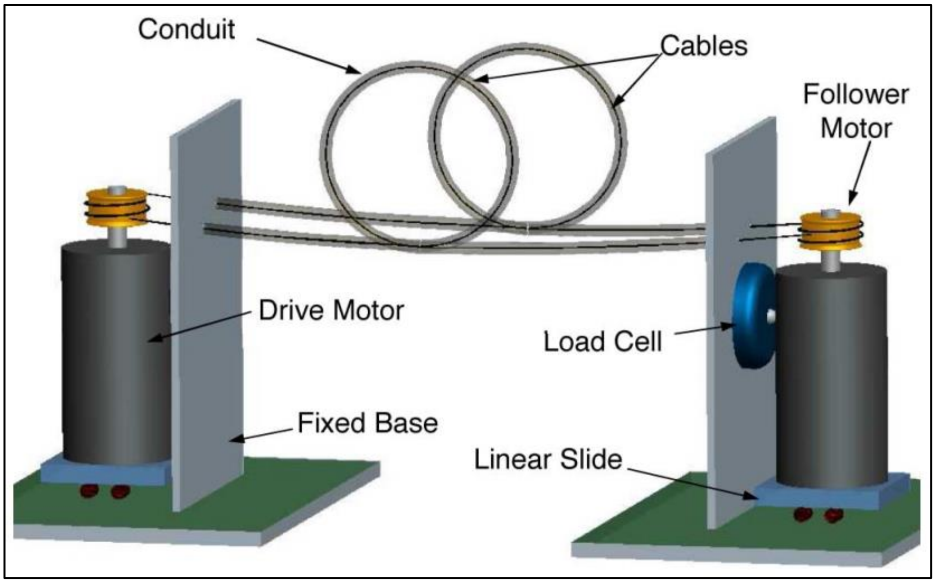

Figure 5. Experimental test to model transmission characteristics across a cable-conduit system

Components That Contribute to Cable Drag

Further research showed how numerous components contribute to cable drag. After speaking with bicycle technicians, we discovered that tight bend radii, such as those in the handlebars, reduce the performance of the cables. Furthermore, we discovered that the various components that are in contact with the cables contribute to the overall cable drag. These components include the following: bosses, stops, donuts, dropout guides, bottom bracket guides, command posts, and other cables.

Bosses:

Bosses are holes, built into the frame that allow the cables to be guided into the frame. Figure 6 demonstrates how the positioning of the bosses affect the angle at which the cables enter, therefore affect the bend radii, oftentimes paired with cable on frame rubbing [5].


Figure 6. Boss in the bicycle frame

Stops:

Stops are used in conjunction with bosses, leading the cable into the bicycle frame and preventing external dirt or objects out of the frame. Internally Routed Cable (ICR) stops fill the gap that occurs between the bosses in the frame and the cables themselves. As seen in Figure 7, ICR stops contribute to the total drag experienced by the cable, as they house the cable and add to hindered performance [6].

Figure 7. Internal Cable Routing Stops

Donuts:

Donuts are rubber pieces inside the top tube of the frame that hold the cables in place, thus reducing the rattling of the cable within the tube. These donuts come in direct contact with the cables, as seen in Figure 8 which shows donuts that are representative of what could be seen within the top tube [7].

Figure 8. Rubber donuts around the cable

Dropout Guide:

The dropout tube, located at the point where the seat stay, chain stay, and dropout come together, helps guide the cable from the internal portion of the chain stay over the dropout. Figure 9 depicts a portion of a dropout guide easing the cable over the dropout and eventually to the rear derailleur [8].

Figure 9. Rear dropout and dropout guide

Bottom Bracket Guide:

The bottom bracket guides, used to positon the shifter cables along the bottom bracket, come in contact with both the front and rear shifter cables. As demonstrated in Figure 10, the bottom bracket guides rub on the cables while the bottom bracket itself adds additional curve in the cables [9].

Figure 10. Example bottom bracket guide

Command Post:

The command post is an adjustable seat post, with a corresponding remote-actuated saddle positioning system. The command post allows the rider to easily change the seat height, but requires another cable routed to the component. Figure 11 shows the geometry a command post cable must navigate through. The bend that the cable must take to get to the command post is tight and provides additional drag, much like the front derailleur [10].

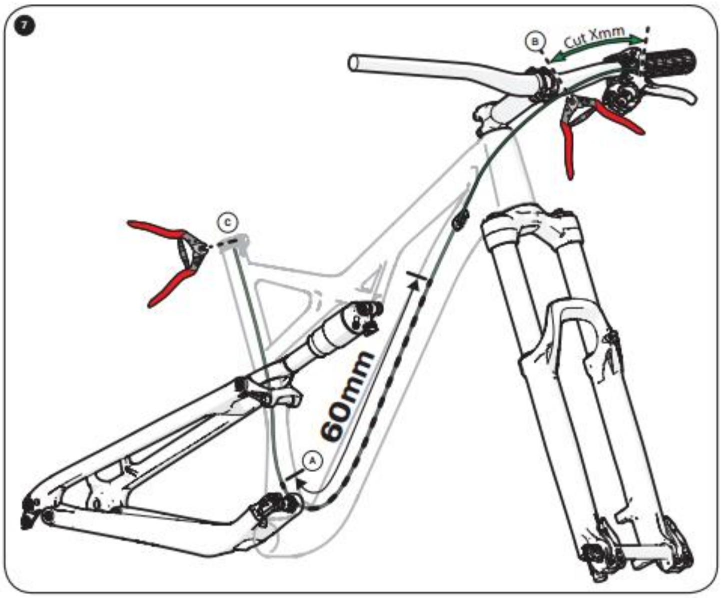

Figure 11. Cable routing necessary for command post actuation

Cable on cable interaction:

Cable on cable interaction causes additional drag and is often hard to prevent without adding additional components which will increase cable bend. Depending on rider preference, cables may be routed to cross each other to make smoother shifting, with less tight bends in the cable. Figure 12 shows the "California Cross", which crosses the cables both externally and internally within the down tube [11].

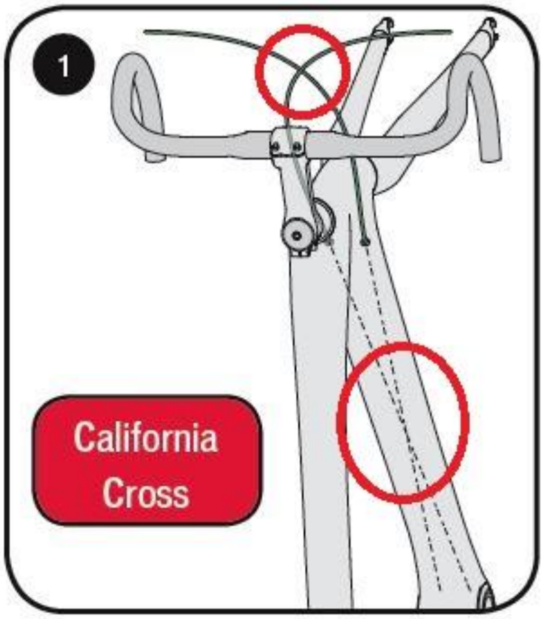

Figure 12. Implementation of the California Cross in a down tube

After more thorough research was conducted following the project proposal, more knowledge about what contributes to cable drag was acquired. This information can be seen above in the components list, which was used to identify crucial pieces necessary in our final design.

Group sets from bicycle component manufacturers comprise of different collections of mechanical parts, such as shifters, brakes, and derailleurs. The question regarding variations in group sets was proposed and further testing from our team proved that different brands and models of group sets, did in fact change the overall drag that a system encountered.

Currently, Specialized has no way to efficiently evaluate drag and component wear in different cable configurations when routing cables through a bicycle frame. Specialized is able to design a frame and test different cable routing configurations; however, this requires creating and manufacturing a prototype, which is costly and time consuming. The Smooth Shifters seek to develop testing and simulation tools in order to analyze the performance of cable systems and related components prior to prototype production. The main design goals will be:

1. To create a physical system to accurate mimic cable routing of a Specialized Tarmac bicycle fame internally routed bicycle frame and a tool to measure the drag in the system.
2. To create a simulation environment which allows a user to build a cable system to check performance without a physical test apparatus. A database of different routing systems and components can then be built up over time for continuous use with different frames.

While a simulation environment would be very useful for the development of future designs, it is superseded in priority by the objective of the physical test setup and data acquisition system, thus may not be completed due to time constraints.

Quality Function Deployment (QFD) and a corresponding house of quality (Appendix A) were employed to find the relative importance of each requirement, based on existing products and customer needs. Subsequent engineering specifications with relative risk and compliance were determined and put into Tables 1 and 2. This section explains the house of quality and the decisions to be made moving forward.

The House of Quality

The house of quality has two main sections in the list of requirements: a section for the design Goal 1 requirements, and another section for the design Goal 2 requirements. The relationship symbols in the middle of the house correlate the engineering specifications with each customer need based on the strength of their relationship. Appendix A also outlines the meaning of each of these symbols. The left side of the house outlines the voice of each customer by rating each requirement based on specific needs.

For our analysis, we took only the opinion of Specialized into account when computing relative customer requirement weight because the final product is primarily in the interest of Specialized. The relative weight is a representation of the importance of that specific requirement. It takes the assigned ranking of the customer requirement and divides by the sum of all rankings.

The right side contains existing products and our evaluation of how well they meet each customer requirement. This was done to compare our final product with currently available solutions and find areas for improvement. The bottom contains the target values for the specifications and each relative weight. The technical importance is used to determine the relative weight of each engineering specification. It is computed by summing the product of the relative weight of the customer requirement with each relationship symbol weight.

The following tables list each engineering specification along with its requirement or target to be met, how that target is to be met (maximum, minimum, etc.), the risk (high, medium, or low), and the compliance. The compliance includes how each specification will be determined sufficient. Listed is any combination of A (analysis), T (testing), I (inspection), and S (similarity to existing products).

Table 1. Engineering specifications for test device

Spec. #	Parameter Description	Requirement or Target	Tolerance	Risk	Compliance
1	Size	3 ft. x 4 ft.	Max	M	A, I
2	Weight	N/A	Max	M	A,I
3	Bend Radius Tolerance	1mm	Max	M	A,T
4	Time to Perform One Test	30 minutes	Max	L	T
5	Number of Runs Before Recalibration	50	Min	M	T, A
6	Time to Learn How to Use	1 Hour	Max	L	T
7	Measurement Resolution	1 N	Max	H	A, T

Table 2. Engineering Specifications for Simulation Environment

Spec. #	Parameter Description	Requirement or Target	Tolerance	Risk	Compliance
1	Computation Time for One Run	1.5 Minutes	Max	L	T, I
2	Expandable Libraries from Test Data	Y/N	Min	H	I, T
3	Time to Create Set-up in GUI	5 Minutes	Max	M	I, T, S

Physical Specification Parameters

The maximum size parameter was modified knowing that the setup needs to be large enough to model a range of frame sizes. The Preliminary Design Report (PDR) size specification of 6 ft. x 4 ft. has since been altered to better accommodate the setup of the final design. Taking the largest Specialized wheel base dimension of 61 inches, and adding an additional 10%, the base length was found to be approximately four feet long. The height parameter was set to three feet to accommodate the frame geometry of the Tarmac, making the necessary dimensions approximately 4 ft. x 3 ft. Initially a weight parameter of 200 lb_f was set for the table, but this specification has also changed. A ferrous table that Specialized already has in house will be used in lieu of the metal plate, therefore the weight parameter is not of importance. An initial bend radius tolerance of three millimeters to recreate cable drag was set up after consulting bicycle mechanics, but further discussion with our sponsor yielded a positioning tolerance of one millimeter, to accurately represent the bends in the cables and the effect that these bends had on the total cable drag.

Operation Parameters

After interviewing mechanics at a local bicycle shop, we found that it could take anywhere between five and thirty minutes to internally reroute cables on a bicycle. Alternatively, after routing a frame ourselves and taking upwards of an hour to complete the job, we quickly realized the intricate geometries the frame provides. Off hand, we ran into the issue of feeding the cable through the handlebars when each cable had to take a specific route, independent of one another and the cables would often interfere with each other. With this information, we made the specification for time to perform one test thirty minutes to ensure the geometries are accurately portrayed. Because accuracy was deemed integral for this test setup, the number of runs before recalibration was an important parameter. We wanted an accurate setup that would perform a number of tests before recalibration was necessary and fifty runs was decidedly sufficient. This test setup needed to be intuitive and user friendly to people with some background on bicycle cable routing. Though it should be intuitive, there will likely be multiple components that would need extra background and information before becoming proficient in using the setup. All things considered, we made one hour to learn a reasonable amount of time to acquire the knowledge necessary to operate the test device.

Performance Parameters

An issue that we found pressing was the accuracy of the testing's readings, as the tension loads experienced by bicycle cables are very small. Specialized has requested to have a measurement resolution of one Newton.

Simulation Parameters

Following our Preliminary Design Report, the scope of the project has continued to change. Though the simulation is still a possibility at the close of the project, the physical test setup is of paramount importance. The computation time for one run was determined based on the amount of time that the test would take as a whole, and a reasonable amount of time to wait solely on computation was one and a half minutes. Specialized has requested a way to collect and store data in order to use it for future purposes. We decided that this feature would need to be integrated into the simulation. The amount of time that it would take to set up the graphical user interface (GUI) was set at five minutes, as we wanted the simulation to be intuitive and eliminate the need for the physical test setup.

Chapter 3. Design Development

After deciding that the final design would require multiple subsystems to be successful, the first ideation session was run, implementing a morphological matrix. The morphological matrix allowed for countless subsystem options to be combined to create a final product. Different ways of attaching fixtures to the base, accurately recreating 3-D cable geometry, and various ways of measuring force were listed individually in the morphological matrix. The various columns focused on each problem individually. Going through each column, many different possibilities can be paired together to get a design with unique characteristics. Knowing that tight bend radii heavily contribute to cable drag, accurate cable routing recreation is an important factor for design. One option that resulted from this session was using cones to vary the bed radii. The cones give a wide range of radii, which can recreate very subtle curves, or very tight turns. The force measurement ideation resulted in ideas such as using linear force gauges, torsional measurement, strain gauges, or three-point digital gauges. Though the morphological matrix method gave many possible results and got the group thinking creatively, many of the ideas paired together were not feasible.

After the morphological matrix, brainwriting was implemented. Mainly focusing on how the force should be measured, each team member had a piece of paper, and wrote down ideas for measuring the force and then was passed to the next member, who could further expand upon it. This method allowed for the development of different ideas to find the most accurate measurement of the force. This also lead to further research to find the range of resolution that would be needed for measuring shifting and braking force.

The idea generation phase lead us to break up the design process into multiple facets in order to compare subsystems of the design.

Decision Matrices

The final product's components were split into four main subsystems: *fixture base*, *fixture connection*, *measurement system*, and *position control*. Each of the four subsystems received their own decision matrix with multiple solutions to the problem. These matrices are shown in full detail in Appendix A.

Each solution was weighed against the criteria of modularity, ease of use, machinability, set-up time, cost, lead time, location resolution, and stability.

Starting with the fixture base, the datum was set with a horizontal magnetic base. Horizontal peg hole and slider bases were considered, but each fell short of the magnetic base in modularity and location resolution. Vertical orientation of the base was also considered, with a vertical grate and magnetic vertical grate. The vertically oriented bases did not score as well as the horizontal magnetic base in machinability or ease of use.

After evaluating the concepts of the base, fixture connections were evaluated, with a dovetail connection as the datum. Judged off the same criteria as above, magnetic, slots, suction cups, and a chuck were weighed against the dovetail connection. Magnets scored the highest in the fact that setup time and location resolution performed better than the other datum. Slots ended up being a viable option as they are easy to use and comparable to the dovetail in the other criteria. Suction cups on the other hand did not offer great location resolution or stability, making them a less reliable option for fixture connection. Lastly, the chuck scored high for modularity, but did not offer a lot in terms of machinability or cost efficiency.

Using the linear force gauge as the datum, a digital torque measurement, a 3-Point digital scale, a strain gauge, linear spring deflection, and torsional spring deflection were weighed against each other to see the pros and cons of each force measurement choice. The digital torque measurement scored low in the set-up time and measurement resolution criteria, while the 3-Point digital gauge was in line with the linear force gauge for all criteria. The strain gauge seemed like the least viable option at the completion of the decision matrix. The strain gauge did not offer a lot of modularity, ease of use, or high measurement resolution in comparison to the linear force gauge. The torsional and linear spring deflection methods scored high in the cost criteria, but suffered in other categories such as ease of use and measurement resolution.

The position control decision matrix was used to determine how the fixtures would be kept in position once they were placed on the base. Set screws were set as the datum and grid lines, lead screws, rack and pinion, ball screws, linear actuators, and turntables were each weighed against the set screws. Grid lines scored highest, as they are easy to use, easily machined, and can be used quickly. Lead screws, rack and pinion, ball screws, linear actuators, and turntables each scored worse that the set screws. Lead screws were not cost effective or easy to use, while rack and pinion and ball screws offered a high measurement resolution but at a high cost. Linear actuators scored low for cost effectiveness and manufacture time. Turntables on the other hand did not offer the greatest cost effectiveness, but was in line with the set screws in all other criteria.

Some initial ideas and their drawings that came out of ideation are included as Appendix A.

Preliminary Top Concepts

From our Preliminary Design Report, each subsystem decision matrix was used in pairwise comparison in finding many solutions to the problem. Though each subsystem decision matrix yielded a highest scoring concept, when pairing it with other subsystems, oftentimes the highest scorer was not the best for the entire concept. For example, the horizontal peg hole resulted in the highest score for the base, but paired with the highest scoring fixture connector, magnets, was not an effective solution. Multiple options paired together gave feasible solutions, such as the horizontal magnetic base, with magnetic connection fixtures, grid line positioning, and a linear force gauge. This pairing offers modularity, a quick setup time, and a reliable positioning resolution.

The exercise in creating each decision matrix mentioned previously resulted in a concept of what the final test set up looked like at the close of the Preliminary Design Report. A concept CAD model is shown below in Figure 13.

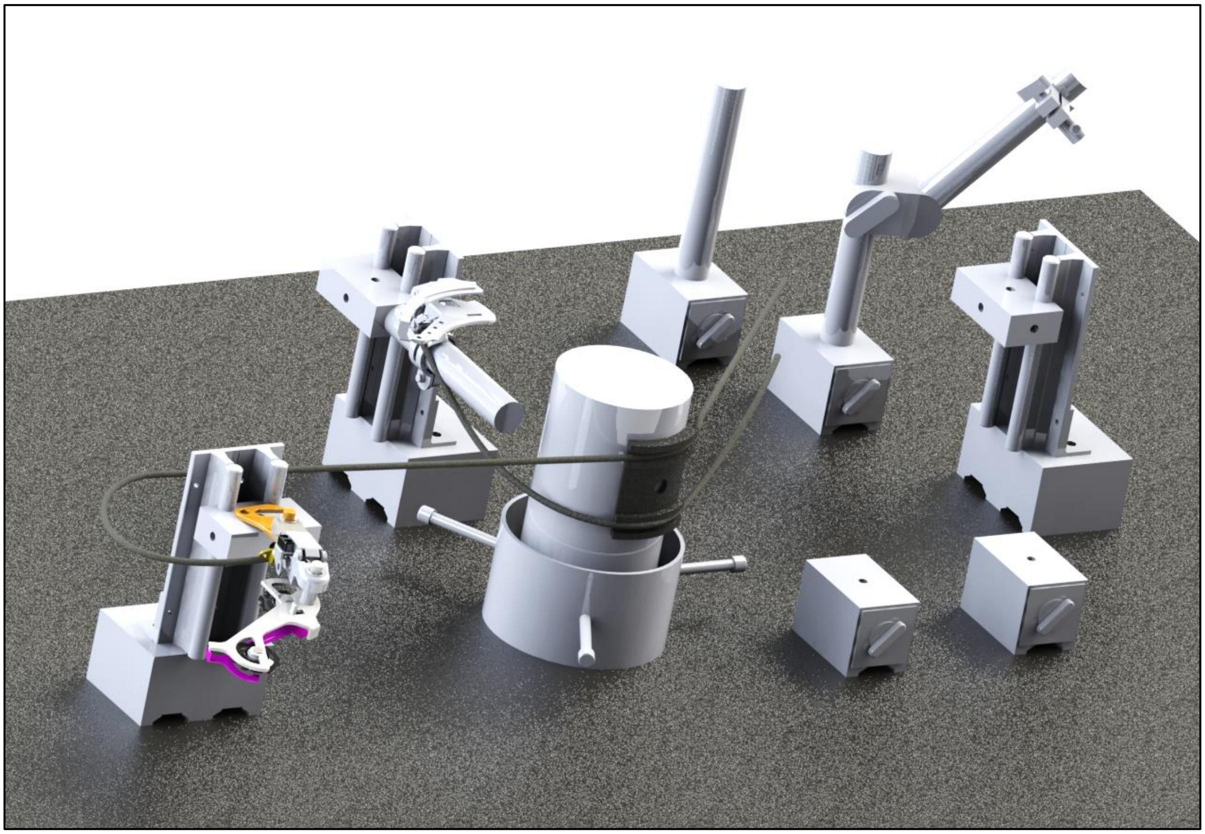

Figure 13. Preliminary CAD concept of test system, at the close of PDR

This model shows an example of what a test setup could look like with the discussed top concepts. The system includes modular fixtures for derailleurs, brakes, a bottom bracket guide, bosses, and basic cable guides all fixed to a metal base. The main top concept for the testing system is the culmination of all the decision matrices and ideation, and stems from a pairwise comparison method used to take the best concepts from each category and find the best solution. Our final concept here turned out to be a large horizontal sheet metal base with magnetic bases that can be mechanically turned on and off to fix all the components to the base. This magnetic base is shown below in Figures 14 [12] and 15 [13] and consists of two rails of iron on the outside with a strip of non-ferrous material in the middle to create a way to "switch off" the magnetism to allow for positioning. All other fixtures are attached to these bases with a set screw on the top of the base.

Figure 14. Picture of magnetic base to be used

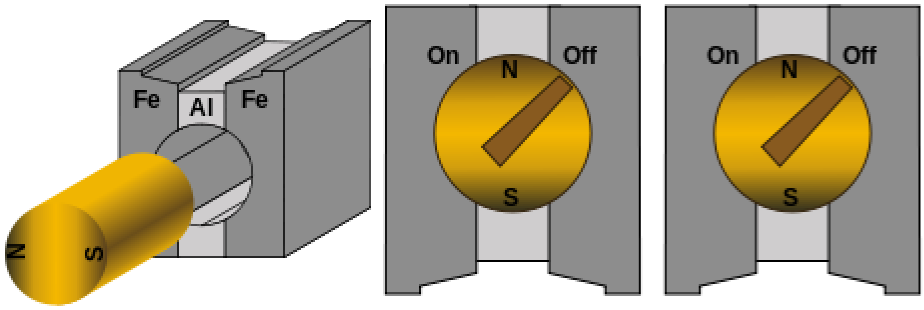

Figure 15. Diagram of magnetic base system

Bottom bracket sizes vary between bikes, and the bottom bracket guides need to guide two cables at the same radius. Our top concept for this fixture, shown in the assembly and below as Figure 16, is simply a thin walled cylinder with three set screws that can accommodate a variety of cylinder sizes to simulate different bottom brackets.

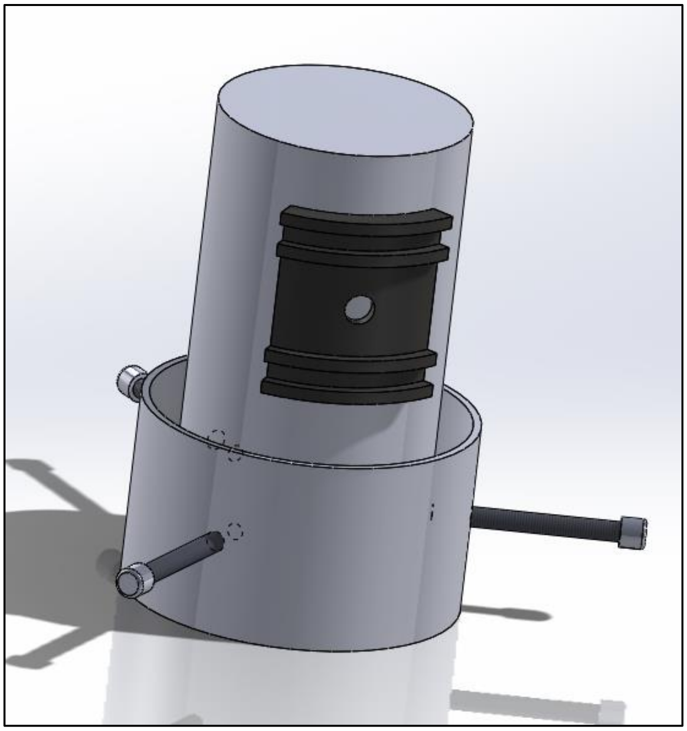

Figure 16. Bottom bracket mounting device

The fixture used to mount the derailleurs shown in the assembly above in Figure 13 will also be used to mount brakes and possibly other components if needed. It consists of two magnetic bases to accommodate two six inch beam rails (attached with brackets) with a sliding block fixture that will be fixed in place with set screws. The sliding block has multiple tapped M8x1.25 holes for mounting a variety of components. This fixture can be found below in Figure 17.

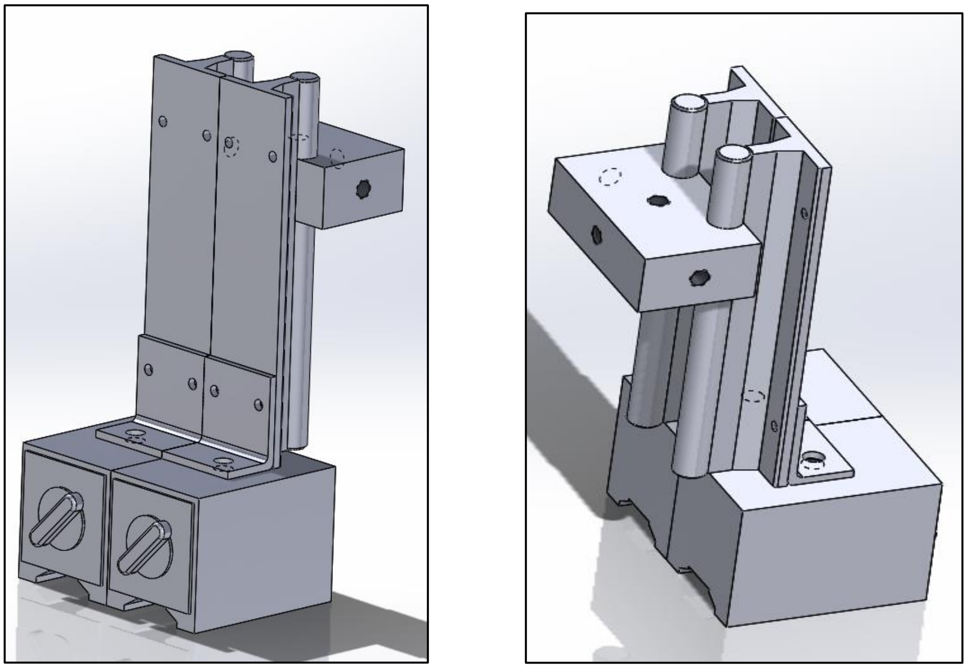

Figure 17. Modular linear rail slider fixture front (left) and back (right) views

Most bosses and eyelets will be fixed with a simple rod coming out of the magnetic bases to guide the cables, but at times this will need to be at an angle, so the last fixture shown below is a possible solution that uses clamps to secure one rod to another at a certain angle, if needed. This fixture is shown below as Figure 18 [14].

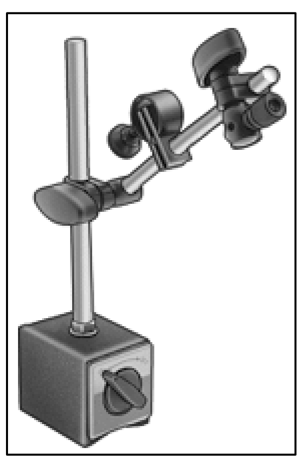

Figure 18. Magnetic base holder

Initial Technical Considerations

In evaluating the feasibility of the preliminary top concept shown in Figures 13-18 and its components, one must consider the loads that each of these cable drag contributing components will see during cable actuation. We know that these loads are fairly small in a static test set up when compared to riding loads. Knowing this fact, the concept of locating each fixture with the magnetic bases shown in Figure 14 is a feasible solution. Rated magnet pull loads, which are a measure of the force required to separate a magnet from a ferrous plate, are around 220 lb_f for the magnetic bases we have researched [12]. Appendix A includes a basic static analysis of a cantilevered magnet subject to an arbitrary load. This analysis shows that the coefficient of friction plays a large role in how much of the rated pull load will be achieved in a realistic application. However, steel on steel coefficients of friction, which is most likely the contact scenario for the magnetic base surfaces, are between 0.5 and 0.8 [15]. Even with this reduction in loading capacity from the rated pull force, the loading condition will still be smaller than allowable.

In addition to magnet stability, stiffness and stability of each component is important to hold the cable configuration in a position that is accurate of the routing geometry on an actual bike frame. Again, the loads seen by each component will be small and should not appreciably deflect our components.

Intermediate Designs

Testing, research, and additional analysis were performed on our top design following the Preliminary Design Review. While the four main subsystems: main base, fixture connections, force measurement, and position control were still considered, different design options were added to each category. The Preliminary Design main base option of a steel plate as the main base was eliminated when the weight and additional cost of a thick ferrous base was brought into consideration. A six foot long piece of 1/4" sheet steel did not seem like a very feasible design, thus a lower raw material cost and lower weight alternative needed to be chosen. Testing on the magnetic bases was also performed following PDR.

Single Magnetic Base to Dual Magnetic Base Redesign

Following PDR, we ordered a magnetic base from McMaster Carr to see if the rated load of 220 lb_f, would in fact hold. Using the vertical positioning pole that screws into the M8 tapped hole of the magnetic base, we used a fish scale to measure the necessary force to move the base from the steel plate. Unfortunately, this testing proved what we feared. Utilizing one magnetic base, we found the tipping force to be 12 lb_f about the weak axis, and 17 lb_f about the strong axis using a single magnetic base. The intended use for the magnetic bases is to position dial indicators; therefore, said bases do not perform well when a load is applied in the transverse direction. Both numbers were found with a lever arm of 10.5 inches, which is the most extreme height we expect a component to be mounted at. With this as our baseline, we measured the force that is required to actuate a derailleur and a brake. By attaching a fish scale to a cable, we found that the required shifting force was approximately 15 lb_f, while the braking force was 6 lb_f, respectively. These loads were clearly too large for the single base design to function properly.

With these results in mind, the notion of fortifying the magnetic bases came into play. Making each single base into a dual magnetic base design with a steel plate connecting the two was designed to increase stability. Flanges were welded onto the dual magnetic bases to increase stability in the weak axis. Taking this design to the machine shop, we created a prototype and performed additional testing.

While this performed better than the single magnetic base design, there were still stability issues. Welding the flanges to a perfect 90 degrees proved harder than anticipated, and as a result, the flanges actually did not add as much stability as we had hoped they would.

80/20 T-slot Design

Preliminary testing of the dual magnetic base design did not leave the team confident that they would allow for accurate fixture positioning without tipping or sliding. An 80/20 T-slot design was developed to achieve the goals and specifications of the project. With tipping and stiffness as main concerns, the T-slot offered a stable base to mount fixtures. The flexibility needed to recreate new frame geometries was also still present in this design. Figure 19, shown below, depicts the 80/20 T-slot design.

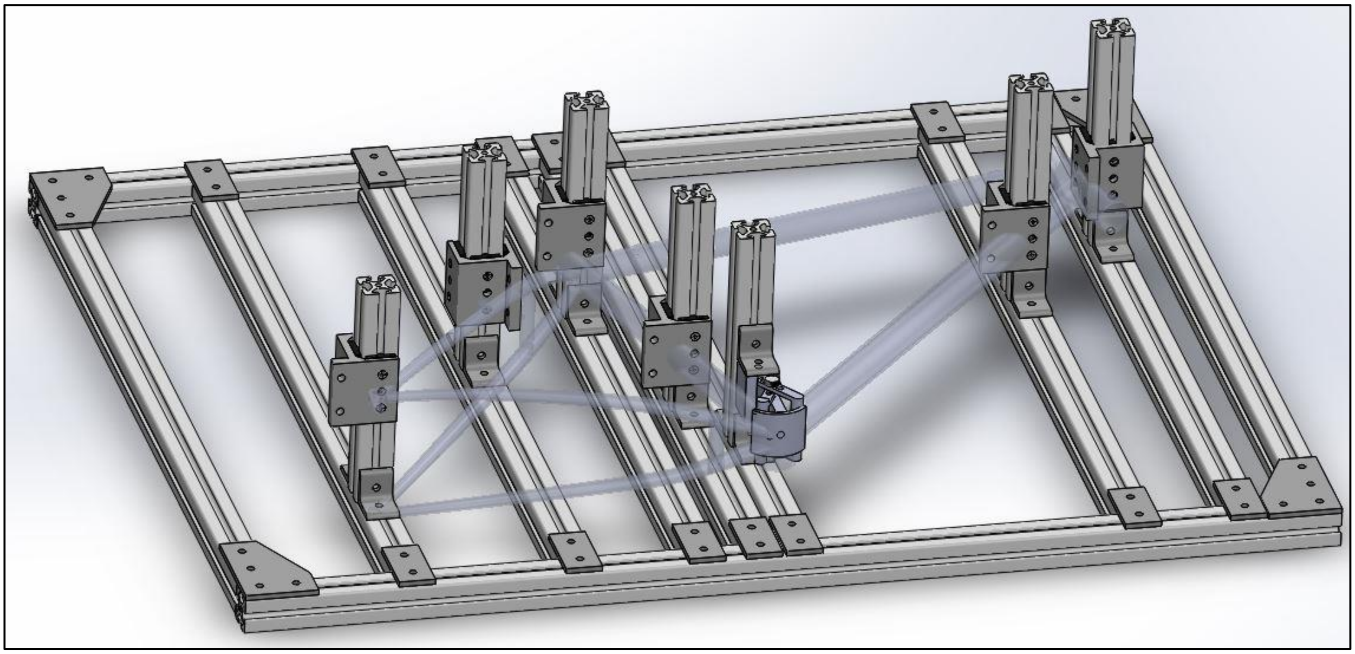

Figure 19. 80/20 T-slot design

The parallel rails would slide and be fixed in place using bolts to achieve any position in the x-direction. The vertical struts would slide along the parallel rails, allowing for movement in the y-direction, while the vertical component would give positional freedom in the z-direction. These three degrees of freedom offer the flexibility necessary to recreate varying frame geometry. Corresponding fixtures to recreate all the contact points on the bicycle frame were design to be mounted on the vertical struts and moved to accurately create the "frame". Custom lengths of 80/20 and all corresponding pieces could be ordered to for our specific design. With the pieces coming in to specifications, the 80/20 T-slot design would require no major manufacturing or machining.

After visiting Specialized and discussing both the magnetic base design and the T-slot design it was decided that magnetic bases would fit the needs of Specialized's test lab more closely. The main concerns regarding this design were the robustness and life span of the extruded aluminum T-sot. The aluminum T-slot was not seen as durable enough, as any drop hazard could possibly decommission the entire system. Additionally, the amount of necessary fasteners to keep each individual component in place was seen as a hindrance for the user. With these considerations in mind, we decided to put the 80/20 T-slot design on the backburner, as an alternative to the magnetic base design.

Rotary Potentiometer Positioning System

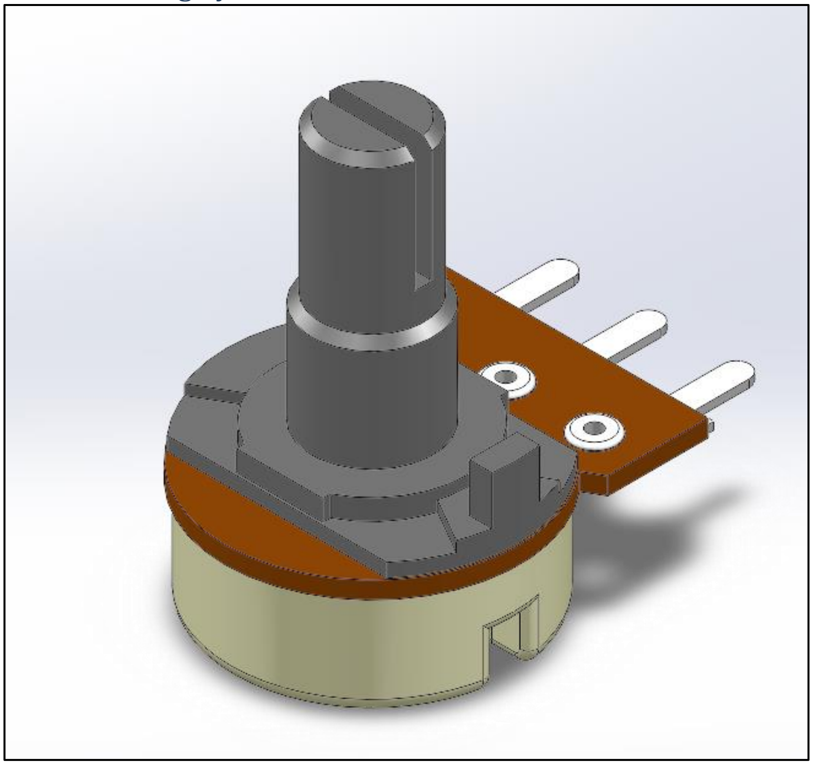

Figure 20. Rotary Potentiometer

Initial positioning plans using a rotary potentiometer, seen above in Figure 20, worked in theory, but in practice proved less than successful. Ideally, full XYZ coordinates could have been calculated from a known radial distance and height of an object, paired with an angular displacement of the potentiometer. A retractable clothes line was to be used to measure the radial length.

The potentiometer was expected to measure angular displacement. Since we need to have positional accuracy to within one millimeter, we knew that we can have an error of only 0.25 degrees. We were unable to get an accurate reading from the potentiometer as there was a dead zone at small angles. The potentiometer would not accurately register any angle less than 30°, making this positioning system inapplicable for a project where small angle changes were of the utmost importance. In addition to the accuracy of the rotary potentiometer itself came the issue of the locating with a string. Precisely lining the string up with the plate on the potentiometer was nearly impossible, and the point where the string was measuring to was not the same as the angle that the potentiometer was registering. With these issues, the rotary potentiometer option was ruled out for positioning.

Chapter 4. Description of Final Design

After preliminary testing, extensive research, and hands on troubleshooting with internal cable routing, we came to realize the difficulty associated with internally routed cables and the given intricacies. To accommodate these difficulties, our final design allows for modularity in order to accurately recreate a specified frame with unique geometry. Said design, seen below in Figure 21, employs dual magnetic bases and mounted vertical slide assemblies. These magnetic bases are mounted to a steel table that Specialized has in house in their testing lab. An inline load cell is used to measure the input tension while gear shift is performed by the test operator. This force is recorded using a Data Acquisition System (DAQ) and

LabVIEW software. The transient shifting force profile can be examined for various cable routing configurations and post processing this data allowed us to determine the relative cable "drag" in the system. The measured values were compared to a cable routing configuration known to have "good" cable drag. Cable drag, or friction, is largely a subjective phenomenon, but this test bed will allow Specialized to quantify drag before designing an entire bicycle frame. A complete drawing packet, comprising of all assembly drawings and detailed part drawings, can be found in Appendix B.

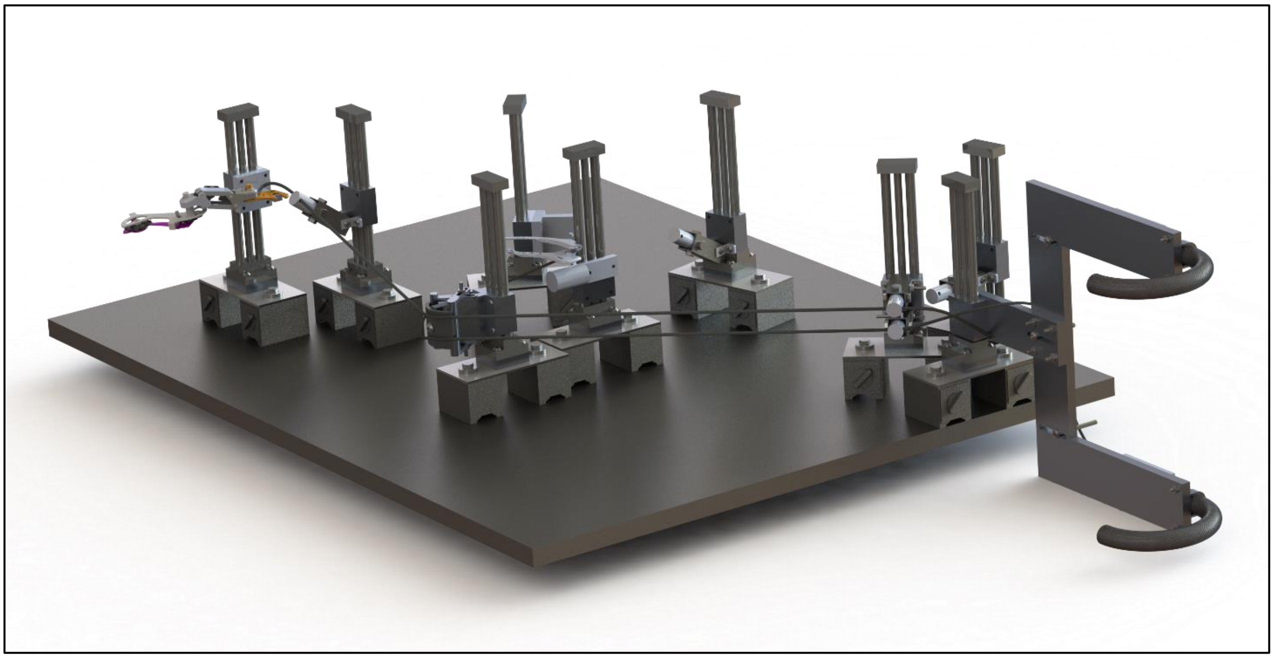

Figure 21. Final Design Layout

Main Base

The main base for the entire test set-up is a steel table located in the test lab at Specialized. The steel table has T-slots running along its length that can provide additional mounting or clamping options if needed. Additionally, a steel plate can be mounted to the current table used by Specialized if a cable configuration would require a magnetic base to be located where there is a T-slot. Using Specialized's thicker ferrous table will ensure that the full pull force of the dual magnetic bases is achieved.

Dual Magnetic Base and Vertical Slide

Dual magnetic bases, fortified with a steel connecting plate, are used to position hard points where a cable comes in contact with a frame component. Galvanized sheet steel and bolts screwed into the M8 holes on the top of the McMaster Carr magnetic bases offer increased stability. These dual magnetic bases also offer modularity as they can be positioned anywhere on the x-y plane of the steel table. Adjustment in the vertical, z-direction, can be achieved using manual vertical adjustment slides made by Generic Slides. The vertical slides are mounted to the connecting plate through a rotary plate [16]. The rotary plate fixes to the dual magnetic bases with a single screw through the bottom of the connecting plate. This allows rotation about the vertical axis so that the strong axis of the magnetic base can be aligned in a manner that favorably resists the tension force from the cable. The dual magnetic base, vertical slide, and rotary plate assembly is shown below in Figure 22.

