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Fall 2015

### Golden Bite Mouth Guard

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Dr. Kirk Quigless has designed the Golden Bite™ athletic mouth guard to properly align the jaw. Literature suggests that the proper alignment of the jaw will provide users with increased performance gains. Accurately determining these gains without bias is a difficult task. Dr. Kirk Quigless needs to quantify the performance gains from his mouth guard. The portable device designed in the Golden Bite™ Mouth Guard Project will record the force exerted by an individual over a period of time. From this data, Dr. Kirk Quigless can determine the change in force output from individuals with and without the mouth guard, proving the validity of the performance gains associated with the Golden Bite™ athletic mouth guard.

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# MEMS 411

## Design

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### Golden Bite™ Mouth Guard Project

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Caitlin Braun, Austin Fiegel,  
Alexandra Michaels, Eric Tyra

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Department of Mechanical Engineering and Materials Science  
School of Engineering and Applied Science  
Washington University in Saint Louis

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## 1 Introduction

### 1.1 Project problem statement

The customer, St. Louis dentist Dr. Kirk Quigless, DDS, has patented the Golden Bite™ athletic mouth guard. The mouth guard is intended to supply an adequate partition of occlusal forces, exerted on opposing teeth when the jaw is clenched, to relieve muscle structure, improve posture, and alleviate pain. In order to achieve this, the mouth guard uses transverse pins embedded within the base walls of the left and right posterior portions. This results in better alignment of the spine, thereby mitigating pain. Proper spine alignment is thought to improve athletic performance, and Dr. Quigless has estimated that performance can be improved by an additional 30% using the Golden Bite™ Mouth Guard. Dr. Quigless seeks a means of quantifying this claim using a portable and digital device that can be used for testing and demonstrating the product to clients and at conferences. The device is intended to measure the strength of an individual with and without the mouth guard in use. The device will need to be successfully operable by people of varying size and strength. It will also need to remove user bias such that the results from the testing performed by Dr. Quigless is valid. The budget for the project is \$400, requiring that the group find creative solutions to design the device.

### 1.2 List of team members

Caitlin Braun, Austin Fiegel, Alexandra Michaels, Eric Tyra

## 2 Background Information Study

### 2.1 Design Brief

The Golden Bite™ athletic mouth guard project will provide a means to study the effect of Golden Bite™ mouth guard on performance of an athlete. It is given that adequate partition of occlusal forces relieves muscle structures and alleviates pain through the use of embedded transverse pins within the base wall of the mouth guard. The external customer, Dr. Quigless needs a device that can be used to quantify and prove the validity of the performance gains he has seen from Golden Bite™ athletic mouth guard users. Ideally the device could be used during a study on the effectiveness of the mouth guard. Users of varying strength and size should be able to use the device to determine strength with and without the use of the mouth guard. The device needs to provide results without bias, and must be accurate and account for human bias. The device will provide results from strength performance testing with and without Golden Bite™ mouth guard, giving Dr. Quigless the ability to present his users with concrete data, and valid measurements of the performance gains associated with his product.



## 2.2 Summary of Relevant Background Information

Table 1 – Summary of Relevant Background Information

Patent No.	Publication Date	Inventors	Title	Keywords
DE10017119A1	9/30/1993	Jeffrey W Osborn Jian Mao	Dental Force Transducer	Dental Force Transducer Human Jaw
WO1993018709A1	10/31/2001	Helge Fischer-Brandies, Wolfgang Orthuber, Klaus Ludwig	Device for measuring forces acting on teeth, teeth models and/or implants has sensors for detecting spatial force and/or torque components on teeth, model tooth crowns, dentures, implants	Dental Device Teeth Forces
US4805455	2/21/1989	Daniel DelGiorno, Henry Medina, William R. Accolla	Muscle testing apparatus and method	Muscle Testing Strength Methods
US6231481	5/15/2001	Kurtis Barkley Brock	Physical activity measuring method and apparatus	Measurement Physical Activity Apparatus Power Strength
US20020086774	12/30/2003	Richard D. Warner	Computerized repetitive-motion exercise logger and guide system	Exercise Logger Repetitive Motion
US4742832	5/10/1988	Richard Kauffmann, Lutz Kauffmann	Muscle measuring apparatus	Measurement Muscle force
US6228000	5/8/2001	Arthur A. Jones	Machine and method for measuring strength of muscles with aid of a computer	Dynamic strength test Forces Computer output

Other relevant Sources (list below)

1. Methods of measurement for muscular strength  
<http://www.humankinetics.com/excerpts/excerpts/methods-of-measurement-for-muscular-strength>
2. Instruments to measure strength  
<http://www.tandfonline.com/doi/abs/10.1080/10671188.1955.10612833?journalCode=urqe17>
3. A comparison of 4 methods measuring forearm flexion strength  
<https://repositories.tdl.org/ttu-ir/bitstream/handle/2346/11280/31295015502361.pdf?sequence=1>
4. Interface Advance Force Measurement Load Cell 100 lb.
5. Golden Bite Mouth guard  
<http://sylwilsonmarketing.com/goldenbite/>
6. Bitech Mouthguard Pins  
<http://www.bitechnologies.com/products/>
7. Interface SM-S Type Load Cell  
<http://www.interfaceforce.com/index.php?SM-S-Type-Load-Cell-&mod=product&show=28>
8. Shocks and Dampers  
[http://www.integy.com/st\\_main.html?p\\_catid=312#.VITpl\\_mrTWI](http://www.integy.com/st_main.html?p_catid=312#.VITpl_mrTWI)
9. Load cell technology  
<http://www.vishaypg.com/docs/11866/vpg-01.pdf>
10. Physical Strength Assessment in Ergonomics  
<http://www.cdc.gov/niosh/mining/userfiles/works/pdfs/psaie.pdf>
11. Hand-held dynamometry for muscle strength measurement in children with cerebral palsy  
<http://onlinelibrary.wiley.com/doi/10.1111/j.1469-8749.2007.00106.x/pdf>

## Concept Design and Specification

### 2.3 User needs, metrics, and quantified needs equations. This will include three main parts:

#### 2.3.1 Record of the user needs interview

Table 2 – User Needs Interview

Customer Data: GoldenBite Mouth Guard Project 2			
Customer: Dr. Quigless			
Address: 8083 Manchester Rd, St. Louis, MO 63144			
Date: 9/11/15			
Question	Customer Statement	Interpreted Need	Importance
What should this device measure?	"Strength would be good, and flexibility and balance would be good as well"	Device measures strength	5
		Device measures flexibility	2
			2

		Device measures balance Device can transform for different tests	1
Are there any safety considerations?	"I will ask someone beforehand if there are any health considerations"	Device has no sharp edges	5
How large would you like the device to be?	"Compact as possible, something you could fit into a brief case would be great. No bigger than trunk of car"	Device is no bigger than 1m <sup>3</sup>	4
Should it be portable?	"A lot of testing will be out in a field"	Device can be maneuvered easily	5
Analog or digital data collection?	"Digital would take away skepticism"	Device uses automatic data collection	3
What kind of environment would you like the device to be used in?	"I hope many people will be able to use it"	Device can be reused multiple times Device can be used by different sizes of people	5 4

### 2.3.2 List of identified metrics

Table 3 – List of Identified Metrics

Need Number	Need	Importance
1	Device measures strength	5
2	Device measures flexibility	2
3	Device measures balance	2
4	Device can transform for different tests	1
5	Device has no sharp edges	5
6	Device is no bigger than 1m <sup>3</sup>	4

7	Device can be maneuvered easily	5
8	Device uses automatic data collection	3
9	Device can be reused multiple times	5
10	Device can be used by different sizes of people	4

### 2.3.3 Table/List of Quantified Needs Equations

Table 4 – List of Quantified Needs Equations

Design Metrics					
Metric Number	Associated Needs	Metric	Units	Min Value	Max Value
1	1	Measures Strength	Binary	0	1
2	2	Measures Flexibility	Binary	0	1
3	3	Measures Balance	Binary	0	1
4	4	Number of tests	Integer	1	3
5	5	Number of sharp edges	Integer	0	10
6	6,7	Volume	m <sup>3</sup>	.0034	1
7	7	Mass	kg	1	50
8	4,7,9,10	Time to set up	Seconds	0	600
9	8	Digital	Binary	0	1

