PHYSICAL TESTING OF POTENTIAL FOOTBALL HELMET DESIGN ENHANCEMENTS

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ABSTRACT

Physical Testing of Potential Football Helmet Design Enhancements

Michael Jeremy Schuster

Football is a much loved sport in the United States. Unfortunately, it is also hard on the players and puts them at very high risk of concussion. To combat this an inventor in Santa Barbara brought a new design to Cal Poly to be tested.

The design was tested in small scale first in order to make some preliminary conclusions about the design. In order to fully test the helmet design; however, full scale testing was required. In order to carry out this testing a drop tower was built based on National Operating Committee on Standards for Athletic Equipment, NOCSAE, specification. The drop tower designed for Cal Poly is a lower cost and highly portable version of the standard NOCSAE design. Using this drop tower and a 3D printed prototype the new design was tested in full scale.

With the results of the full scale testing regime and computer modeling done by another graduate student, it was concluded that the new design did not reduce a player's risk for concussion. The new design increased the SI value for the helmet by a factor of 2.5.

ACKNOWLEDGMENTS

I would like to thank several people who without them my thesis would not have been possible. The main person who I would like to thank is Steven Warnert. Without his help throughout the process my testing and assembly could not have been finished. Additionally, I would like to thank George Rodriguez with his help with accomplishing my small scale testing. I would like to thank my committee chair, Dr. Schuster, and my committee members, Drs. Mello and Self, for their help and assistance throughout the year. Their advice helped me through my thesis and the trials and tribulations which were involved.

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NOMENCLATURE

EDC – Energy Diffusion Coefficient
HIC – Head Impact Criterion
ISO – International Organization for Standardization
NOCSAE – National Operating Committee on Standards for Athletic Equipment
SAE – Society of Automotive Engineers
SI – Severity Index
SIRC – Southern Impact Research Center

1. INTRODUCTION

In today's world the safety of athletes is very important. One of the most dangerous sports for players is American Football. In this sport the players run into each other at full speed and sustain very energetic impacts. These impacts put the players at a great risk for concussions. This fact has been recently brought to mainstream attention by news articles and even a feature motion picture starring Will Smith. To combat this risk, the NFL, NCAA, and major manufacturers have been working of various designs to combat the risk of concussion. An inventor in Santa Barbara, California has also come up with a new design which he feels will be able to better reduce the risk of concussions. His design uses a new method of reducing the impact felt to the player's head.

2. BACKGROUND

The purpose of this new football helmet design is to reduce the risk of concussion in football players. In college football, about 3,400 concussions were endured last year by athletes despite the use of current football helmets. Additionally, many of these players sustained more than one concussion in their athletic career. [1]

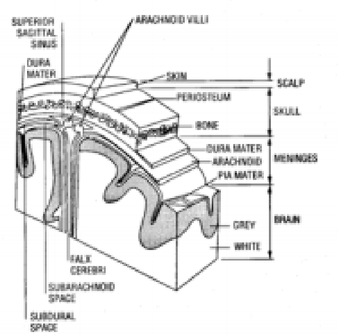


Figure 1. Cross-section of a human head [2]

2.1 Concussions

A concussion is a type of traumatic brain injury. Injuries to the brain are caused by a head impact or sudden head movement. Injuries can be caused by the skull fracturing and pushing against the brain. Additionally, injury can be caused by the brain impacting the interior of the skull or from the brain being stressed through shear, tension, or compression. [2] The anatomy of the human head can be seen in Figure 1.

Concussions can cause a variety of symptoms; from headaches to memory and cognitive problems to the condition Chronic Traumatic Encephalitis, CTE, which can cause death. If a head sustains another impact before the brain is fully able to recover, whether the second impact could have caused a concussion or not, the symptoms can exacerbate and cause even more damage to the brain. [1]

Not much is known about concussions and predicting the possibility of a concussion is a very complex issue. The risk of concussion is based off of both the magnitude and duration of the acceleration. This was first studied by researchers at Wayne State University. The curve they developed is called the Wayne State Tolerance Curve, or WSTC, which shows the tolerance level of humans. Another curve was developed based on WSTC, called the Gadd Severity Index or GSI. The combination of both of these techniques brought about the Head Injury Criterion, or HIC, developed by the NHTSA. [2]

To compute HIC, the formula below is used

$$HIC = \left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a\, dt\right]^{2.5} (t_2 - t_1)$$

Where:
$a \equiv$ resultant acceleration
t_2-t_1 is less than or equal to 36 ms
t_2 and t_1 maximize HIC

Values of HIC above 1000 are considered to be above the safe limit. Later on, the maximum length of time was changed from 36 milliseconds to 15 milliseconds. [2] This criterion is what is regularly used in automotive testing and vehicle impacts for the automotive industry. A value of 1000 is the threshold of safety for general use of HIC_{36} and 700 for HIC_{15}.

Unlike the automotive industry the athletic industry is regulated to use Severity Index or SI. It is very similar to HIC. It is computed using

$$SI = \int_0^T A^{2.5}\, dt$$

Where:
A ≡ resultant acceleration
T ≡ time when acceleration drops below 4 g's
Time 0 is when acceleration rises above 4 g's

This criterion is what is used by NOCSAE, the main body which regulates football and other athletic helmets and protective gear. [3] If the SI value exceeds 1200 it means that the risk of concussion is extremely great and the helmet would be considered a failure.

Both of these criteria are based upon the work of Charles Gadd who first proposed the formulas consisting of the integral of the acceleration raised to a weighting factor be used to quantify concussion risk. This is based upon a curve fit of experimental data of probable concussions that were recorded when the skull of a cadaver fractured. [4]

Another approach which is sometimes used to quantify whether a concussion may occur is simple maximum linear acceleration. This method is used in standards published by ASTM. They specify the max acceleration the head can endure with limited concussion risk to be 300 g's. This method does not take into consideration the full effect of an impulse event since the length of time the impact takes place in is not taken into account.

2.2 Current Helmet Designs

Figure 2. A common football helmet available today [12]

In this day and age there is a lot of research that is going into new helmet designs. Helmets normally consist of four main parts: a rigid shell, a liner, a retention system, and a comfort padding. The rigid shell's main purpose is to prevent things from penetrating the helmet as well as to help distribute the force of an impact around the helmet. The liner's job is to absorb energy and prevent it from being transferred to the head, normally by crushing or other types of deformation. The retention system is required to keep the helmet positioned on the head correctly and to keep it on the head during an impact. Finally, the comfort padding is in place to allow the helmet to be worn for hours without pain to the wearer. [5] A good helmet can slow the acceleration felt by the head by as much as fifty percent. [1]

The purpose of a helmet is twofold: to spread the force of an impact to a greater surface area and to increase the duration of an impact. By increasing the duration of an impact, even if by a millisecond, the same amount of energy is transferred to the helmet but the impulse felt by the brain is reduced. This can turn what may be a hit that causes a concussion, or death, to one which is safe for a player. Like the common phrase, "it's not the fall that kills you, it's the sudden stop," it's the sudden stop which causes a concussion. Making the impact less sudden lessens the risk of concussion. [5]

2.2.1 Football Helmets

Football helmets have the same basic structure of any other helmet but are built to sustain multiple impacts without having to be replaced. A traditional football helmet has a shell made of polycarbonate or a similar polymer. This shell is used to hold together the rest of the helmet as well as display the team's colors and logo. The liner of a football helmet is where the largest difference exists between a typical helmet and one designed for football. The liners in football helmets are made to work multiple times. There are a variety of designs that manufacturers use. Some helmets utilize an egg-crate design made of plastic while others use foam which will not plastically deform. The retention system of a traditional football helmet is a chin strap. The chin strap uses quick release snaps to attach to the helmet. Like the name implies, the strap uses a chin cup which rests against the chin to keep the helmet in place. Comfort padding is another area where helmets manufacturers vary. Most will use a soft foam to provide comfort to the player's head. Used in both the comfort and retention systems of many helmets are inflatable air bladders. These bladders have two purposes: to keep the helmet in contact with the head, its job in the retention system, and to perfect the fit of the helmet, its job in the comfort system.

The current top performing helmet, rated by the NFL, is the Xenith Epic Varsity, as shown in Figure 3. [6] This helmet uses an air filled shock absorber system as a liner.

Figure 3. The Xenith Epic Varsity football helmet

A new helmet which is getting a lot of press is the VICIS Zero1 Impact Reduction helmet. It is a combination helmet which uses both a newly designed liner system and shell they call the LODE shell. This shell locally deforms, just like a car bumper does. This helmet design has won awards from the NFL for its unique and superior features. [7]

2.2.2 Other Helmet Designs

A traditional helmet, one not used in football, is designed to be used only once. Because of this, typical helmets such as motorcycle or bicycle helmets, can more effectively reduce concussion risk. The liner of a motorcycle helmet tends to be made out of a foam material, such as expanded polystyrene. This material crushes or fractures to dissipate the impact energy. [5] Since these helmets can only take a single impact they are not useful for football, where a single player can experience many impacts even in one game.

2.3 Regulatory Agencies and Standards

With the safety of the many athletes in the United States who play football, it is understandable that many agencies produce regulations to make sure protection equipment is adequate. The main agency for the safety of non-professional football players is the National Operating Committee on Standards for Athletic Equipment, or NOCSAE (pronounced “Nock-See”). However, many other agencies publish standards that are relevant to football helmets and their testing. ASTM International also publishes standards that describe the testing and design requirements for football helmets. Standards published by the Society of Automotive Engineers, or SAE, are also used since impact testing of football helmets is similar to impact testing of crash test dummies in cars.

For NOCSAE there are two standards that are most noteworthy for testing of football helmet designs, they are NOCSAE Documents 001 and 002.

Figure 4. An example of the marking a helmet receives when NOCSAE certified

Document 001 describes the test methods for testing headgear. This document describes the test methods as well as the apparatus used to test football and other sports helmets. Document 002 lists the performance specification required for newly manufactured football helmets. It lists things such as the speeds and temperatures a football helmet must be tested at to be certified. If a helmet meets these specifications it receives a marking similar to Figure 4. Another NOCSAE specification of note is Document 004, which lists the specifications for football helmets which are being recertified. Recertification has lower requirements, since the helmet already passed the more stringent newly manufactured specifications.

ASTM also has two standards relating to football helmets. ASTM F429 describes the test method to determine the shock-attenuation characteristics of football helmets and F717 lists the specifications for football helmets. The SAE standard used in football helmet testing is J211-1. This standard describes the electronic instrumentation used for impact tests. It describes methods to determine required sampling frequencies and ranges needed for certain impacts.

3. IMPACT DIFFUSING HELMET DESIGN

There is a new helmet design that is being developed by an inventor. This design's goal is to reduce the risk of concussion in football players from youth to professional. This new design for a football helmet's inventor came up with this idea while watching a game on television. The inventor is Brad Bartholomay, from Santa Barbara, California. Mr. Bartholomay brought his idea for this helmet to Cal Poly professors Peter Schuster and Brian Self to discuss the helmet design and these two professors are now on the committee for this thesis.

Bartholomay's design attempts to lessen the impact felt by the player. The design uses features added to the helmet that try to add to the damping effect of the helmet. There are two experimental samples of this helmet, Experimental Design 1 and 2. These two helmets will be referred to as ED1 and ED2. ED2 is a modification of ED1 which is a modification of a standard, control helmet. Unfortunately, the exact features of the helmet designs that may decrease the concussion risk are proprietary and covered by a non-disclosure agreement. Because of this the designs will not be explained and referred to only by their names.

4. DYNATUP TESTING

The Dynatup test apparatus is the only impact test apparatus owned by the Cal Poly Mechanical Engineering department. It was decided that this apparatus would be used for the testing of Bartholomay's design because impact tests are more representative of the stresses undergone by helmets during a game of football than tests previously run by Mr. Bartholomay.

4.1 Background and Equipment

4.1.1 Purpose of Dynatup Testing

Dynatup testing was conducted so that small scale testing of the helmet designs could be done. The designer of the helmets had a three dimensional model made by additive manufacturing that was previously used by a Senior Project Team in Cal Poly's Industrial and Manufacturing Engineering Department. The testing done by the senior project team; however, did not simulate an impact so a new testing program was desired. Testing these small scale prototypes allowed a quicker turnaround for preliminary results without having to wait for full scale models and a full scale test apparatus to be built.

Figure 5. The Dynatup 8250 that the Mechanical Engineering Departments owns

4.1.2 Dynatup Impact Tester

The California Polytechnic State University's Mechanical Engineering Departments owns an impact test machine called a Dynatup 8250, it can be seen in Figure 5. The machine has a crosshead which is released and accelerated downwards towards a sample by gravity or through a pneumatic cylinder. The machine that the department possesses also has a pneumatically actuated clamp. The clamp uses four pistons to pull a moving plate down which clamps against a stationary plate. The crosshead is able to have a variable weight attached to it to increase or decrease the energy involved in impact. This machine was the impact tester used in the small scale testing for the football helmet prototypes. The crosshead was weighted with a 5.24lbf weight. This weight was chosen because it is the lightest, non-specialty weight so was the safest to use. The Dynatup machine normally has a Tup, a small rod shaped metal impactor with or without a load cell, attached to the crosshead. The tup was replaced for this testing with a specifically designed impactor which carried both the model prototypes, padding from a football helmet, and an accelerometer which was used to measure the acceleration versus time data to be later converted to severity index. The impactor weighed two pounds, bringing the falling weight to 7.24lbf. Instead of the normal sample which would be placed in the pneumatic clamp, an impact surface was placed.

4.2 Apparatus Design and Fabrication

In order to utilize the Dynatup for testing the helmet designs a fixture had to be created to modify the operation of the test apparatus. The fixture was designed in Solidworks and analyzed using hand calculations for the strength of the stem. The fixture was made of two parts, the impactor assembly and the base. The drawings for this fixture are included in APPENDIX A: Dynatup Fixture Engineering Drawings and the fixture can be seen in Figure 6.

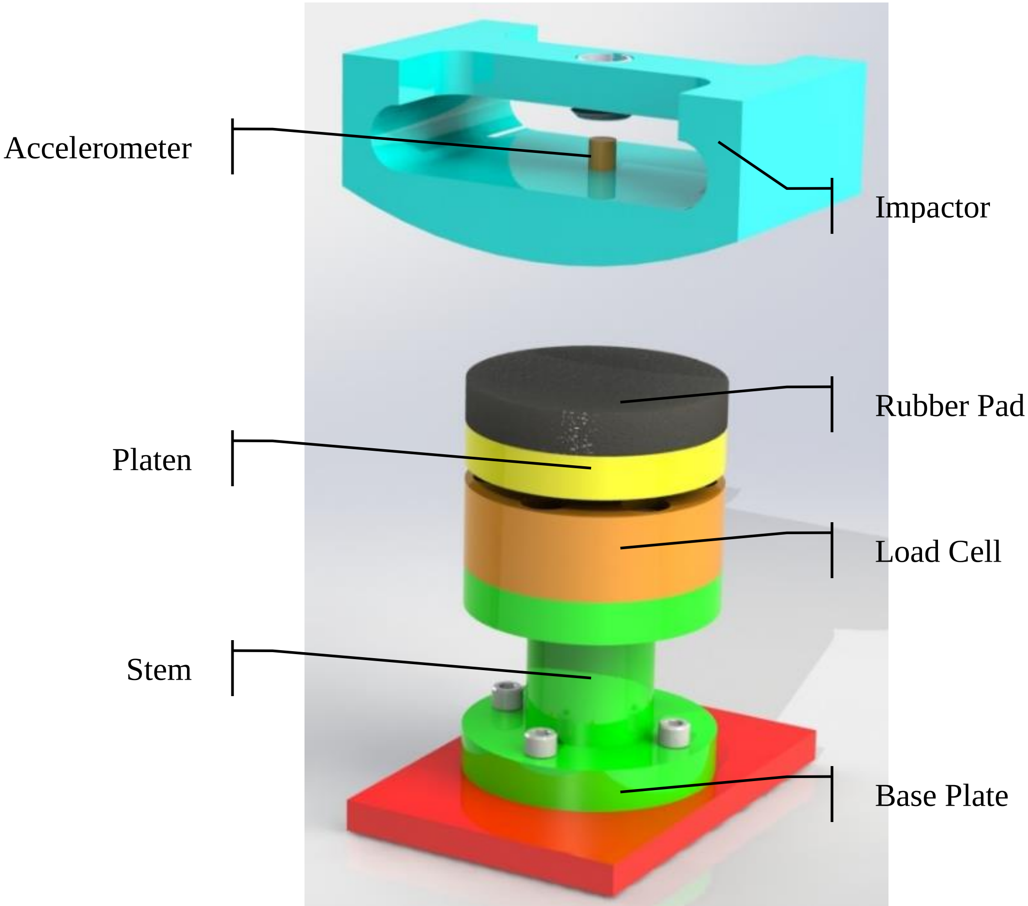


Figure 6. Model of the small scale test fixture

The blue part in Figure 6 is the impactor. It holds the model of the experimental and control helmets. The impactor also holds an accelerometer which is used to quantify the impact. The impactor is held to the crosshead of the Dynatup with the same bolt which is normally used to hold tups onto the machine. The impactor was made of Aluminum 2024 and machined using a CNC mill in the Cal Poly Mustang '60 machine shop.

The other parts in the model make up the base. The purpose of this subassembly is to provide a surface for the impactor to hit. The surface which the impact occurs on is shown as the black piece in Figure 6. The black piece is a piece of Buna-N Rubber with a durometer of 40A. This durometer is specified by NOCSAE to be 38A ± 5 [3]. The specification is for a specific rubber pad called an MEP pad, however these pads are very expensive so the Buna-N pad was substituted. Buna-N was chosen because it was the only rubber available with the correct durometer rating. This pad is attached with adhesive to the platen, yellow in the figure. This platen is used to transmit the force of the impact to a load cell, shown in orange. The platen was machined on a lathe out of Aluminum 7075. The load cell used in this apparatus was an Omega LCH-1K 1000lbf load cell. The load cell is supported by the stem shown in green. This was also machined out of 7075 Aluminum. The stem was analyzed to ensure that it would not fracture or yield under repeated impacts. The stem was analyzed because it has the smallest diameter and the stepped shaft makes it susceptible to stress concentrations.

The first analysis carried out on the stem was an impulse momentum calculation to determine the force that the falling impactor will impart on it. Using the mass of the impactor and the speed at which it falls, 17.94 ft/sec [8], the force can be determined to be 852 lbf. This is calculated using an estimated impact time of one millisecond. The stress in the stem was then calculated to be 3736 psi. This is with the stress concentration factor of the flat bottom groove. Without the concentration factor the stress is only 482 psi. The final step in the calculations was to do fatigue calculations. This determined that for 7075 aluminum the stem is good for over 1000 impacts with a factor of safety of seven.

The stem is held in place by the base plate, in red. The pneumatic clamp of the Dynatup clamps down on the base plate to hold the base of the test fixture in place. The completed base fixture is shown in Figure 7.

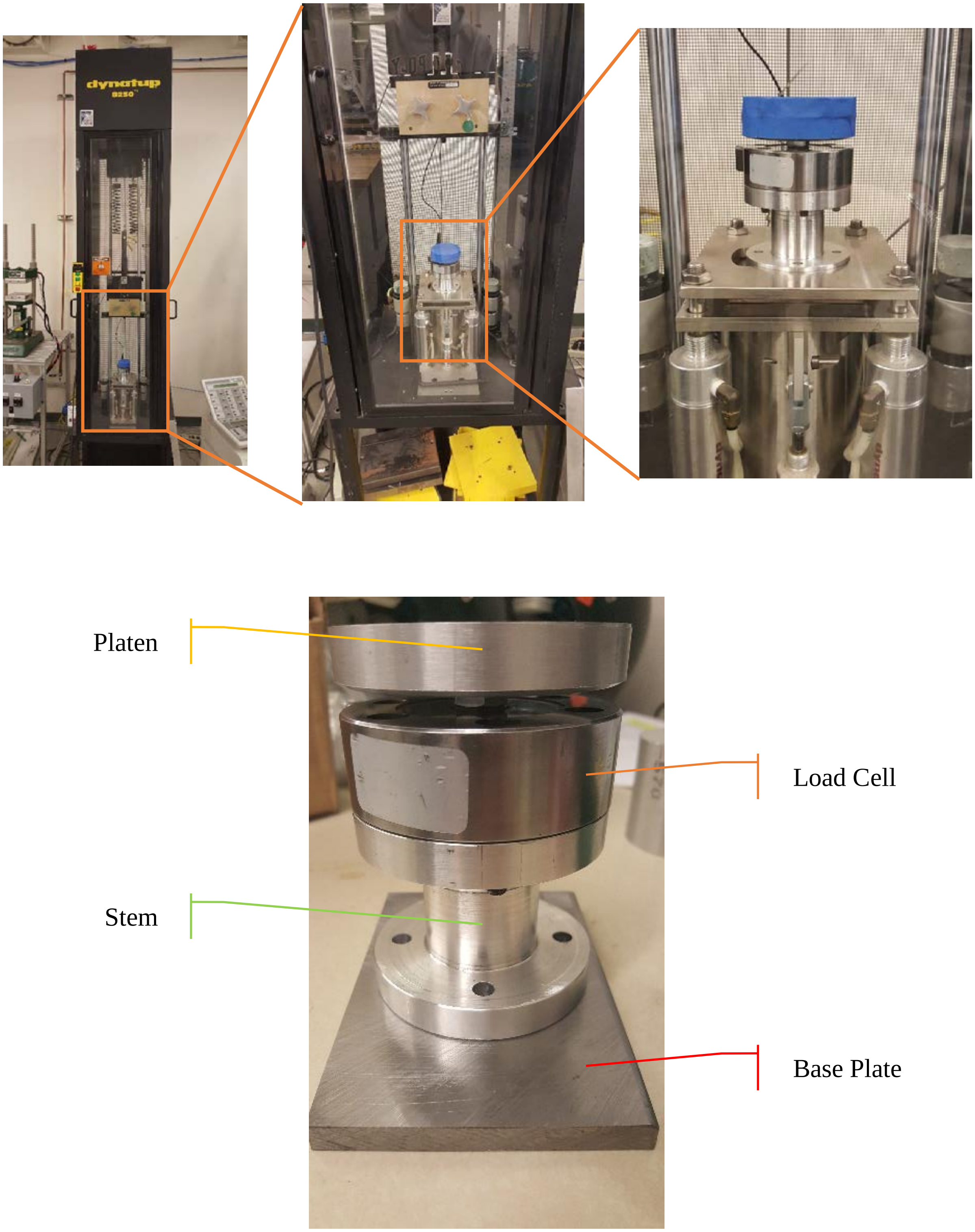


Figure 7. Dynatup test fixture base shown separate and installed in Dynatup

4.3 Test Method

The test fixture which was created for the Dynatup was placed in the machine as shown in Figure 8. The accelerometer used for this test was a PCB 353B15. This is an ICP type accelerometer with a rating of 500g's. The accelerometer was attached to a signal conditioner to allow the data from accelerometer to be measured by the data acquisition system. The DAQ used was an LDS Dactron Focus II. It is normally used as a signal analyzer, but for this testing was merely used as a recording device. The sampling frequency used for this impact event was 16384 Hz. This frequency was picked using the

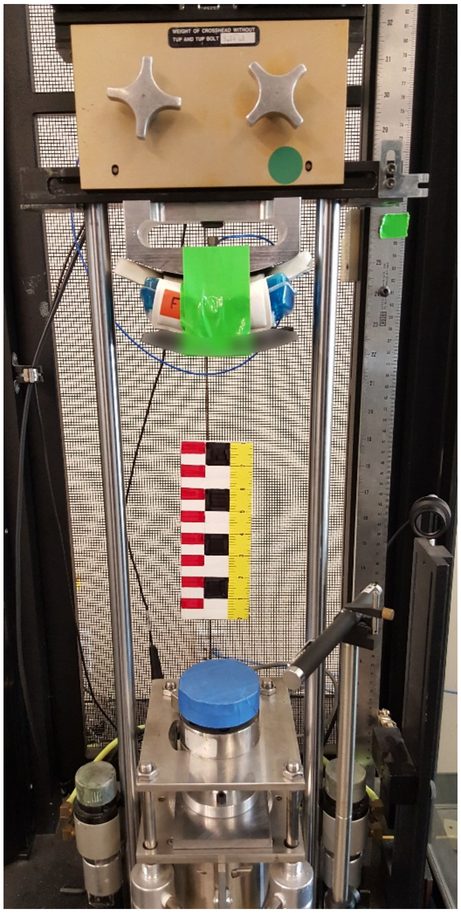


Figure 8. Set up for a test run, sample attached is blurred due to the NDA

charts and tables that are presented by SAE in their specification relating to impact test instrumentation. [9]

The experimental samples; ED1, ED2, and the control; were attached to the impactor with standard padding from a Schutt football helmet sandwiched in between the impactor and the sample. The experimental samples were held to the impactor with duct tape. There were six sets of experimental conditions that were tested in the small scale testing phase. Each of the samples was dropped from two heights, a one foot drop and a two foot drop, to enable different drop speeds to be tested. For each of these different condition sets, ten test runs were conducted to ensure a statistical sample.