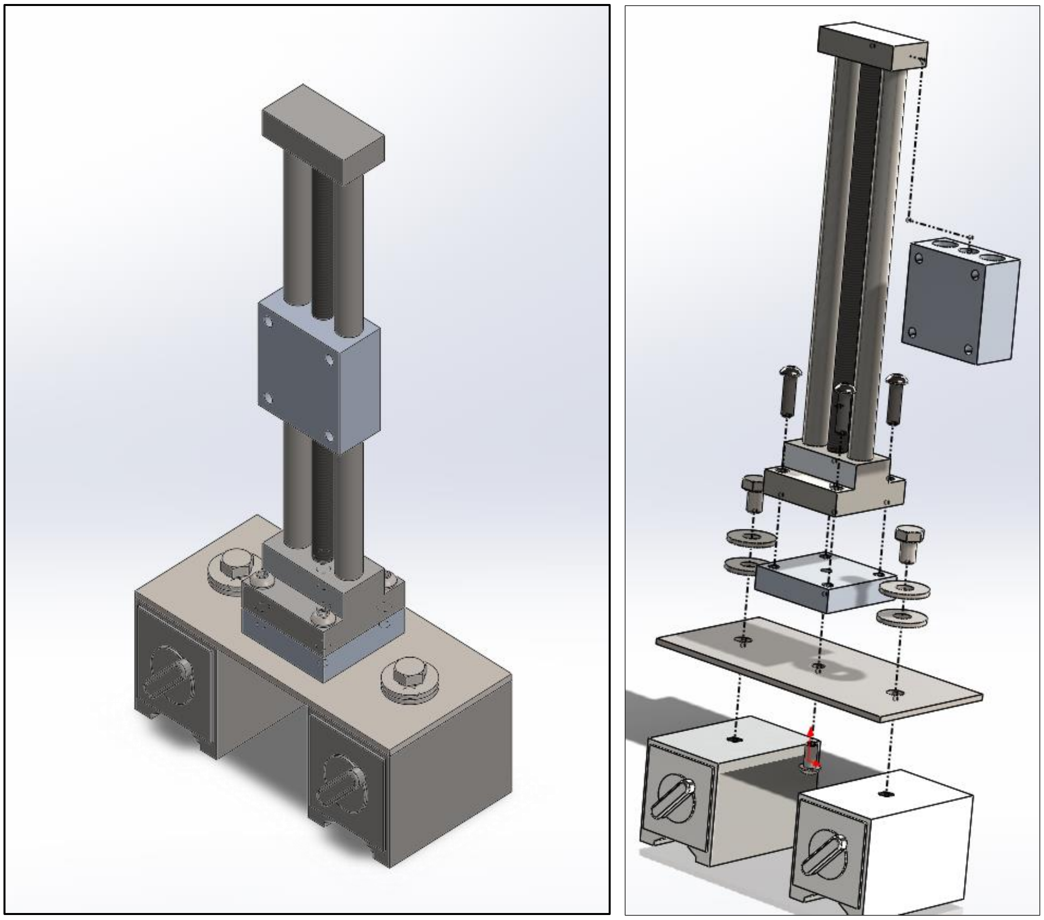

Figure 22. Dual magnetic base assembly with vertical slide and rotary plate

Magnetic bases offer reliable mounting and resist the loads necessary to shift. The magnetic bases offer quick adjustment as well, as the on/off switches make setting up the test a faster process.

With the maximum load applied to the vertical slide assemblies, a deflection of 0.75 millimeters can occur. The vertical slides allow for easy positioning and mounting.

Fixtures

As initial research proved, there are many points on the bicycle frame that the cable comes in contact with. These hard points were modeled in our design because they contribute to the overall cable drag in an actual system. Components are custom to allow for modularity and geometries that do not necessarily exist yet. For our design, we chose to focus on the main components to fix to the magnetic base assemblies: handlebar mounting, cable stopping points, bottom bracket guide, derailleurs, and brakes.

Handlebar Mimicking Fixture

The handlebar assembly designed to accommodate different handlebar geometries can be seen below in Figure 23. The assembly is comprised of bicycle handlebars, a plate, cable stop fixtures, a load cell fixture, and pin fixtures for positioning.

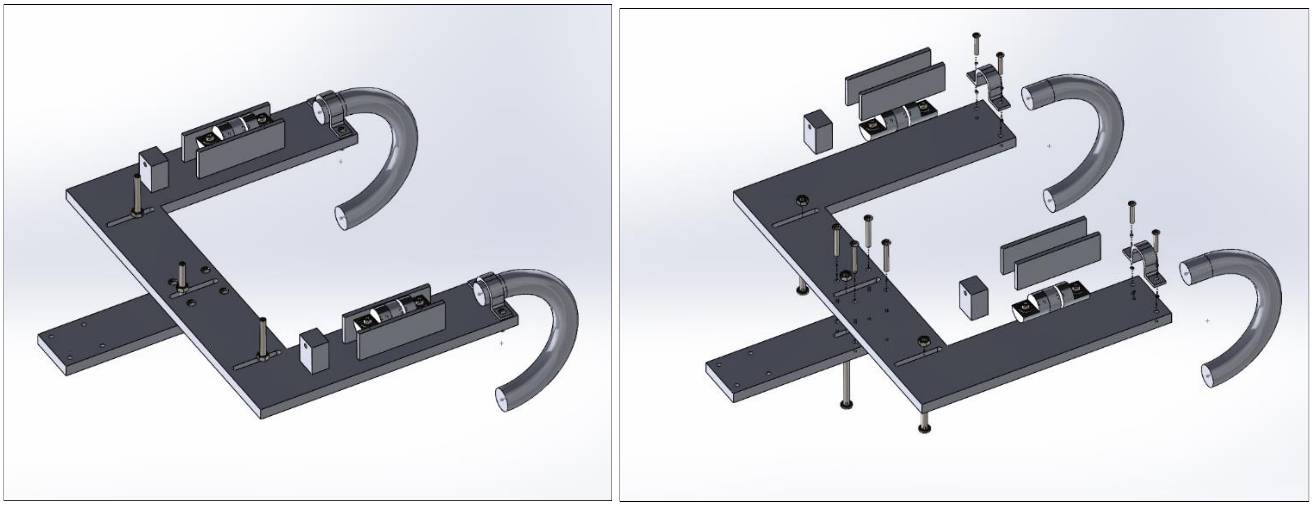

Figure 23. Custom handlebar fixture in assembly and exploded views.

These modular handlebars allow for different geometries that have not been prototyped. Extending the reach of the handlebars accommodates the in-line load cell that needs to be applied on a straight portion of cable. On ordinary handlebars, there is not enough space to allow for the load cell fixture; these modified handlebars with extended reach allow the load cell to move between the supports in a linear fashion. Following the supports and load cell, there are cable stops and positioning pins. The stops represent where the cable would normally come out of the shifter lever, while the pins would position the cable to follow the bends that would normally occur in an internally routed handlebar. The cable can be easily fed around the “pseudo-stem” into the rest of the system, while the applied force can be drawn from the load cell in the custom handlebar fixture. This fixture includes two stock plastic brackets for fixing the cut handlebars, and various bolts and nuts, the specifications for which can be found in Appendix B.

Stem Fixture

The stem fixture was designed to mount the handlebars. Attached to a vertical slide and dual magnetic base assembly, the stem fixture allows the handlebars to hang off the table while the user runs the test. The stem can be seen on the far left in Figure 23, connecting the custom handlebar fixture to a vertical slide.

Cable Stops

Cable stop fixtures, as seen in Figure 24, are comprised of three main pieces, paired with various fasteners: square tubing, brackets, and a custom cylindrical cable stopping point. Accurate recreation of frame geometry is crucial to the testing environment, and this design allows for complete control of position and the necessary six degrees of freedom.

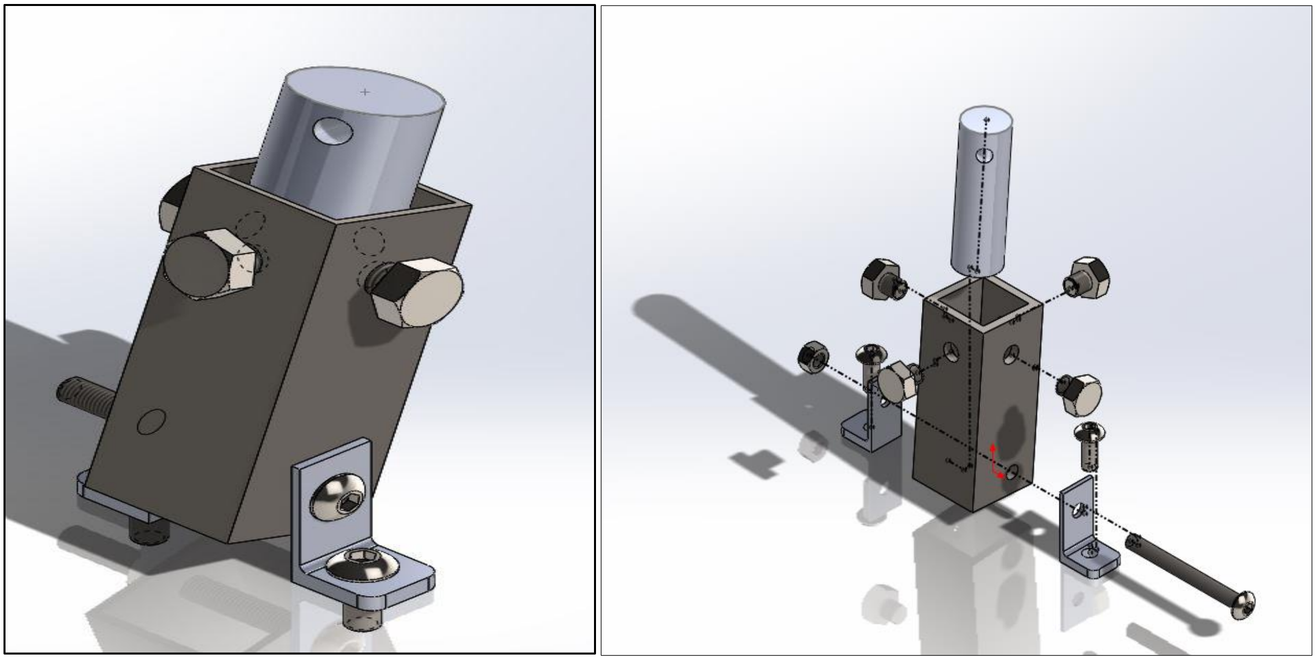

Figure 24. Cable stop fixture in assembled and exploded views

This cable stop fixture utilizes a one inch by one inch steel square tube on the outside. Inside the steel square tube, there is a cylindrical bar stock of 13/16 inch steel with the dimensions of a given cable stop milled near the end of it. The bar stock has a “counter bored” hole to ensure that any style cable stop or other cable-frame interaction components will be able to work with the entire fixture.
Once the holes were drilled, the physical cable stop was placed into the bar stock, and the geometry of the frame was recreated, without adding any additional support that the cable stop would not normally provide. The cylindrical bar stock is capable of moving inwards and outwards, as well as rotating within the square steel tube. The cylindrical bar stock and stop are held in place with bolts which can be tightened down to lock the bar stock in place. The bolt fasteners work with a similar idea of how Christmas tree holders work. The threaded wall of the square tube works in conjunction with the bolts that will continue to thread until it hits the circular bar stock within, thus holding the stock into place. Additionally, the square tubing is able to pivot about the through screw, supported by the brackets, holding the square tube at the desired angle.

A single #10-32 screw runs through the two brackets and the square tube, secured on the opposite end with a nut. With the brackets flush against the square tube, using one screw and nut, the fixture is secure and easy to position. The in and out motion as well as rotation of the cylinder within the square tubing, pivoting of the square tubing, vertical positioning of the slide, rotation of the rotary plate, and the x-y positioning of the magnetic bases account for the six necessary degrees of freedom. The magnetic bases drove the design of the stops positioning system, and can be easily integrated with the rest of the custom fixtures used in the system with the magnetic bases.

Bottom Bracket Guide

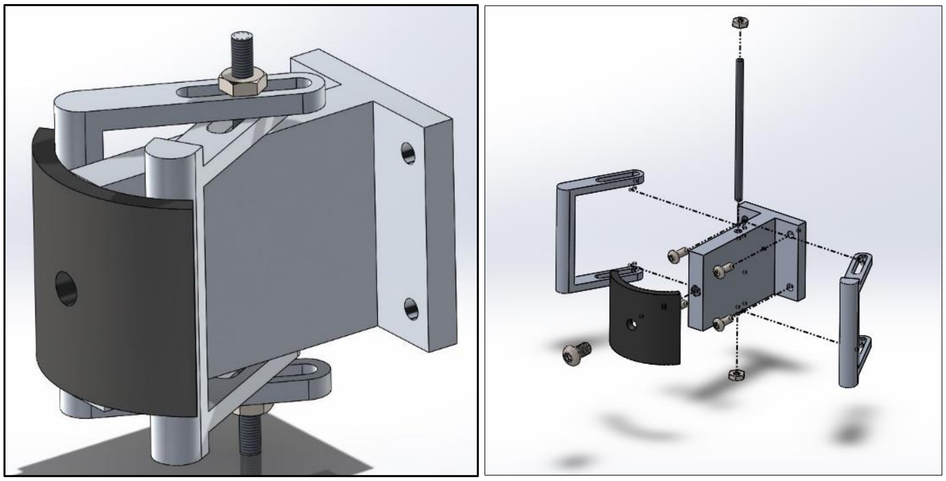

Figure 25. Bottom Bracket guide fixture in assembled and exploded views.

The design for the bottom bracket guide can be seen in Figure 25. The fixture is comprised of six pieces: two support arms, a center fixture with mounting holes, a threaded rod, and two nuts. The design of this fixture is to accept any bottom bracket guide and support it. We chose to use the two support arms because they can be adjusted to any reasonably shaped bottom bracket guide and still support it at three points. A fully rigid fixture would not be capable of adjusting to accept an oddly shaped bottom bracket guide. The two support arms were 3-D printed using the Mechanical Engineering Department printer for prototyping.

Rear Derailleur Mounting Fixture

The rear derailleur fixture can be seen below in Figure 26. This fixture accommodates a derailleur hanger which a rear derailleur can be attached to. Small washers and M3 screws are used to space and fasten the derailleur hanger onto the fixture itself. The noodle block, attached with a C-clamp, can be positioned to dictate the cable loop near the rear derailleur.

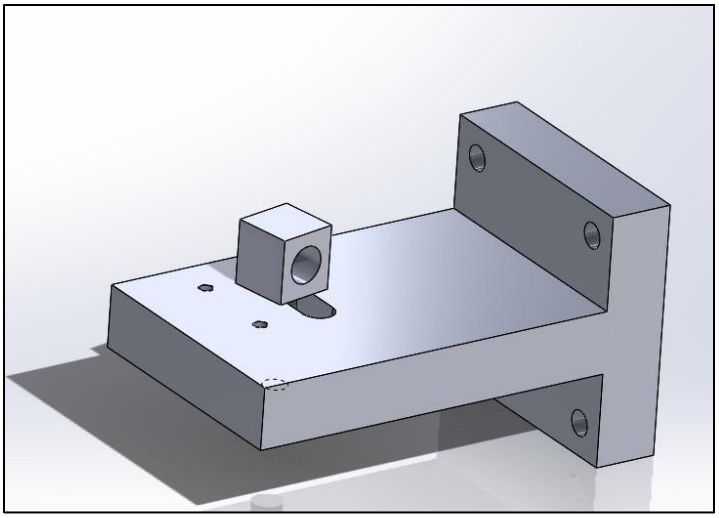

Figure 26. Rear derailleur fixture with noodle block

Front Derailleur Mounting Fixture

The model for the front derailleur fixture can be found in Figure 27. The two holes allow for mounting to a vertical slide assembly and the cylindrical section allows for a braze-on anchor (as seen in Figure 28) to be mounted. The braze-on anchor allows for the attachment of a front derailleur.

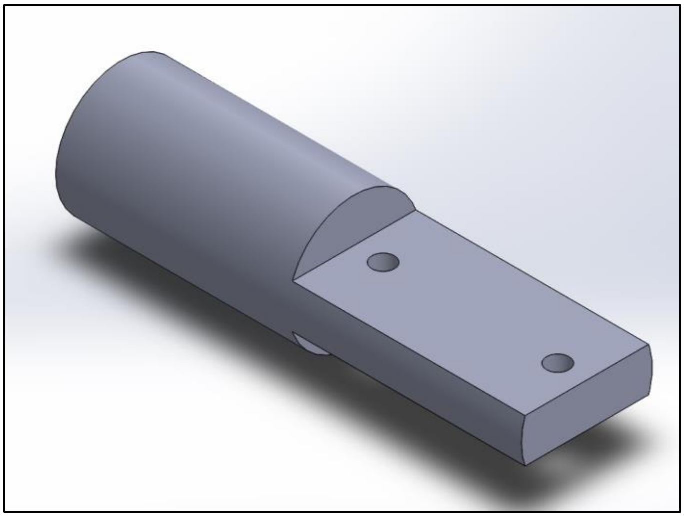

Figure 27. Front Derailleur Fixture

Figure 28. Braze-On Anchor

Brake Fixture

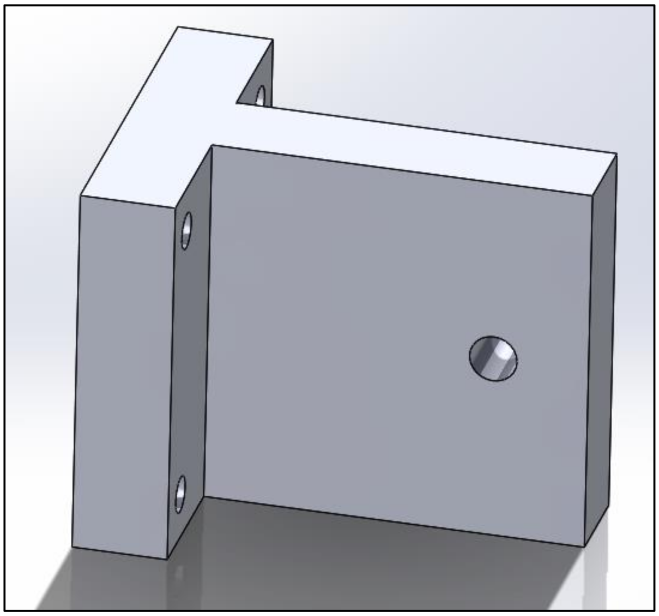

Figure 29. Brake Fixture

The brake fixture is seen above in Figure 29. The back plate attaches to a vertical slide assembly with four screws. The other piece of this design is simply a hole in the attached plate for mounting a caliper rim break.

Analysis/Preliminary Testing

In order to verify that the current design will perform accurately and reliably, some basic hand calculations were performed to estimate the performance of the system. We theoretically calculated the tipping force of a single magnetic base after our first test run using magnetic bases (**S**ee Matlab code and hand calculations in Appendix E). The theoretical calculations were similar to our testing results, both showing that one magnetic base would not be able to handle the loads we expected during operation of our test. The test results and analytically calculated tipping force for one magnetic base were then used to develop a more accurate model for tipping in an updated dual magnetic base design, which is our final design. However, upon testing, we found that sliding became the issue with the new dual base design. Based on testing, the magnetic bases should be able to handle the required operation loads but sliding will most likely be the first mode of failure. A full Failure Mode Effects Analysis can be found in Appendix E. These were our main concerns for failure modes.

Dual Magnetic Base Analysis & Testing

McMaster Carr gives a rated magnetic pull force of 220 lb_f for each of the chosen magnetic bases. Using this fact, we theoretically predicted the tipping force to be around 80 lb_f at a lever arm of 10 inches. Additionally, we predicted that the sliding force would be approximately 100 lb_f. These numbers are much higher than our expected load of 20 lb_f.

After actual testing, however, we found that the magnetic bases would slide at a force of 26 lb_f along the strong axis, and tip at 17 lb_f along the weak axis, when a thin ferrous base is used. For a thick ferrous base, it took 30 lb_f to tip along the strong axis, and 23 lb_f to tip along the weak axis. Since these numbers are greater than our expected loads of 20 lb_f, we feel that the modified magnetic base design is adequate for our application, provided that we design for aligning everything along the strong axes. Should a specific configuration tip or slide a magnetic base, it would not be too much trouble to redesign a base configuration that would resist sliding or tipping for the particular application.

Deflection Analysis

To ensure accuracy in positioning, we want to keep the deflection and bending of the vertical slide fixtures to a minimum. In order to do so, we performed deflection analysis of the fixture, modeling it as a cantilever beam. Complete analysis can be seen in Appendix E. From our results, we deduce that the deflection is not concerning, as it would only deflect the assembly 0.75 mm.

Force Measurement

The force measurement system is comprised of a data acquisition system, a threaded load cell, and a signal conditioner. The signal conditioner will take standard 110 Volt AC power as an input, and outputs the correct excitation voltage for the load cell to function. The DAQ system is USB powered, meaning that its power will be supplied by whatever computer or laptop system it is plugged into. A supplied cable with leads will allow interaction between the signal conditioner and the DAQ box for differential voltage readings to be used with LabVIEW.

Figure 30. NI-6001 USB DAQ

The data acquisition unit used is the NI- 6001 USB system from National Instruments, as seen in Figure 30 [17]. This DAQ system is both cost effective, at $189, and relatively simple. This is very cheap compared to other DAQ systems, which can cost upwards of $1,000. This DAQ system also has a USB plug in cable, which allows for easy access with computers and laptops, making it convenient for testing. In order to get useful, comparative measurements from every test, the acquired data is post processed in Matlab.

Figure 31. Interface sealed stainless steel load cell

The threaded load cell that we have chosen is the Interface WMC sealed stainless steel load cell. This can be seen above in Figure 31 [18]. This load cell is miniature in size and has two male threaded ends. We decided on this load cell, as our design needed the brake or shifter cable to stay in line with the load cell to get accurate measurements. The load cell assembly with the fixtures can be seen in Figure 32, below. The size of the load cell was also a determining factor. We wanted to make sure that the load cell was small enough that it does not contribute to the drag of the system and works with our given application of tension in the cable.

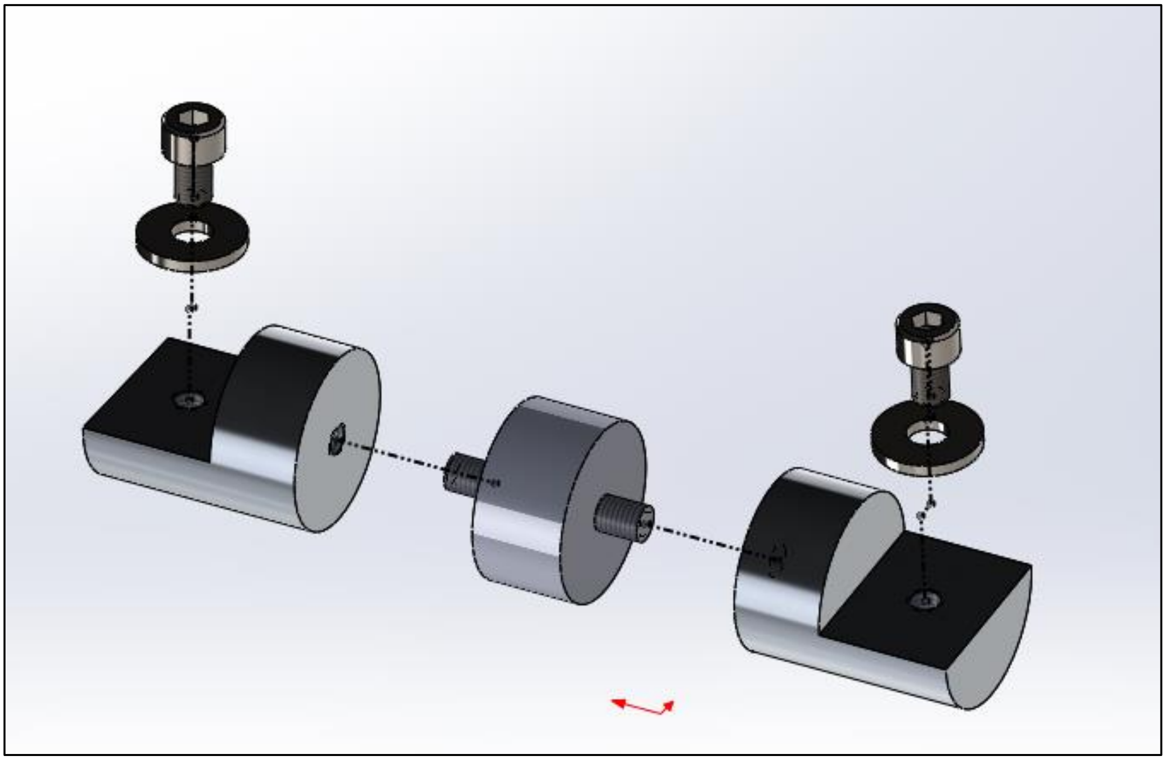

Figure 32. Load Cell Assembly

Figure 33. Interface SGA signal conditioner

In order to use the Interface load cell with the National Instruments DAQ, an amplifier/signal conditioner is required. The load cell outputs millivolts, while the DAQ outputs volts. We chose to use the Interface SGA Signal Conditioner, as seen in Figure 33 [19] above. This signal conditioner ensures that the millivolts from the load cell become amplified in order to be within the working rage of the DAQ. An Interface signal conditioner also eliminates compatibility issues, as both the load cell and the signal conditioner are Interface products.

Positional Measurement

Positioning to ±1 millimeter proved a much more daunting task than initially anticipated. While we tried multiple options for positional measurement, we were not able to get to the specified accuracy. The high level of uncertainty in relative positioning has been deemed the main variable in why the 1 millimeter tolerance was not achieved. Points on components such as the bottom bracket, rear derailleur, cable stops, and handlebars we picked as common points that could easily be measured on any frame. Although these points are consistent with each specific geometry, the error in precision was still present, as each point was slightly different in the system versus the existing frame.

Following the rotary potentiometer method described in Chapter 3, the grid method was implemented. The grid had its own limitations, though it proved to be more accurate than the potentiometer system. Five millimeter increments were the smallest increment we could use for a grid before it became illegible. We were able to get our positioning to within 17% error of the true system. This was not within the specified 1 millimeter resolution. We believe that the error can be attributed to the points on the components we picked, paired with the fact that 5 millimeters was the most accurate grid that could be used.

Location and measurement in the vertical direction was dictated by the vertical slides. The necessary accuracy and precision was provided by these instruments. Height gauges, in house at Specialized can be used to measure the vertical positioning, but digital calipers were used for our purposes when testing.

Chapter 5. Manufacturing

The following section outlines the manufacturing processes and assembly instructions for all parts and fixtures being used. Some designs had to change slightly since the Critical Design Review and these changes are noted in this section. The original schematic of the stock aluminum plate, which contains the handlebar base, pseudo-stem, bottom bracket guide base, brake fixture, load cell supports, rear derailleur fixture, and rotation plates can be found in Figure 34.

We quickly found that the ability to use any brand component (shifters, brakes, derailleurs, etc.) would be a very difficult task. While the original goal was to create a system with modular fixtures to accommodate any component with any geometry, we have determined that this was not a reasonable goal for this project with the current magnetic base design.

The main change in the manufacturing plan from the Critical Design Review was that we chose to get most of our parts manufactured by Water Jet Central instead of the previously planned CNC machining in the Cal Poly machine shops. This option turned out to be less expensive and yielded a faster turnaround than the CNC machining thanks to a generous discount by Water Jet Central. The only issue we experienced with the water jet cut parts was the small draft angle that the parts have on them after being cut. To fix this and create flat surfaces for welding, proper clearance holes, and holes for threading, we had to face the surfaces of some of the parts and re-drill some of the holes. A DXF file with the updated parts can be seen below in Figure 34.

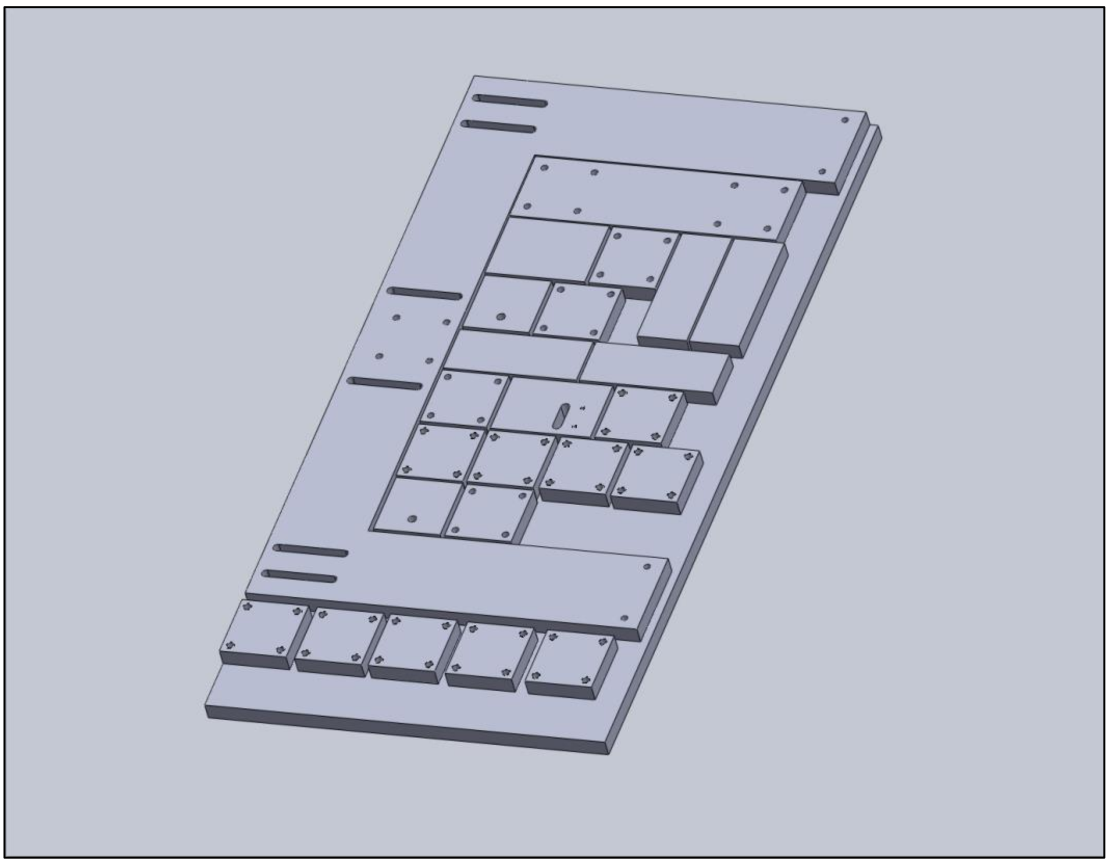

Figure 34. Picture of final layout sent to be water jet cut

Another difficulty that was found in the initial design was the welding done on the fixture pieces that were water jet cut. In order to save time and money, all of the parts were water jet cut from the same half inch thick 6061- T6 aluminum plate. However, many of the parts could have been made from thinner material. The half inch thick aluminum provided challenges when it came to welding because the large thickness required a lot of current, and made it very difficult to weld the material.

The welding professor at Cal Poly was able to complete the necessary welds with only minor difficulty on the load cell supports, bottom bracket fixture, rear derailleur fixture, and two brake fixtures. We planned to weld the stop fixtures to the handlebar fixture ourselves at a later date. Unfortunately, with the thickness of the material, yet relatively small size of the stops, we were unable to follow through with the intended plan. This forced us to fix it in a different way, thus we decided to thread a hole in the bottom of the aluminum block and fix it from the underside of the handlebar fixture with a screw.

Main Base Plates

The main base plates were originally designed to be cut out of sheet steel with the holes machined in the Cal Poly machine shop; however, due to the reliability and fast turnaround that was found with Water Jet Central, we decided to have the main base plates water jet cut to save time. A DXF file of the main base plates, sent to Water Jet Central can be seen below in Figure 35.

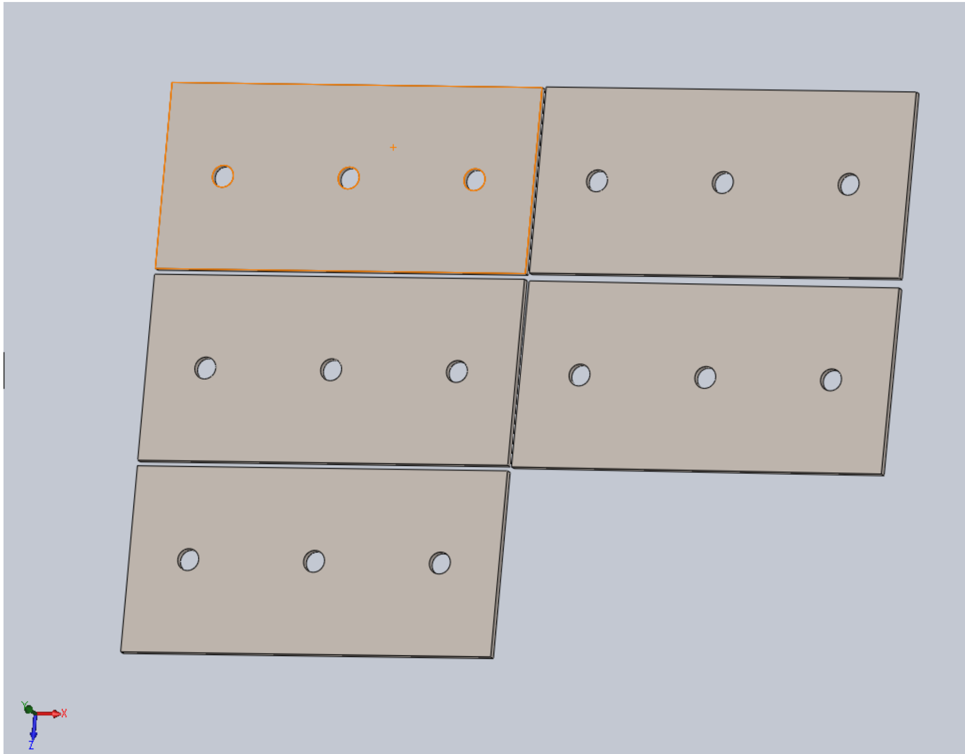

Figure 35. Picture of the 10 gauge steel main base plates

Handlebar Mimicking Fixture

This design changed a lot from the previous design. The original handlebar fixture assembly, seen in Figure 23, involves a variety of parts whose fabrication and assembly process is outlined in this section.

The main base and pseudo-stem of the handlebar fixture assembly were designed to be made from 2ft. x 1ft. x 1/2in stock aluminum plate and precision CNC milled at Cal Poly. This was one of the parts that ended up being Water Jet cut with the rest of the parts and also had a few modifications made to it, as seen in Figure 34. The main base of the handlebar fixture has six slots for positioning cable, four through holes for mounting the pseudo-stem to the base, and four through holes for the clamps used to mount the pieces of actual handlebar seen at the ends. The pseudo-stem has four through holes for mounting to the base and four through holes for mounting to the vertical slide assembly.

The two cable stop fixtures that are seen to the left of each load cell fixture were manually milled from stock aluminum bar. These were then supposed to be TIG welded to the flat plate base for accurate cable positioning and tension measurement; however, as mentioned previously, these were fastened with a bolt instead due to the difficulty of the welding.

The load cell fixtures were fabricated out of stock aluminum rod cut to size with a band saw. The upper half of half the rod was milled away and then the holes drilled and threaded on the manual mill and the whole thing assembled with a set screw and washer. Each load cell is supported with two aluminum plates on either side to prevent sag or wobble that the weight of the load cell fixture causes. These plates were also to be cut out of the stock aluminum plate using CNC milling along with the main base and pseudo-stem and then TIG welded in place on the base plate but were water jet cut instead and then welded as planned.

The slots are used with stock threaded rod and nuts to position the cable and housing coming out of the fabricated cable stop fixtures. The rest of the assembly is completed by fixing the handlebar clamps, stem, and stops with bolts and nuts. A picture of the entire assembly with all the described components can be found below in Figure 36.

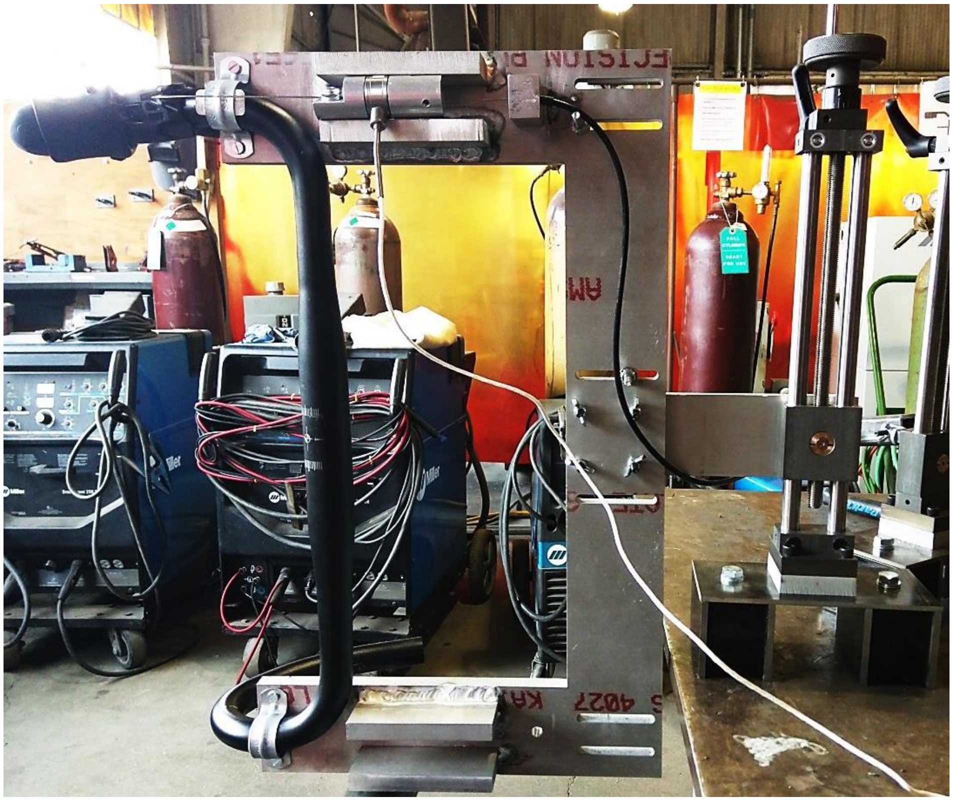

Figure 36. Final assembled handlebar mimicking fixture

The handlebar fixture was the biggest limiting factor on our initial goals. Because of the complexity and large variation in routing in the handlebar area on different bikes, it was very hard to create a fixture that would work for all scenarios. For lower end bikes, the shifters are often not routed inside the handlebar or under the bar tape which is not an issue because the cables can just be in free space with the cable interaction points mounted as usual; however, with internally routed handlebars, the situation becomes more complicated. This is where all the magic happens; the cable force is actuated through a shifter, the load cell is attached in line and must move linearly without drooping, and the cable must take complicated turns that are difficult to get the actual geometry for.

Although most shifters contribute a negligible amount of the drag to the cable just through the mechanism, the different shifters provide their own complications because some shifters have different geometries which are hard to accommodate with a single fixture. To keep the load cell in line with the cable, our fixture was designed so that the cable interaction point at the shifter is separated by a length of space where the load cell fixture resides (for a more detailed explanation of the design, reference the handlebar mimicking fixture section in Chapter 4). This only allows for a shifter where the cable comes straight out the back and down toward the bike. Some shifters have the cable exit the side and then take a sharp turn down into the handlebars or out into free space like in some lower end bikes. This creates a situation in which our fixture could does not work because we cannot accommodate that bend and therefore cannot accurately simulate that situation.

Another problem is the fact that the load cell fixture is relatively heavy and hard to position correctly. The weight of the load cell causes the whole cable to want to droop down which would result in an inaccurate system. The load cell supports were added as a sort of bushing to prevent this, but this obviously induces some extra friction. We believe that this is a large source of inaccuracy in the system that results in slightly higher loads than the actual system would see. Our system is still accurate in the comparison of two different frame geometries, however, because the same amount of drag would be added by the load cell for each test.

Another slight issue with the load cell fixture is that it needs to be exactly in line with the cable. We found that this was not quite achieved in our set-up because the welding of the load cell supports and the placement of the handlebar stop were not perfectly in line with where the cable needed to be. This leads to sideways forces on the load cell, pushing it up against the supports, causing additional drag. Again, while this adds to the drag in the system, two different geometries can still be compared.

Actual Stem Fixture

For the actual stem and handlebar mounting fixture pictured in Figure 24, stock round aluminum bar was cut with a band saw and material removed from either side with a manual mill here at Cal Poly so that it can be fixed to a vertical slide assembly with two #10-32 screws for an actual stem to be mounted on to the still circular part of the tube. Actual handlebars can be fixed to this stem and the cable routed to get an actual feel for the system. This fixture take about one hour to fabricate

Cable Stop Fixture

The cable stop fixture assembly seen in Figure 25 was made from stock square steel tubing, stock round aluminum bar, and two brackets. All of the machining for these fixtures was done by our team here at the Cal Poly machine shops. Due to the specific dimensions on the bracket spacing and available square tubing sizes, the brackets also needed to be slightly altered to achieve the correct spacing. A manual mill was used to machine off sixty thousandths of an inch from the outer face (highlighted in Figure 37, below) of each bracket.

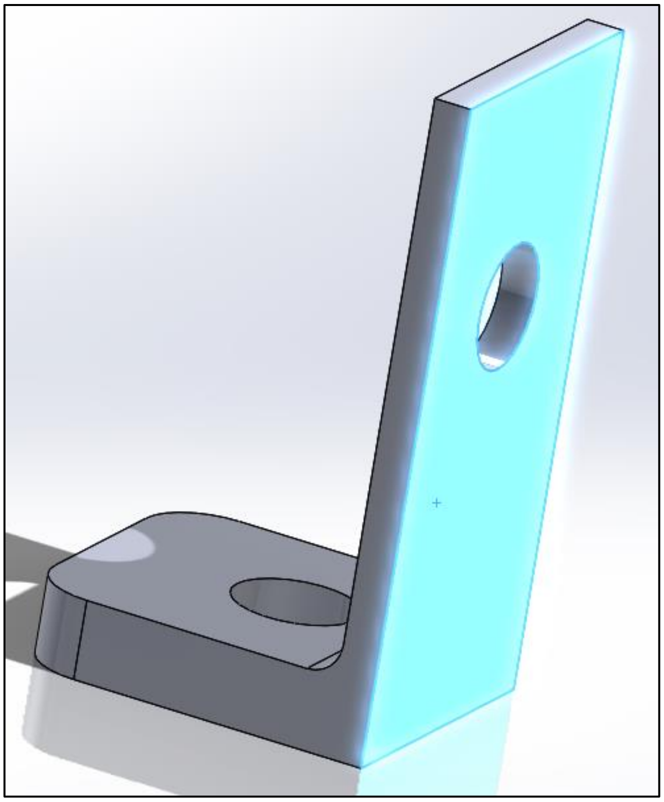

Figure 37. Bracket for cable stop assembly, with face that needs material removed

The steel square tubing and aluminum bar was cut to size on a band saw. The aluminum rod was machined on a manual mill to drill the hole on each side. Last, the square steel tube was machined on a manual mill to drill and tap the hole on each face. The assembly for this fixture needed to be done in a certain order due to the tight space that it operates in. The brackets were fastened to the vertical slide assembly first with screws. The square tubing is then placed inside the brackets and the through bolt inserted and tightened on the other side. The aluminum rod is then placed inside the steel tube and tightened in place with the four bolts. These fixtures take about 5 hours to fabricate.

This design was carried out the way it was intended to and they allow for all six degrees of freedom as discussed in the design section of this report. We believe they are capable of representing any frames that Specialized may need. A picture of these finished assemblies can be found below in Figure 38.

