Free Hub Test Machine

Project # 34
Final Design Report
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Sponsor: Specialized Bicycle Components Inc.

Contact: Marshall Poland

Brett Murphy
bgmurphy@calpoly.edu

Mitch Ambrosini
ambrosin@calploy.edu

Nick Boldt
nboldt@calpoly.edu

Stephen Knaus
sknaus@calpoly.edu

Statement of Disclaimer

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Executive Summary

The purpose of this project is to design and build a machine to test a bicycle freehub in a lab environment. The conditions need to imitate the forces experienced by a bike wheel in a repeatable fashion. To do this we designed a machine that can fatigue the freehub in two distinct modes, pedaling and freewheeling. In the pedaling mode the freehub will be repeatable torqued to find how many engagement cycles freehub can endure before failure. The freewheeling test will spin the freehub in its coasting direction to find how the freehub wears during its lifetime. A freehub is ratchet mechanism on a rear bike wheel that transmits torque when the rider is pedaling but spins freely when the rider is coasting. Our tests will create life-like scenarios to fatigue at an increased rate in a lab setting. From this project we hope to compare different freehubs against each other as well as see where the freehub can be improved.

Chapter 1: Introduction

Sponsor Background and Needs

The market for bicycles has turned into a 6 billion dollar industry that demands innovation to stay on top. The main goal of bicycle manufacturers is to create the fastest, strongest, and lightest bike that is able to give its rider an edge over their competitors. Specialized Bicycle Components is the fourth-largest manufacturer of high-end bicycles. Specialized has brought their design innovations to every part if their bicycles. Their company motto is “Innovate or Die” and they are one of the most innovative companies in the industry. To create components of the highest quality Specialized needs a way to test their products to make sure they are up to their high standards and to compare their components against the competition.

Formal Problem Definition

Over the course of the 2013-2014 school year, our team designed, built, and conducted preliminary testing for a machine to evaluate the durability of the freehub mechanisms found in bicycle hubs. The machine tests two modes of operation: the wear of the pawls from freewheeling and the fatigue of the hub after repeated engagements and disengagements. We designed the machine for use in the test facilities at Specialized. Our design incorporated features to keep the operators of the machine safe.

The main objective Specialized has for this project is to design the test machine so that tests are repeatable across a wide variety of bicycle hubs with realistic forces. They want to be able to

take two different wheel and hub setups, test them, and have a definitive result of which one has better fatigue resistance. This will allow them to compare their existing designs to their competitors' and to refine their hub design accordingly. Because stress analysis of the hub is complex, our goal is to apply all the forces as they are applied in real life to ensure that the test is realistic.

Objectives

Our goal for this project is to build a machine that is capable of testing bicycle freehub assemblies. The machine must allow for repeatable tests, account for both a freewheeling and pedaling scenario, and mimic real life reaction forces. Some of these forces can be seen below (table 1) as well as how we can measure the force. To achieve these goals, the machine will record the elapsed time up until failure and upon detecting this failure will safely halt the test. The machine will be able to test an equivalent of 3 years of riding in 3 days. The end product will safely be able to gather data on free hub failures that Specialized will use in their design process.

Forces	Target value	Measured using
Chain Load	5000 N	pressure regulator/load cell
Rider Weight	1000 N	Weight and tensioner
Spoke Tension	1100 N	standard on wheel
Resistive force required 26” rim	769 N	brake system
Resistive force required 27.5” rim	741 N	brake system
Resistive force required 29” rim	690 N	brake system

Table 1. The forces that our design needs to achieve

These objectives were accomplished through the following engineering guidelines listed in a QFD (Quality Function Deployment) and the table of requirements. These tables can be found in Appendix A and B. The QFD is a tool we used to help develop the specifications and find the correlations between the customer requirements and the actual engineering specifications we will base our design on. The chart has the customer requirements on the left, with each weighted based on their significance. On the right, we rated a competitor design, the Reynold’s test machine and Chun Yen machine, under these requirements on a scale 1-5, with a 5 being the best. On top, we put the specific engineering requirements we decided to use to make the

machine and in the middle we rated the correlation between what Specialized wants and how we plan to accomplish it. An object with a 9 has a strong correlation and 1 or blank means no or little correlation. Multiplying all these numbers gave the weight of our requirements, telling us which factors will be the most critical in our design.

We then grouped these requirements in a table, listing their nominal value, whether this value can go higher or lower, the risk of completion and the compliance. The risk section represents how intense this particular part of the design will be. For example, the controller was one of the highest weighted topics in the QFD, therefore it has a high risk. This means that we will make this one of the highest priorities in our design process. Conversely, making the machine hold the correct sized hubs is more straightforward and will take less analysis, leading to a low risk designation. The compliance column shows how we expect to meet each requirement. The letters stand for Analysis (A), Test (T), Similarity to Existing Designs (S), and Inspection (I).

The two design factors that had a high risk were detecting the failure and making the machine able to perform the two types of testing. Detecting the failure involves making a controller that has a sensor input that will detect if some part of the freehub has failed. From this input, the controller will be able to automatically stop the machine to keep it from hurting anyone or itself. The two modes of testing are pedaling and freewheeling. Our design will need major geometrical design and stress analysis to be able to meet both these test criteria.

Project Management

We broke the project down into 6 subsystems, with a team member responsible for each subsystem. Mitch is responsible for the rim brake and rider weight simulation, Brett is responsible for dropouts and support structure, Stephen is heading the controller and data acquisition subsystem, and Nick is responsible for the chain force application subsystem.

Team Members

Mitch Ambrosini

Mitch is the main point of contact with our Specialized contact, Marshall Poland. This makes planning and scheduling meetings easier without redundant information being passed between people. Mitch will facilitate meetings and inform the team of any necessary sponsor communications. Mitch will also be in charge of material acquisition. He will oversee the ordering and receiving of components that are ordered for the project. Mitch will coordinate with Brett to make sure that the materials selected remain within our budget.

Brett Murphy

Brett acts as the team treasurer. Brett will maintain both travel and material budgets for the duration of the project. Beyond budgetary obligations, Brett will also be in charge of manufacturing considerations. Welding, machining and fabricating will be performed as much as possible at Cal Poly, and any parts that cannot be manufactured in-house or at the Specialized facility will be subcontracted as needed. Brett will evaluate manufacturing tolerance requirements and determine where the parts would most effectively be fabricated.

Nick Boldt

Nick is in charge of recording the information discussed in these meetings. He will maintain meeting notes, a team binder of information, and our Google Docs site containing pertinent information. Nick will also be in charge of planning and executing our prototype and final design fabrication plans. All of the components that could not be purchased off the shelf were machined and or welded in-house. Nick coordinated the CNC machining that was done by Cal Poly student shop techs in the Mustang 60 Machine shop.

Stephen Knaus

Stephen is the team organizer and will track project progress. He will plan our next steps and organize time for the group to work and achieve objectives. If we need to reserve project space or work areas, Stephen will make the reservations. He will also assist Nick in maintaining and organizing information.

Outside of these specific and individual responsibilities our team will work together and share roles to accomplish all of the objectives. Each of us have specialized areas of expertise and will be able to contribute to the group in different ways and it is important that we are all allowed to contribute where we see fit.

Chapter 2: Background

Specialized is interested in investigating high cycle fatigue failure in freehubs. The scope of this project is to design and build a test apparatus that will examine the lifetime of such freehubs under freewheeling and pedaling conditions. To fully understand the problem we started with doing research on how the freehub system works so we can better understand how it will fail.

Existing Products

Through our background research, we found a few machines that have already been designed and built to test freehubs. We tried contacting these companies to see if they were able to give us any information but the companies have not been helpful. These test machines are not for sale and the major bicycle companies do not want information on how they do their testing to get to their competitors. Specialized wanted our group members had so sign an NDA to ensure that Specialized testing information will not get to their competitors. However, we were able to find a few things on message boards and different websites. An online video shows a hub testing machine used by Reynolds Cycling in action (figure 1). In this test the wheel is torqued using a pneumatic cylinder and then stopped with a disk brake on the wheel. This test does not allow for freewheeling or for the inclusion of environmental factors such as mud or water. An additional downside to this design is the lack of the chain force and rider weight on the axle.

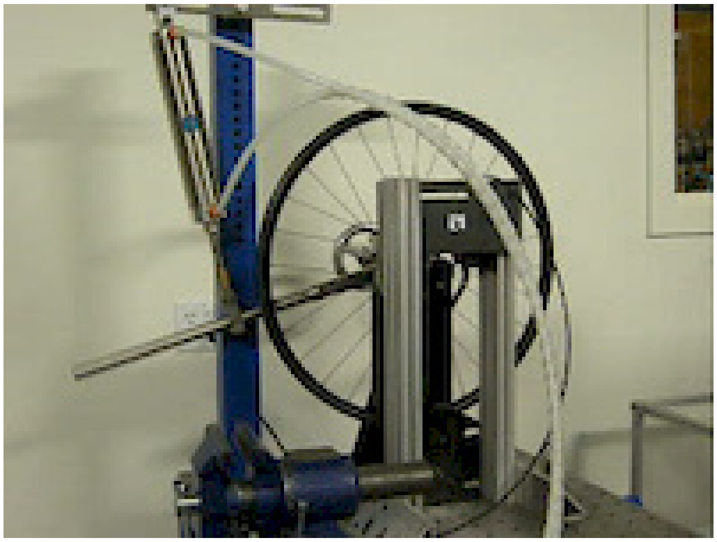


Figure 1. Reynolds Test Machine Apparatus

HJM technology co. manufactures bicycle test machines from their Headquarters in Taiwan. The closest product that they create is a hub ratchet life testing machine. Unfortunately their website lacks any detail and all emails that we have sent have gone unanswered. The poor English on the website leads to the conclusion that they do not speak English well. From the pictures their design looks like it applies a large load in order to break a hub and then run analysis on how the hub broke. A picture of the HJM design can be seen in figure 2. The design does not include environmental factors on the whole wheel nor does it use the spokes and rim.

Figure 2. HJM Hub Ratchet Life Testing Machine

Chen Yen is another company that builds testing machines for bicycles. They are based in China and we had the same difficulties getting information on what their machines are capable of. Chen Yen's test machine can be seen in figure 3. This test machine appears to do a lot more than just test the hub because it is a big machine and appears to test the wheel under various conditions. We talked to our sponsor about both companies and he has contact with both and knows what products they offer. He mentioned that these companies do not make anything that is similar to what we are making and that is why they did not contract with them to create this test machine.

Figure 3. Chun Yen Oscillation Durability Tester

Current State of the Art

There are no current patents on a free hub test machine. This is likely because there is no widespread market for test machines. The market is limited and the few companies that do use these machines order in extremely low volume and to specific requirements that require a separate design process for each machine. This means a patent would provide very little profit to a company. An additional concern is that making a patent for a test machine may give industry rivals an insight into proprietary methods. Because the biking industry is so competitive companies do not want divulge their proprietary information.

How a freehub Works

To design a machine that will test a rear bicycle wheel we first had to understand how the rear wheel freehub system worked and why it was created. Prior to the 1980's, all bicycles used the screw-on freewheel gear cassette system. In this system the gear cassette attached directly to the hub. No screws were needed to keep the cassette on because pedaling forces tightened the gear cassette onto the hub. Removal of the cassette often required a considerable amount of effort due to the large torque that tightens the cassette from the pedaling force. Another flaw of the freewheel mechanism is the drive-side bearing is located in the freewheel, and as more sprockets are added (for more gear combinations) it pushes the bearing further from the support. The farther the bearing is from the support the more flexing stress takes place in the axle which can bend or even break the axle. These two design setbacks led Bicycle companies to look for a better designed rear wheel. In the late 1980s, Shimano introduced the freehub and Cassette design which became the new standard in bikes with multiple rear gears. Figure 4 shows an example of a freehub vs. a freewheel. Notice that on a freewheel the gear cassette attaches directly to the hub and on the freehub the gear cassette goes on the hub (in this photo it is black). Specialized uses the freehub design, so we will not worry about designing the machine to be used with the older freewheel hubs.

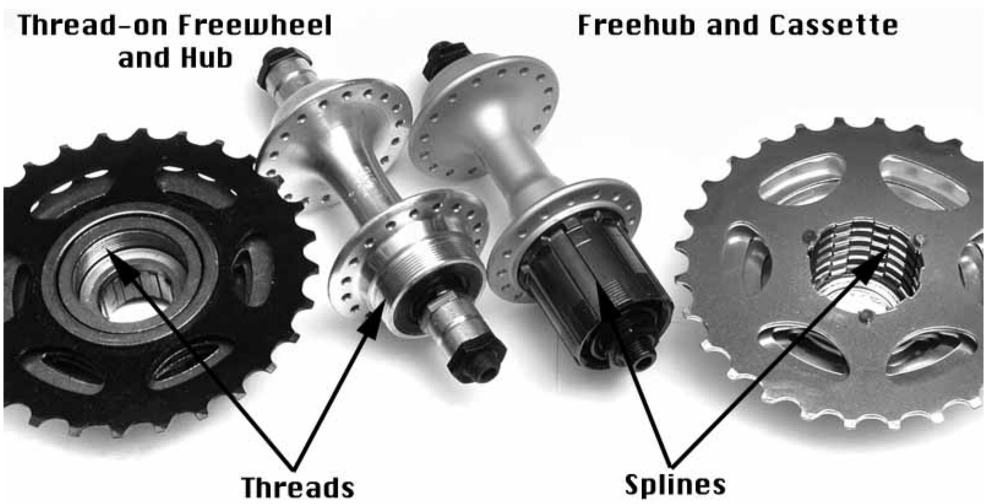


Figure 4. This is an example of the difference in freewheel and the freehub

The freehub is the mechanism in the rear wheel which allows the pedals to disengage from driving the rear wheel when the rider is coasting, but then re-engages when the rider begins pedaling. There are two common freehub designs; the pawl and ratchet design, and the star ratchet design. The most common freehub type is the pawl and ratchet (Figure 5). In this design, the ratchet spins with the rim, and the pawl is fixed to the cassette. When the rider pedals forward, the pawl engages the ratchet, and they both spin together. When the freehub is spinning slower than the wheel, the pawl disengages and the assembly spins. The spring on the back side of the pawl pushes outwards so that when the rider begins pedaling, the pawls “catch” on the ratchet teeth. Pickup speeds can be increased by increasing the number of teeth in the ratchet, or by offsetting some of the pawls, so that not all pawls engage at the same time. Adding pawls increases the complexity, cost and weight while increasing the number of teeth decreases the lifetime. Smaller teeth wear more easily because of less material, and can fail quicker. The number of pawls varies between companies and models, and the type of spring used to hold the pawls in place varies as well. Some hub pawls are held in place with coil springs, while others use leaf springs, and still others use circular springs.

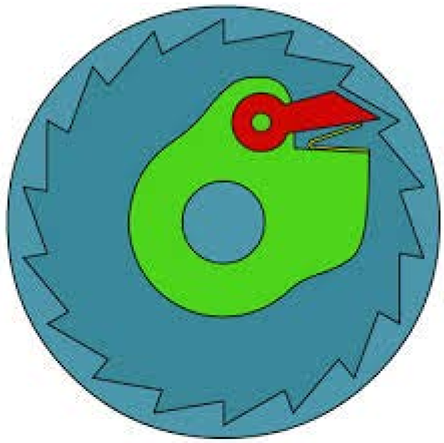


Figure 5. Basic Freehub Design with 1 pawl

Another type of freehub is the star ratchet design. This design uses two ratchets that are pushed together using springs. The ratchets are able to spin freely in one direction but not in the other. DT Swiss has patented the Star ratchet, and Chris King hubs use a type of star ratchet as well. The advantage of the ratchet design is that there are more engagement points, which means that the hub can transmit greater loads without failing. With a 72 tooth ratchet plate, there are 72 points of engagement, and the pickup speed is very fast. Figure 6 shows an example of a start ratchet and figure 7 shows the assembly of a typical rear wheel hub.

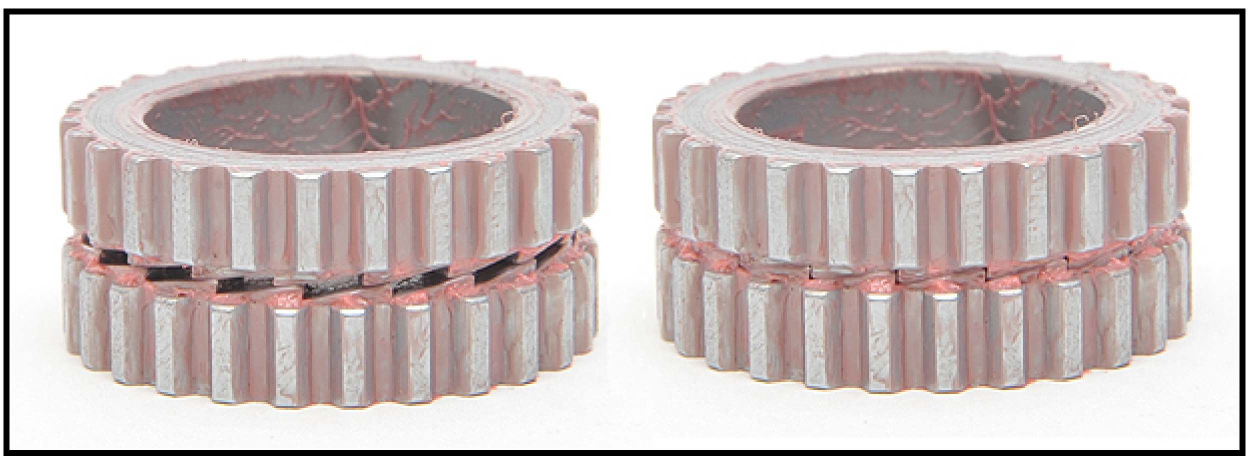


Figure 6. Star Ratchet design

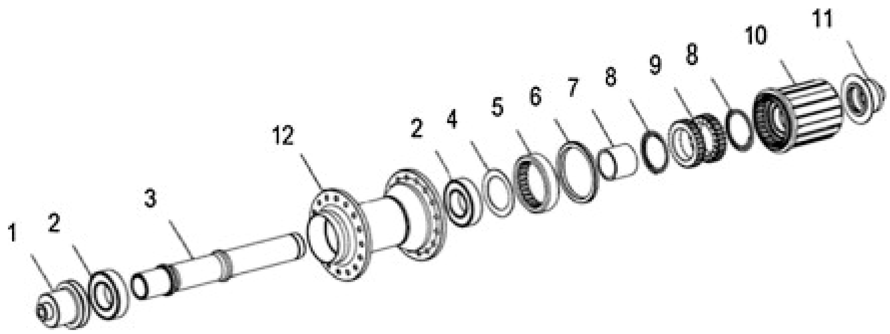


Figure 7. Freehub Assembly

Figure 7 shows an assembly of a freehub along with all the other components found in the rear hub for a typical freehub. This design incorporates a star ratchet. Item 12 in the figure is the main hub body that houses the components as well as mounts the spokes which extend to the rim. The freehub body (item 10) attaches to item 12 and spins independently of the main hub body which is how the pedaling force is transmitted through the wheel. Item 3 is the axle around which the wheel spins. The axle mounts on the dropouts of the frame. Item 9 is the ratcheting mechanism that allows the hub to spin freely while the rider is coasting. This ratchet also reengages to allow the rider to pedal and transmit power to the wheel. The ratcheting system for this design uses two ratchets with one ratchet attached to the main hub body and the other attached to the freehub body.

Specific Technical Data

Rear Wheel Loading

To make our test the most accurate to real life scenarios we needed to analyze what forces would be present on the rear axle under normal operating conditions. Our sponsor gave us a list of forces that our machine would have to replicate so our research was concerning around how important each force is and how it would affect the freehub. The main forces are the rider weight, chain tension, dropout reaction, and the stopping force on the wheel. These can be seen below in the free-body diagram. The forces we use will have an increased magnitude and frequency compared to normal loading to simulate three years of loading over a three day test. The rider weight and chain tension will both be adjustable so that Specialized can test different scenarios and change the length of the test.

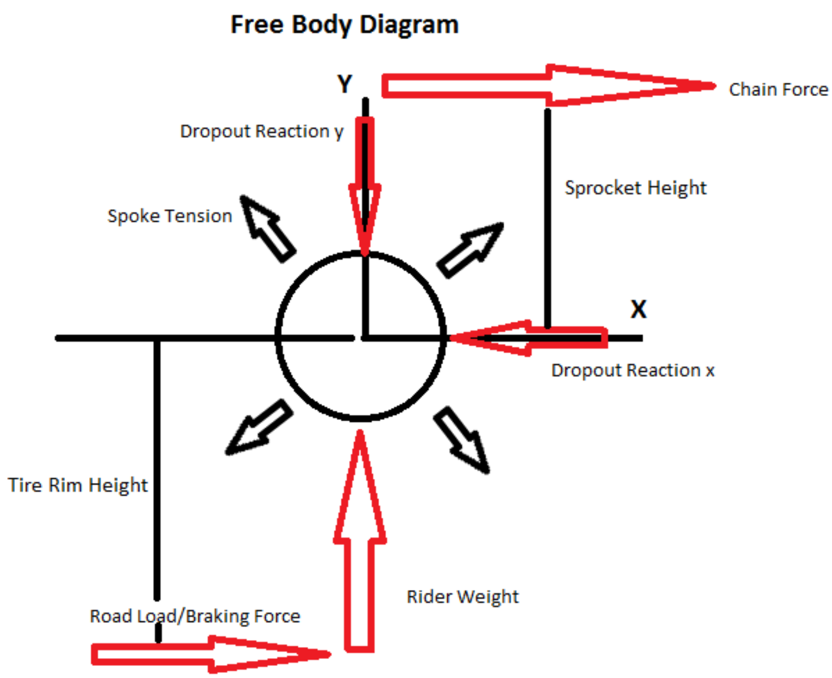


Figure 8. Free Body Diagram on a freehub

The rider weight will play a big role in deflecting the freehub. As the wheel spins the location of the weight relative to the hub will change, which will play a role in how the hub reacts when put under pressure. The rider weight is applied on the saddle, pedals, and handlebars but the exact location of the center of gravity would constantly be changing. To simplify the problem of finding the amount of weight on the rear wheel, Specialized has given us a standard weight of 1000N (225lb). Although this weight seems very high compared to the actual weight of the rider, we must also consider the rider going off a jump would create an impulse that would increase the effective weight dramatically.

The chain tension is the largest force that we will have in the system. This load is transmitted from the rider to the pedals then through the chain which will pull the hub forwards. For our project it is crucial that the chain load and the rider weight are at 90 degrees to each other, mimicking the real life loading scenario. Specialized has specified a chain load of 5000 N (1124lb). This number is related to how much the rider weighs, the level of fitness of the rider, as well as the resistance that is seen by the wheel. It is also amplified so that the test will show results in less time.

The dropout reaction is how the bike frame transmits the loads to the wheels and vice versa. The amount of the force (and deflection) on the freehub is greatly affected by the material and geometry of the dropout as well as what kind of axle is being used. Specialized is not concerned

with the exact loads in the dropouts, rather they only want the forces to be generally lifelike. Although there will be some deflection of the dropouts the deflection that we are most worried about will occur on the freehub between the dropouts. Because of this, and to make the testing more consistent, we have thrown out the idea of using different dropout materials and sticking to one set of mounting points for the wheel. We followed a Specialized design for heavy-duty, realistic dropouts that we will have made.

The friction force (road load) will be the main way that we slow the wheel and will have to hold the wheel still while the freehub is loaded. There are many different ways that we could achieve this. We can use the rider weight to add a resistive force either through a pad that comes in tangentially to apply a load or a strap that could wrap around the wheel. Our initial calculations give us 1500N (337lb) as the force that will be required to stop the 5000N chain force acting on a 26 in wheel and using a 4 inch gear. If we need to add more resistance force we could always add additional rim brakes (similar to those found on a road bike) to increase the resistance force without adding a normal force to the wheel.

The spoke tension is a major factor in the hub dynamics. Each spoke is loaded to around 1100N. These forces pull on the hub body creating a small deflection which will change the bearing clearances and the way that the wheel rotates. To imitate the forces that are on the hub most accurately we have elected to include the tension from the spokes in our testing. The spoke tension pulls out the hub in opposite direction to secure the outer rim in place with the inner hub. This could play a big role in the deflections that the hub experiences during loading and unloading. This will make our test machine bigger because we will have to use the whole wheel instead of just the hub.

Definition of Failure

As we test the freehubs, there are many different components, such as the hub body, pawls, and ratchets, that all can fail first. In some situations, such as failure on single tooth on the ratchet, the freehub will still be able to function past the point of failure. This led us to define the failure of the freehub not as when the first part inside structurally fails, but when the freehub is no longer operational. Failure is when the freehub either seizes up and is no longer able to spin freely in one direction or when the ratchet mechanism breaks and the hub will not lock in the other direction. This will allow us to easily monitor whether or not the freehub has failed. It is likely that the freehub will only fail in the pedaling test and for the freewheeling test it will be necessary to disassemble the hub after the test and check for wear on the pawls and ratchets.

Compatibility

Our test machine will need to be compatible with all types of rear bike wheels. There are three major types of bike wheel sizes, 26”, 27.5”, and 29”. Our machine will be able to test all three. In addition to variation in wheel diameter, the rim geometry changes as well. The rim width varies significantly between road bike and mountain bike wheels, and this also needs to be accounted for. If a rim brake is used, the angle of the braking surface is likely to change from wheel to wheel as well. Some of the hub and axle dimensions can be seen in figure 9.

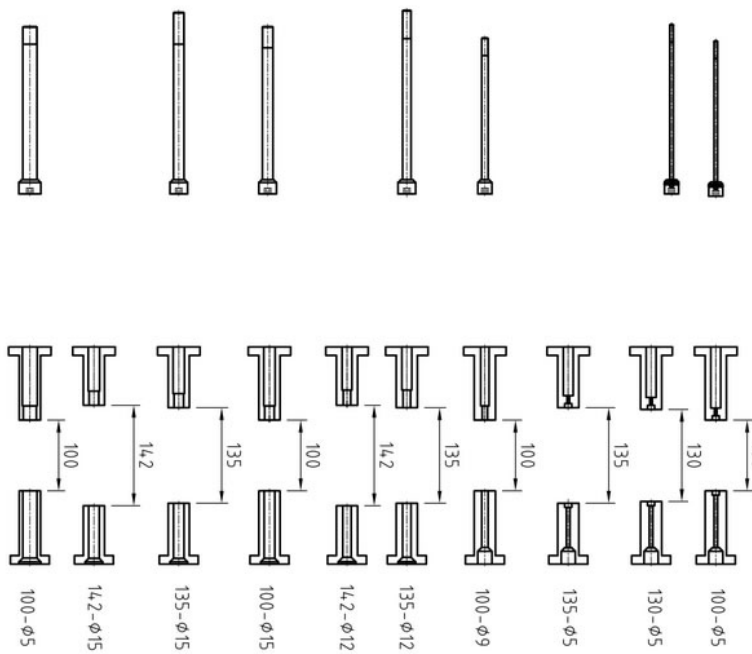


Figure 9. Different Sizes of Freehub Skewers

Pedaling Test

The objective for the pedaling test is to realistically simulate the major forces on the hub, including rider weight, spoke tension and chain force, during hard pedaling. The structure will hold the hub steady with a belt wrapped around the rim and the piston linkage will fit on the hub body’s sprocket receptor. Before the test starts, the regulator on the air supply will need to be adjusted to the correct pressure and the power screw tightened to the correct rider weight. Once these are ready and the pump is turned on, the test can start. The machine will first use the electric motor to rotate the rim to Position A, measured by the first rotary encoder and the piston will reset to its neutral length. At these conditions, the brake will lock the system. Next the piston will fire 10 times, each time loading the same pawl-ratchet combination. Once this loading cycle is complete, the break will release and the motor will clock the wheel to Position B. Another cycle of loading will follow, and the controller will repeat this testing until failure. It will detect the failure based on results generated at the beginning of the test. If the

throw of the piston, measured by separate encoder, goes farther than it did during the first test, the machine will consider this a failure and stop the test.