The initial test plan included using the load cell to corroborate the accelerometer data. This, however; was not possible due to the load cell readout possessed by the Mechanical Engineering department at the time of testing was inoperable. This led to the load cell not being used for the small scale tests.

The data that was recorded for each test run was the acceleration measured by the accelerometer. This was then processed to determine the Severity Index for each run. Additionally, for the first three test runs of each experimental condition the impacts were recorded with a high speed camera recording at 5000 frames per second. Using a scale in the background, the speed of the drops could be calculated by determining the number of frames that the impactor took to drop one inch.

MATLAB was used to analyze the data once the tests were complete. Two MATLAB scripts were written, one to analyze the SI value of a single test and one to analyze the SI of multiple test runs to find an average SI. The scripts can be found in APPENDIX B: Small Scale Testing Analysis MATLAB Code.

4.4 Results and Analysis

The tests were carried out over the course of two days, with all of one height of test done in one day without adjustment. The mean SI was analyzed for ED1 and ED2 at both drop heights and then compared to the control's drop tests.

In order to help analyze the results, a new value was used. The value used is the Energy Dispersion Coefficient, or EDC. The EDC is a value not used by other researchers and was created for this research. This value is the ratio of the second to first impulse, shown as a percentage. The EDC was used as an alternative to the Coefficient of Restitution, known as COR. Originally, COR was to be used but its calculation was unreliable due to the difficulty in determining the arrival and departure speeds of the helmet from the impact pad. Alternatively, EDC is easily calculated from the accelerometer data and is calculated using the same MATLAB scripts used to calculate SI.

The data were refined first by a 4 pole Butterworth low pass filter with a cutoff frequency of 1000 Hz, as required by NOCSAE, and then processed by setting any value of acceleration that is less than 4 g's to zero. This is because the calculation of SI is only triggered once the acceleration passes above 4 g's and is ended when it drops back below

4. Once the data is processed, the MATLAB code identifies the first impulse of the data and determines the SI from that. It then finds the second peak and determines the EDC from both the first and second impulses.

Table 1. Small Scale test results from 1ft drop height for all three helmet types

Control from 1 ft			Experimental Design 1 from 1 ft			Experimental Design 2 from 1 ft		
Run	SI	EDC	Run	SI	EDC	Run	SI	EDC
1	161.29	41.87	1	135.00	42.50	1	135.22	42.01
2	164.04	42.33	2	134.99	42.77	2	136.03	42.74
3	166.53	42.10	3	135.07	42.30	3	136.97	42.84
4	167.04	42.41	4	133.62	42.96	4	136.74	42.39
5	165.57	42.75	5	134.69	42.65	5	134.32	42.46
6	161.42	42.18	6	135.30	41.70	6	135.99	42.16
7	162.04	41.25	7	137.01	42.31	7	136.73	42.36
8	165.27	42.23	8	133.21	42.06	8	134.54	42.36
9	167.19	42.33	9	134.84	42.60	9	135.74	42.50
10	164.67	42.00	10	135.33	42.07	10	134.47	42.75
11	166.02	42.12	11	132.73	42.94			
12	165.93	42.29	12	134.67	43.09			
13	164.93	42.57	13	134.58	42.82			
			14	135.19	43.12			
			15	134.69	42.94			
MEAN	164.76	42.19		134.73	42.59		135.68	42.46
DEVIATION	2.03	0.36		0.96	0.41		1.00	0.26

The one-foot drop results are shown in Table 1 and represented as a boxplot in Figure 9. For the control and ED1 samples extra runs were conducted.

The data, first impulse, and EDC calculation are all plotted by the MATLAB script. The data from one of the 1ft drop height control test is shown in Figure 10. It can be seen from the plot of the data that this test has 6 discernable impact events, each peak coinciding with the helmet bouncing on the impact plate. It is also seen that the filtering of the data reduces the peak acceleration seen by the helmet specimen. This reduction in peak value is why the filter used for the data is standardized. From the plot of the single impulse it is observed that the control impact event shown had an impulse time of about

13 milliseconds and a peak acceleration of about 75 g's, this is consistent with the other control drops from 1ft.

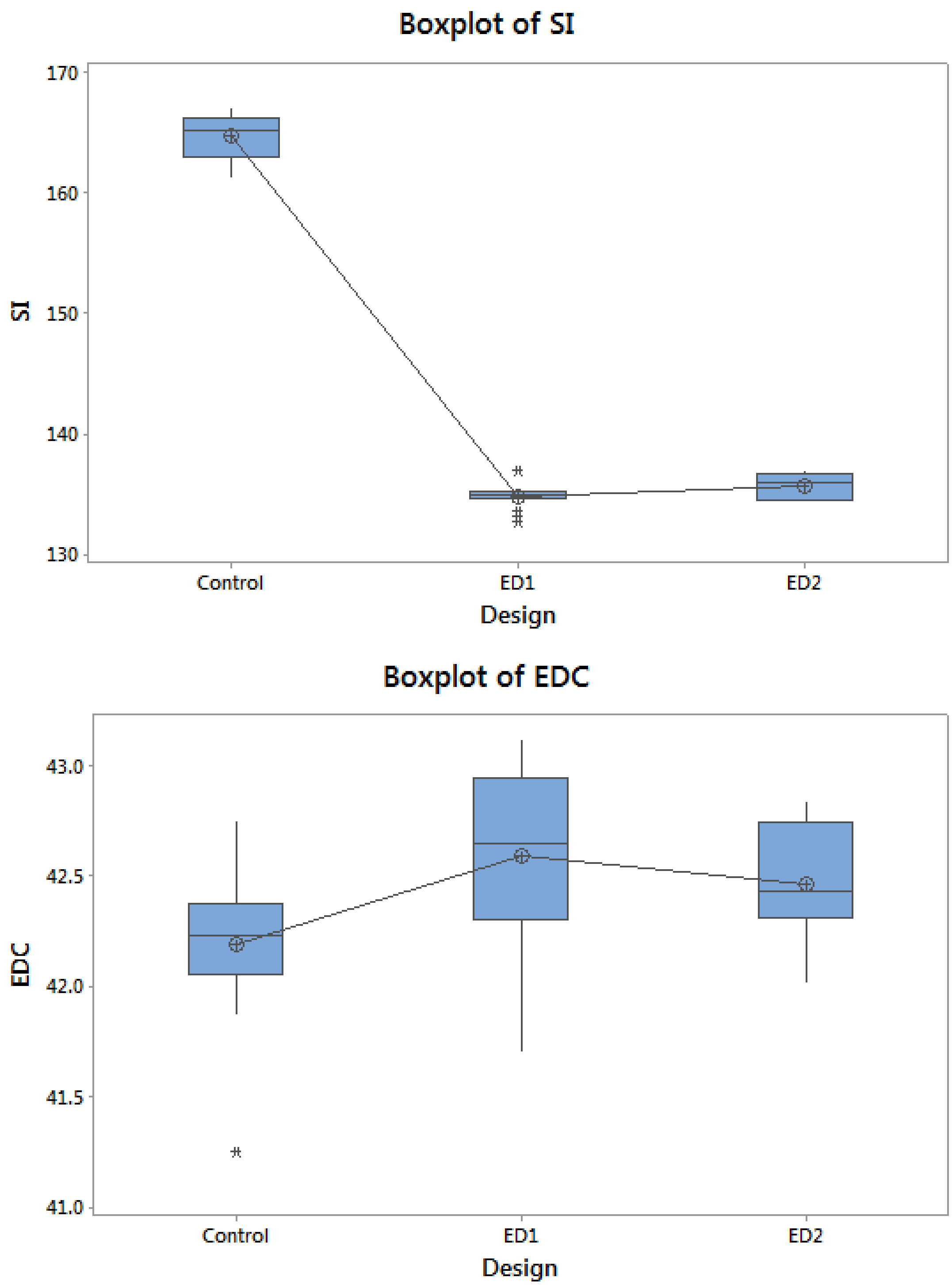
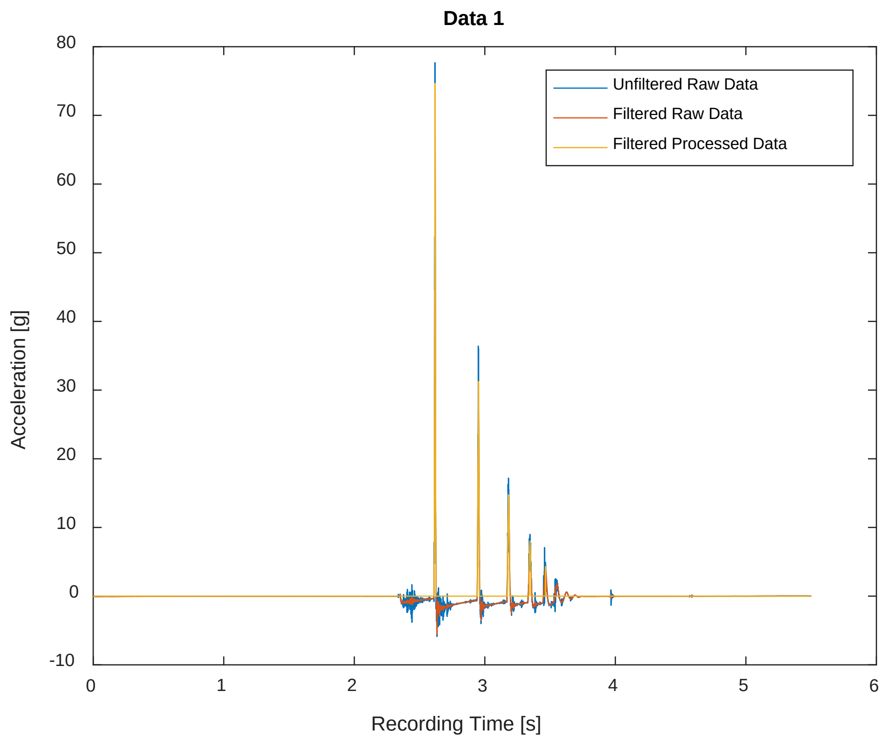


Figure 9. Boxplots for SI and EDC for the 1 ft drop tests



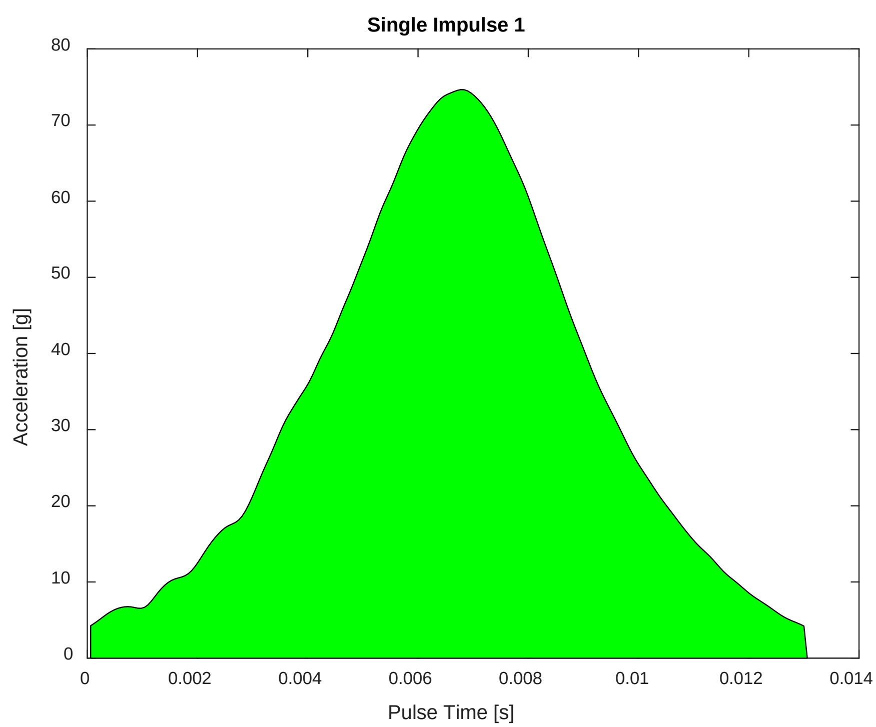


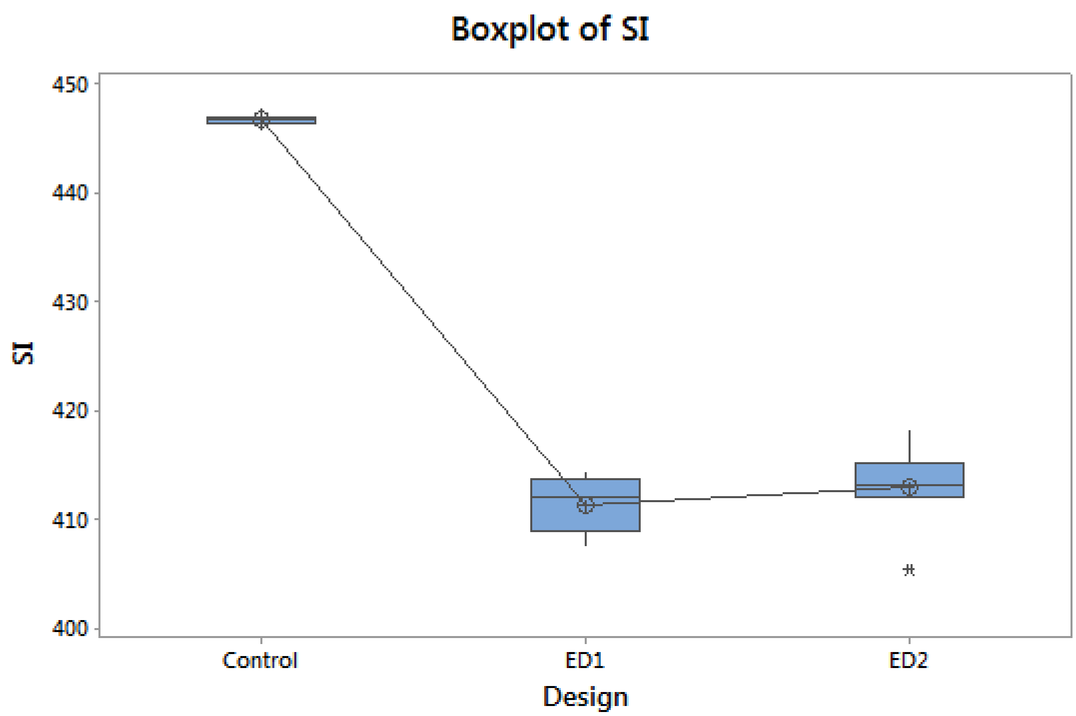
Figure 10. Raw, filtered, processed data from 1ft control, the processed first impulse

Table 2. Data from the small scale two foot drop height tests

Control from 2 ft			Experimental Design 1 from 2 ft			Experimental Design 2 from 2 ft		
Run	SI	EDC	Run	SI	EDC	Run	SI	EDC
1	446.66	49.92	1	408.89	37.09	1	405.33	37.86
2	447.22	49.46	2	412.06	37.21	3	418.30	38.47
3	445.72	50.36	3	412.52	36.44	4	411.99	37.68
4	447.00	50.31	5	407.47	37.20	5	413.05	38.07
5	447.88	50.69	6	413.66	36.86	6	416.54	38.25
6	446.38	50.44	9	409.92	38.50	7	413.44	36.52
7	446.69	50.11	10	414.34	37.64	8	412.00	37.19
8	446.83	49.80				9	412.04	38.31
9	446.83	50.27				10	413.67	36.76
10	446.54	50.28						
MEAN	446.77	50.16		411.26	37.28		412.93	37.68
DEVIATION	0.56	0.35		2.56	0.65		3.59	0.70

The two foot drop data is shown in Table 2 and represented as a boxplot in Figure 11.

The raw data and impulses are similar to the 1 foot drops. The differences are that the 2 foot data has a higher peak as well as a longer impact time, both leading to a higher calculated SI. There are some tests runs missing from the tables due to errors in triggering the DAQ and the first impulse not being recorded correctly.



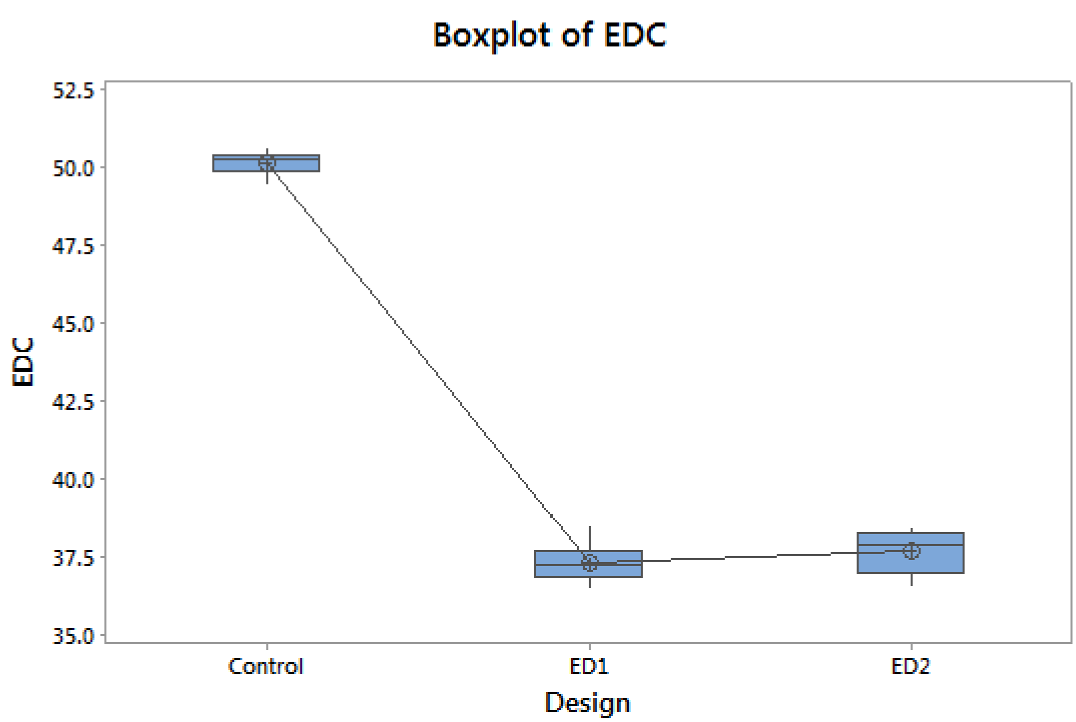
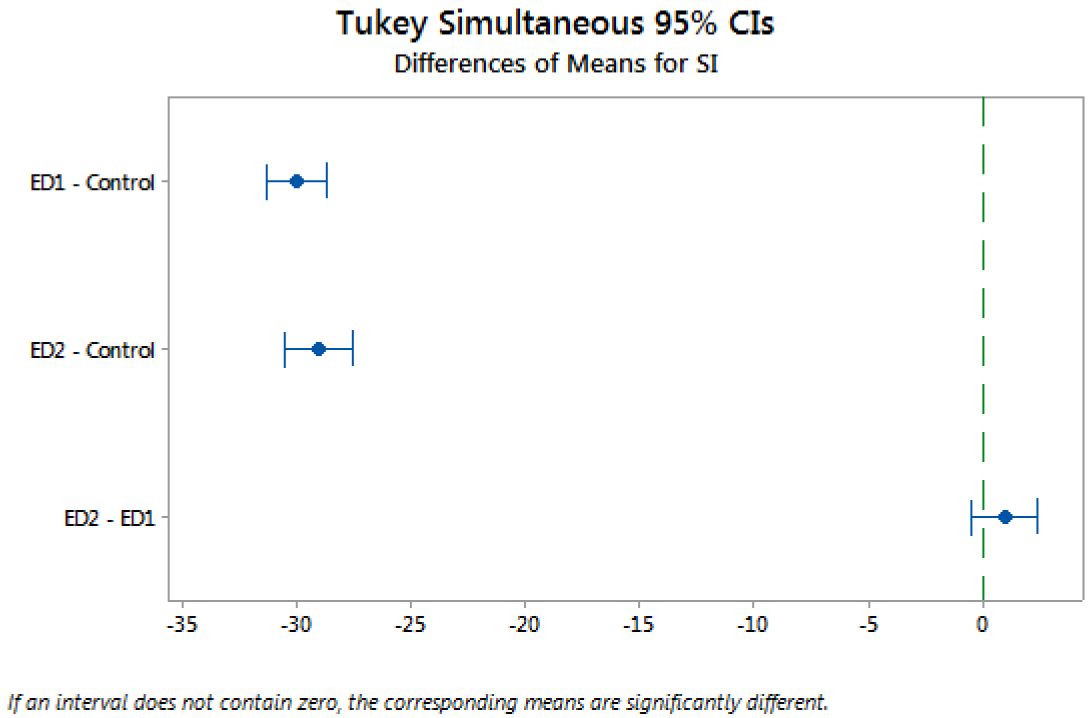


Figure 11. Boxplots for SI and EDC for 2ft drop heights

4.5 Test Specific Conclusions

The small scale tests were conducted to get an idea of whether the design enhancements present in ED1 or ED2 reduce the SI values of the potential designs. In order to make a conclusion from the data that were collected during the small scale tests, a one way ANOVA was used. From the ANOVA, a Tukey comparison was run. These statistical analyses were run in Minitab 17. The Tukey comparisons are able to compare the control, ED1, and ED2 all to each other and determine whether the means of each sample are statistically different from the other means.