## 2.4 Four Concept Drawings

### THE FLAG SLIDER

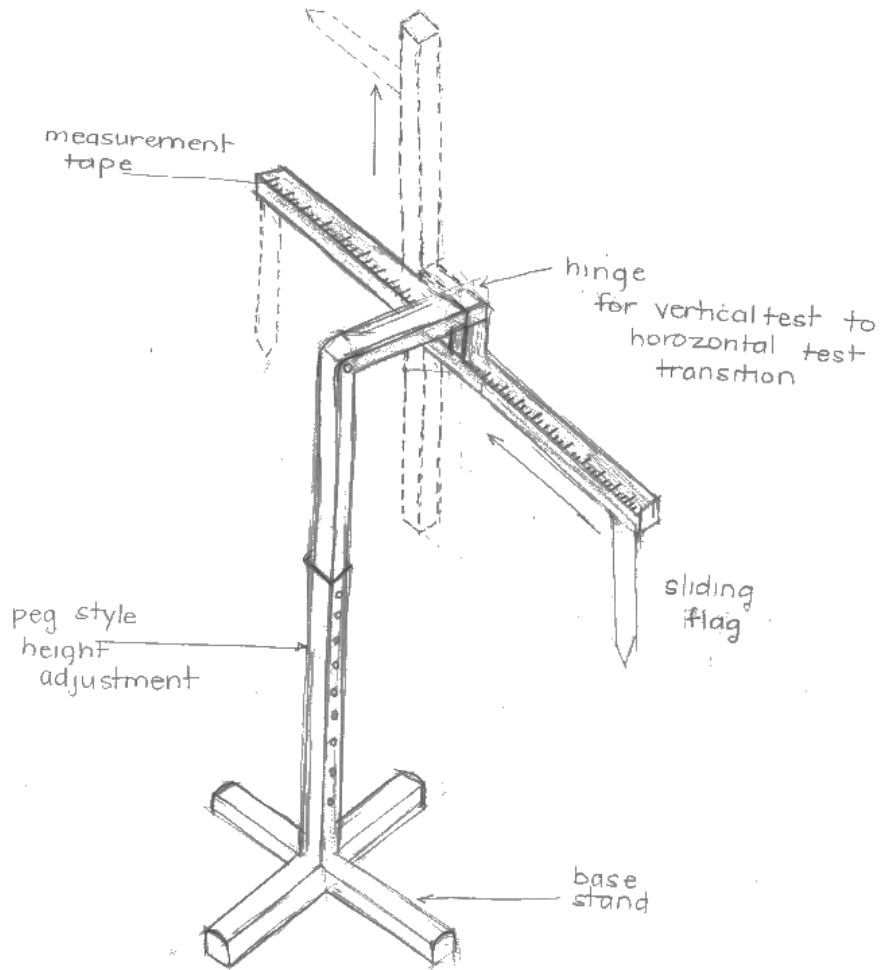


Figure 1 Concept Sketch Flag Slider

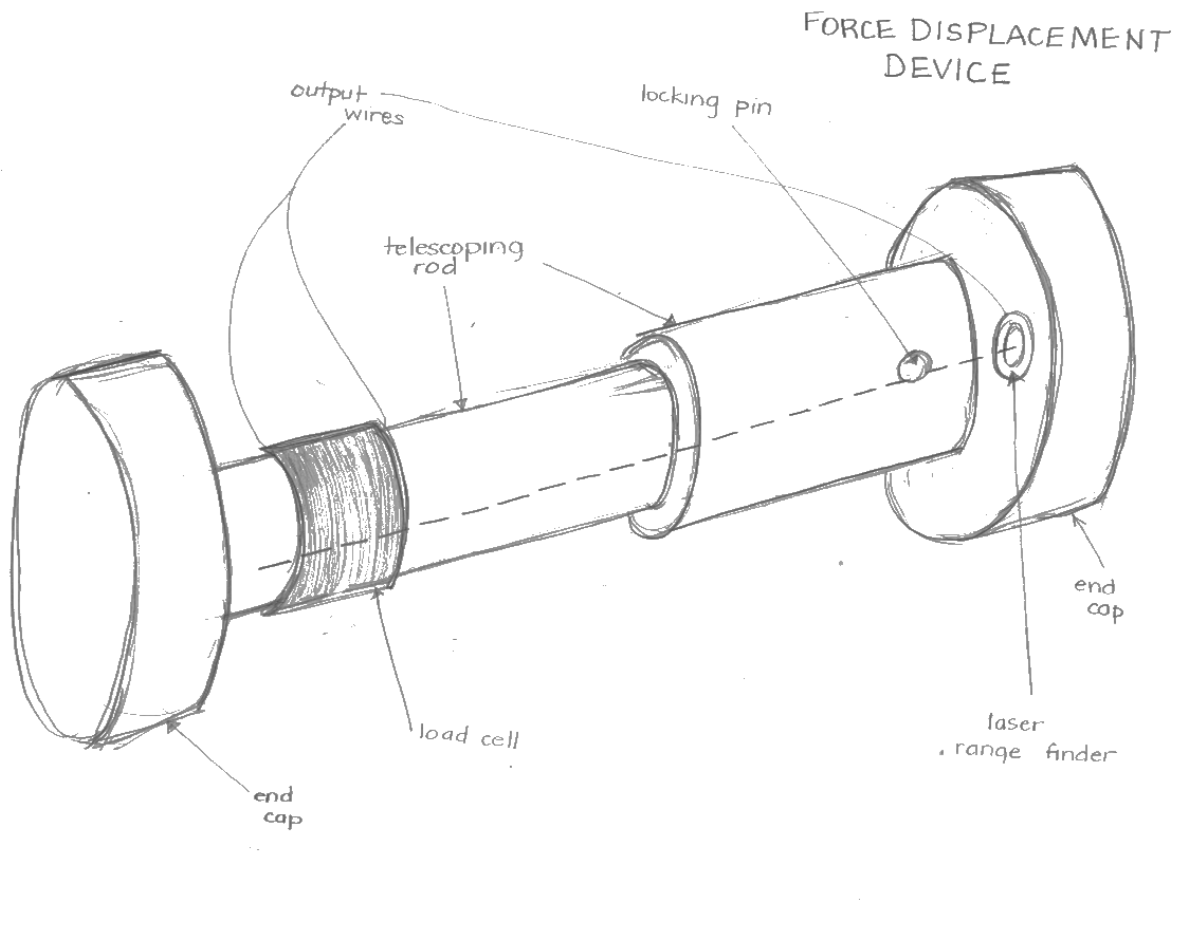


Figure 2 Concept Sketch Force Displacement Device

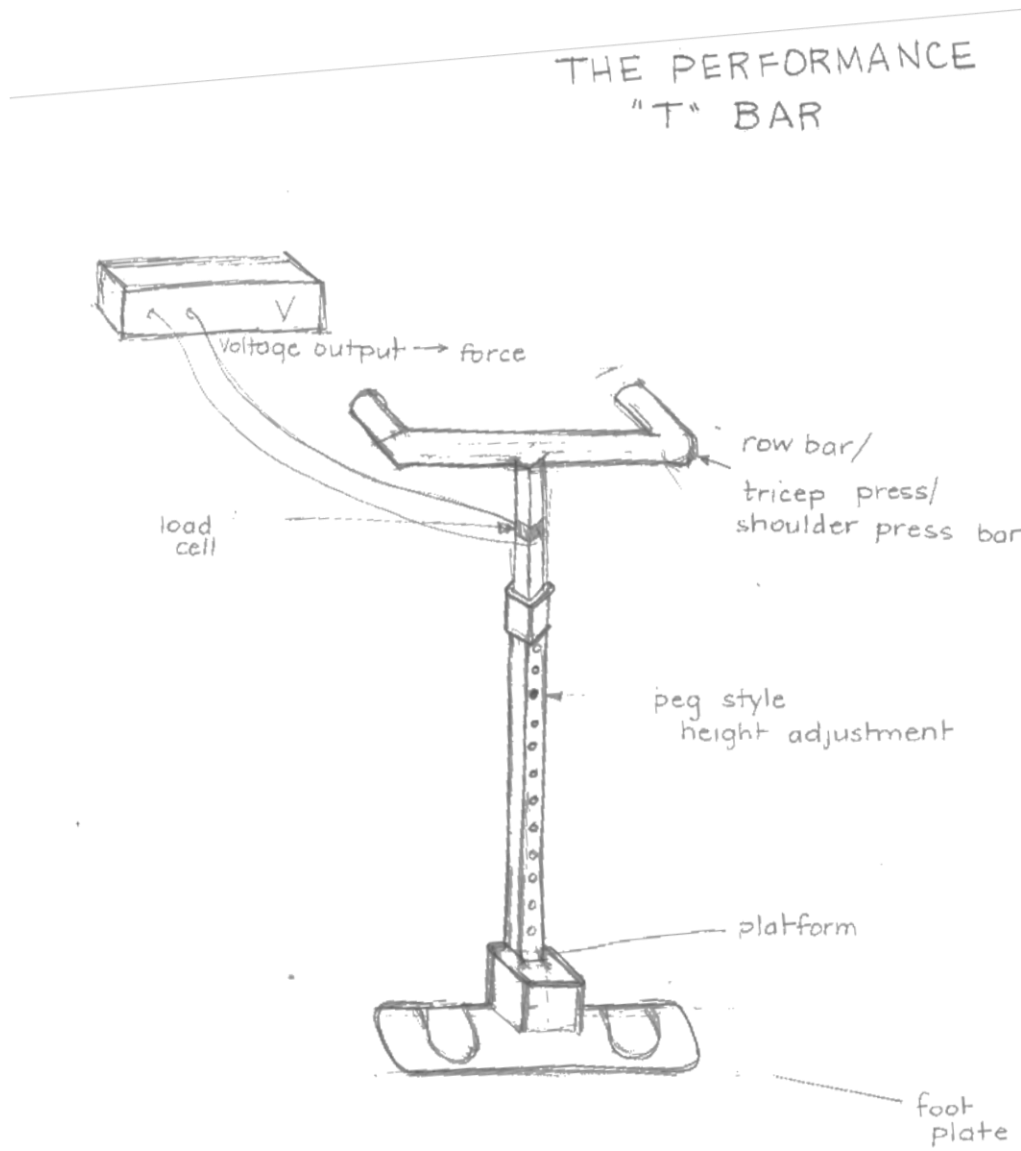


Figure 3 – Concept Sketch Performance T-Bar

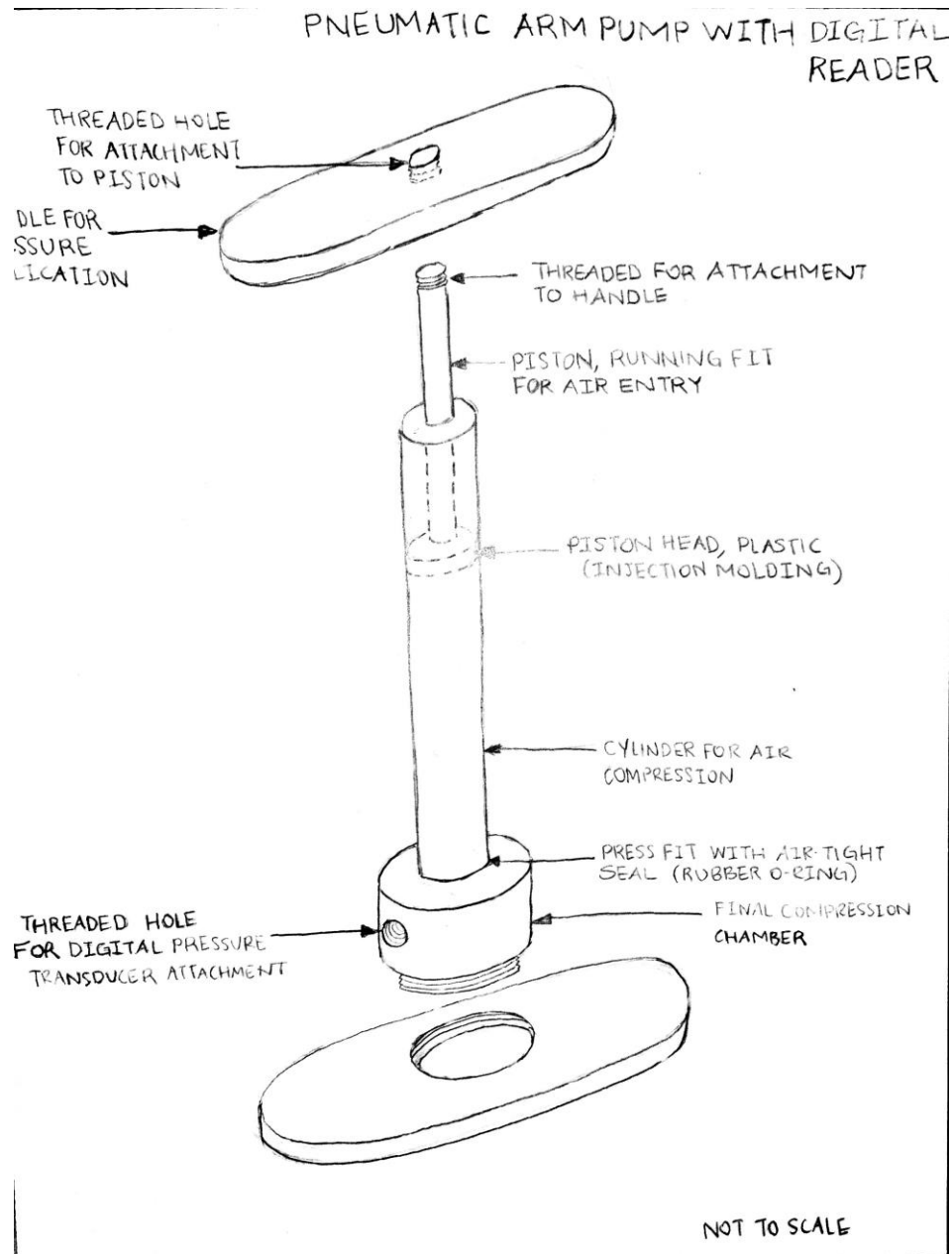


Figure 4 – Concept Sketch Pneumatic Arm Pump

## 2.5 A concept selection process. This will have three parts:

### 2.5.1 Concept scoring (not screening)



		Metric											
		Measures Strength	Measures Flexibility	Measures Balance	Number of Tests	Number of Sharp Edges	Volume	Mass	Time to Set Up	Digital	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
Need#	Need	1	2	3	4	5	6	7	8	9			
1	Device Measures Strength										0	0.14	0
2	Device Measures Flexibility										0	0.06	0
3	Device Measures Balance										0	0.06	0
4	Device can Transform for Different Tests										0	0.03	0
5	Device has No Sharp Edges										0	0.14	0
6	Device is no bigger than 1m^3										0	0.11	0
7	Device can be Maneuvered Easily										0	0.14	0
8	Device uses Automatic Data Collection										0	0.08	0
9	Device can be Reused Multiple Times										0	0.14	0
10	Device can be Used by Different People										0	0.1	0
<b>Units</b>		Binary	Binary	Binary	Integer	Integer	m^3	kg	Seconds	Binary	<b>Total Happiness</b>	<b>0</b>	
<b>Best Value</b>		1	1	1	3	0	0.003	1	0	1			
<b>Worst Value</b>		0	0	0	1	10	1	50	600	0			
<b>Actual Value</b>													
<b>Normalized Metric Happiness</b>													

Figure 5 – Concept Screening Blank

Force Displacement Device		Metric									Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness/Value
		Measures Strength	Measures Flexibility	Measures Balance	Number of Tests	Number of Sharp Edges	Volume	Mass	Time to Set Up	Digital			
Need#	Need	1	2	3	4	5	6	7	8	9			
1	Device Measures Strength	1									1	0.14	0.14
2	Device Measures Flexibility		1								1	0.06	0.06
3	Device Measures Balance			1							0	0.06	0
4	Device can Transform for Different Tests				1						0.67	0.03	0.0201
5	Device has No Sharp Edges					0.9			0.1		1	0.14	0.14
6	Device is no bigger than 1m <sup>3</sup>						1				0.99	0.11	0.1089
7	Device can be Maneuvered Easily						0.5	0.4	0.1		0.975	0.14	0.1365
8	Device Uses Automatic Data Collection									1	1	0.08	0.08
9	Device can be Reused Multiple Times								1		1	0.14	0.14
10	Device can be Used by Different People								1		1	0.1	0.1
<b>Units</b>		Binary	Binary	Binary	Integer	Integer	m <sup>3</sup>	kg	Seconds	Binary	<b>Total Happiness</b>	<b>0.9255</b>	
<b>Best Value</b>		1	1	1	3	0	0.003	1	0	1			
<b>Worst Value</b>		0	0	0	1	10	1	50	600	0			
<b>Actual Value</b>		1	1	0	2	0	0.005	2.3	0	1			
<b>Normalized Metric Happiness</b>		1	1	0	0.67	1	0.99	0.95	1	1			

Figure 6 – Concept Scoring Force Displacement Device

Performance T-Bar		Metric									Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
		Measures Strength	Measures Flexibility	Measures Balance	Number of Tests	Number of Sharp Edges	Volume	Mass	Time to Set Up	Digital			
Need#	Need	1	2	3	4	5	6	7	8	9			
1	Device Measures Strength	1									1	0.14	0.14
2	Device Measures Flexibility		1								0	0.06	0
3	Device Measures Balance			1							0	0.06	0
4	Device can Transform for Different Tests				1						0.33	0.03	0.0099
5	Device has No Sharp Edges					0.9			0.1		0.81	0.14	0.1134
6	Device is no bigger than 1 m <sup>3</sup>						1				0.75	0.11	0.0825
7	Device can be Maneuvered Easily						0.5	0.4	0.1		0.813	0.14	0.11382
8	Device Uses Automatic Data Collection									1	1	0.08	0.08
9	Device can be Reused Multiple Times								1		0.9	0.14	0.126
10	Device can be Used by Different People								1		0.9	0.1	0.09
<b>Units</b>		Binary	Binary	Binary	Integer	Integer	m <sup>3</sup>	kg	Seconds	Binary	<b>Total Happiness</b>		<b>0.75562</b>
<b>Best Value</b>		1	1	1	3	0	0.003	1	0	1			
<b>Worst Value</b>		0	0	0	1	10	1	50	600	0			
<b>Actual Value</b>		1	0	0	1	2	0.25	6.5	60	1			
<b>Normalized Metric Happiness</b>		1	0	0	0.33	0.8	0.75	0.87	0.9	1			

Figure 7 – Concept Scoring Performance T-Bar

Flag Slider		Metric									Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
		Measures Strength	Measures Flexibility	Measures Balance	Number of Tests	Number of Sharp Edges	Volume	Mass	Time to Set Up	Digital			
Need#	Need	1	2	3	4	5	6	7	8	9			
1	Device Measures Strength	1									0	0.14	0
2	Device Measures Flexibility		1								1	0.06	0.06
3	Device Measures Balance			1							0	0.06	0
4	Device can transform for Different Tests				1						0.33	0.03	0.0099
5	Device has No Sharp Edges					0.9			0.1		0.728	0.14	0.10192
6	Device is no bigger than 1m^3						1				0.75	0.11	0.0825
7	Device can be Maneuvered Easily						0.5	0.4	0.1		0.821	0.14	0.11494
8	Device uses Automatic Data Collection									1	0	0.08	0
9	Device can be Reused Multiple Times								1		0.98	0.14	0.1372
10	Device can be Used by Different People								1		0.98	0.1	0.098
<b>Units</b>		Binary	Binary	Binary	Integer	Integer	m^3	kg	Seconds	Binary	<b>Total Happiness</b>		<b>0.60446</b>
<b>Best Value</b>		1	1	1	3	0	0.003	1	0	1			
<b>Worst Value</b>		0	0	0	1	10	1	50	600	0			
<b>Actual Value</b>		0	1	0	1	3	0.25	6.5	10	0			
<b>Normalized Metric Happiness</b>		0	1	0	0.33	0.7	0.75	0.87	0.98	0			

Figure 8 – Concept Scoring Flag Slider

Pneumatic Arm Pump		Metric									Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
		Measures Strength	Measures Flexibility	Measures Balance	Number of Tests	Number of Sharp Edges	Volume	Mass	Time to Set Up	Digital			
Need#	Need	1	2	3	4	5	6	7	8	9			
1	Device Measures Strength	1									1	0.14	0.14
2	Device Measures Flexibility		1								0	0.06	0
3	Device Measures Balance			1							0	0.06	0
4	Device can transform for Different Tests				1						0.33	0.03	0.0099
5	Device has No Sharp Edges					0.9			0.1		1	0.14	0.14
6	Device is no bigger than 1m <sup>3</sup>						1				0.991	0.11	0.10901
7	Device can be Maneuvered Easily						0.5	0.4	0.1		0.9675	0.14	0.13545
8	Device Uses Automatic Data Collection									1	1	0.08	0.08
9	Device can be Reused Multiple Times								1		1	0.14	0.14
10	Device can be Used by Different People								1		1	0.1	0.1
<b>Units</b>		Binary	Binary	Binary	Integer	Integer	m <sup>3</sup>	kg	Seconds	Binary	<b>Total Happiness</b>		<b>0.85436</b>
<b>Best Value</b>		1	1	1	3	0	0.003	1	0	1			
<b>Worst Value</b>		0	0	0	1	10	1	50	600	0			
<b>Actual Value</b>		1	0	0	1	0	0.009	3.5	0	1			
<b>Normalized Metric Happiness</b>		1	0	0	0.33	1	0.991	0.93	1	1			

Figure 9 – Pneumatic Arm Pump

### 2.5.2 Preliminary analysis of each concept's physical feasibility

#### **Concept 1: Force Displacement Device**

The biggest challenges we face when designing this device are the laser mounting position and the strain gauge and laser data output. The laser will need to be able to function under a variety of different physical tests. Each person is different and can input different amounts of force data to the device so it will need to be able to withstand a high strength input as well as be light enough to maintain portability. This design can incorporate more tests in a single device than our other designs and is also the smallest. The Force Displacement Device will be primarily made out of aluminum and have a running fit between the two cylindrical pieces of metal to allow the compression to occur and be measured by the laser. This is a mechanically simple device that has many different applications. It meets many of our derived user needs including measuring strength, flexibility, and being very portable. The data output of the laser and strain gauge will present a unique challenge to our group of finding or designing a program that can measure the output from the device and transmit it to a computer.