Freewheeling Test

The goal for the freewheeling test is to simulate the wear on the ratchet caused by the rotation of the wheel while the free hub is held static. The freehub is still to experience the rider load and spoke tension, but no longer has a chain force. The wheel will fit in the machine the same by attaching the belt, adjusting the rider weight and turning on the pump. The machine then can begin rotating the wheel by the belt drive motor. It will continue the test for the duration, as there will likely not be a failure. The hub can then be disassembled and checked for wear.

Chapter 3: Design Development

In order to complete the project in less than 30 weeks, it is important to use a structured design process. The first and most important step is to completely define the objectives that our machine must meet. We defined customer goals through constant communication with Specialized. These goals are listed in appendix B. From these objectives, we created discrete engineering specifications. We then found which engineering specifications are the most important through a Quality Function Deployment (QFD), shown in appendix A.

Now that we have fully defined the problem and established the scope of the project, we can begin developing concepts that can fulfill our objectives. At this point, we began looking ahead to the rest of the design process. We summarized what we had done and what we had to do in the development of a Gantt chart (appendix C). We took special care to list the hours we expect to spend on each phase so we can track our progress over the next year. We have defined periodic milestones that we will strive to meet.

To find our final solution, we first generated as many concepts as possible. We had several structured brainstorming sessions to get familiar with a few possible designs. Then we performed a morphological review to see how specific subsystem designs will integrate. For several weeks we continued thinking of more ideas and discussing their strengths and weaknesses. To aid us, we each drew design matrices to succinctly judge how each design will perform

Once we select a concept, we will begin to look at an increasingly more detailed design of the concept. This will include where each component will go spatially along with engineering calculations to verify the durability of our design under testing conditions. We will also select components such as pistons, motors and encoders that fulfill our requirements. It is possible

during this process that we will find a new idea or problems with our old that will cause our concept to change.

The first step in prototype construction will be material and part acquisition. Parts will be either be purchased or fabricated in house. Should we need additional high tolerance machining done, we will contact Specialized to see if they can machine it in-house. When the parts have been acquired our team will begin to assemble the system. The machine will then be tested and evaluated according to the engineering requirements. Once a working machine is able to satisfy the requirements, the project will be presented to the sponsor and advisors during the Senior Design Exposition by the end of Spring Quarter 2014 and then transported to Specialized in Morgan Hill.

Conceptual Designs

To get to our final design we went through various initial designs. This is necessary step that every design must go through. Below are some of the best ideas that we came up and we took some of the best ideas from these designs to create our final design.

Concept #1

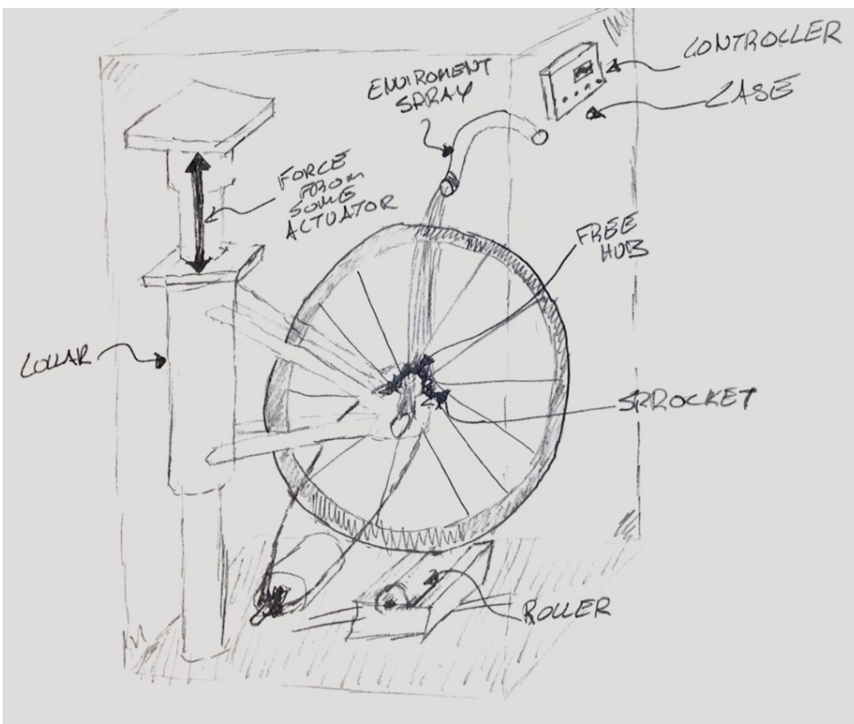


Figure 10. First Concept

Seen above in Figure 10 is one of our original concepts. It has bike dropouts mounted to a sleeve which can freely slide on a post. This design makes it easy to add weight because it can be

placed on top of the sleeve with the drum on the bottom of the wheel pushing the dropouts up. An actuator can apply a downwards normal load and a drum rests against the wheel to provide the reaction force of the road. It is driven by an electric motor and chain attached to a sprocket on the free hub.

There were several major design changes we took from this early concept. Looking at this, and our prototype, we decided that using a chain to deliver the force to the load was impractical. A bike, or even motorcycle, chain would likely stretch and fatigue during under the high loads and cycles we are required to put it through, ultimately leading to failure. We replaced the chain with our current linkage system. We also chose to use an electric motor only for the freewheeling test and use a pneumatic piston for the pedaling test. For the pedaling test, we will have a limited range of motion of the linkage and we may hold a constant force on the hub with no movement. Using an electric motor under these conditions would lead to it running at stall, greatly decreasing the life of any motor we choose to use. Instead, a pneumatic cylinder will be able to provide a constant force with no motion and no accelerated wear to itself. This design also is missing a brake to hold the wheel steady, which is necessary to provide controllable chain loads.

Concept #2

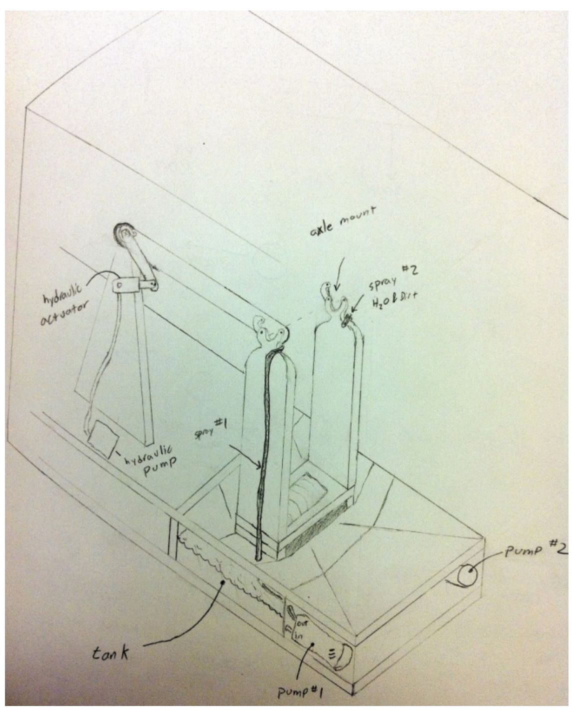


Figure 11. Second concept with pneumatic cylinder

Our next concept had several major design improvements. Instead of the motor, it uses a piston to power the wheel, eliminating the problem of the motor running at stall. The dropout mounts

are mounted on the top of a support structure we design, allowing us to use universal dropout mounts. The movement of the drum at the bottom applies the rider weight in this design. This drum will also break the movement of the wheel so that consistent loads can be applied.

Although better than the first concept, this design still has major flaws. The braking force applied to the rim comes from the friction between the drum and the rim. This friction is dependent on the normal force, which must be at a constant value specified by Specialized. Using this force, the static friction coefficient required was too high to prevent slipping. The design also still uses a chain to provide the load. This chain will likely fatigue and break over several tests.

Final Conceptual Design

Our design, seen in figure 12, is the best design we have found to accomplish all of our objectives. It accomplishes these through six subsystems- environmental factors, dropouts and support structure, pulley and belt drive, controller and data acquisition units, and chain force application. The environmental factors subsystem will control and direct a constant flow of dirty water on the hub to simulate extreme weather conditions. The dropouts and support will hold the hub secure during tests while mimicking real life stiffness and reaction force. The drum and belt drive will apply the rider load, braking and motor forces. The controller and DAQ will run the test by integrating the subsystems and record the data. The chain force will control the movement of the hub body.

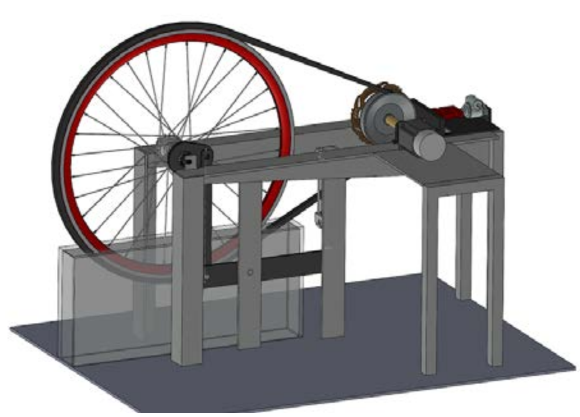


Figure 12. Side-view of Conceptual Design

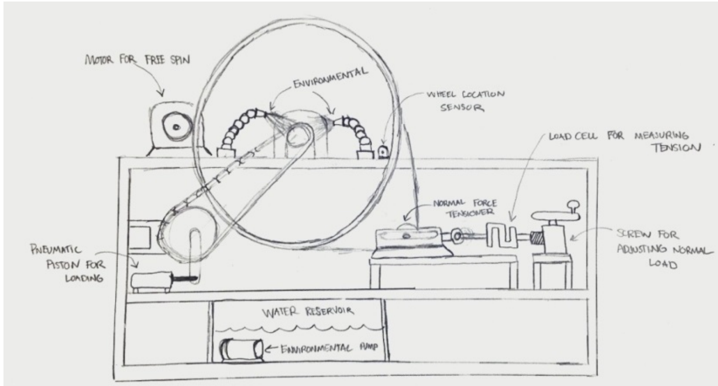
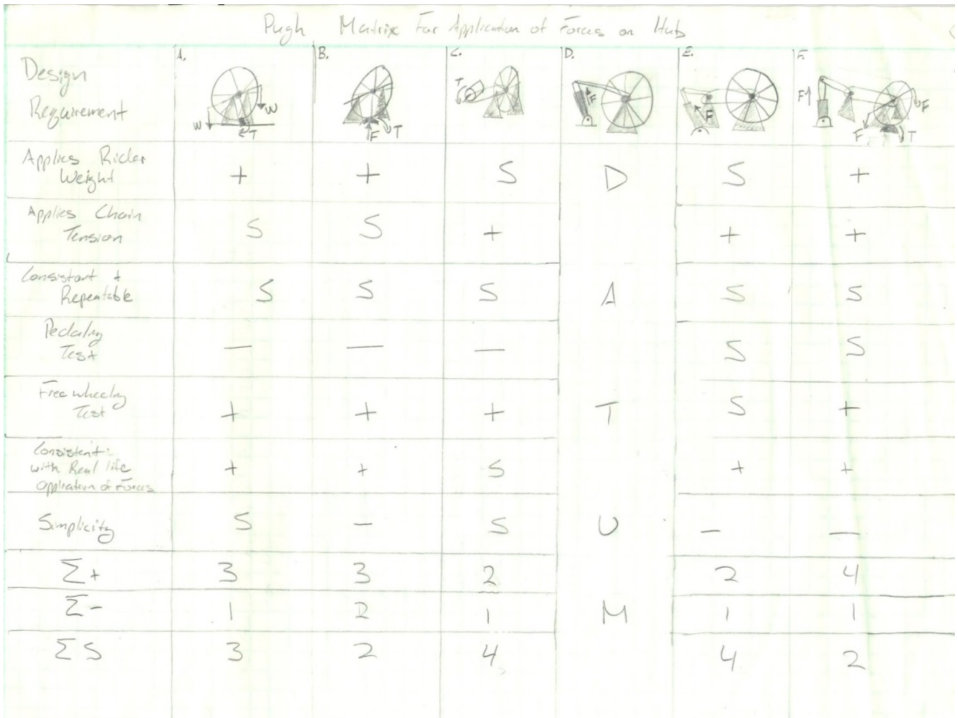


Figure 13. Sketch of Final Design

Concept Selection

After our brainstorming processes, we had to narrow down the concepts to decide which would accomplish our objectives the best. One of the major tools we used to help us was a series of Pugh Matrixes. This type of matrix stresses the iterative design process. Concepts are drawn on the top and the design requirements are detailed along the right. One concept is chosen as the datum to which all other designs are compared. For each design requirement, the design is given a "+" if it fulfills the requirement better than the datum, a "s" if it is the same, or a "-" if it is worse. These scores are then summed. A benefit of this type of design is that we do not rank the concepts, rather we compare their strengths and weaknesses. After the initial draft of the matrix, we can examine these strengths and weaknesses, then combine them from different concepts. We then put these new ideas on the matrix and see how they compare. This process helps manipulate ideas until we reach the optimum combination.



Pugh Matrix For Application of Forces on Hub

Design Requirement	A.	B.	C.	D.	E.	F.
Applies Rider Weight	+	+	S	D	S	+
Applies Chain Tension	S	S	+		+	+
Consistent + Repeatable	S	S	S	A	S	S
Pedaling Test	—	—	—		S	S
Free wheeling Test	+	+	+	T	S	+
Consistent with Real life Application of Forces	+	+	S		+	+
Simplicity	S	—	S	U	—	—
Σ+	3	3	2		2	4
Σ-	1	2	1	M	1	1
ΣS	3	2	4		4	2

Figure 14. Pugh Matrix Aiding in Force Application Design

In Figure 14, we can see the four original ideas, with the fourth being the datum. Each was ranked and each had strong points. We then combined several factors to create the fifth design. Upon evaluation, it was still not accomplishing several key requirements, leading to the sixth design. Our final design is based off many of the concepts incorporated in this last concept.

In addition to structured decision processes, we could eliminate concepts as our understanding of the problem evolved. As we began making more and more detailed designs, we learned more about how the machine will operate. Occasionally, something we learned would prove that a concept would fail to accomplish our goals. Two key examples of this were the electric motor and the drum-driven designs. We learned that the pedaling test would require the motor to run at stall torque for extended periods of time, prompting us to add a pneumatic piston to the design. Then we calculated the friction coefficient required for a drum to hold the rim static under load and found that we would need additional braking force; this lead to the current belt design.

Prototype

Figure 15. Prototype Test Machine to find Static Weight

During our brainstorming process, our group decided to prototype a static test machine, seen in Figure 15. This machine was fabricated out of scrap materials found around the machine shop. We used an old set of dropouts to secure a hub and rim. We welded this assembly to a flat bed frame for stability. To test this setup, we tacked a chain onto both sprockets and slid a cheater bar over one of the pedals.

Our original goal was to add weights to the end of the cheater bar until the hub broke, estimating the static yield load of the hub which we could then use to calculate some fatigue characteristics of the hubs. Unfortunately, the chain in this test setup would break before the hub, so we did not test it due to safety concerns.

Even though we did not find the yield load of this hub, this prototype still taught us some important lessons. This was the first time we considered that the chain may break before the hub and let us to use the current linkage design. Our team is very hands-on and it was invaluable to be able to lay out a general concept and see how it functions.

Later, we were asked to make sure our brake design would work. Specialized was worried that the metal plates we designed to clamp onto the bike rim would slip, making it so we would not be able to consistently test the same position on the wheel. We attached sample clamps to our prototype and then using a cheater bar, loaded the wheel to the appropriate force. We then observed that the clamps did not slide, even under repeated and prolonged test in wet conditions.

Chapter 4: Final Design

Overall Design Description

The final design of the model consists of an outer framework using 80/20 Inc. Industrial Erector, made of extruded aluminum. This framework is fixed to a smaller frame made from steel box stock that supports the pillow blocks and dropouts as well as the piston assembly. These components will be under the highest load, so we wanted them to be attached as rigidly as possible. 80/20 is bolted together whereas our steel frame is both stiffer because it is made of the stronger material and the joints are all welded. The pillow blocks on top of the square steel stock are designed with a 50mm opening to support the dropouts provided to us by Specialized. The steel stock also serves as a mounting point for the piston and linkage assembly that loads the freehub during testing. The linkage amplifies the piston force three times and has an inline load cell to accurately measure the applied force. There is also a linear encoder on the piston, used to accurately track the location of the piston, and hence the location of the freehub.

Four clamps are placed on the wheel at 90-degree increments. The clamps have a rubber compound on the inside of them that contacts the wheel. These clamps interface with a sliding piston assembly mounted to the steel frame. When the two are in contact, the wheel is held stationary while forces are applied to the wheel. The piston can then retract, the wheel will rotate 90 degrees to the next clamp position, and the piston will re-extend. Once it makes contact with the next clamp, the wheel will once again be fixed and testing can continue.

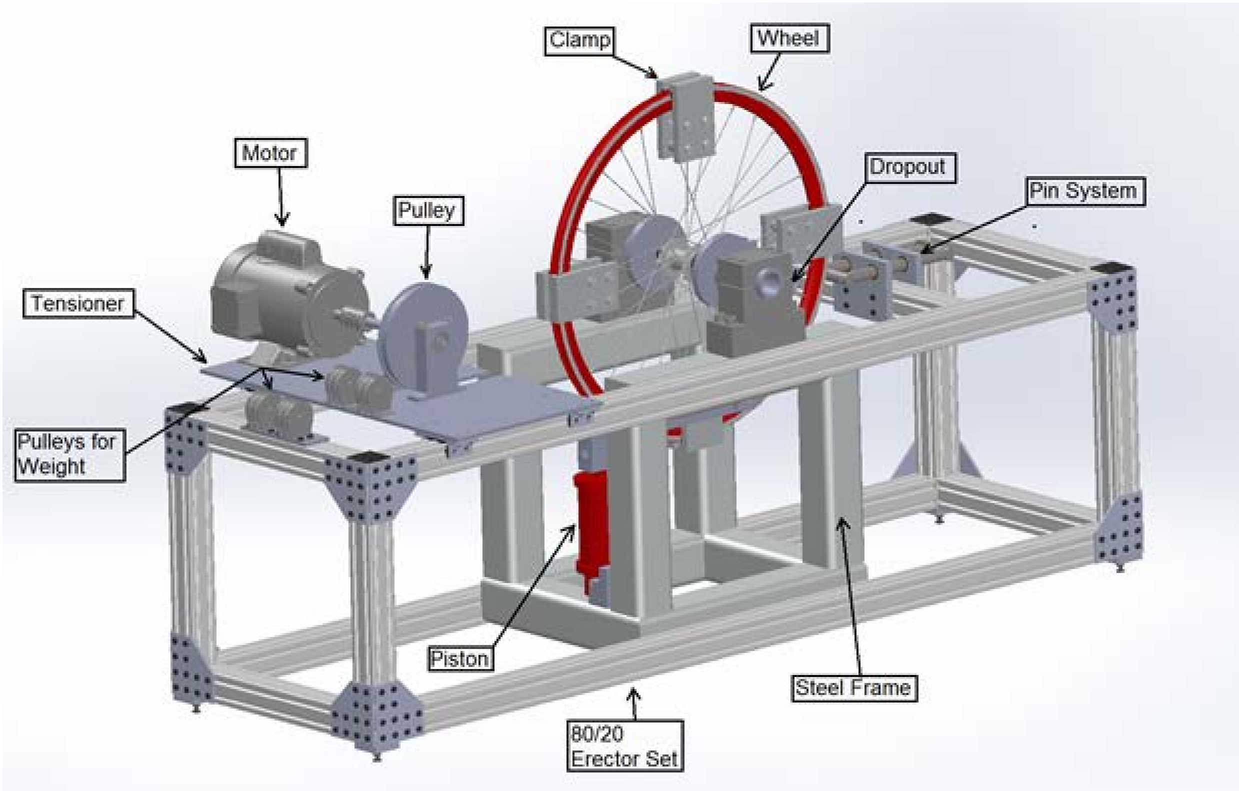


Figure 16. Final design with labels of subsystems

The wheel will be rotated using an AC induction motor connected to a pulley. A v-belt wraps around the wheel and pulley. The AC induction motor can be pulsed on and off to reposition the wheel or set at constant speed for the freewheeling test. The motor and pulley assembly are mounted on an aluminum plate. This plate is mounted on sliders that run on top of the 80/20 erector framework. A weight hangs off of the framework and is connected to a block and tackle system that pulls the motor/pulley assembly back. This serves to tension the belt that runs around the wheel, and replicate the normal forces that would be seen if the wheel were in contact with the ground. The block and tackle system amplifies the weight 8 times to provide the proper rider weight. This allows us to use a 25-pound weight, which the operator can easily and safely handle.

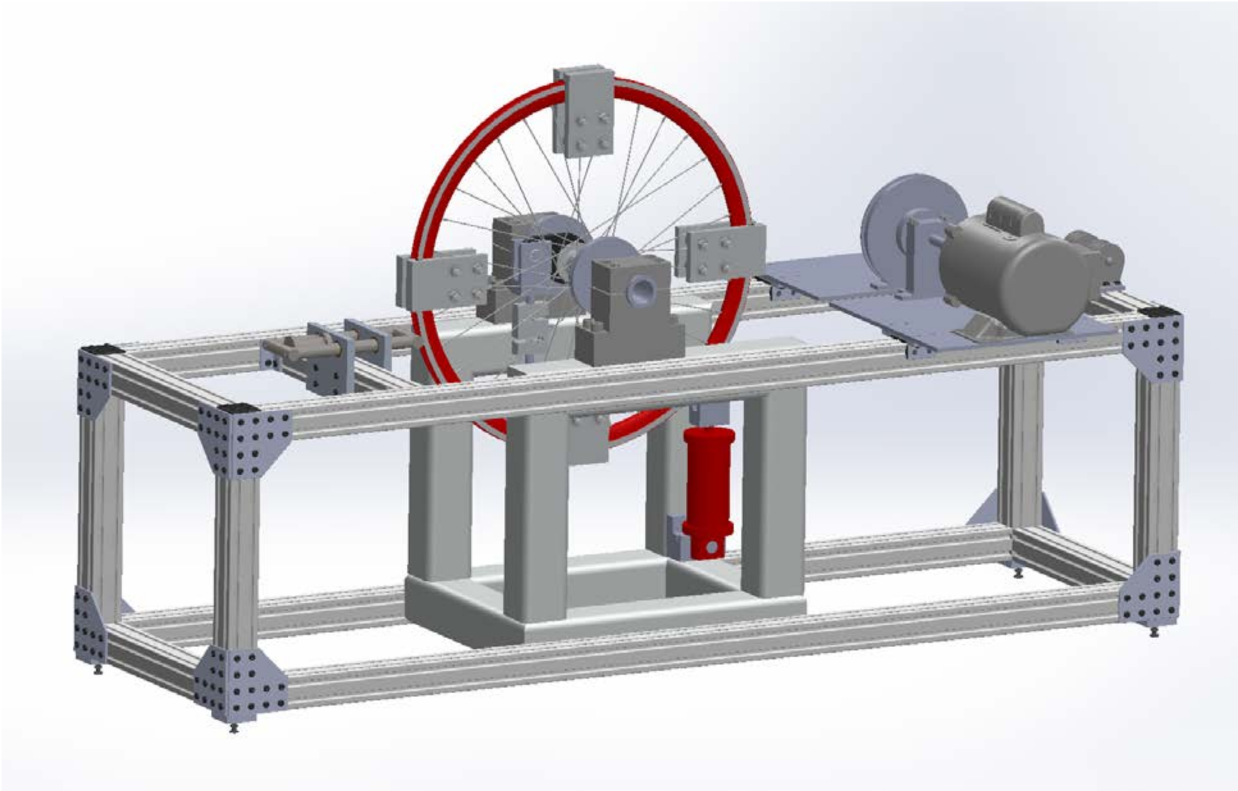


Figure 17. Final Design from other side

Both pistons, the one used for stopping the wheel, and the one used for loading the freehub, will be pneumatic and run off of the supplied airlines at specialized. The entire system will run off of 120V household power. This includes the regulators that control air supply to pistons, the motor, computer, and data acquisition system. The load cell, regulators, linear encoder, and motor control will be connected to the data acquisition system and controlled by the computer.

Although one of the original design goals was to include environmental factors that a real freehub may experience, once manufacturing began, we realized that this goal was infeasible. We talked with Specialized and they agreed that they would rather us take the time to make the rest of the system operational than rush the other, more important parts of the test so that the environmental factors could be included. We left room in our design so that Specialized can easily put these environmental factors in later.

Detailed Design

Tensioner and Motor Assembly

The test machine uses a motor mounted on an adjustable plate to move the wheel. This motor will be used to simulate a freewheeling wheel and to index the wheel during the pedaling test. A shaft coupler connects the motor to a longer shaft. The drive shaft runs through two bearings mounted in pillow blocks. A pulley is placed on the shaft and V-belt runs between this pulley and the wheel rim. The entire assembly is mounted on a plate, which runs on sliders connected to the frame. This allows for multiple wheel diameters to be used with the same V-belt. Because this assembly can move, we are also using the V-belt to apply the rider load. This 90 kg (200 lb.) load is applied perpendicular to the chain force and simulates the rider's weight upon the rear tire. This force is extremely amplified to both assume the worst case scenario and to shorten the time until failure. It as applied through a wire rope running through a pair of double pulleys mounted both on the back of the plate and on the back of the frame. This gives eight to one weight amplification so that a 25lb weight hung from the wire will generate the desired force.

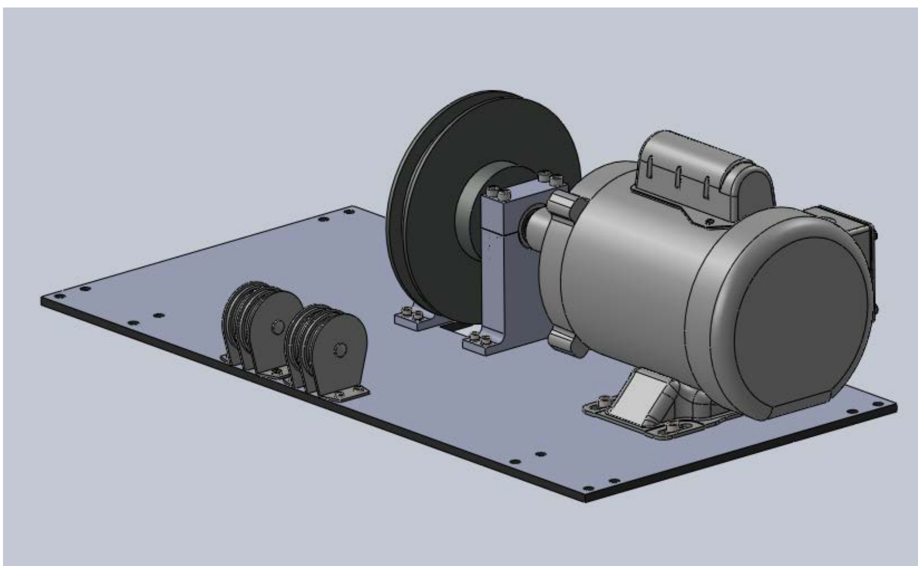


Figure 18. Image of the solid model of tensioner system

We chose to use this belt design to simplify how we apply some of the forces. Instead of mounting a motor directly to the wheel, next to environmental factors, we can mount it safely out of the way, leaving room for other subsystems to be close to the wheel. The belt also increases the force the motor is able to apply on the wheel without slipping. A direct mounted motor would need a much higher normal force to be able to not slip. This normal force would need to be higher than the rider load, which would then make the test less realistic.

We chose to use free weights to apply the rider load instead of a force application such as a power screw. Although the power screw would be smaller, we were afraid that during a three day test, the belt might stretch some. If this happened while using a power screw, the tension on

the wire, and therefore the rider load, would greatly decrease. By hanging a weight, we guarantee that the rider load will be constant even if the belt experiences any stretch. A power screw would also need another device to measure the load.