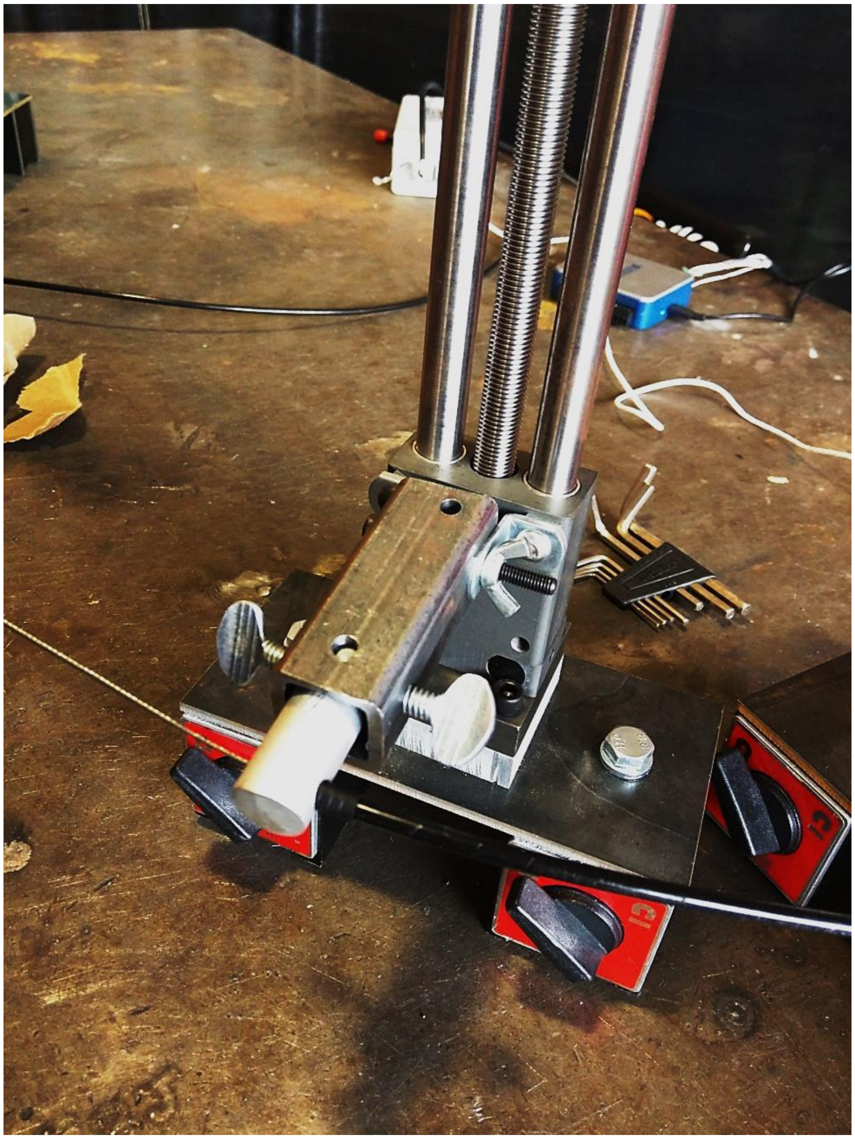
Figure 38. Finished cable stop fixture assembly

Bottom Bracket Fixture

The bottom bracket guide pictured in Figure 26 was water jet cut from the same stock aluminum plate used above for the handlebar mimicking fixture. Two pieces were to be cut out in the water jet process and then TIG welded together. For the prototype, the “arms” seen below in Figure 39 that support the cable guide were 3D printed using the 3D printer in the Cal Poly ME department; however, the final design can still be fabricated using precision CNC milling on site at the Specialized headquarters.

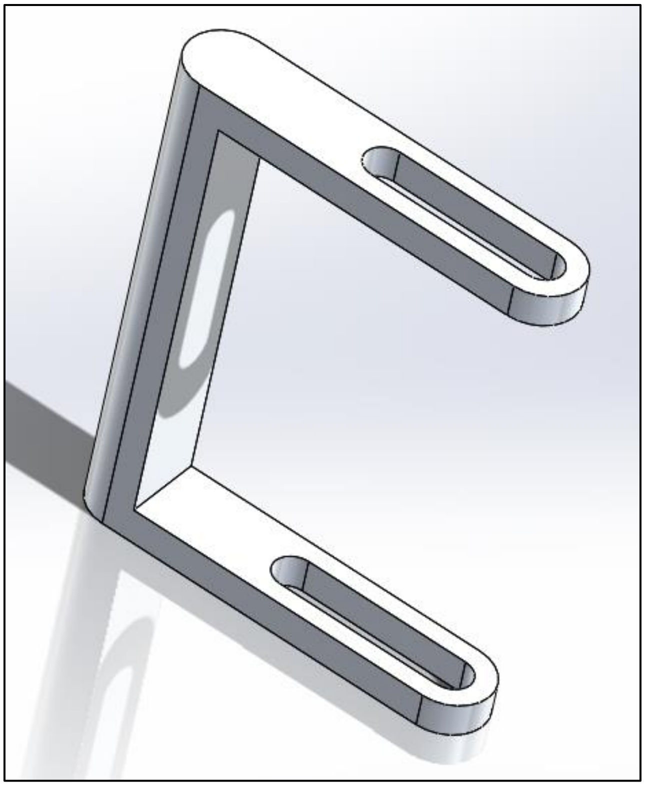

Figure 39. Bottom bracket guide arm

The main body pieces that are welded together were machined on a manual mill before welding to drill the long hole for the threaded rod while the four through holes on the back piece were created when everything was water jet cut. Our final prototype does not have the threaded hole on the front to accommodate the screw of a bottom bracket guide because we did not have access to a guide for testing until the very end of testing and the size and position of those holes vary so much that we found it not feasible to place just one threaded hole for any cable guide; however, the tension in the cables is sufficient to hold a guide in place once it is positioned. The 3D printing took about 1 week to get all the paperwork squared away and the process completed. The machining took thirty minutes and all the welding about two days from when it was dropped off and picked up. A picture of the final prototype can be found below in Figure 40.

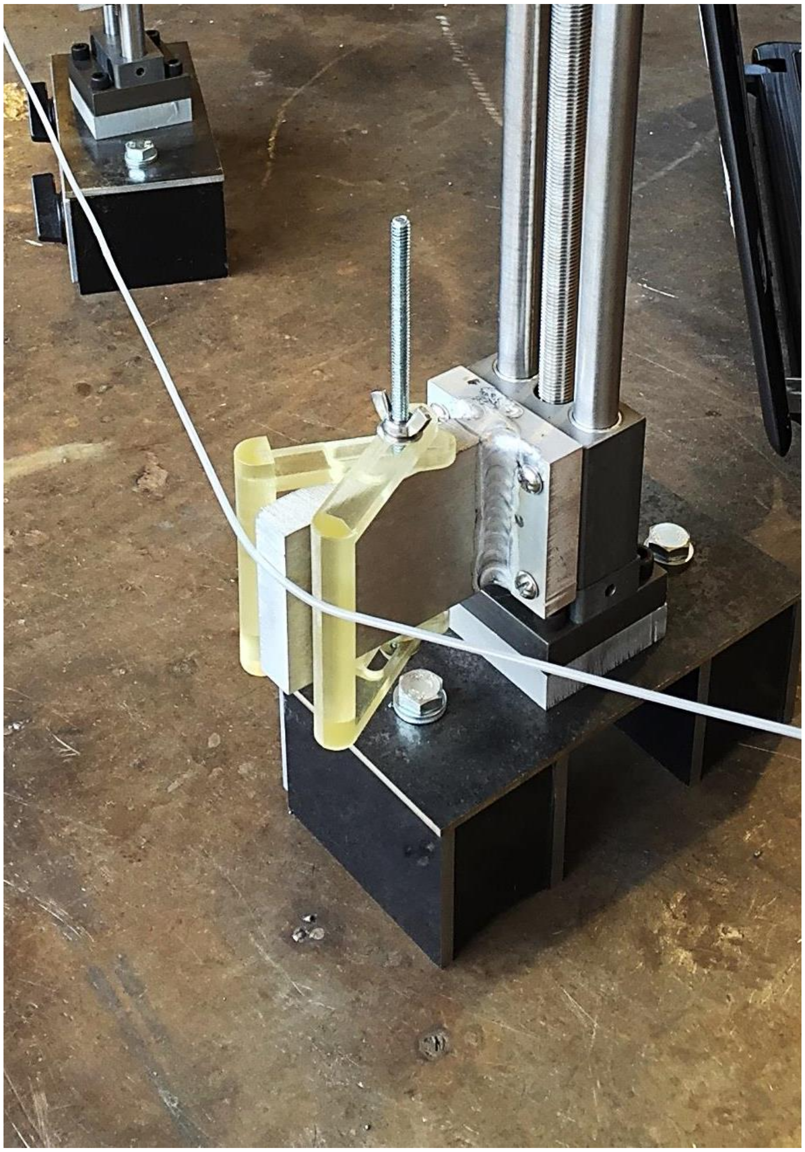
Figure 40. Finished assembly of the bottom bracket guide

Main Base and Vertical Slide Assembly

The main bases seen in Figure 22 are composed of two magnetic bases and a flat plate with two fasteners. The flat plate was water jet cut out of steel plate as mentioned above instead of being cut by our team at the Cal Poly shops. The plate can be fixed to the mounting hole on each magnetic base by the two outer holes and one more hole was cut in the flat plate directly in the middle to fasten the vertical slide assembly from below. The square plate that allows rotation of the vertical slide assembly was cut out of the same aluminum plate that was water jet cut for the handlebar assembly and the four mounting holes for fastening the vertical slide assembly down tapped in the Cal Poly machine shops. One more tapped hole was machined through the middle of this rotating plate to fasten it to the flat plate. The drilled and tapped holes took about one hour to complete and the water jet parts took two days to complete.

These components of our design have performed well in testing and we believe that they are sufficient for the project goals that we wanted to meet. Getting the steel base plates water jet cut saved us a lot of time in manufacturing because they were done in a day and delivered to us when we needed them for a good price. These assemblies can be seen in Figures 38 and 40 above.

Rear Derailleur

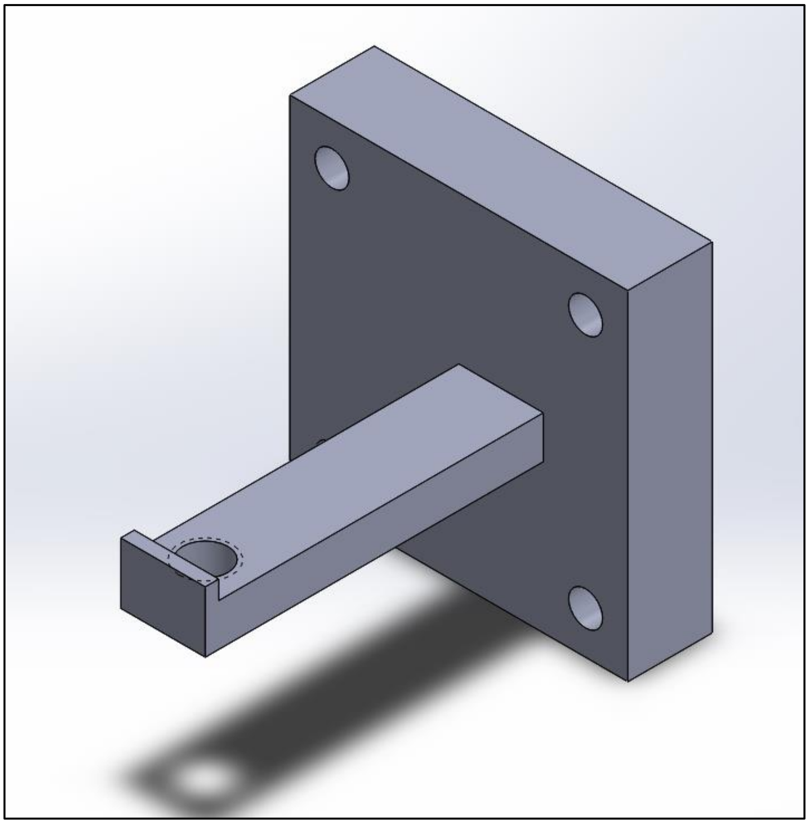

Figure 41. Initial Design of Rear Derailleur Fixture

The initial rear derailleur fixture design, seen above in Figure 41 was designed to be manufactured by our team at the Cal Poly machine shops. Instead of being machined in the CNC process, these parts were also cut out in the water jet process and then welded together. The original design for this piece seen above included a small piece of plastic that was to be placed onto the end of the perpendicular strut with the single hole under the derailleur hanger being fixed there. This was to allow for structurally sound mounting of the derailleur hanger which is what the rear derailleur attaches to. The derailleur hanger has an oddly shaped cutout where it would normally sit on the right dropout and we are going to fill that space with our plastic cut-out. Because this does not need to be perfectly accurate, we planned to trace the shape onto a plastic sheet of acetal delrin and cut that out using a band saw. We instead ended with the design seen in Figure 26 and did not need that plastic piece.

This rear derailleur fixture went through quite a bit of redesign and therefore manufacturing changes after the critical design review. Figure 26 shows the final manufactured version of the rear derailleur fixture. It is designed to accept any rear derailleur hanger and hold various rear derailleurs and was fabricated through water jet cutting. The hanger mounting holes were bored on the drill press. This piece is fixed to the vertical slide assemblies with 4 screws like the other fixtures. The manufacturing for this part took about one hour. A picture of the finished assembly can be seen in Figure 42 below.

Figure 42. Completed rear derailleur fixture assembly

Front Derailleur

The front derailleur fixture, as seen in Figure 24, was fabricated in the exact same fashion as the fixture for an actual stem for the handlebars and therefore had the same time estimates, as laid out above in the actual stem fixture section. The front derailleur fixture was machined exactly as planned, but has not been used or tested yet due to the reduction in the scope of this project. This piece took only about an hour to fabricate.

Brake Fixture

The brake fixture pieces were cut out in the water jet process with all the other half inch aluminum. The assembly can be seen in Figure 29. Similar to the bottom bracket fixture base, two squares of aluminum plate were cut and then welded together as shown. The first piece has four through holes for bolting to the vertical slide assembly with #10-32 screws while the second piece has a single through hole for fixing a rim brake to it. Similarly to the front derailleur fixture, due to our reduction in scope, the brake fixture was never used or tested in our system.

Chapter 6. Design Verification

In order to ensure a functioning test system to be used by Specialized, we wanted to verify that all components work correctly, and all measures are taken in order to have successful test runs. We ran various tests for our verification. The types of tests that were done were time tests, calibration tests, and a comparison test. A Design Verification Plan and Report can be seen in Appendix G.

Time Tests

We wanted to ensure that set up and the operation of one test run would last no more than 30 minutes. Unfortunately, the setup took longer than 30 minutes each time we tested. The amount of fasteners that needed to be tightened, as well as adjusting the height of each component took time. Routing the cable in our setup was also time consuming, as the cable needed to be fed a certain way in order for it to be actuated properly.

Another test that we wanted to perform was to ensure that it takes no more than one hour for someone to learn how to fully perform a testing run. We could not verify this test due to time constraints of the project. We wanted to verify that the other aspects of the system worked before utilizing this test; however, this test can be easily completed by a test engineer at Specialized.

Calibration Tests

We had two calibration tests for the equipment being used for our final system. Our final system includes a load cell and a paper grid. To use the system, we needed to make sure that the load cell and grid were correctly calibrated. In order to do so, we did comparative tests to known forces for the load cell calibration, and we ensured that the grid was correctly printed. A series of loads were applied to the load cell, and a best fit curve to the data was made. This data yielded a correct calibration of 5 volts to 30 pounds. This calibration curve can be seen in Appendix H.

Comparison Test

The most unique test performed was a comparison test for a good lever "feel" of the system setup. In the bicycle industry, there are no set standards for expected forces for shifting and braking. Instead, tests are done based on user input and how crisp a shift, or how complete a brake feels. In order to do a comparison test, we had a user feel an actual bicycle setup that our system's configuration simulated, and then felt our system afterwards. The user then determined if the bicycle and our system gave the same feel. From the tests that we ran, the different users felt that our system represented the correct feel of the bicycle system.

Cost Analysis

A final cost analysis was performed for the final design. The grand total for the entire project came in at $4,406. The entire test setup was initially proposed to be $6,417, but after altering the scope of the project, this budget fell to the final number seen in Table 5. This design was more expensive than anticipated, but high cost items such as the vertical slides and the magnetic bases drove the price up. As seen below in Table 3, the vertical slides, at $439 and the magnetic bases, at $43 added the most to the overall cost. Our team was hesitant to decide upon vertical slides simply because of price. After conferring with Specialized, and weighing out the cost against time spent on manufacturing custom rails, we were encouraged to use the vertical slides. Saving time on the manufacturing process and ensuring consistency, was deemed more important than the steep price associated with the vertical slides.

Table 4 below, shows the final cost breakdown for the raw materials. A proposed budget for these raw materials was $163 initially, but a final cost of $440 came in at the end. The increase to this section can be attributed to the water-jet cutting that we employed. While this added additional cost to this section of the budget, it saved time and money in the machining process. Lastly, the fasteners were initially specified to cost $97 as the cost estimation utilized McMaster Carr pricing which gave bulk numbers for fasteners. Not needing hundreds of each type of fastener, we purchased them locally, in the quantities we needed, and had a grand total for fasteners of $53.

Table 3. Final Cost of Miscellaneous Items

Miscellaneous	Quantity	Price	Total
Signal Conditioner-SGA	1	$345.00	$345.00
NI USB-6001 DAQ	1	$189.00	$0.00 (From Specialized)
Load Cell	1	$660.00	$660.00
Power Cord	1	$18.00	$18.00
Calibration	1	$75.00	$75.00
Vertical Slides	5	$439.00	$2,195.00
Magnetic Bases	10	$43.00	$430.00
Calipers	1	$190.00	$190.00
			$3,913.00

Table 4. Final Cost of Raw Materials

Raw Material	Quantity	Price	Total
Steel Square Tube 1"x 1" x 0.12"	1	$7.97	$7.97
6061 Aluminum Rod (5/8" diameter)	1	$3.68	$3.68
Brackets	10	$0.63	$6.30
6061 Aluminum Plate (1'x2'x1/2")	1	H_20 Jet	$324.00
Multipurpose 6061 Aluminum Bar (3/4"x1"x6")	1	$4.35	$4.35
Multipurpose 6061 Aluminum Rod (1"dia.x6")	1	$5.28	$5.28
Multipurpose 6061 Aluminum Rod (1.125"dia.x6")	1	$6.38	$6.38
11 GA. (.124 thick) Galvanized Steel Sheet (1'x4')	1	H_20 Jet	$80.00
Handlebar Clamp	2	$0.90	$1.80
			$439.76

Table 5. Initial and Final Cost Estimates

Initial Projected Cost	Final Cost
$6,416.98	**$4,405.95**

Safety Considerations

The dual magnetic base design offers the risk of pinching the user's hand. The slight chance that the magnetic base is turned on while a user's appendage is under it is cause for concern. Additionally, knowing the wear of the cable being tested is paramount. The risk of the cable snapping is also present, but with careful monitoring, this risk can be mitigated. Aside from these two safety considerations, the dual magnetic base design is a relatively safe design that if used properly, should not cause any user harm while in operation. The Critical Hazard Checklist (Appendix I) shows that there are not any extreme or pressing hazards associated with the dual magnetic base design. Additionally, the loads that are seen by the system should not exceed 30 lb_f. Thus, we did not find any further reason for safety considerations with the relatively low loads applied.

Chapter 7. Management & Teamwork

After indicating the initial problem at hand, in-depth research was done to determine what causes cable drag and to see what remedies that the current marketplace has. It was apparent that no product currently exists on the market that could satisfy all the requirements set forth. The only alternative is to make an actual prototype of the frame and route the cables through or around it to find the drag that is experienced. This research led to the problem statement, giving direction and scope to the problem at hand. Bicycle shop technicians offered insight into the complaints about cable drag and what type of components add to the total degradation of performance. QFD was used to identify the customer groups as well as the primary engineering requirements.

From the requirements and customer identification, we were then able to move into the conceptual design portion of the project. Using techniques such as morphological matrices, brainstorming, and brainwriting, numerous innovative ideas were explored and the validity of each was weighed out. Working through the initial designs ideas, we were able to see which designs most effectively met the design criteria. Pugh matrices were used to help sift through the ideation and determine the best possible ideas for each subsystem of the entire product. After Pugh matrices for each subsystem were created, the pairwise comparison method was used to find many different combinations of mounting fixtures, creating accurate bends, and measuring force. All of the ideation has culminated in a few top ideas for the design which are included with drawings and CAD models to give an idea of what our system ended up looking like. A Gantt chart, as seen in Appendix F, shows the deadlines and phases that we saw fit to complete the project by the Senior Expo in May of 2015.

A management plan was essential to successfully working through the design challenge in a timely manner. To create a final product that meets all of the design criteria set forth by Specialized, we formulated a structured management plan. This allowed each team member's unique skill set to be used to its fullest, while still allowing each individual to contribute to the project in full. Our management plan aimed to allow individual team members who are either skilled or interested in a certain aspect of the design process to lead the development of that area and to claim ownership of this category in the final product within the team. This team management structure tasked each lead with ensuring the team was on track with respect to his or her own area. In doing so, the team was able to meet all required deliverable dates.

Information Gathering: Brandon Sadiarin

- Prior art and patent search
- Design and component research
- Applicable features from other designs

Progress Documentation: Torey Kruisheer
- Manage Weekly Updates
- Project Records: budget, list of ideas, work completed

Report Consolidation: Torey Kruisheer
- Compile individually created design documentation
- Ensure quality of reports/documents: aesthetics, grammar, content

Engineering Analysis: George Rodriguez
- Theoretical design analysis

Models and Detail Drawings: George Rodriguez
- Create solid models: concept, prototype, production
- Produce detailed component and assembly drawings
- Compile complete B.O.M.

Simulation/Data Acquisition Lead: Brandon Sadiarin
- Uncertainty/error propagation analysis
- Test apparatus and simulation compatibility

Manufacturability Lead: Alex Powers
- Machining, welding, and fabrication lead
- Ensure manufacturability is considered in the design of all components
- Evaluate and determine best manufacturing process for each component

Testing Plan: Alex Powers
- Analyze test data to determine actions for improvement
- Convey test data in intuitive and easy to understand way
- Develop test methods to compare finished product to design requirements

The following timetable outlines the major deadlines scheduled for this project through its completion.

Table 6. List of major project milestones and their corresponding dates of completion

Project Milestone	Date of Completion
Project Proposal	10/23/14
Preliminary Design Report	11/18/14
FMEA, DVP, Analysis Plan	11/25/14
Preliminary Design Review	12/5/14
Test Plan Development	1/14/15
Design Report	1/30/15
Critical Design Review	2/12/15
Manufacturing and Test Review	3/12/15

Project Hardware/Assembly Demo	4/23/15
Senior Project Expo	5/29/15
Final Report	6/5/15

To ensure adherence to each of the aforementioned deadlines, we reported our weekly progress to Professor Sarah Harding. Weekly progress, outlined in a weekly status report, contained goals completed for the previous week as well as projected goals for the current week. Additionally, we conducted weekly telephone calls with Specialized in order to update our progress.

Chapter 8. Testing & Results

With the cable drag test system fully assembled, various tests were run to determine its performance. Tests ranged from using a real Tarmac bicycle frame for system calibration to actuating the system with a single shift using magnetic base assemblies for fixture positioning. The resulting test data confirmed some design choices and matched expected system performance in some ways, while also falling short of our expectations in others. The following figures and tables summarize over 50 tests that were performed using the cable drag test system.

One important test that was performed was a comparison test between the system performance using a real carbon Tarmac bicycle frame and the system we created to model the Tarmac frame's geometry. Figure 40 shows the resulting shifting loads for the real frame and system tests, respectively.

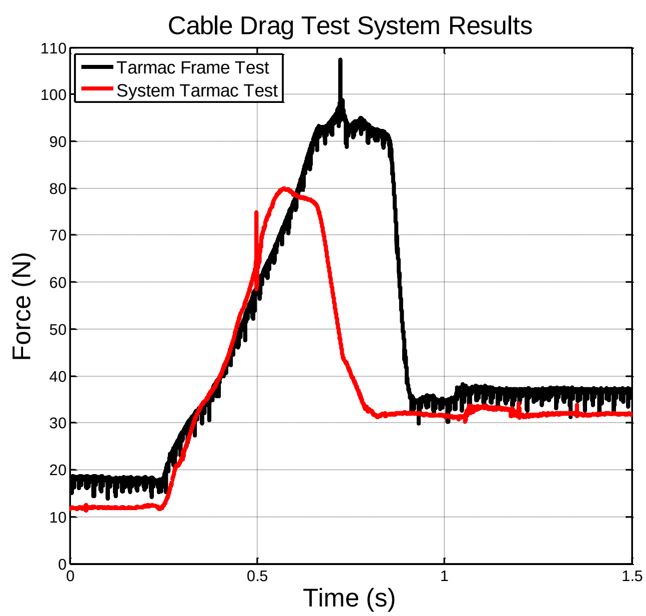

Figure 43. Real Tarmac frame and test system comparison

The required shifting tension for the real Tarmac frame was inexplicably higher than our test system setup. Some of this difference can be attributed to the different initial pretension in the cable prior to shifting. The black line on Figure 40 representing the Tarmac frame started with approximately 6 Newtons more tension force than our test system. We found throughout testing that an initial difference in pretension will result in the same difference being measured in the maximum shifting force measured. Tests were performed to attempt to verify this observation. Figure 41 below shows the effect of varying pretension prior to shifting.

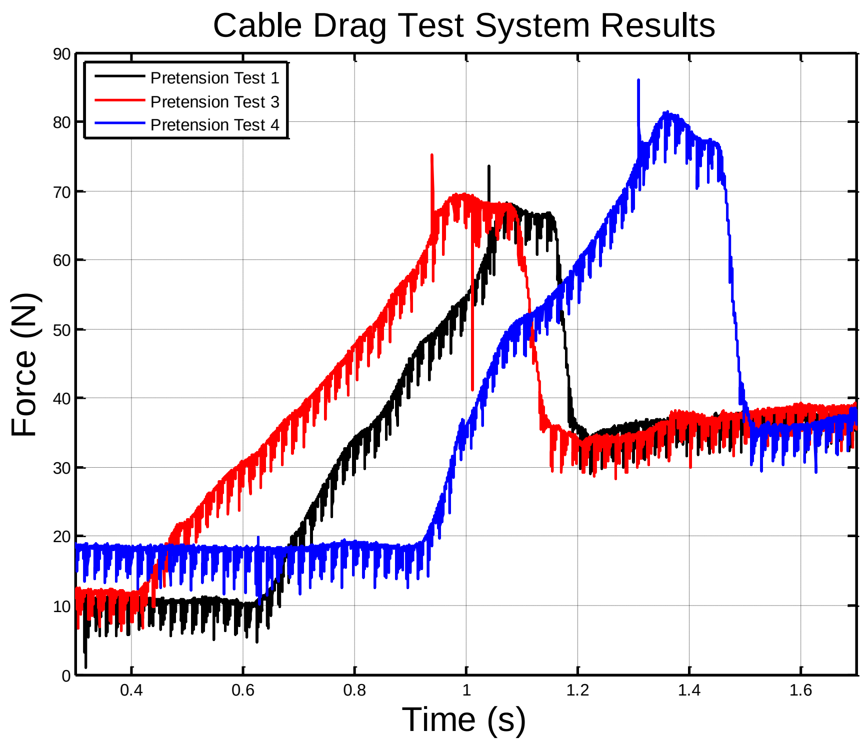

Figure 44. Effect of pretension on required tension force

Another main goal of this project was to be able to simulate cable drag differences for variable cable geometry. In order to ensure that our test system would be able to capture these geometric differences through differences in required cable tension, the geometry was varied and the cable tension was measured. Figure 42 shows these results. The geometry was altered by moving the rear derailleur fixture to a more drastically bent position.

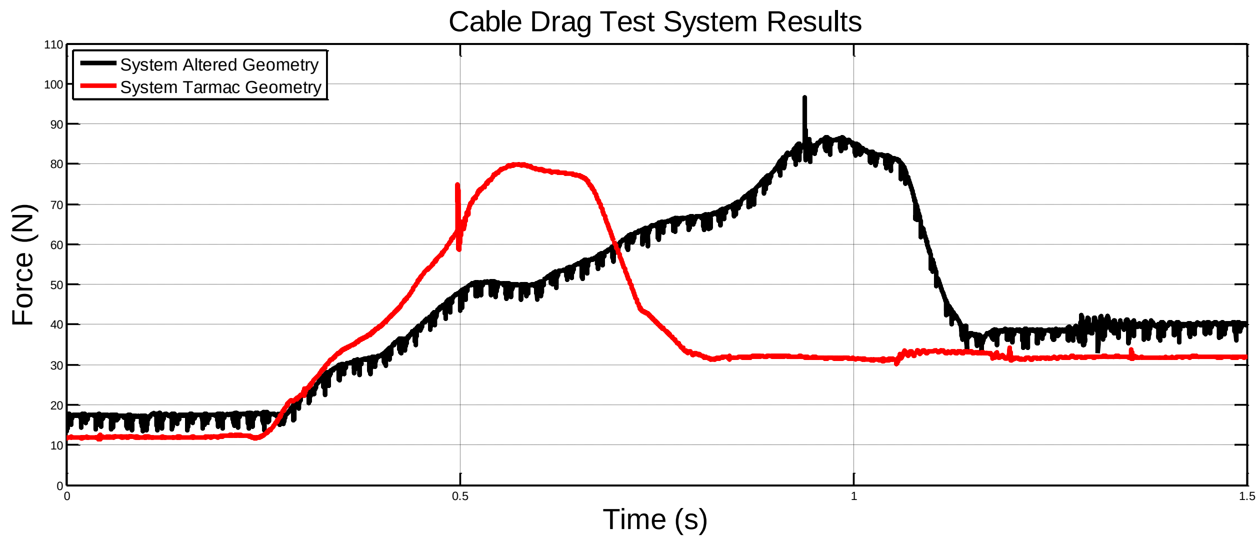

Figure 45. Difference in shifting profile based on varied cable geometry

The testing procedure can be found in Appendix K. This procedure outlines how a user would fully setup, run, and analyze a test.

Chapter 9. Future Recommendations

While this project did not turn out exactly how we had hoped from the beginning, our struggles with different designs and prototyping have given us tremendous insight into the problem at hand and what can be done moving forward. Our team has created a system that can mimic a given frame geometry, that actuates, and that properly measures the drag that a load cell "feels" while in line with a shifter cable. Looking back on the project, there were some things done very well, and other things that provided a learning experience. The primary issues that the team saw with the current design were with the overall magnetic base design and the position measurement.

The magnetic bases were never quite as strong as the design said they should be due to poor surface conditions and a generally weaker interface than what is advertised. If this project were to take a second iteration, our team would suggest the use of stronger and controllable electro magnets. These were researched initially, but were soon thrown out because of how expensive they would be. While they would add to the expense of the project, electromagnets could create a much more accurate and reliable system that could greatly benefit Specialized's test team.

The position measurement portion of this project was an area where the Smooth Shifters felt that they ran out of time to create the best design possible. While a few designs were experimented with, a truly accurate system to the original design specifications was never developed. The team decided to settle for a slightly less accurate method of using a grid with a plum bob on each cable interaction point to get as close as possible to the necessary points so that a system could be tested to its full potential. The Smooth Shifters feel that given more time, a better positioning system could be developed that could get the entire test system within the desired tolerance of ±1mm.

Chapter 10. Conclusion

Knowing that high performance cyclists do not like the way that exposed brake cables look and knowing that exposed cables also increase aerodynamic drag on the bicycle, internally routed cables have become the new standard. Unfortunately, internally routed cables can potentially increase the drag experienced by the rider because different cable housings and small bend radii decrease the performance. This is detrimental to riders because shifting and braking becomes harder, resulting in a less than desirable lever feel. Currently, Specialized lacks an accurate and efficient way to measure brake and shifter cable drag with different configurations. The current system requires Specialized to prototype a bicycle frame and route the cables before any drag measurements can be taken. This technique is not cost nor time effective, as a new prototype has to be made whenever the drag of a different geometry setup needs to be measured. Over the course of this project, the Smooth Shifters had hoped to deliver Specialized the most effective cable drag test setup to satisfy the specifications set out above. This document serves to detail the final progress and ideas, previous background research and decision making, in addition to recommendations for where the project may be able to go next.

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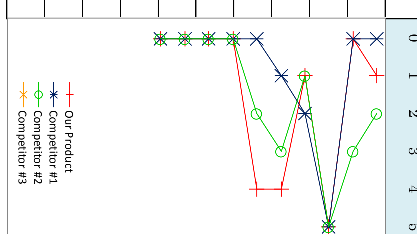
Appendix A

QFD

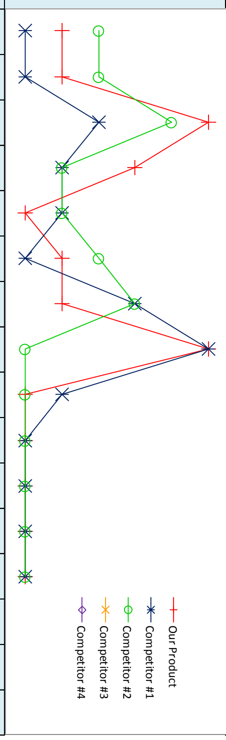
WHO: Customers / NOW: Current Product Assessment - Customer Requirements

Row #	WHAT: Customer Requirements (explicit & implicit)	Relative Weight	Riders	Specialized	Bike Mechanics/ Technicians	Component Manufacturers	Maximum Relationship	Our Current Product	Verizon Patent	Cable Tension Tester and Control System
1	Transportable*	13%	1	5	2	1	9	1	0	2
2	Modular*	13%	1	5	1	2	9	0	0	3
3	Measure Cable Forces*	16%	6	6	6	6	9	5	5	5
4	Easy to use/intuitive test	5%	1	2	6	1	9	1	2	1
5	Reliability	8%	1	3	5	1	9	4	1	3
6	Life Cycle	3%	1	1	1	1	9	4	0	2
7	Expandable	13%	1	5	1	1	9	0	0	0
8	Intuitive User Interface*	5%	1	2	2	1	9	0	0	0
9	Accomodates all Required Inputs*	16%	1	6	1	1	9	0	0	0
10	Time to Run	8%	1	3	4	1	9	0	0	0



HOW: Engineering Specifications / Current Product Assesment - Engineering Specifications

Column #	Direction of Improvement	HOW: Engineering Specifications	Transportable*	Modular*	Measure Cable Forces*	Easy to use/intuitive test	Reliability	Life Cycle	Expandable	Intuitive User Interface*	Accomodates all Required Inputs*	Time to Run	HOW MUCH: Target	Max Relationship	Technical Importance Rating	Relative Weight	Our Current Product	Verizon Patent	Cable Tension Tester and Control System
1	◄	Max Weight	●	◁				○					50 lbf?	9	139.47	9%	1	0	2
2	◄	Max Size	●	◁									4' by 3'	9	131.58	8%	1	0	2
3	◄	Force Measurement Uncertainty			●		○						+/- 1 N	9	165.79	10%	5	2	4
4	◄	Time to Learn		◁		●							1 Hour	9	60.526	4%	3	1	1
5	◄	Time to Perform One Test Set Up	○	○		●	◁						15 Minutes	9	134.21	8%	0	1	1
6	◄	Number of Runs Prior to Recalibration			◁	○	●						50 Tests	9	102.63	6%	1	0	2
7	►	Product Lifetime						●					1000 Tests	9	23.684	1%	1	3	3
8	◄	Bend Radius Tolerance		●	●		◁						+/- 0.7 cm (find out through testing)	9	268.42	17%	5	5	0
9	►	# of Test Parameters		●									4 Parameters	9	118.42	7%	0	1	0
10	◄	Max Computation Time (One Test Set Up)										●	1.5 Minutes	9	71.053	4%	0	0	0
11		GUI								●	○		yes/no	9	94.737	6%	0	0	0
12	►	# of Inputs									●		4 (dependent on most important factors)	9	142.11	9%	0	0	0
13	►	Expandable libraries from test data							●	◁	◁		yes/no	9	139.47	9%	0	0	0
14																			
15																			
16																			



Template Revision: 0.9
Christopher Battles
Date: 4/23/2010

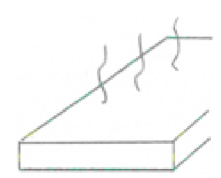
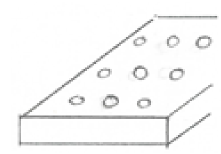
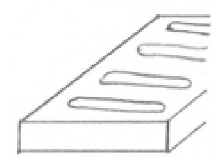
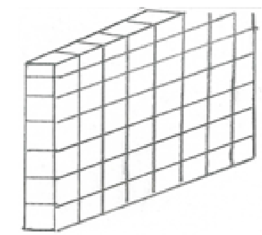
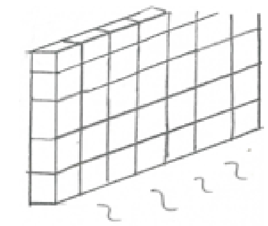
Correlations	
Positive	+
Negative	−
No Correlation	

Relationships	
Strong	●
Moderate	○
Weak	▽

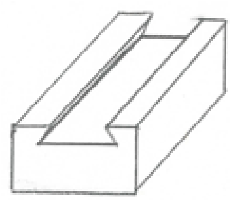
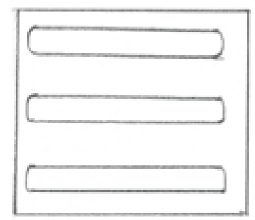
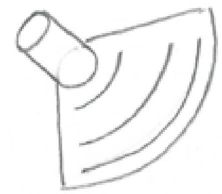
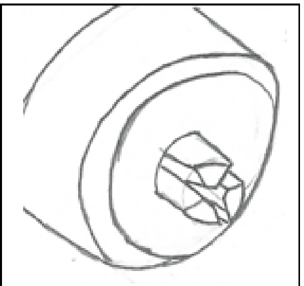
Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

Decision Matrices

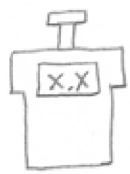
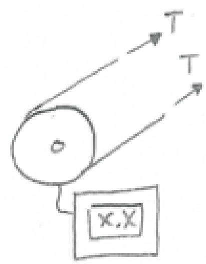
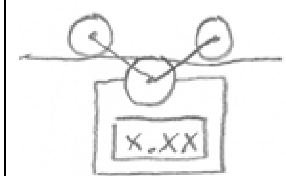
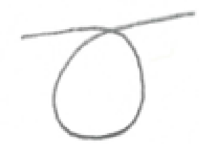
Fixture Base Decision Matrix

					
Concepts / Criteria	Horizontal Magnetic Base	Horizontal Peg Hole Base	Horizontal Slider Base	Vertical Grate	Magnetic Vertical Grate
Modularity		-1	-1	-1	0
Ease of Use		1	1	-1	-1
Machinability		0	0	-1	-1
Set-up Time		1	0	0	0
Cost		1	1	1	1
Lead/Manufacture Time		-1	-1	-1	-1
Location Resolution		-1	-1	-1	-1
Stiffness/Stability		1	0	-1	-1
Totals	DATUM	1	-1	-5	-4

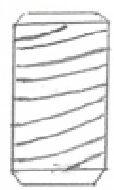
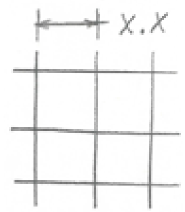
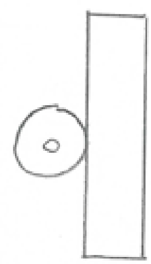
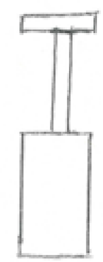
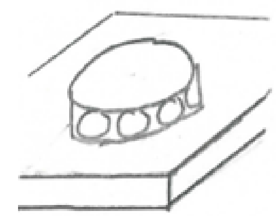
Fixture Connection Decision Matrix

					
Concepts / Criteria	**Dovetail**	**Magnetic**	**Slots**	**Suction Cups**	**Chuck**
Modularity		1	0	0	1
Ease of Use		-1	1	-1	0
Machinability		0	0	1	-1
Set-up Time		1	0	0	0
Cost		-1	0	0	-1
Lead/Manufacture Time		1	-1	1	-1
Location Resolution		1	0	-1	0
Stiffness/Stability		-1	0	-1	0
Totals	DATUM	1	0	-1	-2