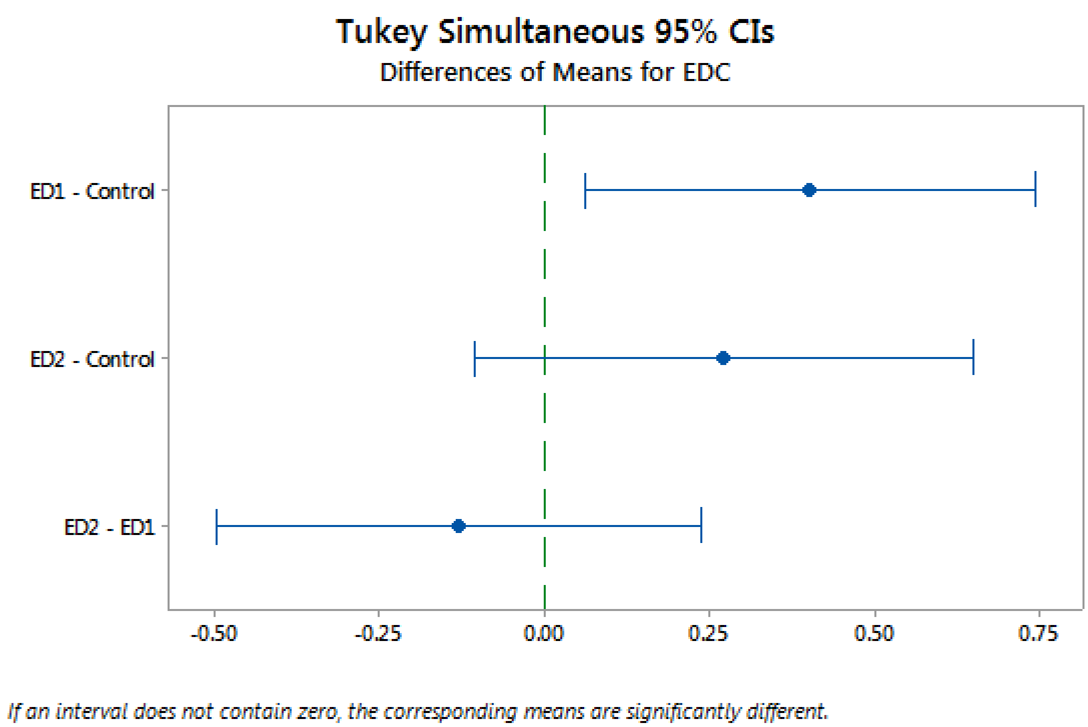
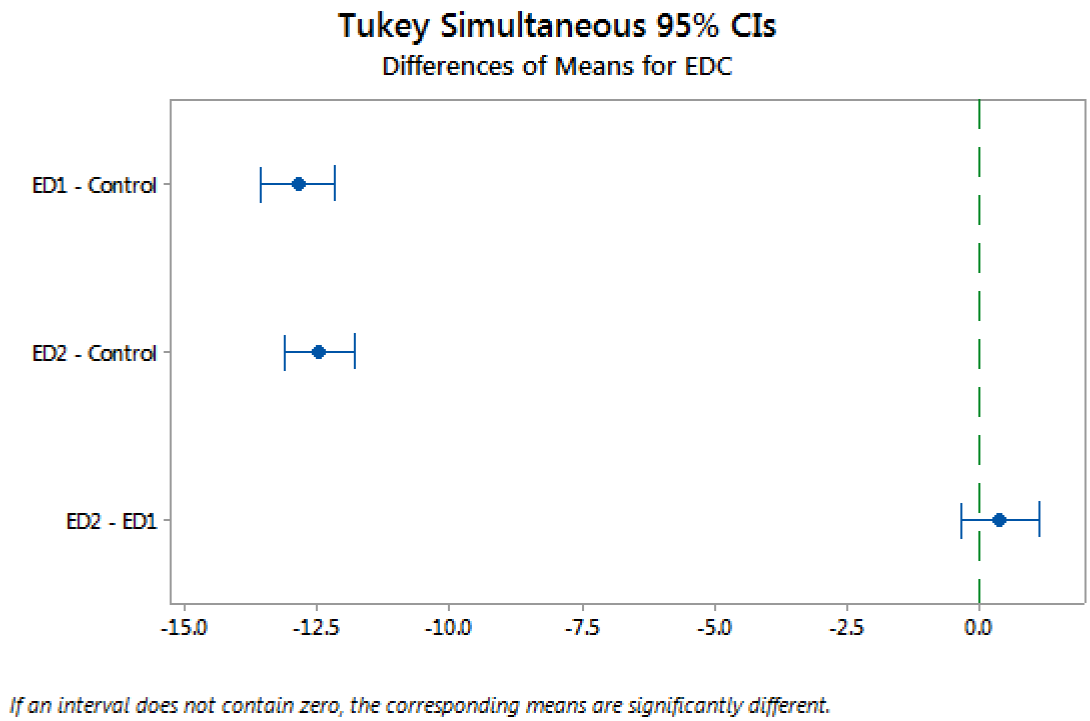


Figure 12. Tukey comparison plots for 1ft drop height of SI and EDC



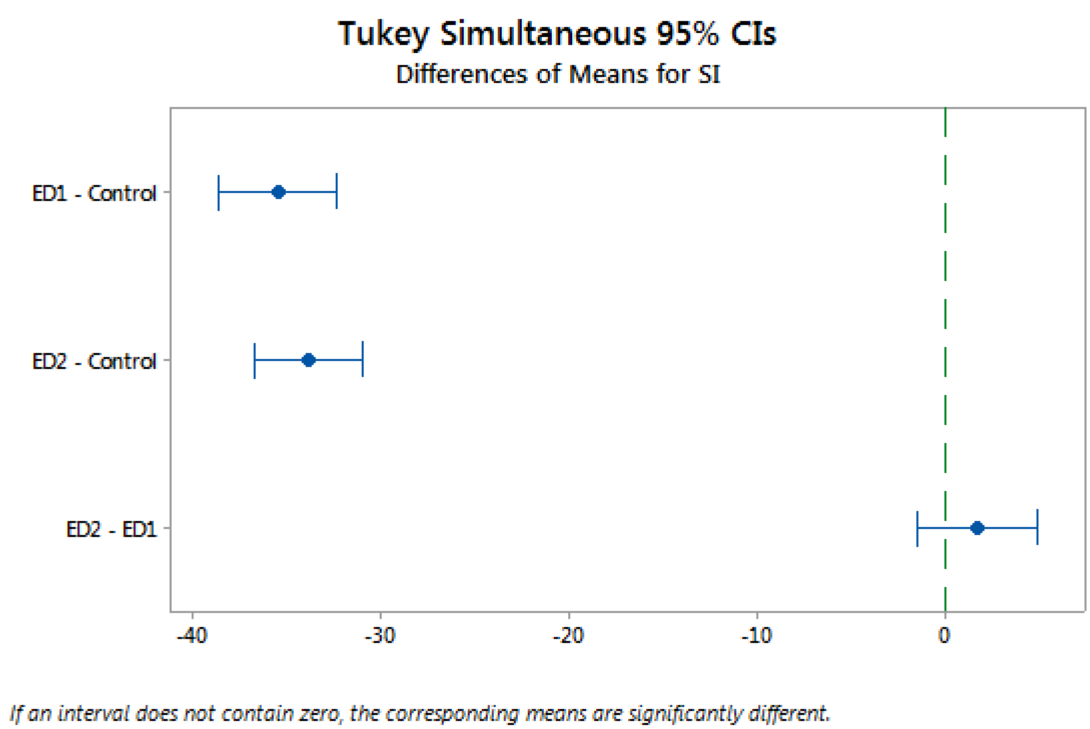


Figure 13. Tukey comparison plots for 2ft drop height for SI and EDC

Figure 12 shows the conclusions from 1ft drop tests. It shows that for SI, both ED1 and ED2 perform better than the control helmet. The SI is reduced by 18% by using the design of ED1 versus the control. ED1 and ED2 are not statistically different. It also shows that with respect to EDC, the ED1 specimen performs better than the control but ED2 does not.

The conclusions from the 2ft drop tests are shown in Figure 13. The two foot drops show a statistical difference between the control and the ED1 and the control and ED2, but not between ED1 and ED2. The reductions in SI values versus the control are 8%. There is also 1% increase in EDC between the experimental designs and the control.

Between the 1ft and 2ft drop test regimes conclusions can be made about the specific test presented in the small scale testing. It was determined that both ED1 and ED2 reduce SI value. However, the differences between ED1 and ED2 are negligible. Because of this, ED2 was dropped from future test regimes as well as the computer modeling conducted by Steven Warnert. [10]

The reduction in SI was lower for the 2ft drop than the 1ft drop. As much as it may be desired to find some sort of trend in this fact, it would not be a valid conclusion. This is because an infinite number of lines can be drawn between the two points of varying curvatures. All that is known is that from a 2ft drop the prototypes performed worse than they performed from a 1ft drop.

All the conclusions made from the small scale tests are only truly applicable to the prototypes used in the testing. The prototypes that were provided by the project sponsor were very different from the way the designs would actually be implemented in real production. This means that the conclusions made from the small scale tests must be taken with the knowledge of their limitations, such as the non-real world proportions of the prototypes and the incorrect material.

5. FULL SCALE TESTING

It was determined that full scale testing was required in order to make a final determination on whether Mr. Bartholomay's design enhancements have merit. Unfortunately, Cal Poly did not possess a device which would be able to accommodate the testing of a full size helmet. It was decided a purpose built impact tester would be constructed to accomplish the required testing. The design and manufacture of this apparatus was a major portion of the work for this thesis.

5.1 Background

Full scale testing of football helmets is the standard test method used in industry. These tests are done to either NOCSAE or ASTM standards with NOCSAE being the most common. Testing of football helmets has become a top priority for the sports industry to achieve reductions in concussion risk.

5.1.1 Regulatory Standards

The full scale testing of the designs was done as close to the standards set forth by NOCSAE in Document 001. The drop test device specified by NOCSAE is designed by the Southern Impact Research Center, or SIRC, and is a twin guide wire drop tower. The drawings provided by SIRC can be found in APPENDIX C. The drop tower specified by ASTM is very similar to that specified by NOCSAE, seen in Figure 14. [11]

The requirements that the helmets must be tested to are specified in NOCSAE Document 002. [8]

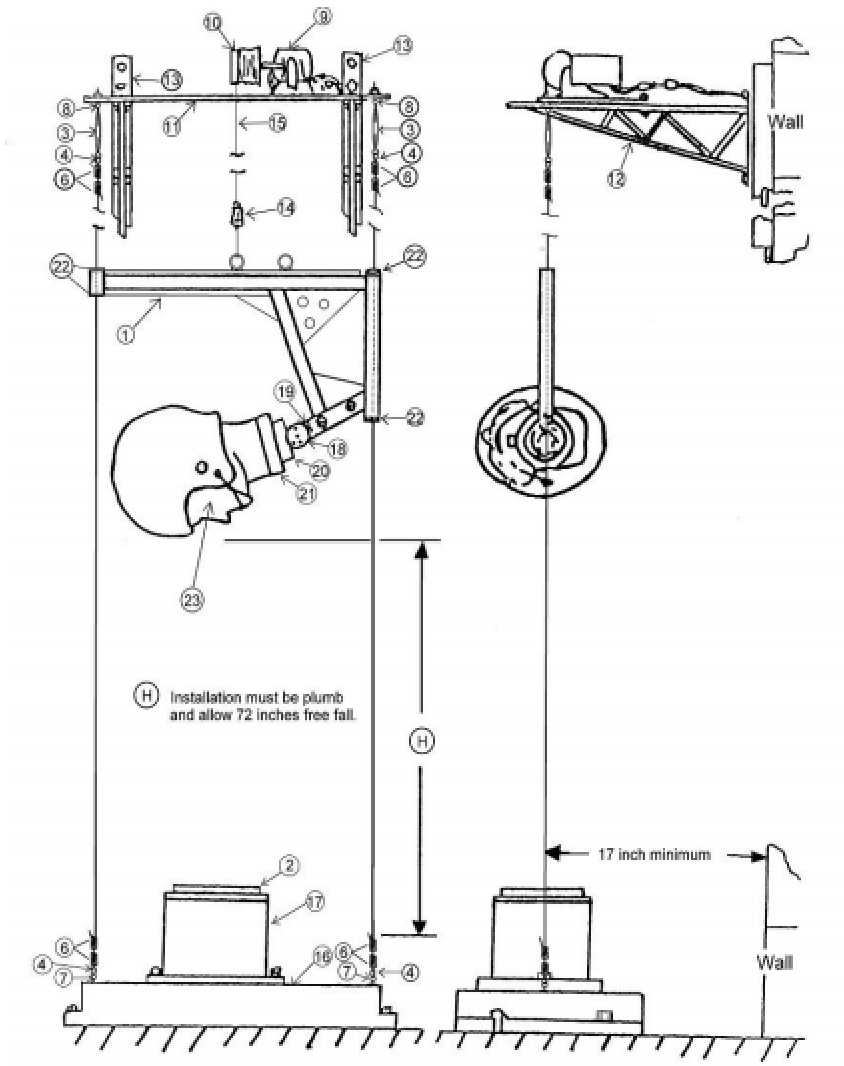


Figure 14. NOCSAE specified drop tower design

5.1.2 Other Helmet Testing Methods

There are two main categories of helmet test machines: drop towers and impactors. A drop tower uses gravity or other methods to accelerate the helmet into an impact surface guided by some sort of system into the surface. Impactors instead move an impactor into the helmet while the helmet remains mostly stationary.

There are two main types of drop towers, the twin wire and the monorail. Both NOCSAE and ASTM football helmet testing specifications specify twin wire systems. [3] [11] Twin wire systems use two tensioned wires as the guides to ensure the helmet impacts the correct spot. Wire guided towers allow the helmet to move slightly more freely due the flexible nature of the wires. Monorail towers on the other hand use a single rigid support with a roller system to guide the helmet into the impact surface. This system is much more rigid.

Impactors come in several types. Everything from pneumatic rams to pendulums are used to accelerate an impactor into a helmet. In many of these systems the helmet is mounted on a crash test dummy headform, sometimes able to slide to simulate the compliance of the human neck. Impactors specifically made for baseball batting helmet testing fire baseballs with pneumatic cannons into the helmet.

5.2 Apparatus Design and Fabrication

In order to carry out the testing of full scale helmets a testing apparatus had to be designed and built. In order to stay as true as possible to the design set forth by NOCSAE, the design was based upon NOCSAE's design with some modifications for

Figure 15. The NOCSAE style drop tower designed for Cal Poly

Cal Poly's purposes. Specifically, changes were made for portability and cost. Normal NOCSAE drop towers are fixed in place and permanently attached to a wall; this new design, however, can be moved anywhere and only requires four floor mounting points. The drawings for the design can be found in APPENDIX A and the tester can be seen in Figure 15. The drop tower was funded by grants from a College of Engineering R-IDC, Returned Indirect Cost, grant and a Cal Poly university Baker-Koob grant. A majority of the apparatus was constructed by Michael Schuster with assistance from Steven Warnert and the Mechanical Engineering shop technicians in the Mechanical Engineering department's machine shops. The Bill of Materials is included in APPENDIX D: Helmet Drop Tower Engineering Drawin.

5.2.1 Frame

The frame of the drop tower is one of the main differences between the drop tower designed for Cal Poly and the standard drop tower per NOCSAE specifications. In the NOCSAE specifications the drop system is attached to a wall and the floor. This was not possible at Cal Poly due to university rules not allowing things to be attached to the buildings. Attaching the test fixture to a building also would require a space where the fixture could stay permanently.

To accommodate a portable system a frame was designed. Its purpose is to hold the entire system together. The frame supports the system as well as provides a method of rigidly attaching the system to the ground. There are three parts of the frame: the baseplate and lower frame, the hinge assembly, and the upper frame.

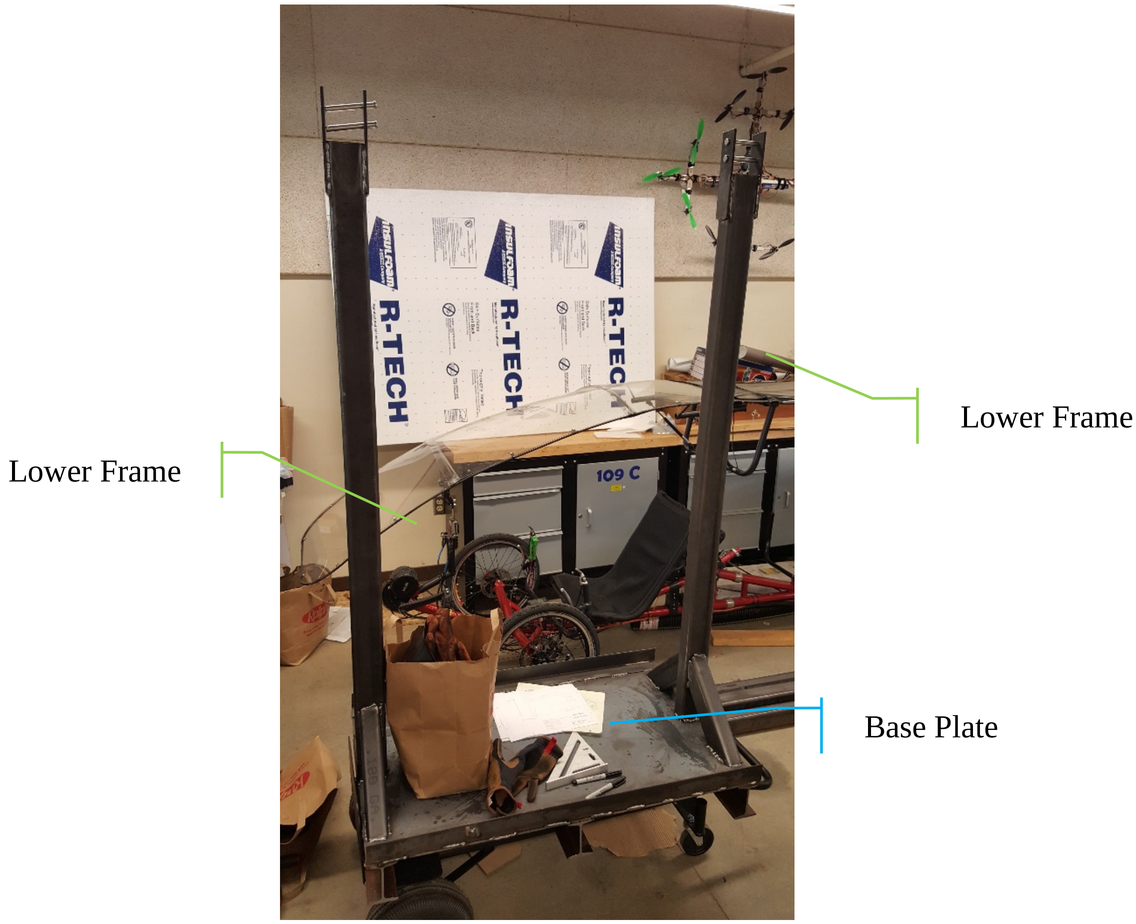


Figure 16. Bottom frame of the drop tower

The baseplate and lower frame is the bottom portion of the structure and can be seen in Figure 16. Starting from the bottom is the base. The base is sized similar to a standard pallet. This allows a standard forklift or pallet jack to move the system around campus. Resting on top of the base is the impact surface, a Buna-N rubber pad. This pad is specified by NOCSAE to be a durometer of 38A ± 5. The actual pad that NOCSAE specifies is called a MEP pad. [3] This pad was not used because it was too expensive, costing around $600 for a single pad. Another difference from the standard NOCSAE design is in the baseplate. Whereas the NOCSAE design uses a sliding anvil as an impact surface, this design uses the top surface of the baseplate with a much larger impact area.

There are mounting holes on the baseplate which allow the structure to be rigidly attached to a strong floor with a one-foot rail spacing. Additionally, concrete anchors could be purposefully sunk to attach the structure to the ground. Bolting the structure to the ground allows it to be lighter without having to worry about the structure moving during impacts. Attached to the base plate are the two lower frame beams. Like the rest of the frame beams, the lower beams are made from 2x3 inch steel tubing with 3/16 inch walls. This tubing was chosen because of availability and cost.