Positioner and Brake

For our test machine we want to imitate three years of use on a freehub in a test that last three days. In order to make the freehub fail faster we decided to test a certain number of pawl/tooth combinations that would allow us to accelerate the fatigue process. Our first thoughts were to use the control system to track the location of the freehub body with respect to the rim and brake the system to stop the wheel on certain locations. This proved to be too difficult because we could not come up with a good enough way to track the location of the rim and analysis would be required for every new freehub to calculate the tooth locations.

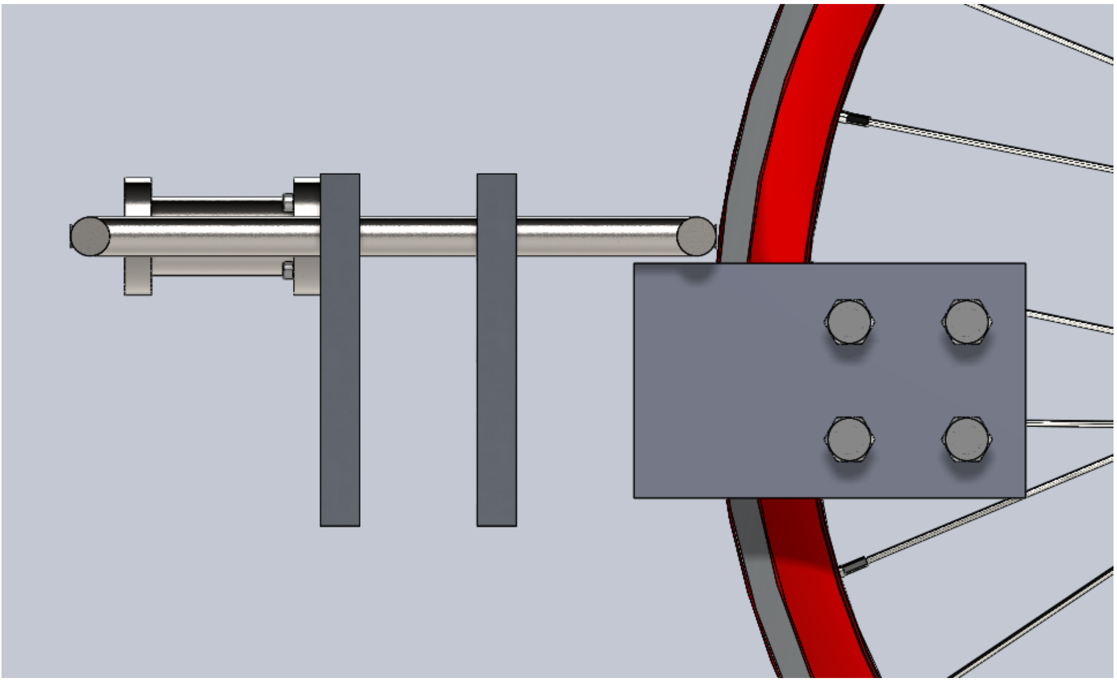


Figure 19. Orientation of the Pin and Clamp system

The solution that we have come up with is to use clamps that mount to the rim and a pin system that comes out to stop the wheel. In our test we will mount a certain number of clamps around the wheel and then use a pin that is able to stop the wheel by engaging a clamp. This should ensure that we are able to stop the wheel at the same locations every time. When we want to move to the next position, or clamp location, the pin has a pneumatic cylinder that pushes the pin back and the motor attached to the belt pulley can spin the wheel. When the wheel starts to move the air flow to the pneumatic cylinder will be stopped and springs will push the pin back onto the rim. The pin will slide along the rim until it hits the next clamp and testing can begin

again on the next location. The solid model of this subsystem can be seen in figure 19 and a close up of the clamp can be seen in figure 20.

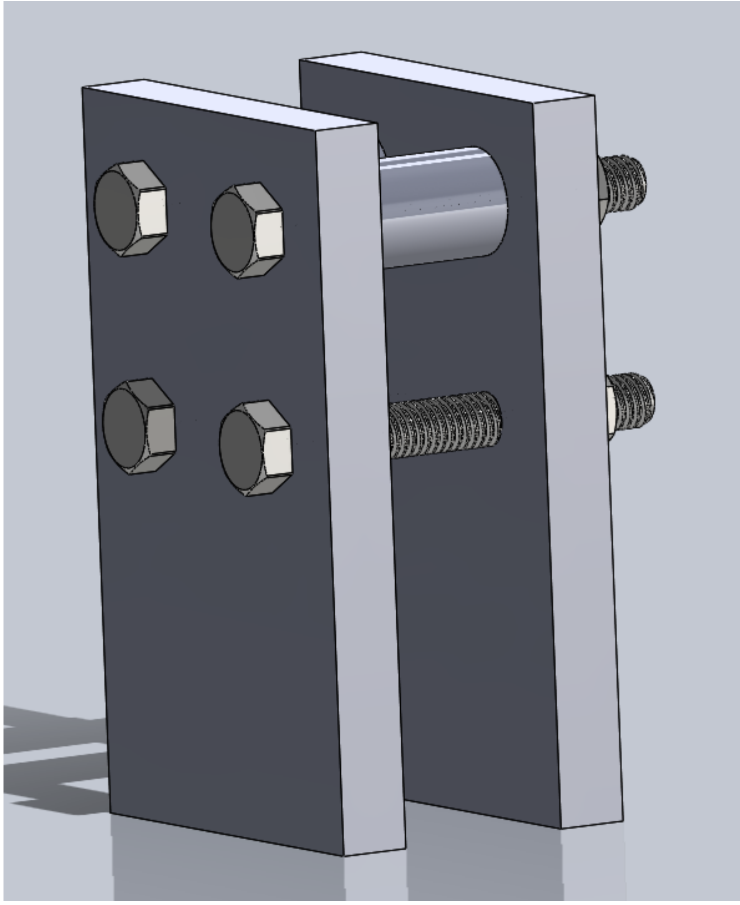


Figure 20. Close-up of a Clamp

Frame

The main framework of the system will be built with 80/20 Incorporated's Industrial Erector set. The 25-series components were selected. The square stock is 50mm by 50mm. There are two channels running down the sides of the stock with 25mm spacing from rail center to rail center. Seen in the figure below is outer framework, including the corner braces, M6 x 10mm bolts, and leveling feet. All of these items are available through 80/20 Inc.

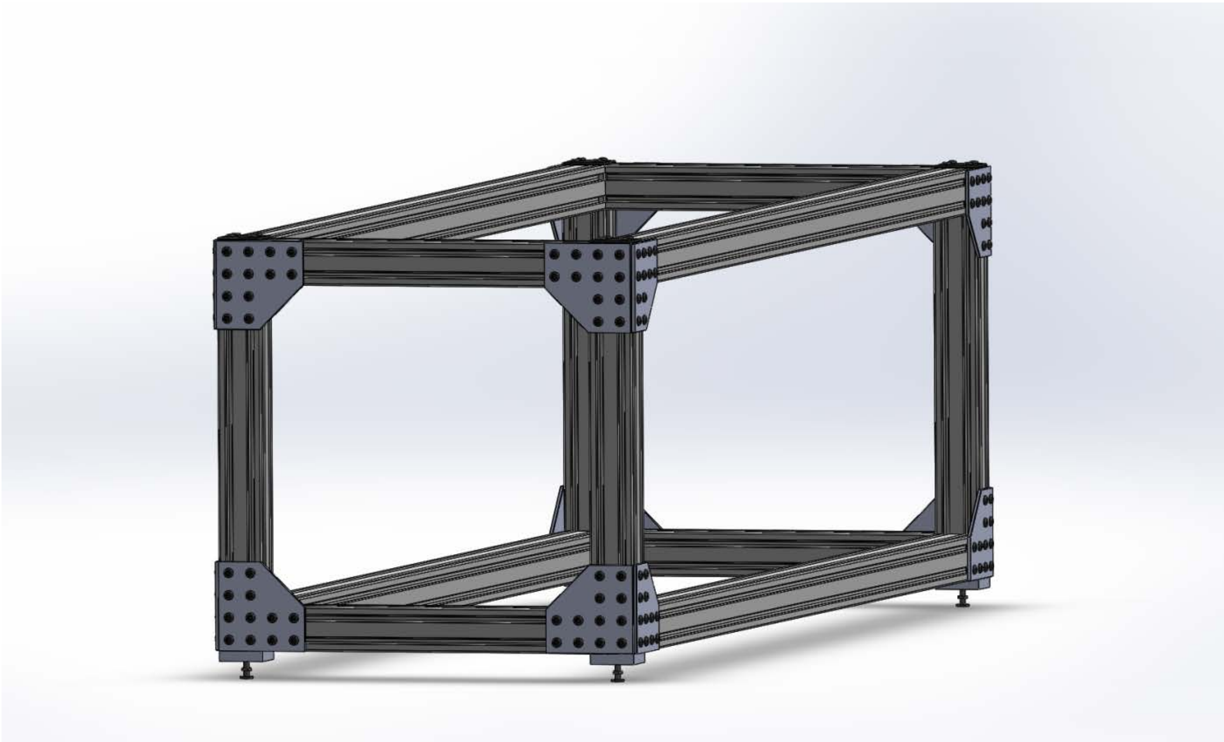


Figure 21. 80/20 outer support frame

After running an analysis on the 80/20 structure, we determined that the stress exerted during testing would deflect the erector framework beyond allowable. Because of this, a 3-inch square steel tubing will serve as a mounting framework for the wheel and piston assemblies. This will prevent deflection at key points. The rest of the assembly will be mounted to the 80/20 material. The steel framework with the wheel assembly can be seen in the figure below.

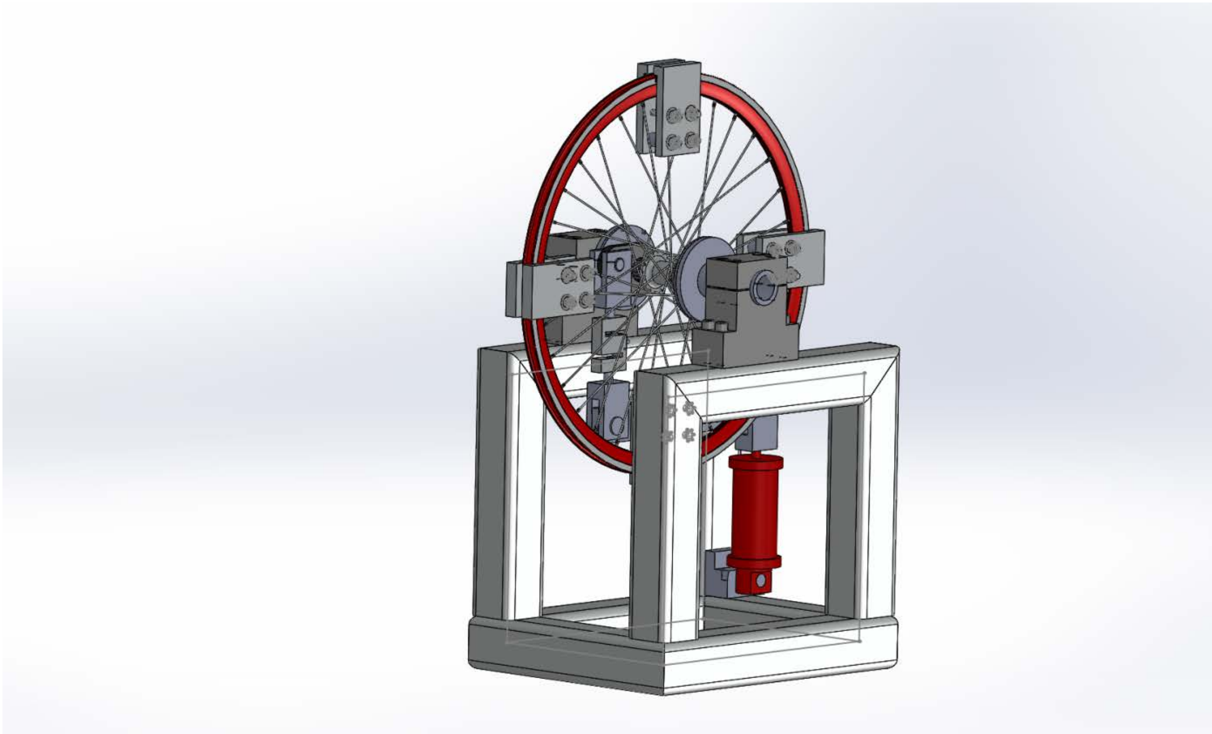


Figure 22. Inner Steel Frame Assembly

Environmental Factors

Specialized has requested that the design incorporate environmental factors that are capable of mimicking real life weather while the hub is being tested. To do this we will be spraying dirty salt water on the hub to imitate riding in the rain near salt water or even cleaning a bike in salt water. This subsystem we will have a tank, pump, piping, stirrer, sprayers and shielding that will be able to spray the contaminants onto the hub. The pump that we have selected is a salt water pump that can handle some debris. The piping we will use is PVC and the shielding will be made from Polycarbonate. We elected to recycle the water because for a three day test it would be difficult to have the same consistency of dirt, salt, and water with fresh water coming in. From our environmental test we were able to see that the amount of water that gets on the hub is very small. Most pumps have a flow rate that is too high for our needs so to be able to control the amount of water going onto the hub we will have a feedback loop that will take away the extra flow. This extra flow will be used to mix the water and contaminants in the tank to keep an even constituency. Every test needs to have the same amount of contaminants and water so the solution would need to be prepared beforehand with a recipe saying how much of each ingredient is needed. For every test the water and contaminants will need to be changed and so we accounting for this by adding an exit port on the tank to allow it to drain.

Figure 23. Coolant Sprayers

The pump will bring the solution into a hose that goes up from the base of the machine where the tank is located to the freehub. We will use any-which-way sprayers which are the same coolant sprayers that a CNC machine uses in order to allow us the greatest adjustability. From our tests we determined that more water gets onto the cassette and freehub body that on the hub. To account for this we will have two any-which-way sprayers that spray more water onto the cassette and less onto the hub. There is a possibility that the contaminants would get stuck somewhere in the machine other than flowing back down to the tank but this effect is repeatable every test and is negligible.

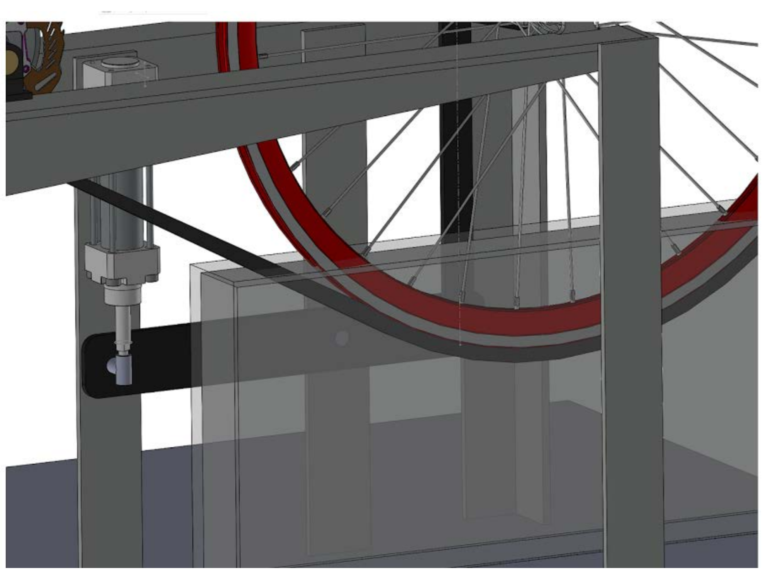


Figure 24. Environmental Subsystem

Dropouts

The dropouts are the part of the bicycle frame where the wheel mounts, as seen in Figure 25. The stiffness, flex, and deflection of the bike frame play a significant role in the behavior of the hub. For this reason, it is important that these properties are replicated as closely as possible in the testing machine constructed. Specialized has already invested time into researching this and has previously conducted a finite element analysis of bicycle dropouts. The computer model included the dropouts, and 1.5 inches of the chain and seat stays. This is very similar to what is visible in the figure below.

Figure 25. Bicycle Dropouts

From here, stiffness and deflection data was collected. Another model of the testing apparatus dropouts was constructed and compared to the stiffness and deflection data. The materials and thicknesses were modified until both models exhibited similar properties. The team plans to adapt these testing dropouts to the new system. Slight modification will be required, however, stiffness and deflection values will be revisited before the parts are machined. The preexisting system is designed to spin the axle, but this dropout will need to hold the axle stationary. This modification is fairly straightforward. To account for variation in wheel widths and axle diameters the dropout will be mounted on pillow blocks that allow the dropouts to slide in and out. The change in width of different hubs is 50mm, which results in a desired movement of

25mm on each side. The dropout mounts will be design to hold a standard QR design hub. The various thru-axle hubs will be compatible with the QR design after a simple sleeve is inserted into the freehub to reduce the size of the axle opening.

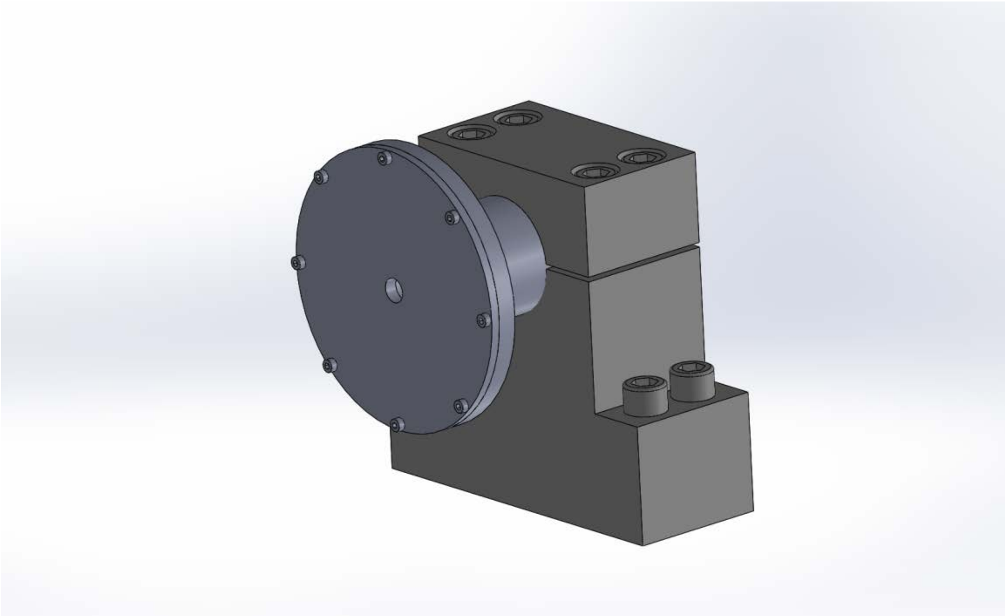


Figure 26. Dropout in Pillow Block

Control System

Our test machine will use various electronic components, all controlled by a LabView program. It will run off of wall power supply at 120V routed through a GFCI. This GFCI is a major safety component, which will switch if there is a significant short in our system. This is especially important due to the saltwater, which may come into contact with some electrical components, creating a hazard. From this, the power will travel through an emergency stop into a box. This stop will immediately disconnect any power from the machine, halting the test. The box will be complete dead front construction, and will contain any bright shiny connections in our system. This will keep operators safe from the potentially hazardous electrical connections that operate the machine.

Figure 27. DAQ that will be used in the Test Machine

In the box, the power is split into four lines. The first line will go through a fuse and a relay to the motor. The other three lines go through a fuse, then a relay to a solenoid operating pneumatic valve. The piston applies the chain load. It has two solenoids so it can be double acting, and the braking piston has one line. The National Instruments DAQ provided by Specialized will provide 5V DC current to switch the relays. This DAQ will also monitor inputs from the linear encoder and force transducer; this wiring is outlined in Figure 28.

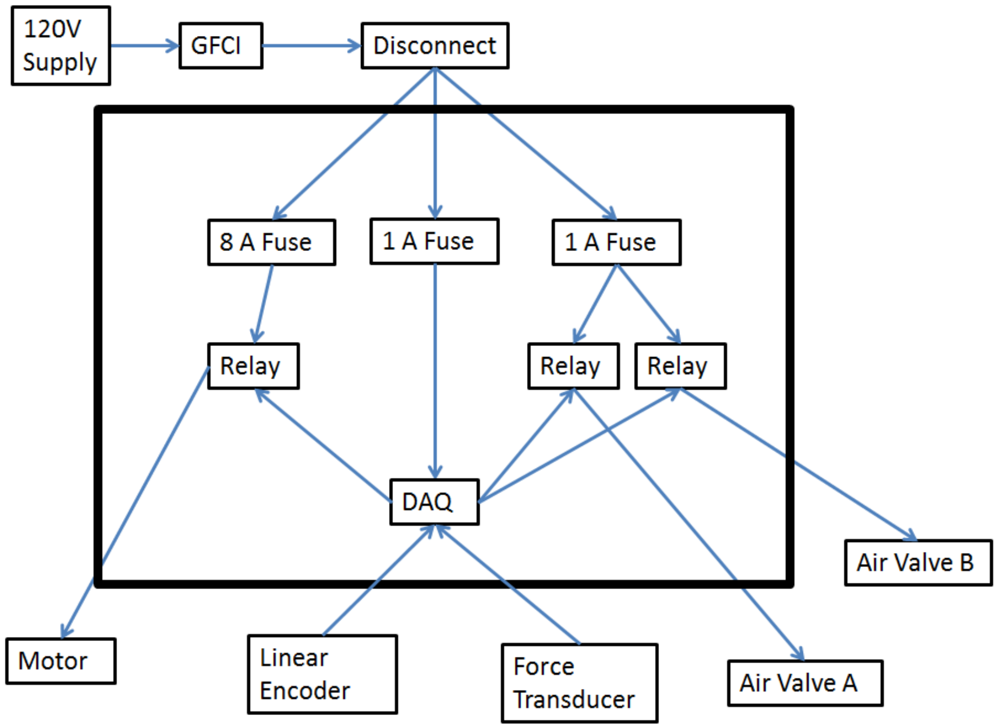


Figure 28. Electrical Diagram, Box shows everything in the Control Box

The DAQ will operate the different components and subsystems to perform two distinct tests. The first test is a freewheeling test, where the DAQ will turn on the motor and turn the wheel at a constant speed. The motor will run at 1725 rpm, leading to a wheel speed of about 25 mph. This test will continue for a set time of 72 hours. It will stop if the enclosure is opened or if the disconnect button is pushed.

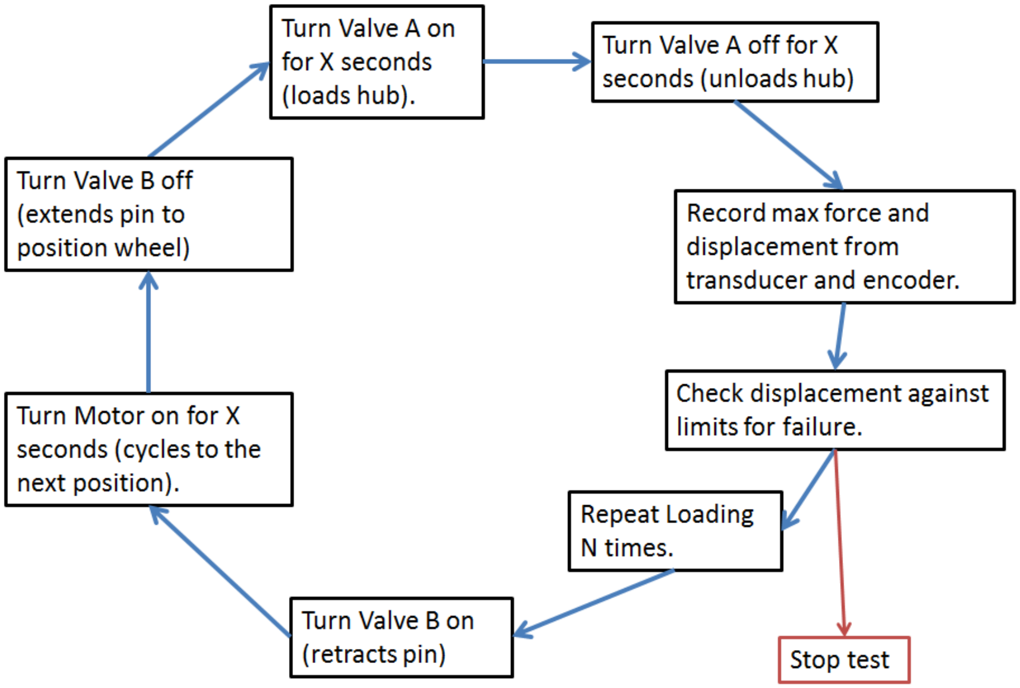


Figure 29. Controller Logic Diagram

The second test is the pedaling test and its control process is outlined in figure 29. This test consists of pedaling motion approximated as a chain load to the free hub, applied in four different locations, determined by brackets, which will be attached to the wheel rim. These brackets will hit a pin assembly connected to a controlled pneumatic piston, stopping the wheel's rotation at a unique location. Due to the ratchet mechanism, the wheel will not be able to bounce back, fixing the position. Once the wheel is positioned, the piston attached to the crankshaft will fire, loading the freehub. To speed up the test, we will fire the piston multiple times at each position before indexing to the next. To index, the pin will retract, freeing the wheel. Then the motor or crankshaft can begin spinning the wheel. While the wheel is spinning, the pin will extend again to stop the wheel at the next spot to test. Each cycle will record the maximum force and displacement. Failure is defined as when the displacement exceeds a user-defined limit. These limits are unique to each position and will be able to be adjusted at any time during the test to account for the time it takes the test to settle.

Pneumatic Lever Arm

A major part of the pedaling test will be the cyclic loading of the hub with a chain load. This force will be generated by a double acting pneumatic cylinder, which pushes on the free hub

body through a force amplifying linkage assembly. The original plan for this assembly was to use pins to connect the linkages to the frame and still allow the rotation of the lever arm. When looking at the overall layout of the test machine, we found that there would either not be a good place to mount this assembly, or that the piston would interfere with the wheel. We also were having troubles ensuring that the linkage would line up correctly with the freehub. This led us to mount a bar across the bottom of the frame in a set of bearings. A linkage assembly will be able to slide on this bar through the use of a bushing. This linkage has two stainless steel arms, pined together. One arm is attached to the piston and the other is attached to the freehub. This linkage must also be able to interface with the freehub. To do this, we took a standard set of sprockets from a bike and machined them down into a square shape. We then press fit this square into a stainless holder which attaches to the linkage.

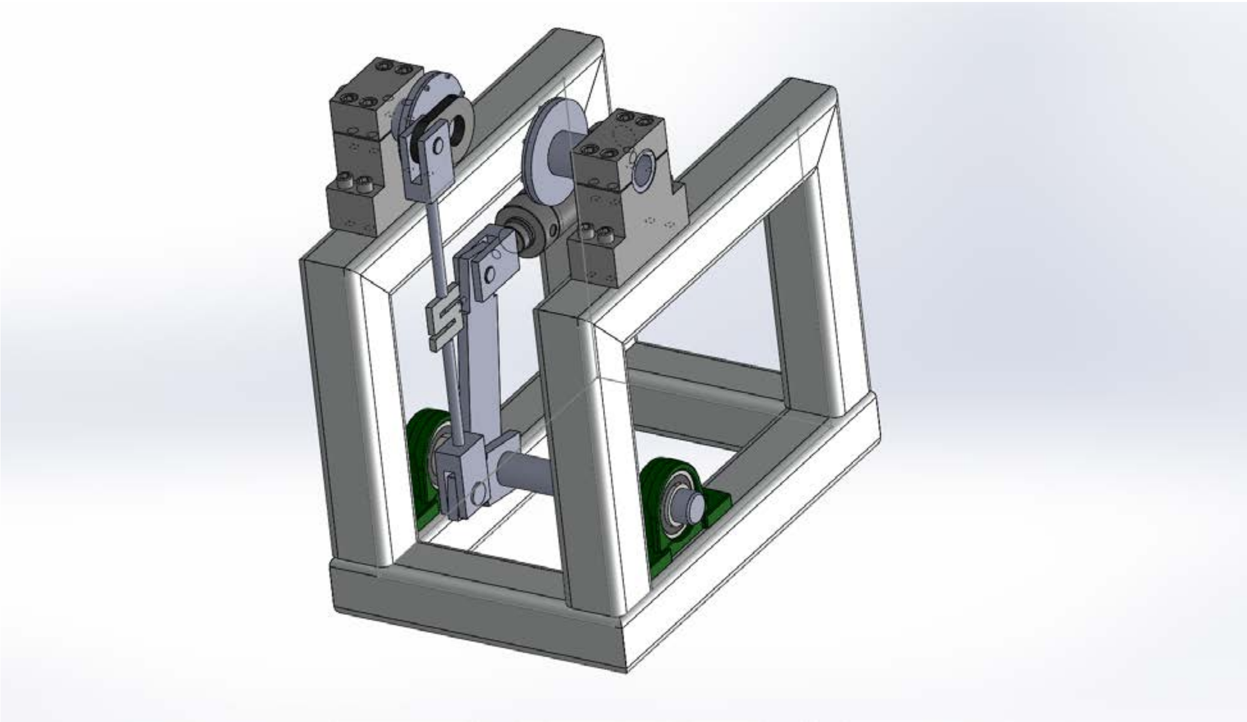


Figure 30. Pneumatic Lever Arm

Analysis Results

Parts of our project will be experiencing high stresses, so it is important for us to calculate the stresses in each component and design so that these stresses are under the yield stress. We also have to be careful that no parts fatigue. Our machine will be testing fatigue failure in a freehub, so it will be subjected to high cycles and possible fatigue failure.