#### **Concept 2: The T-Bar**

This device is the simplest mechanical device on the table that can still perform a number of different physical tests. The design allows for low cost and fewest materials required for assembly. It is adjustable by design to facilitate a wide range of individual's use of the device. The challenges that the T-Bar faces are its limited collapsibility and small number of tests that can be performed in one set up. The material chosen would be aluminum to maintain its portability and lightweight but strong frame. There may be some sharp edges in the final product that could be a safety concern as well. This design is the easiest to manufacture out of all of them.

#### **Concept 3: The Flag Slider**

This design allows for the user to push a flag across a circular slide bar and will allow for the displacement to be measured. This design is simple and easy to manufacture. There are only a few possible sharp edges in this layout as well. The flag material would be a heavy duty plastic and the frame would be aluminum. The machine will be able to be adjusted for a variety of users. It will also feature a hinge that will facilitate the rotation of the slide to change testing procedures from horizontal to vertical. This will allow the user to perform different tests on the same test stand. This design does not require electrical input and can be measured directly from the displacement of the flag, thus increasing the portability of the device. It is collapsible however, it will not become as small the other designs. This design will integrate very well into existing

performance measurement protocols because of its similarity to some existing vertical jump testing equipment.

#### **Concept 4: The Pneumatic Arm Pump**

This device is designed to demonstrate an individual's arm strength. The design is relatively simple and its constituent parts are not difficult to manufacture – most parts are cylindrical in shape and edges can be filed to reduce risk of injury. The threading of different parts would pose the greatest challenge in the manufacturing process. With the exception of the piston head made from plastic and airtight seals made of rubber, the entire arm pump frame is lightweight aluminum, which allows for portability. Because a digital reading of the compressed air pressure provides for greater accuracy than an analog reading, this device requires a digital pressure gauge, which can be purchased relatively inexpensively. The pressure transducer screws into a small hole in the arm pump's final compression chamber, as shown in the design sketch. This device requires no electric output for data collection, as the user's applied pressure can be immediately read from the digital gauge.

##### **2.5.3 Final summary**

Concept 1 was chosen as the winning device because of the advantages it has over the other three devices. More specifically, it can accurately measure two tests (strength and flexibility) while the other three devices can only measure one. Furthermore, it measures strength, which was the more important test requested by Dr. Quigless, unlike the Flag Slider, that would only measure flexibility. Another advantage of the device is its size. It has a relatively small volume when compared to the other concepts and should be easily maneuvered by one person. Because the device is small, and would be made from aluminum, it would be easy for the customer to transport. This concept takes minimal to set up for use, unlike the Performance T- Bar. The use of a load cell in the device will provide a digital readout for the strength of an individual. The load cell can withstand a large force, while maintaining accuracy in force readings, making the device appropriate for use by nearly any individual. The telescoping rod that locks into place would also allow the device to be used to measure strength at a number of different lengths settings, making it more applicable to a wider demographic of individuals. When unlocked, the telescoping rod can be used to measure flexibility. By using a laser to measure the initial and final distance between the two ends of the device, the flexibility of the individual can be tested. The device would use batteries to supply power to the load cell and the laser. The laser and load cell would then be hooked up to the customer's computer. The difference in force and displacement when an individual is or is not wearing the mouth guard can be recorded automatically to the customer's computer using a digital data collection system. This is the only device that is capable of providing a data for both strength and flexibility of an individual, and could be stored easily for future analysis by the customer. This device was chosen because it best satisfies the needs of the customer.

## 2.6 Force Displacement Device Performance Goals

1. FDD has a volume less than or equal to .005 m<sup>3</sup>.
2. FDD acquires strength data for 2 people in 5 minutes or less.
3. FDD is requires no time for set up.
4. All sharp edges are eliminated or covered.
5. FDD has a mass of 2.5 kg or less.
6. FDD does not break or damage when dropped from 7 foot height.
7. FDD can measure up to 200 pounds of force.
8. FDD can compress 12 inches.
9. FDD allows for different threaded attachments.
10. FDD can be used to press against a wall.
11. FDD can measure displacement changes to the nearest 1/12 inch.

## 2.7 Design constraints

### 2.7.1 Functional

Dr. Quigless specified the need of a portable device to take around for conference and patient demonstrations, thus we deemed the maximum size 1 m<sup>3</sup>. After selecting our final design concept, we knew the design would be much smaller and on the order of a hand-held sized device. A linear load path would be the simplest way to measure force, so the device is designed to compress and expand linearly, and a resistive component will oppose the user's compressive force applied.

A lightweight material is needed to contribute to the portability of the device. Using aluminum for the machined components will allow for a lightweight device and strength and durability.

For force measurement, a mechanical input is translated to an electrical signal by the load cell, which determines the force applied by the user. The load cell transmits the data to a data acquisition system, which outputs this information to the software called DAQami. The software will provide a visual representation of the electronic signal output by the load cell.

### 2.7.2 Safety

The device should be user friendly, simple to use and have no potential to harm the user. Specifically, the device will have no sharp corners or edges. Any preexisting health conditions will be assessed by Dr. Quigless before using with a patient.

### 2.7.3 Quality

The force displacement device needs to be durable and able to withstand repeated forceful tests over the course of thousands of trials. Trials will take place in Dr. Quigless's office, conference demonstrations, and potentially in clinical studies.

### 2.7.4 Manufacturing

All structural materials used for the device are cylindrical in shape, which can be easily machined using standard machine shop methods. Using aluminum rods as the stock material would eliminate the waste



inevitable to using stock with a rectangular cross section. The equipment used to provide a resistive force to the device's user will come from an external supplier. The force displacement device is designed for individual production as necessary, rather than mass production. Therefore, consistent supplier reliability over a sustained period of manufacturing time is not a factor to consider for this product. However, it is expected that the limited number of parts provided from an outside supplier are dependable in their functions.

The assembling of the device is designed to be simple should it need to be taken apart and rebuilt for any reason, such as part replacement. Fasteners including bolts, screws, and nuts, are used to secure part elements in place.

### **2.7.5 Timing**

Dr. Quigless, as well as the MEMS department, required that the product be finished by the end of the semester (roughly 3 months). With the design drawings, the product can be completed within two weeks.

### **2.7.6 Economic**

The current market for the force displacement device is solely Dr. Quigless' use. He seeks to use the device to demonstrate athletic performance improvement among individuals wearing the Golden Bite™ mouth guard. The market has the potential to be expanded, for example, should other professionals seek to use the device as a strength measuring technique in areas other than the application of the mouth guard.

### **2.7.7 Ergonomic**

The user needs are as follows: simple operation, minimal instruction; no complicated functions for person being tested. Test/demonstration administrator interacts simply with the system. Once it is set up (involves connecting equipment together, opening software); the only thing the administrator needs to do is collect the data by clicking start and stop in the software interface.

In addition to this, the handles provide comfort, so that the user won't drop the device. The width of the device is such that the user will not strain his or her joints when trying to compress or pull on the device.

### **2.7.8 Ecological**

There were no ecological constraints on the device. It is important to note that the materials used to construct the device are almost entirely aluminum and can all be recycled if desired.

### **2.7.9 Aesthetic**

Visible inner workings of the equipment, which aid in the user understanding what is happening. There should be no sharp corners on the device to limit potential injuries. Milled metal parts allow for cool outer appearance of the device.

### **2.7.10 Life cycle**

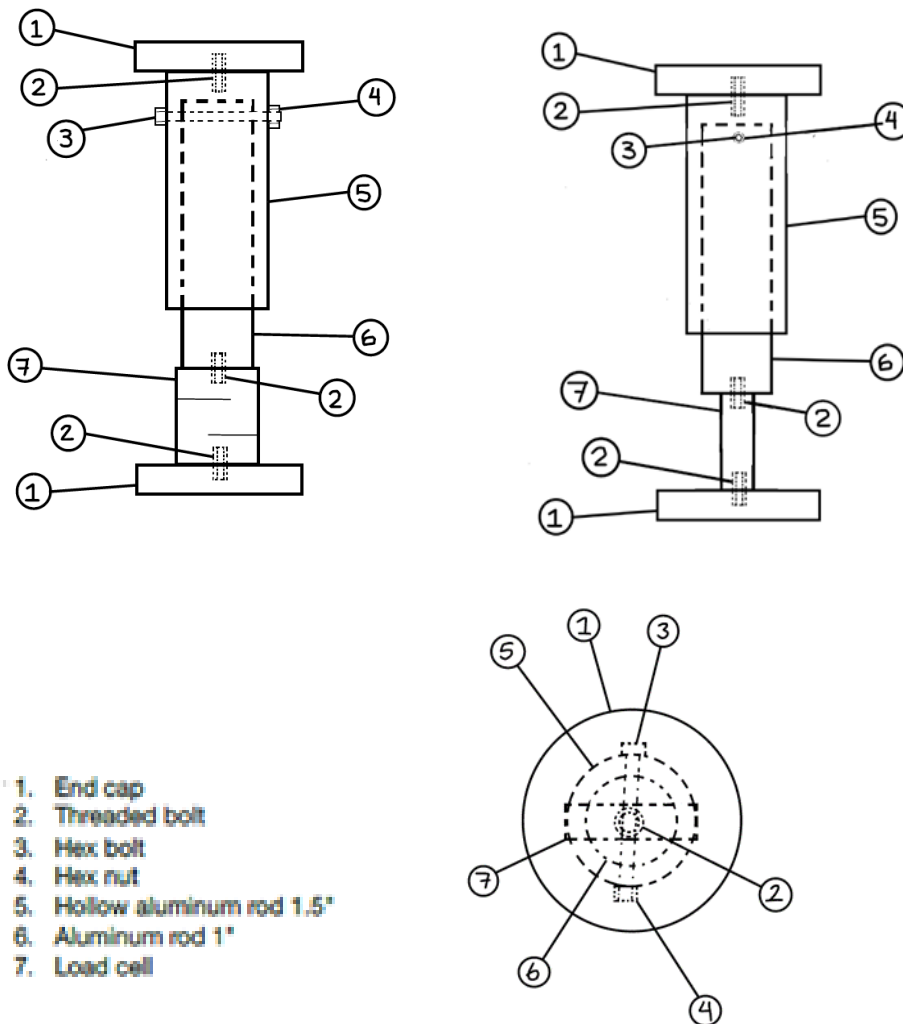
The device needs to withstand thousands of trials. The load cell is durable and since the springs are in parallel, they will not wear as quickly. The device requirement was that it needed to withstand testing in fields with athletes. If maintenance is required, the device is easily disassembled, so that replacing parts is not cumbersome.

### 2.7.11 Legal

It was made clear by Washington University in St. Louis that clinical trials could not legally be held when testing with this device over the semester. Other than this, there were no legal constraints put on the project.