The hinge system connects the upper and lower frame sections as seen in Figure 17. The

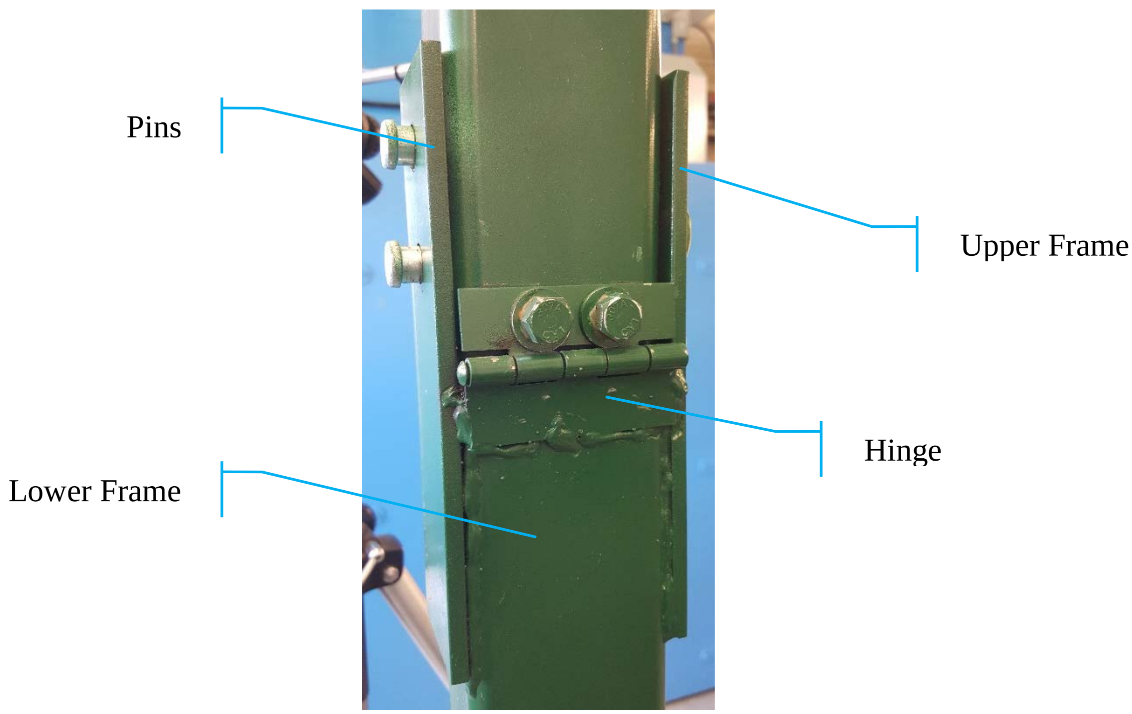


Figure 17. Hinge section of frame

purpose of the hinge is to allow the frame to collapse to a height which will fit through a standard door frame. This adds to the portability of the system. The lower portion of the hinge is welded to the lower frame and the upper portion is bolted to the upper section. This enables slight misalignment of the frame sections. The sections are held upright with clevis pins running through plates welded to the lower frame and cotter pins. These pins are supported in double shear and ideally support limited load if the frames are properly aligned and assembled. This is due the fact that the upper frame will rest on the lower frame when assembled.

The upper frame is made of three beams. The two side beams are bolted to the hinges. The top beam is drilled to accept the eye bolts from the drop system. The entire frame can be seen in

Figure 18.

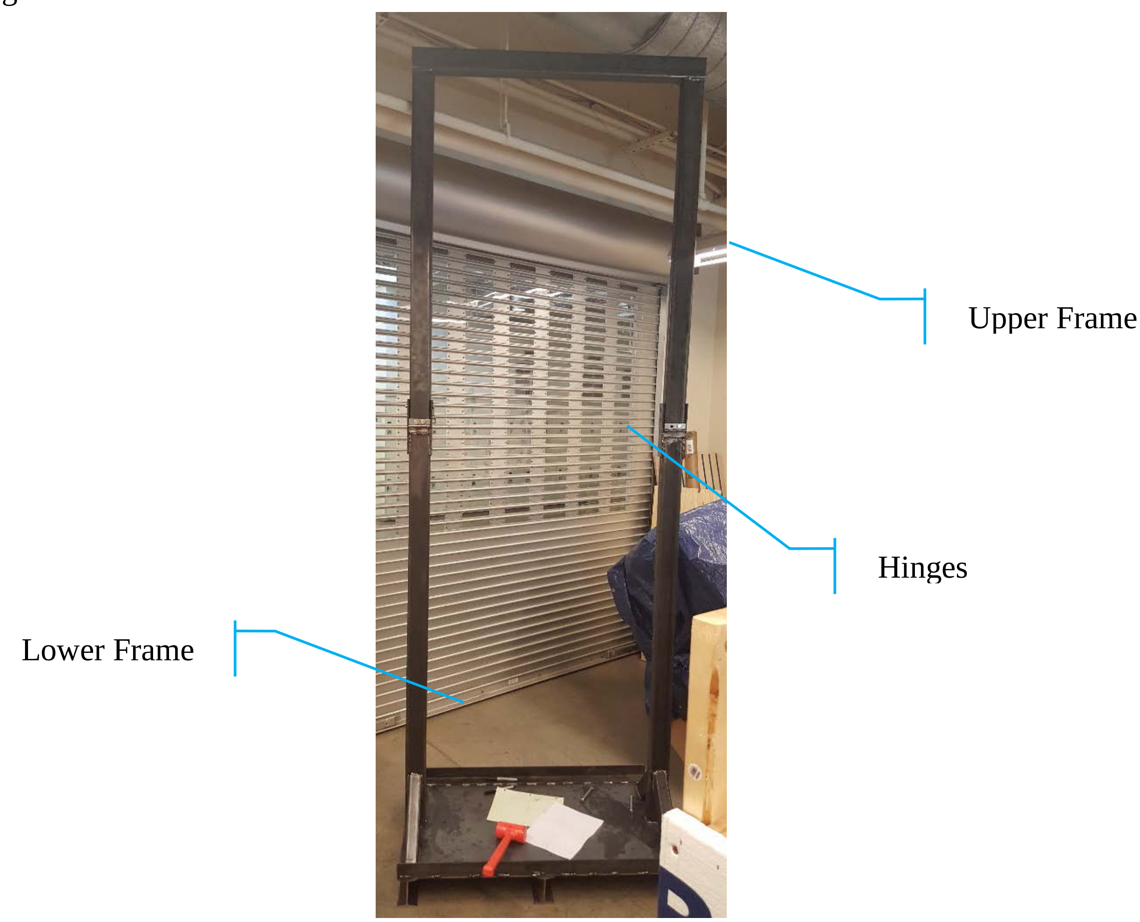


Figure 18. The entire unpainted frame

The frame was analyzed for both bending of the top beam and buckling of the upright supports. The cables of the drop system are tensioned to 300lbf [11]. This specification is per ASTM standards as NOCSAE does not specifically give a tension requirement. These calculations gave a factor of safety for buckling of greater than 8 and a deflection in the top beam of around 0.006 inches. Both of these values are acceptable.

5.2.2 Drop System

The drop system consists of all of the rigging and parts used to actually drop a helmet into the impact surface. The drop system has the following major parts: the cabling, the lift bar and winch, and the carriage.

The cabling consists of the steel cables and the rigging required to keep the cables under

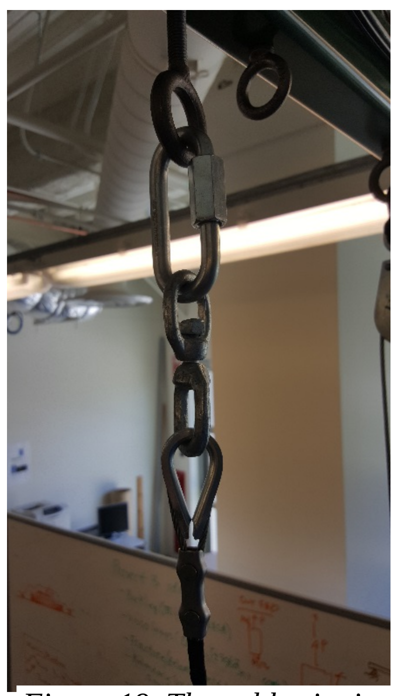


Figure 19. The cable rigging to connect the cable to the upper frame

tension. The cables themselves are one-eighth inch diameter galvanized steel cables with tensile strengths of 400lbf. These cables were chosen because they were the strongest commonly available cables with the required diameter. To keep the cables under tension, an eyebolt with a long thread is run through the top beam of the frame. Each eyebolt is then tightened with a serrated locknut to provide the tension. The base of the cabling is attached to an eyebolt in the baseplate. The cable ends are finished with thimbles to protect the cables and wire clamps. To attach the cables to the eyebolts screw links are used. Between the cable and the top screw link is a rotating link to allow the top eyebolt, which provided the tension, to be turned. The upper rigging is shown in Figure 19. The cabling tension was not measured for this series of testing due to the lack of a method to measure it. There are commercially available devices designed for measuring the tension in rigging, such as sailboat rigging, which could be used but were unavailable for this testing.

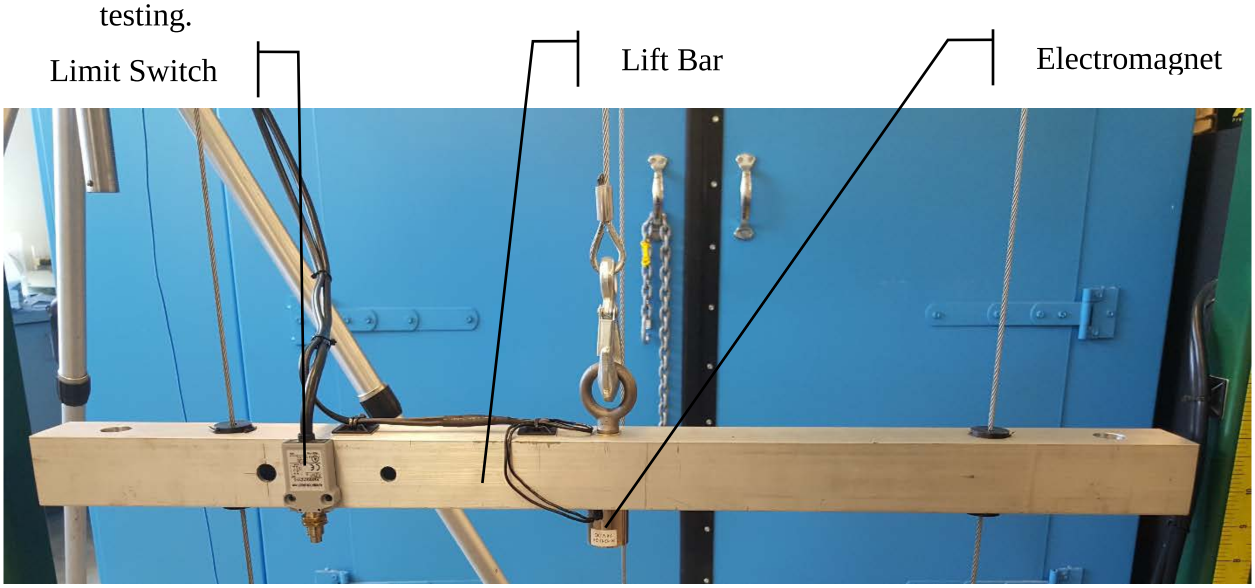


Figure 20. The lift bar showing the electromagnet, the limit switch, and the eyebolt

The lift bar is the assembly which is responsible for lifting and releasing the carriage, it is seen in Figure 20. It is an aluminum bar which runs along the guide wires. To reduce the friction with the cables, delrin bushings are used. These bushings were designed by SIRC. The bar is lifted and lowered by the winch, which is attached by an eyebolt screwed into a threaded insert. The carriage is held in place as well as released by an electromagnet. The magnet has a pull force of 50lb. The magnet attracts a steel plate attached to the carriage. Additionally, the lift bar holds a limit switch to stop the winch from being able to lower it once the carriage is engaged. The lift bar is under very little stress since the only load is the aluminum carriage and so was not analyzed for strength.

Figure 21. Harbor Freight winch responsible for positioning of lift bar

The winch, shown in Figure 21, is a standard 120 VAC winch available from Harbor Freight. It is rated for 1500lb but is only used to lift the lift bar and carriage which together weigh less than 2% of the rated load. The only modification made to the winch was the removal of the standard control pendant and wiring it into the control system. The winch is mounted to the angle iron on the base plate. The winch cable is run through pulley attached to the top bar of the frame with a shackle.

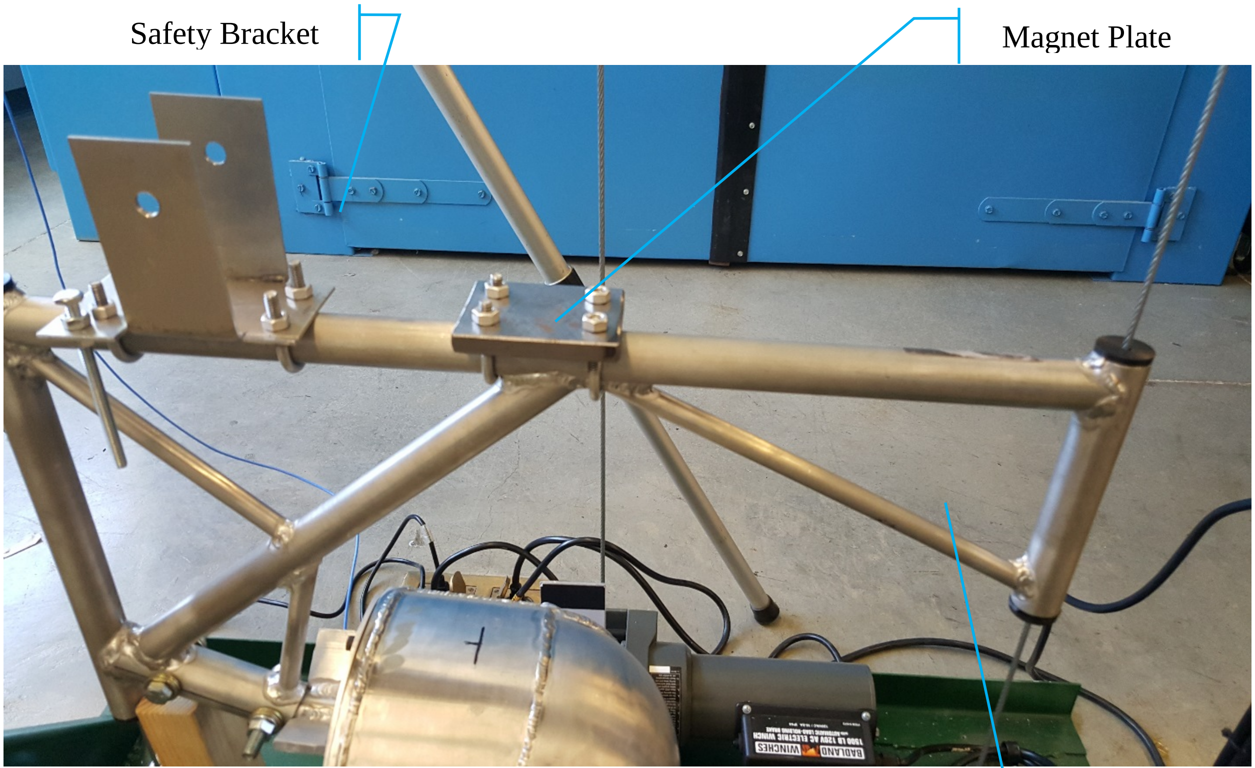


Figure 22. SIRC designed carriage

The carriage is the part of the drop tower which actually drops. The carriage holds the headform or any other item being tested. The carriage with the headform attached is shown in Figure 22. The carriage for the most part was designed by SIRC and is made mostly of Aluminum 6061. The SIRC design was chosen because it matches the requirements set forth in the NOCSAE standards and would be the hardest part to change if full certification was desired on the machine. Two parts were added to the carriage. The first is a steel plate attached to the top bar near the middle of the carriage. This plate is what allows the electromagnet to attract the mostly nonferrous carriage. Also attached is the safety bracket. This bracket serves two purposes. The first purpose is the enable a pin to be run though it and the lift bar to ensure the carriage cannot drop even if the electromagnet loses power. This increases the safety for an operator working on the machine. The bracket also is what pushes the limit switch on the lift bar. A screw can be adjusted up and down so that the limit switch is activated in the correct spot. Both the added features, the magnet plate and the safety bracket, are attached to the carriage with aluminum u-bolts. The carriage was designed by SIRC and is used on many drop towers so did not need any further analysis of its strength.

Figure 23. The safety bracket attached to the carriage

5.2.3 Headform

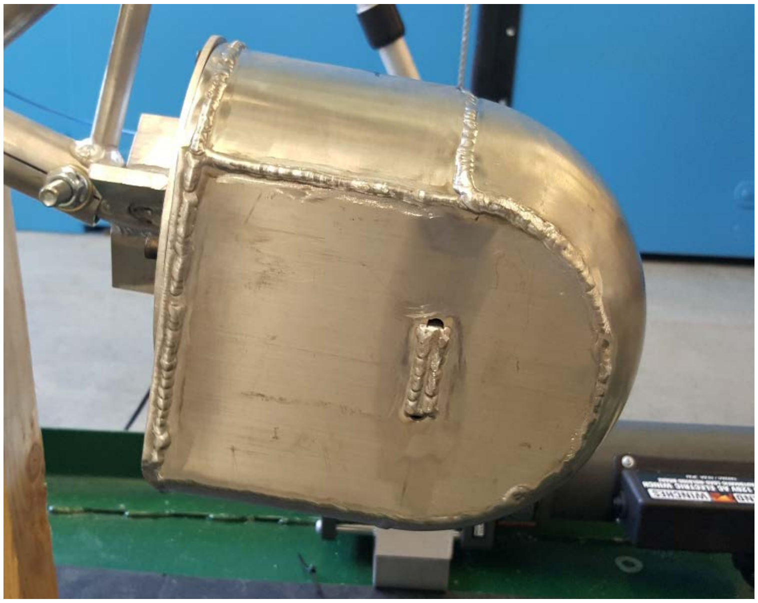


Figure 24. Cal Poly drop tower's headform

The headform is the structure which wears the football helmet. It is the approximate dimensions of a human head. The actual headform that is called out in the NOCSAE standards and used in the SIRC designed drop tower proved to be overly expensive so a work around was designed. The headform that was designed for the Cal Poly drop tower is made out of aluminum. It is specifically made out of a hemisphere, made by metal spinning, pieces of large diameter tubing, and plate. Inside of the headform is a shelf which holds the accelerometer. To align the accelerometer with the head, the shelf was polished so that screw stud could be aligned properly. The headform is designed to be attached with a movable neck joint to allow different surfaces of the helmet to be impacted. The neck is designed by SIRC, called the stem and rotator. These parts were required to be CNC machined and were not completed in time for testing due to manufacturing errors. To act as a stop gap measure, a simple non-articulating stem was welded in place. The parts were not completed even at the completion of the testing for this project.

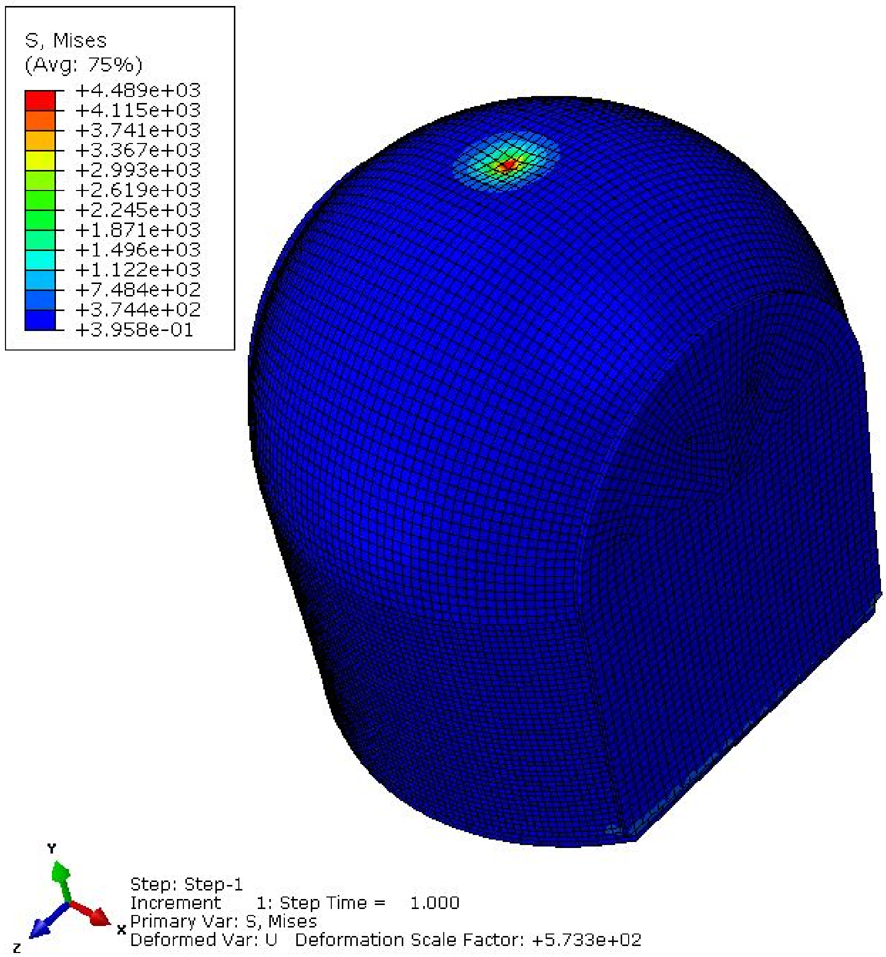


Figure 25. FEM of headform

Since the headform endures the brunt of the impact forces it was analyzed for strength. The analysis of the headform proved very difficult by hand. Because of this it was decided to use a simple finite element model to study the yield of the headform. The model was built using 3D brick continuum elements with all the pieces of the headform tied together, to simulate the welds. A 50lbf was applied to the center of the hemisphere. This load was applied because it is the load equal to a drop from 17 ft/s with an impact time of 17 milliseconds. The model can be seen in Figure 25. The headform carries a factor of safety of 4 for yield based upon the yield strength of Aluminum 3003. In actuality, the force imparted upon the headform would be less due to the padding in the helmet.

Using the helmet in actual testing has proved that the headform itself has undergone no damage. The only damage is to the mounting stem, which will be discussed later.