In the motor/belt assembly, most parts are under similar forces, so we can choose the ones most likely to fail and analyze those. The pillow block will be transmitting the rider weight to the belt attached to the rim. With this force, it has a yield factor of safety of 3. The M6 bolts on the inner side of the pillow blocks will be transmitting the highest force. In the worst case scenario, these bolts will still have a factor of safety of greater than 45. Because the rider weight will be a constant force, these components will not experience high cycles and fatigue. The shaft, however, will be rotating and experiencing cycles which can cause fatigue. Calculations show that the shaft will have a yield factor of safety of 7.7 and a fatigue factor of safety of 3.9. All of these calculations can be found in appendix E.

Part	Yield Factor of Safety	Fatigue Factor of Safety
Pillow Block Screws	45.2	-
Shaft	7.67	3.92
Pillow Block	3.0	-
Dropout	4.5	3.8
Pin Shaft	2.94	2.65

Table 2. Factors of Safety

The 80/20 Erector material was analyzed for deflection with the included Tech Toolkit that 80/20 Inc. provides. In some loading cases, the beams would deflect up to 5.5mm. The team decided that this was an unacceptable amount. A deflection of 5.5mm could easily cause binding between different components during machine operation. For this reason, we shift the higher loads to the steel stock framework to eliminate these issues.

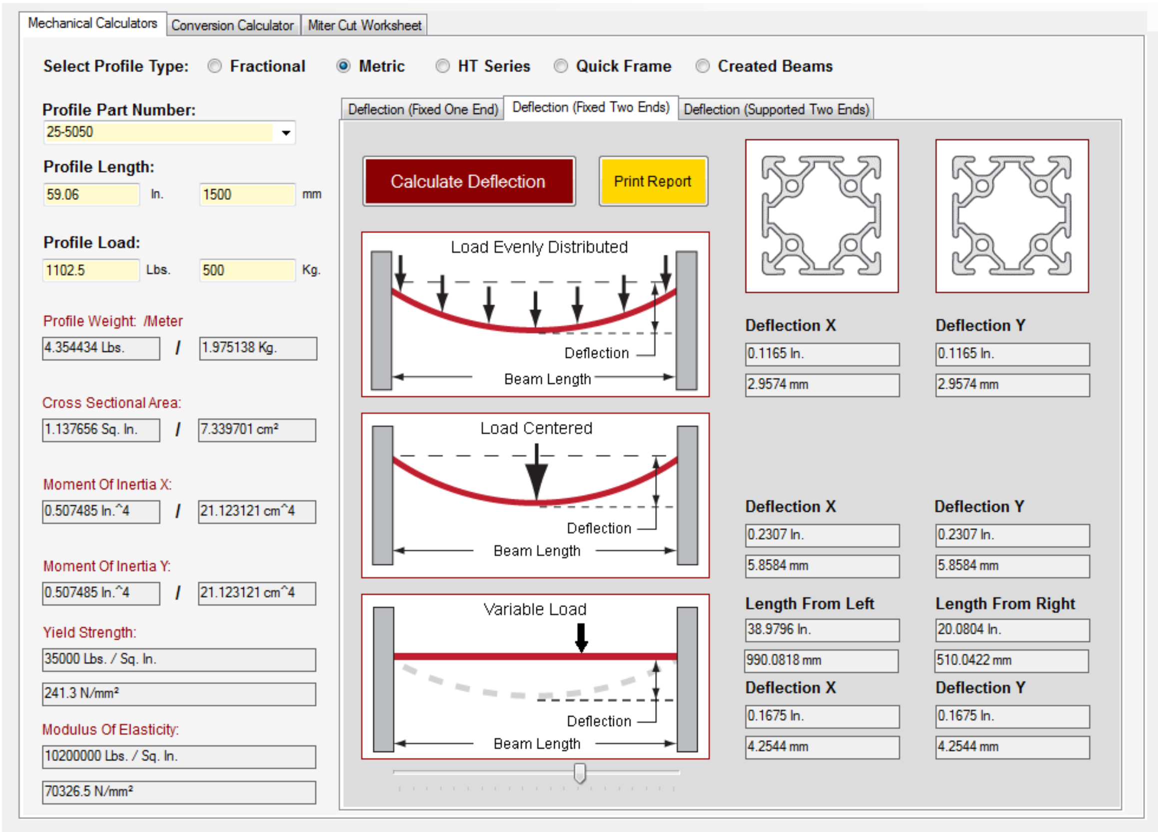


Figure 31. 80/20 Deflection Program

Cost Analysis

The completed bill of materials with cost analysis can be seen in Appendix F. Our budget from Specialized was 10,000 dollars and we made the machine using about 5,000 dollars. This means we have plenty of money left over to allow Specialized to put into the machine to make it more adaptable for their space.

Material Selection

Materials were selected to meet several different requirements specified by Specialized. Most materials are either corrosion resistant or were painted with a corrosion resistant coating to protect them. The environmental testing on the wheel will most likely introduce moisture into the entire system. Every component needs to be protected and able to handle the moisture without failing.

The 80/20 erector framework is constructed of aluminum and selected for its strong extruded structure and light weight. There are a lot of components on the device and it weighs a lot, so the lightweight of the framework is an advantage. The 80/20 is not able to support the loading of the piston. After performing several analyses of the system, we discovered the extruded aluminum would deflect beyond acceptable limits under full machine loading. Because of this, the inner framework is constructed of 2.5 inch steel square tube. The rigidity and deflection characteristics of the material met our design requirements.

When possible, aluminum was selected for components that were not critical to loading. This was done to save weight on the overall structure. If the components were designed for repetitive loading, they were constructed of stainless steel. This ensured strength and protective from environmental elements.

Geometry

The machine was designed to be a tabletop device. Specialized requires the device be placed on a waist level table during testing. Because of this requirement, we designed the device with a small of a footprint at possible. All components were strategically placed reduce the overall size of the machine. Everything is contained within the 80/20 Framework, which is roughly 1.5 feet, by 4 feet long.

Component Selection

Each component was selected based on individual requirements. The introduction of environmental factors played a large role in most component selection. The piston, linear encoder, and load cell are all very near to where the spray nozzles would be located. These devices need to be able to withstand a large amount of spray. The spray would be a mixture of dirt, water, and potentially salt. The components are not submersible, however they all have a water resistance certification.

All components also had to meet design requirements for freehub loading. The piston, magnified by the lever arm, exerts more than enough force to meet the loading requirements set forth by Specialized. The load cell is rated to match the force of the piston and will provide accurate data under maximum loading. The motor was selected based on design requirements for the simulated speed of the wheel during coasting. The motor will run at 1725-rpm. Taking into consideration the speed reduction caused by the size of the pulley to the wheel, a 250-rpm wheel speed is still satisfied.

Electrical Systems

An extensive electrical system is required to run the machine. Power must be supplied to the load cell, linear encoder, and motor. In addition to these main components, each air valve is controlled by a solenoid that much be connected to power as well as the data acquisition system for control.

The data acquisition system has two inputs connected; linear position and load cell data. It also has four outputs including; motor control and three solenoid control connections. The DAQ is connected to the main control box via a serial connector. Each input and output runs through the pins in the serial connector. A diagram of the pin numbering system can be seen in appendix P. This was designed so that the DAQ could be unplugged and used on some of the other Specialized test machines already in existence.

The final wiring diagram for the project can be referenced in Appendix Q.

Safety

Our system has several safety factors we have to consider. The main hazard will be the numerous moving and rotating parts that could potentially catch clothing or hair or create pinch points. As our machine is designed to exert high forces this could cause serious injury. To prevent this, we will enclose the rotating parts in a Plexiglas shell. The shell will have a door and the controller will not run the machine if the door is open. This will prevent anyone from accidentally getting caught in a moving part. Not only will the controller turn off the power, it will apply the brake to stop the wheel's rotation so that if the wheel is spinning it will stop.

At least the motor, brake and DAQ will be run off of electricity, leading to possible shock hazards. We will have our electrical design reviewed by a Cal Poly electrician to ensure that they are safe. We also will have any electrical components outside of the water containment zone so that the water cannot interact with the electricity. This containment will also keep the water from getting on the floor, creating a slipping hazard.

Maintenance and repair considerations

Due to the corrosive nature of the salt water used in the environmental factors portion of the test machine, periodic visual inspections will need to be performed to check for excessive corrosion. The painted components may need to be repainted after a period of time if the paint is worn or chipped. If the components become too corroded, the structural integrity may be jeopardized. Very few parts of the machine should need replacement or repair. The main component that may need replacement is the dirty salt water. Should the machine need to be moved, stored for a long period of time, or worked on, the water should be drained, and stored in the 5 gallon HDPE bucket provided with the test machine. The bearings are pre-impregnated with oil, so they do not need to be lubricated. The Plexiglas walls should be wiped down occasionally so that the test machine maintains a pleasant appearance. Everyone knows that a clean workplace is a happy workplace.

Chapter 5: Product Fabrication

Description of manufacturing processes

An important part of this project was the manufacturing phase. Not only did Specialized wish for us to design the test machine, they also wished for us to deliver a functioning product to their test facility. To accomplish this we used the on-campus machine shops available to all students.

One of the main reasons that we decided to use the 80/20 frame was to cut down on manufacturing time. The steel frame was made out of box steel, which was cut to length on a horizontal band saw, then welded together using a MIG welder. Most of the other parts were machined using a mix of drill presses and mills. Ideally, a mill would have been used to drill every hole we needed, but due to the number of students needing to use the machines, our time using a mill was limited. This led us to only use the mill for parts that required tight tolerances, such as the mounting plate for the motor and v-belt pulley and the piston-brake support.

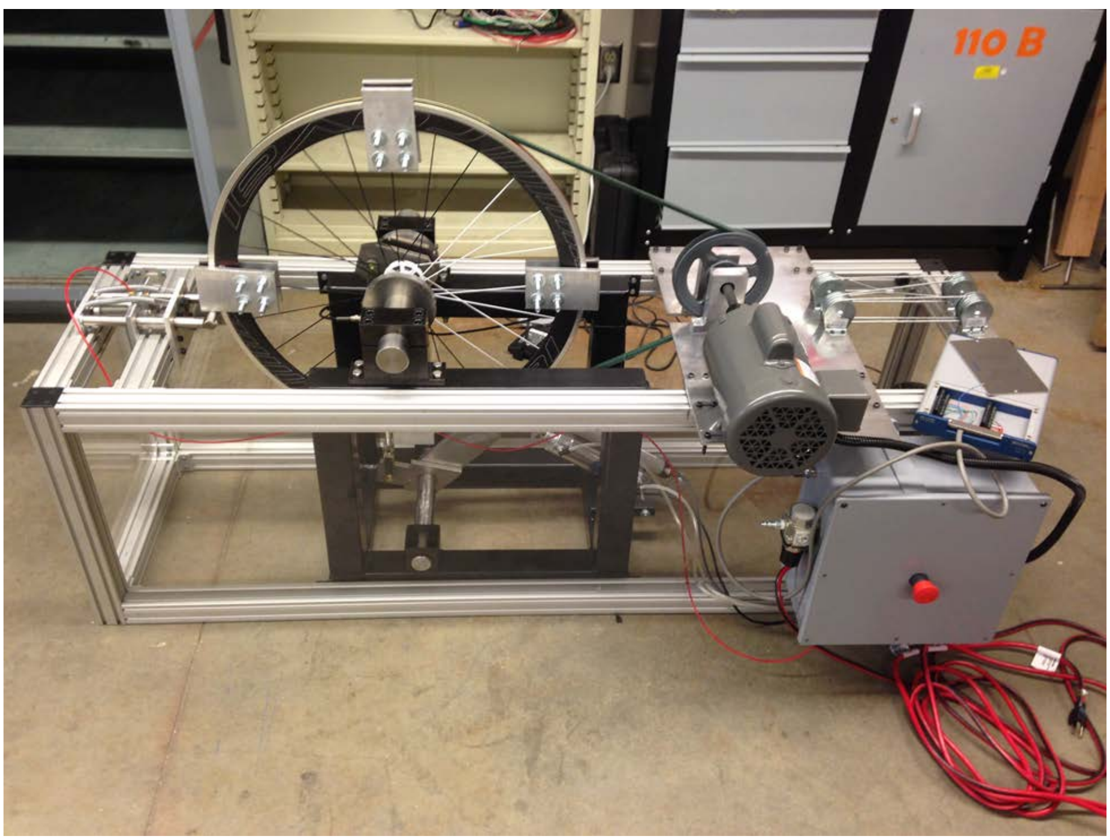


Figure 32. Finished Project from the side

Most of our material was aluminum so that we could apply environmental factors and not worry about corrosion of steel, leading to easier machining. The piston-linkage that applies the chain load experiences too high of loading to be made of aluminum; instead we used stainless steel. Although this was stronger, it was also much harder to machine. Some of the more complex parts we had designed were taking too long to machine, so we found ways to adapt our design to be able to use off the shelf parts.

The dropout supports designed by Specialized in-house were CNC machined. These parts were made of stainless steel, with tight tolerances and small features. Due to the tight tolerances and precision features, we chose to have the dropouts fabricated on a CNC machine. We hired one of the Cal Poly shop techs to supervise the process. Originally, the dropouts were designed of two parts, one of which had an extremely large step put into billet material. This seemed to be impractical and a waste of material, so we adjusted the design so that it could be made from three separate pieces which now bolt together.

Figure 33. Top view of dropouts

Figure 34. Extender tubes mid fabrication

In our design, we had thought that the bracket that would connect the load cell to the splines would also have to be made with a CNC mill, due to the exact spline pattern we were looking to replicate. We found that this pattern was usually broached in specialty machine shops, not done on a mill. The thickness of the half inch stainless steel also presented a problem for most broaching machines. This forced us to buy a standard bike cassette and mill it into a square so that could be pressed into the receiving bracket.

Figure 35. Splines inside the stainelss Steel link

Manufacturing of the piston linkage assembly was drawn out process. The team ran into many obstacles and we were constantly redesigning the system. Due to the loads that were going to be placed on the system, we selected strong steel components. These components made manufacturing very difficult due to long machining times. Proper tolerance was also an important aspect of the process.

The first linear encoder purchased was either broken or incompatible with our LabView system. After struggling to make it work, we purchased a new encoder. The new encoder design forced us to redesign the mounting system. The new encoder is visible in the figure below mounted above the air piston.

The figure below shows the piston assembly that loads the freehub assembly. As the piston extends and retracts, it pivots the lever arm around the large stainless steel shaft mounted to the

bottom of the frame. The forces are translated upwards through the threaded shaft, through the load cell, and into the freehub body.

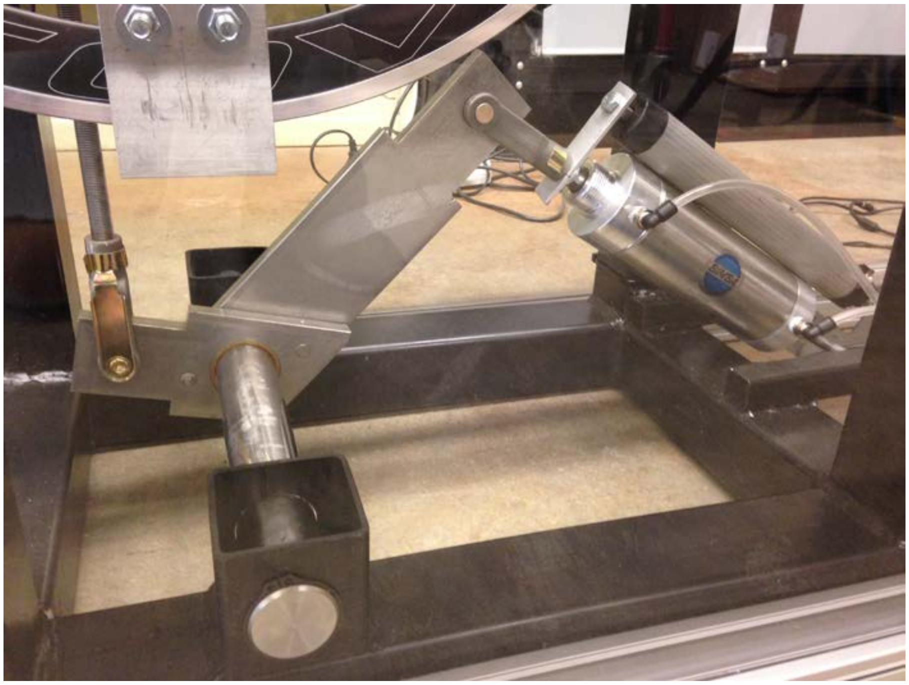


Figure 36. Piston Linkage Assembly

The positioner and brake assembly manufacturing process was relatively straightforward. The main complications were related to the manufacturability of the stainless steel rods used. We broke a bit off inside one of the rods after hours of manufacturing had been invested. The main assembly can be seen in the figure below. No major redesigns occurred during the process. Springs return the brake to the forward position while an airline connected to the piston, can retract the brake when necessary for repositioning.

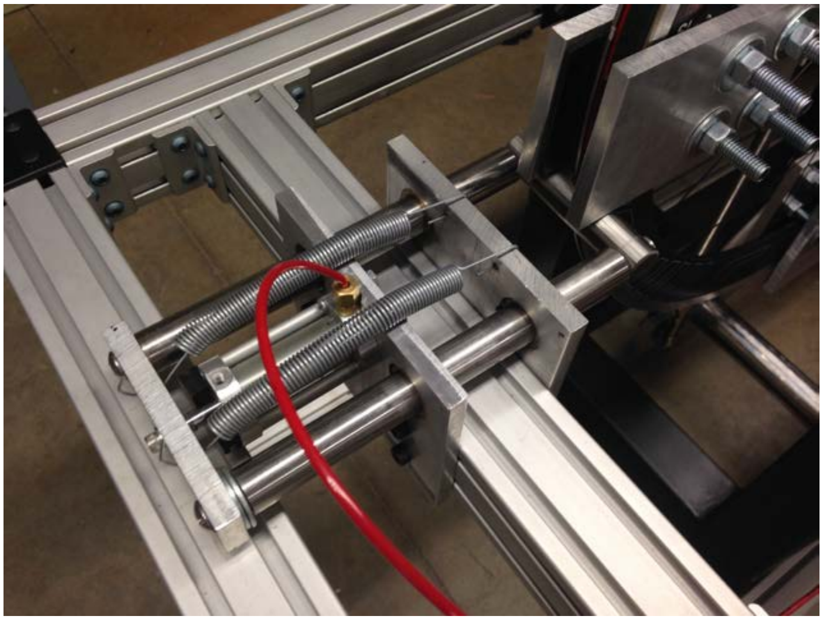


Figure 37. Positioner and Brake

The tensioner assembly includes the motor that free spins the wheel and is also used to apply the normal force to the wheel to simulate rider weight. A large aluminum plate is mounted to the top of the framework on sliders. A weight system hangs off the back of the framework to tension the belt that connects the motor to the wheel.

Figure 38. Tensioner Assembly

The figure below shows the final wiring box. This box contains all electrical components safely where they can't harm the user. The data acquisition system connects to four relays that control the motor and three solenoids for the airlines. There is also a large safety shutoff switch that cuts power to the entire system in event of an emergency.

The leads for the data cable that connects the DAQ needed to be soldered onto the 15-pin VESA DDC2/E-DDC connectors. Soldering shorts were a big problem due to the close proximity of the leads. Eventually after all solders were proficient, the continuity between the two connectors was tested; there were no shorts between the wires. Five-minute epoxy was applied to the leads to provide insulation to ensure that the wires would not short out in the future.

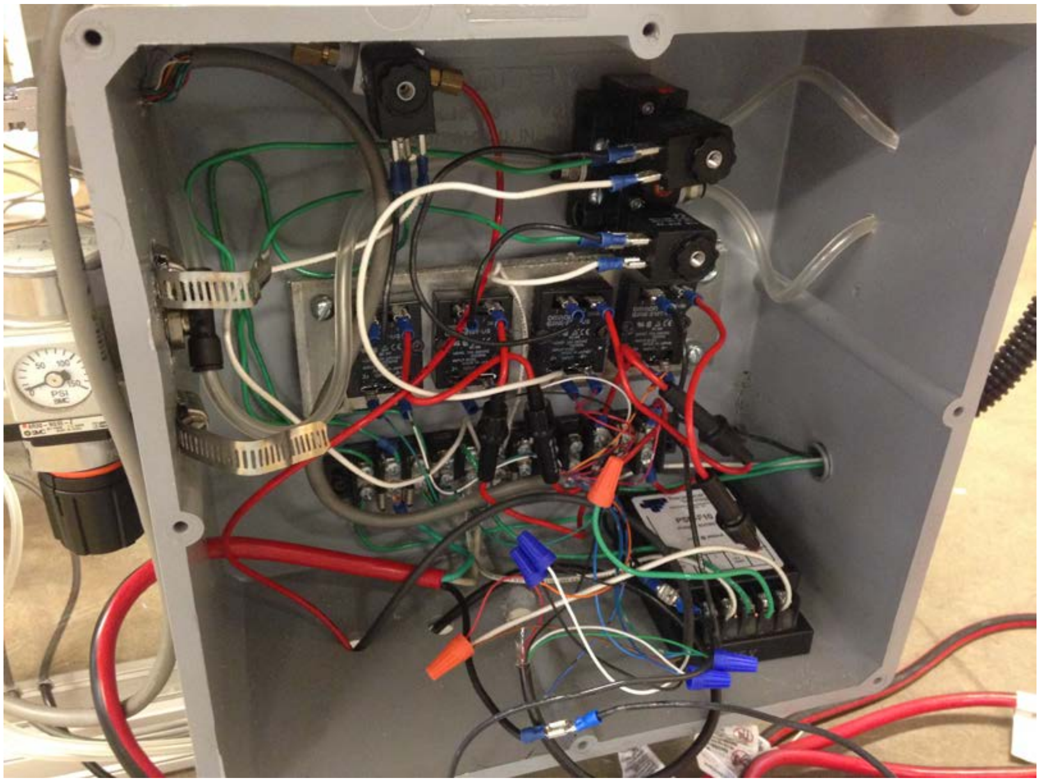


Figure 39. Wiring Box

Simplified Prototype

The final design for the test machine is extremely complicated with many moving components and electronics. Within the project timeline, it would not have been feasible to construct a fully working prototype that featured all of the components to be included on the final design. Due to this, we chose to prototype only the components that we deemed most critical to the loading test. The group, as well as Specialized expressed concern with the brake design that used two large

pads on either side of the rim. The design was chosen for various reasons, namely to accommodate many different rim designs. The braking component was the main assembly that we verified during prototyping.

Recommendations for the future

After completing initial construction, it is apparent that small changes could be made to the design to improve it in the future. After running tests repetitively, it is apparent that some settling of components has occurred. The dropouts should be realigned with a shim system. The difference is not substantial, and does not cause binding in the device, but better alignment could be achieved. In addition to this, there is a large moment acting on the pillow blocks during loading. Primary loading is occurring on the pillow block closest to the piston. Flex is visible during testing. To fix this, a counter support could be added to the end of the pillow block to help support the system. The small air cylinder in the pin brake system does not have an air line running from one of the air cavities. Although it is not critical to have an air hose, but if there are environmental factors it would be good to close off the hole with an adaptor and air hose.

Chapter 6: Design Verification

The first test we have already performed was on the prototype that was mentioned earlier. This test was mainly to help familiarize ourselves with our concept of a lever arm applying a chain force on a freehub and to test our clamp-brake design. Our other preliminary test was to determine how water is realistically applied to a freehub when riding in rainy weather conditions. We mounted a GoPro on a mountain bike facing rearwards as seen in the figure below, and went for a ride on a wet day. From this data we found that not much water got onto the freehub but there was comparatively a lot more water on the freehub and cassette than on the hub. To account for this, we recommend that two sprayers be used: one aimed at the cassette area and one aimed at the hub with different flow rates for each.

Figure 40. Picture from the GoPro attached to the Dropout on a rainy day

A majority of our testing will occur after manufacturing. We will then test the reaction times of the motor and pistons, so that our Labview code can accurately time how these components are moving. This is especially important for the indexing step so we can make the transitions between positions as smooth as possible. Finally, we will test the complete test scenario to check that our code is working. We will make sure during this test that the safety features work and that the test will stop upon failure.

Test Description

At the end of the manufacturing process, we began testing the machines functionalities. We first started without any air pressure in the system. We provided electric current safely to each subsystem to verify that the wiring was operational and correct. After receiving signals from all electrical devices into the data acquisition system, we could move to the next step.

The first verification test we performed on our test machine was to test the data cable for continuity and any potential solder shorts. All wires had proficient continuity, and none of the wires were shorted to each other. Next we applied a 5VDC voltage to the digital output lines that run to the relays in order to test the relays and air solenoids. All of these parts functioned properly, but when we tested the motor, we blew the motor fuse. After checking the motor specs, it was obvious that we had specified too small of a fuse for the motor.

Initial bench testing of the main air solenoids proved to be problematic. The solenoids would energize, but the valve would not actuate. After much deliberation, and troubleshooting, we decided to call customer service. Customer service walked us through their troubleshooting, and deemed that the part was defective. After some additional reading, it was found that the valve had to be hooked up to a load in order for the valve to function. After hooking up the actuator to the cylinder, our problems were resolved.

Next we connected the machine shop airlines with a pressure of 80 pounds per square inch. The data acquisition system was then used to open and close the air valves controlling the individual components. There were no major obstacles to overcome in this process. Once all of the channels were properly assigned in LabView, the main hurdle was perfecting the coding inside the program to make everything run the way we would like it to.

Detailed Results

After all components were working within specifications, it was time to perfect the LabView code. The programs outputs need to be responsive to the inputs. For instance, if the wheel deflects more than it should, the machine should automatically unload. We need to account for wheel windup and overall wheel settling. These factors will require an initial setup for new wheels to establish a baseline before reliable data can be collected. Specialized will have to perform this task when each new wheel is mounted. Our Design Verification Plan and Report can be referenced in Appendix R.

Project Phases and Milestones

Important Dates	
December 3, 2013	Conceptual design Presentation
December 5, 2013	Conceptual Design Report
February 6, 2014	Critical Design Review
March 4, 2014	Manufacturing and Test Review
March 11, 2014	Project Update
April 28, 2014	Project Hardware/Assembly Demo
May 29, 2014	Senior Project Design Expo
June 6, 2014	Final Report Due (Hardcopy and PDF)

Table 3. Important Dates

We have met the dates shown above throughout the year. Our next step is to ship the remaining parts are machine to Specialized in Morgan Hill. They will have the final say in how the machine will be used and what they need to tweak in order to make the machine work for their needs. We have designed a working machine that is able to do the requirements that Specialized

has asked for but there is still more work needed to be done in order to make the machine practical. A Gant cart is in appendix C with the project deadlines.