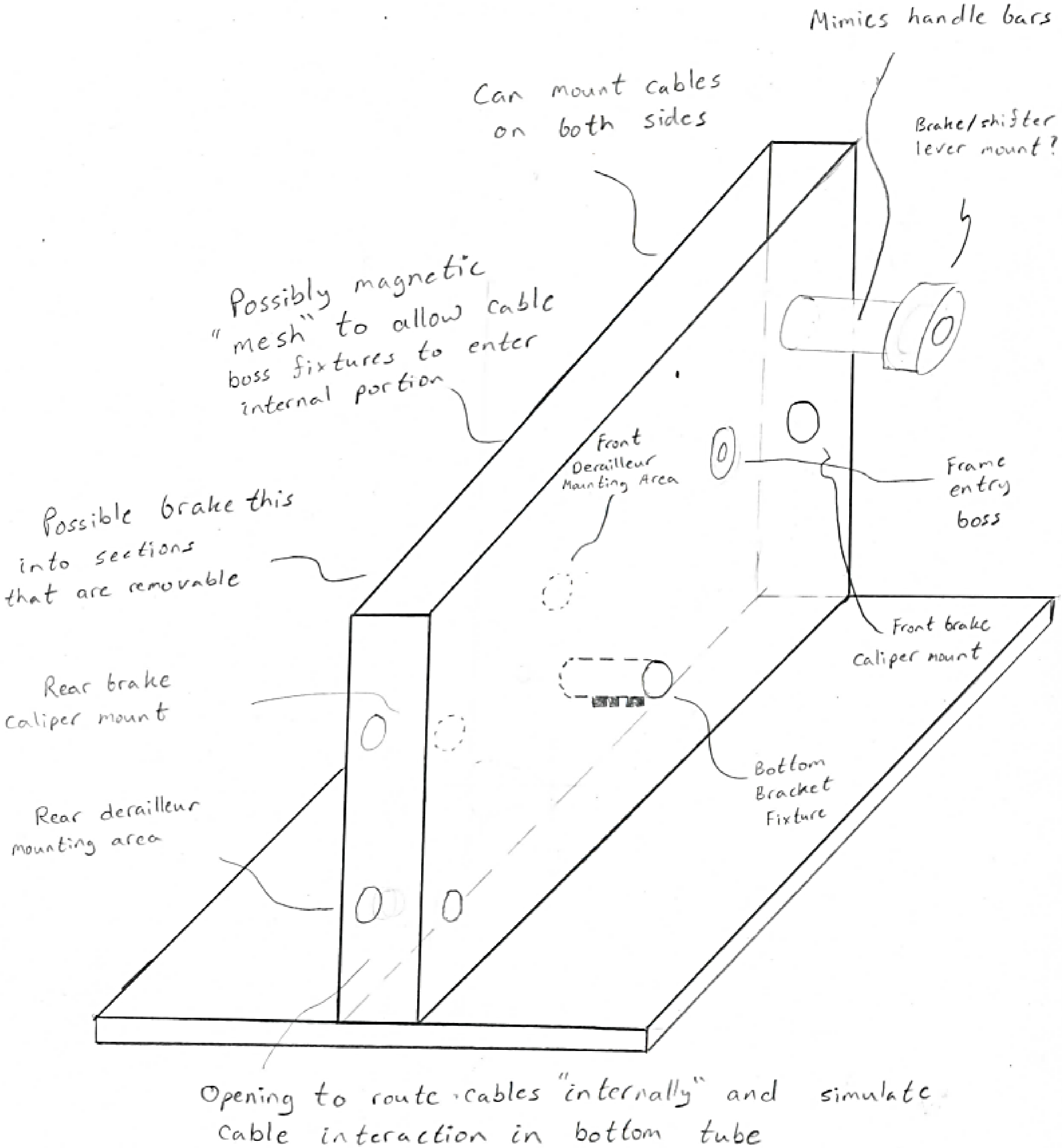
Measurement System Decision Matrix

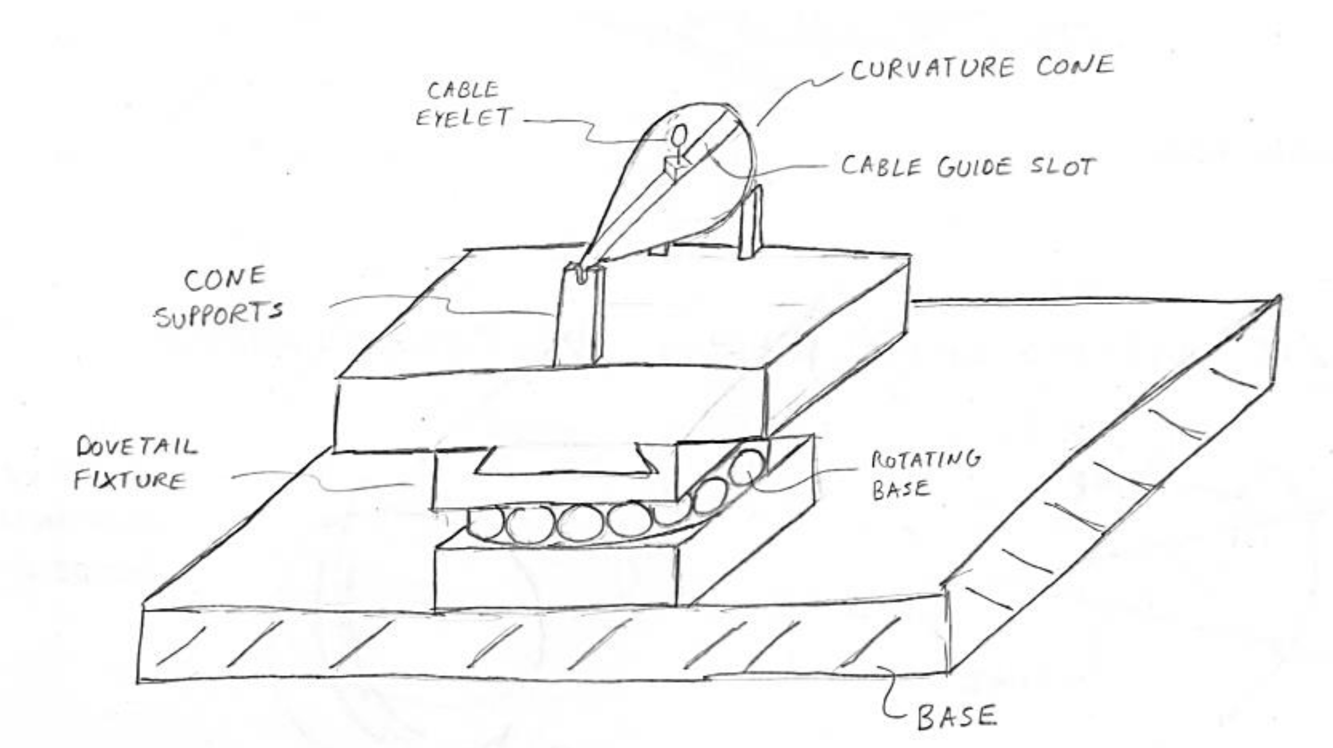
Concepts / Criteria	Linear Force Gauge	Digital Torque Measurement	3-Point Digital Gage	Strain Gage	Linear Spring Deflection	Torsional Spring Deflection
						
Modularity		0	0	-1	-1	-1
Ease of Use		0	0	-1	-1	-1
Machinability		0	0	0	0	0
Set-up Time		-1	0	-1	-1	-1
Cost		0	0	0	1	1
Lead/Manufacture Time		0	0	0	0	0
Measurement Resolution		-1	0	-1	-1	-1
Totals	DATUM	-2	0	-4	-3	-3

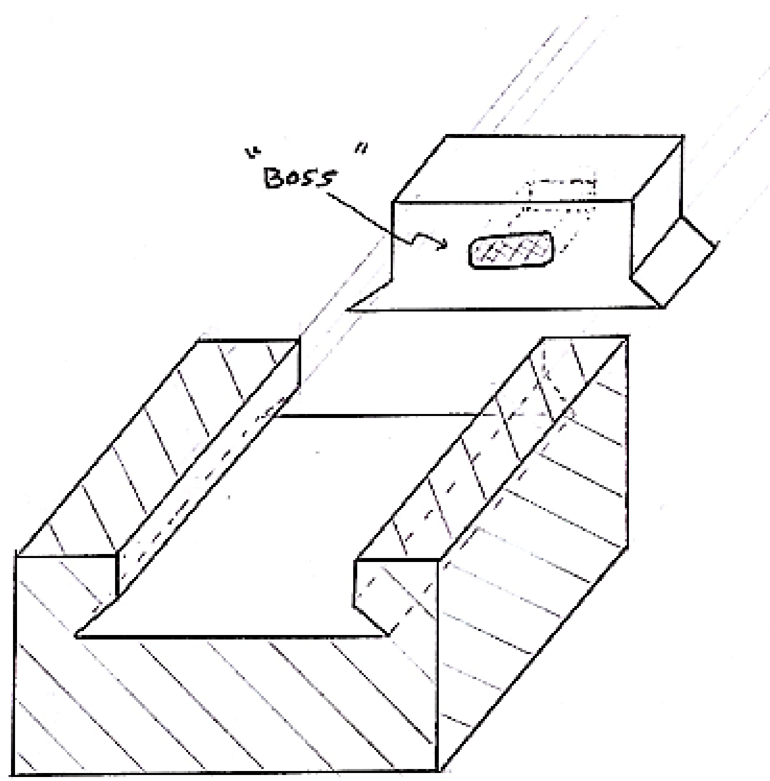
Position Control Decision Matrix

							
Concepts / Criteria	**Set Screws w/slots or rails**	**Grid Lines**	**Lead Screws**	**Rack and Pinion**	**Ball Screws**	**Linear Actuators**	**Turntable**
Modularity		0	0	0	0	0	0
Ease of Use		1	-1	-1	-1	-1	0
Machinability		1	0	0	0	0	0
Set-up Time		0	0	0	0	0	0
Cost		0	-1	-1	-1	-1	-1
Lead/Manufacture Time		1	-1	-1	-1	-1	0
Measurement Resolution		0	1	1	1	1	0
Totals	DATUM	3	-2	-2	-2	-2	-1

Preliminary Drawings

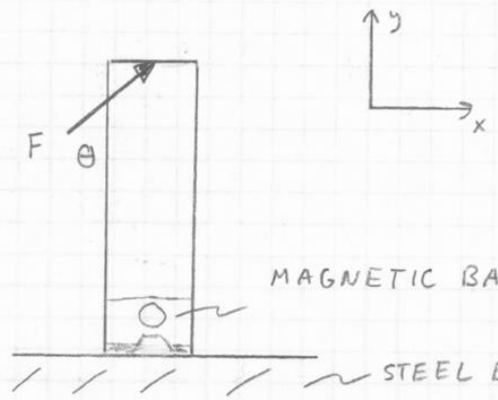


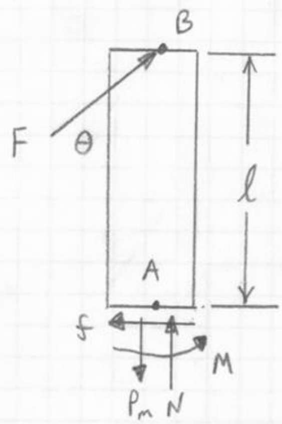

CABLE EYELET
CURVATURE CONE
CABLE GUIDE SLOT
CONE SUPPORTS
DOVETAIL FIXTURE
ROTATING BASE
BASE


"BOSS"

MAGNET LOADING

P_m - MAGNET PULL FORCE
f - FRICTION FORCE
F - APPLIED LOAD
θ - APPLICATION ANGLE





$$\Sigma F_y: F\cos\theta + N - P_m = 0$$
$$N = P_m - F\cos\theta$$

$$\Sigma F_x: F\sin\theta = f = \mu N$$

$$+\circlearrowright \Sigma M_B: M - f\ell = 0$$
$$M = f\ell = \mu N \ell$$
$$M = \mu(P_m - F\cos\theta)\ell$$

$$+\circlearrowright \Sigma M_A: M - F\sin\theta\,\ell = 0$$
$$M = F\sin\theta\,\ell$$

$$\therefore\ \mu(P_m - F\cos\theta)\cancel{\ell} = F\sin\theta\,\cancel{\ell}$$

$$P_m = \frac{F\sin\theta}{\mu} + F\cos\theta$$

$$P_m = F\left(\frac{\sin\theta}{\mu} + \cos\theta\right)$$

FOR MAGNET TO STAY GROUNDED,

$$P_m > F\left(\frac{\sin\theta}{\mu} + \cos\theta\right)$$

THIS SHOW THE COEFFICIENT OF FRICTION, μ, PLAYS AN IMPORTANT ROLE IN THIS LOADING CASE.

Safety Design Checklist

- Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and shear points?
  - Pinch points at force actuation and points of derailleur movement
- Can any part of the design undergo high accelerations?
  - No
- Will the system have any large moving masses or large forces?
  - No
- Will the system produce a projectile?
  - No
- Could the system fall under gravity creating injury?
  - Yes
- Will a user be exposed to overhanging weights in the design?
  - No
- Will the system have any sharp edges?
  - No
- Will any part of the electrical systems not be grounded?
  - No
- Will there be any large batteries or electrical voltage in the system above 40 V either AC or DC?
  - No
- Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
  - No
- Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
  - No
- Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
  - No
- Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
  - No
- Can the system generate high levels of noise?
  - No
- Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?
  - No
- Is it possible for the system to be used in an unsafe manner?
  - No
- Will there be any other potential hazards not listed above?
  - No

Actions List:

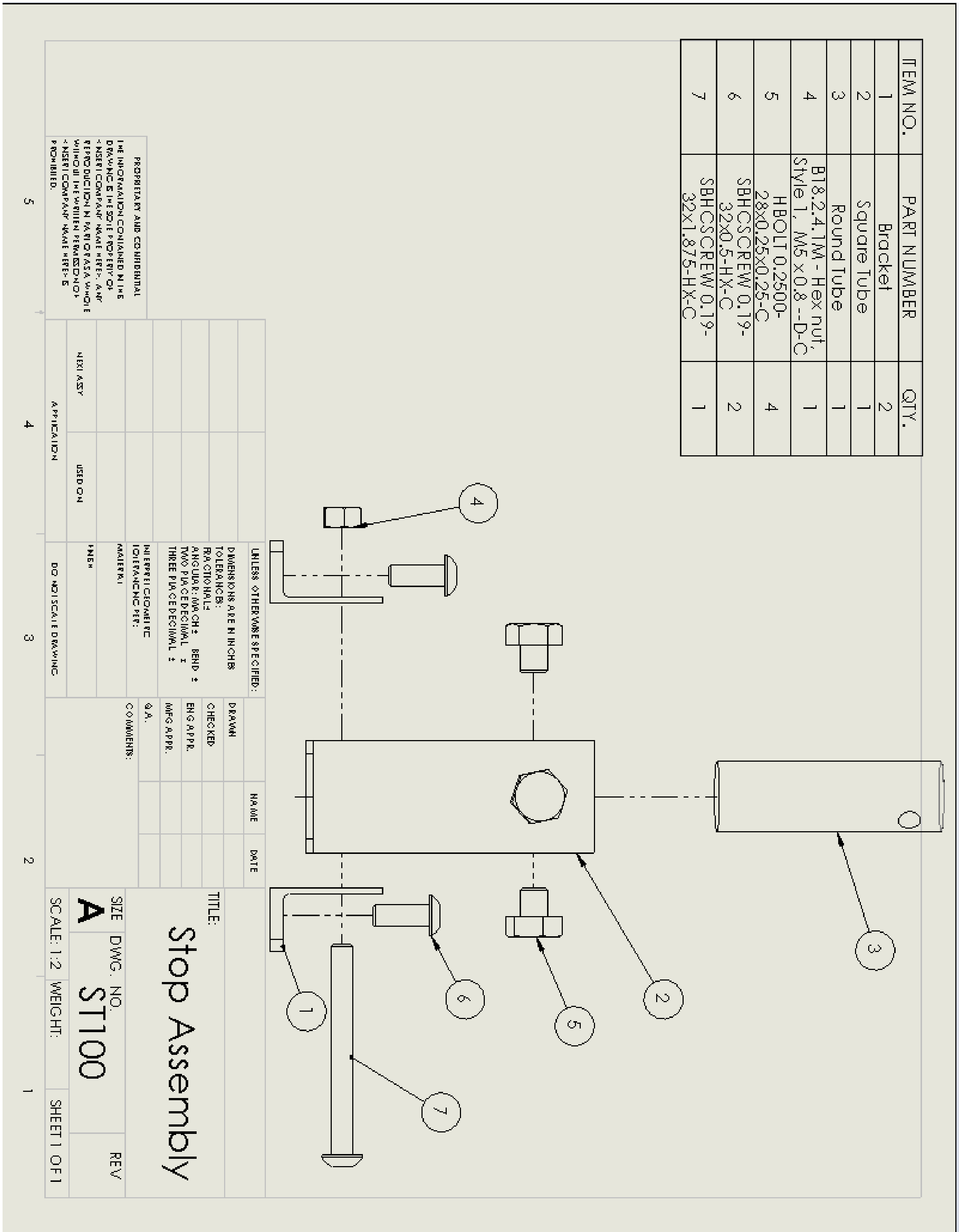
Hazard	Corrective Actions	Estimated Completion Date	Actual Completion Date
Pinch Points	Warning labels	5/22/15	
System Falling	Ensure mounting table is securely fastened	5/22/15	5/27/15

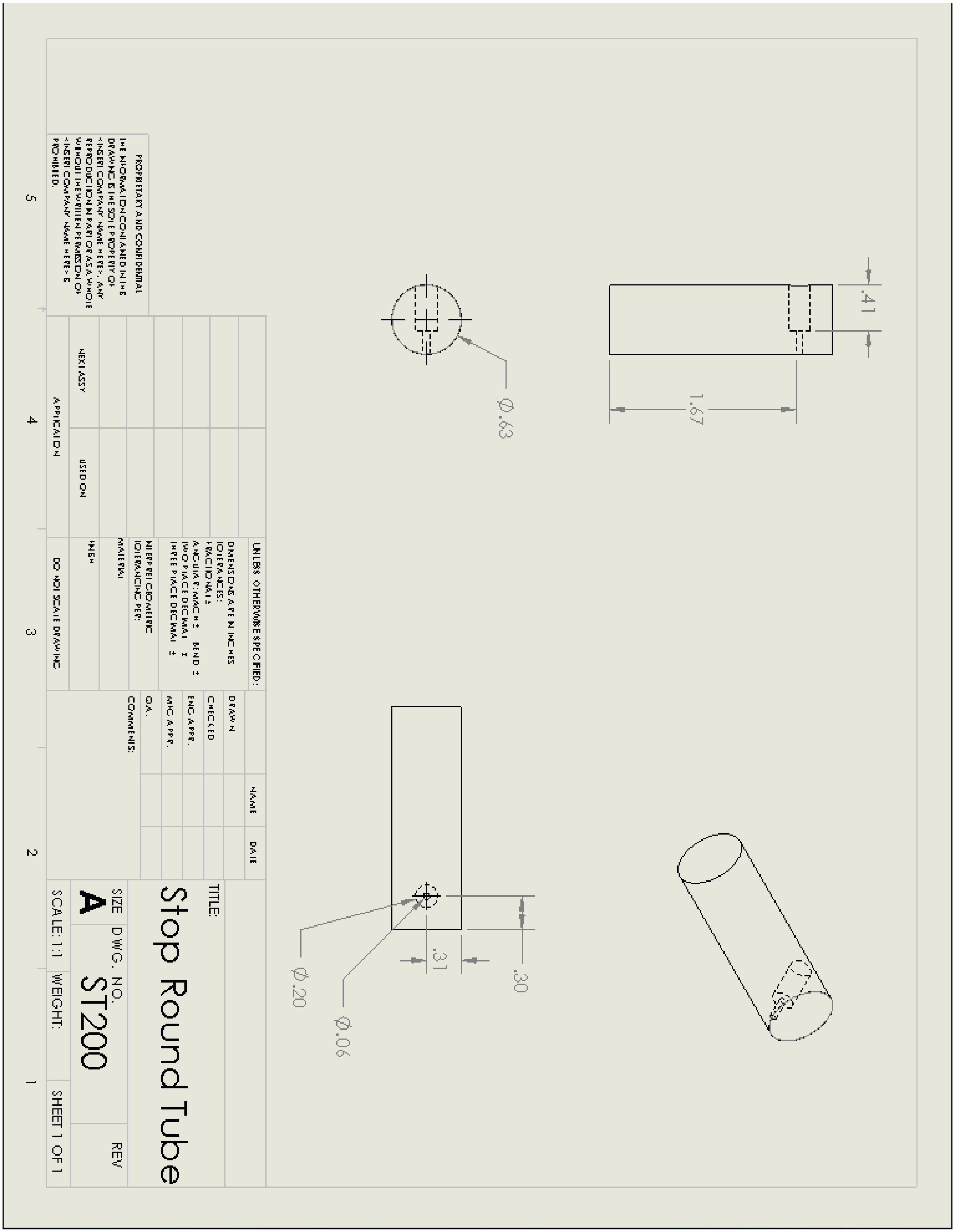
Appendix B

DRAWING NUMBERS LIST

Fixtures	
Bottom Bracket	*BB100-X00*
BB Assembly	BB100
BB Center Fixture	BB200
BB Slide Arm Inner	BB300
BB Slide Arm Outer	BB400
Pseudo BB Guide	BB500
Handlebars	*HB100-X00*
HB Assembly	HB100
HB Fixture Base	HB200
HB Fixture Stem	HB300
HB Fixture Stop	HB400
HB Load Cell Support	HB500
HB Fixture HB	--
Load Cell Fixture	LC200
HB Clamp	--
Stops	*ST100-X00*
Stop Assembly	ST100
Stop Round Stock	ST200
Stop Square Tube	ST300
Stop Bracket	ST400
Derailleurs	*F/RD100*
Front Derailleur Guide	FD100
Rear Derailleur Guide	RD100
CNC Assembly	*CNC100 -X00*
BB1	CNC100
BB2	CNC200
Brake1	CNC300
Brake2	CNC400
Vertical Slide Dual Assembly	*VS100 -X00*
Vertical Slide Assembly	VS100
Magnetic Base	--
Magnetic Base Connecting Plate	VS200
Vertical Slide Rotary Plate	VS300
Vertical Slide	--
Load Cell	LC100-X00
Load Cell Assembly	LC100
Load Cell Fixture	LC200
Measurement	AM100-X00
Angular Measurement System	AM100
Rotary Potentiometer	--
Lining Plate	AM200

STOP FIXTURE





Stop Round Tube
TITLE:
SIZE
A
DWG. NO.
ST200
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
UNLESS OTHERWISE SPECIFIED:
DO NOT SCALE DRAWING
APPLICATION
NEXT ASSY
USED ON
MATERIAL
FINISH
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
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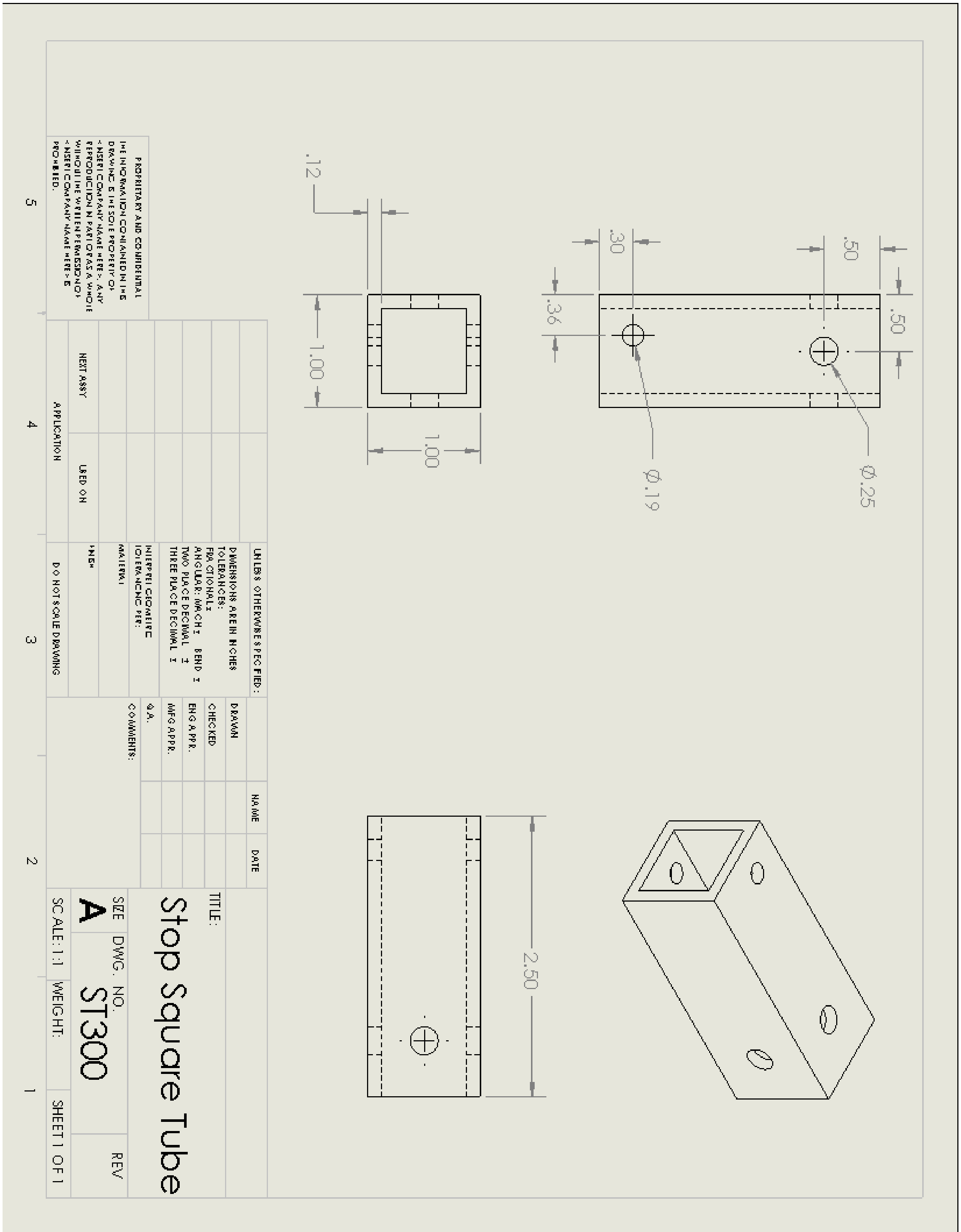
.41
.30
.31
Ø.20
Ø.06



PROPRIETARY AND CONFIDENTIAL
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
MATERIAL
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
TITLE:
Stop Square Tube
SIZE
A
DWG. NO.
ST300
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
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1.00
1.00
.30
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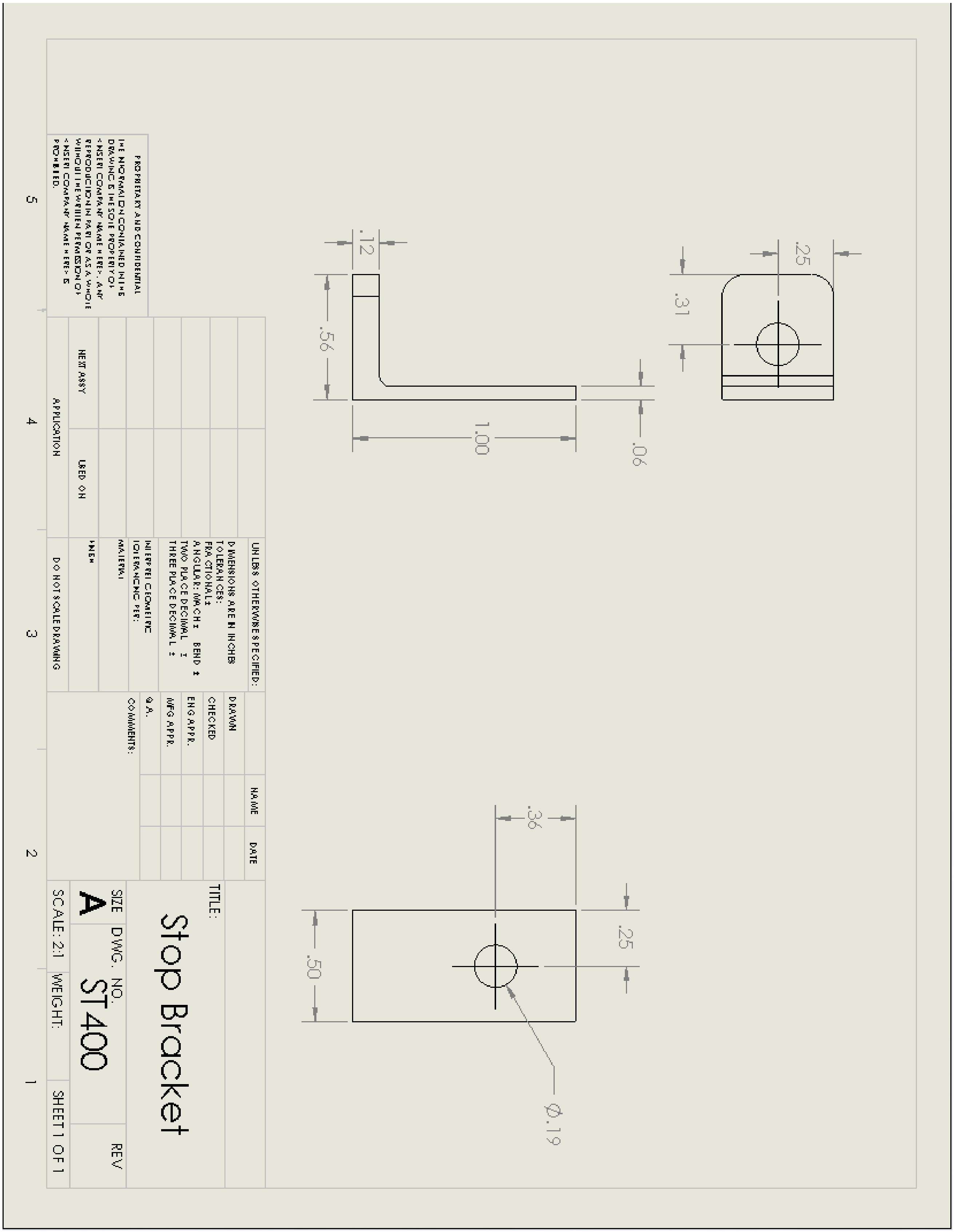
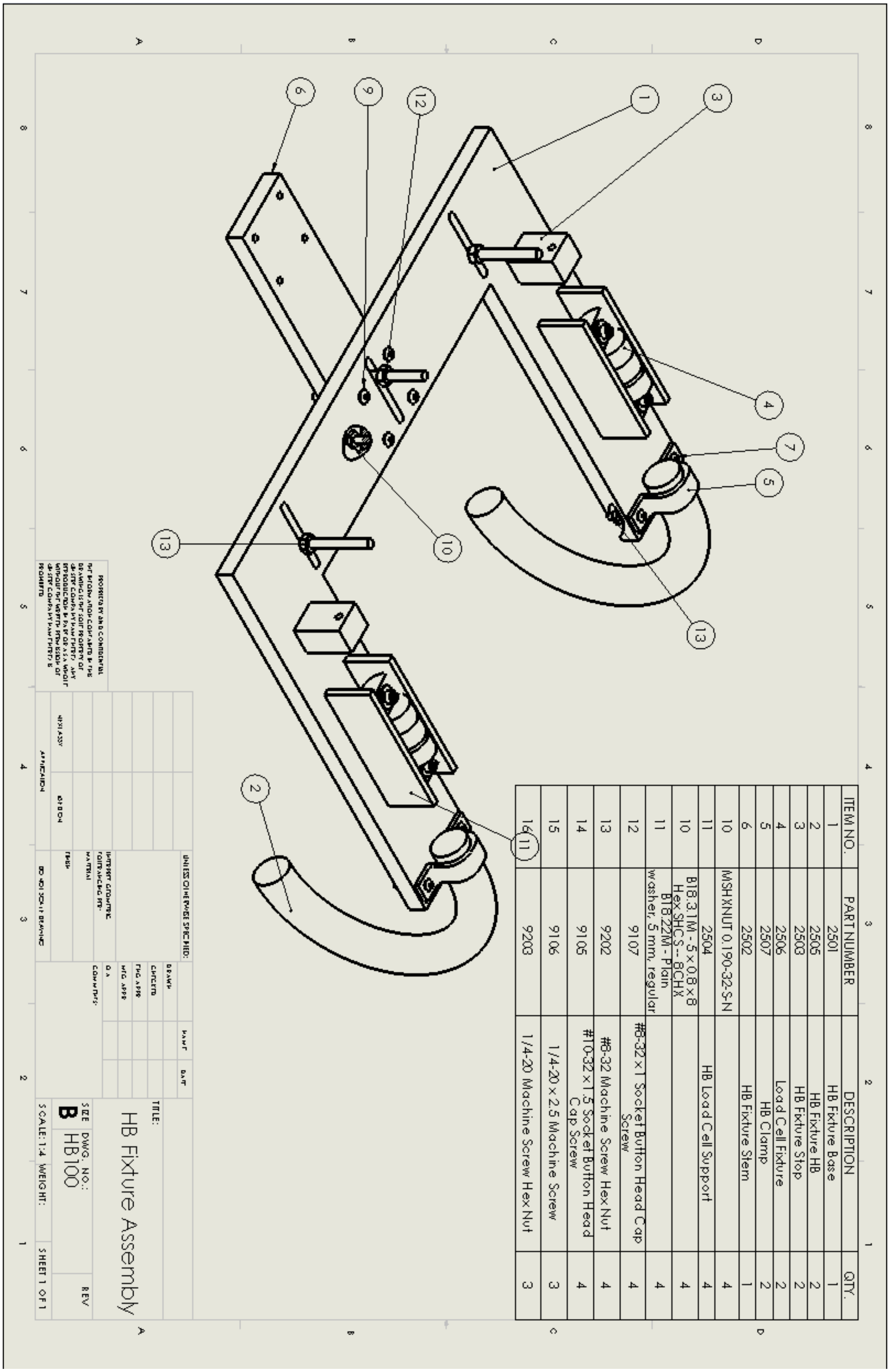
Ø.19
Ø.25
2.50
1
2
3
4
5

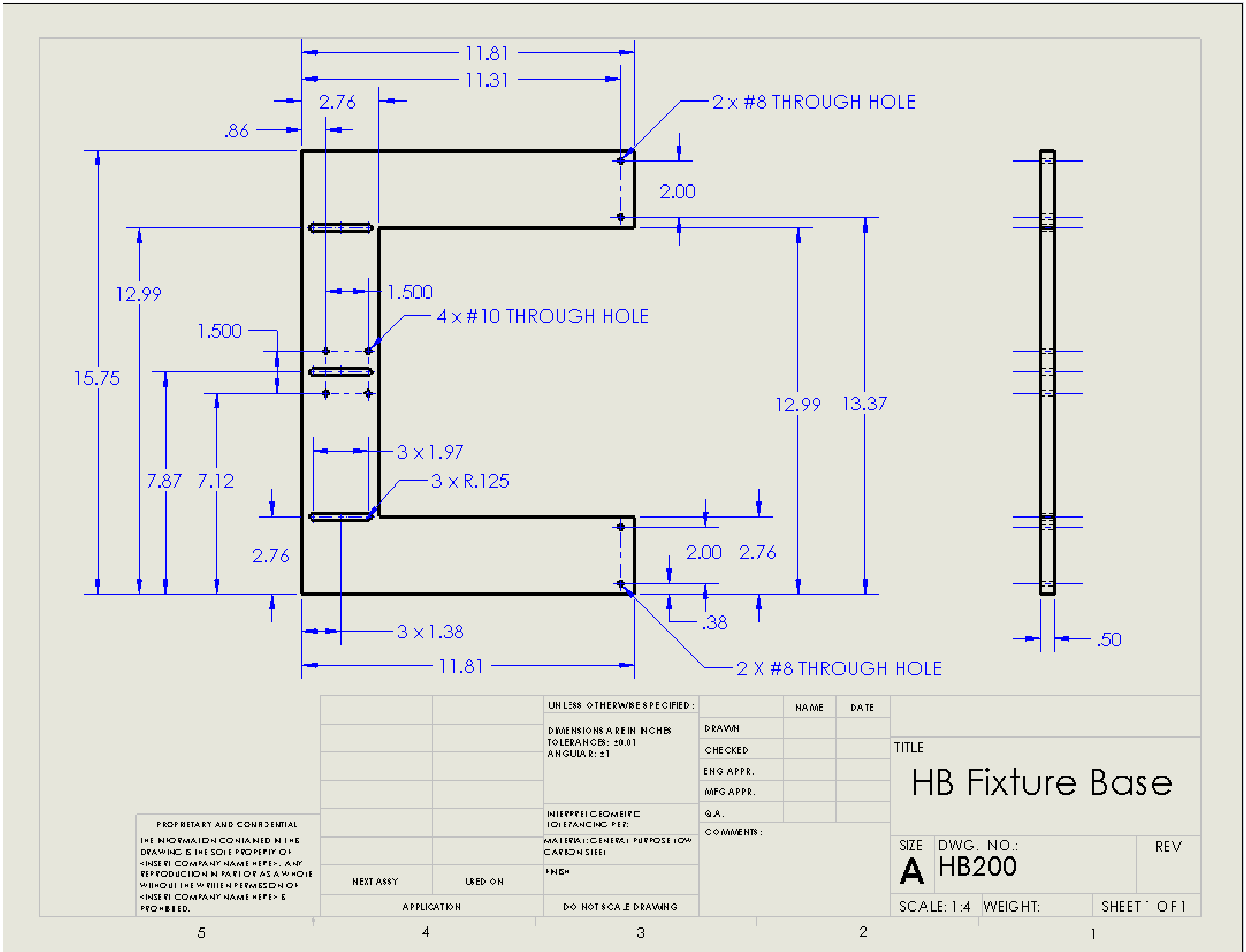


.12
.56
1.00
.06
.25
.31
.36
.25
.50
Ø.19
PROPRIETARY AND CONFIDENTIAL
NEXT ASSY
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
MATERIAL
FINISH
DO NOT SCALE DRAWING
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
TITLE:
Stop Bracket
SIZE
A
DWG. NO.
ST400
REV
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1

HANDLEBAR FIXTURE



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	2501	HB Fixture Base	1
2	2505	HB Fixture HB	2
3	2503	HB Fixture Stop	2
4	2506	Load Cell Fixture	2
5	2507	HB Clamp	2
6	2502	HB Fixture Stem	1
10	MSHXNUT 0.190-32-S-N		4
11	2504	HB Load Cell Support	4
10	B18.3.1M - 5 x 0.8 x 8 Hex SHCS -- 8CHX		4
11	B18.22M - Plain washer, 5 mm, regular		4
12	9107	#8-32 x 1 Socket Button Head Cap Screw	4
13	9202	#8-32 Machine Screw Hex Nut	4
14	9105	#10-32 x 1.5 Socket Button Head Cap Screw	4
15	9106	1/4-20 x 2.5 Machine Screw	3
16	9203	1/4-20 Machine Screw Hex Nut	3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11.31
2.76
.86
2 x #8 THROUGH HOLE
2.00
12.99
15.75
1.500
1.500
4 x #10 THROUGH HOLE
12.99
13.37
7.87
7.12
3 x 1.97
3 x R.125
2.76
2.00
2.76
.38
3 x 1.38
11.81
2 X #8 THROUGH HOLE
.50
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±0.01
ANGULAR: ±1
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
HB Fixture Base
PROPRIETARY AND CONFIDENTIAL
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
SIZE
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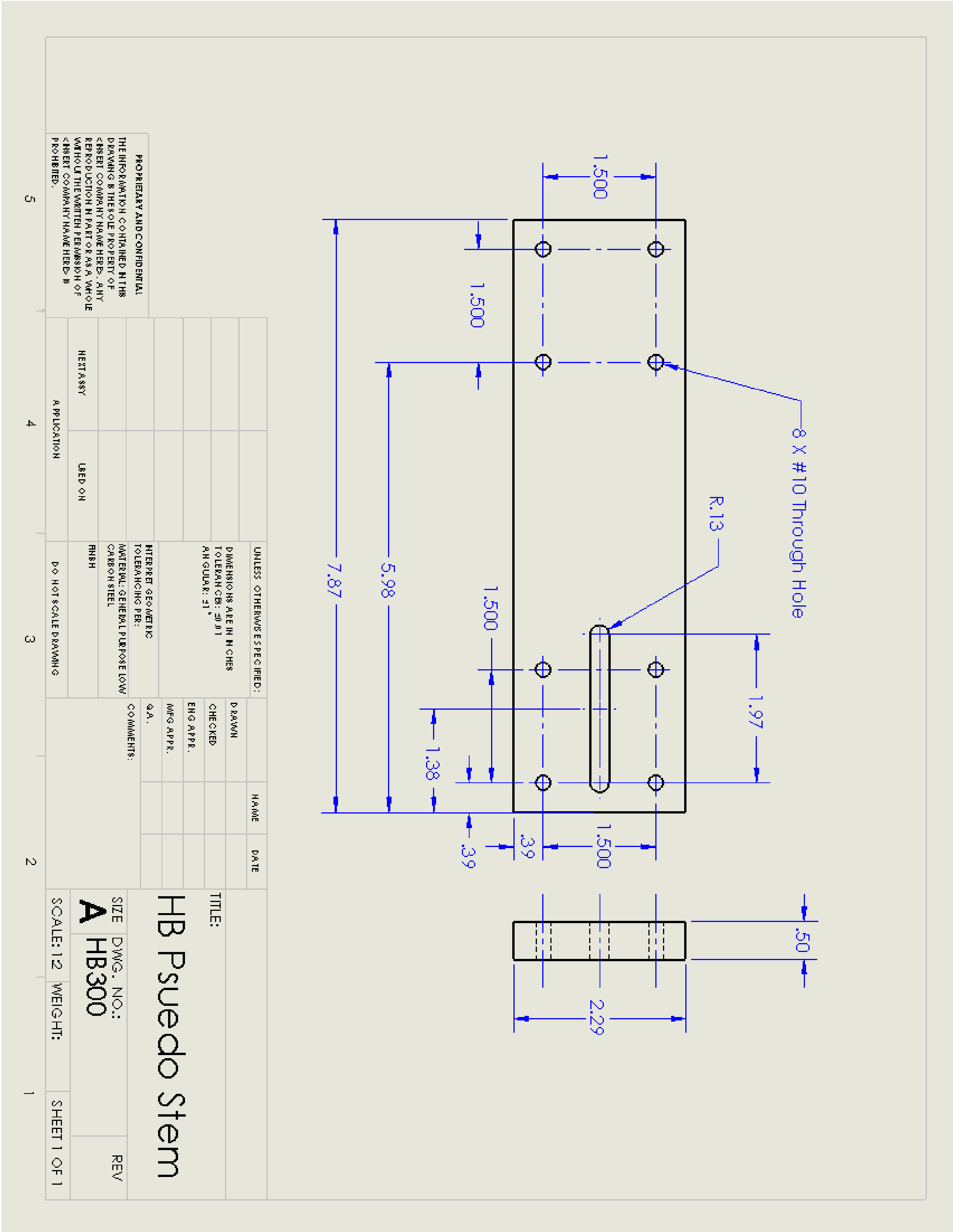
DWG. NO.:
HB200
REV
SCALE: 1:4
WEIGHT:
SHEET 1 OF 1
5
4
3
2
1


1.500
1.500
8 X #10 Through Hole
R.13
1.500
7.87
5.98
1.97
1.38
.39
.39
1.500
.50
2.29
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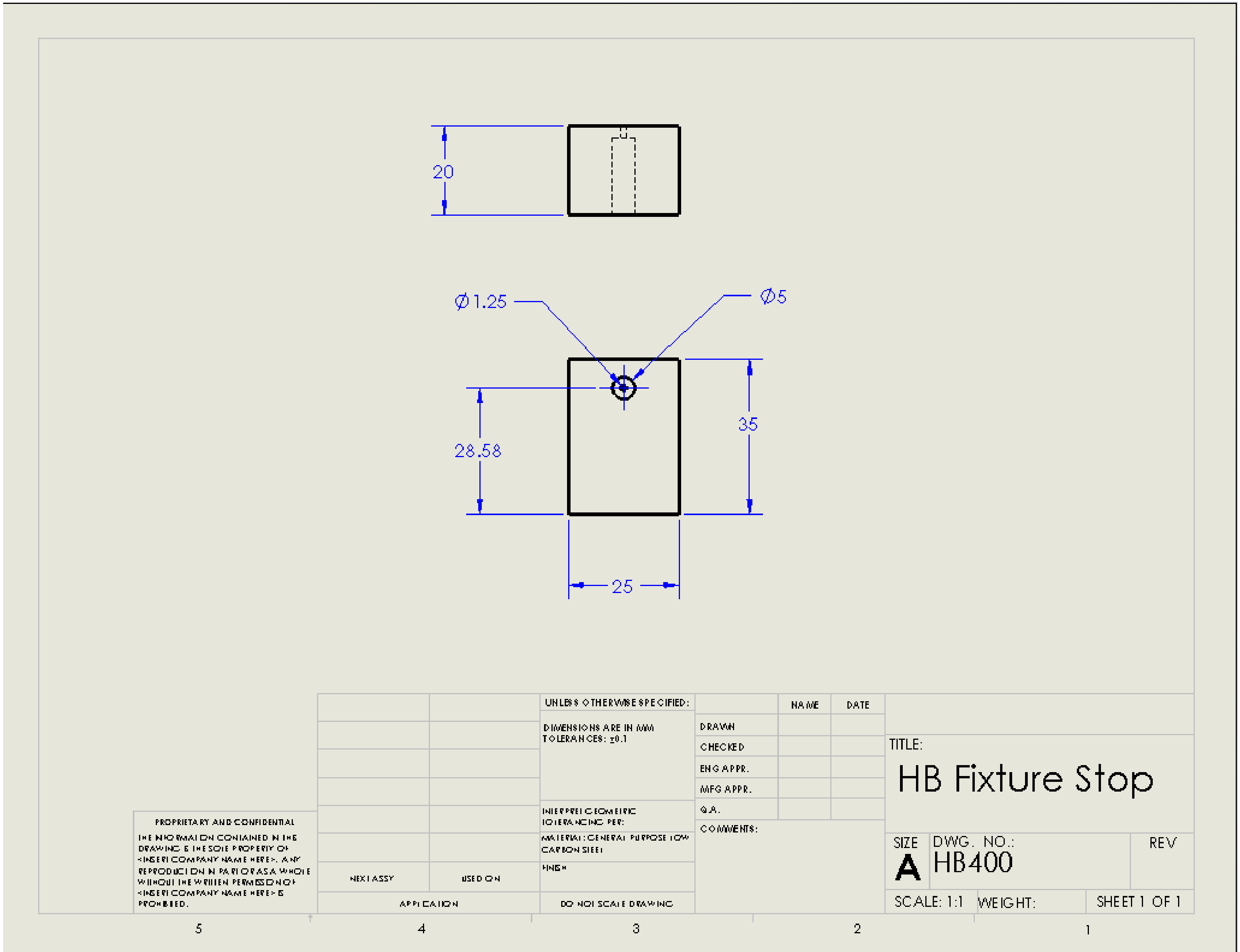
NEXT ASSY
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±0.01
ANGULAR: ±1°
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL: GENERAL PURPOSE LOW CARBON STEEL
FINISH
DO NOT SCALE DRAWING
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
TITLE:
HB Psuedo Stem
SIZE
A
DWG. NO.:
HB300
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
5
4
3
2
1