5.2.4 Control System

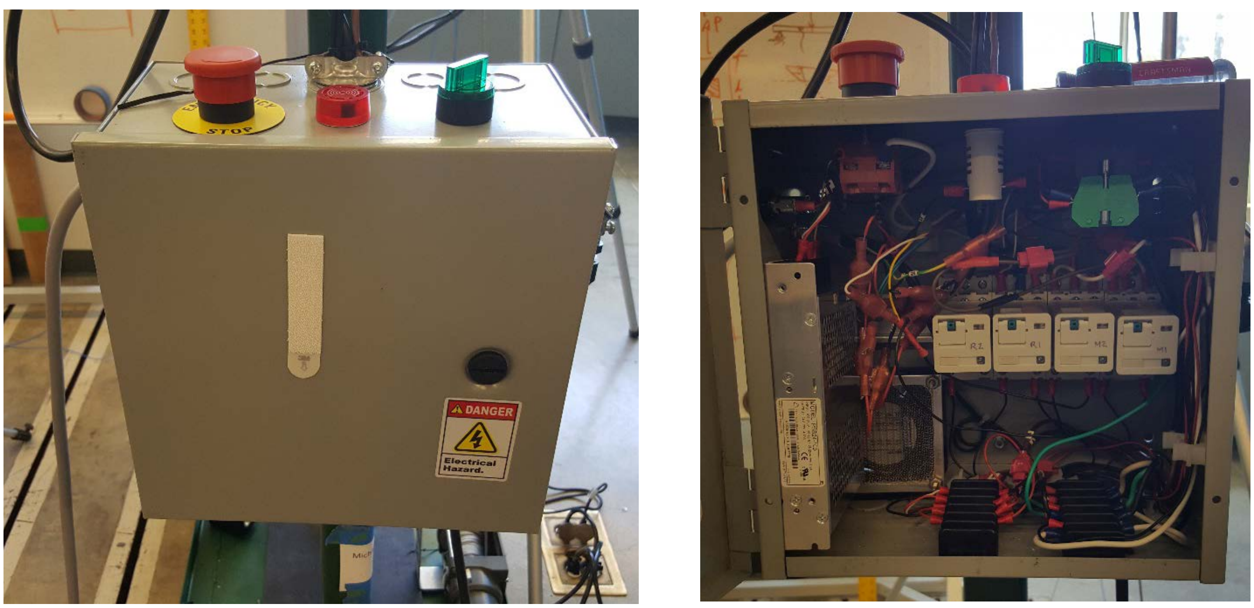


Figure 26. The outside and inside of the control system enclosure

The control system has two functions, each with its own circuit. Both circuits are contained inside an enclosure, show in Figure 26, mounted to the lower frame of the drop tower. The entire machine operates off of a single 120 volt power cord. To cool the enclosure, a 120 volt fan is on at all times while the machine is running. A single power switch activates all circuits in the control system. The system has analog control, using three electromagnetic relays. The control system was checked for safety by Ben Johnson, Cal Poly's supervising electrician.

The first function/circuit is for winch motor control. This system replaces the traditional pendant on the winch to allow all the controls for the system to be encased in one pendant. To replace the pushbuttons of the original pendant, two relays were installed. One relay sends power into the motor one direction to winch the lift bar up and the second relays sends power in the reverse direction to lower the lift bar. The two relays are controlled by a monetary three position, center off rotary switch. When the switch is turned either direction a 24v signal is sent to activate the relay. Also part of the winch circuit are two limit switches. One limit switch is to stop the downward motion of the lift bar. This is a pushbutton limit switch activated by a screw on the safety bracket of the carriage. The second limit switch stops the upward motion of the lift bar. This limit switch has a metal bar which sticks out and is rotated by the lift bar. This limit switch is attached to the frame with magnets to enable its height to be easily adjusted. Both of these limits switches cut off the signal going to the respective relay shown in Figure 26. For safety, the system's emergency stop button will shut off all power going to the motor disabling it from moving either direction.

Figure 27. The drop tower control pendant

The second function/circuit is the electromagnet control circuit. In order for the electromagnet to be able to release the carriage, the polarity of the magnet must be reversed. This is because a latent charge builds up in the magnet and is still charged if the power is only shut off. If the power to the magnet were only shut off, instead of the polarity switched, there would be a lag before the carriage was released. The polarity is reversed with a relay. When power is applied to the system the relay applies power to the magnet and it builds a charge in one direction. Once the relay is activated it reverses the current flowing to the magnet to reverse the polarity. The electromagnet operates on 24 volt D.C. power. To create the 24VDC supply voltage there is a power supply in the electrical enclosure powered through a fuse with the 120VAC input power. There are several safety systems in place to help prevent inadvertent release of the carriage. These safety features were based on those of the Dynatup drop tester. The first safety feature is a double action release. To activate the relay both a momentary, rotary switch and then a pushbutton must be activated before the 24-volt signal is sent to the relay. Additionally, when the rotary switch is activated a buzzer and safety light turn on to enable both audible and visual indication the carriage is ready to drop. A final safety feature is the machine's emergency stop button which when activated stops the relay from switching and the carriage from releasing. This allows the carriage to still stay attached to the lift bar without the possibility of its dropping accidently.

The control pendant for the drop tower also has light indicators. When the lowering limit switch is activating a white light, the "Carriage" light, illuminates. This alerts the operator that the carriage is now attached to the lift bar and is ready to be raised. Once the raising limit switch is activated the light on the rotary safety switch will illuminate. When both the white and orange lights are lit the operator now knows the carriage is at the right height. Once the safety switch is turned, the release button is illuminated orange in addition to the safety buzzer and light.

5.2.5 Instrumentation

Figure 28. LDS Dactron Focus II DAQ

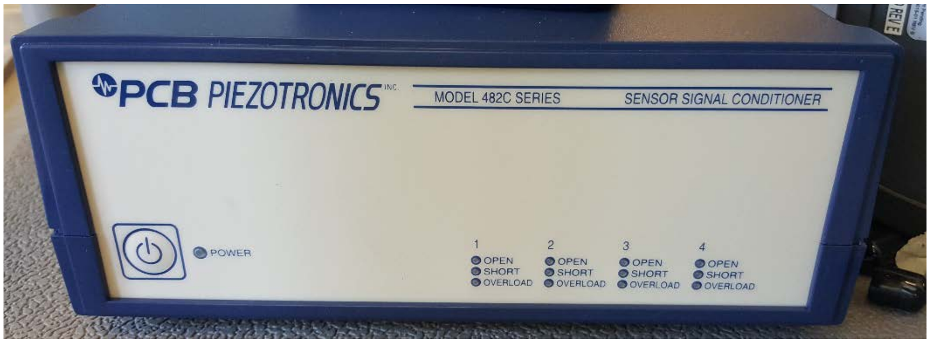


Figure 29. The PCB 482C05 Signal Conditioner

The system’s instrumentation is very similar to that used for the small scale testing. The major difference is that the full scale drop tower uses a three axis accelerometer versus the small scale testing’s single axis accelerometer. The change to a three axis accelerometer allows the instrumentation to match that required by the NOCSAE standards. [3] Using a three axis accelerometer also allows for varying orientations of the headform so that the helmet can be impacted in multiple locations. The accelerometer used is a PCB 356A02. The specification sheet for this accelerometer can be found in APPENDIX F: Specification Sheets. The accelerometer signals are sent through a PCB 482C05 ICP signal conditioner before being recorded by the LDS Dactron data acquisition system, shown in Figure 29 and Figure 28 respectively. The sampling frequency for the full scale testing was 16384 hertz, just like the small scale testing, due to the SAE impact instrumentation specification. [9]

Figure 30. Photoscale for velocity measurement

In addition to the accelerometer system required by the NOCSAE standards, a high speed camera was used. [3] The high speed camera was used to determine the actual drop velocities of the helmet as well as to visualize the movement of the helmet. To determine the speed a photoscale was used. The scale is a series of one inch bars attached via magnets to the baseplate, it was positioned directly behind the helmet.

5.2.6 Verification

In order to ensure the drop tower was consistent between tests, a series of verification tests were run. These tests were run using a surplus Cal Poly football team helmet. The helmet was dropped four times from a two foot height and five times from a four foot height. The SI values from these tests are in Table 3.

Table 3. Drop test machine verification runs

Run	2ft Drop SI (159 in/s)	4ft Drop SI
1	555.28	1422.2
2	681.34	1324.0
3	642.34	1107.3
4	662.80	1360.1

For each height, the standard deviation of SI values was calculated. Dividing the standard deviation by the mean SI value gives a value which can be used as the tolerance for the drop tower. The values for the heights are presented in Table 4. The drop speed variation was negligible.

Table 4. Drop tower tolerances for both test heights

Drop Height	Tolerance of SI
2 ft	14%
4 ft	10%

5.3 Test Procedure

The drop tower was designed with a specific test procedure in mind. During initial testing the test procedure designed for the machine was less practical than thought so a different procedure was used.

5.3.1 Design Test Method

The test method that the machine was designed for can be found in Appendix G.

5.3.2 Test Method Used

The test method that was used for the full scale testing was:

1. Apply power to drop tower
2. Apply power to instrumentation
    a. Signal conditioner
    b. DAQ
    c. High Speed Camera
    d. Laptops
3. Secure Helmet to headform with duct tape
4. Raise lift bar to correct height
5. Raise carriage by hand, ensure carriage is captured by magnet
6. Measure helmet to impact pad height to ensure correct height is achieved
7. Retreat safe distance and clear area of unnecessary personnel
8. Pretrigger high speed camera
9. Start DAQ
10. Turn Safety Switch
11. Release carriage
12. When impact is heard, trigger high speed camera
13. Stop DAQ
14. Save data and video
15. Readjust helmet
16. Repeat 5-16
17. When testing completed, remove power from all instrumentation and drop tower

5.3.3 Test Specimens

There were two test specimens involved in the full scale testing. These specimens were fabricated using additive manufacturing techniques. The specimens were created by a company found by the sponsor of the project. The company was chosen by the sponsor because it had a significantly lower quote to manufacture the helmets than several other more well-known companies. Unfortunately, this lower price resulted in lower quality. To carry out the testing it was desired to use prototypes manufactured with the Selective Laser Sintering, or SLS, process. The SLS process uses a laser to sinter particles of plastic together to form a complete item. The material used would have been an impact resistant nylon. The main benefit of the SLS process is the fact that it does not need to use support material while printing because the vat of plastic particles acts as its own support material.

The helmets were ultimately manufactured with the Filament Deposition Modeling, or FDM process. This process uses a plastic filament that is extruded into layers. Each layer is built on the next, ultimately building up the final part. This process uses ABS plastic as its material. This method is much cheaper than SLS and is why the sponsor chose a company which used it. There are two main problems with the FDM process, however; the requirement of support material and that the layers are not completely fused to the others. In order for an FDM model to be made support material has to be printed because the FDM printer cannot extrude plastic in midair. The layers not be fused together adds places which are weaker between every layer making the prototype highly anisotropic.

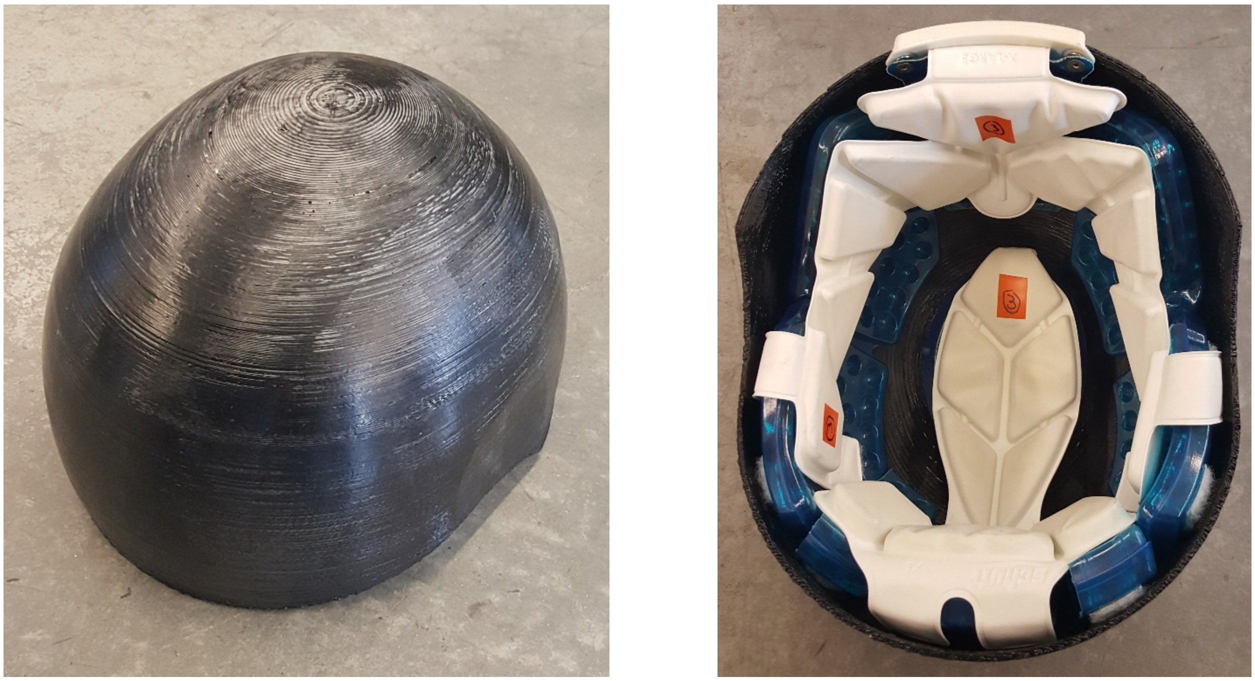


Figure 31. FDM control shell outer surface and inner surface with padding installed

The additive manufactured prototypes were just shells of helmets. Since the helmet shells were made out of ABS, not polycarbonate like a real football helmet, a control helmet with no added features was made as well as the experimental. The control helmet, shown in Figure 31, was made to try to eliminate any influences due to material. To fully simulate football helmets, padding had to be added. Padding was removed from a retired Cal Poly football helmet and was attached to the inside surface of the prototype shells. The same padding set was used in both the control and experimental helmet.

For the machine verification tests a second retired football helmet was used. The football helmet was equipped with the same type of padding used in the control and experimental prototypes. The retired helmet was a Schutt helmet made out of polycarbonate.

The prototype helmets produced unfortunately had several flaws. One was in manufacturing and the other two were due to the problems discussed earlier. During manufacturing the company which manufactured the prototypes added a coating to the outside of the helmet shells to make them stronger and to try to prevent the layers from delaminating. The amount of coating that was used on the experimental and control helmet prototypes were different however. This may have an effect on the results of the experiments. Second, support material was used in the manufacture of the experimental

Figure 32. Control helmet after being destroyed by drop testing

prototype. This support material interfered with the features incorporated into the experimental helmet. Finally, both helmets broke during the impact tests. The helmets peeled apart at the layer boundaries, as seen in Figure 32 for the control helmet. The helmets were able to survive five drops each from 2 feet but both failed when drops were attempted from 4 feet.

5.4 Drop Tower Observations, Discussion, and Future Work

After fabrication and assembly was completed on the drop tower, there were several observations and modifications made.

The first observation was that the limit switches were not reliable. Because of the fact that the winch still continues to spool or unspool even after power is removed, the winch would keep moving even though the limits were reached. When the lowering limit switch is reached the winch loses tension and the cable can get tangled. The upper limit switch removes power from the motor when activated, but the lift bar continues another 5 inches. This issue caused the limit switches to not be used for the full scale testing. Since the limit switches, specifically the upper limit switch, were not reliably stopping the system, they were not relied on to provide a consistent drop height. Instead the lift bar was raised to the right height and then the carriage was raised to the lift bar by hand for each drop.

The bolts connecting the hinges to the upper frame were left loose during assembly. This was to allow the cotter pins to be aligned easier. The holes proved to not be perfectly inline and a dead-blow mallet is needed to align the holes. Since the pins are taking all the force required to hold the frame in alignment, leaving these bolts loose is not detrimental.

An issue currently present with the drop tower is that the lift bar occasionally is not able to lower smoothly. This is because the lift bar alone does not have enough weight to reliably unspool cable from the winch drum. To combat this, more weight should be added to enable the lift bar to better unspool the cable. Adding weight could help alleviate another issue. The lift bar does not lower horizontal. This does not cause any

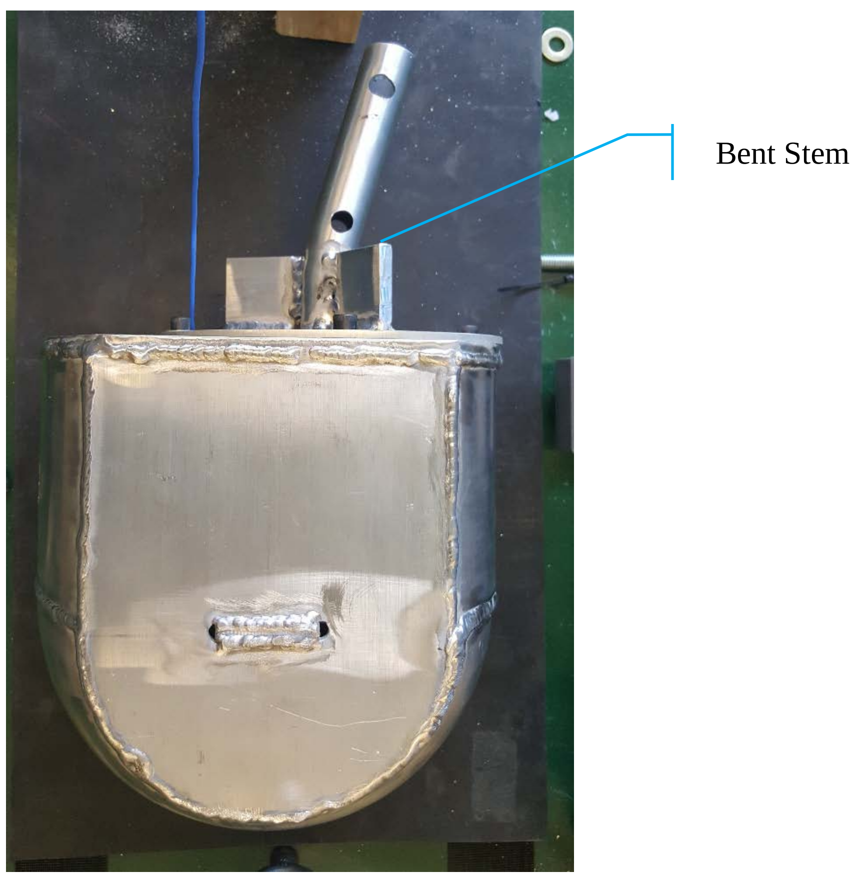


Figure 33. The bent stem attached to the headform

issues with operation but could be fixed when adding weight to ensure it is balanced on either side of the lift point.

Another issue, only present in the current iteration of the drop tower, is that the mount between the headform and the carriage bent due to the impacts. This is most likely due to the hollow tube used as a stem to replace the actually SIRC designed stem. The bending of the stem may have had an influence on the test results, but no trends were found in the data so it is presumed to not have a noticeable effect. The bent stem can be seen in Figure 33.

To ensure that the tests are more repeatable, the cable tension should be checked. Like earlier stated, checking the cable tension could be accomplished by purchasing a gauge made normally for checking the tension of sailing riggings. The cables for this test were tensioned by feel which could have led to slight errors.

The values that are obtained from the current drop test machine should also be checked against those obtained by outside laboratories for the same helmet. This would allow the machine's value to be trusted more easily. For this specific testing regime it did not matter how the tests compared to tests done on another machine since it was simply comparing two different samples. As long as everything was the same between tests the exact accuracy of the machine is not of great concern.

To enable full NOCSAE testing to be conducted on the drop tower the headform should be switched to an actual NOCSAE headform. This would enable true NOCSAE tests to be performed and would allow the helmets to fit better on the machine. Additionally, if the correct headform attachment hardware was used the helmets could be impact in all the required spots. The current headform and attachment allows the helmet to be impacted in the front and back but not on the sides.

5.5 Results and Analysis

Since the prototype helmets failed during testing, there is not a wealth of data available to analyze. However, a statistical sample was gathered for the 2 foot drop height.