Conclusion and Recommendation

This was a highly complex project that brought together many different skills such as designing the mechanical system of the test machine, the actual manufacturing of it, and wiring an electrical system and programming a control system to support the machine. Overall, we have designed and built a successful test machine. The machine meets all of the major goals that specialized had given us. It will perform a freewheeling test, spinning a wheel at 25 mph while applying an amplified rider load and realistic dropout forces. It will also simulate the pedaling of the wheel by reproducing a chain load applied to the freehub while a brake is applied at the rim. All forces are as realistic as possible, with the chain load and rider weight spaced 90 degrees apart. The pedaling test is also able to index through multiple position so that the ratchet mechanism is loaded evenly, again providing the most realistic test.

Although our control system will execute each of the tests, it is not yet complete. The machine can take both force and displacement readings, but as of yet it is not programmed to detect failure via the over-extension of the piston during the testing. Due to the huge amount of data generated over a three day test, we have not been able to program a way to display this force and displacement data meaningfully. The most important part of this project has always been the actual test, and Specialized has agreed that the details of the control system can be worked out as they actually implement the test, as long as the general procedure is outline.

A reach goal of ours was to implement an environmental system that would spray the hub with saltwater or another contaminate to see that effect of the fatigue of the system. After starting the manufacturing, we saw that this would be more than we would be able to build during the time we had available. Again Specialized said that they wanted us to devote time to making the actual test fully functional and that they would add environmental factors later if they still needed them.

Finally during testing, we found that there is some flex in the system. The main source comes from the pillow-blocks which house the dropouts. These pillow-blocks are bolted onto the steel frame. Although the frame is stiff enough to withstand the force, the pillow blocks are cantilevered above them, and with the less rigid bolt joint, they are able to visibly deflect. A possible solution would be to manufacture a fitting to more securely hold these mounts stationary. Another solution is to hold the end of the dropout tube which would give a large moment arm to hold the dropout steady.

We believe we have delivered a product that Specialized can use in the future to test various wheel and freehub combinations. We hope our project will help them design and build better bicycle components and remain competitive in the market. Our team is glad to be apart of this

process and has learned a great deal about bike components, the design process, manufacturing, as well a host of other real world skills that will help us in our jobs in the future.

Appendix A: QFD Analysis

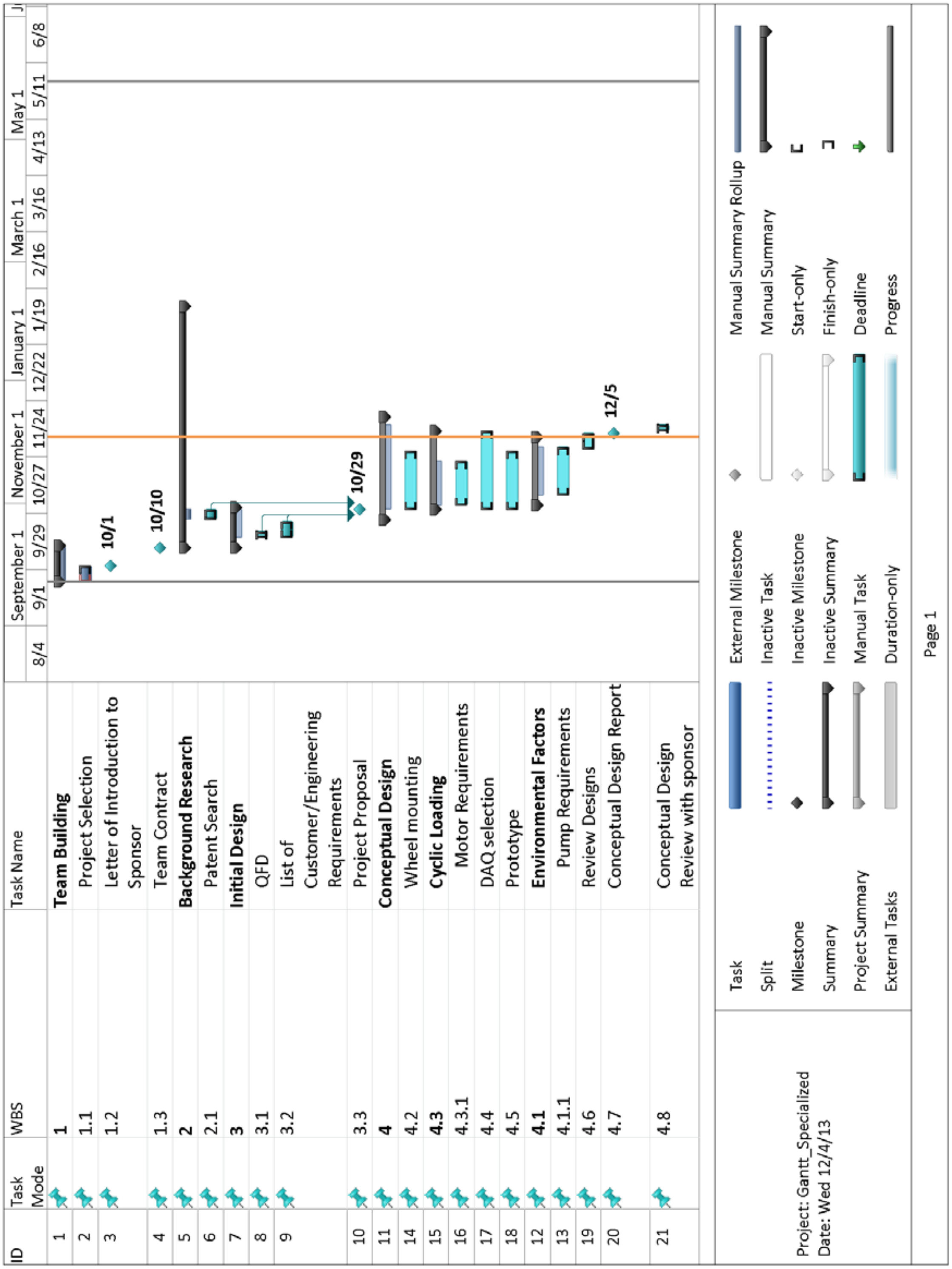
Freehub test machine

	Specialized (Step #1) Requirements (Whats)	Weighting (Total 100)	Engineering Requirements (HOWS)											Benchmarks	
			Size	fits hubs listed in ppt	Applies rider weight	Realistic Dropouts	Applies Constant Spoke Tension	Chain Tension	Constant freewheeling RPM	Detects failure	counter for cycles	Cost	Adjustable water spray	Reynolds	Chun-yen
Customer Requirements (Step #2)	small as possible	3	9											4	1
	fits designated hubs	7	3	9										3	3
	includes rider weight	7			9	3								1	4
	dropout reaction	7			3	9		3						1	4
	spoke tension	7					9							5	5
	chain force	7						9						5	2
	consistent repeatable	10			3	3	3	3	3	3	9		9	5	5
	tests freewheeling	8			3	3	3		9	3	9		9	1	5
	tests pedaling	8			3	3	3	9		3	9		9	5	2
	adjustable forces	7			9	9	3	9	3					5	4
	controller w/ stop function	7								9				3	5
	Tested after production	7						9	9	3	3		3	5	5
	under 10k	5										9		3	2
	enviromental factors	9											9	1	1
	aesthetically pleasing	1	1											5	4
	safety	12								9				5	5
	Units		ft	in	lbf	N	N	N	rpm	s	cycles	$	gpm		
	Difficulty		2	3	3	2	3	3	2	5	2	2	2		
	Targets		<3x2.5	see report	100	Compares to real life	1100	1000	30	1	exact	<10k	1		
	Our product		5	5	5	5	5	5	5	5	5	5	5		
	Absolute importance factors		49	63	225	225	162	312	186	270	255	45	336		
	Relative importance factors		2.3	3.0	10.6	10.6	7.6	14.7	8.7	12.7	12.0	2.1	15.8		
	Ranking		9	8	5	5	7	2		3	4	10	1		

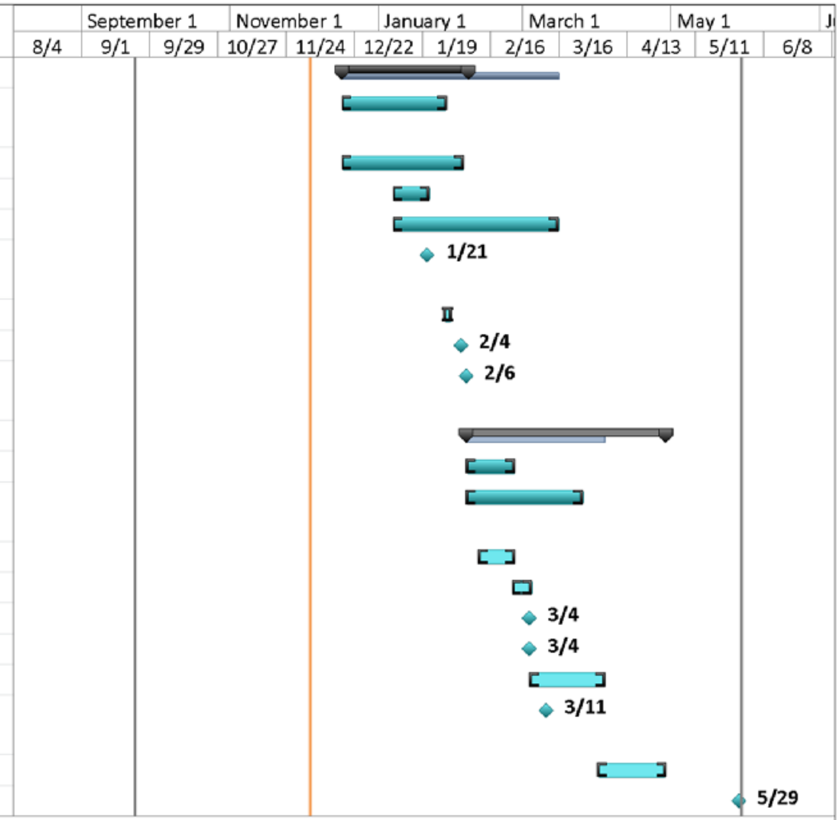
Appendix B: Objectives Table

Spec #	Parameter Description	Requirement or Target	Tolerance	Risk	Compliance
1	Testing Types	2	Exact	High	A,T
2	Testing time to Failure	3 Days	Max	Medium	A,T
3	Count Cycles	Until Failure	Exact	Medium	A,T
4	Safety	No Accidents	Max	Medium	A,T,I
5	Failure Detection	Stops Immediately	Min	High	A,T
6	Mimic real life environment	Water, Saltwater, Mud	Min	Medium	A,T
7	Tests under Bike and Rider Weight	180 lbf	Min	Medium	A,T
8	Applies Pedal Forces	5000 N	Min	Medium	A,T
9	Freewheels at constant rpm	250 rpm	Min	Medium	A,T
10	Spoke tension	1100 N	Max	Medium	A,T
11	Holds Hubs	130,135,142 mm hubs	Min	Low	A
12	Cost	$10000	Max	Low	A

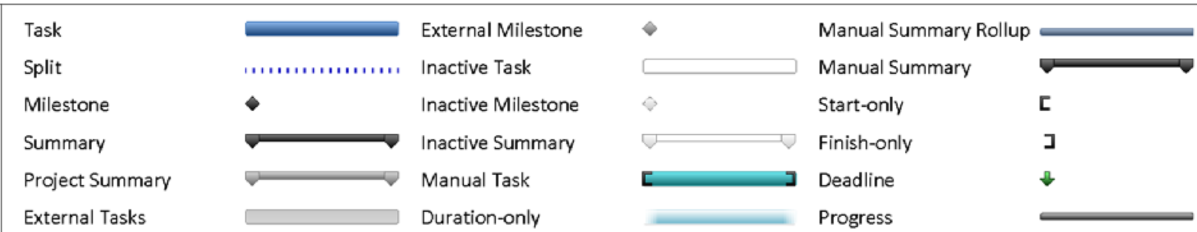
Appendix C: Gant Chart



ID	Task Mode	WBS	Task Name
22		5	**Critical Design**
23		5.1	Improve conceptual designs
25		5.3	Calculations
24		5.2	Bill of Materials
26		5.4	Create Control program
27		5.5	Order long lead time parts
28		5.6	Critical Design Practice
29		5.7	Critical Design Report
30		5.8	Critical Design Review with Sponsor
31		6	**Manufacturing**
32		6.1	Order Materials
36		6.5	Implement DAQ system
37		6.6	Build Prototype
38		6.7	Improve Design
33		6.2	Test Review
35		6.4	Test Review
39		6.8	Second Prototype
34		6.3	Project Update Memo
40		7	Testing
41		8	Senior Project Expo



Project: Gantt_Specialized
Date: Wed 12/4/13



Appendix D: EES Friction Calculation

```
T_c = 5000 {Chain Tension}
N = 1000 {Normal Force}
R_w = 13 {Radius of Wheel}
R_f = 2 {Radius of Freehub}
R_d = 5 {Radius of Drum}
L = 23 {Distance between centers}
theta = 62.84
(T_1) = (R_w*(T_2) - N*(R_f))/R_w
(T_2)= (N - ((T_1)*cos(theta)))/cos(theta)
beta = 234.32*(pi/180)
mu_s = ln(T_2/T_1)/beta

beta_d = 125.68*(pi/180)
mu_s_d = ln(T_2/T_1)/beta_d

_d = ((T_1*cos(theta))-T_2*cos(theta))/mu_s_d
```

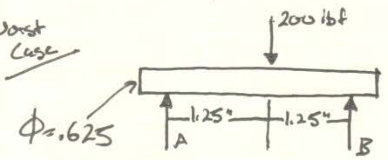
Unit Settings: SI C kPa kJ mass deg

β = 4.09 [rad]	β_d = 2.194 [rad]	L = 23 [in]	μ_s = 0.0344 [dim]
$\mu_{s,d}$ = 0.06414 [dim]	N = 1000 [N]	N_d = -1095 [N]	R_d = 5 [in]
R_f = 2 [in]	R_w = 13 [in]	θ = 62.84 [deg]	T_1 = 1018 [N]
T_2 = 1172 [N]	T_c = 5000 [N]		

Appendix E: Design Analysis

Motor Shaft Analysis

Worst Case



A=100

B=100

$M_{MAX} = 125$ lb·in

$\sigma_y = 40$ kpsi

$\sigma_{UT} = 45$ kpsi

$$\sigma = \frac{125 \text{ lbf}}{\frac{\pi}{4}\left(\frac{5}{16}\right)^3}$$

$\sigma = 5.22$ ksi

$$FS = \frac{40}{5.22} = \boxed{7.67}$$

FATIGUE

$S_e = 22.5$ ksi

$S_e' = K_a K_b K_c K_d K_e K_f S_e$

$K_a = 2.7(45)^{-.265}$

$= .995$

$K_b = .879(.625)^{-.107}$

$K_b = .924$

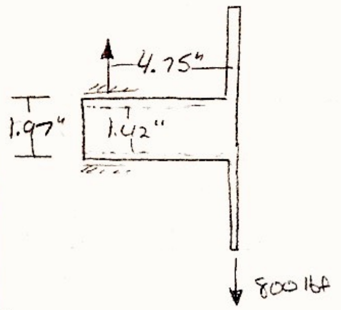
$K_c = K_d = K_e = K_f = 1$

$S_e' = (.995)(.924)(22.5 \text{ ksi})$

$S_e' = 20.5$ ksi

$$FS = \frac{20.5}{5.22} = \boxed{3.92}$$

Dropout Analysis



$M_{max} = 3900$ lb·in

$\sigma = \frac{Mc}{I}$

$= \frac{(3900 \text{ lb·in})(1.97/2)}{\frac{\pi}{4}\left(\left(\frac{1.97}{2}\right)^4 - \left(\frac{1.42}{2}\right)^4\right)}$

$\sigma = 6.9$ ksi

Yield:

$\sigma_y = 31.2$ ksi

Factor of Safety: $\frac{31.2}{6.9}$

$= \boxed{4.5}$

Fatigue:

$S_e = 1/2\, S_{ut}$

$S_{ut} = 73.2$ ksi

$S_e = 36.6$ ksi

$S_e' = K_a K_b K_c K_d K_e K_f S_e$

$K_a = 2.7(73.2)^{-.265}$

$K_a = .866$

$K_b = .879(1.97)^{-.107}$

$K_b = .917$

$K_c = K_d = K_e = K_f = 1$

$S_e' = (.866)(.917)(36.6)$

$S_e' = 25.9$ ksi

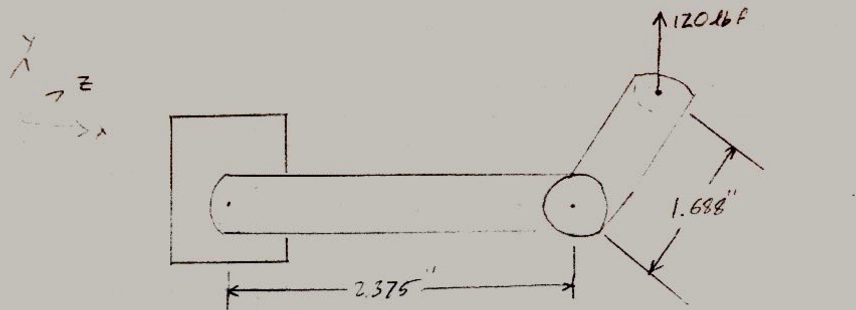
Factor of Safety: $\frac{25.9}{6.9} = \boxed{3.8}$

460 × 4
1500 × 4
378.2 × 4

MLA

Analysis on Pin beam.

I modeled have of the beam and used it to find the safety factors. On 3/4" bar.



Reactions at A:

$R_{Ay} = -120\,lbf$

$M_{Az} = 120\,lbf(2.375)$

$= 285\ in \cdot lbf$

$M_{Ax} = 120\,lbf(1.688 - 0.375)$

$= 157.56\ in \cdot lbf$

Results

Yield Fos = 2.94

Fatigue Fos = 2.65

Deflection

$$w(L) = \frac{PL^3}{3EI}$$

$L = 2.375$

$E = 28000\,ksi$

$I = \frac{\pi}{4} r^4 = \frac{\pi}{4}(.375")^4$

$I = 0.01553\ in^4$

$$w(L) = \frac{120\,lbf\,(2.375\,in)^3}{3(28000000\,psi)(0.01553\,in^4)}$$

$= 0.00123\,in$

$\sigma_{max} = \sigma_z + \sigma_x$

$= M_{z\,max}\frac{c}{I} + M_{x\,max}\frac{c}{I}$

$= 285\,in \cdot lbf\,(.375)/I - 157.56(.375)/I$

$= 10686.3\ psi$

$$FoS = \frac{\text{Yield } \sigma}{\sigma_{max}} = \frac{31.2}{10.6} = \boxed{2.94}$$