## 3 Embodiment and fabrication plan

### 3.1 Embodiment drawing



### 3.2 Initial Parts List

Table 5 – Initial Parts List

Number	Part	Use	Part No	Quantity	Cost
1	Multipurpose 6061 Aluminum Rod, 5" Diameter, 1" Long	End caps (no handle)	McMaster 1610T48	2	\$36.18 (for two)
2	ASTM A193 Grade B7 Steel Threaded Stud, ¼"-28 Thread, 1-1/2" Long, Fully Threaded	Securing load cell and handles	McMaster 98750A439	3	\$2.85 (for three)
3	Grade 8 Steel Fully Threaded Rod, 10-24 Thread, 2" Long	For locking pin	McMaster 90322A633	1	\$1.06
4	Type 18-8 Stainless Steel Hex Nut, 10-24 Thread Size, 3/8" Wide, 1/8" High	For locking pin	McMaster 91841A011	Pack of 100	\$3.98
5	Multipurpose 6061 Aluminum Rod, 1-1/2" Diameter, 1' Long	Hollow outer shaft of device	McMaster 8974K18	1	\$16.54
6	Multipurpose 6061 Aluminum Rod, 1" Diameter, 1' Long	Solid inner shaft of device	8974K13	1	\$9.10
7	AmCells STL-200 S-Type/S-Beam Alloy Steel Load Cell 200lb	Measuring load	Tacuna Systems STL-200	1	\$129.95
8	Multipurpose 6061 Aluminum, 5" Diameter, 3" Long	End caps (w/ handles)	McMaster 1610T48	2	\$75.36 (for two)
9	Rubber Suction Cup, 3-1/8" Diameter, 1-17/32" High, ¼"-20 Screw, 3/8" Screw Projection	Suction cup for flexibility test	McMaster 53535A45	1	\$10.57
10	Arduino Uno Rev3	Program for reading analog voltage	Sparkfun	1	\$24.95
11	Rotary Potentiometer – 10k Ohm, Linear	For use with Arduino	Sparkfun	1	\$0.95
				<b>Total cost:</b>	<b>\$311.49</b>

### 3.3 Draft detail drawings for each manufactured part

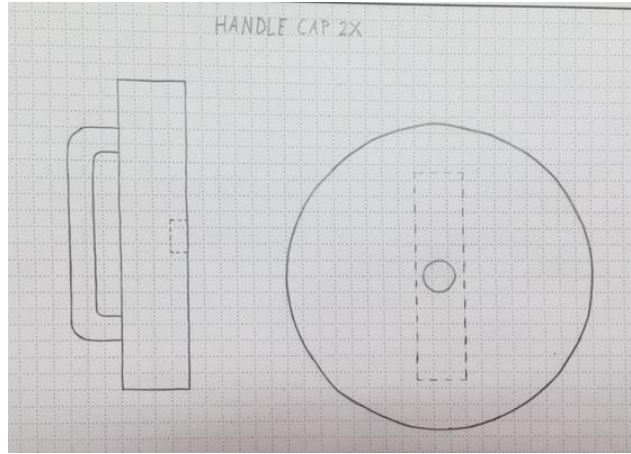


Figure 10 - Part 1: Aluminum End Cap with Handle Draft Drawing

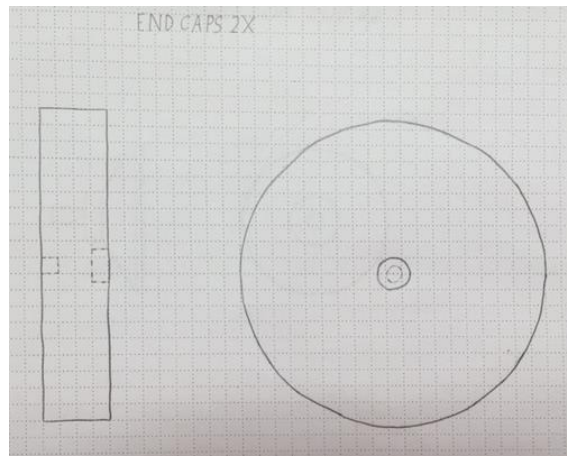


Figure 11 - Part 1: Aluminum End Cap Draft Drawing

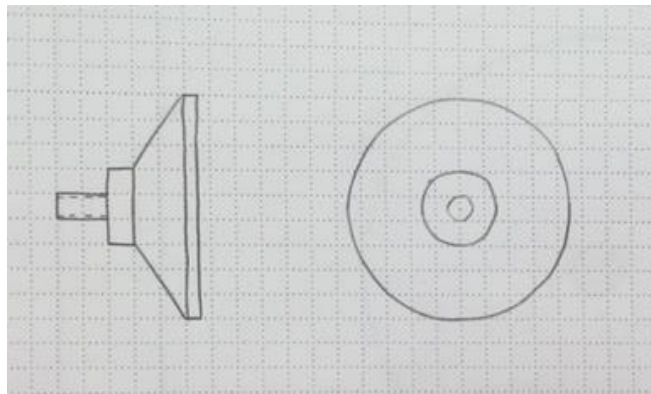


Figure 12 - Part 9: Rubber End Cap Suction Cup Draft Drawing

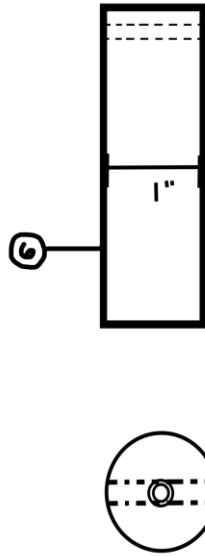


Figure 13 - Part 6: 1" Aluminum Rod, 6" in length Draft Drawing

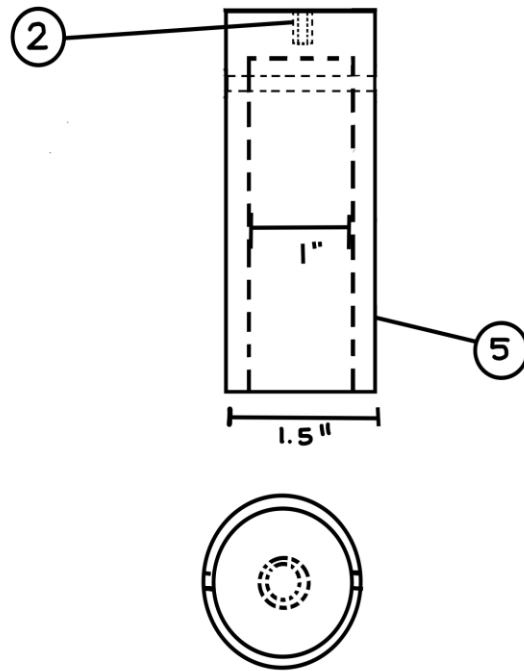


Figure 14 - Part 5: Hollow 1.5" Aluminum Rod, 6" in length Draft Drawing

### 3.4 Description of the design rationale for the choice/size/shape of each part

Part 1: Selected Aluminum as the choice material due to light weight and strong composition. The 5 inch diameter disk was selected to allow for a wide range of mounting options into a future test stand. These disks will allow for future tests and adaptations to be done with the device. The two end caps will be threaded into the load cell and into part 3. McMaster 1610T48

Part 2: Steel bolt which will be threaded into the end caps/handles/end attachments and into the telescoping rods (parts 5-6). Steel was chosen to provide maximum strength. The thread size is the same size as can be threaded into the load cell, which is 1/4-28. McMaster 98750A439

Part 3: To lock the telescoping rods and prevent their motion a locking pin made of steel is needed. Steel is chosen because this part needs to withstand all of the force input from the user. McMaster 90322A633

Part 4: Hex nut to secure the locking pin into place. Steel is preferred for strength and is readily available. McMaster 91841A011.

Part 5: Aluminum material is selected to reduce weight while maintaining ease of machinability and strength. The length of the rod allows for the telescoping action to occur after the interior has been bored and reamed out. This rod has a loose running fit inside of part 5, with a through hole bored through to allow for the locking pin to pass through. McMaster 8974K18.

Part 6: Aluminum material is selected to reduce weight while maintaining ease of machinability and strength. The length of the rod allows for the telescoping action to occur along the full length of the device. This rod has a loose running fit inside of part 5, with a through hole bored through to allow for the locking pin to pass through. McMaster 8974K13.

Part 7: Load cell that can accommodate both tension and compression is selected to allow for the widest range of tests to be performed. This load cell can withstand up to 200lbs with a 150% safety of operation. This ensures that a human will be able to push full force into in the device without risking the equipment. The threads on the device are 1/4-28 threads and this device will thread into part 6 and part 1/other attachments/handles/etc. Tacuna Systems STL-200.

Part 8: Aluminum disk that will allow us to machine out handle attachments for the strength test. 3 inch thickness was selected to allow for 1inch to be dedicated to threading the handle onto the device and the other 2 inches will allow us to machine out a handle for the human hand to grip and apply force to. The 5 inch diameter was chosen to accommodate a majority of hand sizes. McMaster 1610T48.

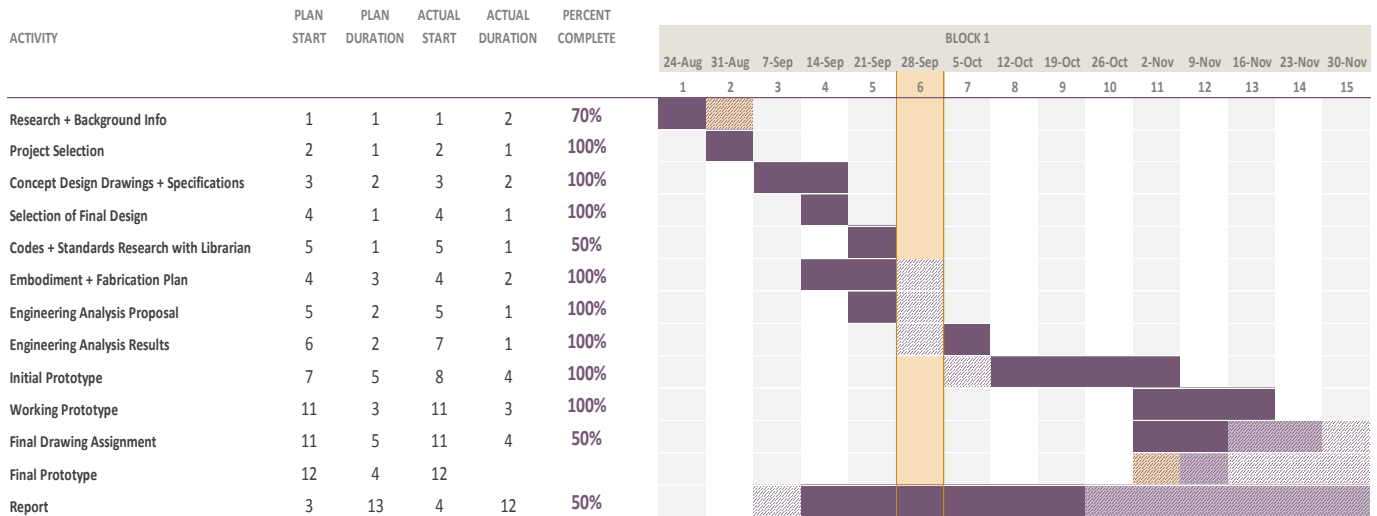
Part 9: The rubber suction cup is on the parts list to facilitate the sit and reach test. The rubber material is selected to allow for the device to be mounted to a wide range of surfaces and has a threaded end to allow for insert into one of the end caps. McMaster 53535A45.

Part 10: The Arduino Uno is here to assist in the data collection of the voltage output from the load cell. This will allow us to accurately receive, record, and output data to the user about the different displacements the load cell experiences. SparkFun.

Part 11: This part will allow an alternative method to an analog measurement of the flexibility test. Instead of notching the outside of part 6, this linear potentiometer will ensure accurate displacement measurement and also can be received by the Arduino board. Sparkfun.

### 3.5 Gantt chart

Table 6 – Gantt Chart



## 4 Engineering analysis

### 4.1 Engineering analysis proposal

#### 4.1.1 Proposal Form

##### **ANALYSIS TASKS AGREEMENT**

PROJECT: Golden Bite Mouth Guard

NAMES: Austin Fiegel, Caitlin Braun, Eric Tyra, Alexandra Michaels

INSTRUCTOR(S): Dr. Malast and Dr. Jakiela

The following engineering analysis tasks will be performed:

1. Determine range of loads that device needs to be able to measure.
  - Use existing load cell in MEMS department to identify what we need.
  - Measure max force applied to load cell when undergoing intended use.
2. Determine type of load cell and data acquisition.
  - Compression vs. Tension based load cells?
  - How many tests does the load cell need to perform?
  - Determine the type of analysis software and how the data will be recorded and analyzed.
3. Estimate total weight and size of device to see how much material modification is necessary to maintain portability.
4. Select materials for handles and device attachments to reduce weight if required by results of engineering analysis task #3.
  - Compare metal to rubber or plastics endcaps
5. Determine potential weak points in the design?
  - Ensure device will not bend
  - Screws will not shear or break
  - Ensure that the device can accommodate wide range of people
  - Dampers will not break
6. Check that the dampers will provide adequate load variation.

The work will be divided among the group members in the following way:

Austin - 1

Caitlin – 2 and 6

Alexandra – 3 and 4

Eric - 5

Instructor signature: \_\_\_\_\_; Print instructor name: \_\_\_\_\_

(Group members should initial near their name above.)



## 4.2 Engineering analysis results

### 4.2.1 Motivation

Our before analysis consisted primarily of material and component selection. We focused on selecting materials and determining the mechanical limits of our device through known physical and mathematical formulae. We also considered the use of the device to ensure that the components selected would not fail during use.

We examined the material properties of a number of different materials, including aluminum, steel, rubber and plastic. We needed a material that was both strong, yet lightweight. Because steel is very heavy, we decided it would not be appropriate for our prototype. We did not want the device to plastically deform or buckle under load. The ability to machine numerous parts was also important, as there were many components in our device that needed to be connected, requiring custom parts. We selected aluminum for each assembled part of the design, as it provides the structure and strength. This was ideal for a long-lasting device that would be used repeatedly in the field and potentially for clinical testing. The low density of aluminum also resulted in a lightweight device, which was very important to our client, Dr. Quigless. The aluminum could be machined easily. We would be able to connect multiple components using bolts and screws by tapping and threading holes in the aluminum. We could also make adjustments to the size of each part as needed through milling operations. Furthermore, there was a large quantity of aluminum scrap available for use. We needed to make the device as low cost as possible, and by using aluminum, much of the materials for the device would be free.

Following the initial material selection, we needed to determine what load size load cell would be appropriate to test the strength of an individual. In order to test this, we ran a series of measurements on the load cell with a variety of people to determine the maximum force they could exert on the load cell. This test was done on men who followed a strength training plan, and represented the upper 90 percentile of strength. The results from the test were then doubled, introducing a factor of safety for any individuals with significantly more strength than those who had undergone the testing.

Additionally, as we explored the use of the device, we realized the importance of taking into account participant bias. The client, Dr. Quigless, plans to use this device with patients to demonstrate the performance improvement associated with wearing the Golden Bite mouth guard. When an individual used the device with the mouth guard, they may subconsciously or consciously preform either better or worse than without the mouth guard. A user knowing that there should be a difference between the test with and without the mouth guard would cause bias in the results. The user should not be able to easily determine the force they are exerting. Without any changes to the device between testing, the user would be able to feel a difference. The initial design did not remove the bias, as there was no variation between tests. Because of this, we decided that it would be necessary to incorporate a variable load in the device, making the test feel different to the user each time.

Collectively, the before analysis was used to ensure that the first prototype would meet the needs of the client. The materials selection, physical and mathematical modeling of our system, and considerations related to the testing performed by our client using our device allowed us to refine

our design. We had limited tools, materials, and money for the project, making it very important to preform pre-prototype analysis, to reduce the number of iterations necessary to obtain our final device design. By preforming the before analysis we could ensure that our device would meet our budget, relevant codes and standards, the identified metrics, and most importantly Dr. Quigless' needs.