20
Ø1.25
Ø5
35
28.58
25
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES: ±0.1
INTERPRET GEOMETRIC
TOLERANCING PER:
MATERIAL: GENERAL PURPOSE LOW
CARBON STEEL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
HB Fixture Stop
SIZE
A
DWG. NO.:
HB400
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
NEXT ASSY
USED ON
APPLICATION
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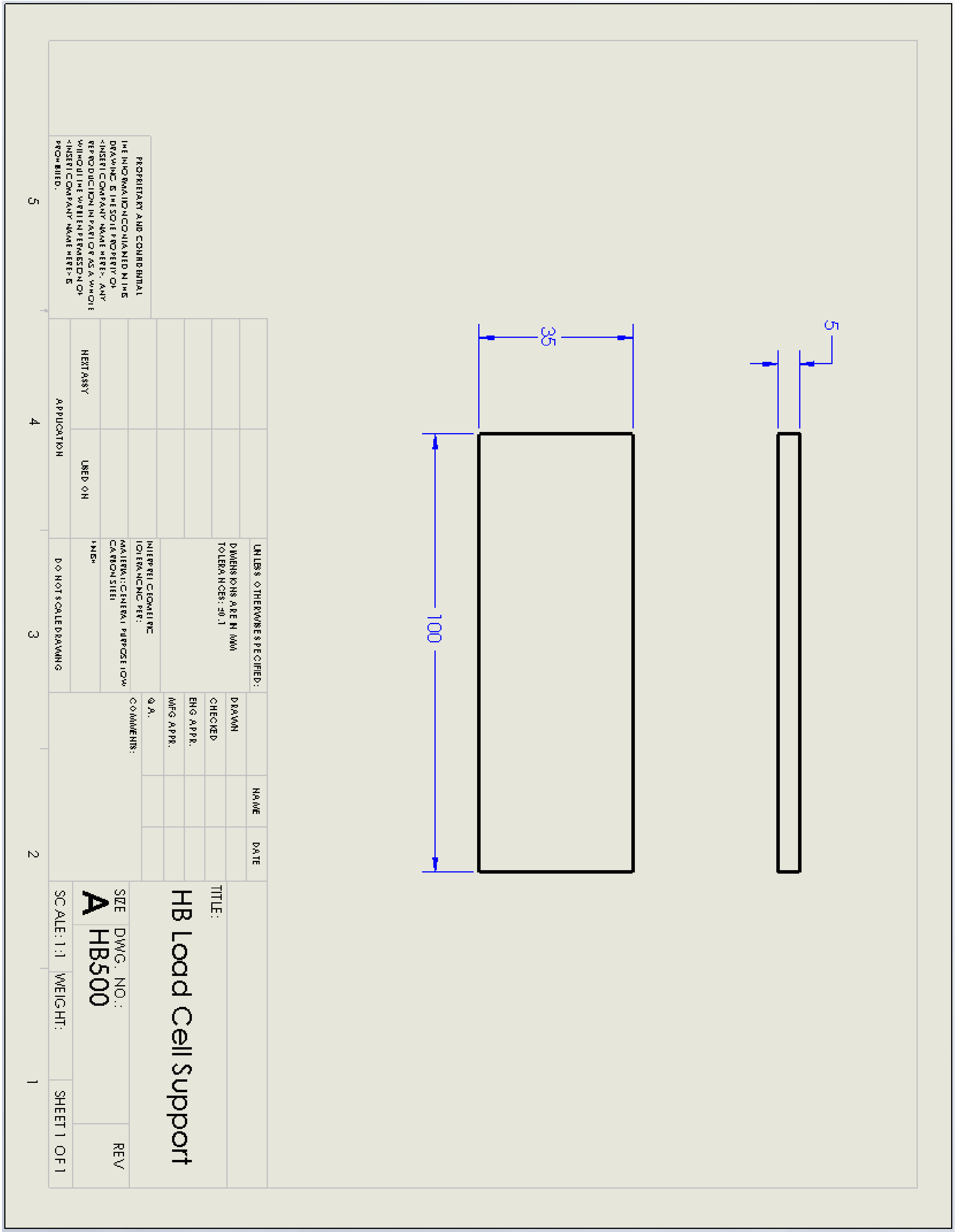
5
4
3
2
1


35
5
100
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES: ±0.1
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL: GENERAL PURPOSE LOW CARBON STEEL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
TITLE:
HB Load Cell Support
SIZE
A
DWG. NO.:
HB500
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
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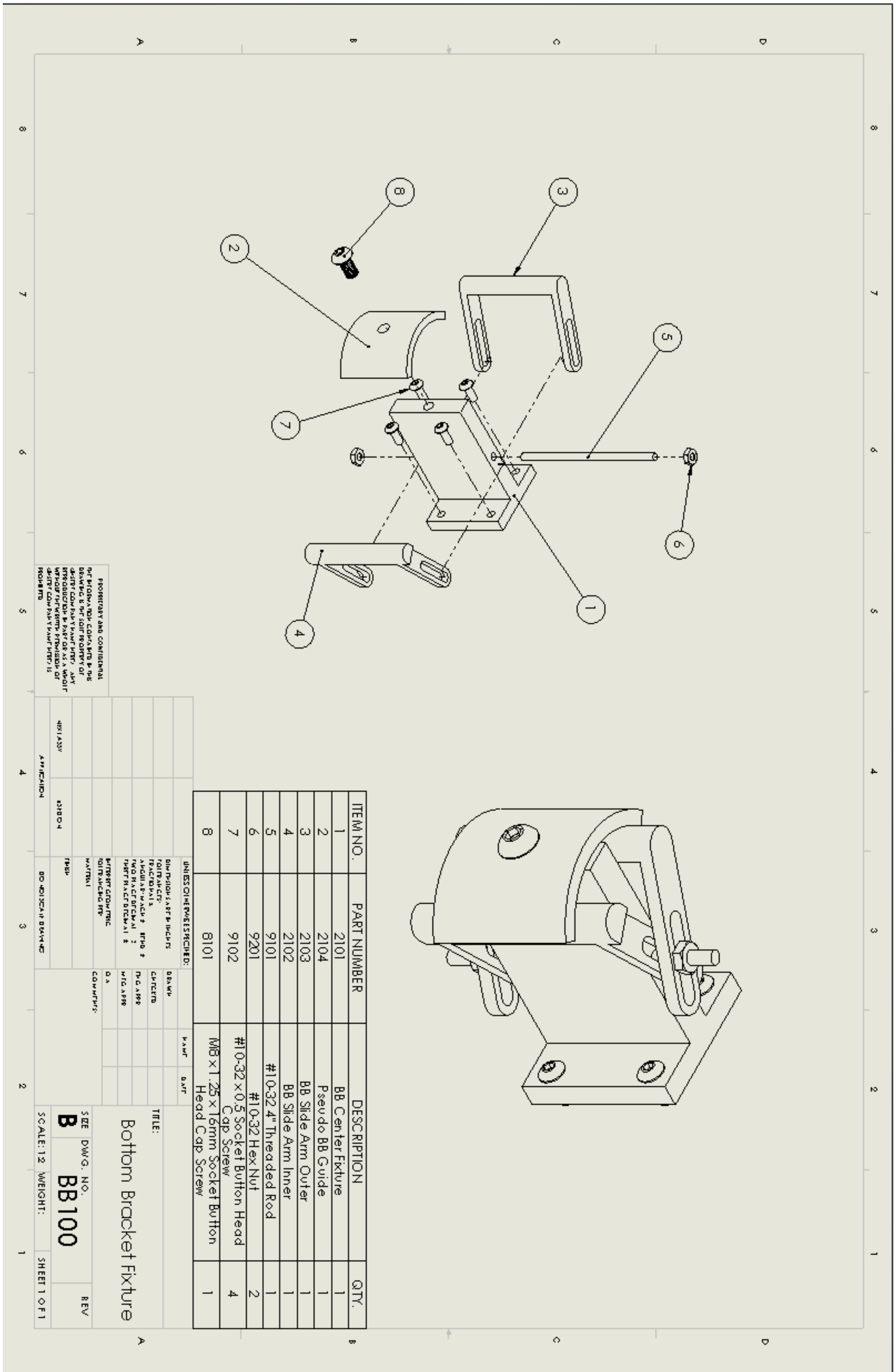
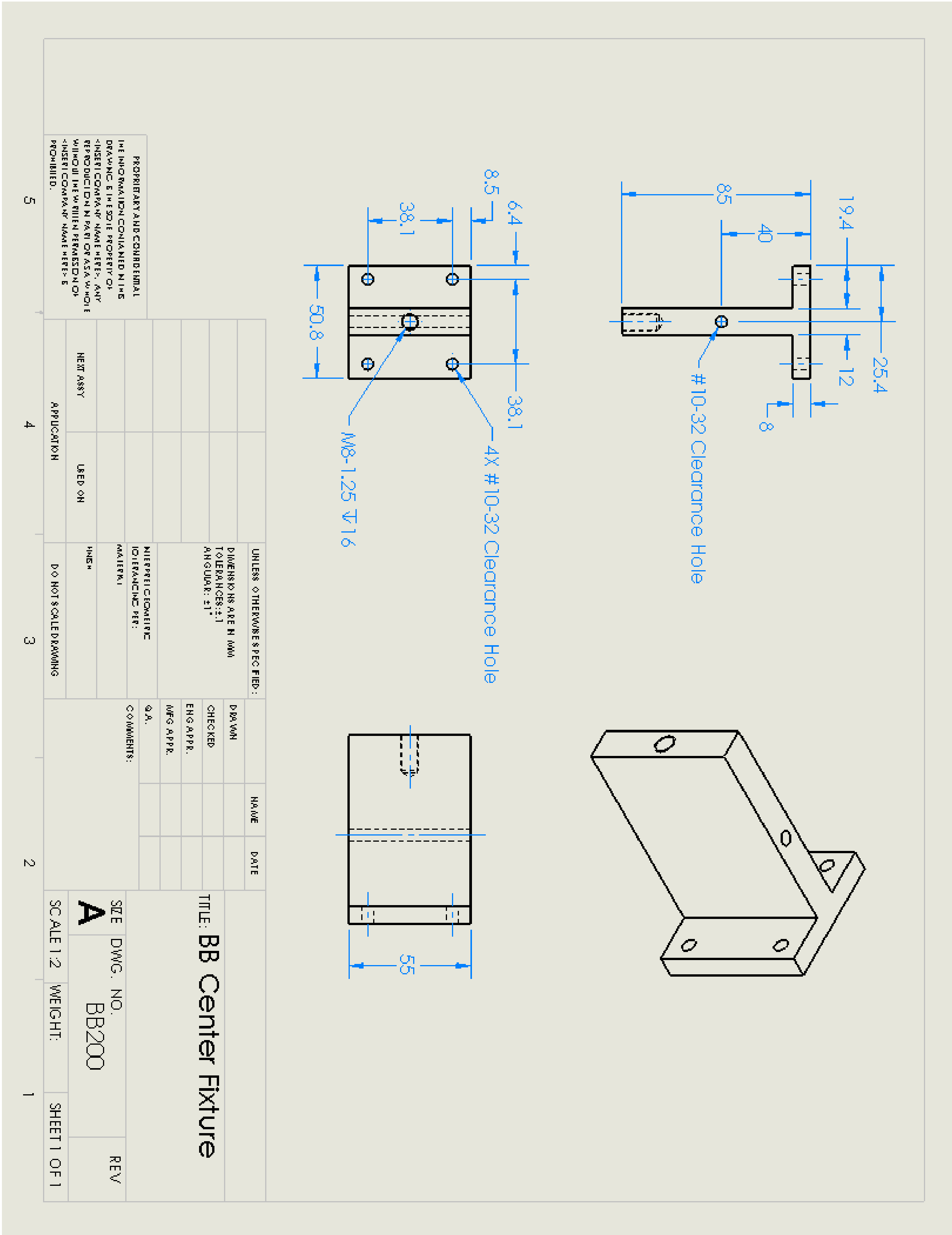
BB GUIDE FIXTURE





BB Center Fixture
BB200
85
40
19.4
25.4
12
8
#10-32 Clearance Hole
8.5
6.4
38.1
50.8
38.1
4X #10-32 Clearance Hole
M8-1.25 ⊽16
55
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES: ±.1
ANGULAR: ±1°
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
TITLE:
SIZE
A
DWG. NO.
REV
SCALE 1:2
WEIGHT:
SHEET 1 OF 1
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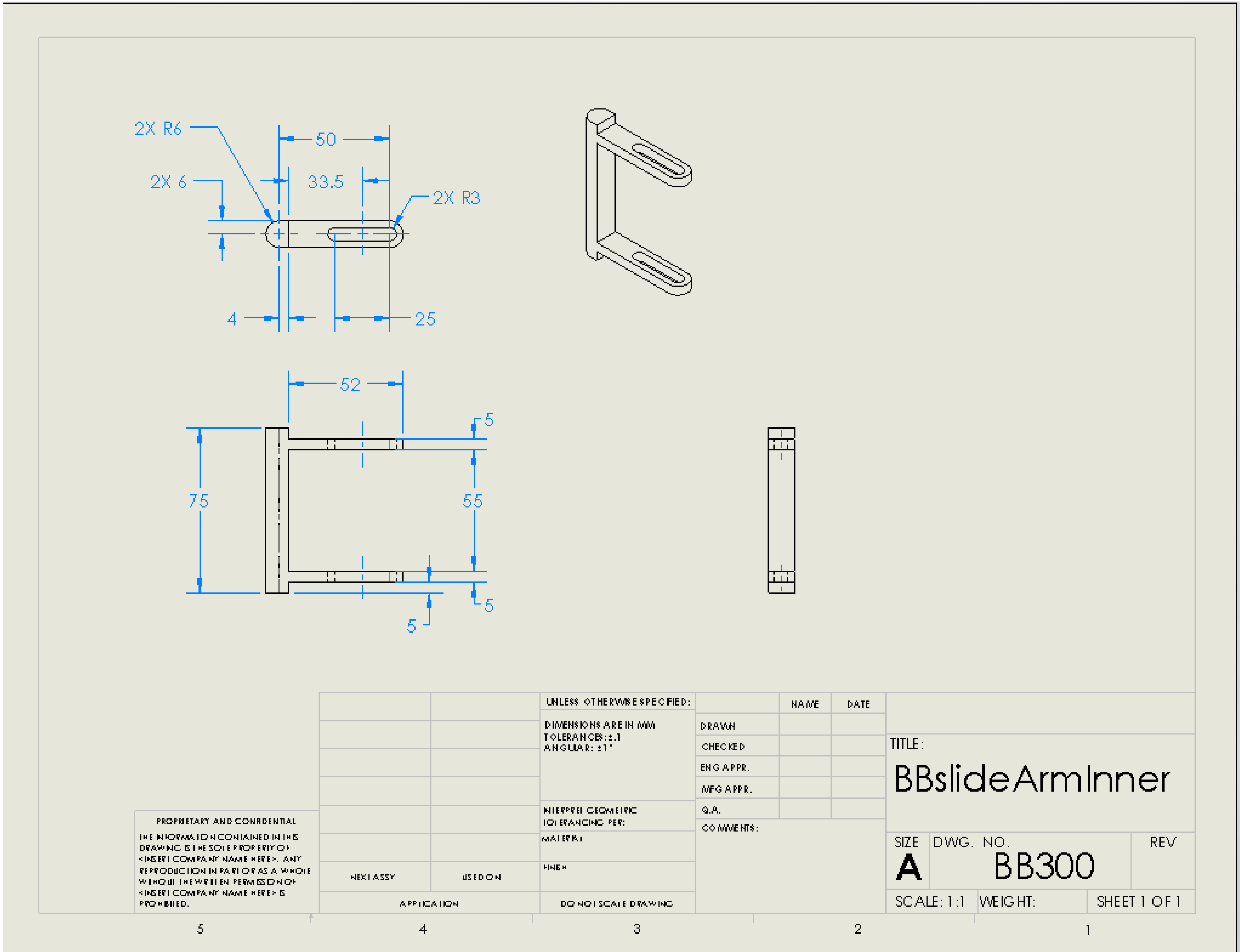
5
4
3
2
1



2X R6
2X 6
50
33.5
2X R3
4
25
52
75
55
5
5
5
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.
NEXT ASSY
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES: ±.1
ANGULAR: ±1°
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
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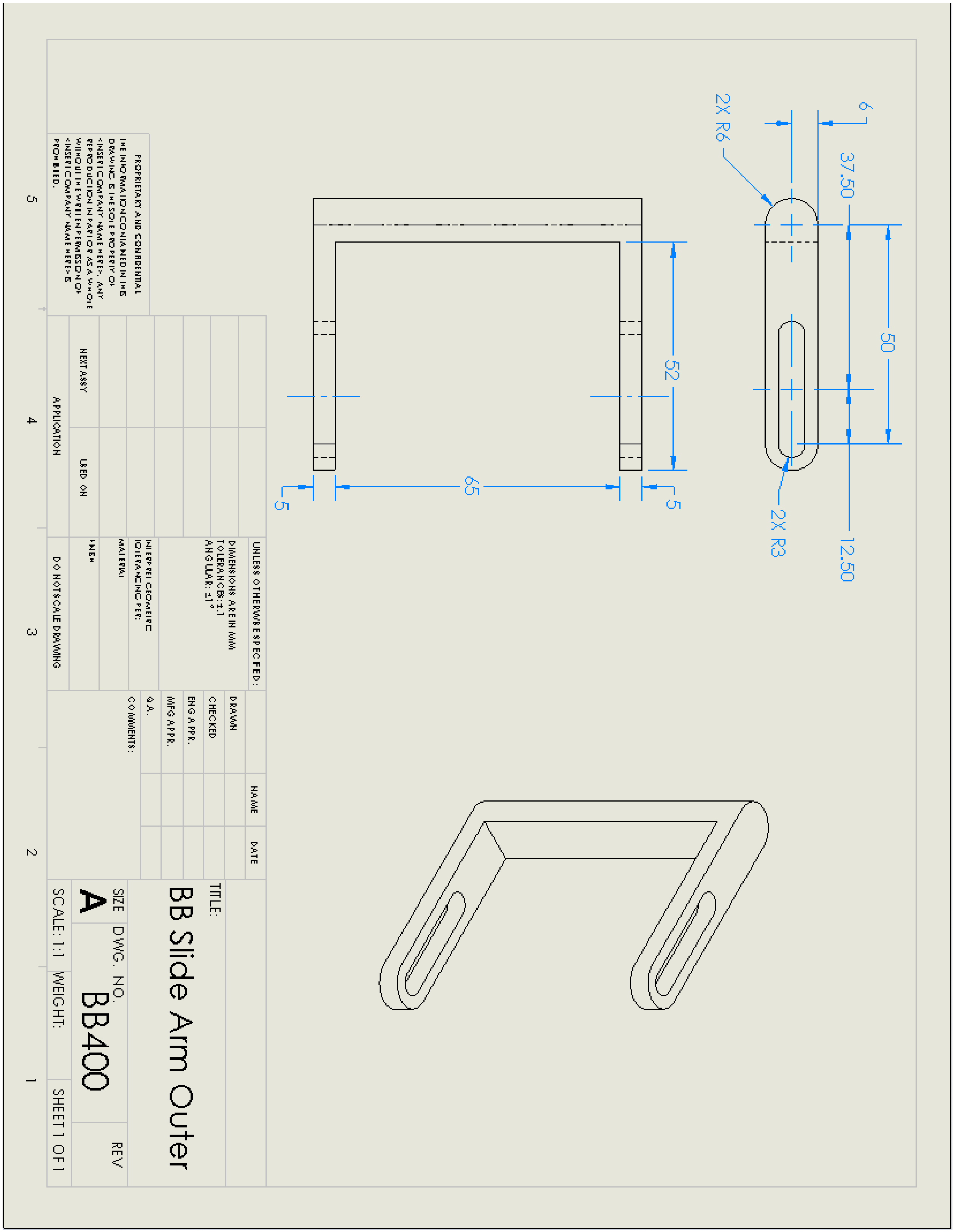
SIZE
A
DWG. NO.
BB300
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
5
4
3
2
1


BB Slide Arm Outer
TITLE:
SIZE
A
DWG. NO.
BB400
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
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DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
MATERIAL
FINISH
NEXT ASSY
USED ON
APPLICATION
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PROPRIETARY AND CONFIDENTIAL
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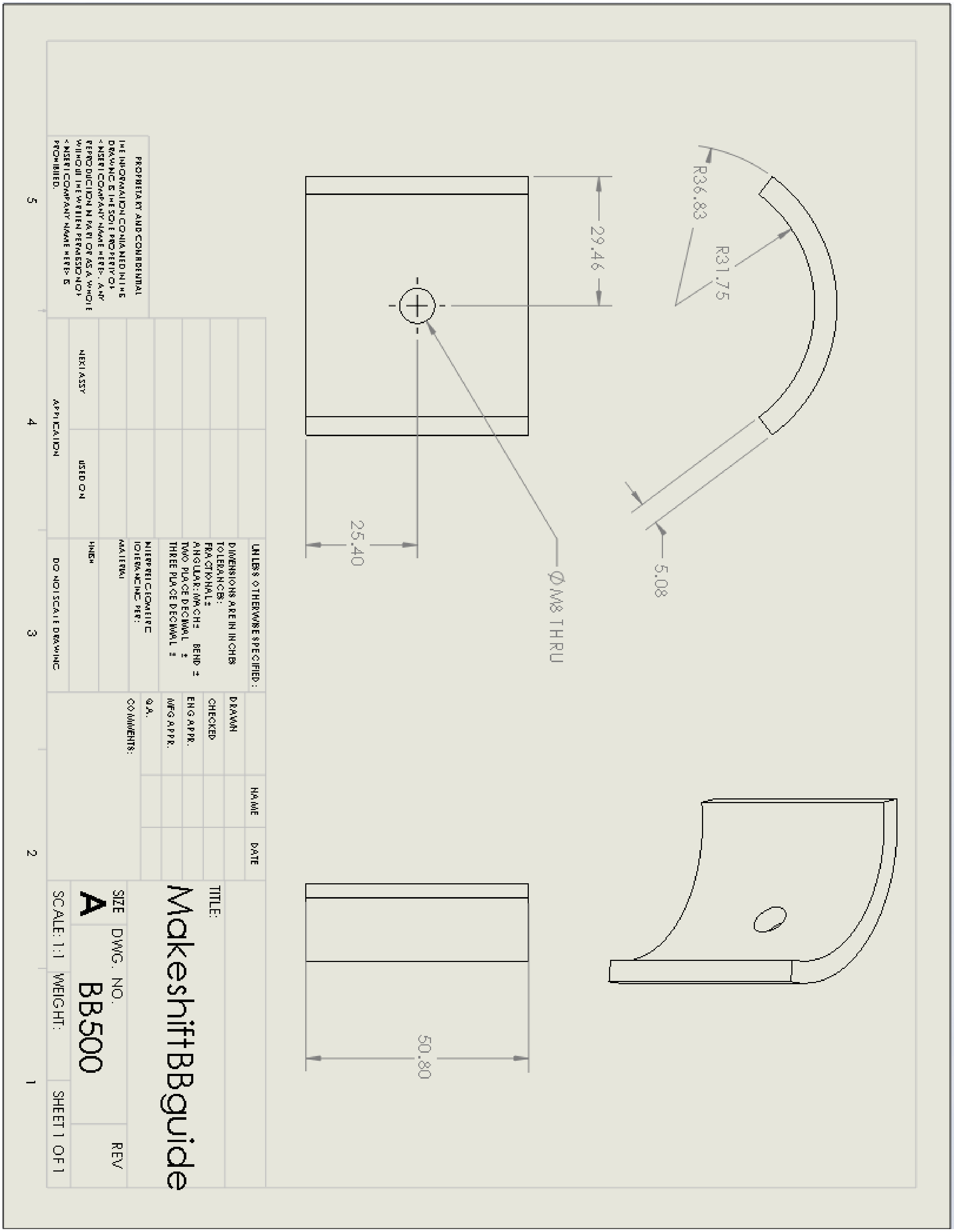
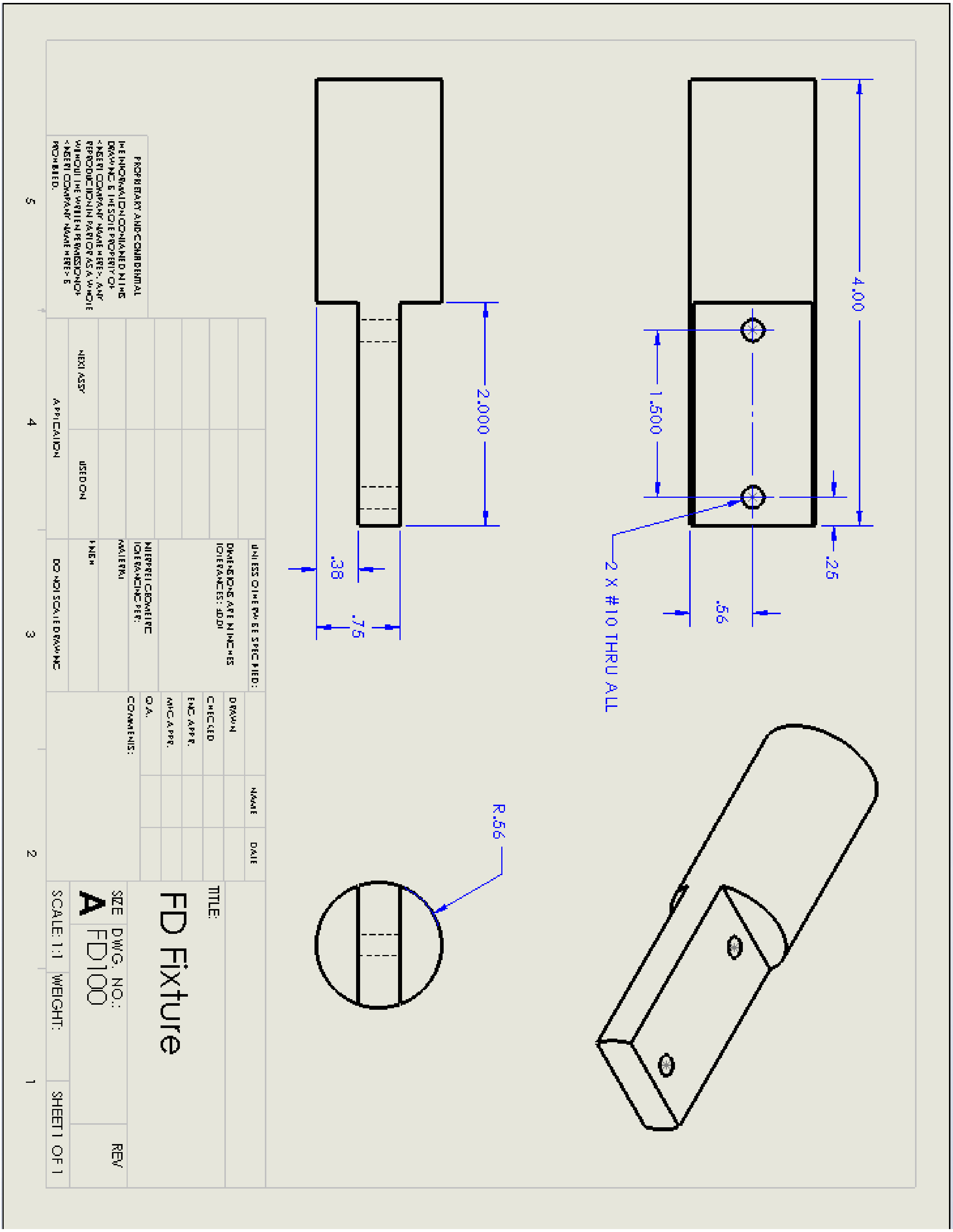
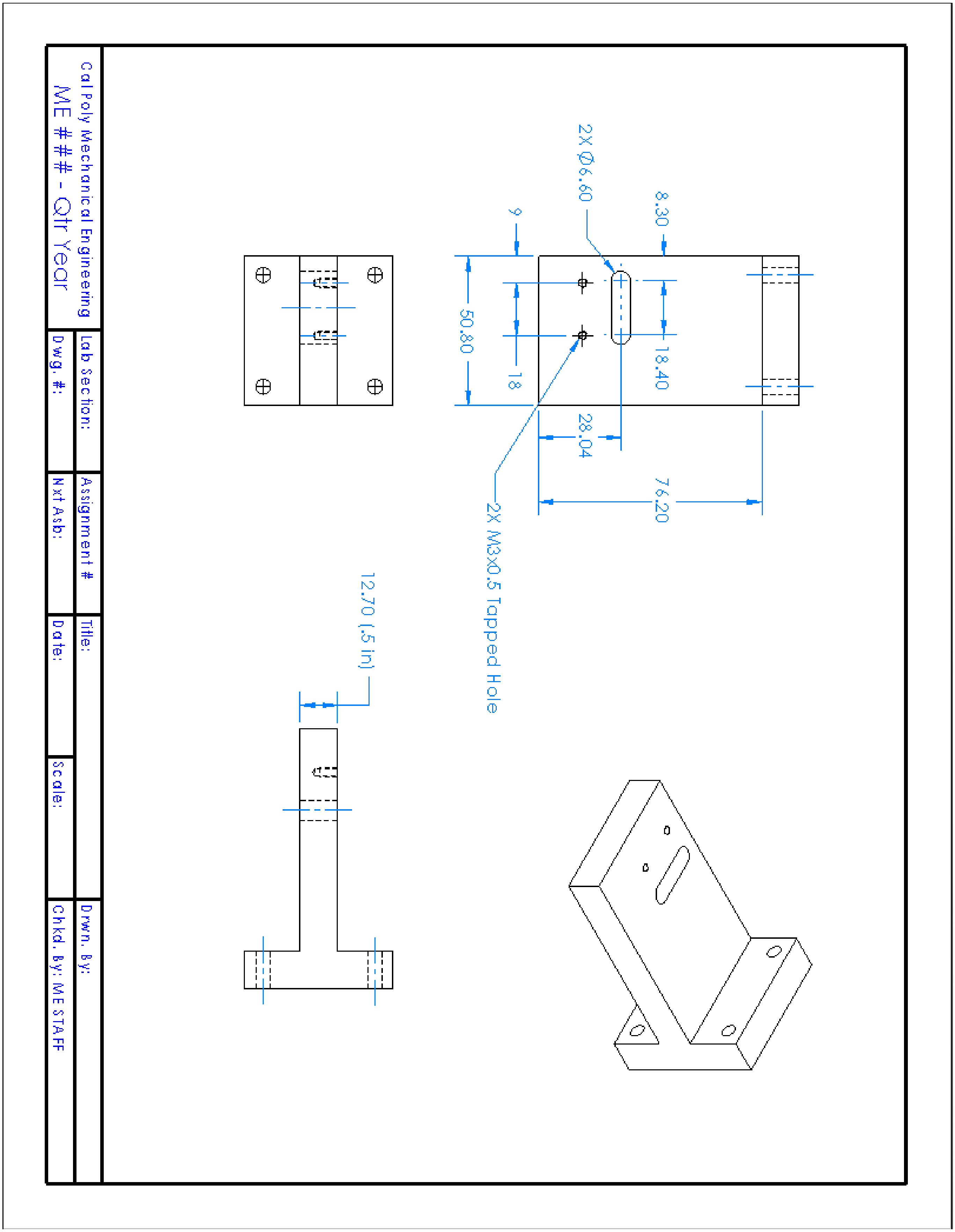
2X R3
37.50
50
12.50
52
65
6
5
5


R36.83
R31.75
29.46
25.40
5.08
Ø M8 THRU
50.80
PROPRIETARY AND CONFIDENTIAL
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
TITLE:
MakeshiftBBguide
SIZE
A
DWG. NO.
BB500
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1