Fatigue

$$S_e' = k_a k_b k_c k_d k_e k_f S_e$$

ground

$$k_a = (1.34)(73.2)^{-0.085} = 0.846$$

$$k_b = 0.879(.75)^{-0.107} = 0.906$$

$$k_c = 1$$

$$k_d = 1$$

$$k_e \quad 1$$

$$k_f = 1$$

$$S_e = \tfrac{1}{2}\sigma_u = \tfrac{1}{2}(73.2) = 36.6$$

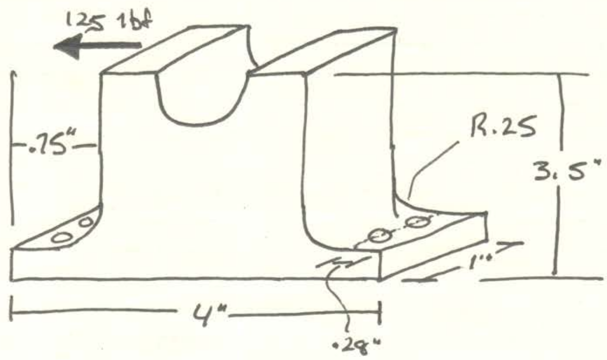
$$S_e' = (0.846)(0.906)(36.6)$$

$$S_e' = 28.05$$

$$FoS = \frac{S_e'}{\sigma_{max}} = \frac{28.05}{10.6} = \boxed{2.65}$$

TOPS 35502

Pillow-Block Analysis



$$F = \frac{(125\ lbf)(3.5\ in)}{4 - .28\ in}$$

$F = 117\ lbf$

Using M6 screw

$\Rightarrow A_t = 20.1\ mm^2 \times \left(\frac{1\ in}{25.4\ mm}\right)^2$

$A_t = .0312\ in^2$

$$\sigma = \frac{117\ lbf}{.0312\ in^2}$$

$= 3.76\ ksi$

$$FS = \frac{3.76\ ksi}{170\ ksi} = \frac{170}{3.76} = \boxed{45.2}$$

Max Moment = $(125\ lbf)(3.5")$

$= 437.5\ lb \cdot in$

$$\sigma = \frac{(437.5\ lb\,in)(1/8")}{\frac{1}{12}(1)(1/4)^3}$$

$\sigma = 13.37\ ksi$

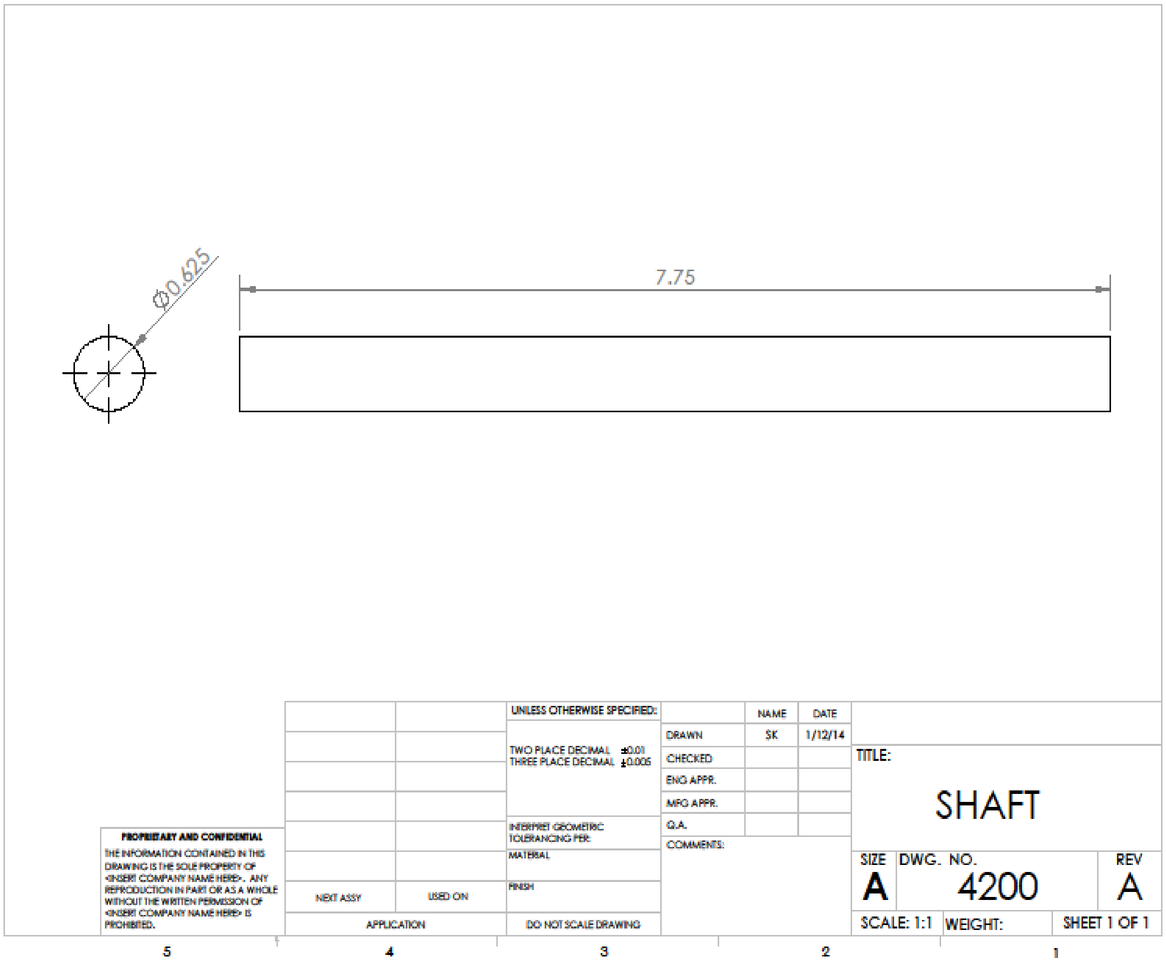
$$FS = \frac{40}{13.37} = \boxed{3.0}$$

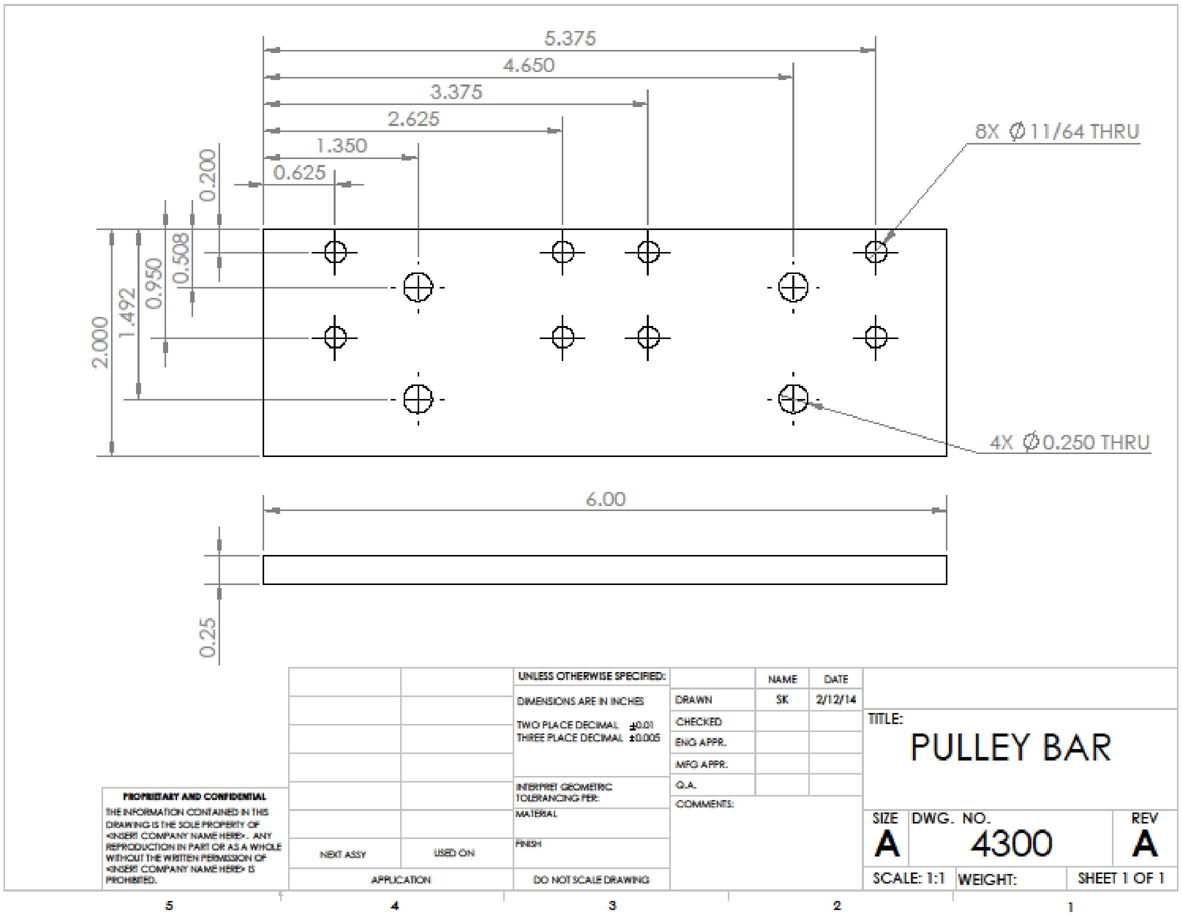
Appendix F: Complete Bill of Materials

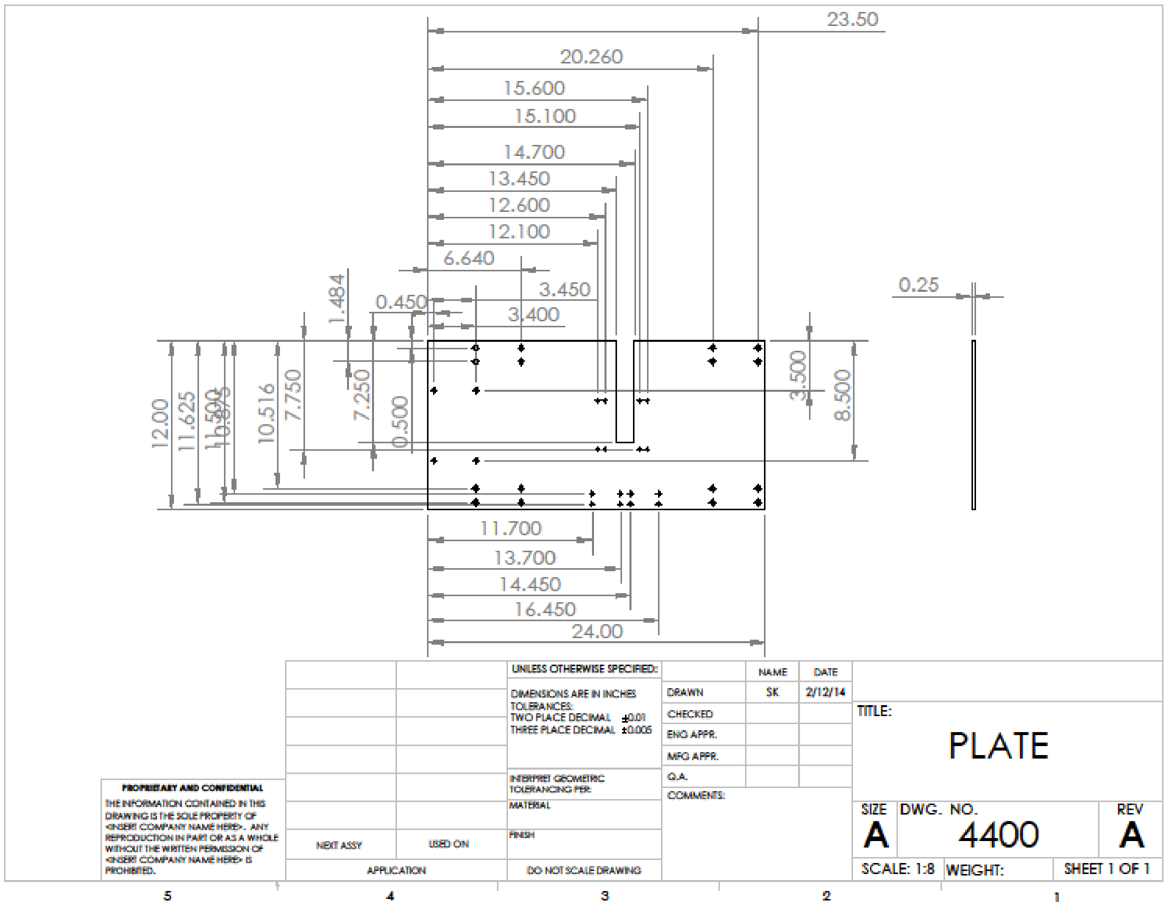
Purchaser	Date	Supplier	Reference #	Total
Specialized	21-Feb	Bimba	Bimba 2-21	$151.77
	21-Feb	Drokits	Drokits 2-21	$94.93
	21-Feb	McMaster	McMaster 2-21	$727.22
	27-Feb	McCarthy	McCarthy 2-27	$251.78
	6-Mar	Speedy Metals	Speedy Metals 3-6	$293.14
	14-Mar	Grainger	Grainger 3-14	$270.48
	14-Mar	McMaster	McMaster 3-14	$193.93
	27-Mar	Teco Pnuematics	Teco 3-27	$717.24
	13-May-14	Teco Pnuematics	Teco 5-13	$60.91
	21-May-14	Merchant Measurement Specialties, Inc	SO CW26395	$400.45
	27-May-14	Grainger	Grainger 5-27	$72.16
			Subtotal	**$3,234.01**
Brett	3-May-14	OnlineMetals.com	232288	$176.83
	3-May-14	OnlineMetals.com	232289	$65.64
	17-Apr-14	Home Depot	HD417	$6.99
	24-Apr-14	Home Depot	HD424	$4.67
	12-May-14	Home Depot	HD512	$8.63
	16-May-14	Home Depot	HD516	$11.29
	28-Apr-14	Miners Ace Hardware	MIN428	$18.65
	16-May-14	Miners Ace Hardware	MIN516	$16.62
	17-May-14	Miners Ace Hardware	MIN517	$22.02
	16-May-14	RadioShack	RADIO516	$12.63
	24-May-14	Miners Ace Hardware	MIN524	$17.09
	26-May-14	Miners Ace Hardware	MIN526	$52.29
	30-May-14	O' Reilly Auto Parts	OREILLY530	$34.55
	27-May-14	RadioShack	RADIO527	$12.38
			Subtotal	**$460.28**
Mitch	22-Feb-14	Home Depot	HD222	$19.68
	18-Apr-14	Miners Ace Hardware	MIN418	$52.66
	2-May-14	Miners Ace Hardware	MIN502	$8.14

	6-May-14	Miners Ace Hardware	MIN506	$4.85
	15-May-14	Miners Ace Hardware	MIN515	$18.76
			Subtotal	**$104.09**
Nick	24-Apr-14	Midwest Control Products Corp.	34240	$144.53
	8-May-14	Central Coast Bearing	63904	$96.63
	24-Apr-14	Miners Ace Hardware	MIN424	$5.38
	9-May-14	CBO Inc	325401	$19.62
	20-May-14	Home Depot	HD520	$146.85
	27-May-14	Miners Ace Hardware	MIN527	$60.23
	27-May-14	Napa Auto Parts	NAPA527	$5.80
			Subtotal	**$479.04**
Stephen	30-Apr-14	McCarthy Steel	31109	$60.31
	16-May-14	McMaster-Carr	85498056	$27.39
	8-May-14	Big 5 Sporting Goods	BG508	$25.91
	10-May-14	Home Depot	HD510	$36.29
	15-May-14	Home Depot	HD515	$370.26
	8-May-14	Miners Ace Hardware	MIN508	$61.28
	8-May-14	RadioShack	RADIO5081	$24.29
	8-May-14	RadioShack	RADIO5082	$12.77
	12-May-14	RadioShack	RADIO512	$12.10
	28-May-14	Home Depot	HD528	$3.33
	20-May-14	Miners Ace Hardware	MIN520	$19.19
	28-May-14	Miners Ace Hardware	MIN528	$6.37
	30-May-14	RadioShack	RADIO530	$3.39
	30-May-14	Staples	STAPLES530	$7.01
			Subtotal	**$669.89**
			Reimbursement Subtotal	**$1,713.30**
			Total	**$4,947.31**

Appendix G: Motor/Tensioner Drawings




5.375
4.650
3.375
2.625
1.350
0.625
0.200
0.508
0.950
1.492
2.000
8X Ø11/64 THRU
4X Ø0.250 THRU
6.00
0.25
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
SK
2/12/14
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
PULLEY BAR
SIZE
A
DWG. NO.
4300
REV
A
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
5
4
3
2
1


23.50
20.260
15.600
15.100
14.700
13.450
12.600
12.100
6.640
3.450
3.400
0.450
1.484
0.25
12.00
11.625
10.516
7.750
7.250
0.500
3.500
8.500
11.700
13.700
14.450
16.450
24.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
SK
2/12/14
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
PLATE
SIZE
A
DWG. NO.
4400
REV
A
SCALE: 1:8
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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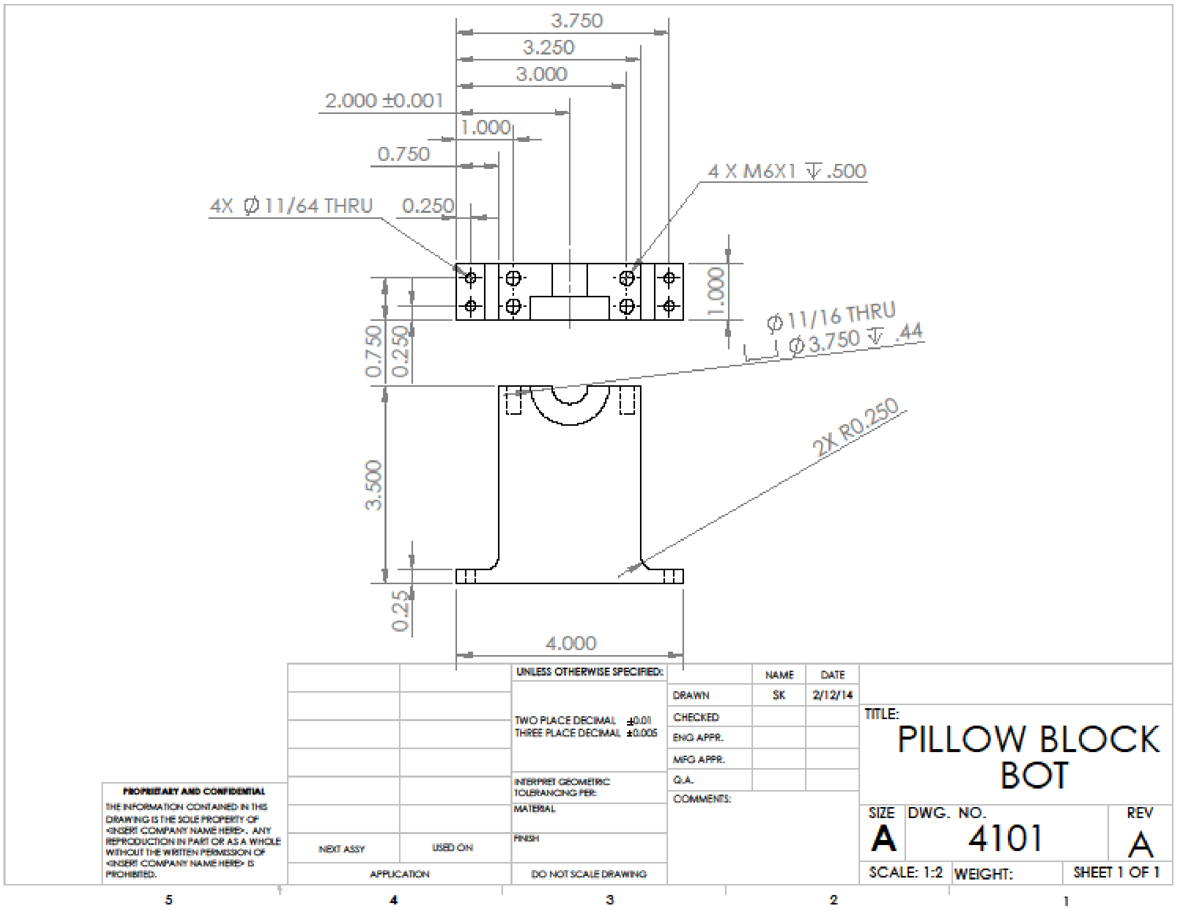
NEXT ASSY
USED ON
APPLICATION
5
4
3
2
1



3.750
3.250
3.000
2.000 ±0.001
1.000
0.750
4X Ø 11/64 THRU
0.250
4 X M6X1 ↧ .500
1.000
Ø 11/16 THRU
⌴ Ø 3.750 ↧ .44
0.750
0.250
2X R0.250
3.500
0.25
4.000
UNLESS OTHERWISE SPECIFIED:
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
SK
2/12/14
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
PILLOW BLOCK BOT
SIZE
A
DWG. NO.
4101
REV
A
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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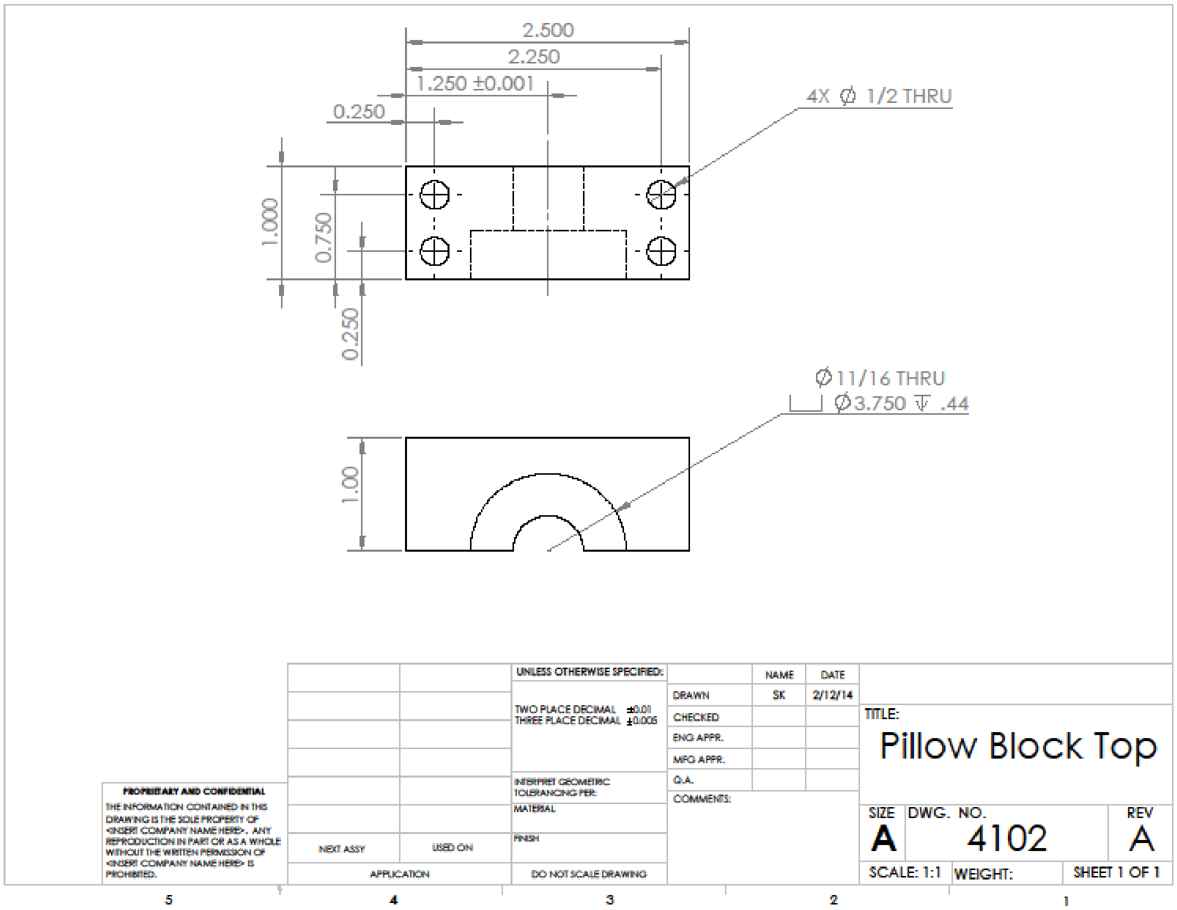
5
4
3
2
1


2.500
2.250
1.250 ±0.001
0.250
4X ∅ 1/2 THRU
1.000
0.750
0.250
∅11/16 THRU
⌴ ∅3.750 ↧ .44
1.00
UNLESS OTHERWISE SPECIFIED:
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
SK
2/12/14
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Pillow Block Top
SIZE
A
DWG. NO.
4102
REV
A
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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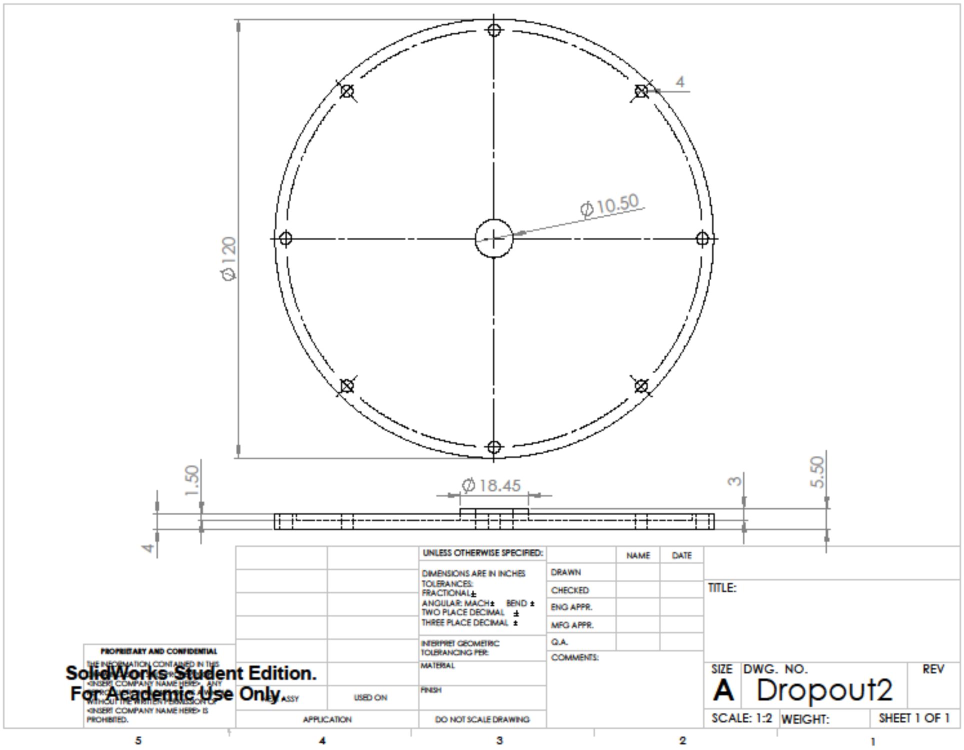
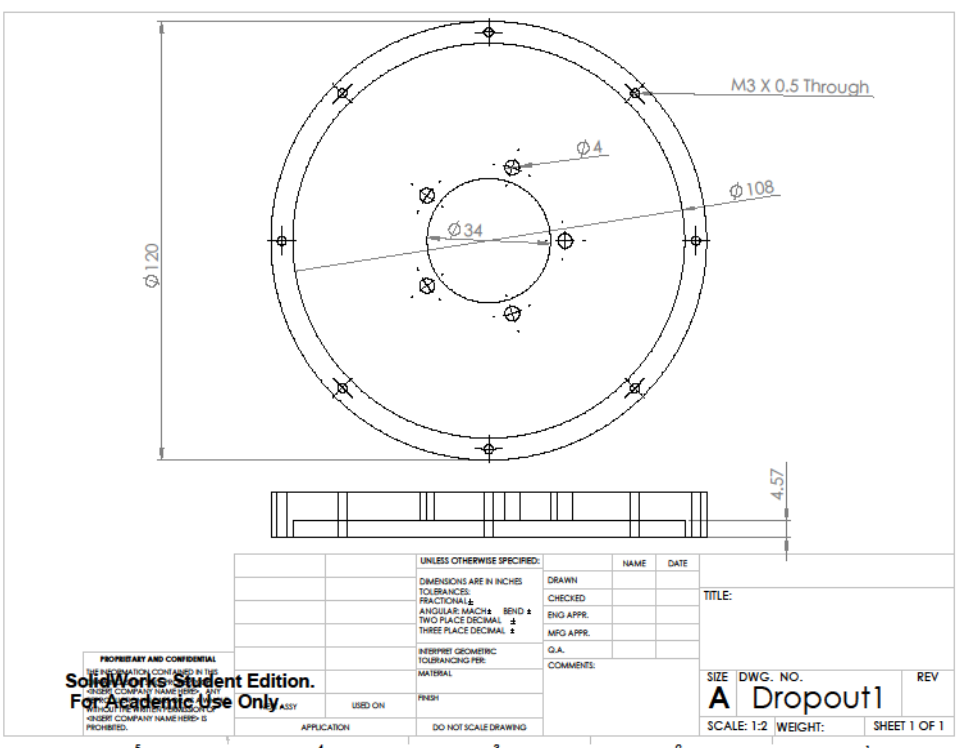
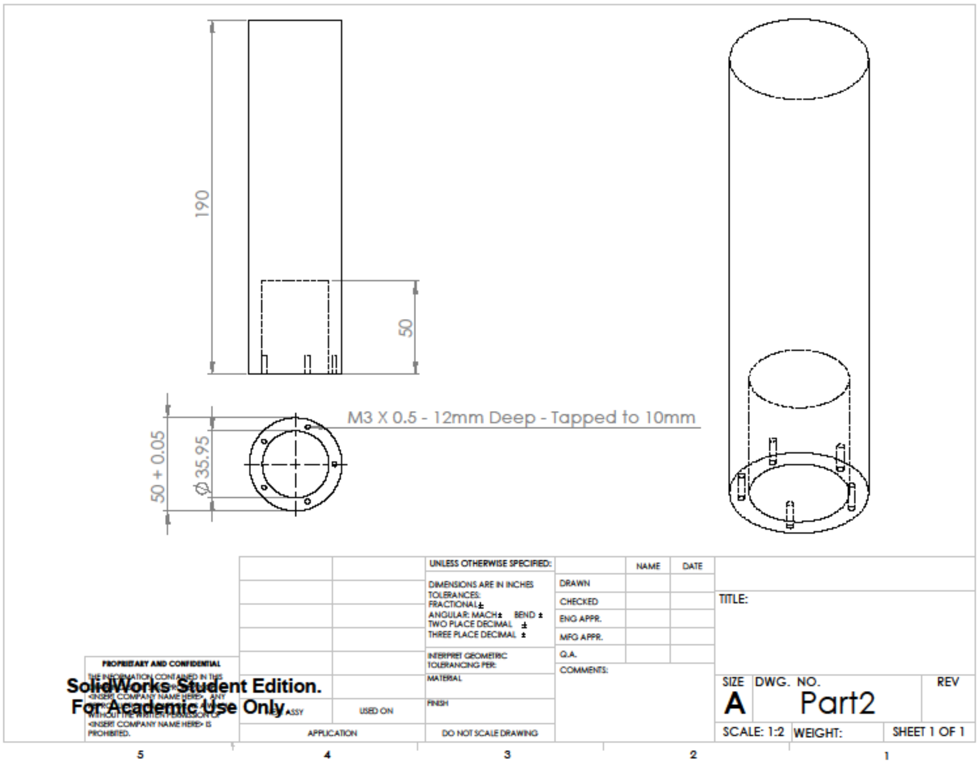
5
4
3
2
1