The data obtained is very different from that of the small scale tests. It required different processing to obtain usable data. The raw data from one of the 2ft control tests is shown

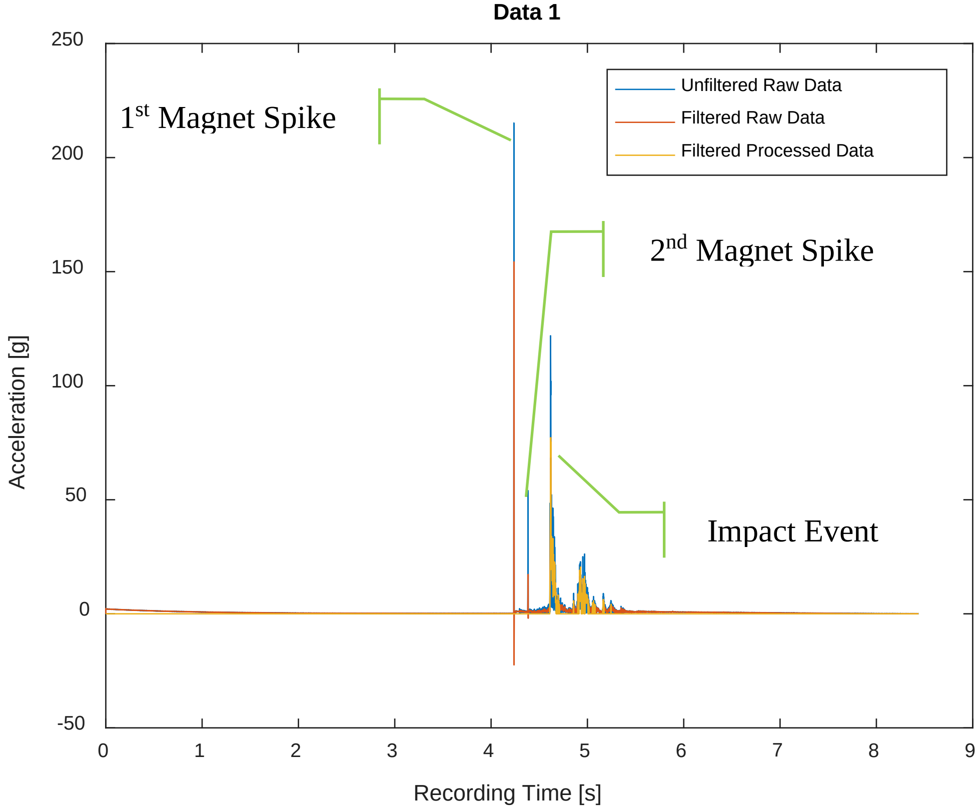


Figure 34. The data from a 2ft control test

in Figure 34. It can be seen that there are two very high magnitude but short in duration spikes in the beginning of the data. These peaks were discovered to be from the reverse in polarity of the electromagnet release. The second, shorter spike, is from the carriage dropping out of the influence of the electromagnetic field. These two spikes had to be removed from the data in order to find the correct SI value. To remove these spikes the MATLAB program used to analyze the data, which can be found in

APPENDIX E: Full Scale Testing Analysis Cod, searched for impulse events less than 3 milliseconds and removed them from the data. The graphs were then visually checked to make sure no important spike was removed. The first impulse of actual importance in the data is shown in Figure 35. It can be seen from this plot that the impact event is a lot longer, close to 65 milliseconds, than the small scale tests. This is due to the fact the data is a resultant of multi-axis acceleration. When the headform impacts the impact surface it

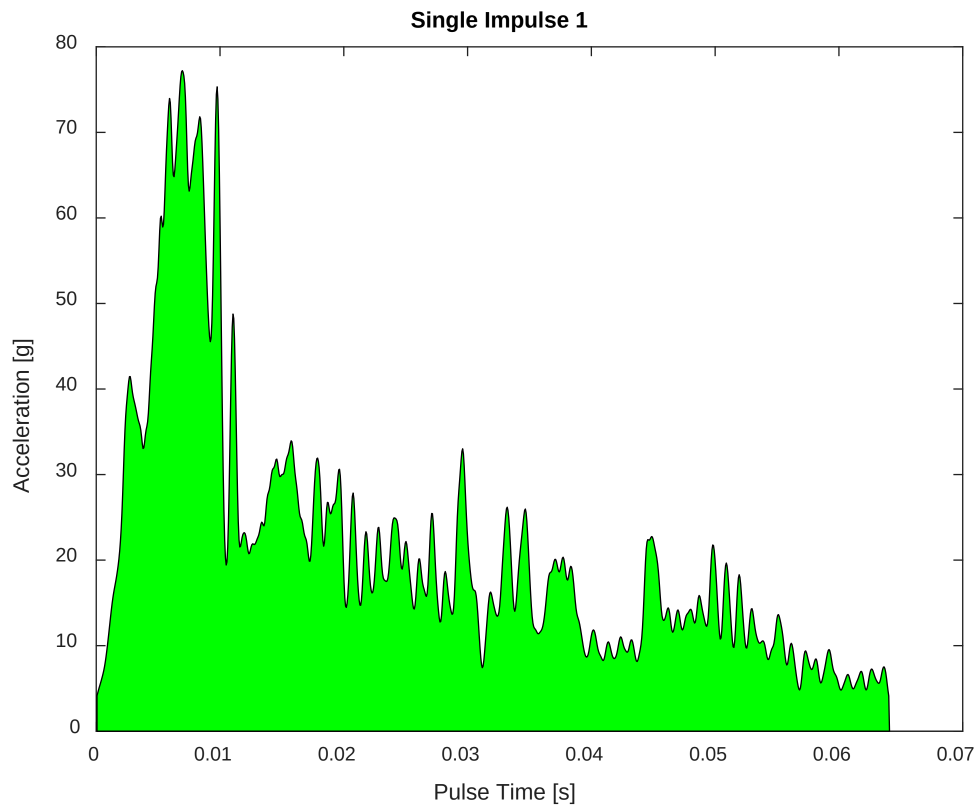


Figure 35. Single impulse (filtered) from full scale control test

undergoes a lot more motion than just the vertical bounce. It shakes back and forth as well as pitches and yaws. All these other aspects of the acceleration add to the acceleration time. In order to cut down on the effects of these other degrees of freedom the data was windowed to the impact time recorded in the high speed camera videos of the impacts. These impact times were around 25 milliseconds for the contact between the helmet and the impact pad.

In addition to the windowed and normal SI values it was decided to also use both HIC_{36} and HIC_{15}, which by definition are also windowed. These values are commonly used in impact tests so they have a lot of credibility in the impact test community. ASTM tests for concussion risk in football helmets by using the max acceleration, to further study the events this criterion was used as well. [11] All the data criteria that were used to analyze the results of the drop tests are shown in Table 5.

Table 5. Results from the full scale testing of the football helmet prototypes

Concussion Risk Criteria	**Control Helmet**	**Experimental Helmet**
Severity Index (1200 = FAIL)	326.90	878.52
Windowed Severity Index	275.65	811.11
HIC 15 (700 = FAIL)	169.60	436.46
HIC 36 (1000 = FAIL)	167.85	456.13
Max Acceleration (300 G's = FAIL)	88.92 G	173.56 G

EDC was not used for the full scale tests because of the nature of the data. It was very hard to determine the first two main peaks.

5.6 Test Specific Conclusions

The use of full scale prototypes allows us to make a better conclusion about the actual properties and abilities of the experimental design. The results do have to be taken with the same caution as the small scale results; they truly only apply to the current prototypes and an actual helmet may perform differently.

For the small scale testing, statistical tests were used to determine whether the experimental helmets performed better than the control. For the full scale tests statistical tests were not needed because of the great difference in performance between the control and experimental helmets. The results shown for the full scale tests show that the control helmet performs better than the experimental helmet by a factor of 2.5. The five criteria used to study the concussion risk reduction in football helmets all show the same result: the experimental helmet did significantly worse.

Since the five most commonly used impact criteria for impact tests all show the same thing, it is a safe conclusion that the experimental helmet design does not work in the prototype form. The helmet performs worse based on three different organization's criteria.

6. CONCLUSIONS

Now that both the small scale test and the full scale tests are done conclusions can be drawn about the design enhancements imagined by Mr. Bartholomay. While it may seem that the full and small scale results have contradictory results, the differences between the tests can explain that.

With everything known from the full scale tests and the computer modeling conducted separately, the conclusion can be made that the design enhancements provide no reduction to concussion risk compared to a standard football helmet. The design enhancements that were studied in this battery of tests do not seem to work any better than football helmet designs on the market now.

The NOCSAE style drop tower is capable of providing results that are consistent to within a tolerance to be expected from impact events. Impact events, especially those with as many moving parts as a football helmet, have great amounts of error so the tolerance levels of the drop tower are to be expected. The machine still needs to be validated against other laboratories to ensure its accuracy.

REFERENCES

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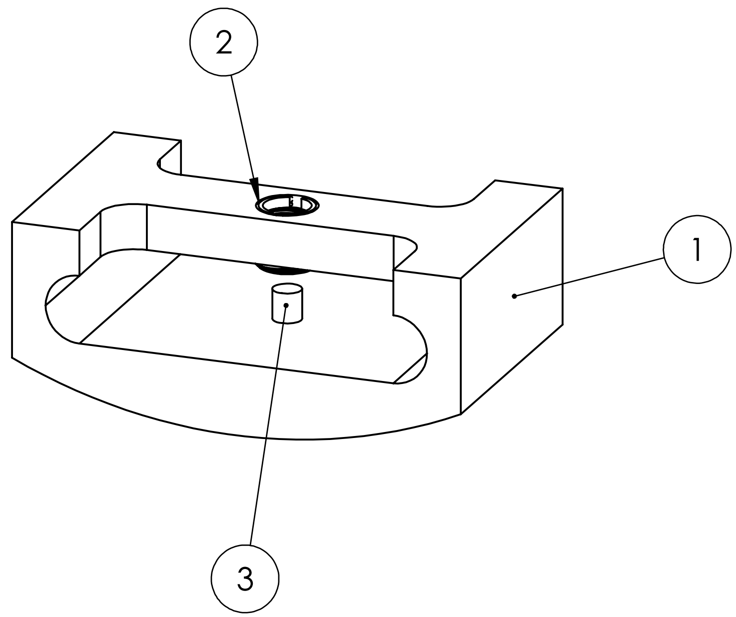
APPENDICES

APPENDIX A: DYNATUP FIXTURE ENGINEERING DRAWINGS

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	DT-01	IMPACTOR	1
2	90248A086	1/2-20 THREADED INSERT	1
3	353B15	PCB ACCELEROMETER	1



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.03
THREE PLACE DECIMAL ±.003

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	M. SCHUSTER	12/2/15
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

NEXT ASSY:

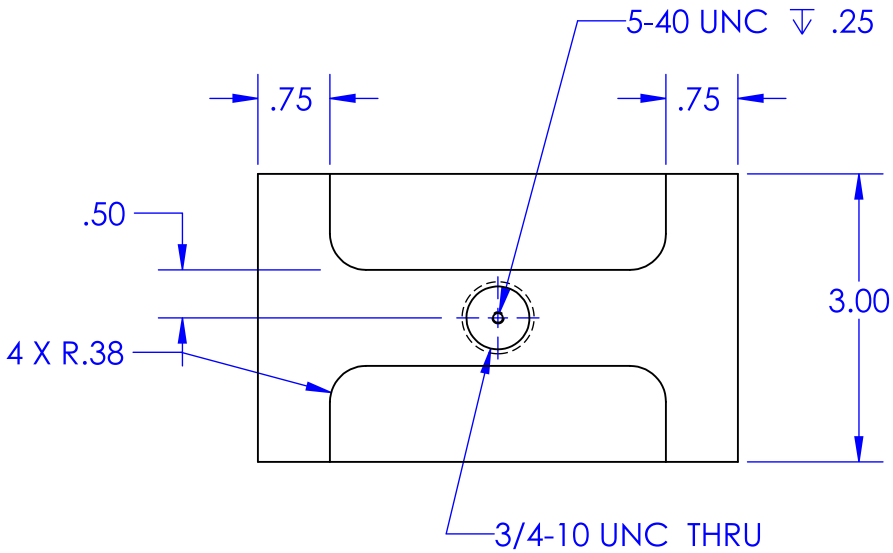
CAL POLY

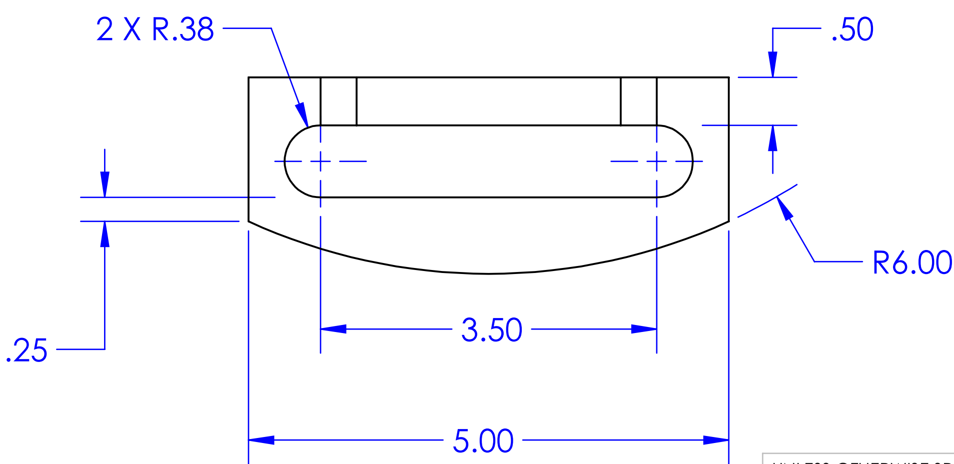
TITLE:

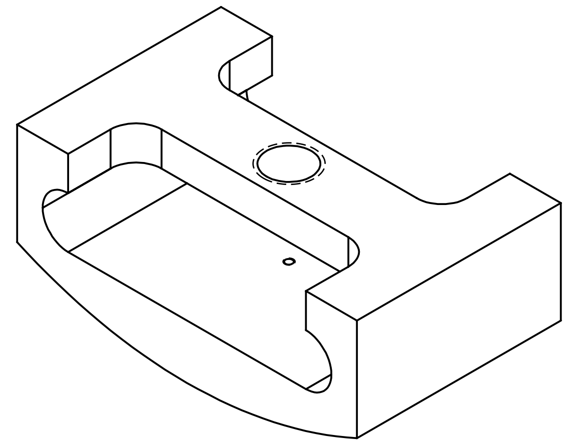
IMPACTOR

SIZE **A** DWG. NO. DTA-01 REV

SCALE: 1:2 WEIGHT: SHEET 1 OF 1







UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.03
THREE PLACE DECIMAL ±.003

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL: ALUMINUM 2024

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	M. SCHUSTER	12/2/15
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

NEXT ASSY: DTA-01

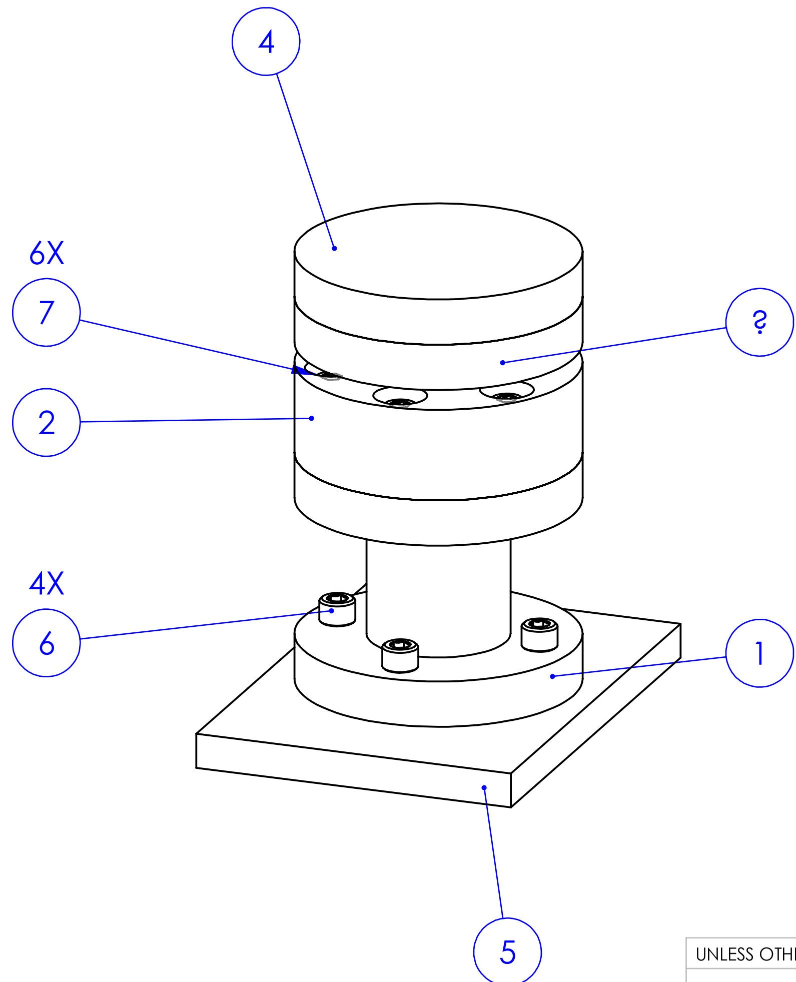
CAL POLY

TITLE:

IMPACT HEAD

SIZE	DWG. NO.	REV
A	DT-01	

SCALE: 1:2 WEIGHT: SHEET 1 OF 1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	DT-02	BASE SUPPORT STEM	1
2	LCH-1K	OMEGA LOAD CELL	1
3	newplaten		1
4	DT-04	RUBBER IMPACT PAD	1
5	DT-05	BASE PLATE	1
6	91251A541	.875" 1/4-20 SCREW	4
7	91251A560	1.125" 1/4-20 SCREW	6

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.03
THREE PLACE DECIMAL ±.003

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL: VARIOUS

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	M. SCHUSTER	11/10/15
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

NEXT ASSY: DTA-01

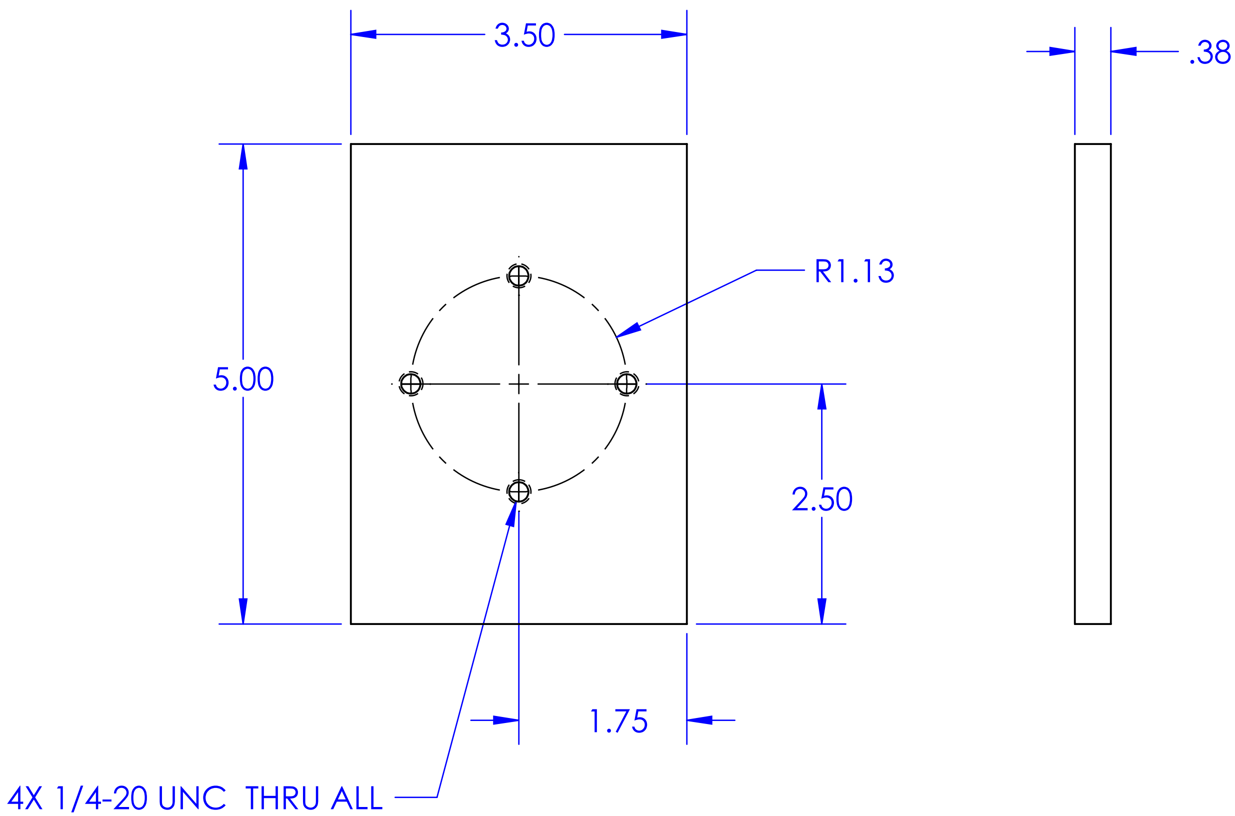
CAL POLY

TITLE:

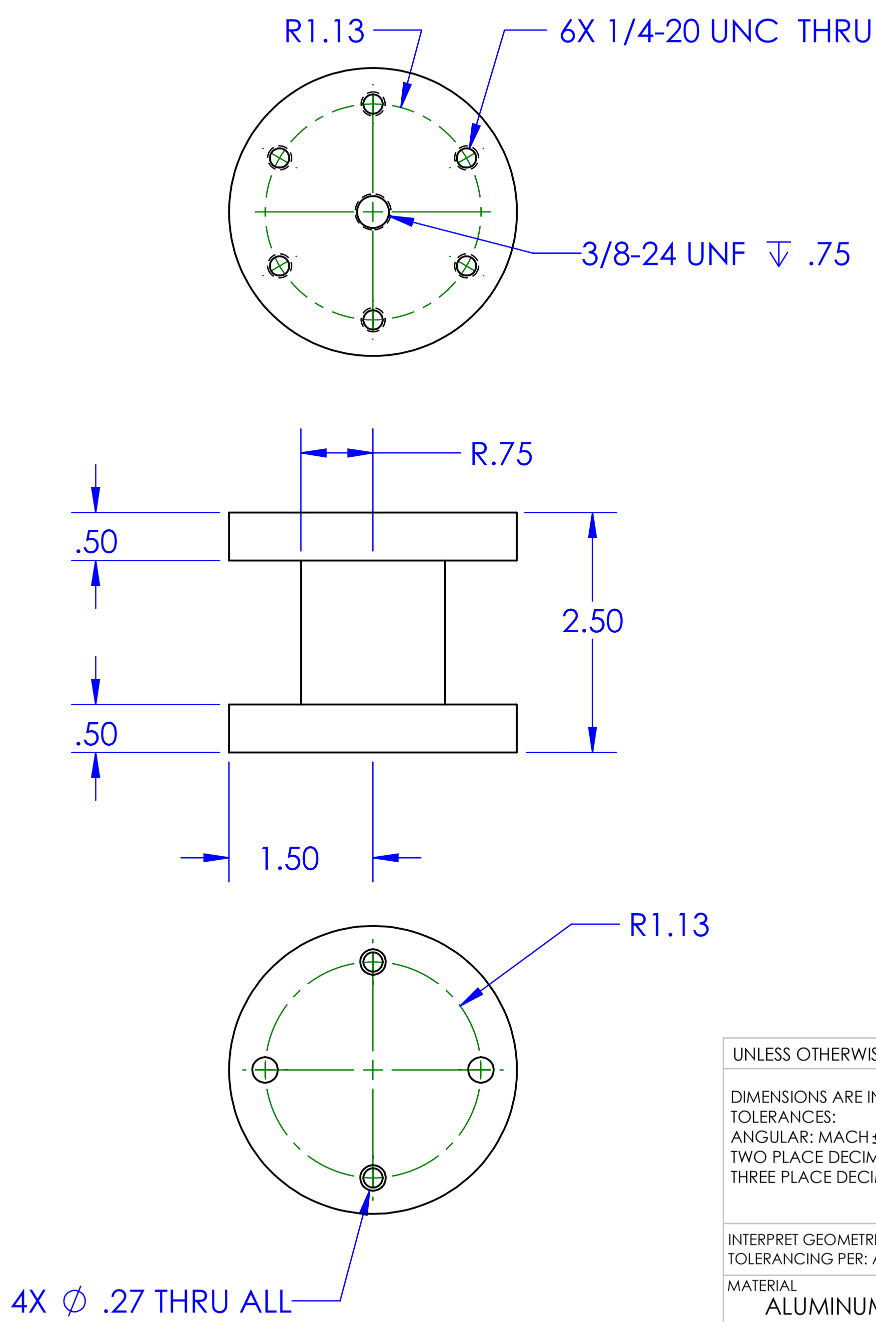
DYNATUP IMPACT BASE

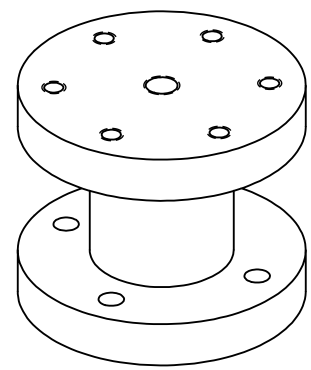
SIZE: A | DWG. NO. DTA-02 | REV

SCALE: 1:2 | WEIGHT: | SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	CAL POLY
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.03 THREE PLACE DECIMAL ±.003	DRAWN	M. SCHUSTER	12/2/15	TITLE: CLAMP PLATE
	CHECKED			
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	Q.A.			
MATERIAL STEEL	COMMENTS:			SIZE A
FINISH				DWG. NO. DT-05
				REV
DO NOT SCALE DRAWING	NEXT ASSY: DTA-02			SCALE: 1:2
				WEIGHT:
				SHEET 1 OF 1