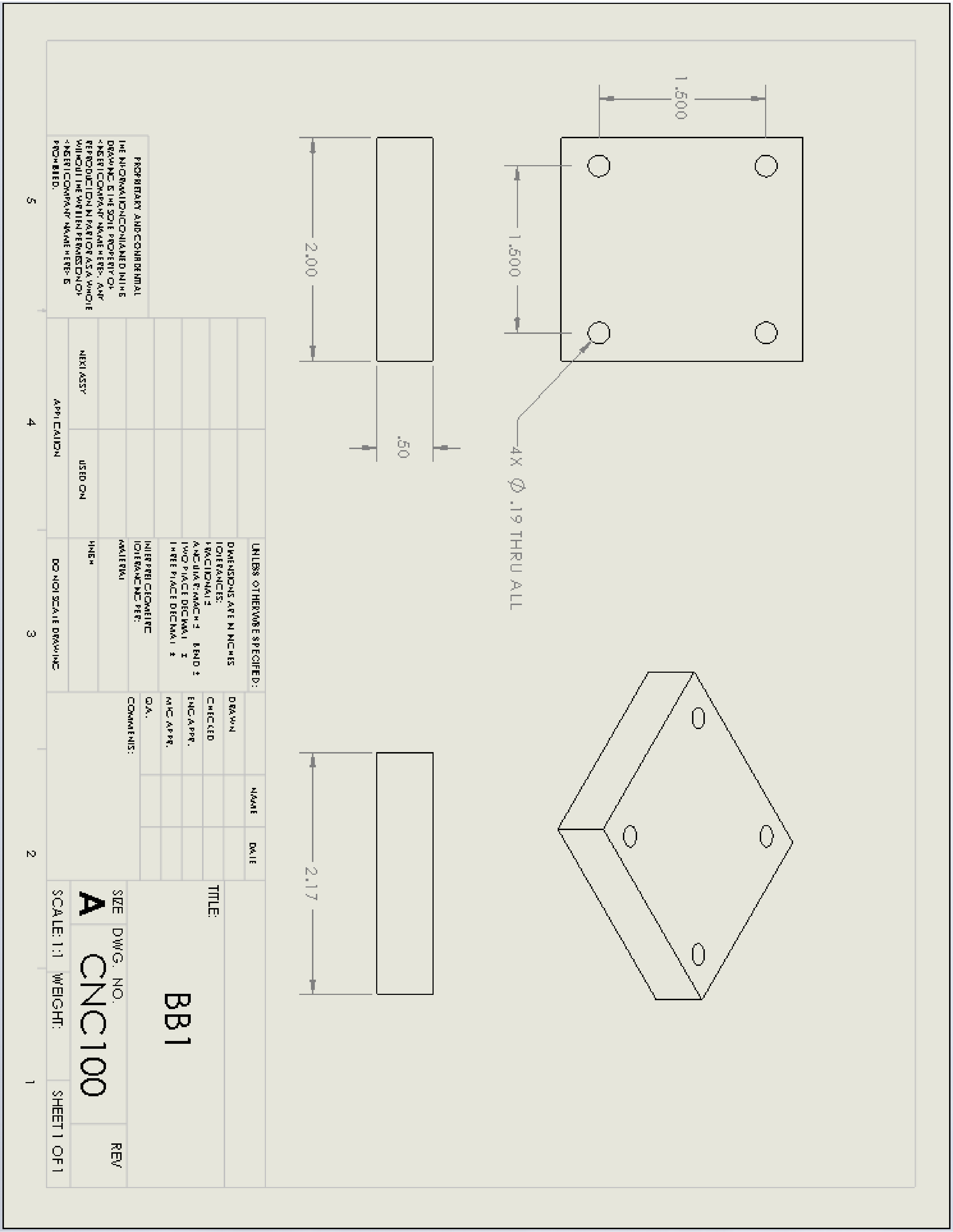
FRONT DERAILLEUR FIXTURE

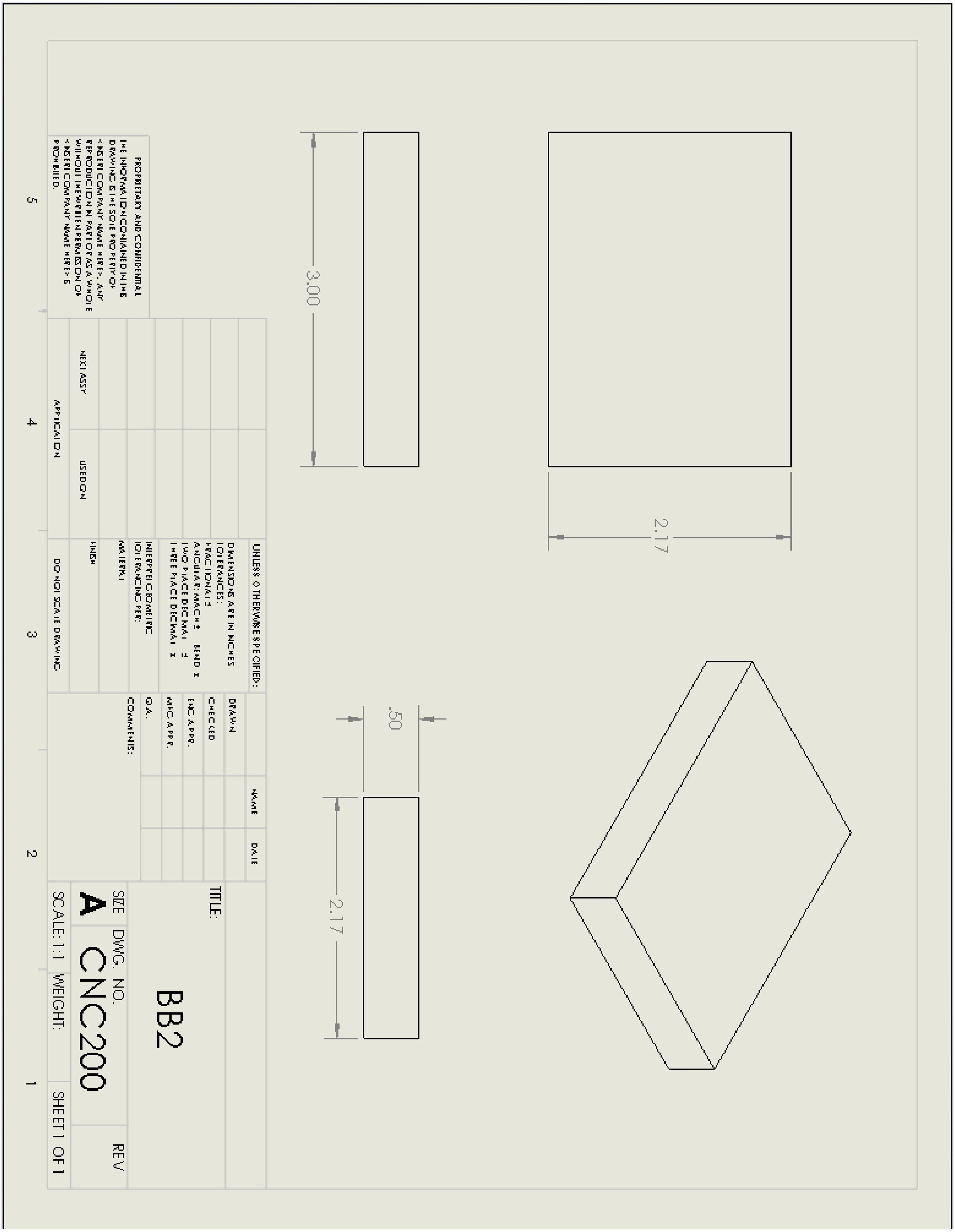


REAR DERAILLEUR FIXTURE



PARTS THAT NEED TO BE CNC MILLED




3.00
2.17
.50
2.17
PROPRIETARY AND CONFIDENTIAL
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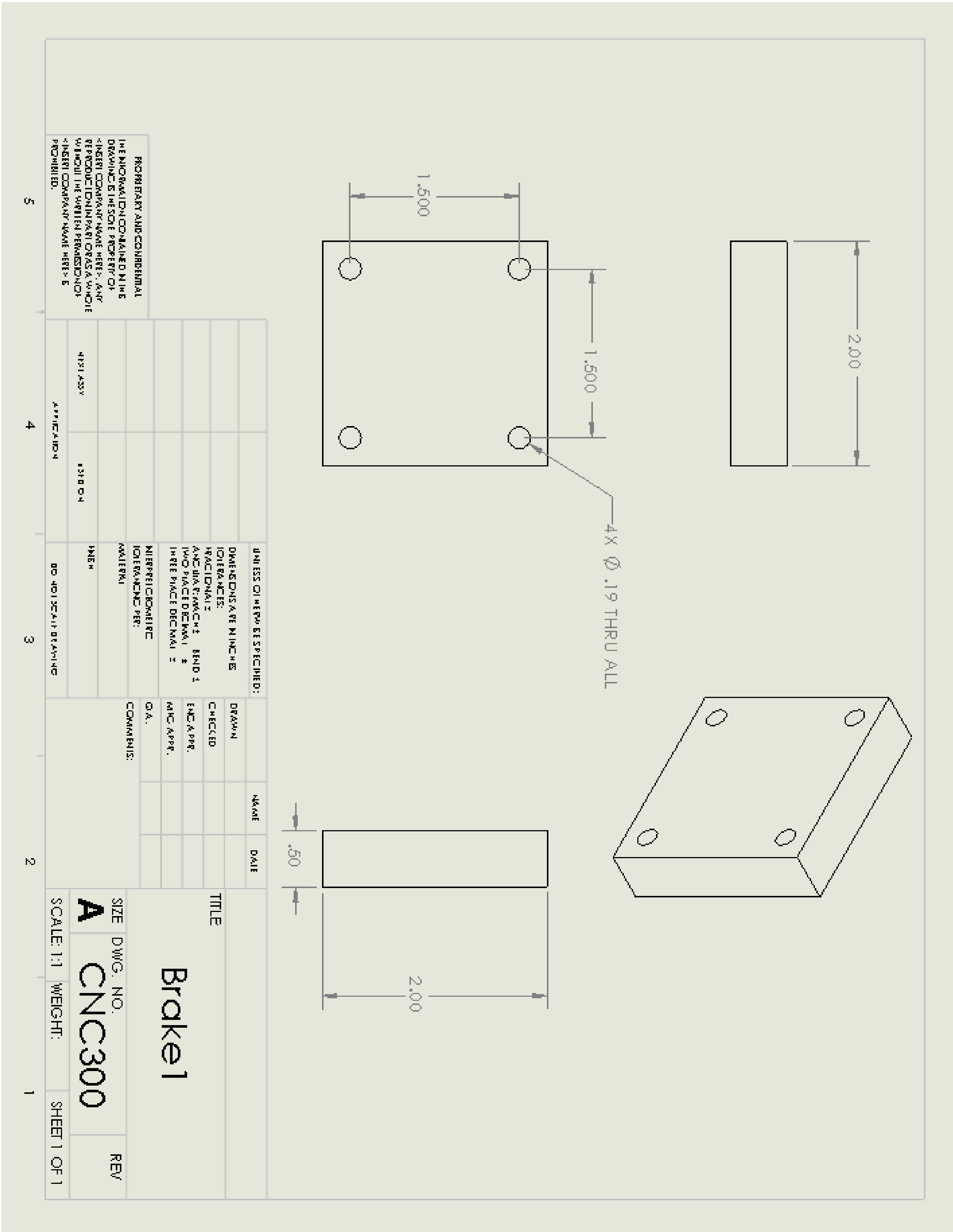
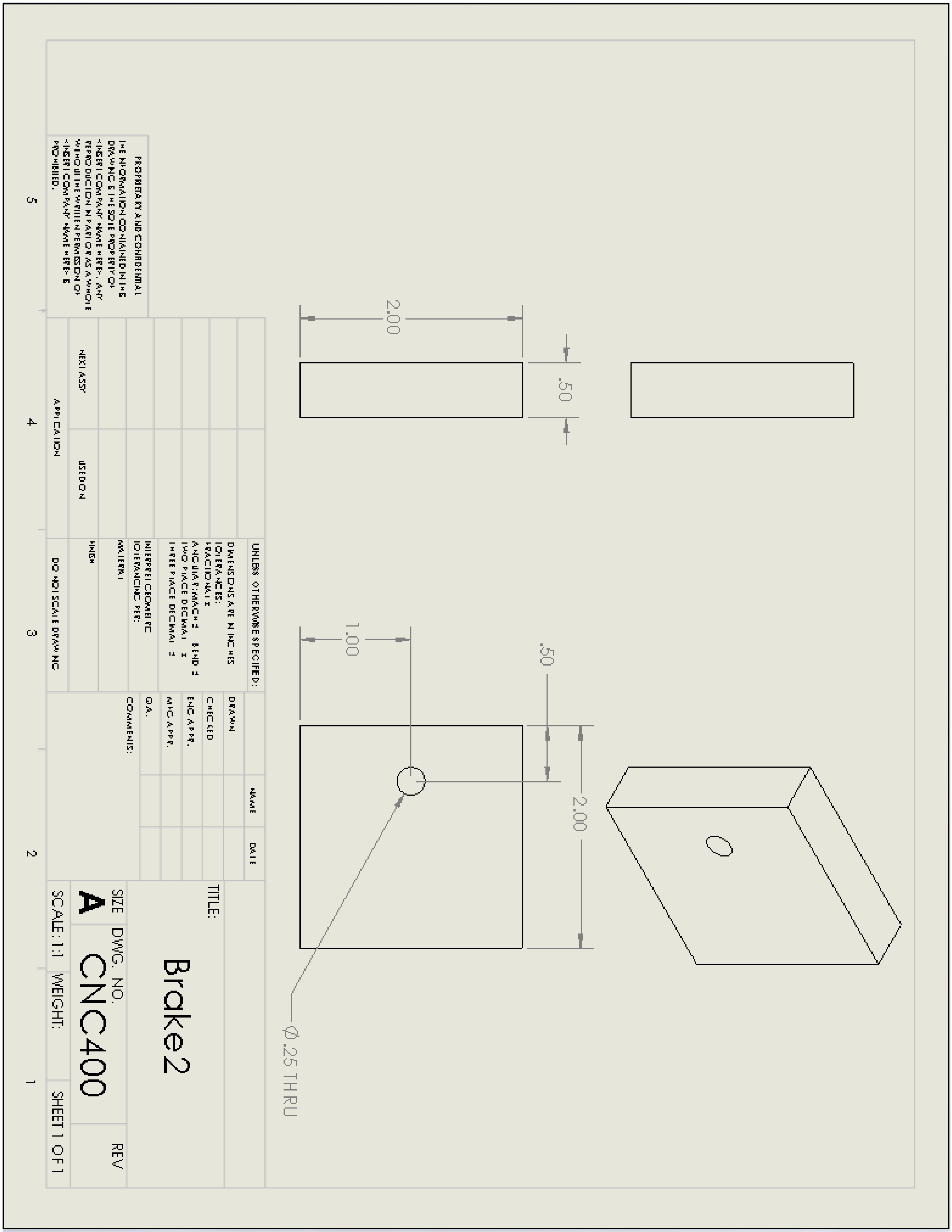
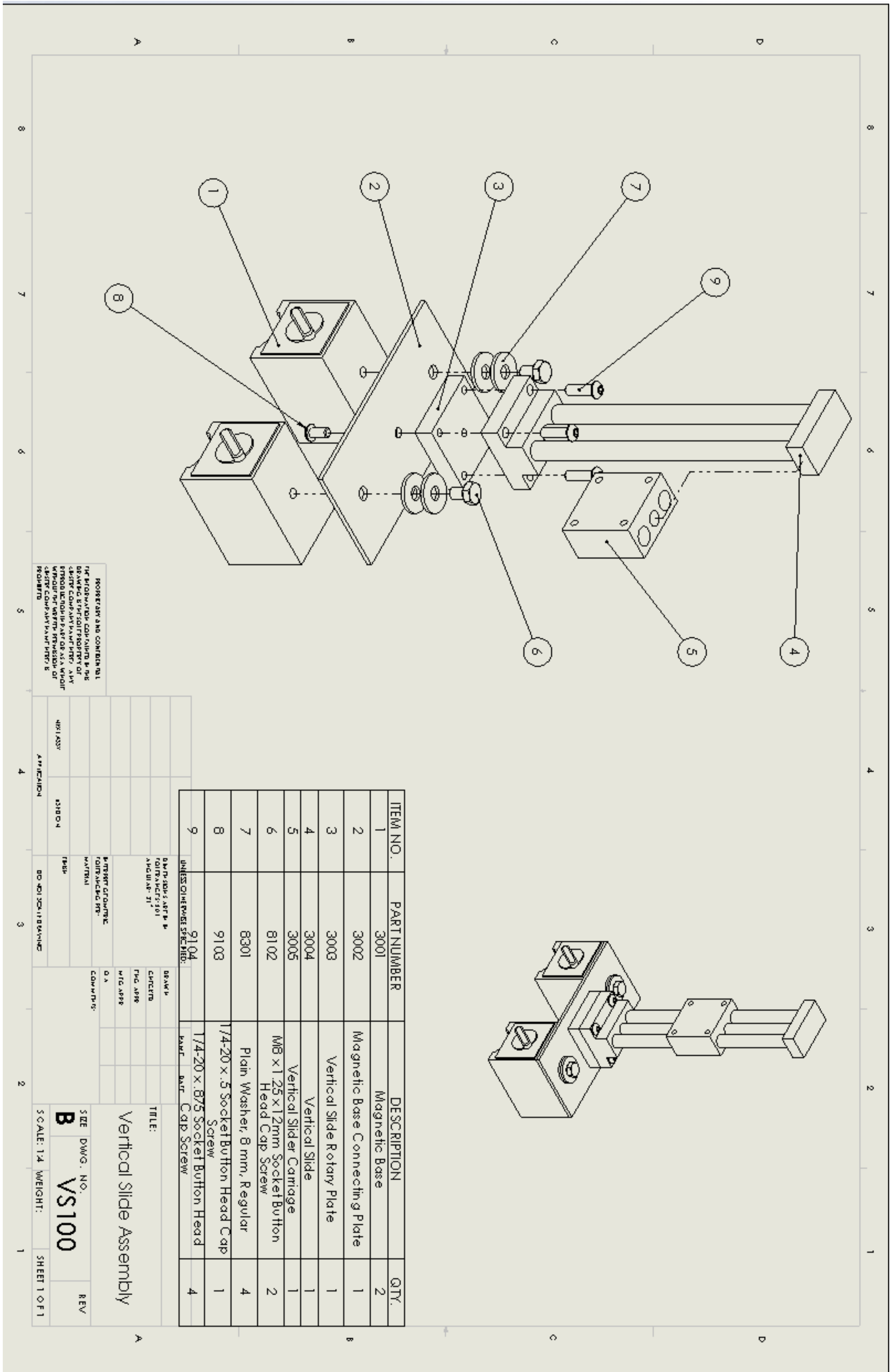
TOLERANCES:
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
FINISH
MATERIAL
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
TITLE:
BB2
SIZE
DWG. NO.
REV
A
CNC200
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
1
2
3
4
5


1.500
1.500
2.00
4X Ø .19 THRU ALL
.50
2.00
TITLE
Brake1
SIZE
A
DWG. NO.
CNC300
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1

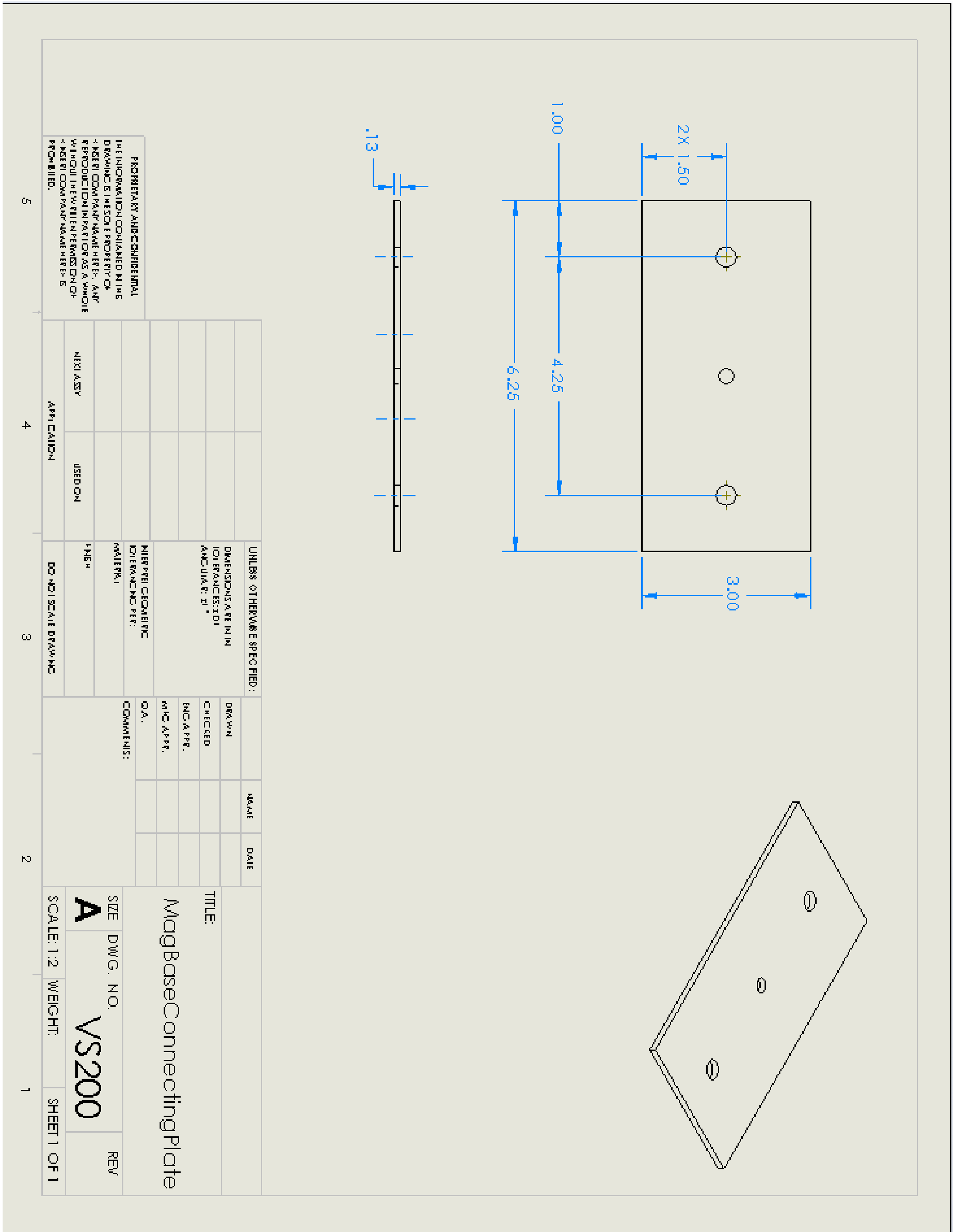


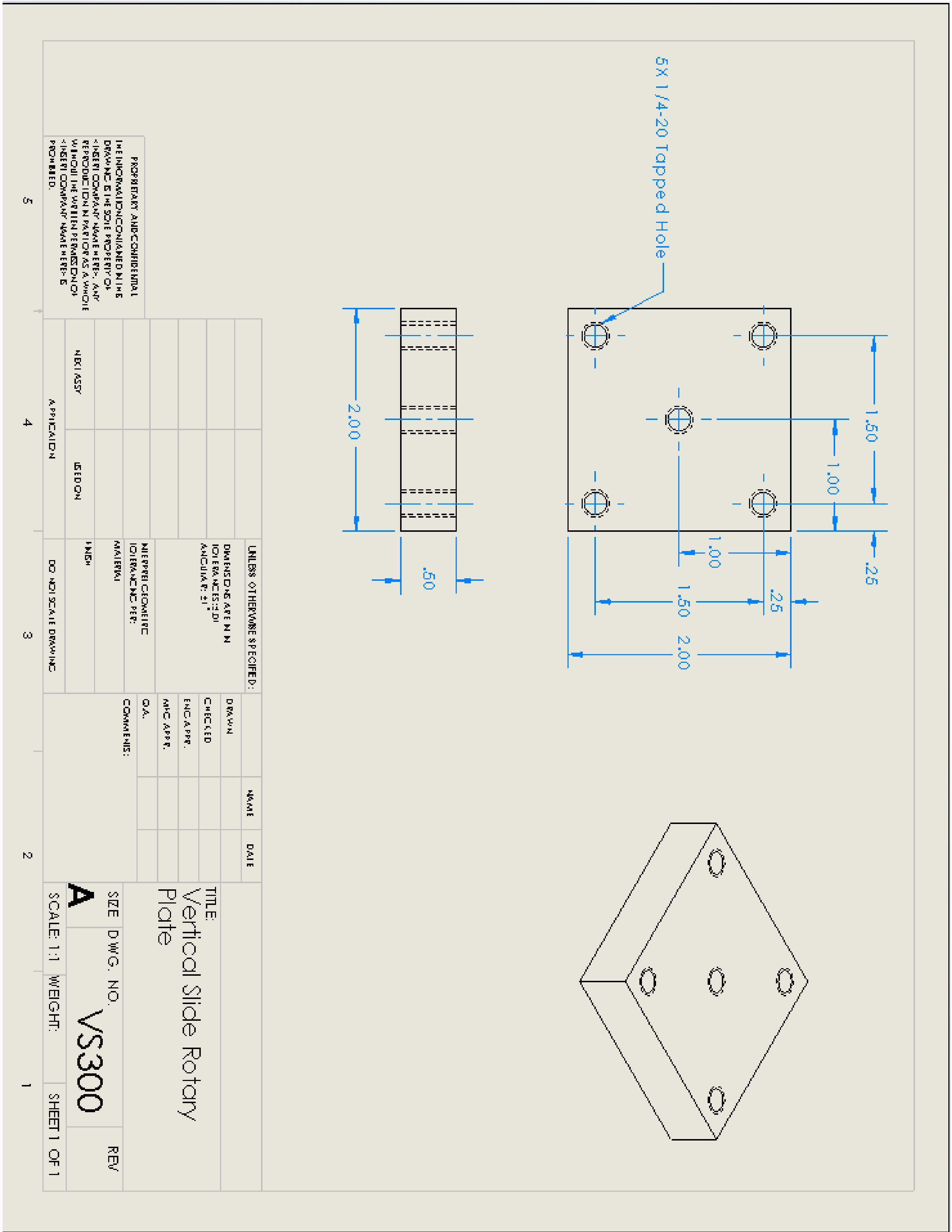
2.00
.50
1.00
.50
2.00
Ø.25 THRU
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NEXT ASSY
USED ON
APPLICATION
FINISH
DO NOT SCALE DRAWING
TITLE:
Brake2
SIZE
A
DWG. NO.
CNC400
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1

VERTICAL SLIDE ASSEMBLY



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	3001	Magnetic Base	2
2	3002	Magnetic Base Connecting Plate	1
3	3003	Vertical Slide Rotary Plate	1
4	3004	Vertical Slide	1
5	3005	Vertical Slider Carriage	1
6	8102	M8 x 1.25 x 12mm Socket Button Head Cap Screw	2
7	8301	Plain Washer, 8 mm, Regular	4
8	9103	1/4-20 x .5 Socket Button Head Cap Screw	1
9	9104	1/4-20 x .875 Socket Button Head Cap Screw	4


2X 1.50
1.00
4.25
6.25
3.00
.13
UNLESS OTHERWISE SPECIFIED:
DRAWN
CHECKED
NAME
DATE
TITLE:
MagBaseConnectingPlate
SIZE
A
DWG. NO.
VS200
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
COMMENTS:
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL


5X 1/4-20 Tapped Hole
1.50
1.00
.25
1.00
1.50
.25
2.00
2.00
.50
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN IN
TOLERANCES: ±.01
ANGULAR: ±1°
GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
TITLE:
Vertical Slide Rotary Plate
SIZE
A
DWG. NO.
VS300
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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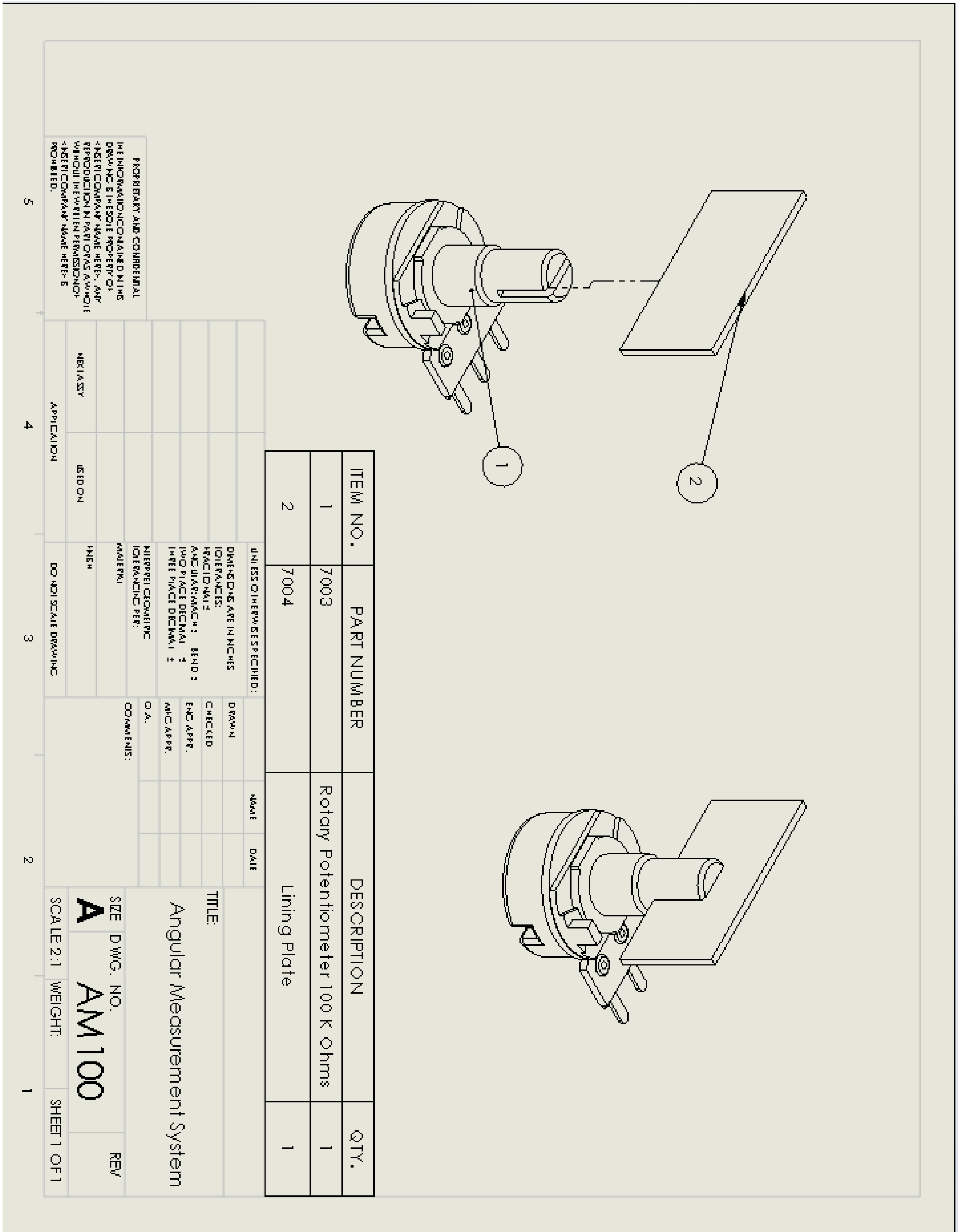
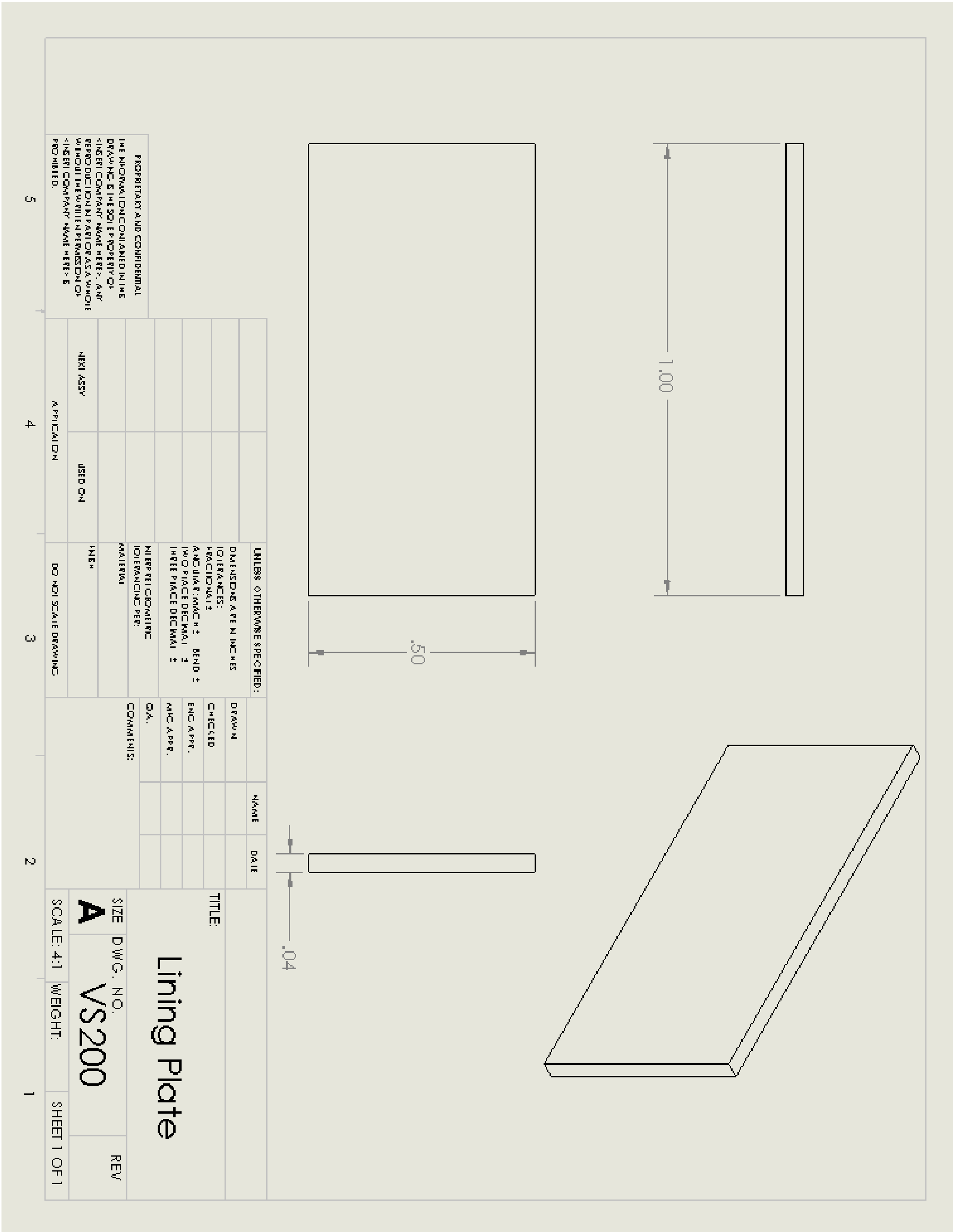
5
4
3
2
1


ITEM NO.
PART NUMBER
DESCRIPTION
QTY.
1
7003
Rotary Potentiometer 100 K Ohms
1
2
7004
Lining Plate
1
TITLE:
Angular Measurement System
SIZE
A
DWG. NO.
AM100
REV
SCALE 2:1
WEIGHT:
SHEET 1 OF 1


1.00
.50
.04
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Lining Plate
SIZE
A
DWG. NO.
VS200
REV
SCALE: 4:1
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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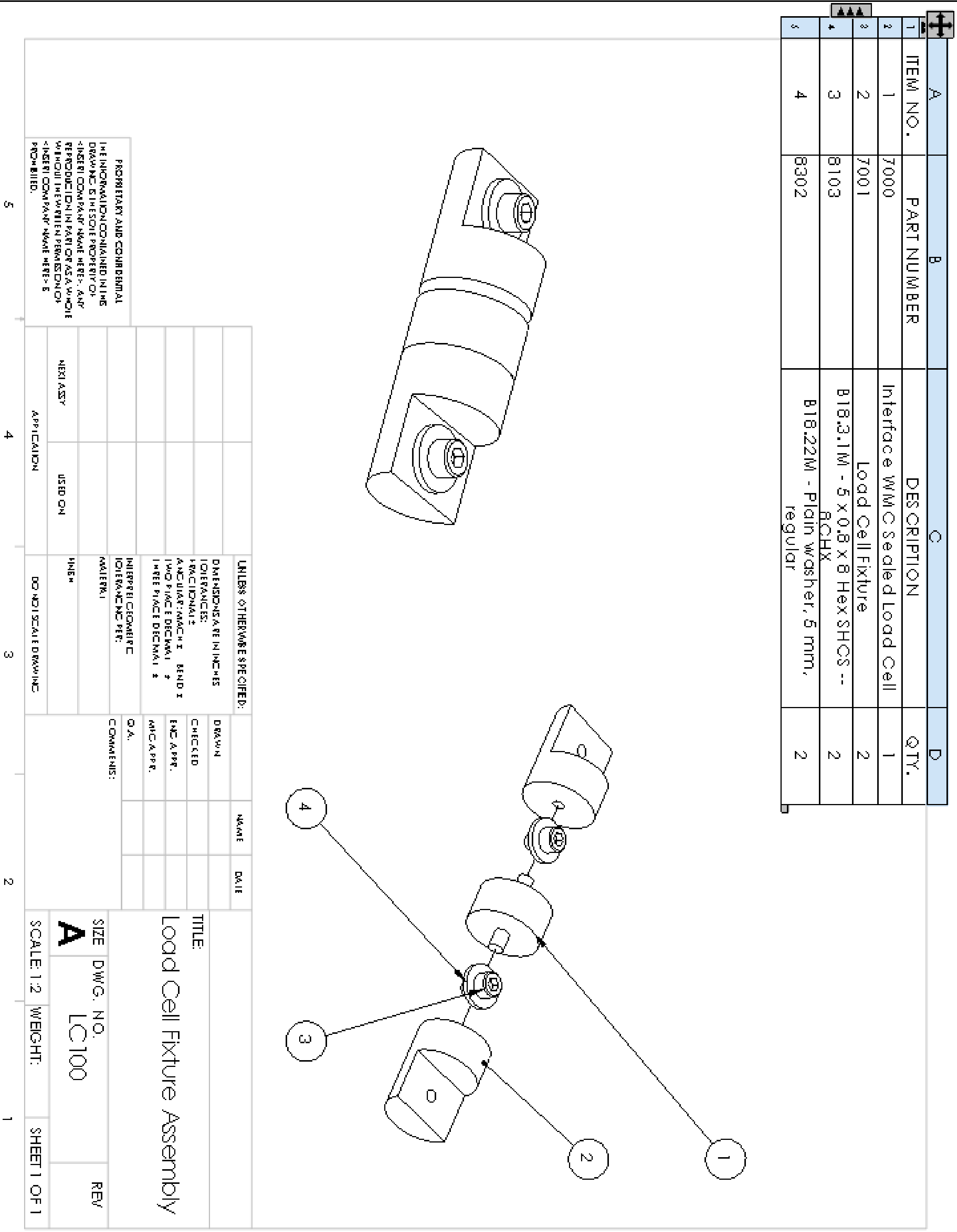
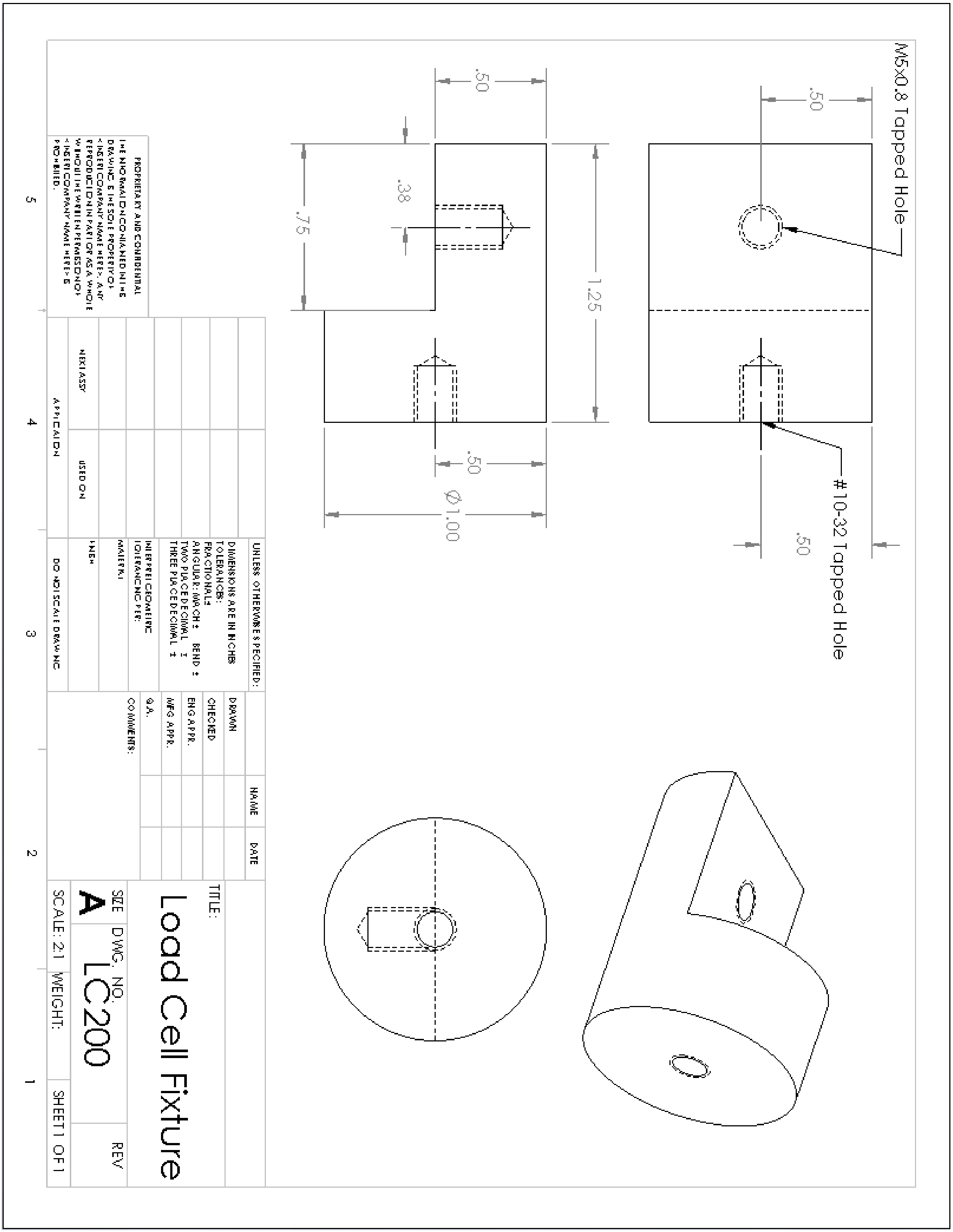
5
4
3
2
1

LOAD CELL



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	7000	Interface WMC Sealed Load Cell	1
2	7001	Load Cell Fixture	2
3	8103	B18.3.1M - 5 x 0.8 x 8 Hex SHCS -- 8CHX	2
4	8302	B18.22M - Plain washer, 5 mm, regular	2


M5x0.8 Tapped Hole
.50
.50
.38
.75
1.25
.50
Ø1.00
#10-32 Tapped Hole
.50
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
TITLE:
Load Cell Fixture
SIZE
A
DWG. NO.
LC200
REV
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1
5
4
3
2
1

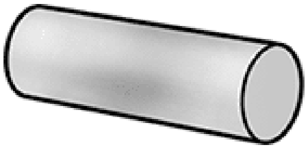
Appendix C (List of Vendors)

1. Generic Slides
    a. Phone: (412)492-7272
    b. Fax: (412)492-7271
    c. Email: sales@genericslides.com
    d. 1049 William Flynn Highway Suite 300, Glenshaw, PA 15116
2. McMaster Carr
    a. Phone: (562)692-5922
    b. Fax: (562) 695-2323
    c. Email: la.sales@mcmaster.com
    d. P.O. Box 54960, Los Angeles, CA 90054-0960
3. Interface, Inc. Corporation
    a. Phone: (480)948-5555
    b. Fax: (480) 948-1924
    c. Email (SLO area): ElliotS@interfaceforce.com
    d. 7401 East Butherus Drive, Scottsdale, AZ 85260
4. National Instruments Corporation
    a. Phone: (877) 387-0015
    b. Email (California): thaison.verasiri@ni.com
    c. 11500 N Mopac Expwy, Austin, TX 78759-3504
5. Metals Depot International
    a. Phone: (859)745-2650
    b. Fax: (859)745-0887
    c. Email: mdsales@metalsdepot.com
    d. 4200 Revilo Road, Winchester, KY 40391

Appendix D (Data Sheets)

Multipurpose 6061 Aluminum Rod

1" Diameter



Alloy	6061
Shape	Rod
Finish	Unpolished
Diameter	1"
Diameter Tolerance	±0.006"
Yield Strength	35,000 psi
Hardness	Soft (95 Brinell)
Material Condition	Heat Treated
Temper	T6511
Specifications Met	ASTM B221
Material Composition	
Silicon	0.4-0.8%
Iron	0-0.7%
Copper	0.05-0.4%
Manganese	0-0.15%
Magnesium	0.8-1.2%
Chromium	0.4-0.8%
Nickel	0-0.05%
Zinc	0-0.25%
Titanium	0-0.15%
Zirconium	0-0.25%
Other	0.15%
Aluminum	95.1-98.2%
Nominal Density	0.097-0.1 lbs./cu. in.
Modulus of Elasticity	10.0 ksi × 10^3
Elongation	8-17%
Melting Range	1,080° to 1,205° F
Thermal Conductivity	1390 Btu/hr × in./sq.ft. @ 75° to 77° F
Electrical Resistivity	24 Ohm-Cir. Mil/ft. @ 68° F

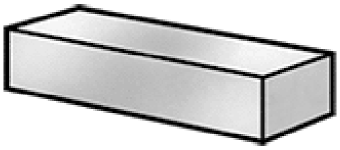
The most widely used aluminum, Alloy 6061 is a popular choice for vehicle parts and pipe fittings. It has better corrosion resistance and weldability than Alloys 2024 and 7075, but it's not as strong. It is nonmagnetic, heat treatable, and resists stress cracking. Temperature range is -320° to 300° F.

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

Diameter tolerance for 1/8" to 1 7/8" dia. rods is ±0.006". Length tolerance for 1/2-ft. lengths is +1/8", -0.015". Length tolerance for 1-ft. to 6-ft. lengths is ±1".

Multipurpose 6061 Aluminum

3/4" Thick, 1" Width



Length

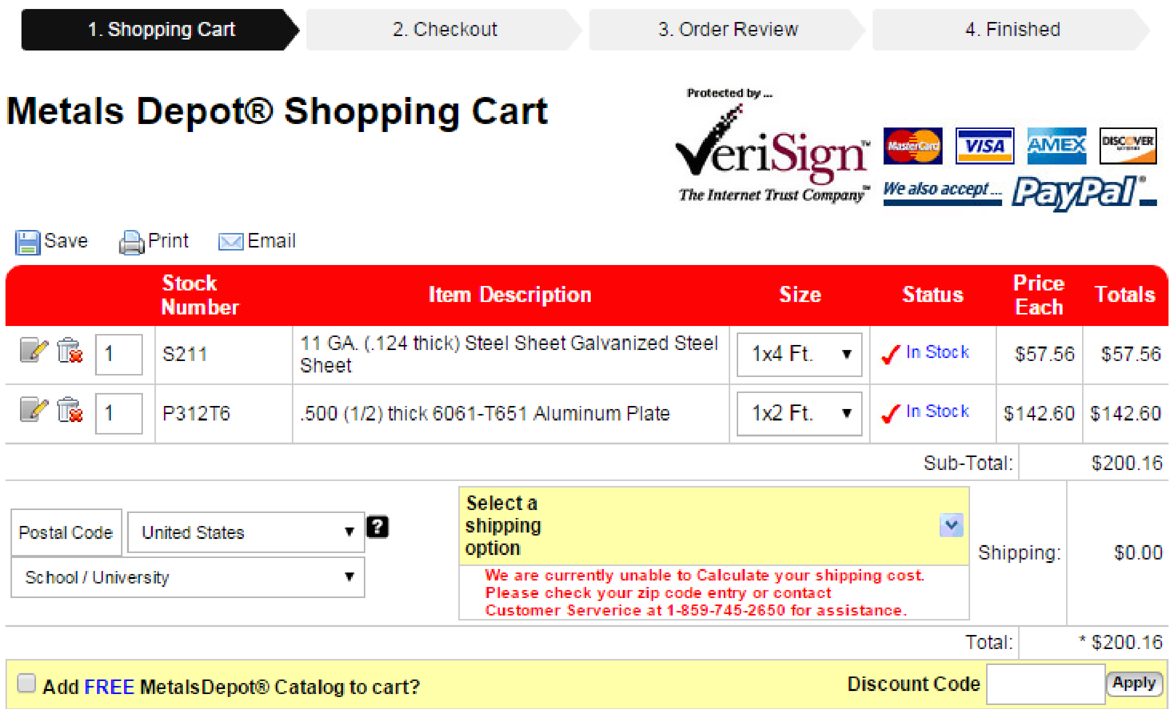
- 1/2 ft.
- 1 ft.
- 2 ft.
- 3 ft.
- 6 ft.

[ ] Each

ADD TO ORDER

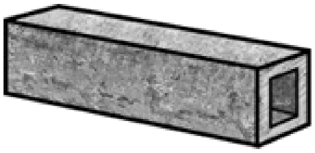
8975K14

Alloy	6061
Shape	Rectangular Bar
Finish	Unpolished
Thickness	3/4"
Thickness Tolerance	±0.010"
Width	1"
Width Tolerance	±0.014"
Yield Strength	35,000 psi
Hardness	Soft (80 Brinell)
Material Condition	Heat Treated
Temper	T6511
Specifications Met	ASTM B221
Material Composition	
Silicon	0.4-0.8%
Iron	0-0.7%
Copper	0.05-0.4%
Manganese	0-0.15%
Magnesium	0.8-1.2%
Chromium	0.4-0.8%
Nickel	0-0.05%
Zinc	0-0.25%
Titanium	0-0.15%
Zirconium	0-0.25%
Other	0.15%
Aluminum	95.1-98.2%
Nominal Density	0.097-0.1 lbs./cu. in.
Modulus of Elasticity	10.0 ksi × 10^3
Elongation	8-17%
Melting Range	1,080° to 1,205° F
Thermal Conductivity	1390 Btu/hr × in./sq.ft. @ 75° to 77° F
Electrical Resistivity	24 Ohm-Cir. Mil/ft. @ 68° F


1. Shopping Cart
2. Checkout
3. Order Review
4. Finished
Metals Depot® Shopping Cart
Protected by ...
VeriSign
The Internet Trust Company
We also accept ...
PayPal
Save
Print
Email
Stock Number
Item Description
Size
Status
Price Each
Totals
1
S211
11 GA. (.124 thick) Steel Sheet Galvanized Steel Sheet
1x4 Ft.
In Stock
$57.56
$57.56
1
P312T6
.500 (1/2) thick 6061-T651 Aluminum Plate
1x2 Ft.
In Stock
$142.60
$142.60
Sub-Total:
$200.16
Postal Code
United States
School / University
Select a shipping option
We are currently unable to Calculate your shipping cost. Please check your zip code entry or contact Customer Serverice at 1-859-745-2650 for assistance.
Shipping:
$0.00
Total:
* $200.16
Add FREE MetalsDepot® Catalog to cart?
Discount Code
Apply

Low-Carbon Steel Square Tube

1" Wide, 1" High, .120" Wall Thickness



Length

1 ft.

3 ft.

6 ft.

Each

ADD TO ORDER

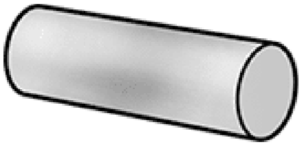
6527K314

Grade	1005-1026
Shape	Square Tube
Finish	Rough
Wall Thickness	0.120"
Wall Thickness Tolerance	±0.012"
Width	1"
Height	1"
Width/Height Tolerance	±0.030"
Straightness Tolerance	1/16" per 3 ft.
Yield Strength	72,000 psi
Hardness	Not Rated
Specification Met	ASTM A513
Construction	Hot Rolled
Material Composition	
Carbon	0.13-0.20%
Manganese	0.30-0.90%
Silicon	0.15-0.30%
Phosphorus	0.04% Max.
Sulfur	0.50% Max.
Iron	98.06-99.42%
Nominal Density	0.283 lbs./cu. in.
Electrical Resistivity	15.9 microhm-cm @ 32° F
Thermal Conductivity	29.4 Btu/sq. ft./ft./hr./°F @ 212° F
Thermal Coefficient of Expansion per °F	$6.7\text{-}7.5 \times 10^{-6}$
Elongation Range	10-36%

One of the most widely used types of steel, low-carbon steel is weldable, machinable, and can be surface hardened by heat treating. It is suitable for a variety of applications, such as structural and power transmission components.

Multipurpose 6061 Aluminum Rod

5/8" Diameter

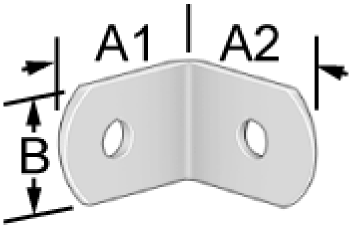


Length, ft.	
	Each
1/2	ADD TO ORDER
1	8974K48
2	
3	
6	

Alloy	6061
Shape	Rod
Finish	Unpolished
Diameter	5/8"
Diameter Tolerance	±0.006"
Yield Strength	35,000 psi
Hardness	Soft (95 Brinell)
Material Condition	Heat Treated
Temper	T6511
Specifications Met	ASTM B221
Material Composition	
Silicon	0.4-0.8%
Iron	0-0.7%
Copper	0.05-0.4%
Manganese	0-0.15%
Magnesium	0.8-1.2%
Chromium	0.4-0.8%
Nickel	0-0.05%
Zinc	0-0.25%
Titanium	0-0.15%
Zirconium	0-0.25%
Other	0.15%
Aluminum	95.1-98.2%
Nominal Density	0.097-0.1 lbs./cu. in.
Modulus of Elasticity	10.0 ksi × 10^3
Elongation	8-17%
Melting Range	1,080° to 1,205° F
Thermal Conductivity	1390 Btu/hr × in./sq.ft. @ 75° to 77° F
Electrical Resistivity	24 Ohm-Cir. Mil/ft. @ 68° F

Bracket

Zinc-Plated Steel, 5/8" and 1" Length of Sides



Each

ADD TO ORDER

In stock
1-49 Each $0.63
50 or more $0.48
1556A26

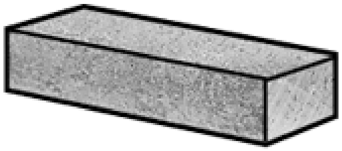
Material	Zinc-Plated Steel
Length (A1), (A2)	5/8", 1"
Width (B)	1/2"
Thickness	0.12"
Screw/Nail Size	No. 9
Number of Holes	2

Also known as angle brackets, corner brackets, and mending plates, these brackets support corners and joints. They do not include mounting fasteners.