Appendix H: Dropout Drawing






190
50
M3 X 0.5 - 12mm Deep - Tapped to 10mm
50 + 0.05
Ø 35.95
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
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
SIZE
A
DWG. NO.
Part2
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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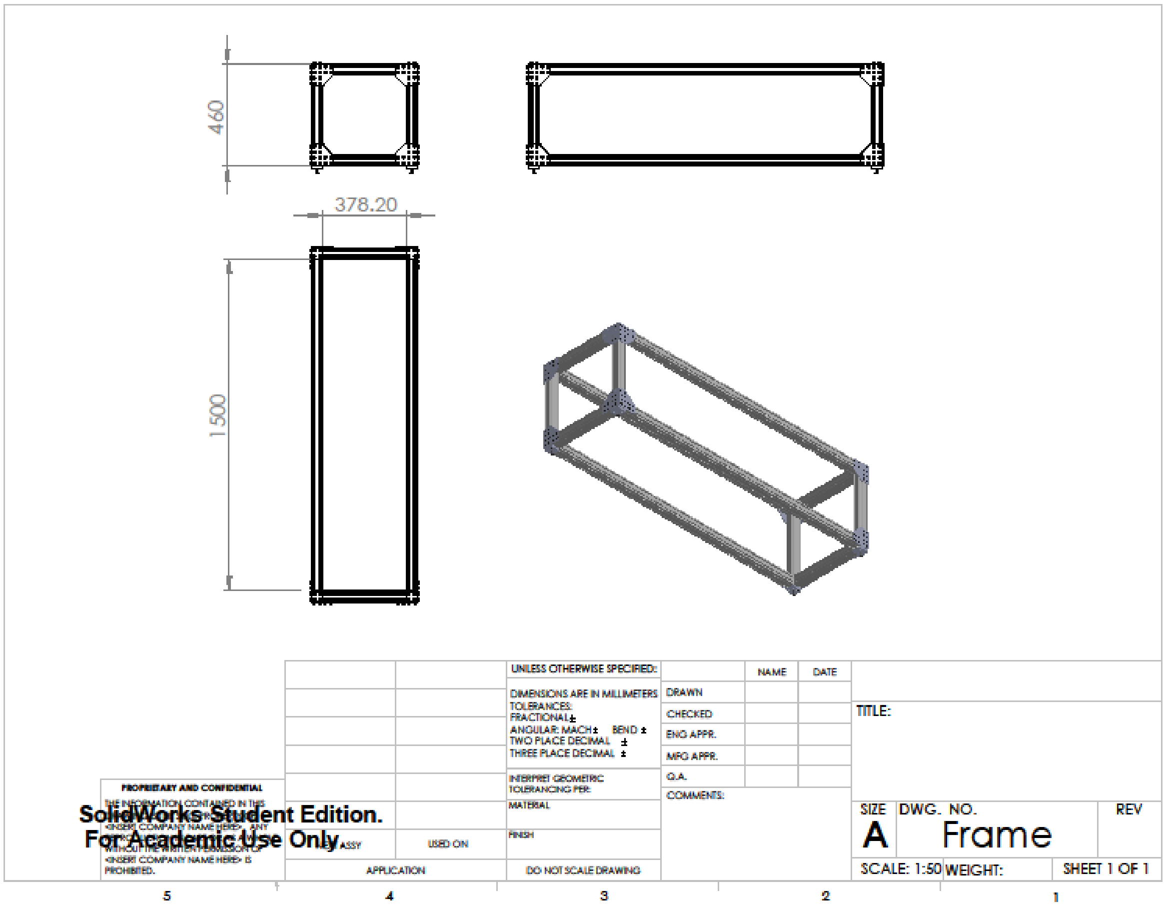
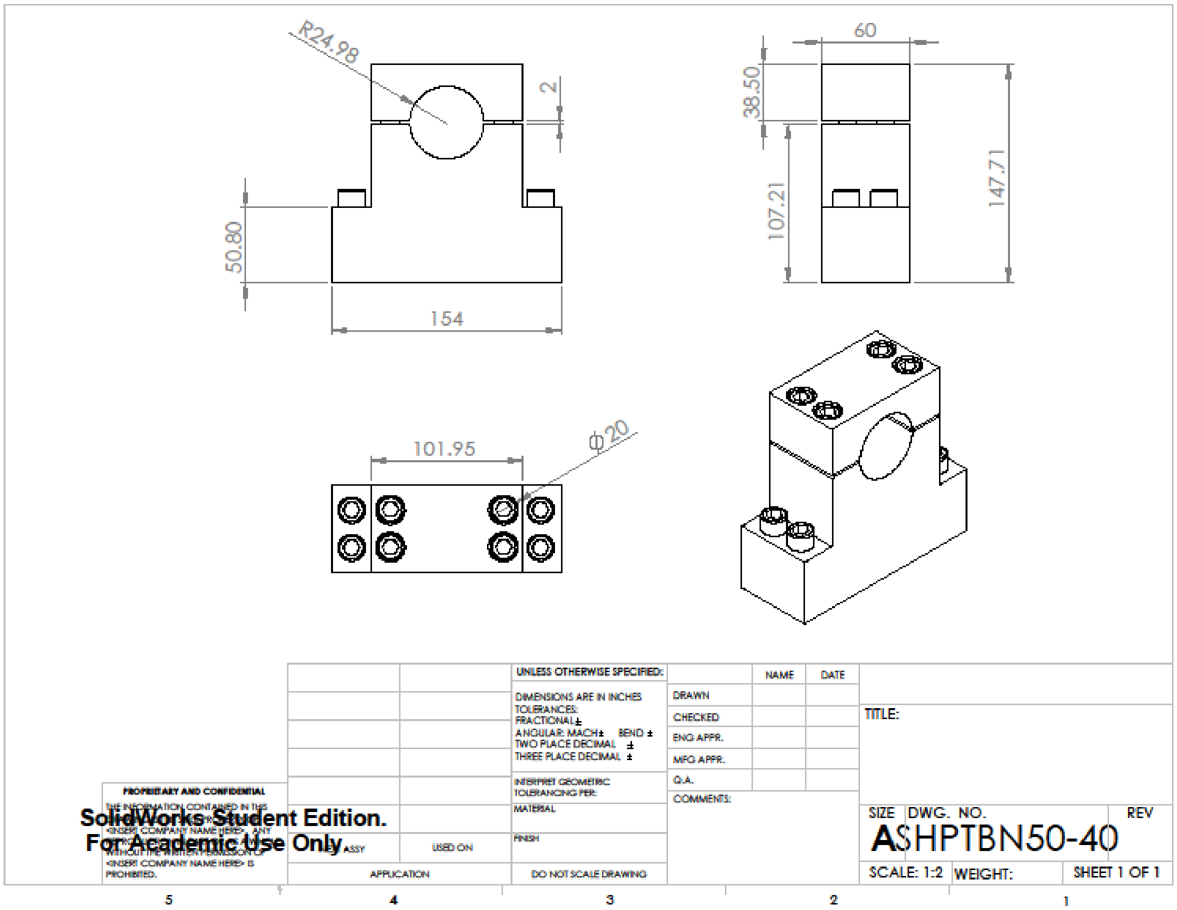
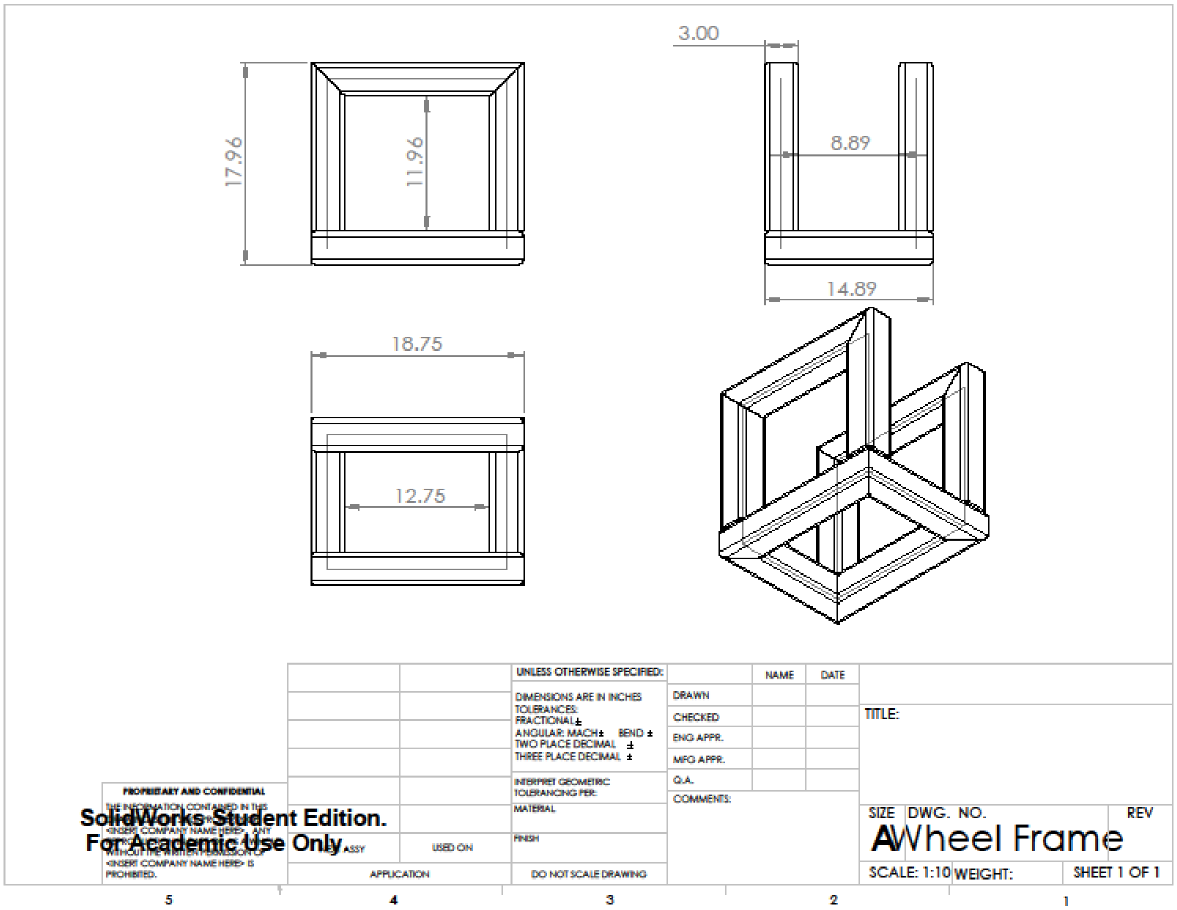
For Academic Use Only.
USED ON
APPLICATION
5
4
3
2
1

Appendix I: Frame Drawings




R24.98
2
60
38.50
147.71
107.21
50.80
154
101.95
ϕ20
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
USED ON
APPLICATION
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
SolidWorks Student Edition.
For Academic Use Only.
SIZE DWG. NO. REV
A SHPTBN50-40
SCALE: 1:2 WEIGHT: SHEET 1 OF 1
5
4
3
2
1


3.00
17.96
11.96
8.89
14.89
18.75
12.75
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
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
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
SIZE
DWG. NO.
REV
A
Wheel Frame
SCALE: 1:10
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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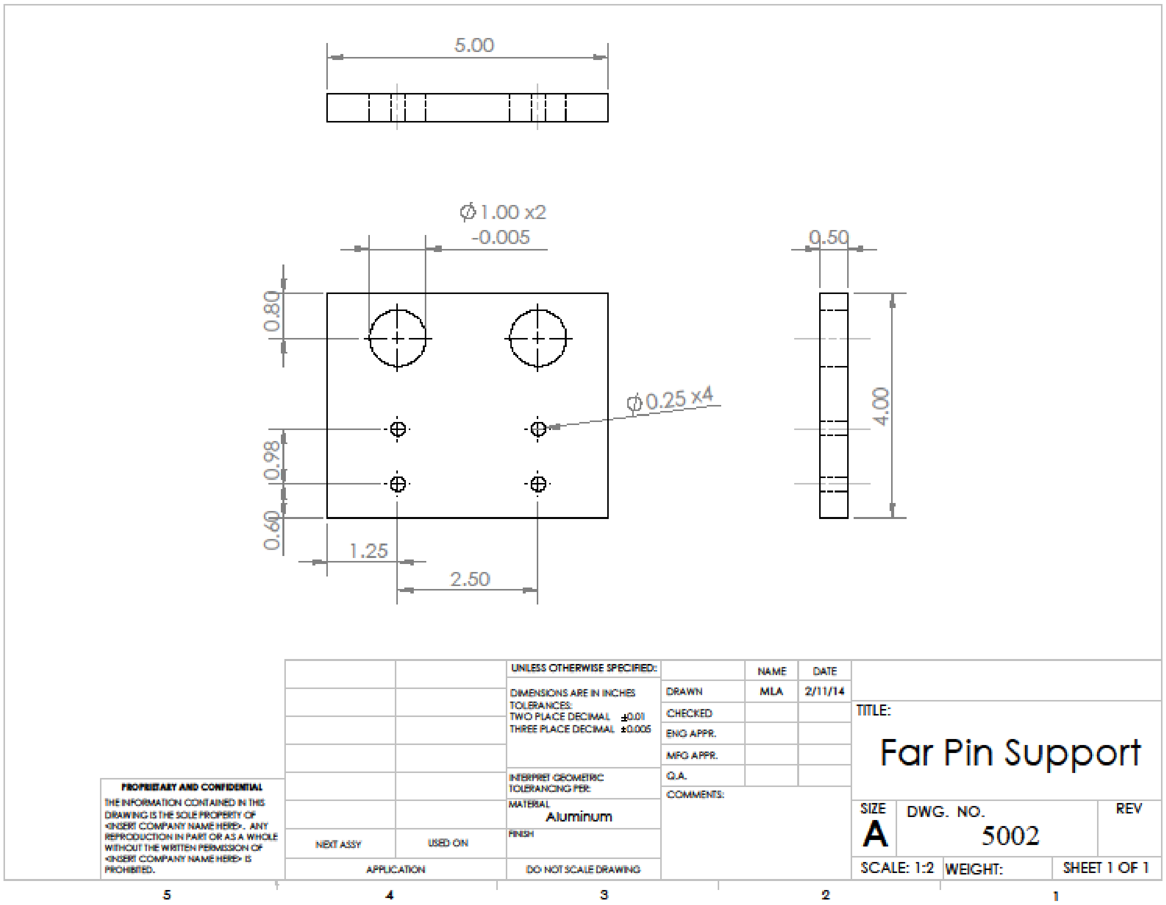
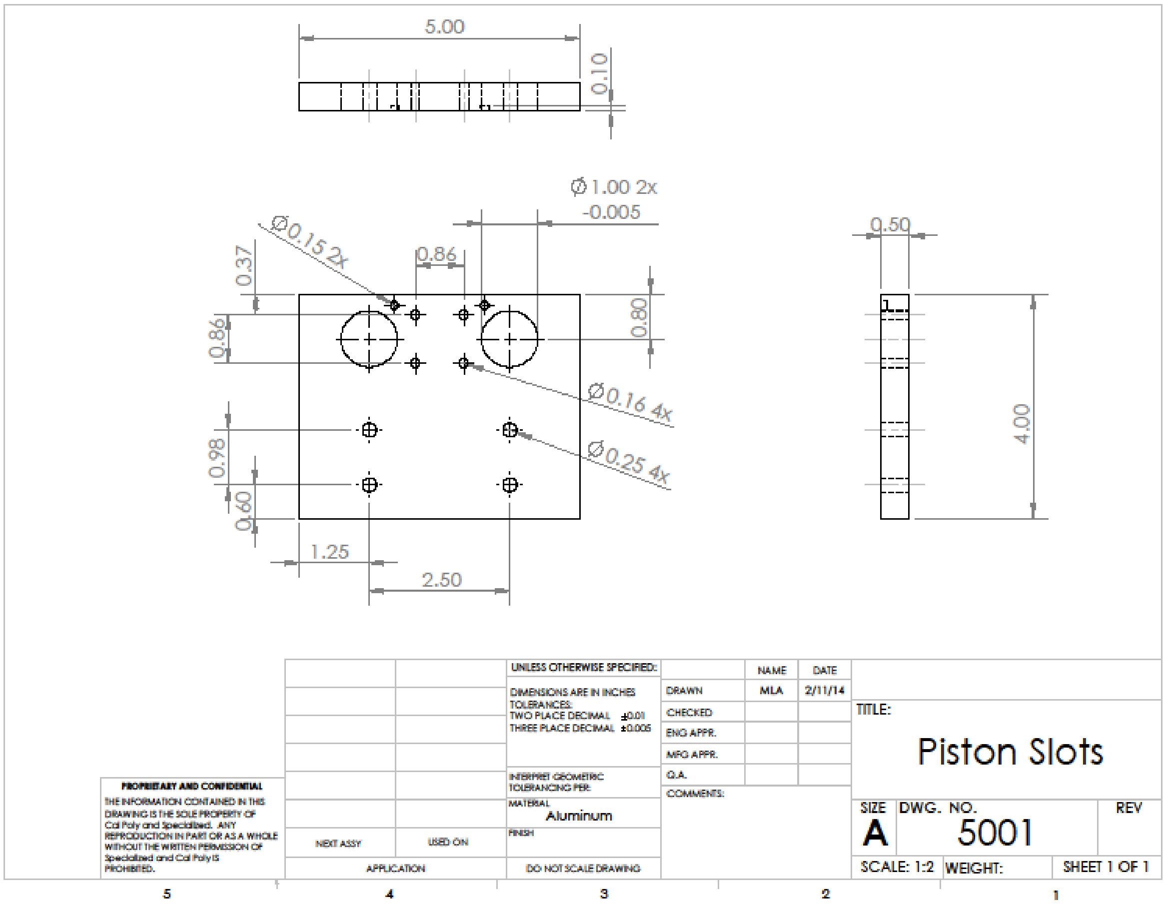
USED ON
APPLICATION
5
4
3
2
1

Appendix J: Pin System Drawings





5.00
0.10
Ø1.00 2x
-0.005
Ø0.15 2x
0.86
0.37
0.86
0.80
0.50
Ø0.16 4x
Ø0.25 4x
0.98
0.60
1.25
2.50
4.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Aluminum
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
MLA
2/11/14
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Piston Slots
SIZE
A
DWG. NO.
5001
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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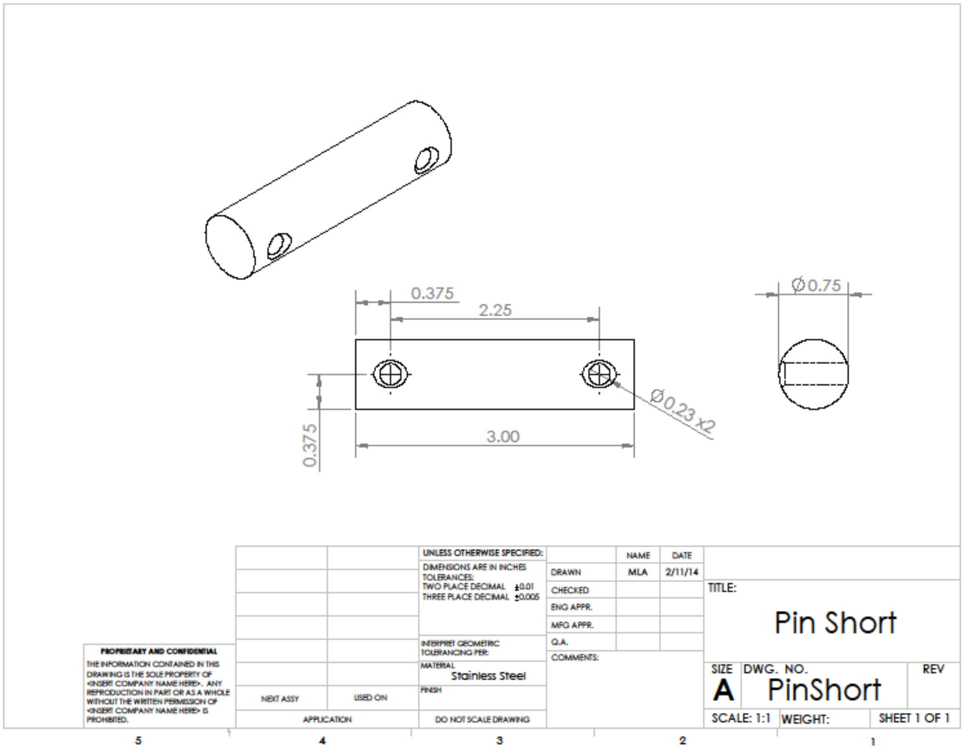
NEXT ASSY
USED ON
APPLICATION
5
4
3
2
1


0.375
2.25
Ø0.75
Ø0.23 X2
0.375
3.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Stainless Steel
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
MLA
2/11/14
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Pin Short
SIZE
DWG. NO.
REV
A
PinShort
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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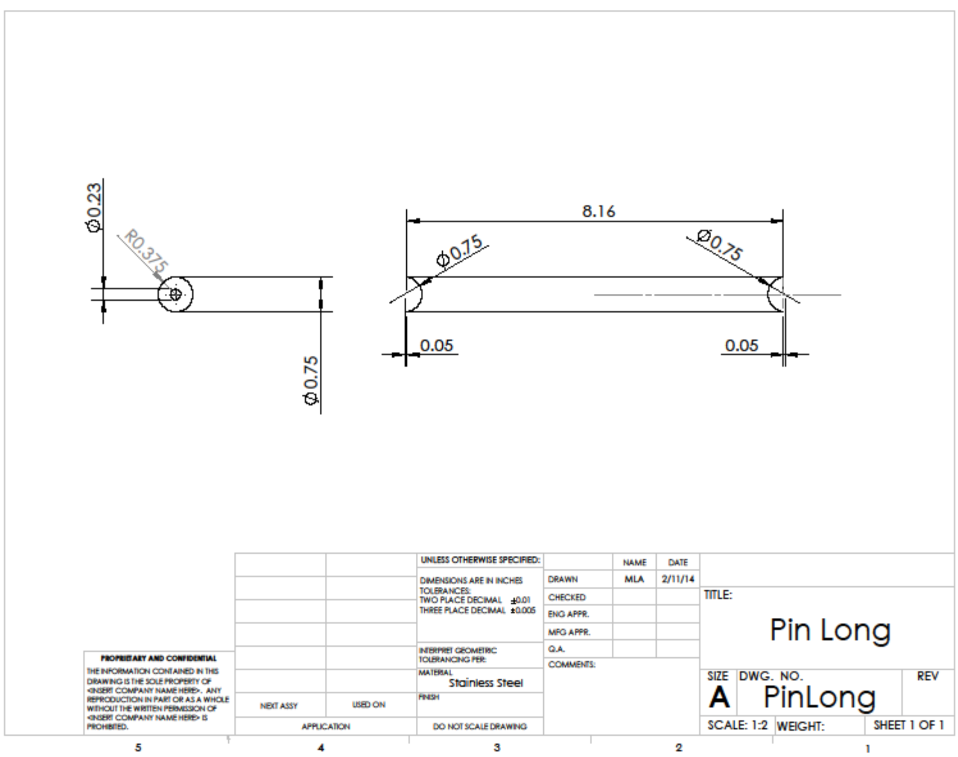
5
4
3
2
1


Ø0.23
R0.375
Ø0.75
8.16
Ø0.75
Ø0.75
0.05
0.05
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Stainless Steel
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
MLA
2/11/14
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Pin Long
SIZE
DWG. NO.
REV
A
PinLong
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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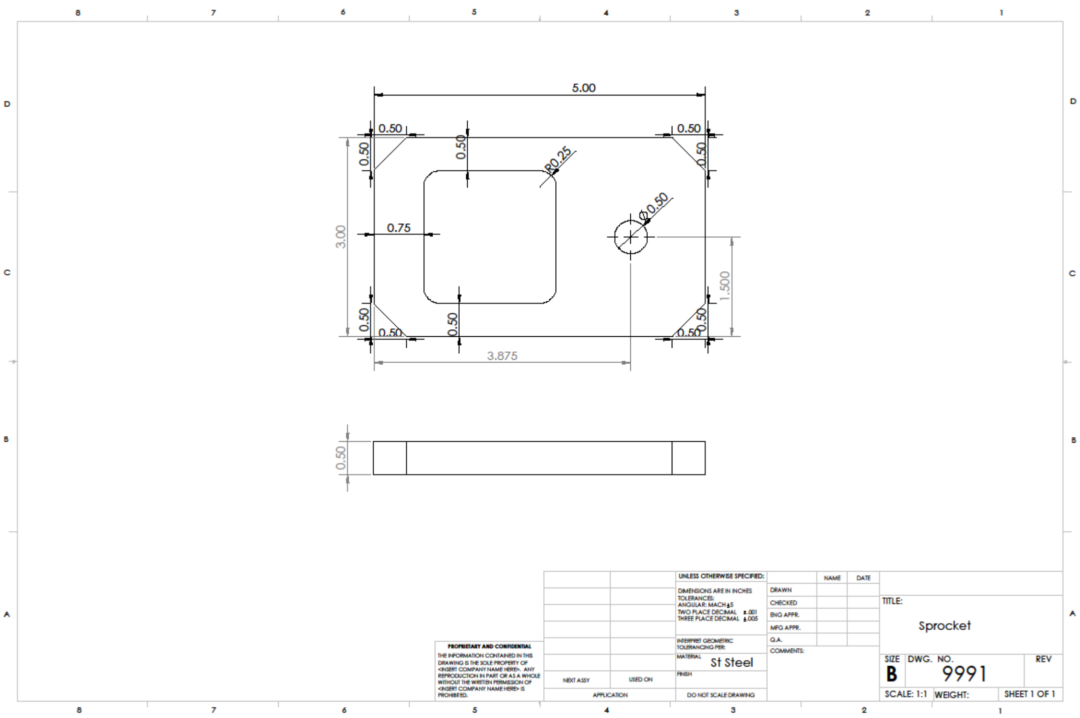
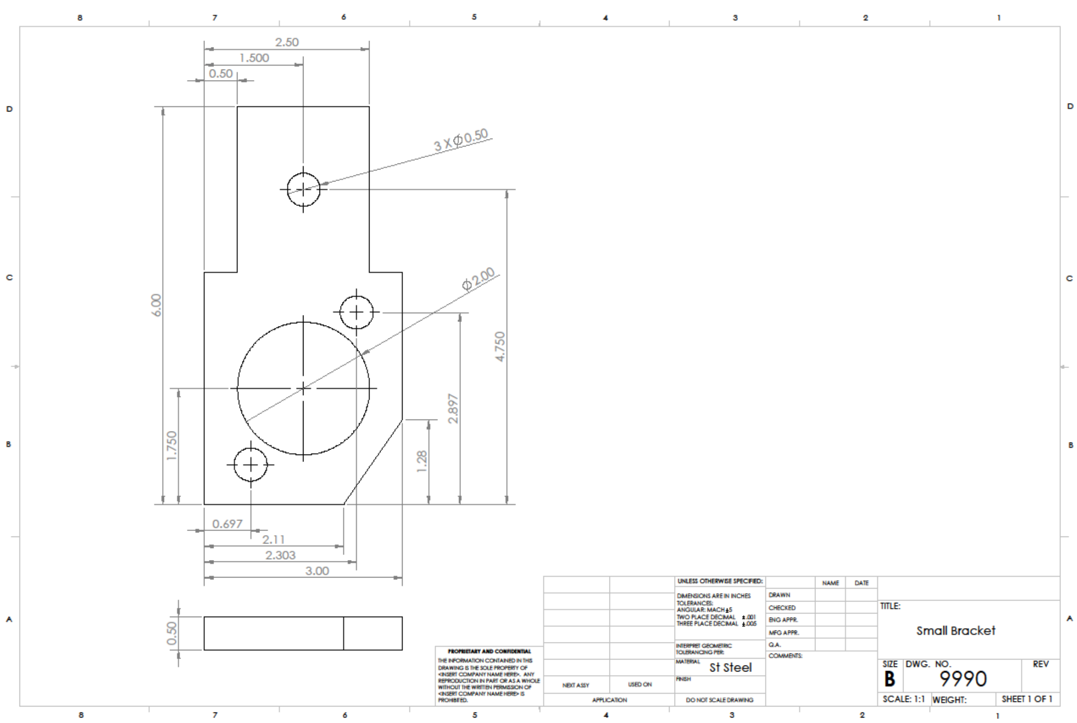
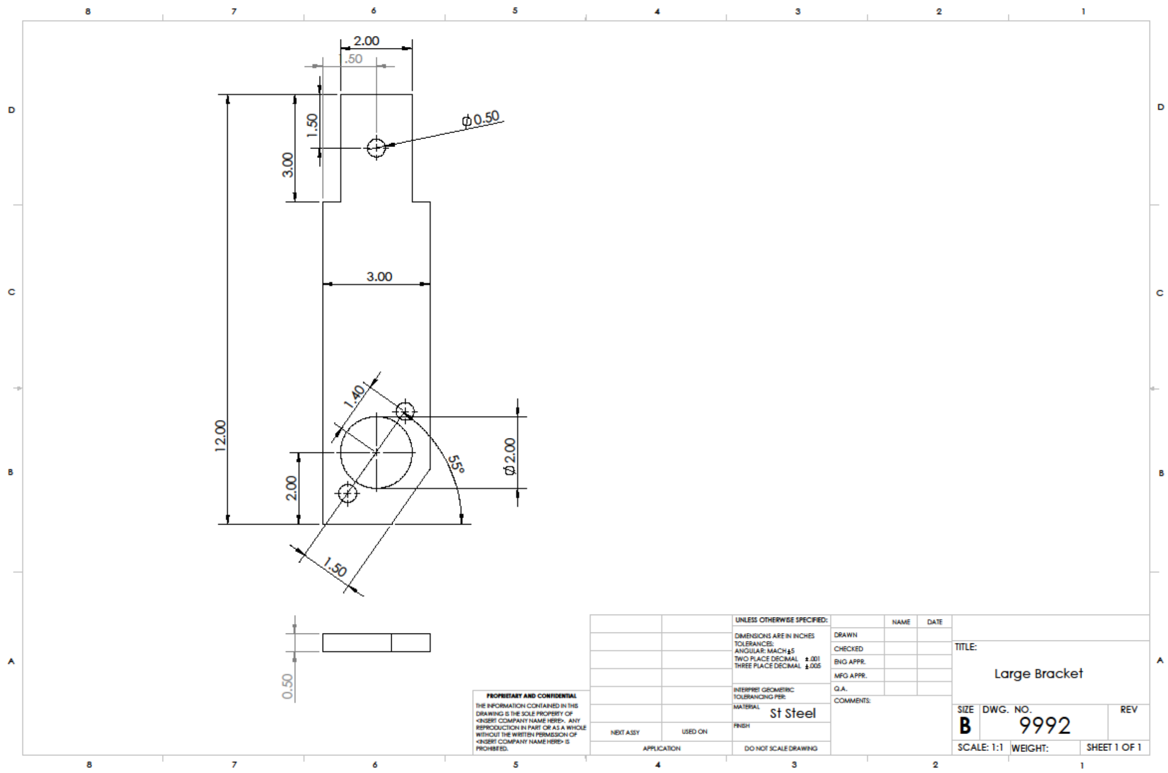
5
4
3
2
1

Appendix K: Piston Assembly






2.00
.50
1.50
3.00
ϕ0.50
3.00
12.00
1.40
Ø2.00
55°
2.00
1.50
0.50
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±5
TWO PLACE DECIMAL ±.001
THREE PLACE DECIMAL ±.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL St Steel
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
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NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Large Bracket
SIZE B
DWG. NO. 9992
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1

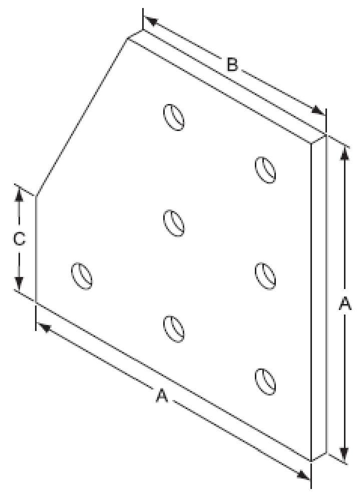
Appendix L: 80/20 Catalog Pages

NOTE: For more mounting hardware options, see page 757.