### 4.2.2 Summary of Analysis Done

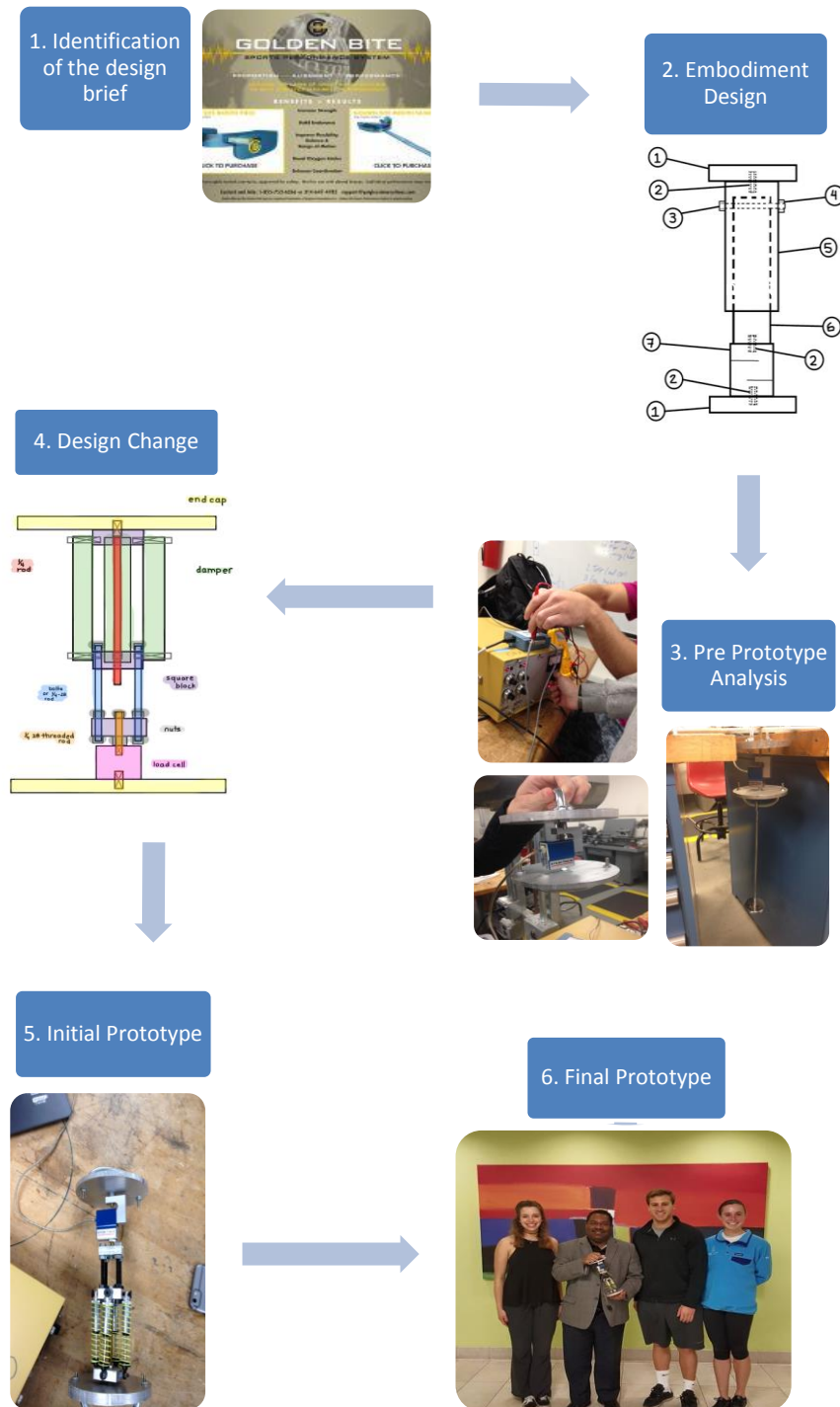


Figure 15 – Analysis Flowchart

1. Identification of the design brief: Design a portable and digital device to quantitatively measure the strength of its user, per the request of Dr. Kirk Quigless, DDS.
2. Embodiment design: Created 4 different designs sketches and rated them using the user needs that were gathered. Picked the winner based off the highest rating generated by the concept scoring spreadsheets seen in prior sections.
3. Pre-prototype analysis: Materials were selected because of their high strength to weight ratio, ease of machining, and cost. Aluminum stock was in abundance in the machine shop and some brass rods had to be ordered, which met the requirements.
4. Design Change: The use of a telescoping rod is eliminated. We decided to use variable-resistance shock absorbers to provide the user with a different feeling of resistance to their applied force. This was to eliminate user bias from anyone who knew about the mouth guard before testing began. Additional aluminum blocks were added to the design to serve as connection points between the various elements of the device. These blocks served to transfer the load from the user to the load cell directly down the linear path of the device.
5. Initial Prototype: Device constructed using the updated design plan and machined using a variety of machines including: Bridgeport mill, lathe, band saw, and grinding wheel.
6. Final Prototype: The device was modified to restrict and extra degree of freedom taking the total down from two to one (linear). This way the entirety of the load is concentrated in one direction directly to the load cell. Note that this step is a result of the aforementioned analysis.

### 4.2.3 Methodology

The engineering analysis was performed using a variety of methods. There were written calculations as well as some testing to determine different component materials, sizes and durability.

The weakest point on our design was the small bolts holding the spring/damper assembly to the metal block closest to the handle. The calculation determining the amount of shear stress each bolt would see is shown here below.

$$\tau = \frac{F}{A} = \frac{100lb}{\pi(0.1in)^2} = 3,183.098862psi$$

This shear stress is divided by 4 because each of the 4 bolts share the load equally. They only see an axial load from the device.

$$\tau = 795.775psi$$

According to steelconstruction.info, the maximum shear stress for Grade B7 steel is approximately 36,000psi. Therefore, the factor of safety for the bolts shearing is:

$$F. O. S = \frac{36,000psi}{795.775psi} \approx 45.2$$

There is also a bending moment placed on one of the rods in the interior of the device that limits the second degree of freedom. This rod can undergo a moment if the device is not purely compressed.

$$M = (20\text{lbs})(3\text{in}) = 60\text{lb} \cdot \text{in}$$

$$\sigma = \frac{My}{I} = \frac{(60\text{lb} \cdot \text{in})(0.125\text{in})}{\frac{\pi}{4}(0.125\text{in})^4} = 39,113.91881\text{psi}$$

According to ezlok.com, the approximate maximum tensile stress of brass is 68,000psi. Therefore, the factor of safety for the rod is:

$$\text{F. O. S} = \frac{68,000\text{psi}}{39,113.91881\text{psi}} \approx 1.7$$

Finally, there could be a bending moment on the rod inside each of the 4 damper assemblies. This rod can undergo a moment when the device is not purely compressed.

$$M = (5\text{lbs})(3.5\text{in}) = 17.5\text{lb} \cdot \text{in}$$

$$\sigma = \frac{My}{I} = \frac{(17.5\text{lb} \cdot \text{in})(0.1\text{in})}{\frac{\pi}{4}(0.1\text{in})^4} = 22,281.69\text{psi}$$

According to matweb.com, the approximate maximum tensile stress of stainless steel is 73,200psi. Therefore, the factor of safety for the rod is:

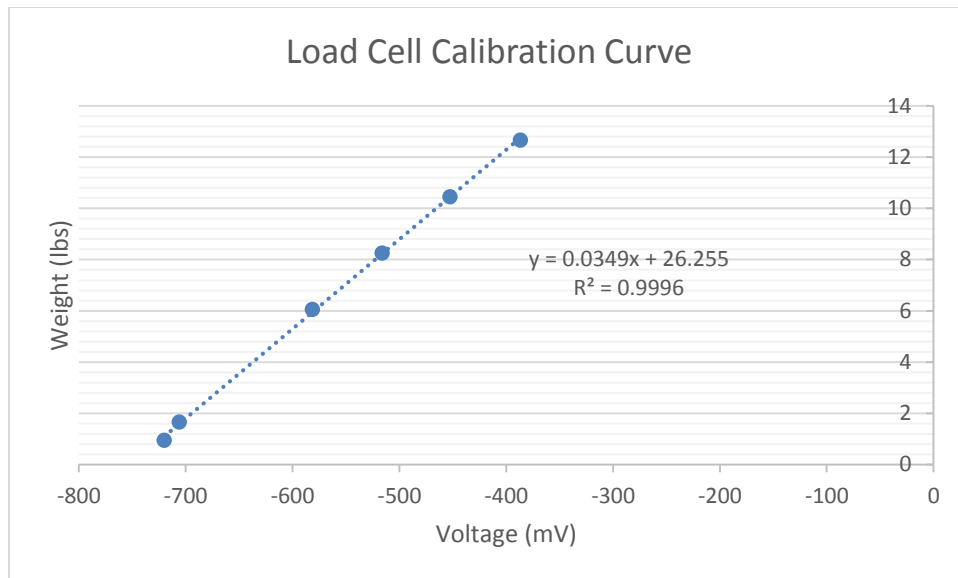
$$\text{F. O. S} = \frac{73,200\text{psi}}{22,281.69\text{psi}} \approx 3.3$$

The load cell used on the device needed to be calibrated prior to use. This would allow our group to convert the voltage output of the load cell into pounds and thus allow the user to see the force output in a familiar way. This also allows any difference in performance due to the Golden Bite Mouth Guard to be seen in a unit familiar with weight lifting.

To calibrate the load cell it was removed from the device and attached to a set of handles on its own. Using calibration weights provided by the university, the load cell was calibrated by slowly increasing the amount of weight the device was supporting and plotting a curve to the outputted voltage from this process.

#### 4.2.4 Results of Engineering Analysis

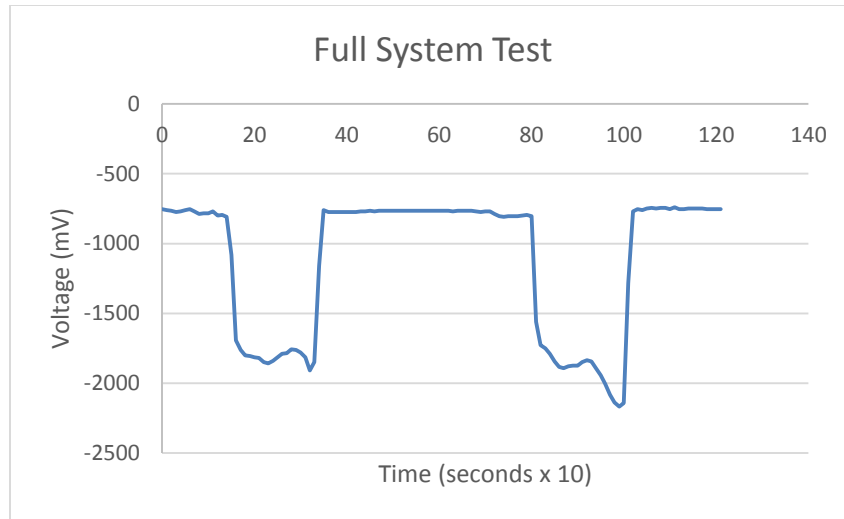
Load Cell Calibration Curve is shown below. This was the result of the load cell calibration process.



This shows that a calibration constant of  $-0.0349$  lbs/mV was determined from these testing procedures. The negative sign is introduced to account for the device being put in compression and will negate any preload present on the device due to it being part of an assembly.

The device was then reassembled and tested to see how much force could be exerted by a human being on the full system assembly. The initial testing results showed that our group members could only exert a maximum of 84 pounds on the device. The load cell is rated for 100 lbs with a 150% max out rating as well. Since the device was not near its limits, this load cell was determined to be useful for this application.

The full system assembly was tested again but this time with the Golden Bite mouth guard present for the testing procedures. The device was adjusted to a random spring setting and then was compressed and recorded. The spring settings were adjusted, and the Golden Bite mouth guard was put in. The test was repeated and the data recorded. The results showed that the Golden Bite Mouth Guard caused an 11.95% increase in the strength of the user. The figure shown below is the data received during the mouth guard full system test held in a vertical position.



It is important to note that the data acquired in this final report is not statistically significant and was performed by members of this design team. The data found suggests that a full clinical study should be done to ascertain how accurate this force measurement is and to arrive at a more conclusive number to represent an increase in performance.

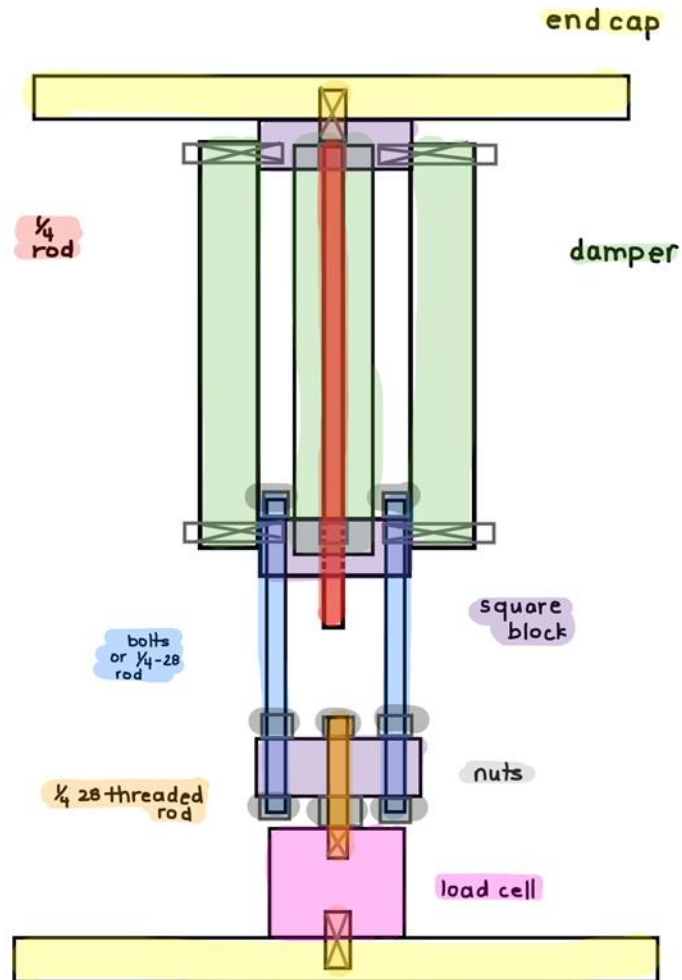
#### 4.2.5 Significance of Engineering Analysis

Please refer to Section 3.1 for our initial embodiment drawings.