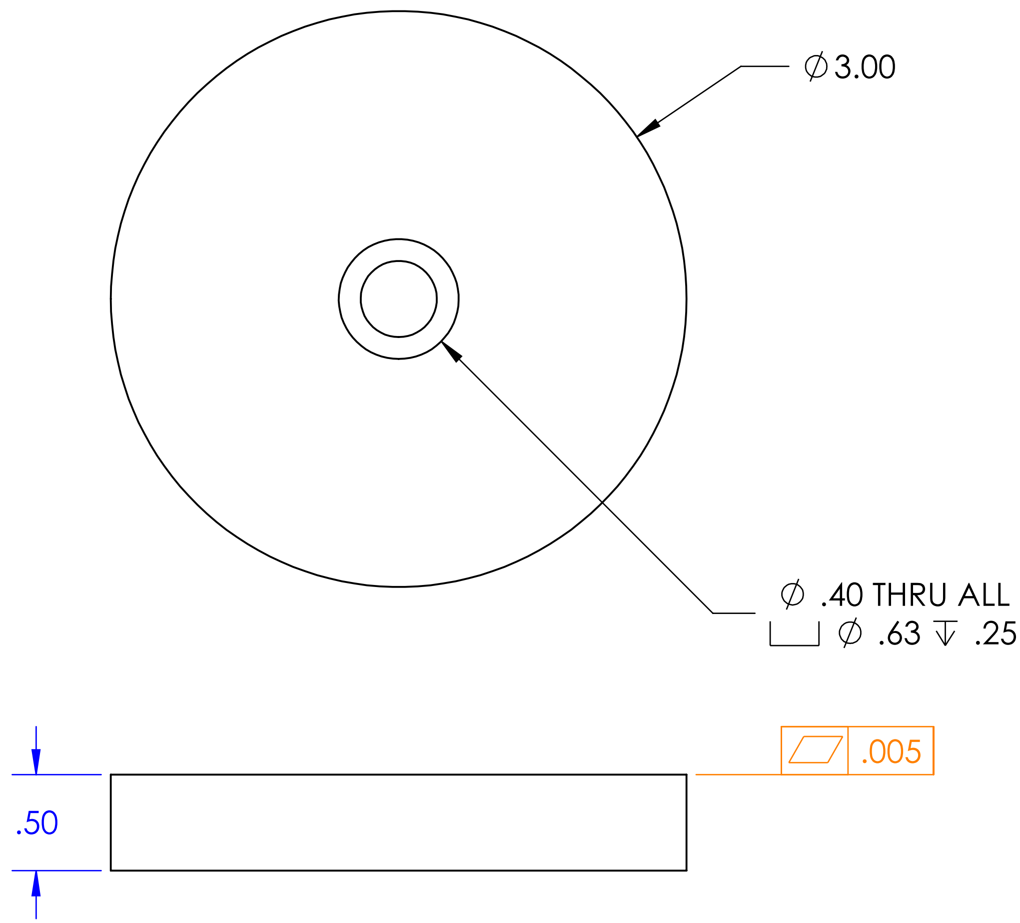
UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.03 THREE PLACE DECIMAL ±.003	DRAWN	M. SCHUSTER	12/2/15
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	Q.A.		
MATERIAL ALUMINUM 7075	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING	NEXT ASSY: DTA-02		

CAL POLY

TITLE:

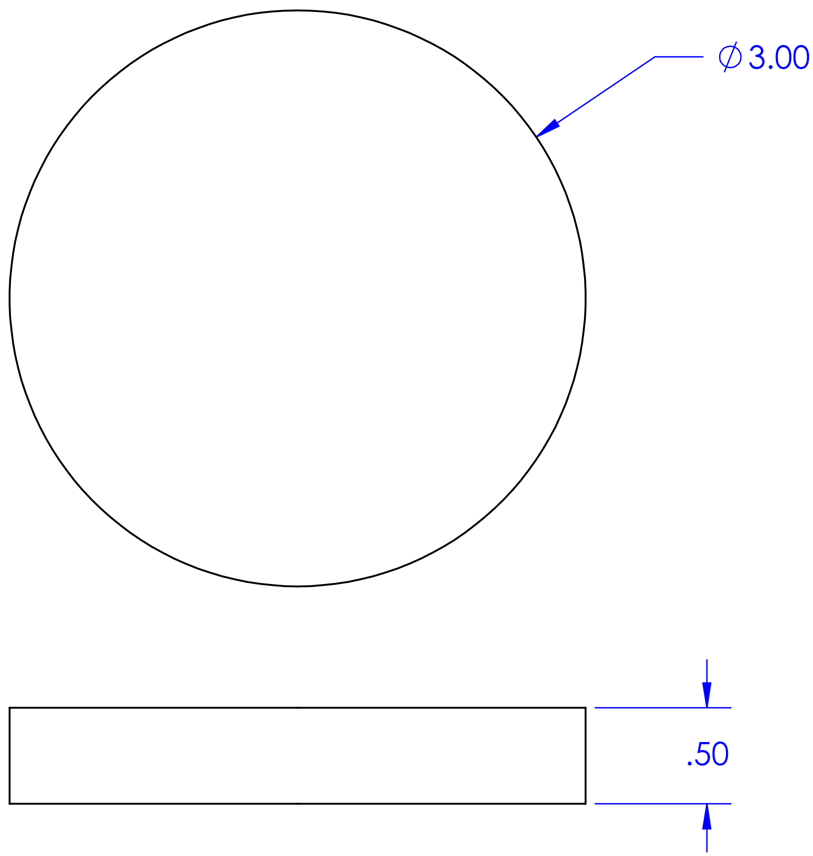
STEM

SIZE	DWG. NO.	REV
A	DT-02	
SCALE: 1:2	WEIGHT:	SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	CAL POLY
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.03 THREE PLACE DECIMAL ±.003	DRAWN	M. SCHUSTER	12/2/15	TITLE: PLATEN
	CHECKED			
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	Q.A.			
MATERIAL ALUMINUM 7075	COMMENTS:			SIZE A DWG. NO. DT-03 REV
FINISH	NEXT ASSY:	DTA-02		SCALE: 1:1 WEIGHT: SHEET 1 OF 1
DO NOT SCALE DRAWING				

MATERIAL DUROMETER MUST BE 38 ± 5 SHORE A



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.03 THREE PLACE DECIMAL ±.003	DRAWN	M. SCHUSTER	12/2/15
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	Q.A.		
MATERIAL BUNA-N	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING	NEXT ASSY: DTA-02		

CAL POLY

TITLE: RUBBER PAD

SIZE	DWG. NO.	REV
A	DT-04	
SCALE: 1:1	WEIGHT:	SHEET 1 OF 1

ID	Drawing	Part Number	Description	QTY	Unit Qty	Source	Unit Price	Net Price
1	DT-01	N/A	2024-T351 3" Square Bar, 6" length	1	1	OnlineMetals	$ 67.56	$ 67.56
2	DT-02,DT-03	90465K36	7075 Aluminim Rod 3" Dia, 6" length	1	1	McMaster Carr	$ 67.43	$ 67.43
3	DT-05	1631T41	A516 Carbon Steel 3/8" Plate, 6"x6"	1	1	McMaster Carr	$ 33.53	$ 33.53
4	DT-04	8635K168	Buna-N 1/2"Thick, 12"x12", 40A Durometer	1	1	McMaster Carr	$ 29.86	$ 29.86
5	DTA-1	91251A543	1/4-20 Socket Head Cap Screw, 1-3/8" Length		10	McMaster Carr	$ 6.04	$ 6.04
6	DTA-1	91251A541	1/4-20 Socket Head Cap Screw, 7/8" Length		50	McMaster Carr	$ 8.09	$ 8.09
7	DTA-2	90248A086	Thread Locking Steel Insert	1	5	McMaster Carr	$ 7.88	$ 7.88
							TOTAL	**$ 220.39**

APPENDIX B: SMALL SCALE TESTING ANALYSIS MATLAB CODE

Table of Contents

SI Analysis

Michael Schuster 2/18/2016

analyses data to determine SI

```
clear all
close all
clc
fprintf('SI Analyzer\n')
fprintf('Michael Schuster\n\n')
```

User Inputs

```
fs = 16384;

% AccSen = 1; %accelerometer sensitivity (g/mv)
% AccOff = 0; %accelermoter offset (g)

%LoadSen = 1; %load cell sensitivity (lb/mv)
%LoadOff = 0;

file = 'G:\Full Scale Data\exp\2ft\input3(t) 19.txt';
```

file Import

```
data = importfile(file,31);

rdata = data(:,2);

figure(1)
plot(data(:,1),rdata)
hold on

fprintf('Import Complete\n')
```

Data filtering

```
fdata = butter16(rdata);
```

```
plot(data(:,1),fdata)

fprintf('Filtering Complete\n\n')
```

Individual SI

```
for i = 1:length(fdata)
  if fdata(i) <= 4
      fdata(i) = 0;
  end
end

plot(data(:,1),fdata)
legend('Unfiltered Raw Data','Filtered Raw Data','Filtered Processed
 Data')
ti1 = 'Data';
title(ti1)
xlabel('Recording Time [s]')
ylabel('Acceleration [g]')

[m,p] = max(fdata);

for j = 1:length(fdata)
    if j < p && fdata(j) ~= 0
        break
    end
end

for k = 1:length(fdata)
    if k > p && fdata(k) == 0
        break
    end
end

y = fdata(j:k);

hold off
figure(2)
plot((1/fs)*(1:length(y)),y,'g')
ti2 = 'Single Impulse';
title(ti2)
xlabel('Pulse Time [s]')
ylabel('Acceleration [g]')

y = y.^2.5;
SIval = trapz((1/fs)*(1:length(y)),y);
fprintf('SI = %0.2f\n',SIval)

if SIval > 1200
    disp('Helmet Fails')
else
    disp('Helmet Passes')
end
```

Energy Dissipation Coefficient

```
[m2,p2] = max(fdata(k:end));

EDC = m2/m*100;
fprintf('Energy Dissipation Coefficient = %0.2f%%\n',EDC)

for r = 1:length(fdata)
    if r > p2 && fdata(r) == 0
        break
    end
end

EDCpl = fdata(j:(r+k+100));

figure(3)
plot((1/fs)*(1:length(EDCpl))+((1/fs)*j),EDCpl,'c')
hold on
plot((1/fs)*p,m,'o',(1/fs)*(p2+k),m2,'o')
plot([(1/fs)*j (1/fs)*(p2+k)],[m m],'b',[(1/fs)*j (1/fs)*(p2+k)],[m2
 m2],'r')
%stem((1/fs)*p,m)
%stem((1/fs)*(p2+k),m2)
hold off
title('EDC Calculation')
xlabel('Recording Time [s]')
ylabel('Acceleration [g]')
%mid = mean((1/fs)*p),(((1/fs)*(p2+k)));
%xxx = [mid mid]./((1/fs)*(r+k+100));
%xxx = [.5 .5];
%yyy = [m m2]./m;
%annotation('doublearrow',xxx,yyy)
```

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Multi-file SI Analysis for SMALL SCALE

Michael Schuster 2/18/2016

analyses data to determine SI

```
clear all
clc
fprintf('Multi-file SI Analyzer\n')
fprintf('Michael Schuster\n\n')
```

User Inputs

```
fs = 16384;     %Sampling Frequency

maxplot = 2;    %max # of runs which plots will be produced for

fld = 'F:\1 THESIS\2 Data\Small Scale\Experimental\Open-2ft';
  %Target Folder
fn = ls(fld);

tbl = 'test.txt';    %Desired Table txt filename
```

Folder Parsing

```
w = 1;
pp = 1;

fn = ls(fld);
sfn = size(fn);
for q = 1:sfn(1)
    if strncmpi(fn(q,:),'input1',6) == 1

        fn2 = fn(q,:);

        fprintf('\n<strong>Run %d:</strong>\n',w)
```

File Import

```
        data = importfile(strcat(fld,'\',fn2),31);
```

```
rdata = data(:,2);

if w <= maxplot
    figure(pp)
    plot(data(:,1),rdata)
end
hold on

fprintf('Import Complete\n')
```

Data filtering

```
fdata = butter16(rdata);

if w <= maxplot
    plot(data(:,1),fdata)
end

fprintf('Filtering Complete\n')
```

Individual SI

```
for i = 1:length(fdata)
  if fdata(i) <= 4
      fdata(i) = 0;
  end
end

if w <= maxplot
    plot(data(:,1),fdata)
    legend('Unfiltered Raw Data','Filtered Raw Data','Filtered
Processed Data')
    ti1 = ['Data ',num2str(w)];
    title(ti1)
    xlabel('Recording Time [s]')
    ylabel('Acceleration [g]')
end

[m,p] = max(fdata);

for j = 1:length(fdata)
    if j < p && fdata(j) ~= 0
        break
    end
end

for k = 1:length(fdata)
    if k > p && fdata(k) == 0
        break
    end
end
```

```
        y = fdata(j:k);

        hold off
        pp = pp+1;
        if w <= maxplot
            figure(pp)
            %plot((1/fs)*(1:length(y)),y,'g')
            hh = area((1/fs)*(1:length(y)),y);
            hh.FaceColor = [0 1 0];
            ti2 = ['Single Impulse ',num2str(w)];
            title(ti2)
            xlabel('Pulse Time [s]')
            ylabel('Acceleration [g]')
        end

        y = y.^2.5;
        SIval(w) = trapz((1/fs)*(1:length(y)),y);
        %fprintf('Run %d SI = %0.2f\n',[w SIval(w)])

        if SIval(w) > 1200
            pass(w) = 0;
        else
            pass(w) = 1;
        end
```

Energy Dissipation Coefficient

```
        [m2,p2] = max(fdata(k:end));

        EDC(w) = m2/m*100;
        %fprintf('Energy Dissipation Coefficient = %0.2f%%\n',EDC(w))

        for r = 1:length(fdata)
            if r > p2 && fdata(r) == 0
                break
            end
        end

        EDCpl = fdata(j:(r+k+100));

        pp = pp+1;

        if w <= maxplot
            figure(pp)
            plot((1/fs)*(1:length(EDCpl))+((1/fs)*j),EDCpl,'c')
            hold on
            plot((1/fs)*p,m,'o',(1/fs)*(p2+k),m2,'o')
            plot([(1/fs)*j (1/fs)*(p2+k)],[m m],'b',[(1/fs)*j (1/
fs)*(p2+k)],[m2 m2],'r')
            %stem((1/fs)*p,m)
            %stem((1/fs)*(p2+k),m2)
            hold off
            ti3 = ['EDC Calculation ',num2str(w)];
```

```
            title(ti3)
            xlabel('Recording Time [s]')
            ylabel('Acceleration [g]')
            %mid = mean((1/fs)*p),(((1/fs)*(p2+k)));
            %xxx = [mid mid]./((1/fs)*(r+k+100));
            %xxx = [.5 .5];
            %yyy = [m m2]./m;
            %annotation('doublearrow',xxx,yyy)
        end

        w = w+1;
        pp = pp+1;

    end
end

SImean = mean(SIval);
EDCmean = mean(EDC);

fprintf('\n\n<strong>Mean SI = %0.2f</strong>\n',SImean)
if min(pass) ~= 1
    fprintf('Helmet Fails\n')
else
    fprintf('Helmet Passes\n')
end

fprintf('<strong>Mean EDC = %0.2f%%</strong>\n\n',EDCmean)
```

Table Creation

```
T = table([1:(w-1)]',SIval',EDC','VariableNames',{'Run','SI','EDC'});
disp(T)
writetable(T,tbl)

disp('DONE')
```

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```
function input1t1 = importfile(filename, startRow, endRow)

%IMPORTFILE Import numeric data from a text file as a matrix.
%   INPUT1T1 = IMPORTFILE(FILENAME) Reads data from text file FILENAME
 for
%   the default selection.
%
%   INPUT1T1 = IMPORTFILE(FILENAME, STARTROW, ENDROW) Reads data from
 rows
%   STARTROW through ENDROW of text file FILENAME.
%
% Example:
%   input1t1 = importfile('input1(t) 1.txt', 31, 16414);
%
%    See also TEXTSCAN.

% Auto-generated by MATLAB on 2016/02/12 13:54:17
```

Initialize variables.

```
delimiter = '\t';
if nargin<=2
    startRow = 31;
    endRow = inf;
end
```

Format string for each line of text:

```
column1: double (%f)

% column2: double (%f)
% For more information, see the TEXTSCAN documentation.
formatSpec = '%f%f%[^\n\r]';
```

Open the text file.

```
fileID = fopen(filename,'r');
```

Read columns of data according to format string.

This call is based on the structure of the file used to generate this code. If an error occurs for a different file, try regenerating the code from the Import Tool.

```
dataArray = textscan(fileID, formatSpec, endRow(1)-
startRow(1)+1, 'Delimiter', delimiter, 'EmptyValue'
 ,NaN,'HeaderLines', startRow(1)-1, 'ReturnOnError', false);
for block=2:length(startRow)
    frewind(fileID);
    dataArrayBlock = textscan(fileID, formatSpec, endRow(block)-
startRow(block)+1, 'Delimiter', delimiter, 'EmptyValue'
 ,NaN,'HeaderLines', startRow(block)-1, 'ReturnOnError', false);
    for col=1:length(dataArray)
        dataArray{col} = [dataArray{col};dataArrayBlock{col}];
    end
end
```

Close the text file.

```
fclose(fileID);
```

Post processing for unimportable data.

No unimportable data rules were applied during the import, so no post processing code is included. To generate code which works for unimportable data, select unimportable cells in a file and regenerate the script.

Create output variable

```
input1t1 = [dataArray{1:end-1}];
```

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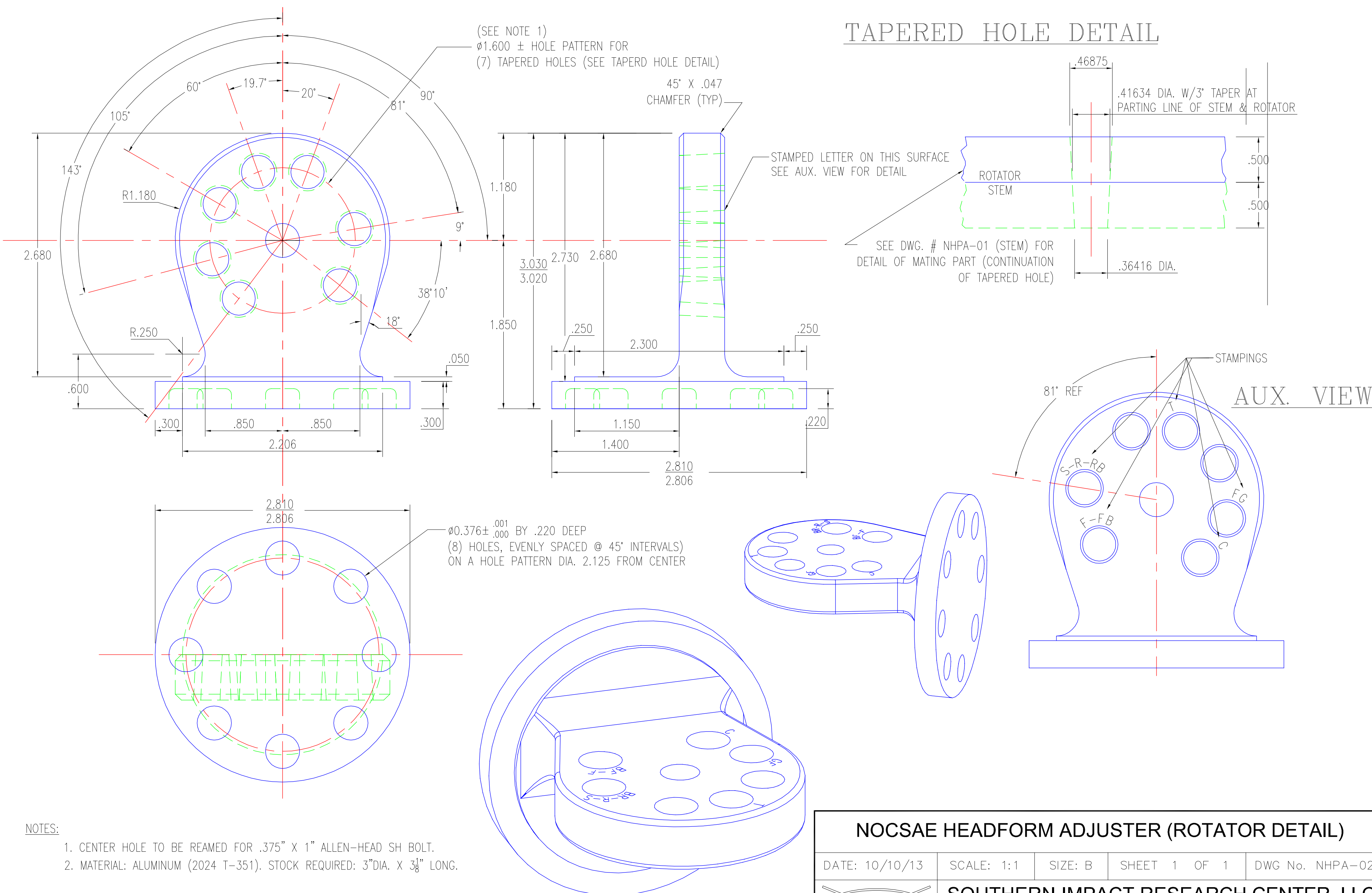
```
function y = butter16(x)
%UNTITLED16 Filters input x and returns output y.