Note: Prices are approximately 25% lower when you buy 50 or more of the same bracket.

Low-Carbon Steel Rectangular Bar

3/4" Thick, 1" Width



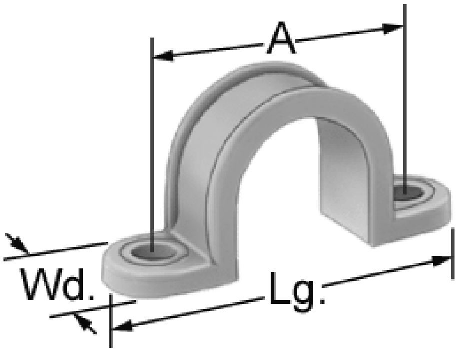
Length	
1/2 ft.	Each
1 ft.	ADD TO ORDER
2 ft.	8910K758
3 ft.	
6 ft.	

Grade	1018
Shape	Rectangular Bar
Finish	Unpolished
Thickness	3/4"
Thickness Tolerance	-0.006"
Width	1"
Width Tolerance	-0.006"
Yield Strength	54,000 psi
Hardness	Medium (Rockwell B70)
Specification Met	ASTM A108
Construction	Cold Drawn
Material Composition	
Carbon	0.13-0.20%
Manganese	0.30-0.90%
Silicon	0.15-0.30%
Phosphorus	0.04% Max.
Sulfur	0.50% Max.
Iron	98.06-99.42%
Nominal Density	0.283 lbs./cu. in.
Electrical Resistivity	15.9 microhm-cm @ 32° F
Thermal Conductivity	29.4 Btu/sq. ft./ft./hr./°F @ 212° F
Thermal Coefficient of Expansion per °F	$6.7\text{-}7.5 \times 10^{-6}$
Elongation Range	10-36%

One of the most widely used types of steel, low-carbon steel is weldable, machinable, and can be surface hardened by heat treating. It is suitable for a variety of applications, such as structural and power transmission components.

Plastic Clamp

for 1-5/16" Outside Diameter, 1" Pipe Size



Packs of 25

ADD TO ORDER

In stock
$6.78 per pack of 25
3192T53

For OD	1 5/16"
For Pipe/Rigid Conduit Size	1"
Length	2 5/8"
Width	9/16"
Thickness	1/8"
Mounting Hole Diameter	3/16"
(A)	2"

As an alternative to metal clamps, use these plastic clamps to avoid the corrosion problems of metal-to-metal contact when securing pipe and conduit. All are made of polypropylene. Color is gray. Temperature range is -30° to 190° F. Fasteners are not included.

Zinc Aluminum Coated Steel Hex Nut

Grade 8, 1/4"-20 Thread Size, 7/16" Wide, 7/32" High

Packs of 100

ADD TO ORDER

In stock
$6.74 per pack of 100
93827A211

Material	Grade 8 Steel
Thread Size	1/4"-20
Width	7/16"
Height	7/32"
Additional Specifications	Ultra Coated
RoHS	Compliant

Also known as full or finished nuts, these common nuts are also our most popular. They typically come in sizes 1/4" and larger and have a Class 2B thread fit. Sizes 1 1/2" and smaller have dimensions that meet ANSI/ASME B18.2.2.

Low-Strength Steel Hex Nut

Zinc Plated, 8-32 Thread Size, 11/32" Wide, 1/8" High

Packs of 100

ADD TO ORDER

In stock
$1.49 per pack of 100
90480A009

Thread Size	8-32
Width	11/32"
Height	1/8"
Additional Specifications	Zinc-Plated Steel
RoHS	Not Compliant

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

Zinc-plated steel nuts are not rated for hardness.

Low-Strength Steel Hex Nut

Zinc Plated, 10-32 Thread Size, 3/8" Wide, 1/8" High

Packs of 100

ADD TO ORDER

In stock
$1.71 per pack of 100
90480A195

Thread Size	10-32
Width	3/8"
Height	1/8"
Additional Specifications	Zinc-Plated Steel
RoHS	Not Compliant

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

Zinc-plated steel nuts are not rated for hardness.

18-8 Stainless Steel Hex Head Cap Screw

1/4"-28 Thread, 3/8" Long, Fully Threaded

Packs of 50

ADD TO ORDER

In stock
$5.59 per pack of 50
92240A101

Material	18-8 Stainless Steel
Thread Size	1/4"-28
Head Width	7/16"
Head Height	5/32"
Screw Size	1/4" (0.250")
Length	3/8"
Thread Length	Full
RoHS	Compliant

Made from stainless steel, these screws are corrosion resistant in harsh environments. They may be mildly magnetic. Length is measured from under the head.

Inch screws have a minimum tensile strength of 70,000 psi, a Class 2A thread fit, and a minimum Rockwell hardness of B70. Dimensions meet ASME B18.2.1. For screws in sizes 4-40 to 12-24, see hex-head machine screws.

18-8 Stainless Steel—Screws resist chemicals and solvents.

18-8 Stainless Steel Button-Head Socket Cap Screw

10-32 Thread, 1-3/4" Length

Packs of 25 | In stock
$5.81 per pack of 25
92949A274

ADD TO ORDER

Thread Size	10-32
Length	1 3/4"
Thread Length	7/8" to Full
Additional Specifications	18-8 Stainless Steel
RoHS	Compliant

The button head provides a wide bearing surface, a low head, and a finished appearance. Length is measured from under the head. Not recommended for high-strength fastening.

Inch screws have a Class 3A thread fit, a minimum tensile strength of 70,000 psi, and a minimum Rockwell hardness of B55.

Zinc-Plated Alloy Steel Button-Head Cap Screw

8-32 Thread, 1" Length

Packs of 25

ADD TO ORDER

In stock
$7.03 per pack of 25
91306A340

Thread Size	8-32
Length	1"
Thread Length	Full
Additional Specifications	Zinc-Plated Alloy Steel

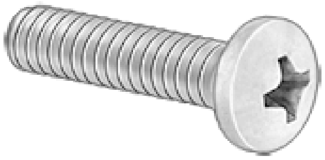
For a finished appearance, these screws have a low rounded head. A wide bearing surface distributes the load. Length is measured from under the head. Not recommended for high-strength fastening.

Inch screws meet ASTM F835. Strength is comparable to that of Grade 5 screws. They have a Class 3A thread fit, a minimum Rockwell hardness of C37, and a minimum tensile strength of 120,000 psi.

Zinc Plated—Screws have a protective coating that adds corrosion resistance for outdoor use.

Zinc-Plated Steel Pan Head Phillips Machine Screw

1/4"-20 Thread, 2-1/2" Length



Packs of 50

ADD TO ORDER

In stock
$9.95 per pack of 50
90272A552

Length	2 1/2"
Additional Specifications	Zinc-Plated Steel 1/4"-20—#3 Drive
RoHS	Not Compliant

Screws up to 2" long are fully threaded; those longer than 2" have at least 1 1/2" of thread. Length is measured from under the head.

Zinc-Plated Alloy Steel Button-Head Cap Screw

10-32 Thread, 1-1/2" Long

Packs of 50

ADD TO ORDER

In stock
$8.88 per pack of 50
91306A277

Thread Size	10-32
Length	1 1/2"
Thread Length	Full
Additional Specifications	Zinc-Plated Alloy Steel
RoHS	Compliant

For a finished appearance, these screws have a low rounded head. A wide bearing surface distributes the load. Length is measured from under the head. Not recommended for high-strength fastening.

Inch screws meet ASTM F835. Strength is comparable to that of Grade 5 screws. They have a Class 3A thread fit, a minimum Rockwell hardness of C37, and a minimum tensile strength of 120,000 psi.

Zinc Plated—Screws have a protective coating that adds corrosion resistance for outdoor use.

Zinc-Plated Alloy Steel Button-Head Cap Screw

1/4"-20 Thread, 7/8" Long

Packs of 50

ADD TO ORDER

In stock
$6.75 per pack of 50
91306A279

Thread Size	1/4"-20
Length	7/8"
Thread Length	Full
Additional Specifications	Zinc-Plated Alloy Steel
RoHS	Compliant

For a finished appearance, these screws have a low rounded head. A wide bearing surface distributes the load. Length is measured from under the head. Not recommended for high-strength fastening.

Inch screws meet ASTM F835. Strength is comparable to that of Grade 5 screws. They have a Class 3A thread fit, a minimum Rockwell hardness of C37, and a minimum tensile strength of 120,000 psi.

Zinc Plated—Screws have a protective coating that adds corrosion resistance for outdoor use.

Zinc-Plated Alloy Steel Button-Head Cap Screw

10-32 Thread, 1/2" Length

Packs of 50

ADD TO ORDER

In stock

$10.80 per pack of 50

91306A356

Thread Size	10-32
Length	1/2"
Thread Length	Full
Additional Specifications	Zinc-Plated Alloy Steel
RoHS	Compliant

For a finished appearance, these screws have a low rounded head. A wide bearing surface distributes the load. Length is measured from under the head. Not recommended for high-strength fastening.

Inch screws meet ASTM F835. Strength is comparable to that of Grade 5 screws. They have a Class 3A thread fit, a minimum Rockwell hardness of C37, and a minimum tensile strength of 120,000 psi.

Zinc Plated—Screws have a protective coating that adds corrosion resistance for outdoor use.

Zinc-Plated Alloy Steel Button-Head Cap Screw

1/4"-20 Thread, 1/2" Length

[ ] Packs of 50

ADD TO ORDER

In stock
$12.08 per pack of 50
91306A375

Thread Size	1/4"-20
Length	1/2"
Thread Length	Full
Additional Specifications	Zinc-Plated Alloy Steel
RoHS	Compliant

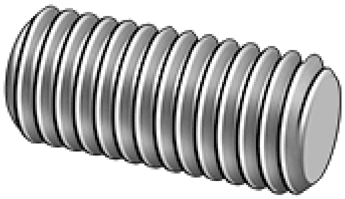
For a finished appearance, these screws have a low rounded head. A wide bearing surface distributes the load. Length is measured from under the head. Not recommended for high-strength fastening.

Inch screws meet ASTM F835. Strength is comparable to that of Grade 5 screws. They have a Class 3A thread fit, a minimum Rockwell hardness of C37, and a minimum tensile strength of 120,000 psi.

Zinc Plated—Screws have a protective coating that adds corrosion resistance for outdoor use.

Low-Strength Steel Threaded Stud

Zinc Plated, 10-32 Thread, 4" Long, Fully Threaded



Packs of 10

ADD TO ORDER

In stock
$5.33 per pack of 10
95475A515

Material	Steel
Finish	Zinc Plated
Thread Size	10-32
Thread Direction	Right Hand
Length	4"
RoHS	Compliant

Use these economical studs and rods for light duty applications. Inch sizes have a minimum tensile strength of 53,000 psi and a minimum Rockwell hardness of B61. Thread fit is Class 1A.

Zinc-plated studs and rods are corrosion resistant and can be used outdoors.

NI USB-6001

Low-Cost Multifunction DAQ for Basic, Quality Measurements

E-mail this Page | Print | PDF | Rich Text

Zoom/Alternate Images

- 8 analog inputs, 20 kS/s; 14-bit resolution
- 13 digital I/O lines; one 32-bit counter
- Lightweight and bus powered for easy portability
- Easily connect sensors and signals with screw-terminal connectivity
- OEM version available
- Compatible with ANSI C, C# .NET, VB .NET, LabVIEW, LabWindows™/CVI, and Measurement Studio
- Consider the NI USB-6002 or NI USB-6003 for higher sampling rates and resolutions

Overview | Specifications | Pricing | Resources

Part Number	Description	Est Ship	US Dollars	Qty
782604-01	USB-6001 14-Bit 20 kS/s Multifunction I/O and NI-DAQmx	1 - 3	$ 189.00	0
782909-01	High speed USB - 1 Meter Cable - Micro to Std Male	5 - 10	$ 21.00	0
782909-02	High speed USB - 2 Meter Cable - Micro to Std Male	5 - 10	$ 31.00	0
779511-01	NI USB-600x Series Prototyping Accessory	5 - 10	$ 37.00	0

Product Family	Multifunction DAQ
Measurement Type	Digital Voltage
Form Factor	USB
Operating System / Target	Windows
RoHS Compliant	Yes
Isolation Type	None
Product Certifications	RoHS
Analog Input	
Single-Ended Channels	8
Differential Channels	4
Analog Input Resolution	14 bits
Maximum Voltage Range	-10 V - 10 V
Number of Ranges	1
Simultaneous Sampling	No

SGA Signal Conditioner

AC/DC Powered Millivolt to Analog Converter

PREV NEXT

Products & Prices | Specifications | Dimensions | Documentation

Starting at $345.00

- User selectable analog output ±10V, ±5V, 0-10V, 0-5V, 0-20mA, 4-20mA
- 110 VAC, 220 VAC OR 18-24 VDC power
- Switch selectable filtering 1 Hz to 5 kHz
- Single channel powers up to 4 transducers
- Selectable full scale input range 0.06 to 30 mV/V
- Switch selectable offset ±70% FS
- Sealed ABS enclosure

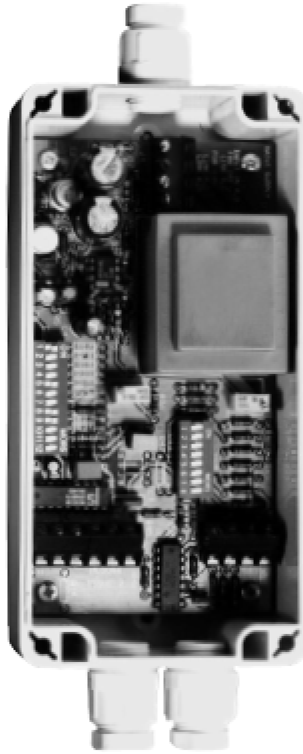
Versatile signal conditioner featuring user selectable outputs of +/-10V, +/-5V, 0-10V, 0-5V, 0-20mA and 4-20ma. DC or AC powered with switch selectable filters from 1 to 5kHz and a sealed ABS enclosure. Supports shunt calibration and a wide range of gain settings.

English Standard | Metric Standard

Model	Capacity	Lead Time	Description	Price	Qty	
SGA	-		SGA AC/DC Powered In-Line Signal Conditioner	$345.00	1	Add to Order
Accessories						
PWRCRD-SGA-110			SGA Power Cord	$20.00	1	Add to Order

Model SGA AC/DC Powered Signal Conditioner

- User selectable analog output ±10V, ±5V, 0-10V, 0-5V, 0-20 mA, 4-20 mA
- 110 VAC, 220 VAC OR 18-24 VDC power
- Switch selectable filtering 1 Hz to 5 kHz
- Single channel powers up to 4 transducers
- Selectable full scale input range 0.06 to 30 mV/V
- Switch selectable offset ±70% FS
- Sealed ABS enclosure



SPECIFICATIONS

POWER

AC	110 VAC 60 Hz or 220 VAC 50 Hz
DC	18-24 VDC

EXCITATION

Voltage	10 VDC ±5%
Current	118 mA

PERFORMANCE

Output	±10V, ±5V Bipolar 0-5V, 0-10V Unipolar 0-20 mA, 4-20 mA Unipolar
Input Range	±0.06 to ±30 mV/V Switch selectable
Max Bandwidth	6 kHz
Filter	1 Hz to 5 kHz Switch selectable
Offset	±70% FS Course and fine adjust
Nonlinearity	0.03% FS
Span Temp. Coefficient	0.004%/°F Max
Zero Temp. Coefficient	0.5 µV/°F Max

ENVIRONMENTAL

Operating Temp.	+32°F to +122°F
Dimensions	6.3 in X 3.1 in X 2.2 in
Enclosure	Sealed ABS case, Compression cable seals

ACCESSORIES

AC Power Cord (PWRCRD-SGA-110)

WMC Sealed Stainless Steel Mini Load Cell

5-500 lbf

PREV NEXT

Products & Prices | Specifications | Dimensions | Documentation

Starting at $660.00

- The WMC is Interface's smallest T&C load cell.
- Proprietary Interface temperature compensated strain gages
- Tension and compression
- Small Size
- Environmentally sealed

2.5 kN

WMC Submersible Option is Available.

5 ft Integral Cable Included.

English Standard | Metric Standard

Model	Capacity	Lead Time	Description	Price	Qty	
WMC	5, 10 lbf		5 & 10 lbf Capacity, Sealed Stainless Steel Mini Load Cell	$709.00	1	Add to Order
WMC	25, 50, 100, 250, 500 lbf		25, 50, 100, 250 & 500 lbf Capacity, Sealed Stainless Steel Mini Load Cell	$660.00	1	Add to Order

Model WMC Miniature Sealed Stainless Steel Load Cell

Capacities 5-500 lbf

Why the Interface model WMC Miniature Sealed Stainless Steel Load Cell is the best in class:

- Proprietary Interface temperature compensated strain gages
- Tension and compression
- Small size
- Environmentally sealed

SPECIFICATIONS

ACCURACY - (MAX ERROR)
Nonlinearity–% FS ....±0.15
Hysteresis–% FS ....±0.15
Nonrepeatability–% RO ....±0.05
Creep, in 20 min–% ....±0.05

TEMPERATURE
Compensated Range–˚F ....15 to 115
Compensated Range–˚C ....-10 to 45
Operating Range–˚F ....-65 to 250
Operating Range–˚C ....-54 to 121
Effect on Output–%/˚F – MAX ....±0.002
Effect on Zero–% RO/˚F – MAX ....±0.005

ELECTRICAL
Rated Output–mV/V (Nominal) 2.0
Zero Balance–% RO ....±2.0
Bridge Resistance–Ohm (Nominal) 350
Excitation Voltage – MAX ....12.0 V DC
Insulation Resistance – Megohm ....> 5000

MECHANICAL
Calibration ....Tension
Safe Overload–% CAP:
5,10 lbf 150
25-500 lbf 150
Cable length–ft 5

STANDARD CONFIGURATION

5 ft Integral Cable

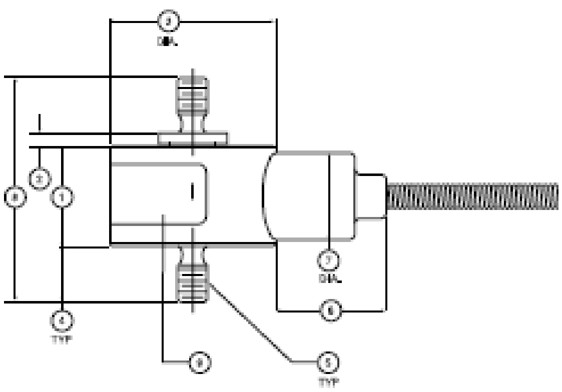
OPTIONS

Extra Cable Length

ACCESSORIES

Instrumentation

Consult factory for more technical information



DIMENSIONS

See Drawing	CAPACITY (lbf)					
	5, 10		25, 50, 100		250, 500	
	Inch	mm	Inch	mm	Inch	mm
①	0.45	11.4	0.52	13.21	0.52	13.21
②	0.06	1.5	0.12	3.05	0.03	0.76
③	0.75	19.1	1.00	25.4	1.00	25.4
④	0.25	6.4	0.25	6.4	0.38	9.7
⑤	6-32 UNF		10-32 UNF		1/4-28 UNF	
⑥	0.50	12.7	0.50	12.7	0.50	12.7
⑦	0.39	9.9	0.39	6.4	0.39	6.4
⑧	1.01	25.6	1.14	29.0	1.31	33.3
⑨	label		label		label	

Features

- Single and dual section control
- Metal shaft styles
- Carbon element
- Center and multiple detent options
- Wide range of resistance tapers
- Plain or knurled shaft options

BOURNS PRO AUDIO

PDB18 Series - 17 mm Rotary Potentiometer

Electrical Characteristics

Taper..Linear, audio
Standard Resistance Range
........................1 K ohms to 1 M ohms
Standard Resistance Tolerance.....±20 %
Residual Resistance.................1 % max.

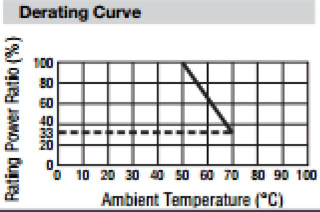
Environmental Characteristics

Operating Temperature...-10 °C to +50 °C
Power Rating
Linear ....0.2 watt
Dual Section..................0.125 watt
Audio...0.1 watt
Dual Section.....................0.06 watt
Maximum Operating Voltage
Linear .... 200 V
Audio.. 150 V
Sliding Noise .... 47 mV max.

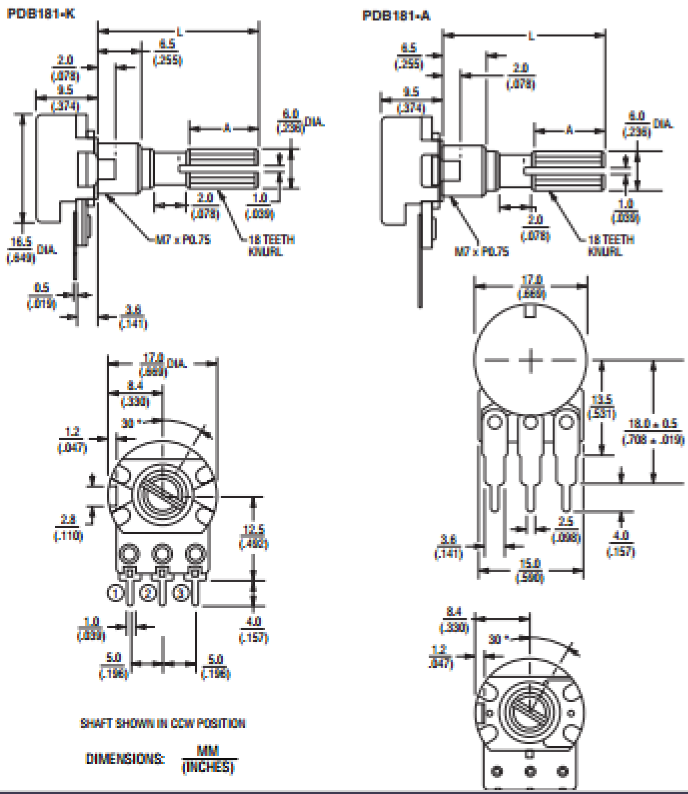
Mechanical Characteristics

Mechanical Angle.....................300 ° ±5 °
Rotational Torque .... 10 to 150 gf-cm
Detent Torque............... 150 to 500 g-cm
Stop Strength......................5 kg-cm min.
Rotational Life ....15,000 cycles
Soldering Condition
.... 260 °C max. within 3 seconds
Hardware.................One flat washer and mounting nut supplied per potentiometer with bushing

Derating Curve

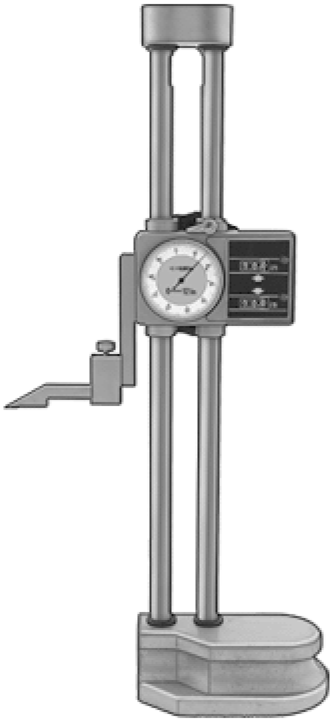


Product Dimensions



Economy Dual-Reading Height Gauge

0-12" Range, 5" Length x 3-5/16" Base Width



Each

ADD TO ORDER

In stock
$261.97 Each
19765A72

Range	0-12"
Base	
Length	5"
Width	3 5/16"
Accuracy	±0.0015"

In addition to the dial, two mechanical digital counters display measurements (one counts up; the other counts down).

Dial measures in 0.001" increments; the counters in 0.1" increments. A carbide-tipped scriber with clamp is included.

Magnetic Base

220-lb. Pull, M8 x 1.25 Mounting Hole Thread

Each

ADD TO ORDER

In stock
$42.86 Each
1977A15

Magnetic Pull	220 lbs.
Base	
Length	3"
Width	2"
Height	2 3/16"
Mounting Hole Thread Size	M8×1.25
Additional Specifications	Magnetic Bases Standard
Shipping	Regulated by the U.S. Department of Transportation

Easily moved from place to place, bases have threaded mounting holes to hold upright posts and fixtures. All have a magnetic-release switch.

Economy and standard bases have one top mounting hole and a V-grooved bottom.

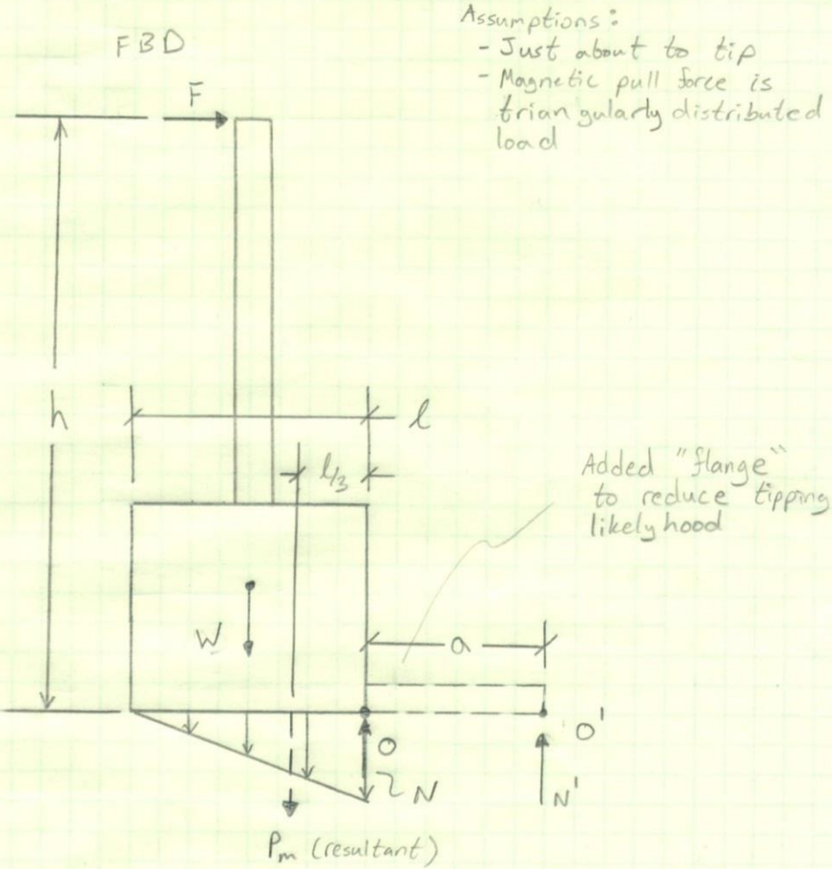
Appendix E (analysis)

Hand Calculations

Magnetic Base Tipping Analysis

Diagram:

Assumptions:
- Just about to tip
- Magnetic pull force is triangularly distributed load



Analysis: Assuming no "flange"

$$+\circlearrowleft \Sigma M_o: \; W\frac{\ell}{2} + P_m\left(\frac{\ell}{3}\right) - Fh = 0$$

$$F = \frac{\ell}{h}\left(\frac{P_m}{3} + \frac{W}{2}\right)$$

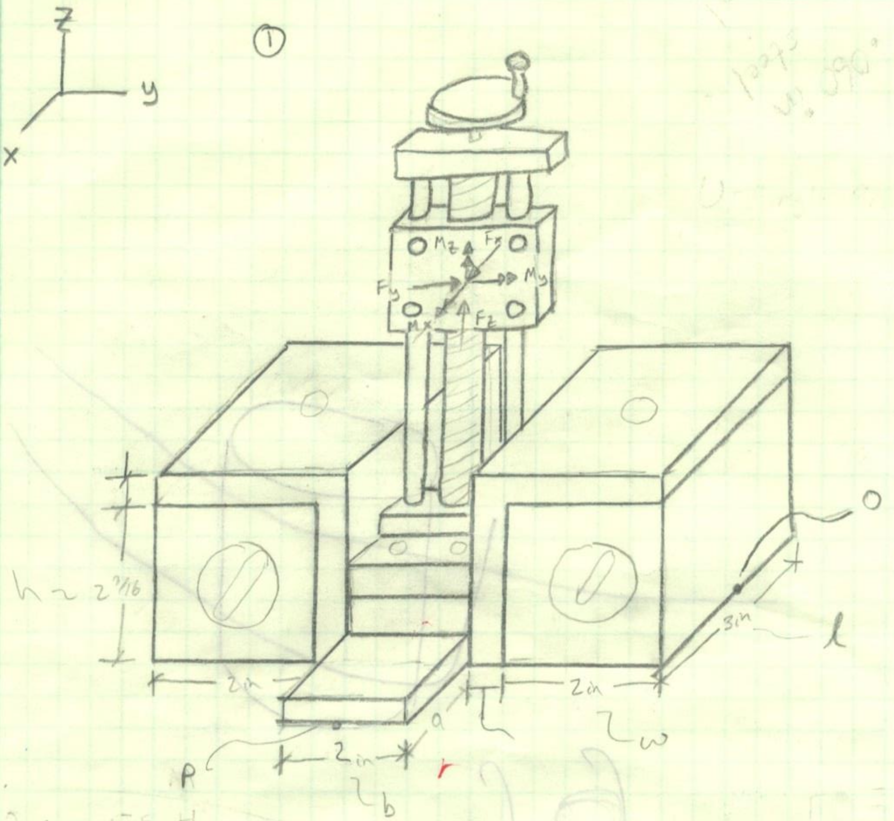
$$F_{tip} = \frac{\ell}{6h}\left(2P_m + 3W\right) \longleftarrow (1)$$

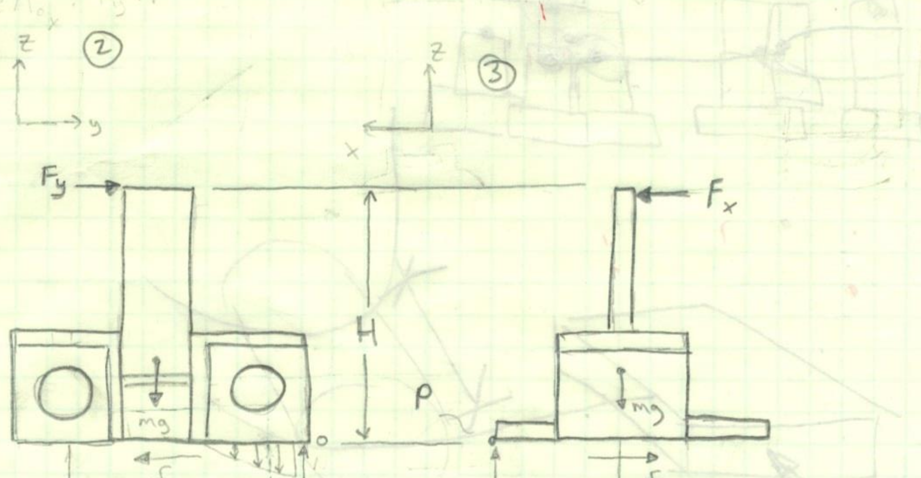
W/ "Flange"

$$+\circlearrowleft M_{o'}: \; W\left(\frac{\ell}{2}+a\right) + P_m\left(\frac{\ell}{3}+a\right) - Fh = 0$$

$$F_{tip} = \frac{W\left(\frac{\ell}{2}+a\right) + P_m\left(\frac{\ell}{3}+a\right)}{h} \longleftarrow (2)$$

Tipping / Sliding





②

$$\Sigma F_y = -f + F_y = 0$$

$$F_{y_{slide}} = f = \mu N = \boxed{\mu(2P_m + mg) = F_{y_{slide}}}$$

$$\Sigma F_z = N - 2P_m - mg = 0$$

$$N = 2P_m + mg$$

$$+\circlearrowleft \Sigma M_{O_x} = -F_y H + \frac{\omega}{3} P_m + \left(\omega + \frac{b}{2}\right) P_m = 0$$

$$\boxed{F_{y_{tip}} = \frac{P_m}{H}\left(\frac{4}{3}\omega + \frac{b}{2}\right)}$$

③

$$\Sigma F_z = N - 2P_m - mg = 0$$

$$N = 2P_m + mg$$

$$\Sigma F_x = -f + F_x = 0$$

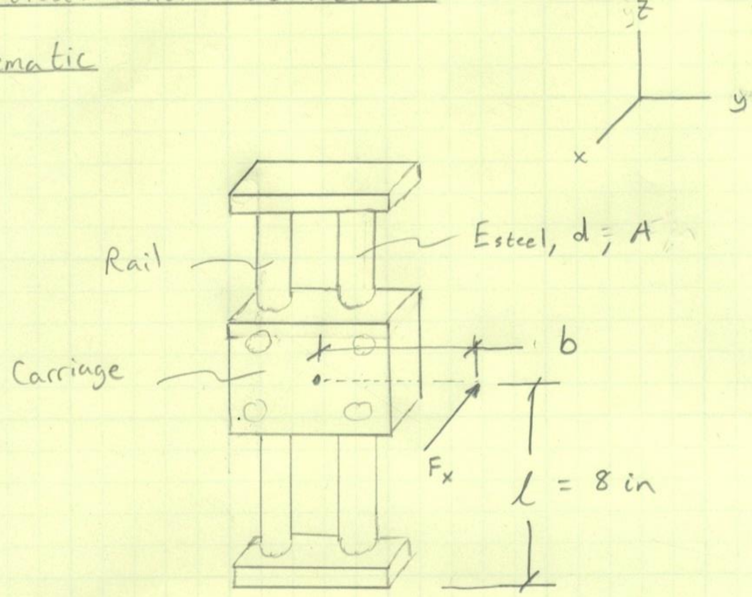
$$F_x = \mu N = \boxed{\mu(2P_m + mg) = F_{x_{slide}}}$$

$$+\circlearrowleft \Sigma M_{P_y} = F_x H - \left(\frac{l}{2} + a\right)(2P_m + mg) = 0$$

$$\boxed{F_{x_{tip}} = \frac{\left(\frac{l}{2} + a\right)(2P_m + mg)}{H}}$$

Vertical Slide Deflection

Schematic



Known: $E_{steel} = 29 \times 10^6$ psi, $d = .5$ in, $A = \frac{\pi}{4}(.5\text{ in})^2 = .196\text{ in}^2$

$F_x = 30$ lbf, $l = 8$ in, $G = 10.9 \times 10^6$ psi

Analysis:

For analysis of δ_x deflection, assume each rail takes 1/2 of load.

$$\delta_x = \frac{\frac{1}{2} F_x l^3}{3 E_s I} = \frac{15\text{ lbf}(8\text{ in})^3}{3(29\times10^6\text{ psi})(\frac{\pi}{64}(.5\text{ in})^4)}$$

$$\boxed{\delta_x = .029\text{ in} = .73\text{ m}}$$

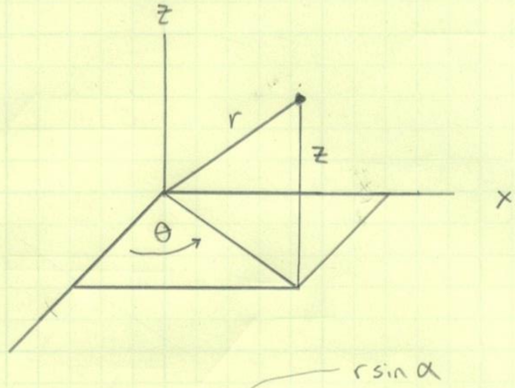
Torsion: Assume all load on 1 rail w b = 4 in

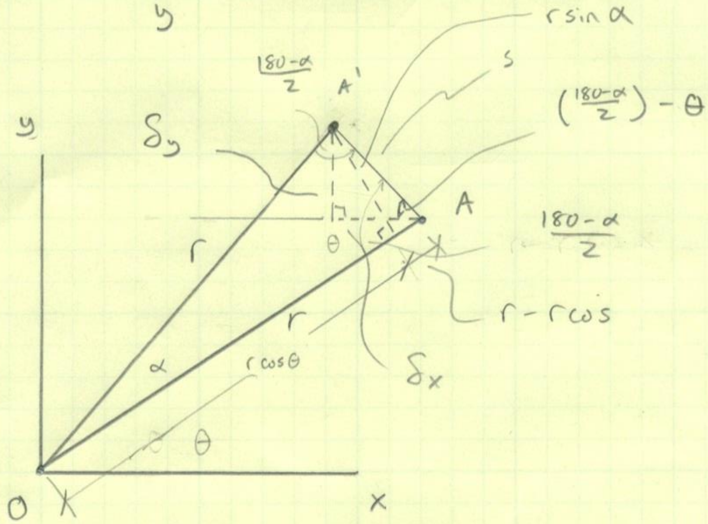
$$\phi_z = \frac{TL}{JG} = \frac{(30\text{ lbf})(4\text{ in})(8\text{ in})}{10.9\times10^6\text{ psi}\,(\frac{\pi}{32}(.5\text{ in})^4)} = .0144\text{ rad}$$

$$= .0144\text{ rad}\left(\frac{180\text{ deg.}}{\pi\text{ rad}}\right) = \boxed{.822^\circ = \phi_z}$$

These are extreme assumptions & show stiffness is still allowable.