After the analysis, our prototype changed significantly. Our initial design, shown in Section 3.1, had two telescoping rods designed to expand and contract when a force was applied along its long axis. This device also allowed for measuring flexibility in a style similar to a traditional sit-and-reach test. However since strength was selected as the design metric for this project, the flexibility and telescoping rod idea was eliminated.

The initial designs required more material, creating a heavier device, and its physically larger parts required more machining. It did not provide a variable load, which was deemed necessary to eliminate user bias while using the device.

The first prototype was influenced the most by the need to eliminate user bias. The addition of the spring/damper assembly into our prototype altered the design significantly and caused a lot of flaws that required redesign. However, doing away from the telescoping rod mechanism allowed our group to move forward with the more important design considerations.



The final prototype involved slight modifications from the initial prototype. Because the initial prototype had an extra degree of freedom which allowed the device to twist about its long axis, an additional bolt was added to restrict motion to a single degree of freedom along the device's longitudinal axis when put under compression.

#### 4.2.6 Summary of code and standards and their influence.

We used the standards for calibrating the load cell to read a force output as opposed to an output that reads in millivolts. See annotated bibliography for summary and influence.

ASTM E4 - Practices for Force Verification of Testing Machines [2]

<http://www.astm.org/Standards/E4.htm>

ASTM E74 - Practice for Calibration of Force Measuring Instruments for Verifying the Force Indication of Testing Machines [3]



<http://www.astm.org/Standards/E74.htm>

## 4.3 Risk Assessment

### 4.3.1 Risk Identification

There are no risks involved with the device except for sharp corners that may be present on the device. Any preexisting medical conditions of the user will be identified and analyzed by Dr. Quigless before having the patient use the device.

### 4.3.2 Risk Analysis

To analyze this risk, the number of sharp edges or corners are counted on the device. The more corners or edges on the device, the more risky the device is.

### 4.3.3 Risk Prioritization

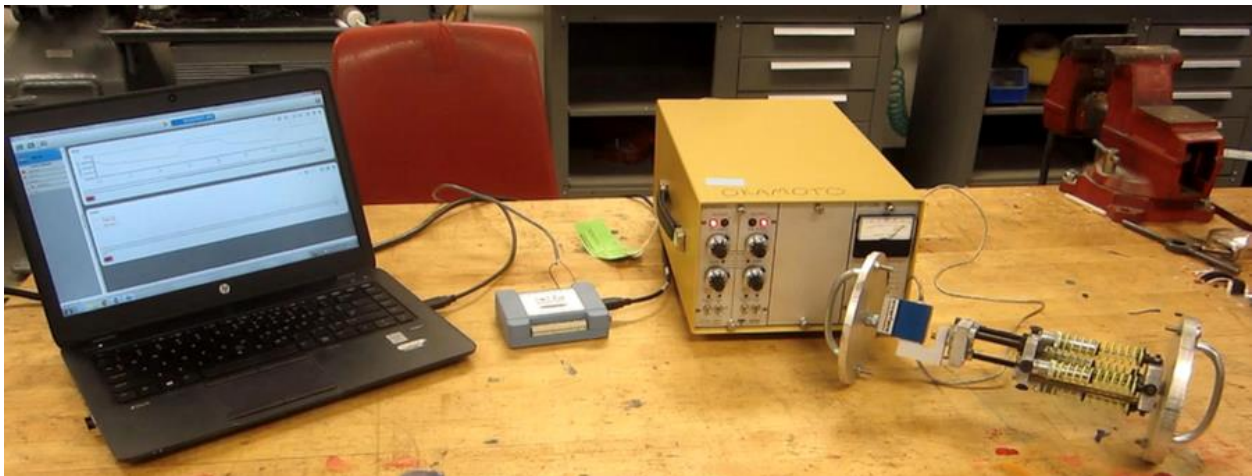
Since there is only one risk involved with the device, there is no priority. It is important to note that all sharp edges initially present on the design were grinded down and smoothed to eliminate the risk.

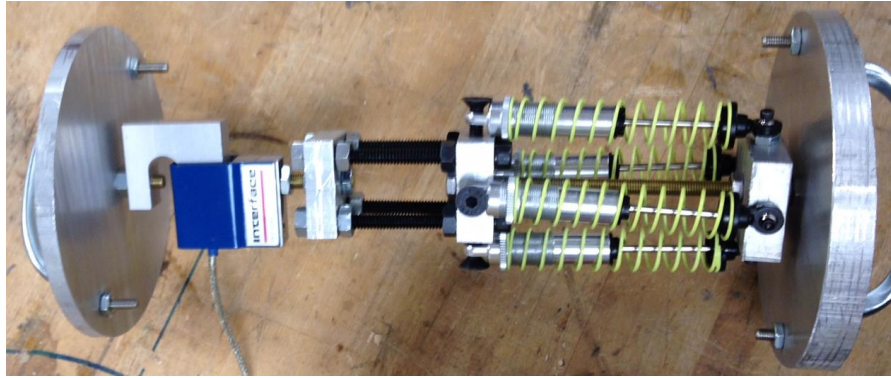
## 5 Working prototype

**5.1 A preliminary demonstration of the working prototype (this section may be left blank).**

**5.2 A final demonstration of the working prototype (this section may be left blank).**

**5.3 Digital photographs showing the prototype**





5.4 A short videoclip that shows the final prototype performing  
<https://www.youtube.com/watch?v=ZHKd8WggWp0>

## 5.5 Four Additional Digital Photographs and Their Explanations

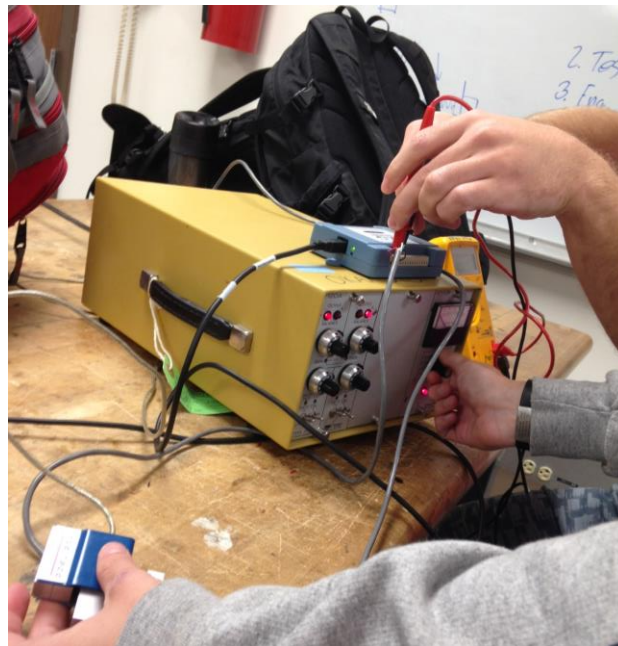


Figure 16 – First Setup of Signal Amplifier

This photo shows the team setting up the signal amplifier for the first time for the golden bite mouth guard testing system.

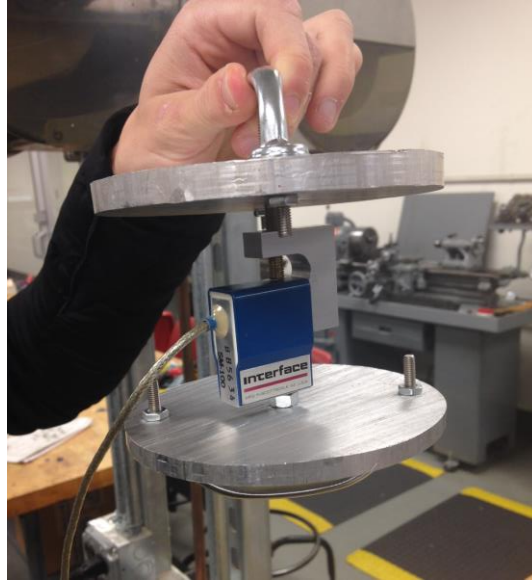


Figure 17 – Load Cell Setup for Calibration

This picture shows the modified testing rig used to assist with the calibration of the load cell.



Figure 18 – Close Up of Machined End Cap

This image shows a more detailed view of the student made end cap.

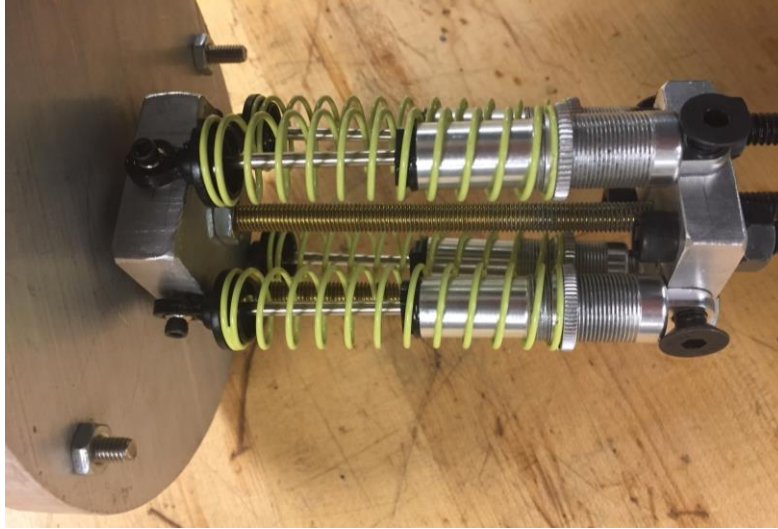


Figure 19 – Detailed view of Sliding Mechanism

The above image shows a close up view of the sliding mechanism of the final prototype. It also shows the threads of the damper assembly and how they can be adjustable.