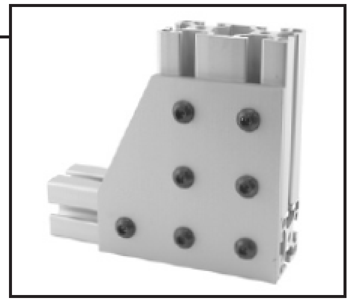
Metric

Joining Plates

7 Hole 90° Joining Plate



Page 757



25 Series Recommended Mounting Hardware:

Part No.	Qty	Description
75-3404	7	M6 x 10mm BHSCS & Econ T-Nut

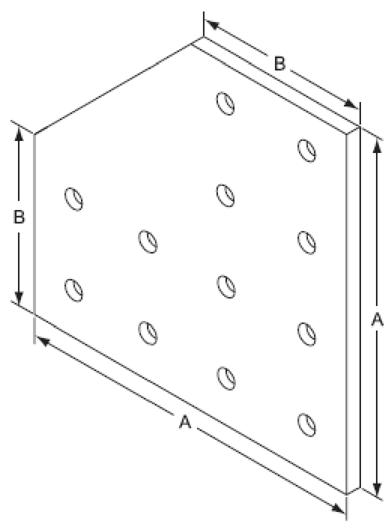
40 Series Recommended Mounting Hardware:

Part No.	Qty	Description
75-3422	7	M8 x 16mm BHSCS & Econ T-Nut
OR		
75-3500	7	M8 x 20mm Econ. T-Slot Stud, Washer, Hex Nut

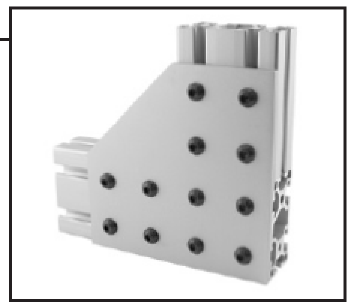
Part No.	A	B	C	kg.
25-4129	75.00	50.00	25.00	.060
40-4329	120.00	80.00	40.00	.188

4

12 Hole 90° Joining Plate



Page 757



25 Series Recommended Mounting Hardware:

Part No.	Qty	Description
75-3404	12	M6 x 10mm BHSCS & Econ T-Nut

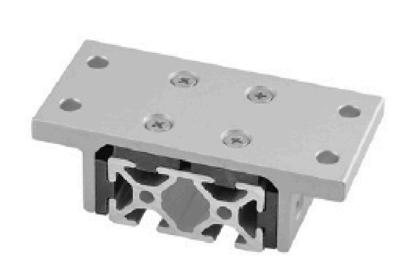
40 Series Recommended Mounting Hardware:

Part No.	Qty	Description
75-3422	12	M8 x 16mm BHSCS & Econ T-Nut
OR		
75-3500	12	M8 x 20mm Econ. T-Slot Stud, Washer, Hex Nut

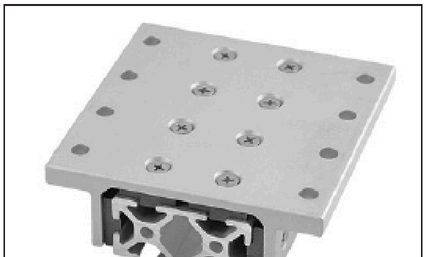
Part No.	A	B	kg.
25-4128	100.00	50.00	.107
40-4328	160.00	80.00	.331

80/20® Inc.
The Industrial Erector Set®
THE STANDARD

Double Flange Linear Bearings continued

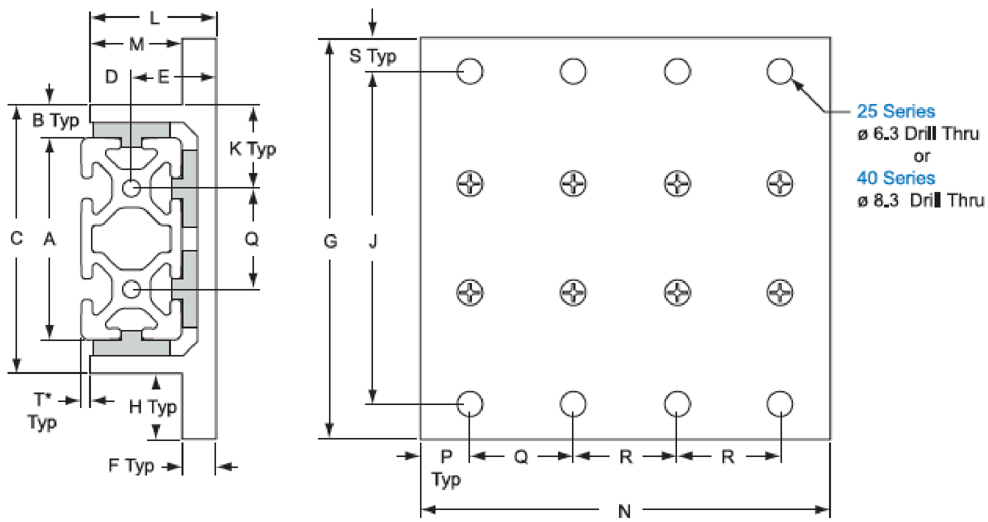


25-6723 40-6823



25-6724 40-6824

- **Bearings include bearing pads, screws and shims**



Part No.	A	B	C	D	E	F	G	H	J	K	L	M	N	P	Q	R	S	T*	kg.
25-6723	50.00	8.10	66.20	10.69	20.30	8.00	99.26	16.50	82.30	22.53	31.25	23.25	47.00	11.00	25.00	—	8.48	1.80	.111
25-6423**	50.00	8.10	66.20	10.69	20.30	8.00	99.26	16.50	82.30	22.53	31.25	23.25	47.00	11.00	25.00	—	8.48	1.80	.111
25-6724	50.00	8.10	66.20	10.69	20.30	8.00	99.26	16.50	82.30	22.53	31.25	23.25	100.00	12.50	25.00	25.00	8.48	1.80	.234
25-6424**	50.00	8.10	66.20	10.69	20.30	8.00	99.26	16.50	82.30	22.53	31.25	23.25	100.00	12.50	25.00	25.00	8.48	1.80	.234
40-6823	80.00	12.90	105.30	17.42	32.55	9.00	143.30	19.00	124.30	32.65	50.00	41.00	75.00	17.50	40.00	—	9.50	2.58	.386
40-6523**	80.00	12.90	105.30	17.42	32.55	9.00	143.30	19.00	124.30	32.65	50.00	41.00	75.00	17.50	40.00	—	9.50	2.58	.386
40-6824	80.00	12.90	105.30	17.42	32.55	9.00	143.30	19.00	124.30	32.65	50.00	41.00	160.00	20.00	40.00	40.00	9.50	2.58	.812
40-6524**	80.00	12.90	105.30	17.42	32.55	9.00	143.30	19.00	124.30	32.65	50.00	41.00	160.00	20.00	40.00	40.00	9.50	2.58	.812

*25 Series: Add 25mm when using a 25-5050 profile.

*40 Series: Add 40mm when using 40-8080 profiles or 120mm when using a 40-8016 profile.

** Brake Kit Ready Bearings are pre-drilled with brake holes, refer to page 1009 for additional information.

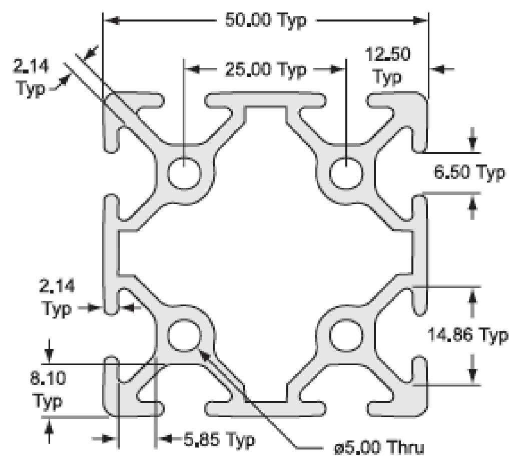
Metric

25-5050 T-Slotted Profile - 25 Series

- Compatible with all 25 Series fasteners
- Eight open T-slots for mounting accessories
- The 25-5050 profile is ideal for applications where strength and open T-slots are required
- The center cavity can be pressurized up to 1.034 N/mm² (150 psi); refer to pages 934-935
- Compatibility Code*: 6-25

VIBRATION** PROOF™

Part No.	25-5050
Material	6105-T5
Finish	Clear Anodized
Weight Per Meter	1.9748 kg/m
Stock Length (+/- 3mm)	4m - Part No. 25-5050-4M 6m - Part No. 25-5050-6M
Moment Of Inertia	IX=21.1231 cm^4 IY=21.1231 cm^4
Estimated Area	7.3397 cm^2



Quick Machining Reference

Machining Service	Service Number
Cut to Length	25-7012 (see page 1029)
5.1mm Access Hole	25-7051 (see page 1031)
Anchor Counterbore	25-7042 (see page 1033)
Tap Profile End	25-7067 (see page 1030)

* See Compatibility Code information on page 642.
** See 2° Drop-Lock information on page 640.

Appendix M: Load Cell Specificcations

STS S-Beam Stainless Steel Load Cell Features:

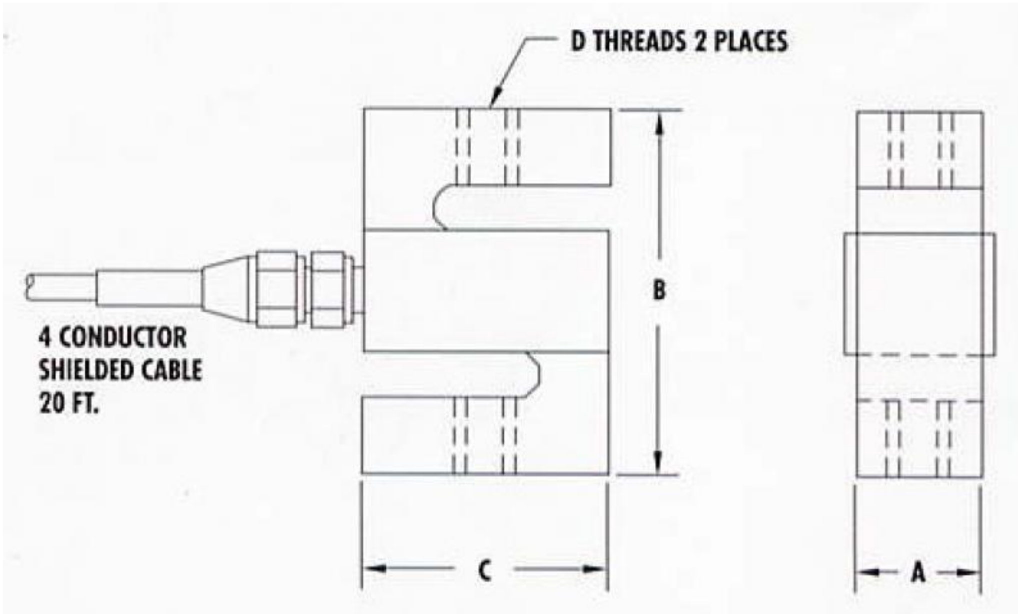
- Stainless Steel
- Meets OIML and HB44 III Standards
- Cable Length: 20 ft.

STS S-Beam Stainless Steel Load Cell Specifications:

Model	STS
Capacity	1.5klb
Serial No.	T90911
Acutal Output	3.0124 mV/V
Zero Balance	<± 2% of Full Scale
Creep (1 Hour)	<± 0.05% of Full Scale
Non-Linearity	<± 0.03% of Full Scale
Hysteresis	<±0.03% of Full Scale
Repeatability	<±0.02% of Full Scale
Temperature Effect on Output	<16 PPM/°C of Applied Load
Temperature Effect on Zero	<26PPM/°C of Applied Load
Operating Temperature Range	-40 to +80 °C
Compensated Temperature Range	-10 to +40 °C
Safe Overload	150% of Full Scale
Ultimate Overload	300% of Full Scale
Input Impedance	385 ± 30 Ohms
Output Impedance	350 ± 3 Ohms
Insulation	> 5,000M Ohm
Recommended Excitation	10V DC/AC
Maximum Excitation	20V DC/AC
Date of Factory Calibration	2013/04/20

Pinout :

Red + Excitation;
Green + Signal;
Black - Excitation;
White - Signal



CAPACITY (lb)	A	B	C	D
250 — 1.5K	0.75	3.00	2.00	1/2—20

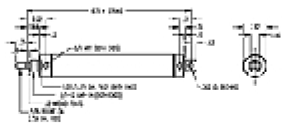
Appendix N: Piston Specifications

Air, Inc
8 Forge Park
Franklin, MA,02038-3135,US
Phone: 508-528-3020 • **Fax:** 508-528-7050
Email: sales@airinc.net • **Website:**www.airinc.net

Item # MRS-504-DXP, 2 1/2" Bore MRS Air Cylinder

List Price $118.05

Specifically designed to operate Bimba position sensing switches to actuate programmable controllers, relays, solenoids, timers, or any other electrically operated equipment. MRS cylinders have an additional groove in the piston to accommodate a magnet. They differ from the M option because they combine features of the "Z" line with Original Line construction; check dimensional drawings for each size for more specific information. Type 303 stainless steel rods are standard.



SPECIFICATIONS

Type	Double End or Rear Pivot Mounting
Bore Size	2 1/2 in.
Stroke Length	4 in.
Maximum Stroke	32 in.
Adder per Inch of Stroke	0.20
Bore Designator	50
Dim. A	2.98
Base Weight	2.90 lbs.
Piston Rod Material	303 Stainless Steel
Optional Accessory	D-8314-A Rod Clevis D-8320 Mounting Bracket D-8326-A Pivot Bracket
Options No Charge	Magnalube G (G) No Thread (NT)
Options With Charge	Bumper Adder (B) Extra Rod Extension (EE) High Temp Seals (V) Low Profile Switch Track (T) Moly Coat (F) Non Lube Seals (E)

Appendix O: Linear Actuator Specifications

Linear Potentiometer

Precision Potentiometric Output
Ranges: 0-3 to 0-30 inches [0-75 to 0-750 mm]
3K – 10K ohms • IP65

CE

CLWG

Specification Summary:

GENERAL
Full Stroke Ranges .... 0-3 to 0-30 in. (0-75 to 0-750 mm)
Output Signal .... voltage divider (potentiometer)
Linearity .... ± 0.04 to 0.1% full stroke, see ordercode
Repeatability .... < 0.01 mm
Resolution .... essentially infinite
Life Expectancy .... 50 million cycles
Enclosure Material .... aluminum
Sensor .... conductive plastic linear potentiometer
Operating Speed .... 200 inches (5 M) per second, max.

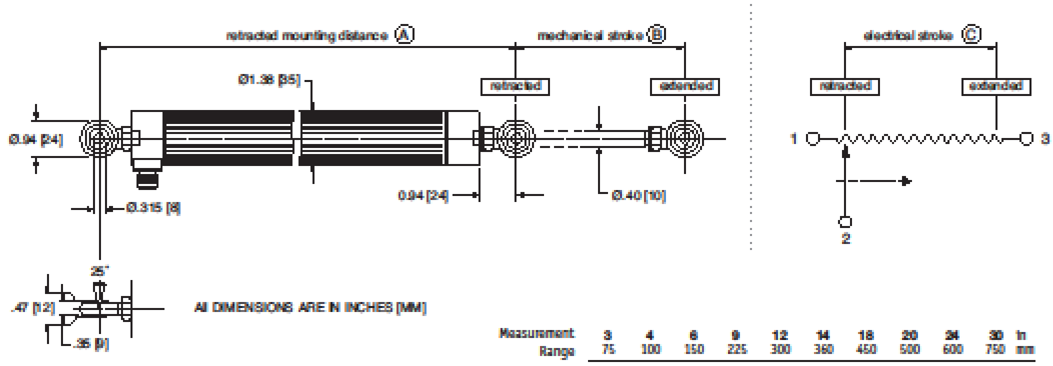
ELECTRICAL
Input Resistance .... 5K to 10K ohms (±20%), see ordercode
Recommended Maximum Input Voltage .... 25-30 V(AC or DC)
Recommended Operating Wiper Current .... ≤ 1 µA

ENVIRONMENTAL
Enclosure Design IP65
Operating Temperature .... -22º to 212ºF
Vibration .... up to 10 G's to 2000 Hz maximum

Developed specifically for a wide range of demanding applications, Celesco's CL series position transducers offer unrivalled performance in terms of accuracy, repeatability, life expectancy and ease of mounting. Such applications include industrial automation, automotive and robotics.

The CLWG uses a twin-bearing actuating rod, backlash-free pivot heads and a superior wiper system to provide outstanding linearity and performance.

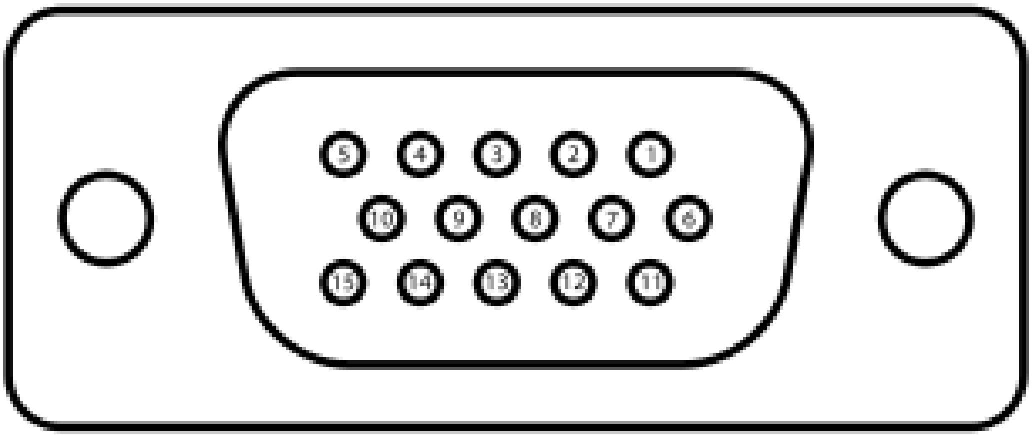
Outline Drawing



Measurement Range	3 / 75	4 / 100	6 / 150	9 / 225	12 / 300	14 / 360	18 / 450	20 / 500	24 / 600	30 / 750	in / mm
Ⓐ	9.72 / 247	10.75 / 273	12.72 / 323	15.75 / 400	18.74 / 476	21.69 / 551	26.18 / 665	28.74 / 730	33.70 / 856	40.94 / 1040	in / mm
Ⓑ	3.11 / 79	4.13 / 105	6.10 / 155	9.09 / 231	12.09 / 307	14.49 / 368	18.11 / 460	20.08 / 510	24.09 / 612	30.07 / 764	± 0.02 in / ± 2 mm
Ⓒ	2.99 / 76	4.01 / 102	5.98 / 152	8.98 / 228	11.97 / 304	14.41 / 366	17.99 / 457	20.00 / 508	24.02 / 610	30.00 / 762	in / mm

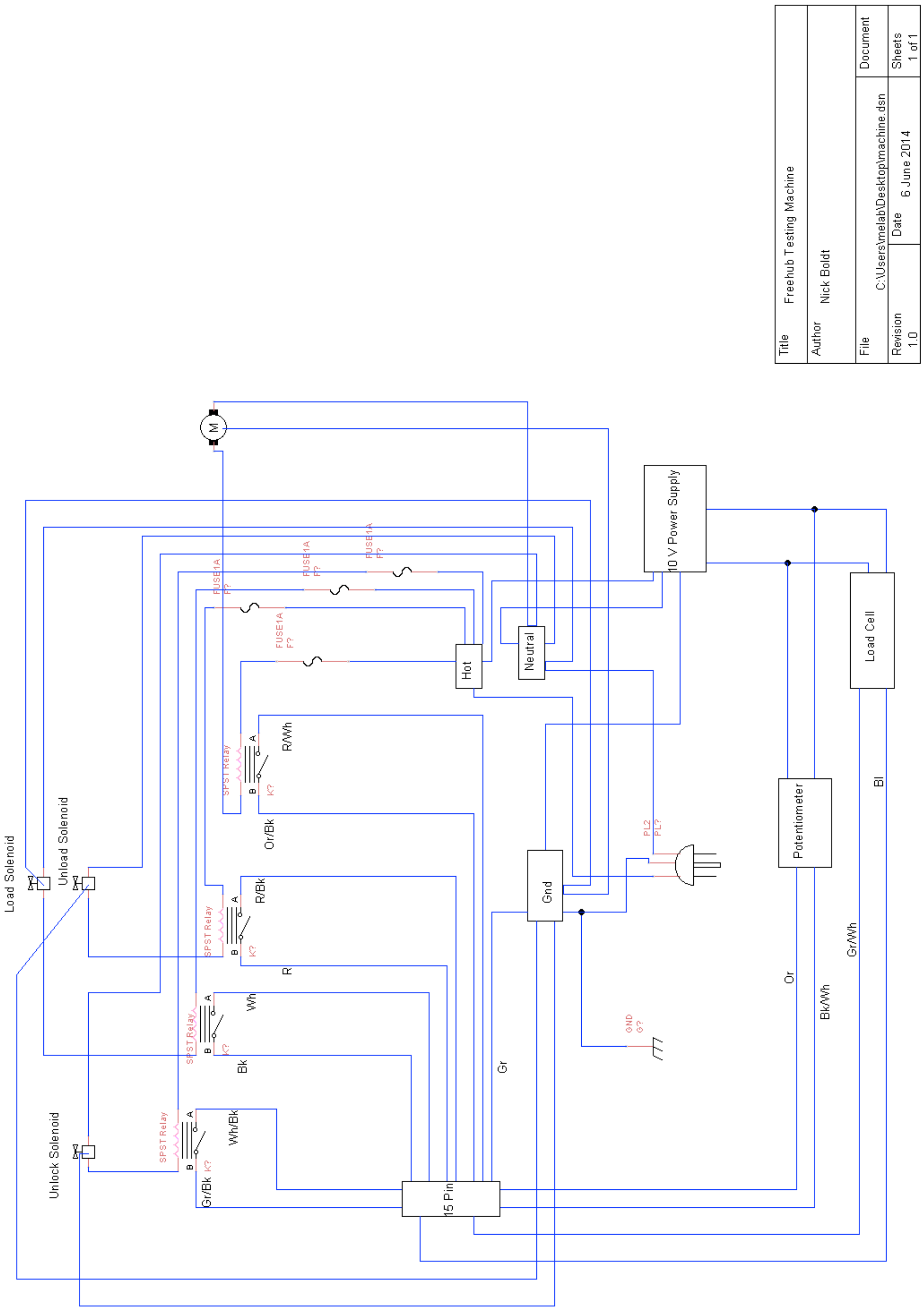
Appendix P: DAQ Pin System

Data Cable Pin out



VGA	Wire	DAQ Pin	DAQ	Machine Box
Pin 1	Green/Black	89	P2.4	Brake Relay +
Pin 2	White/Black	90	D GND	Brake Relay -
Pin 3	Black	91	P2.5	Load Relay +
Pin 4	White	92	D GND	Load Relay -
Pin 5	Red	93	P2.6	Unload Relay +
Pin 6	Red/Black	94	D GND	Unload Relay -
Pin 7	Orange/Black	95	P2.7	Motor Relay +
Pin 8	Red/White	88	D GND	Motor Relay -
Pin 9	Orange	20	AI 5	Potentiometer
Pin 10	Black/White	25	AI GND	Potentiometer
Pin 11	Green	30	Ground	Ground
Pin 12	Blue/Black	None	None	None
Pin 13	Green/White	23	AI 6	Load Cell (Green wire)
Pin 14	Blue	22	AI GND	Load Cell (White wire)
Pin 15	None	None	None	None

Appendix Q: Project Wiring Diagram



Appendix R: Design Verification Plan and Report

DESIGN VERIFICATION PLAN AND REPORT

System:	Freehub Testing Machine	**Supplier Name:**	Cal Poly Senior Project Team 53 x 11	**Core Team: (list names)**	Nick Boldt, Stephen Knaus, Brett Murphy, Mitch Ambrosini
Subsystem:		**Supplier Code:**	82200	**Affected Program(s):**	Cal Poly Senior Project
Assembly Name:	**Supplier Address:** 1 Grand Ave			**Cal Poly Design Engineer**	
Freehub Testing Machine	**City:** San Luis Obispo	**Zip / Postal Code:**	93407	**Name:**	Nick Boldt
Component (s):				**Title:**	Student
	State: California	**Country:**	USA	**Email:**	boldt.nick@gmail.com
				Phone:	(559) 240-7216
				Fax:	

Test Stage ED = Engineering Develt Test, DV = Design Verification, PV = Production Verification, CCT = Continued Compliance Testing **Target Requirements. State required** probability or reliability and confidence of meeting criteria, e.g. R90, C90 or all must pass. **Sample Type / Level** A = Prototype (Handmade), B = Prototype (Tooled), C = Production Tool (Not Process), D = Production Tool & Process

Testing details and Results

Test Number	Specification / Test Name	Test Method or Test Procedure	Date of Test	Acceptance Criteria	Test Results Status Accept / Reject	Tests Completed by	Test Stage	Notes / Remarks
1	Hub Failure Test	load test machine crank by standing on 5 ft cheater pipe	17-Nov-14	Freehub Failure	Fail	Stephen	ED	Test Machine crank failed before freehub did.
2	Clamp Verification	load wheel check for clamp slippage	2-Mar-14	No Slippage	Pass	Mitch	DV	
3	Rain Bike ride test	Ride mtn bike in rain	23-Mar-14	Record Video and analyze	Pass	Brett	ED	Not much water is sprayed on hub shell. Mostly on cassette and freehub
4	Data Cable Short test	None of Pins Shorted due to Soldering	21-May-14	No Shorts	Pass	Nick	PV	
5	Data cable connector continuity	Check resistance of wires	21-May-14	<5ohms	Pass	Nick	PV	
6	Load Relay and Solenoid	Apply 5VDC to relay	26-May-14	Audible click of solenoid	Pass	Nick	PV	
7	Unload Relay and Solenoid	Apply 5VDC to relay	26-May-14	Audible click of solenoid	Pass	Nick	PV	
8	Motor Relay	Apply 5VDC to Motor relay	26-May-14	Motor powers up	Pass	Nick	PV	Blew motor fuse. Was using 8A fuse. Motor rated for continuous current 8A. Need bigger fuse
9	Brake Relay and Solenoid	apply 5VDC to Brake relay	26-May-14	Audible click of solenoid	Pass	Nick	PV	
10	Test Piston Valve Solenoid	Energize Solenoid valve 120VAC with air line	27-May-14	Actuation of Valve	Fail	Nick	PV	Called Customer Service regarding bench test. They agree valve is defective. Valve outlets were not hooked up to pneumatic cylinder, but air input was hooked up to air source
11	Test Piston and Valve	Hook up air lines to piston and energize solenoids with 120 VAC	30-May-14	Actuation of Piston	Pass	Nick	PV	Consulted Product Manual and determined valve must be hooked to piston for bench testing Valve is not defective.
12	Linkage Test	Energize relay with air lines hooked up	2-Jun-14	Engagement of freehub	Pass	Nick	DV	

Verification Report Authorization

I affirm that the samples used for verification testing are representative of our parts, and I authorize the use of this data.

Supplier Authorized Signature ______________________ Date ______________

Appendix S: Works Cited

"Absolute Multiturn Rotary Encoder with Fieldbus Interface Max. 26 Bit | ATM60 Series SICK." *Absolute Multiturn Rotary Encoder with Fieldbus Interface*. N.p., n.d. Web. 05 Dec. 2013.

Benedict, Tayler. "Fox 32 Talas 120 CTD 29" Fork 24% OFF!" *Paul Components 10-Speed RHUB W/ Industry Nine Freehub Now Available*. Bike Rumor, 19 Dec. 2012. Web. 15 Oct. 2013.

Benedict, Tyler. "Fox 32 Talas 120 CTD 29" Fork 24% OFF!" *Paul Components 10-Speed RHUB W/ Industry Nine Freehub Now Available*. Bike Rumor, 19 Dec. 2012. Web. 05 Nov. 2013.

"Bicycle Testers - Chun Yen Testing Machines Co., Ltd." *Bicycle Testers - Chun Yen Testing Machines Co., Ltd.* Chun Yen Machines Co., n.d. Web. 04 Nov. 2013.

Brown, Sheldon "Kah Sept" "Freewheels." *Freewheel or Cassette?* Harris Cyclery, 2008. Web. 20 Nov. 2013.

HAYTHORNTHWAITE, Ed. "How Things Work: The Freehub Body." *Dirt How Things Work The Freehub Body Comments*. Dirt, 30 Apr. 2012. Web. 25 Oct. 2013.

"Hub Ratchet Life Testing Machine| HJMTEST | TOP QUALITY." *Hub Ratchet Life Testing Machine| HJMTEST | TOP QUALITY*. HJM Technology Co., n.d. Web. 08 Nov. 2013.