XYZ Measurement Accuracy





$$\frac{r - r\cos\alpha}{s} = \cos\left(\frac{180-\alpha}{2}\right) \Rightarrow s = \frac{r - r\cos\alpha}{\cos\left(\frac{180-\alpha}{2}\right)}$$

$$\delta_x = -S\cos\left[\frac{180-\alpha}{2} - \theta\right], \quad \delta_y = S\sin\left[\frac{180-\alpha}{2} - \theta\right]$$

$$\delta_x = -\frac{(r - r\cos\alpha)}{\cos\left(\frac{180-\alpha}{2}\right)}\cos\left[\frac{180-\alpha}{2} - \theta\right]$$

$$\delta_y = \frac{+(r - r\cos\alpha)}{\cos\left(\frac{180-\alpha}{2}\right)}\sin\left[\frac{180-\alpha}{2} - \theta\right]$$

Matlab Code: Magnetic Base Analysis

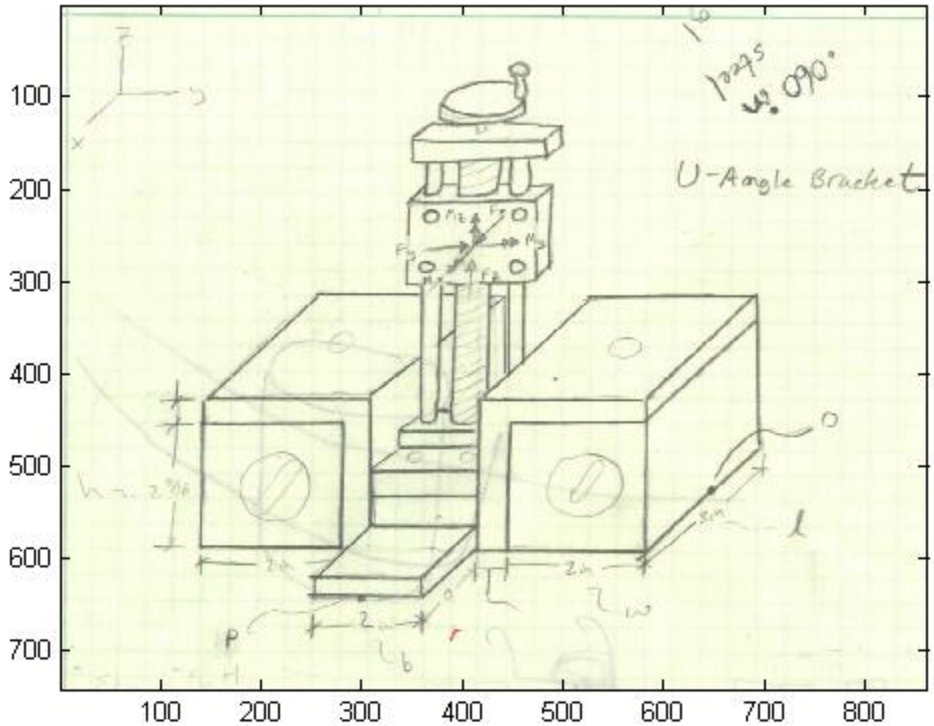
```
clear all

close all
```

Display Parameter Figure

```
pic = imread('BaseGeometry.jpg');

image(pic)
```



Double Base Parameters

```
W = 7; %[lbf] Weight on center of magnetic base

Pm = 220; %[lbf] Rated pull load of single magnetic base

H = 10; %[in] Height load is applied at

l = 3; %[in] Depth of magnetic base in x-direction

a = 1; %[in] Flange extension length in x-direction

b = 2; %[in] Flange width in y-direction between magnetic bases

w = 2; %[in] Width of single magnetic base in y-direction

h = 3; %[in] Height of single magnetic base in z-direction

t = 1; %[in] Thickness of connecting plate
```

```
mu = .2; % Coefficient of Friction
```

Double Magnetic Base Analysis

y-z plane

```
Fy_slide = mu*(2*Pm + W);

Fy_tip = Pm/H*(4/3*w + b/2);

% x-z plane

Fx_slide = mu*(2*Pm + W);

Fx_tip = (l/2 + a)*(2*Pm + W)/H;
```

Single Base Parameters

```
W = 3; %[lbf] Weight on center of magnetic base

Pm = 440; %[lbf] Rated pull load of magnet

h = 10.5; %[in] Height load is applied at

l = 3; %[in] Critical width of magnetic base

a = 1; %[in] Flange extension length
```

Single Magnetic Base Analysis

No "flange" assumption

```
F1 = l/(h)*(Pm/3.58 + W/2); % Allowable applied force [lbf]

M1 = W*l/2 + Pm*l/3.58; % Allowable resultant moment [lbf-in]

% % NOTE: modified equation above to match test results; experimentally 3.58

% % Should really be 3 theoretically

%


% % "Flange" assumption

F2 = (W*(l/2 + a) + Pm*(l/3.58 + a))*(1/h); % Allowable applied force [lbf]

M2 = (W*(l/2 + a) + Pm*(l/3.58 + a)); % Allowable resultant moment [lbf-in]
```

Print Results

```
fprintf('\n*********Parameters*********\n')

fprintf('Total weight on base: %3.1f lbf \n',W)

fprintf('Rated pull load on base: %3.1f lbf\n',Pm)

fprintf('Critical width of magnetic base: %3.1f in.\n',l)

fprintf('Height of applied load: %3.1f in.\n',h)
```

```
fprintf('\n*******For no "flange" assumption*******\n')
fprintf('Allowable Force is %3.1f at %3.1f in. height\n',F1,h)
fprintf('Allowable Moment is %3.1f lbf-in\n',M1)

fprintf('\n******For "flange" assumption******\n')
fprintf('Allowable Force is %3.1f at %3.1f in. height\n',F2,h)
fprintf('Allowable Moment is %3.1f lbf-in\n',M2)
```

```
*********Parameters*********
Total weight on base: 3.0 lbf
Rated pull load on base: 440.0 lbf
Critical width of magnetic base: 3.0 in.
Height of applied load: 10.5 in.

*******For no "flange" assumption*******
Allowable Force is 35.5 at 10.5 in. height
Allowable Moment is 373.2 lbf-in

******For "flange" assumption******
Allowable Force is 77.7 at 10.5 in. height
Allowable Moment is 816.2 lbf-in
```

Plotting

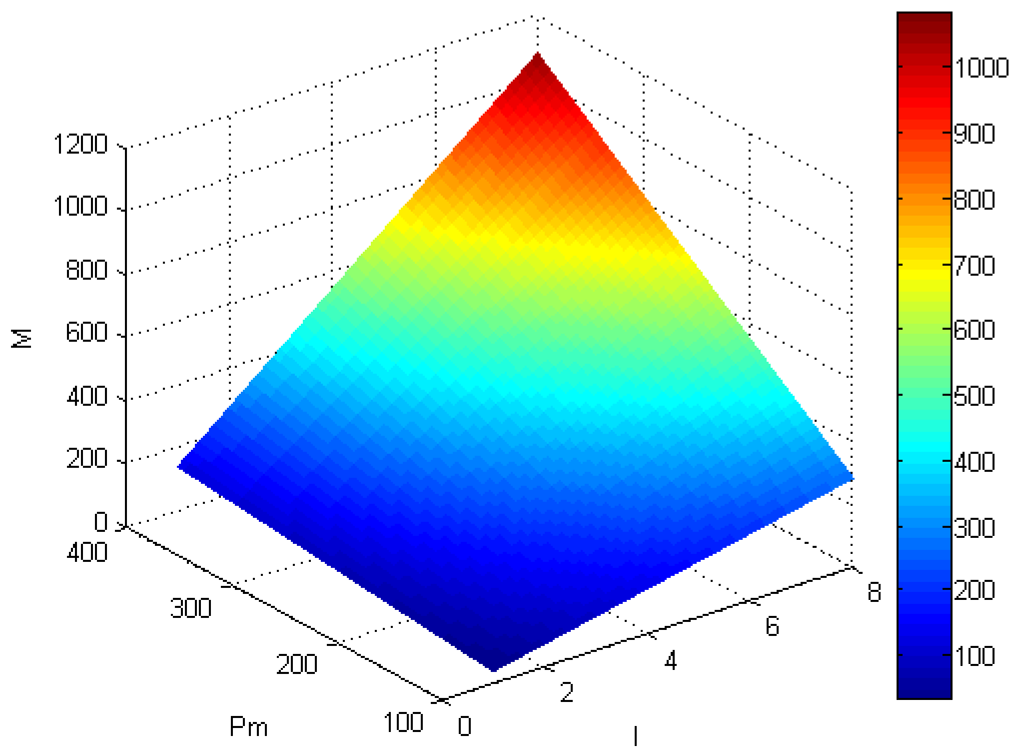
Create mesh

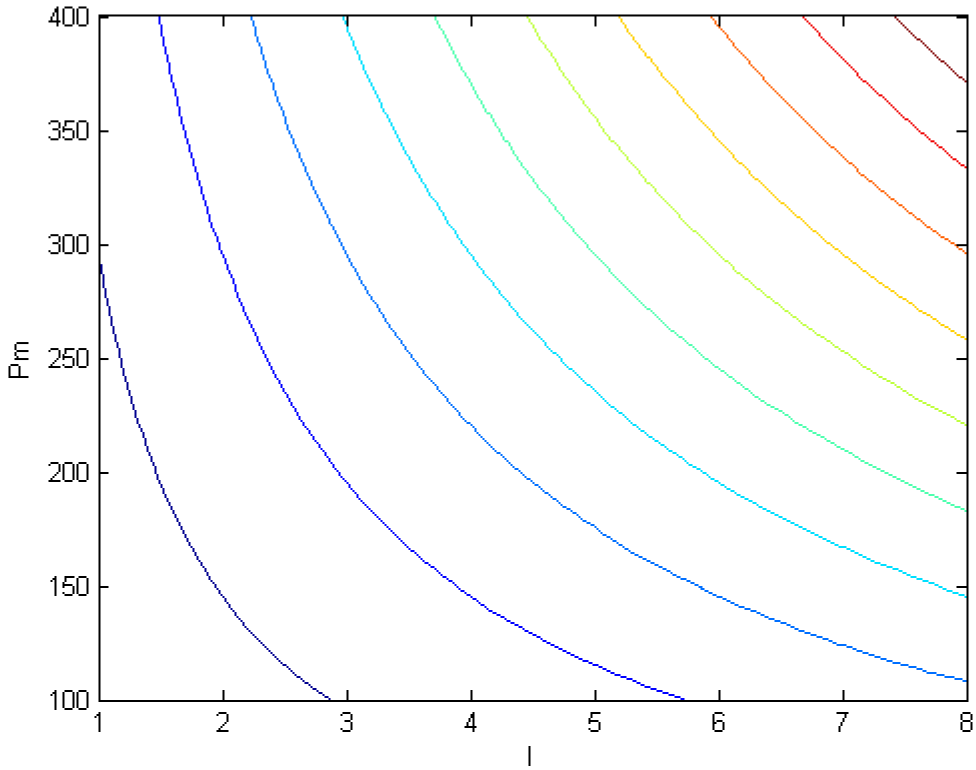
```
l_plot = linspace(1,8,50);
Pm_plot = linspace(100,400,50);
[l_plot,Pm_plot] = meshgrid(l_plot,Pm_plot);
M_plot = W*l_plot./2 + Pm_plot.*l_plot./3;

figure
surf(l_plot,Pm_plot,M_plot,'LineStyle','none')
colorbar
xlabel('l')
ylabel('Pm')
```

```
zlabel('M')

figure
contour(l_plot,Pm_plot,M_plot)
xlabel('l')
ylabel('Pm')
```





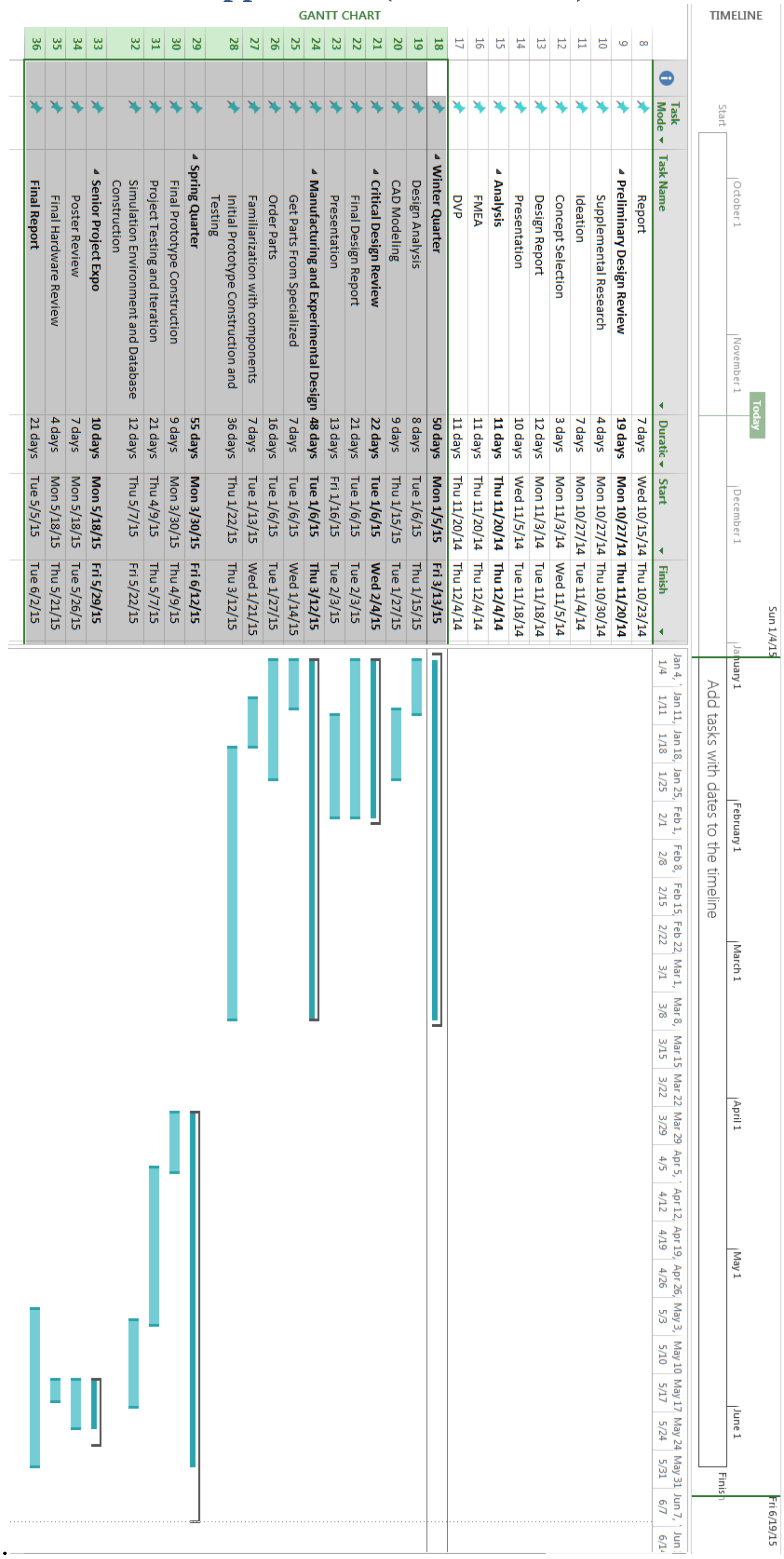
Design Failure Mode Effects and Analysis

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occur	Detec	RPN	Recommended Action(s)
Load Cell Measurement	Disengaging	Loss of test / inaccurate data	7	Insecure Fixturing/Vibration	5	3	105	Close monitoring / Multiple tests / Regular Recalibration
	Breaking of Load Cell	Loss of test	7	Overuse/Dropping onto floor	2	4	56	Close monitoring / Multiple tests / Regular Recalibration
	Decalibration	Inaccurate data	2	General use	2	4	16	Check calibration regularly against known set up

Component Fixtures	Deflection	Inaccurate data	7	Tensioning cable	6	6	252	Testing / Analysis
	Shearing of threads	Loss of test	7	Overloading	2	1	14	Testing / Analysis
	Fatigue	Inaccurate data	7	Many tests over time	2	3	42	Analysis
Cable	Slack	Inaccurate data	2	Overuse / degradation over time / inappropriate setup	1	6	12	Have appropriate setup, and regularly check for slack and loose points
	No actuation	Loss of test	5	Inappropriate setup	1	3	15	Regularly check setup
	Broken	Inaccurate data	3	Overuse / Over loading	2	1	6	Avoid unnecessary loads
Base	Inaccuracy of Potentiometer reading	Inaccurate positioning	6	Decalibration	3	1	18	Check calibration regularly against known set up
	Misalignment of positioning device (height sensor and potentiometer)	Inaccurate positioning	5	Decalibration	5	1	25	Regular Recalibration
	Breaking of potentiometer	Inability to position	6	Overuse/degradation over time	2	4	48	Replace potentiometer when necessary
	Slack in measuring string	Inaccurate positioning	2	Decalibration	1	6	12	Regularly check setup
	Breaking of Height Sensor	Inability to position	6	Overuse/degradation over time	2	4	48	Replace height sensor when necessary
	Inaccuracy of Height Sensor reading	Inaccurate positioning	5	Decalibration	5	1	25	Regular Recalibration

	Breaking of measuring string	Inability to position	5	Overuse/degradation over time	2	4	40	Replace string when necessary
Magnetic Base Fixture	Pulling off base	Loss of test	7	Overloading	1	6	42	Avoid unnecessary loads
	Sliding across base	Loss of test	7	Overloading	1	6	42	Avoid unnecessary loads
	Tipping	Loss of Test	7	Overloading	5	6	210	Avoid unnecessary loads

Appendix F (Gantt Chart)



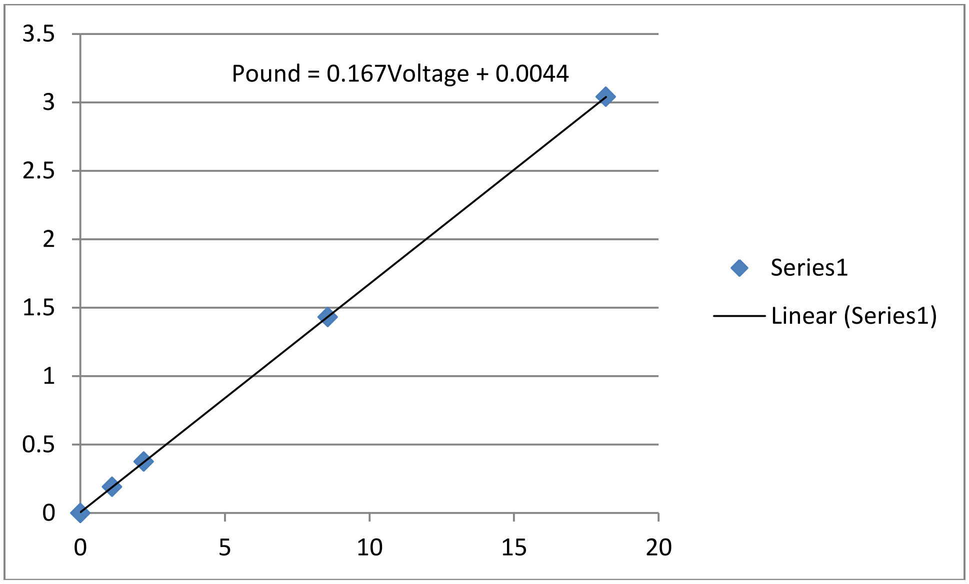
	Task Mode	Task Name	Duration	Start	Finish
8		Report	7 days	Wed 10/15/14	Thu 10/23/14
9		**Preliminary Design Review**	**19 days**	**Mon 10/27/14**	**Thu 11/20/14**
10		Supplemental Research	4 days	Mon 10/27/14	Thu 10/30/14
11		Ideation	7 days	Mon 10/27/14	Tue 11/4/14
12		Concept Selection	3 days	Mon 11/3/14	Wed 11/5/14
13		Design Report	12 days	Mon 11/3/14	Tue 11/18/14
14		Presentation	10 days	Wed 11/5/14	Tue 11/18/14
15		**Analysis**	**11 days**	**Thu 11/20/14**	**Thu 12/4/14**
16		FMEA	11 days	Thu 11/20/14	Thu 12/4/14
17		DVP	11 days	Thu 11/20/14	Thu 12/4/14
18		**Winter Quarter**	**50 days**	**Mon 1/5/15**	**Fri 3/13/15**
19		Design Analysis	8 days	Tue 1/6/15	Thu 1/15/15
20		CAD Modeling	9 days	Thu 1/15/15	Tue 1/27/15
21		**Critical Design Review**	**22 days**	**Tue 1/6/15**	**Wed 2/4/15**
22		Final Design Report	21 days	Tue 1/6/15	Tue 2/3/15
23		Presentation	13 days	Fri 1/16/15	Tue 2/3/15
24		**Manufacturing and Experimental Design**	**48 days**	**Tue 1/6/15**	**Thu 3/12/15**
25		Get Parts From Specialized	7 days	Tue 1/6/15	Wed 1/14/15
26		Order Parts	16 days	Tue 1/6/15	Tue 1/27/15
27		Familiarization with components	7 days	Tue 1/13/15	Wed 1/21/15
28		Initial Prototype Construction and Testing	36 days	Thu 1/22/15	Thu 3/12/15
29		**Spring Quarter**	**55 days**	**Mon 3/30/15**	**Fri 6/12/15**
30		Final Prototype Construction	9 days	Mon 3/30/15	Thu 4/9/15
31		Project Testing and Iteration	21 days	Thu 4/9/15	Thu 5/7/15
32		Simulation Environment and Database Construction	12 days	Thu 5/7/15	Fri 5/22/15
33		**Senior Project Expo**	**10 days**	**Mon 5/18/15**	**Fri 5/29/15**
34		Poster Review	7 days	Mon 5/18/15	Tue 5/26/15
35		Final Hardware Review	4 days	Mon 5/18/15	Thu 5/21/15
36		**Final Report**	**21 days**	**Tue 5/5/15**	**Tue 6/2/15**

Appendix G (DVP&R)

TEST PLAN					
Item No	Specification or Clause Reference	Test Description	Acceptance Criteria	Test Responsibility	Test Stage
1	Time to Set up and Perform Test	Measure time it takes to set up and perform one run	Less than 30 min	Team	PV
2	Time to learn how to use	Teach a test engineer how to perform tests and average times	Less than 1 hour	Team	PV
3	Position measurement calibration	Ensure positioning measurement device is correctly calibrated prior to start	Ensure grid is printed correctly	Brandon and George	CV/DV
4	Position measurement resolution	Ensure positioning measurement device has a fine enough tolerance	Less than 1 mm	Brandon and George	CV/DV
5	Force measurement calibration	Ensure force measurement device is correctly calibrated prior to start	Ensure a 30 pound force corresponds to a 5 volt reading	Team	DV
6	Force measurement resolution	Ensure force measurement device has a fine enough tolerance	Less than 1 N	Team	DV
7	# of runs before load cell recalibration	Do 50 runs and ensure no accuracy is lost	More than 50 runs	Brandon	PV
8	Correct simulation	Ensure setup has correct "feel" when being operated	Comparative analysis with a Tarmac bicycle frame setup	Team	PV

	TEST REPORT							
	SAMPLES TESTED		TIMING		TEST RESULTS			NOTES
Item no	Quantity	Type	Start date	Finish date	Test Result	Quantity Pass	Quantity Fail	
1	50	C	4/25/15	5/20/15	more than 30 minutes		50	It takes more than 30 minutes to set up. Problems included positioning bases, and routing cable
2		C	4/25/15	5/20/15	TBD			
3	2	A/B	2/28/15	3/12/15	17% Error	1	1	First test was likely fine. Second test had slip ups on measurements- accidental repositioning of components.
4	2	A/B	2/28/15	3/12/15	see notes	2 (qualitatively)		Despite the grid having 5 mm ticks, it seems that we can be accurate to 1 mm.
5	5	B	3/23/15	4/14/15	30 lbf corresponds to 5.0144 V	4	0	weight of the load cell seems to contribute to the 0.0144 offset of the expected 5.0 Volts
6	14	B	3/23/15	4/14/15	1.0 V corresponds to 0.037 N	14	0	Load cell reads out the level of millivolts, which corresponds to a fraction of a Newton- well within the tolerance of 1 N
7	50	C	4/25/15	5/20/15	All results have similar results			Since results are similar, it can be assumed that the accuracy stays.
8	20	C	4/25/15	5/20/15	The test has a correct feel	20		The test feels correct when shifting.

Appendix H (Load Cell Calibration)



Pound	Voltage
0	0.0044
15	2.5094
30	5.0144

Appendix I (Safety Checklist)

ME428/429/430 Senior Design Project 2014-2015

SENIOR PROJECT CONCEPT DESIGN HAZARD IDENTIFICATION CHECKLIST

Team: Smooth Shifters Advisor: Professor Sarah Harding

Y	N	
☐	X	Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
☐	X	Can any part of the design undergo high accelerations/decelerations?
☐	X	Will the system have any large moving masses or large forces?
☐	X	Will the system produce a projectile?
☐	X	Would it be possible for the system to fall under gravity creating injury?
☐	X	Will a user be exposed to overhanging weights as part of the design?
☐	X	Will the system have any sharp edges?
☐	X	Will any part of the electrical systems not be grounded?
☐	X	Will there be any large batteries or electrical voltage in the system above 40 V either AC or DC?
☐	X	Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
☐	X	Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
☐	X	Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
☐	X	Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
☐	X	Can the system generate high levels of noise?
☐	X	Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?
☐	X	Is it possible for the system to be used in an unsafe manner?
☐	X	Will there be any other potential hazards not listed above? If yes, please explain on reverse.

For any "Y" responses, add a complete description, list of corrective actions to be taken, and dates to be completed on the reverse side.

Appendix J (Bill of Materials)

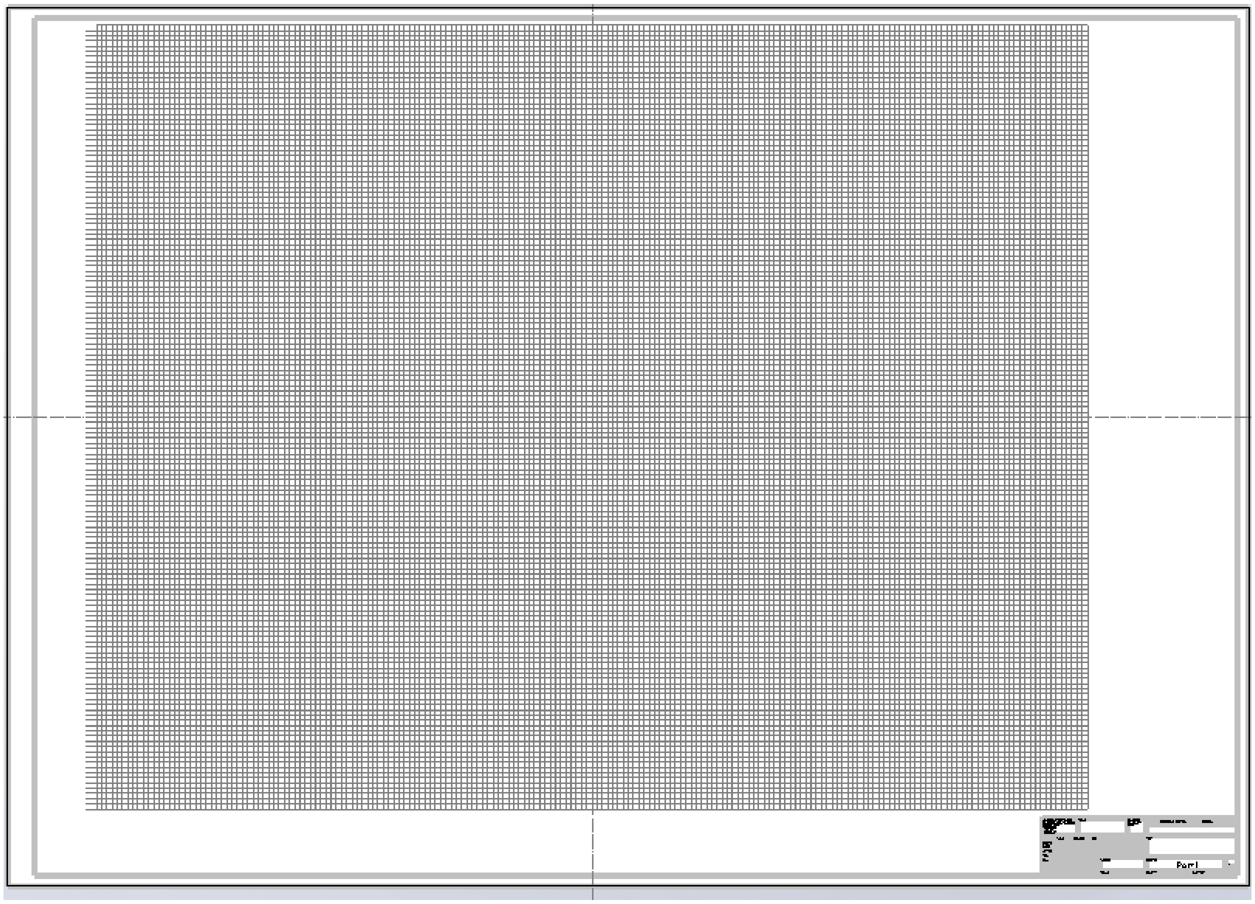
Fixtures	**2000**
BB	*2100*
BB Center Fixture	2101
BB Slide Arm Inner	2102
BB Slide Arm Outer	2103
Pseudo BB Guide	2104
Stops	*2200*
Square Tube	*2201*
Round Stock	*2202*
Brackets	*2203*
Rear Der.	*2300*
Front Der.	*2400*
HB	*2500*
HB Fixture Base	*2501*
HB Fixture Stem	*2502*
HB Fixture Stop	*2503*
HB Load Cell Support	*2504*
HB Fixture HB	*2505*
Load Cell Fixture	*2506*
HB Clamp	*2507*
Vertical Slides	**3000**
Magnetic Base	3001
Magnetic Base Connecting Plate	3002
Vertical Slide Rotary Plate	3003
Vertical Slide	3004
Vertical Slider Carriage	3005

Miscellaneous	**7000**
WMC Sealed Stainless Steel Load Cell	7001
Load Cell Fixture	7002
SGA Signal Conditioner	7003
Potentiometer	7004
Potentiometer Plate	7005
Retractable Clothesline	7006
NI 6001 USB DAQ	7007
Metric Fasteners/Nuts	8000
M8 x 1.25 x 16mm Socket Button Head Cap Screw	8001
M8 x 1.25 x 12mm Socket Button Head Cap Screw	8002
M5 x 0.8 x 8 mm Socket Button Head Cap Screw	8003
Washers	8300
Plain Washer, 8 mm, Regular	8301
5 mm Plain Washer	8302
English Fasteners/Nuts	9000

Fasteners	9100
#10-32 4" Threaded Rod	9101
#10-32 x 0.5 Socket Button Head Cap Screw	9102
1/4-20 x .5 Socket Button Head Cap Screw	9103
1/4-20 x .875 Socket Button Head Cap Screw	9104
#10-32 x 1.5 Socket Button Head Cap Screw	9105
1/4-20 x 2.5 Machine Screw	9106
#8-32 x 1 Socket Button Head Cap Screw	9107
#10-32 x 1.75 Socket Button Head Cap Screw	9108
1/4 - 28 x .375 Stainless Steel Cap Screw	9109
Nuts	*9200*
#10-32 Machine Screw Hex Nut	9201
#8-32 Machine Screw Hex Nut	9202
1/4-20 Machine Screw Hex Nut	9203

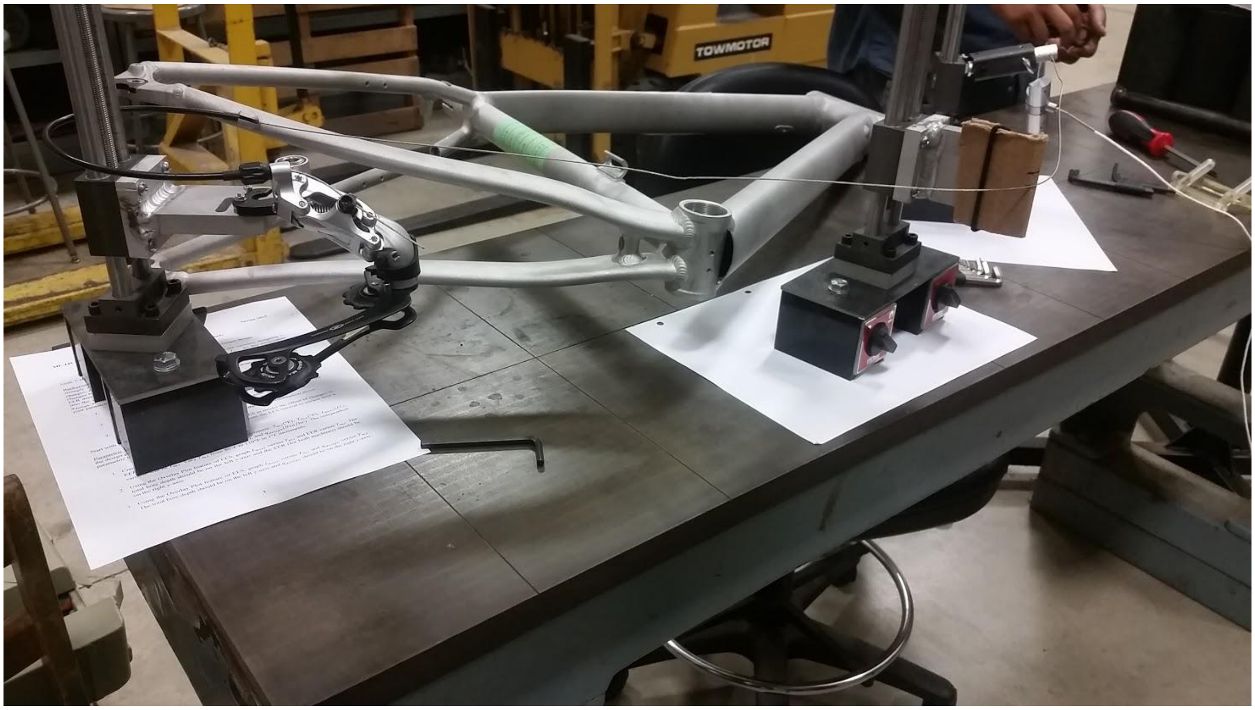
Appendix K (Procedure)

1. Determine specified “hard contact” geometry points via Solidworks/equivalent CAD software.
2. Plot these points on the 5 mm incremented grid.
3. Print grid and decided points from CAD using a plotter.



4. Fix plotted grid to steel table, using clamps, to ensure accurate measurement (may need to remove paper grid from underneath magnetic bases).
5. Measure the distance of cable necessary from the hand shifter to the load cell on the faux handlebars.
    a. Cut the cable in two.
    b. Using the screw and nut, secure each end of the cut cable into the load cell fixture, ensuring the cable is in line on either end of the load cell.
6. Mount each fixture to the carriage of the vertical slide using #10-32 x ¾” screws
7. Generally position each fixture in the z-direction:
    a. Use adjustment wheel on the top of the vertical slide to dictate height
    b. Lock the vertical slide in place using the lever on the top right of the slide

8. Line up the dual magnetic bases for each respective fixture using the grid and plotted position points
    a. Turn on the magnetic bases, securing the system to the steel table

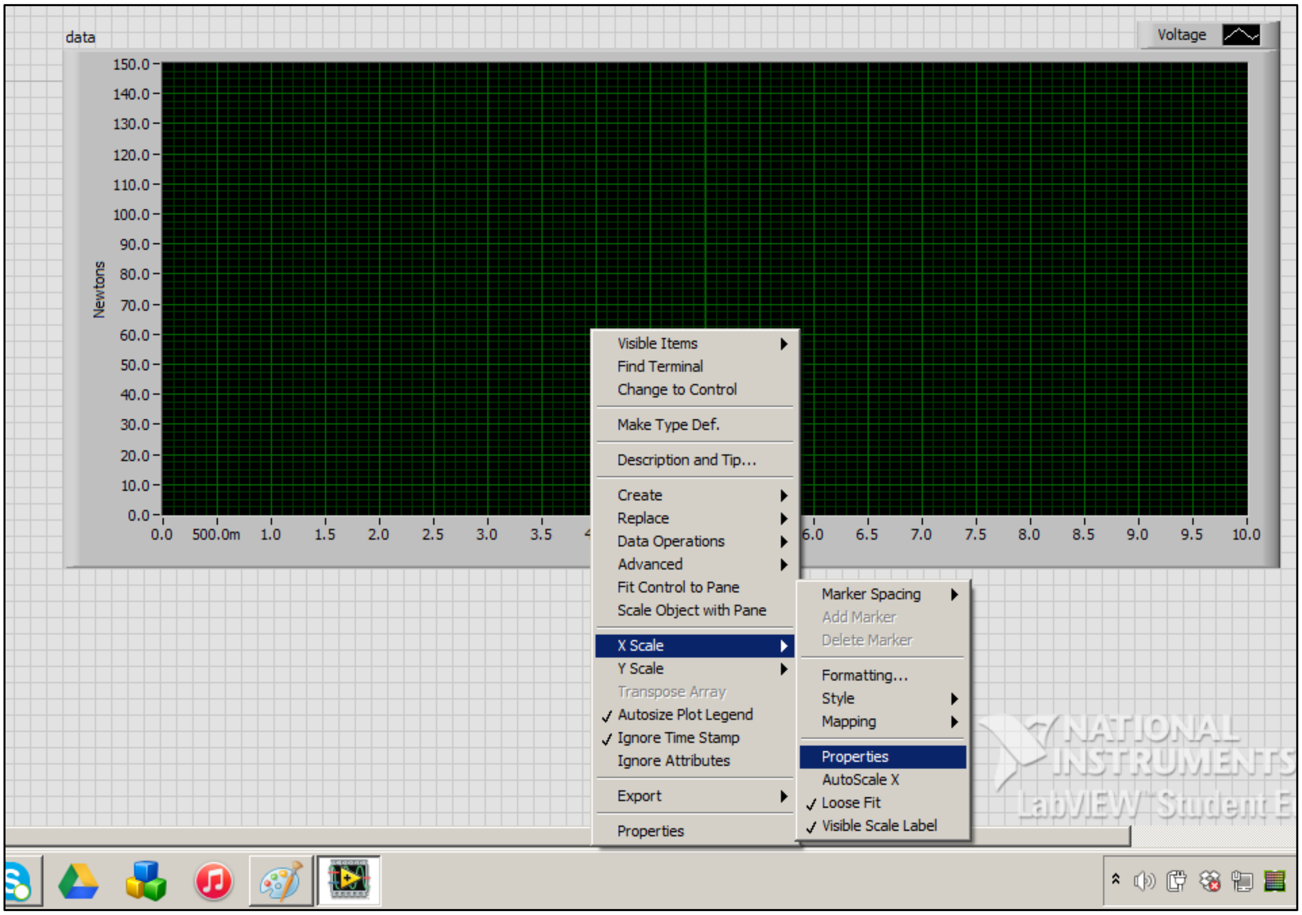


9. Adjust/secure the rotation of the vertical slide using the M6 socket head screw located under the vertical slide, between the magnetic bases
    a. Adjust the vertical slide to ensure that the cable will run along the strong axis of the dual magnetic bases, preventing tipping
10. Fine adjustment of faux handlebars:

a. Adjust the pegs on the faux handlebars to represent the desired path where the cable will travel.
b. Ensure stability of handlebars on dual magnetic base fixture by also supporting the hanging handlebars using a roller support stand (seen below)

11. Fine adjustment of cable stop fixtures:
    a. Using the #10-32 screw and wing nut, secure the steel tubing at the desired angle
    b. Adjust the inner cylinder, which dictates the distance and angle of the ferrule and corresponding cable
    c. Secure the inner cylinder with the thumb screws
12. Fine adjustment of the bottom bracket guide fixture:
    a. Adjust and position the arms to accept the desired bottom bracket guide
    b. Secure this position with the two nuts on either end of the threaded #10-24 rod
13. Fine adjustment of the rear derailleur fixture:
    a. Position the "noodle" stop block using the slot and
    b. Secure when the desired bend radius coming out of the rear derailleur is achieved
14. Feed the cable through each positioned fixture
    a. Include cable housing where necessary
15. Initialize Labview with the "Cable Drag" vi (virtual instrument)
16. Connect load cell wires into the data acquisition unit
    a. plug red striped lead into the a0 +port
    b. plug solid red lead into the a0- port
17. Plug in power supply for load cell, and plug in data acquisition unit into computer
18. In the "Cable Drag" block diagram, adjust the DAQ assistant as necessary
    a. Single up shift - 100k samples, and scan rate of 10-12k
    b. Single up and down shift - 100k samples, and a scan rate of 10-12 k
    c. Full up and down shift - 200k samples, with a scan rate of 10k

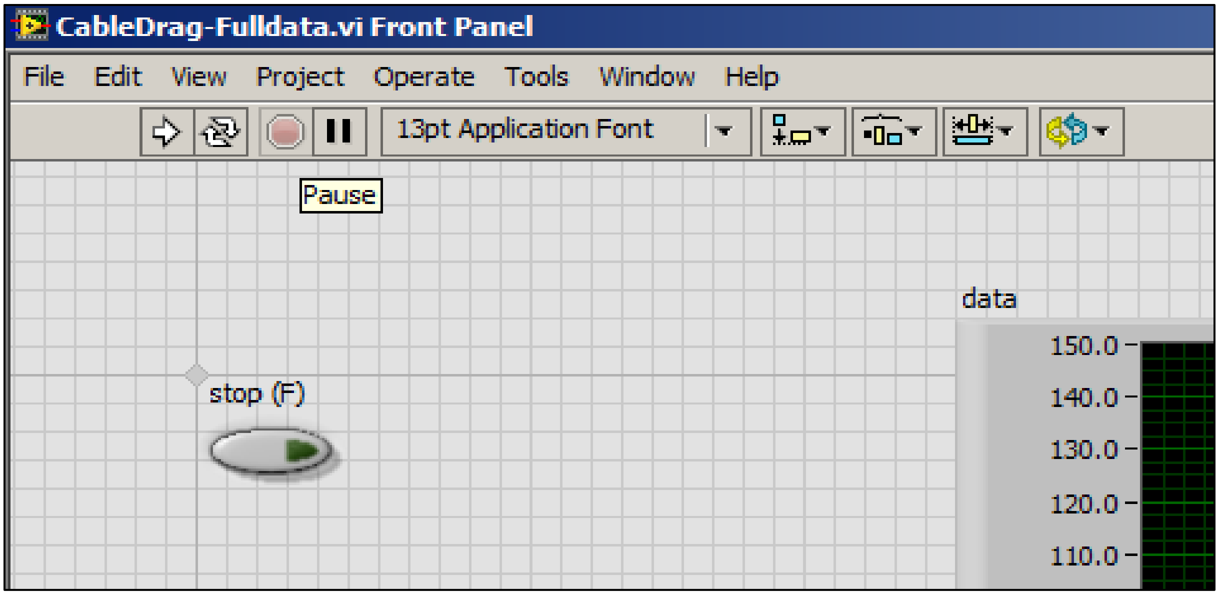
19. In the “Cable Drag” front panel, adjust the time axis of the graph by right clicking the graph display, going to x scale, and going to properties



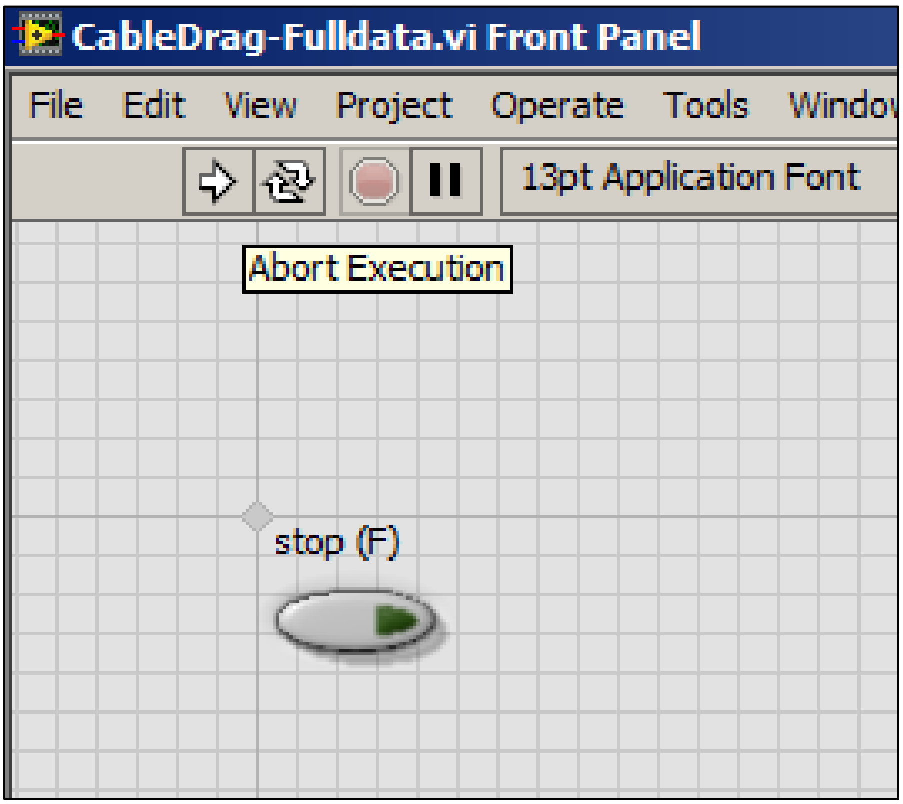
a. Single shift - 7 seconds max
b. Single up and down shift - 15 seconds max
c. Full up and down shift- 20 seconds max

20. Initialize a test in Labview, and then proceed to actuate the cable via the hand shifter/brake found on the handlebar assembly
a. a graph of the data can be seen in the Labview front panel of the VI
b. Wait approximate three seconds before cable actuation
c. Actuate via shifter/brake mechanism found on handlebar assembly

21. Wait for a prompt to save
a. Save as a temporary name first (e.g. “1”, “2”, “a”, or similar)
b. pause the run until data acquisition is completed

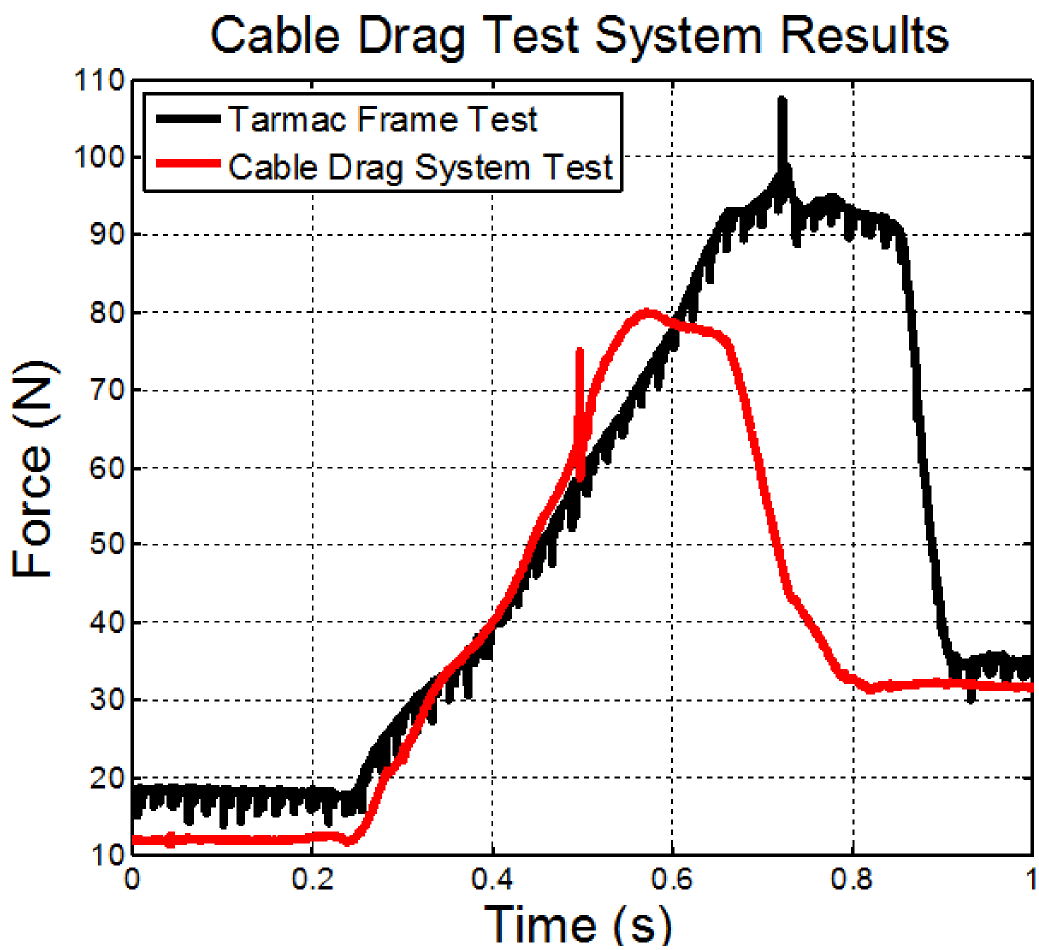


c. Abort the execution in Labview



d. Rename the saved excel file as desired

22. Import data into Matlab file
23. Follow procedure in Matlab file to compare data
    a. Have one file for a datum data set
    b. Have other files as deemed necessary
    c. Follow instructions for peak value outputs, curve smoothing, etc



24. Repeat process as necessary for different frame geometries