## 6 Design documentation

### 6.1 Final Drawings and Documentation

6.1.1 A set of engineering drawings that includes all CAD model files and all drawings derived from CAD models.

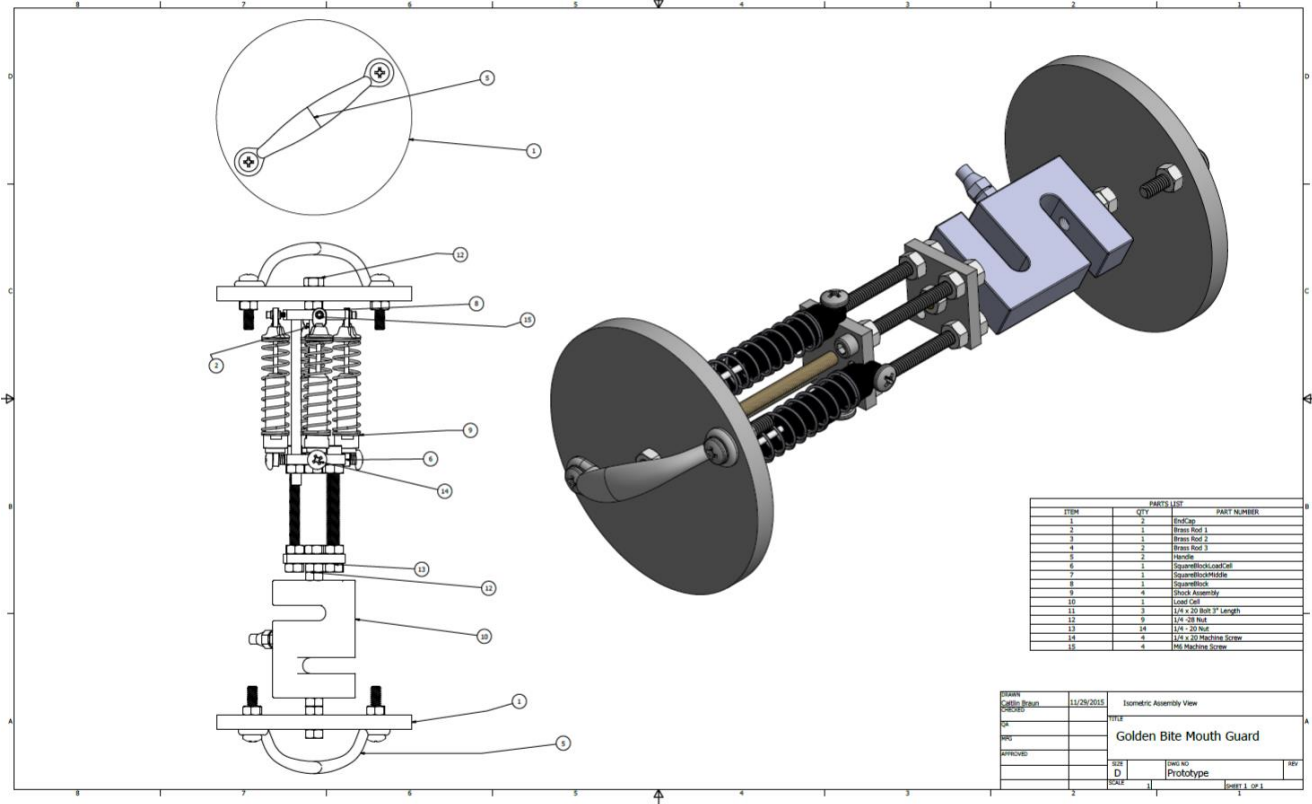


Figure 20 – Full CAD Assembly Drawing

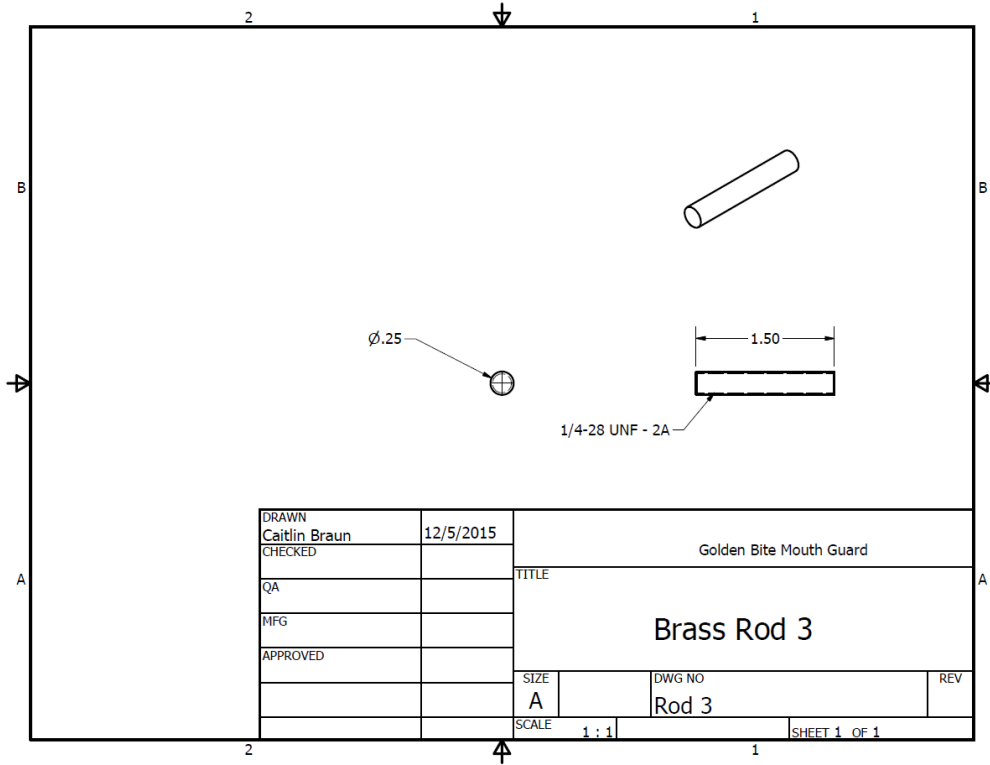


Figure 21 – Brass Rod 3 Part Drawing

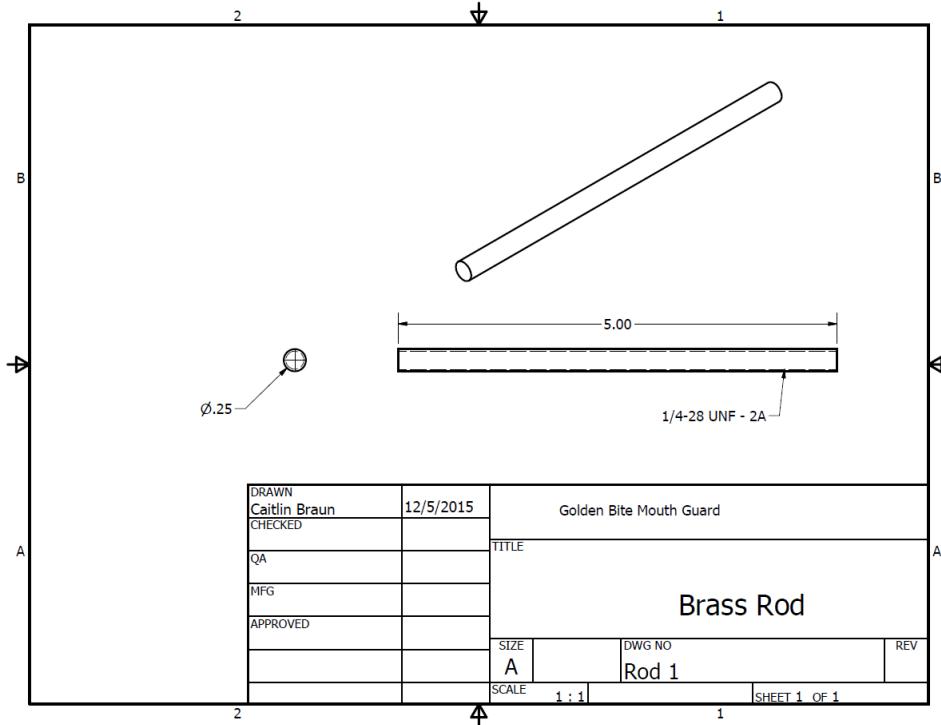


Figure 22 – Brass Rod Part Drawing

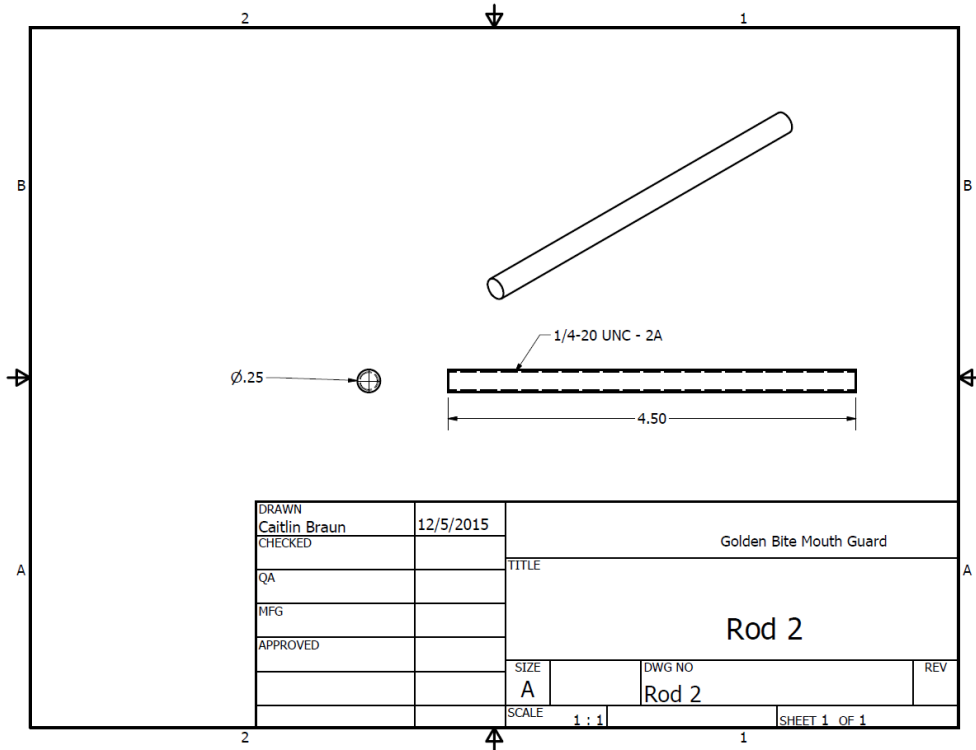


Figure 23 – Brass Rod 2 Part Drawing

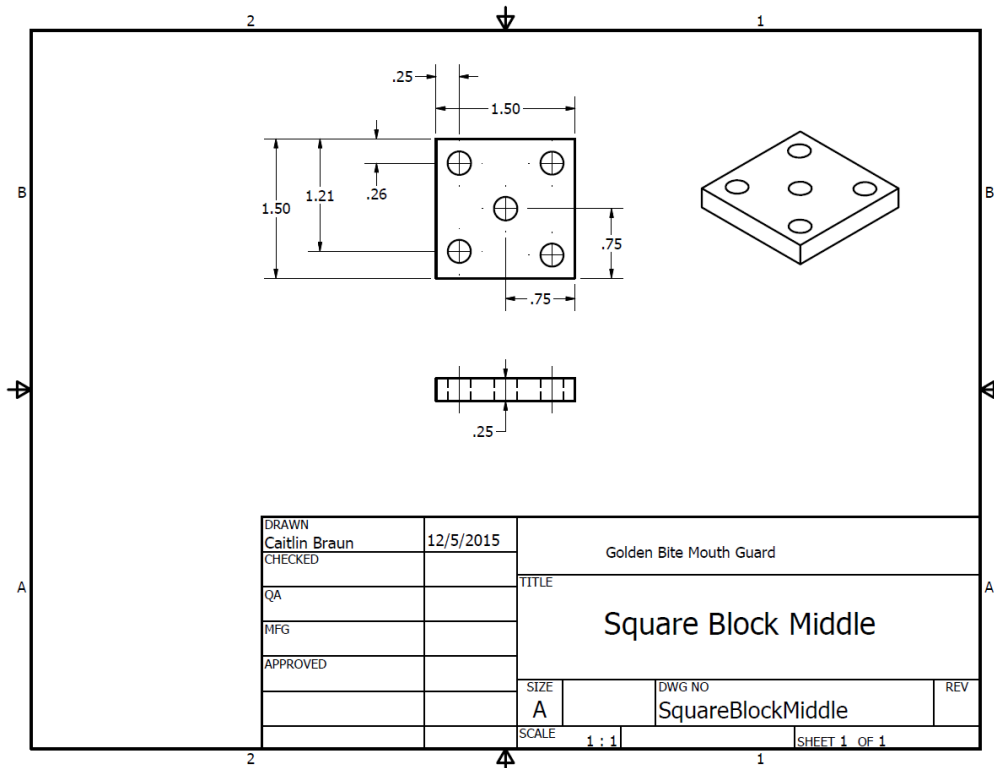


Figure 24 – Square Block Middle Part Drawing



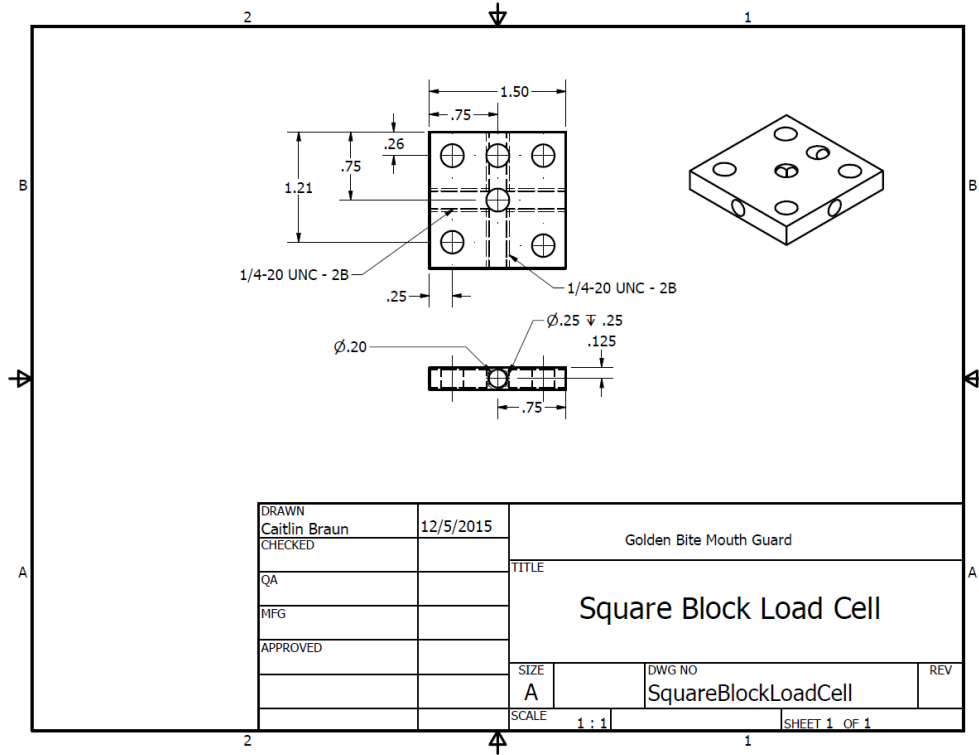


Figure 25 – Square Block Load Cell Part Drawing

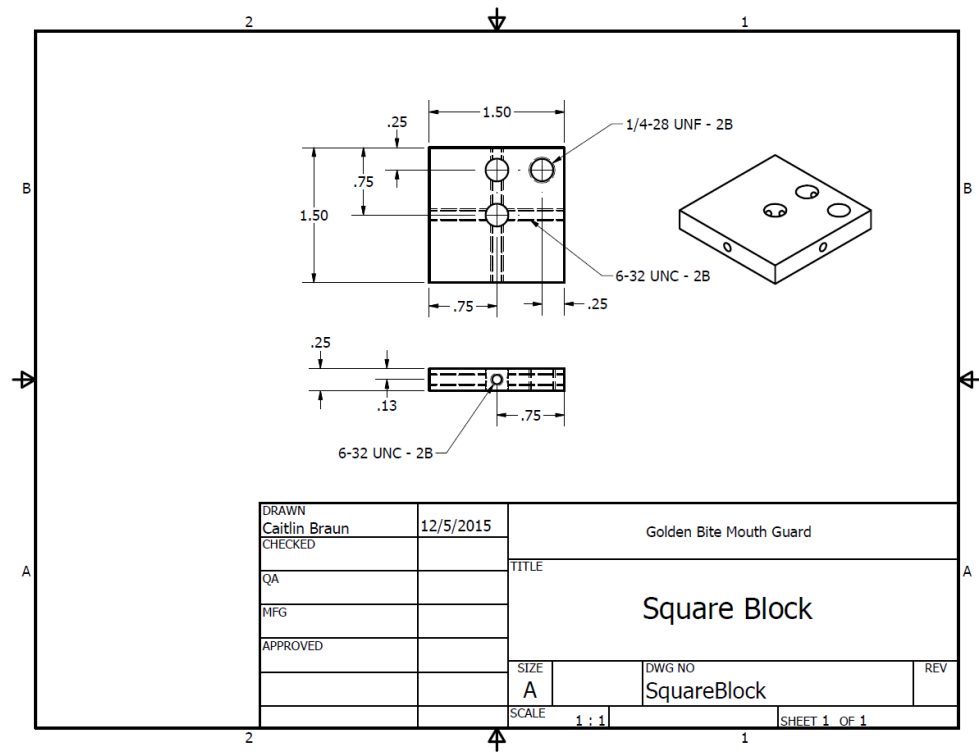


Figure 26 – Square Block Part Drawing



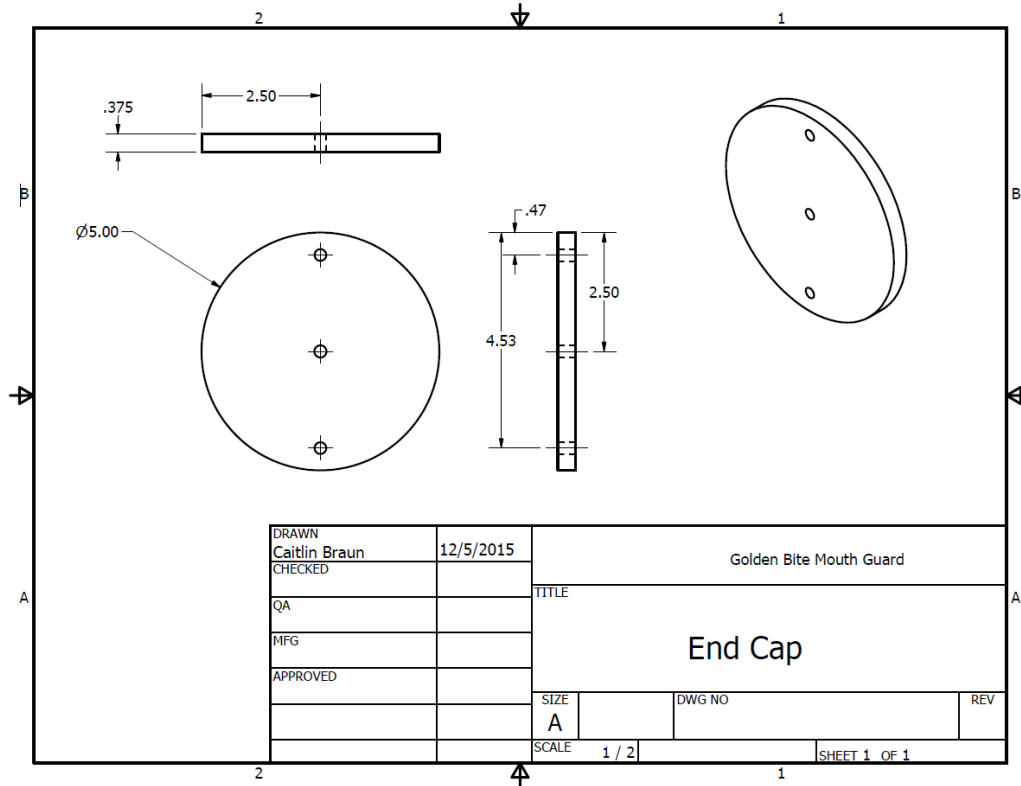


Figure 27 – End Cap Part Drawing

6.1.2 Sourcing instructions

Number	Part	Source	Quantity
1	End Cap	Scrap 6061 Aluminum 5" Diameter, 1.5" Long	2
2	Brass Rod	<a href="http://www.amazon.com/gp/product/B000FOYLCO?psc=1&amp;redirect=true&amp;ref=oh_aui_detailpage_o04_s00">http://www.amazon.com/gp/product/B000FOYLCO?psc=1&amp;redirect=true&amp;ref=oh_aui_detailpage_o04_s00</a> Purchased ¼ x 28 Brass Rod cut to 1.5" (\$5.99)	1
3	Brass Rod 2	<a href="http://www.amazon.com/gp/product/B000FOYLCO?psc=1&amp;redirect=true&amp;ref=oh_aui_detailpage_o04_s00">http://www.amazon.com/gp/product/B000FOYLCO?psc=1&amp;redirect=true&amp;ref=oh_aui_detailpage_o04_s00</a> Purchased ¼ x 28 Brass Rod cut to 1.5" (\$5.99)	1
4	Brass Rod 3	<a href="http://www.amazon.com/gp/product/B000FOYLCO?psc=1&amp;redirect=true&amp;ref=oh_aui_detailpage_o04_s00">http://www.amazon.com/gp/product/B000FOYLCO?psc=1&amp;redirect=true&amp;ref=oh_aui_detailpage_o04_s00</a> Cut to 1.5"	2

		<a href="http://www.ylco.com/?psc=1&amp;redirect=true&amp;ref=oh_aui_detailpage_o04_s00">YLCO?psc=1&amp;redirect=true&amp;ref=oh_aui_detailpage_o04_s00</a> Purchased ¼ x 28 Brass Rod cut to 1.5" (\$5.99)		
5	Handle	<a href="http://www.mcmaster.com/#1645a2/=10136r0">http://www.mcmaster.com/#1645a2/=10136r0</a> Purchased Handle (\$3.04)	N/A	2
6	Square Block Load Cell	Scrap 6061 Aluminum Square Rod 1.5" x 1.5"	Rod cut and milled to ¼" to create square blocks to assemble load cell	1
7	Square Block Middle	Scrap 6061 Aluminum Square Rod 1.5" x 1.5"	Rod cut and milled to ¼" to create square blocks to assemble dampers	1
8	Square Block	Scrap 6061 Aluminum Square Rod 1.5" x 1.5"	Rod cut and milled to ¼" to create square blocks to assemble dampers	1
9	Shock Assembly	<a href="http://www.amazon.com/gp/product/B00A6U4Z4Q?psc=1&amp;redirect=true&amp;ref=oh_aui_detailpage_o05_s00">http://www.amazon.com/gp/product/B00A6U4Z4Q?psc=1&amp;redirect=true&amp;ref=oh_aui_detailpage_o05_s00</a> Purchased Duratrax Shock Set (\$29.99)	N/A	4
10	Load Cell	Interface B85634 100lb Tension and Compression Load Cell Obtained from Wash U Laboratories	N/A	1
11	¼ x 20 Bolt 3" Length	Obtained from machine shop	N/A	3
12	¼ x 28 Nuts	Obtained from machine shop	N/A	11
13	¼ x 20 Nuts	Obtained from machine shop	N/A	4
14	¼ x 20 Machine Screw	Obtained from machine shop	N/A	4
15	M6 Machine Screw	Obtained from Machine Shop	N/A	4

## 6.2 Final Presentation

### 6.2.1 A live presentation in front of the entire class and the instructors

Given on 12/02/2015. See link in 6.2.2

### 6.2.2 A link to a video clip version

<https://www.youtube.com/watch?v=QhTK8jkhaRI>

## 6.3 Teardown

### TEARDOWN TASKS AGREEMENT

PROJECT: Golden Bite Mouth Guard NAMES: Caitlin Braun<sup>CB</sup> INSTRUCTOR: Dr. Malast

Eric Tyra ET

Alexandra Michaels AM

Austin Feigel AF

The following teardown/cleanup tasks will be performed:

1. All scrap will be returned to the cabinets in the Machine Shop
2. The prototype and all components associated with the prototype will be passed on to Dr. Malast, so that she can deliver the device to Dr. Quigless.
3. CLEAN UP A PORTION OF PATS SHOP

Instructor comments on completion of teardown/cleanup tasks:

Instructor signature: Mark J. Gerwin ; Print instructor name: <sup>Dr. Jakeila</sup> ~~Dr. Malast~~

Date: 12/2/2015

(Group members should initial near their name above.)

## 7 Discussion

### 7.1 Using the final prototype produced to obtain values for metrics, evaluate the quantified needs equations for the design.

Need#	Need	Metric											Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value		
		Measures Strength	Measures Flexibility	Measures Balance	Number of Tests	Number of Sharp Edges	Volume	Mass	Time to Set Up	Digital							
		1	2	3	4	5	6	7	8	9	10	11	12	13			
1	Device Measures Strength	1													1	0.14	0.14
2	Device Measures Flexibility		1												0	0.06	0
3	Device Measures Balance			1											0	0.06	0
4	Device can Transform for Different Tests				1										1	0.03	0.03
5	Device has No Sharp Edges					0.9			0.1						0.99	0.14	0.1386
6	Device is no bigger than 1m <sup>3</sup>						1								1	0.11	0.11
7	Device can be Maneuvered Easily						0.5	0.4	0.1						0.99	0.14	0.1386
8	Device uses Automatic Data Collection									1					1	0.08	0.08
9	Device can be Reused Multiple Times										1				0.9	0.14	0.126
10	Device can be Used by Different People											1			0.9	0.1	0.09
11															0	0	0
12															0	0	0
13															0	0	0
Units		Binary	Binary	Binary	Integer	Integer	m <sup>3</sup>	kg	Seconds	Binary					Total Happiness		0.8532
Best Value		1	1	1	3	0	0.0034	1	0	1							
Worst Value		0	0	0	1	10	1	50	600	0							
Actual Value		1	0	0	3	0	0.0034	1	60	1							
Normalized Metric Happiness		1	0	0	1	1	1	1	0.9	1							

Using the evaluation spreadsheet, the final prototype receives a high grade of 0.85 out of 1. Therefore, the needs were met effectively. The device is set-up easily and quickly and can be used to do a variety of different tests, which is what Dr. Quigless desired. The rating was not perfect, however. This was because the device does not measure flexibility and balance.

### 7.2 Sourcing issues

We did not have any part sourcing issues during the designing and prototyping of our device. The only outsourced parts were the four shock absorbers, which were easily ordered from the manufacturer and delivered within two days. Because the device's machined parts are simple and have a high dimensional tolerance, using scrap material from the machine shop worked very well for our purposes. For the future, a smaller signal amplifier could be purchased, which would reduce the bulkiness of the device considerably. Also, a different software could potentially be used that displays the force as a function of time.

#### 7.2.1 Was the project more or less difficult than you had expected?

Overall, the project was a bit more difficult than what was expected because of the additional factor of eliminating user bias. The group had to think rapidly about a solution to this problem, but luckily the solution was met. Furthermore, it was very difficult designing and fabricating the device in a single semester. In the future, this project should be spread out over the course of a full year.

### **7.2.2 Does your final project result align with the project description?**

Yes. The final prototype meets the specifications presented by Dr. Quigless. Although the device does not allow for the testing of flexibility and balance, it quantitatively measures strength, which is the factor most important to our client.

### **7.2.3 Did your team function well as a group?**

Yes. We communicated effectively with one another, and each member brought different skills to the table. The team environment was one of mutual respect for each other and of each other's ideas.

### **7.2.4 Were your team members' skills complementary?**

Yes. Each member brought a different skill set and perspective to the group, which helped to solve problems. Some of the group had more experience in the machine shop than others, but some enjoyed doing research more than others, which balanced out quite well and allowed everyone to contribute to the project in their own way.

### **7.2.5 Did your team share the workload equally?**

Yes. The work was divided up quite well and in a way that worked around everyone's schedules. Work was usually done in a collaborative environment with everyone in the same place. Some research was done individually and then shared at meetings.

### **7.2.6 Was any needed skill missing from the group?**

We are fortunate to be part of a team where we had a wide range of skills and the attitude to solve problems we did not initially know how to tackle. However, more machining expertise would have been beneficial to the group particularly skills with G-Code and CNC milling.

### **7.2.7 Did you have to consult with your customer during the process, or did you work to the original design brief?**

We had an initial consultation with the customer to discuss the user needs and learn more about the Golden Bite™ mouth guard itself. We held an additional meeting with the customer to present him with our final prototype design, which impressed and excited him.

### **7.2.8 Did the design brief (as provided by the customer) seem to change during the process?**

The design brief remained constant. Dr. Quigless did not present any updates to us or require any changes.

### **7.2.9 Has the project enhanced your design skills?**

Yes. Having a design process laid out to us in a step-by-step fashion has given us a better idea of how a product goes from a concept to a physical and functional device.

### 7.2.10 Would you now feel more comfortable accepting a design project assignment at a job?

Yes. This experience has made all of us more comfortable with the design process and subsequently feel more ready to tackle a design project assignment in the workplace.

### 7.2.11 Are there projects that you would attempt now that you would not attempt before?

Yes. Our group feels much more comfortable with full system CAD modeling and extensive amount of time it takes to tackle a large computer assembly project.

## 8 Appendix A - Parts List

Number	Part	Material/Description	Quantity
1	End Cap	6061 Aluminum	2
2	Brass Rod	¼ x 28 Brass Rod	1
3	Brass Rod 2	¼ x 28 Brass Rod	1
4	Brass Rod 3	¼ x 28 Brass Rod	2
5	Handle	6061 Aluminum	2
6	Square Block Load Cell	6061 Aluminum Square Rod 1.5" x 1.5"	1
7	Square Block Middle	6061 Aluminum Square Rod 1.5" x 1.5"	1
8	Square Block	6061 Aluminum Square Rod 1.5" x 1.5"	1
9	Shock Assembly	Duratrax Shock Set	4
10	Load Cell	Interface B85634 100lb Load Cell	1

## 9 Appendix B - Bill of Materials

Number	Part	Description	Quantity
1	End Cap	6061 Aluminum 5" Diameter	2
2	Brass Rod	¼ x 28 Threaded Brass Rod – 5in	1
3	Brass Rod 2	¼ x 28 Threaded Brass Rod – 4.5in	1
4	Brass Rod 3	¼ x 28 Threaded Brass Rod – 1.5in	2
5	Handle	Handle	2
6	Square Block Load Cell	6061 Aluminum Square Rod 1.5" x 1.5"	1
7	Square Block Middle	6061 Aluminum Square Rod 1.5" x 1.5"	1
8	Square Block	6061 Aluminum Square Rod 1.5" x 1.5"	1
9	Shock Assembly	Duratrax Shock Set	4

<b>10</b>	Load Cell	Interface B85634 100lb Load Cell	1
<b>11</b>	¼ x 20 Bolt 3" Length	Fastener	3
<b>12</b>	¼ x 28 Nuts	Fastener	11
<b>13</b>	¼ x 20 Nuts	Fastener	4
<b>14</b>	¼ x 20 Machine Screw	Fastener	4
<b>15</b>	M6 Machine Screw	Fastener	4

## 10 Appendix C - CAD Models

CAD models appear in Section 7.1.

## 11 Annotated Bibliography (limited to 150 words per entry)

[1] 2013, "Golden Bite: The Best Mouthguard Ever," from <http://sylwilsonmarketing.com/goldenbite/>

This is a marketing website used to promote the Golden Bite™ mouth guard. It provides general background information on the product, details about how the mouth guard works, and product testimonials. This website was used for images and for general Golden Bite information.

[2] ASTM, 2014, "Standard Practices for Force Verification of Testing Machines," ASTM E4-14.

ASTM E4-14 states the necessity of users to know that forces applied to a force-measuring device and subsequently indicated are translatable to the International System of Units (SI). In order to trace forces to SI units, the force-measuring device must have known force characteristics and have been calibrated according to ASTM E74-13a. For the purposes of this project, the force detected by the device is translated to the English system in pounds, or pounds force. This is the most common unit of force in United States concerning weightlifting and athletics.

[3] ASTM, 2013, "Standard Practice of Calibration of Force-Measuring Instruments for Verifying the Force Indication of Testing Machines," ASTM E74-13a.

ASTM E74-13a is the practice that describes how force-measuring devices, specifically elastic force-measuring instruments and force-multiplying systems, must be calibrated. This practice is specific to devices that measure static forces rather than dynamic and high-speed forces. This source was useful to us because the load cell used fit into this category of force measuring device.