% MATLAB Code
% Generated by MATLAB(R) 8.6 and the Signal Processing Toolbox 7.1.
% Generated on: 17-Feb-2016 22:05:41

%#codegen

% To generate C/C++ code from this function use the codegen command.
% Type 'help codegen' for more information.

persistent Hd;

if isempty(Hd)

    % The following code was used to design the filter coefficients:
    %
    % N    = 4;      % Order
    % F3dB = 1000;   % 3-dB Frequency
    % Fs   = 16384;  % Sampling Frequency
    %
    % h = fdesign.lowpass('n,f3db', N, F3dB, Fs);
    %
    % Hd = design(h, 'butter', ...
    %     'SystemObject', true);

    Hd = dsp.BiquadFilter( ...
        'Structure', 'Direct form II', ...
        'SOSMatrix', [1 2 1 1 -1.62241701874291 0.749495988750496; 1 2
 1 1 ...
        -1.37827832665825 0.486234658545862], ...
        'ScaleValues', [0.0317697425018976; 0.0269890829719025; 1]);
end

s = double(x);
y = step(Hd,s);
```

Published with MATLAB® R2016a

APPENDIX C: SIRC DROP TOWER DRAWINGS



NOTES:

1. CENTER HOLE TO BE REAMED FOR .375" X 1" ALLEN-HEAD SH BOLT.
2. MATERIAL: ALUMINUM (2024 T-351). STOCK REQUIRED: 3"DIA. X 3⅛" LONG.

NOCSAE HEADFORM ADJUSTER (ROTATOR DETAIL)

DATE: 10/10/13	SCALE: 1:1	SIZE: B	SHEET 1 OF 1	DWG No. NHPA-02

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304 DUNAVANT DR
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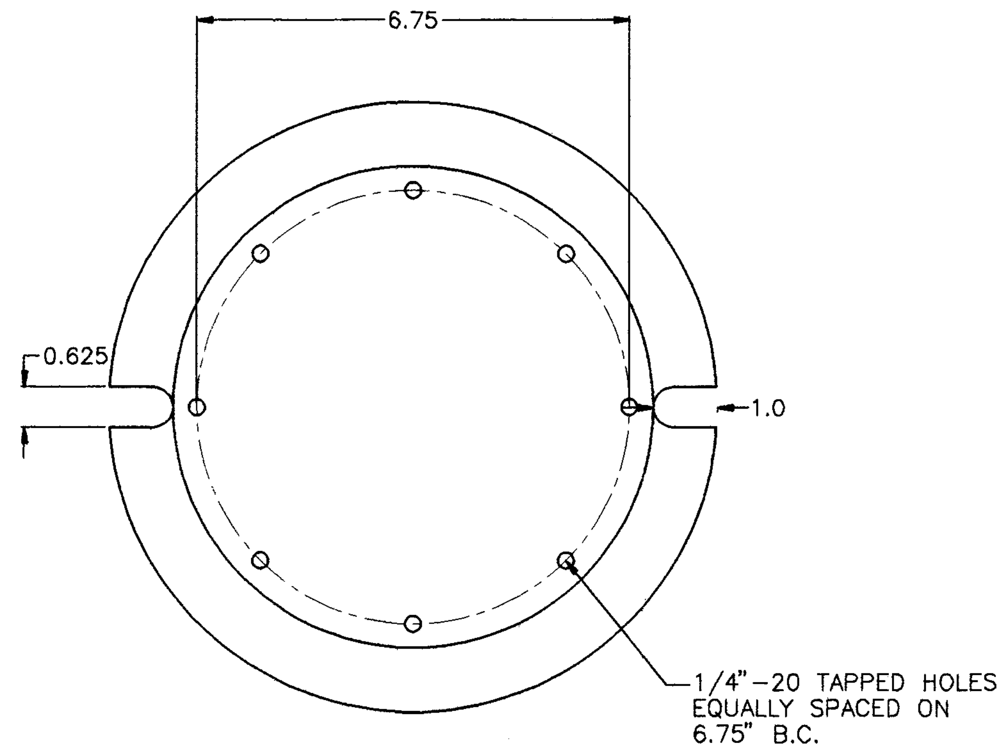
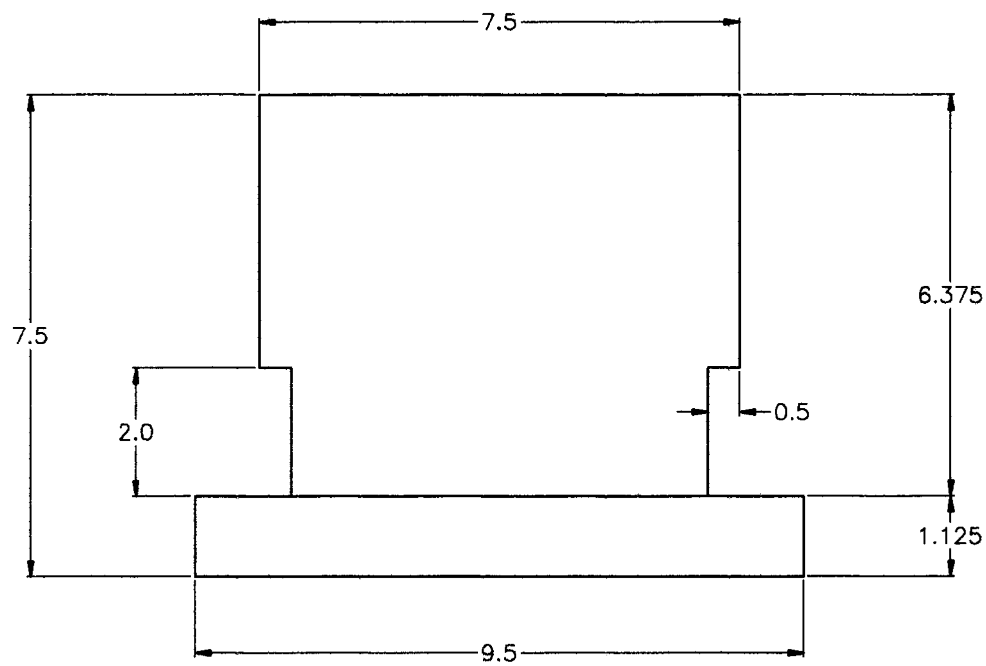
PHONE 865-523-1662
FAX 865-523-1233





NOTES:

MATERIAL: STEEL 10" DIA. x 7.5" LONG

TEST ANVIL			
2-14-98	SCALE: 1:3	SHEET 1 OF 1	DRAWING: TA-02

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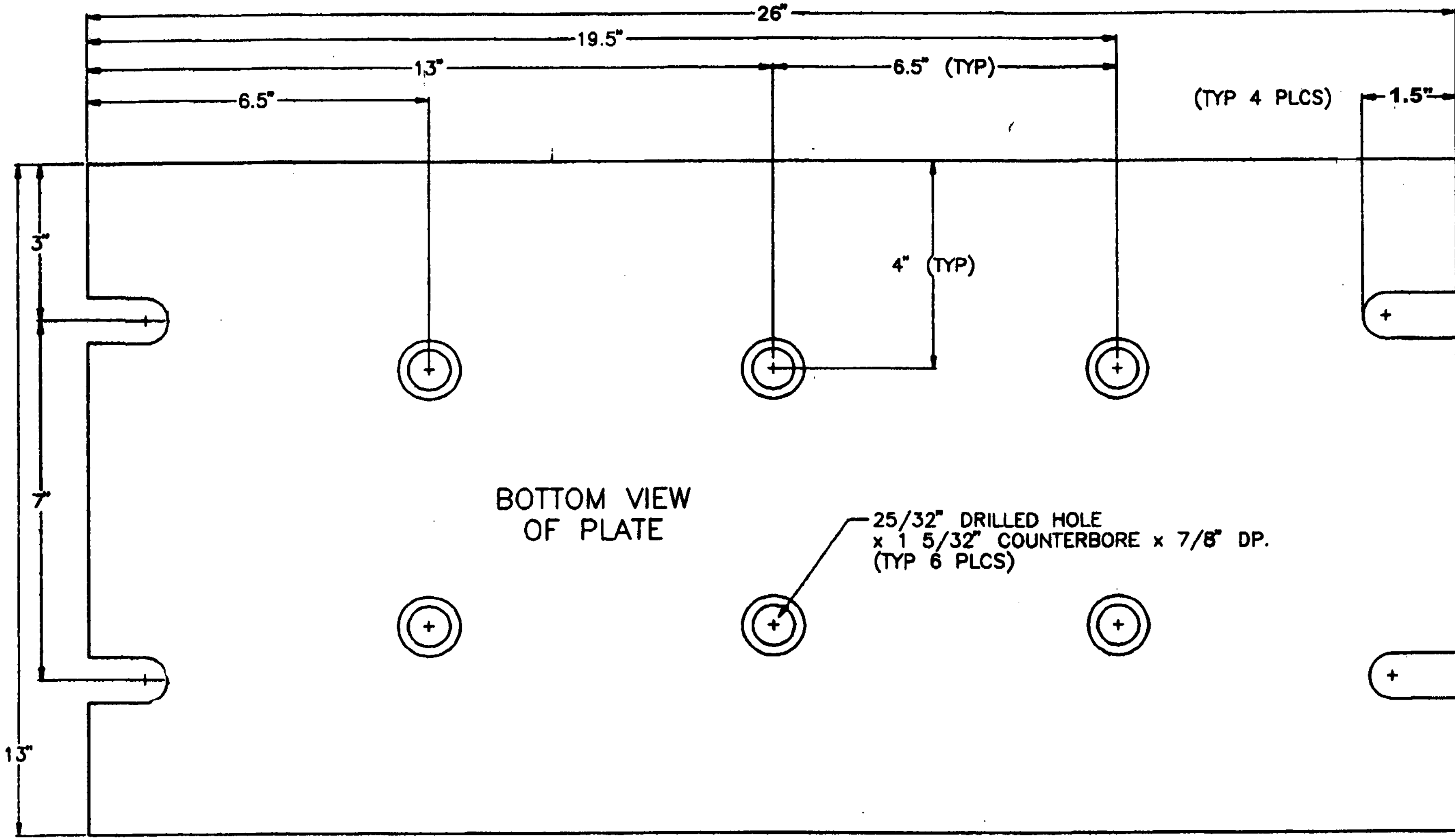
7205 Canmore Lane
Knoxville, TN 37919
Phone (423) 588-1580
Fax (423) 588-1422



NOTES:

MATERIAL: STEEL PLATE 1 1/4" x 13" x 26"
BOTTOM OF PLATE TO BE GROUND AFTER ASSEMBLY

ANVIL BASE PLATE (BOTTOM ASSEMBLY)			
3-30-99	SCALE: 1:3	SHEET 1 OF 1	DRAWING: TA-04

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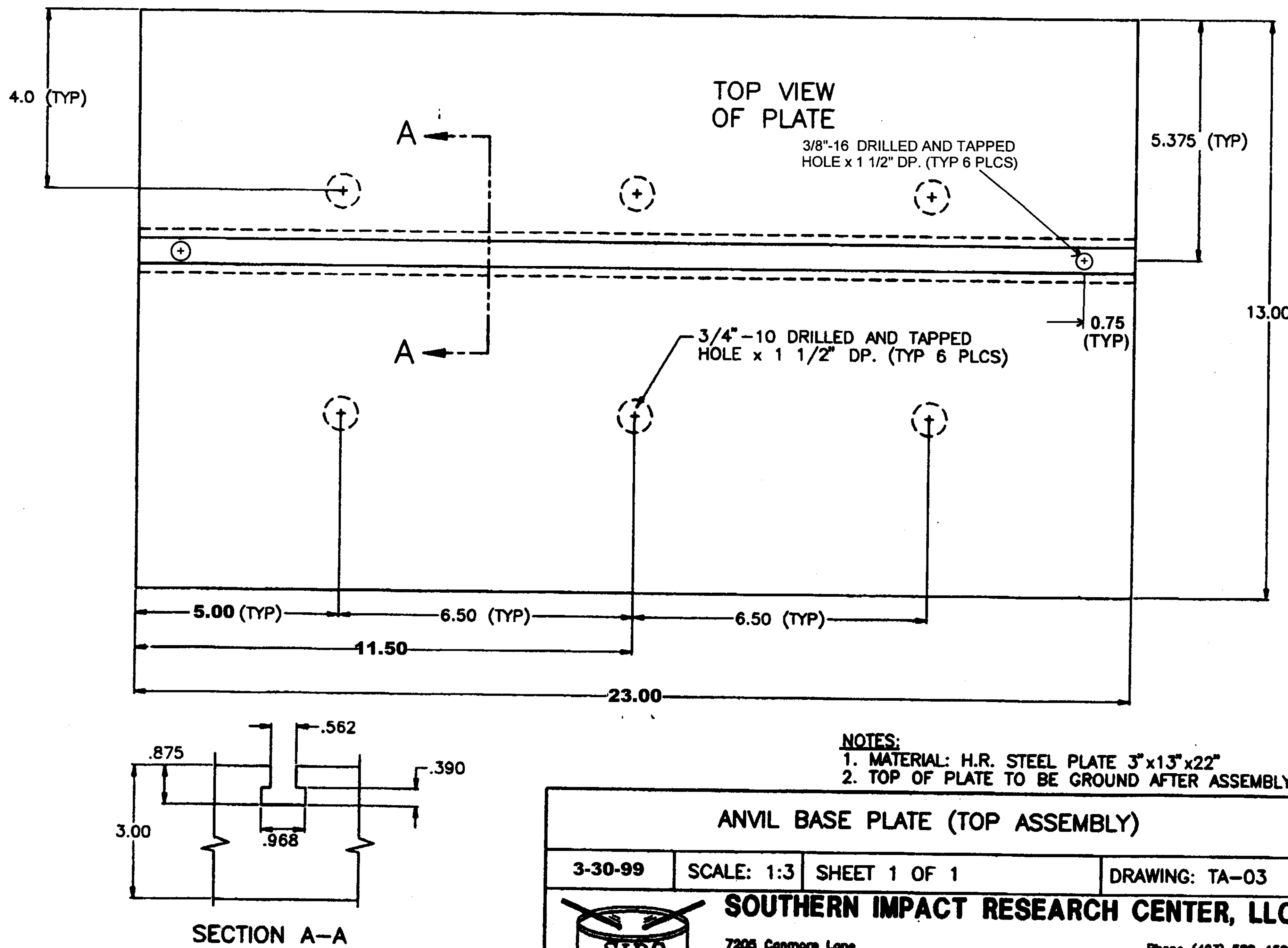

NOTES:
1. MATERIAL: H.R. STEEL PLATE 3"x13"x22"
2. TOP OF PLATE TO BE GROUND AFTER ASSEMBLY

ANVIL BASE PLATE (TOP ASSEMBLY)			
3-30-99	SCALE: 1:3	SHEET 1 OF 1	DRAWING: TA-03

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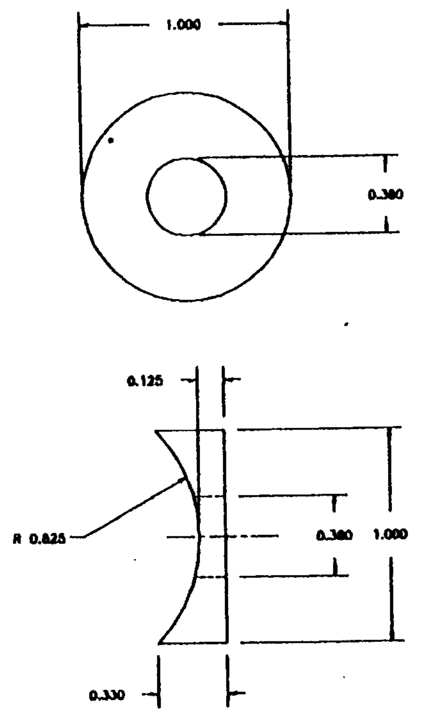

NOTES:
MATERIAL: 6061 ALUM.

BEVELED ALUMINUM WASHER			
2-14-98	SCALE: 2:1	SHEET 1 OF 1	DRAWING: BAW-01

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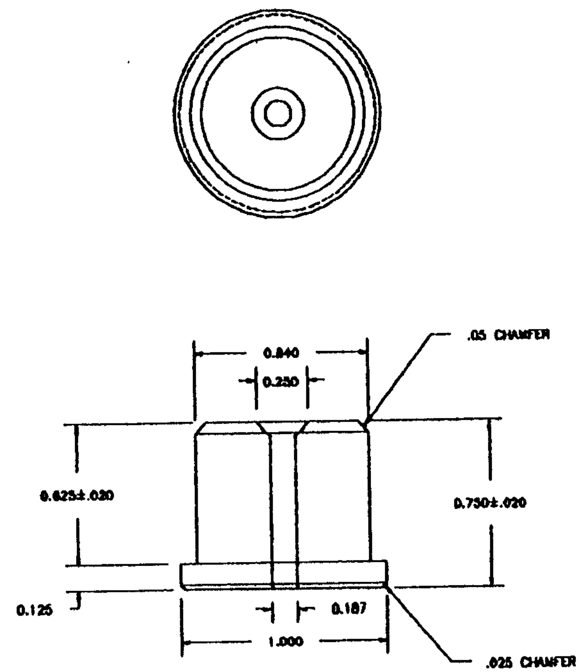
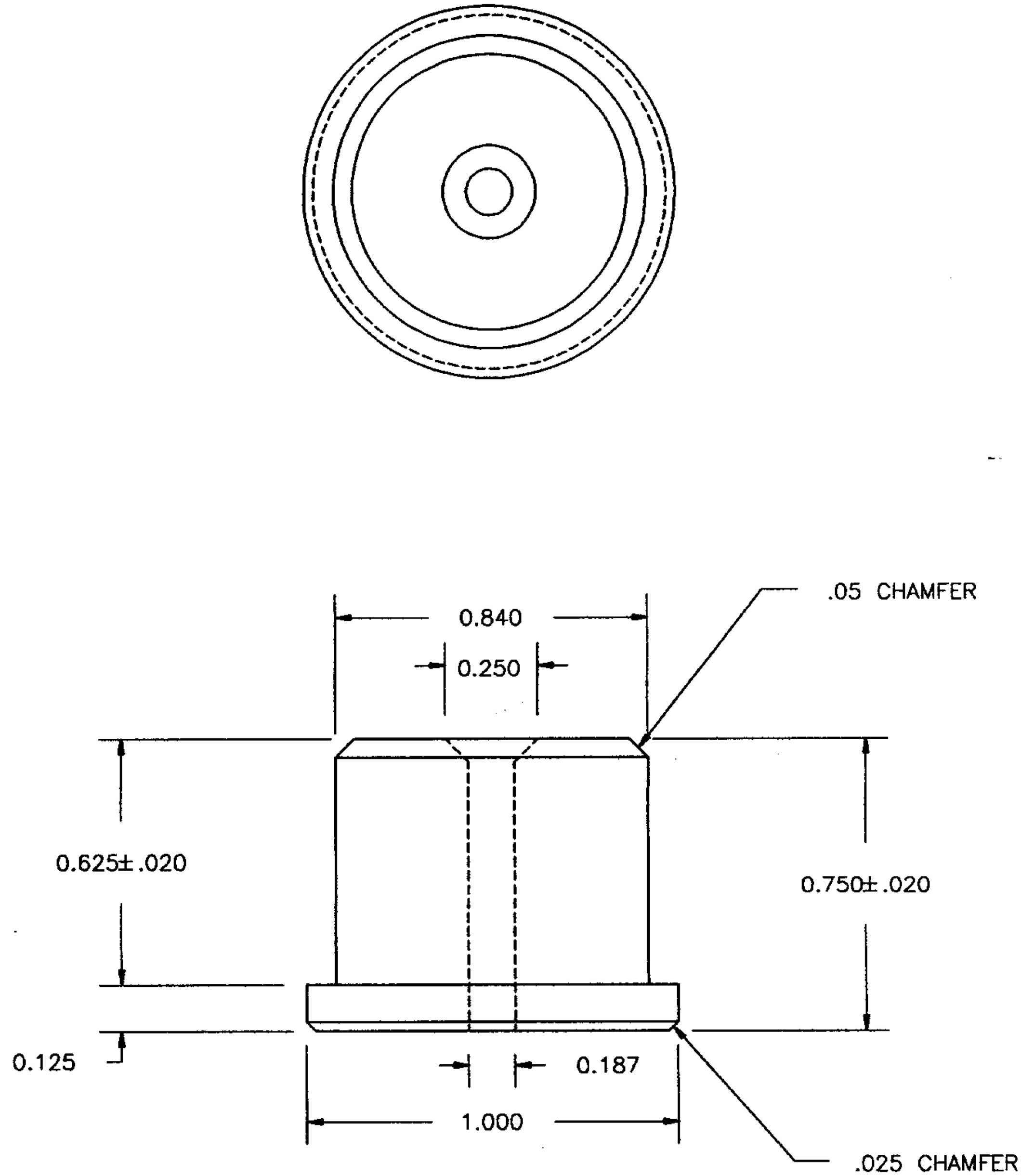


NOTES:
MATERIAL: WHITE DELRIN

NYLON BUSHING – NOCSAE CARRIAGE			
2-14-98	SCALE: 2:1	SHEET 1 OF 1	DRAWING: NB-01

SOUTHERN IMPACT RESEARCH CENTER, LLC



NOTES:

MATERIAL: WHITE DELRIN

NYLON BUSHING – NOCSAE CARRIAGE			
2–14–98	SCALE: 2:1	SHEET 1 OF 1	DRAWING: NB–01

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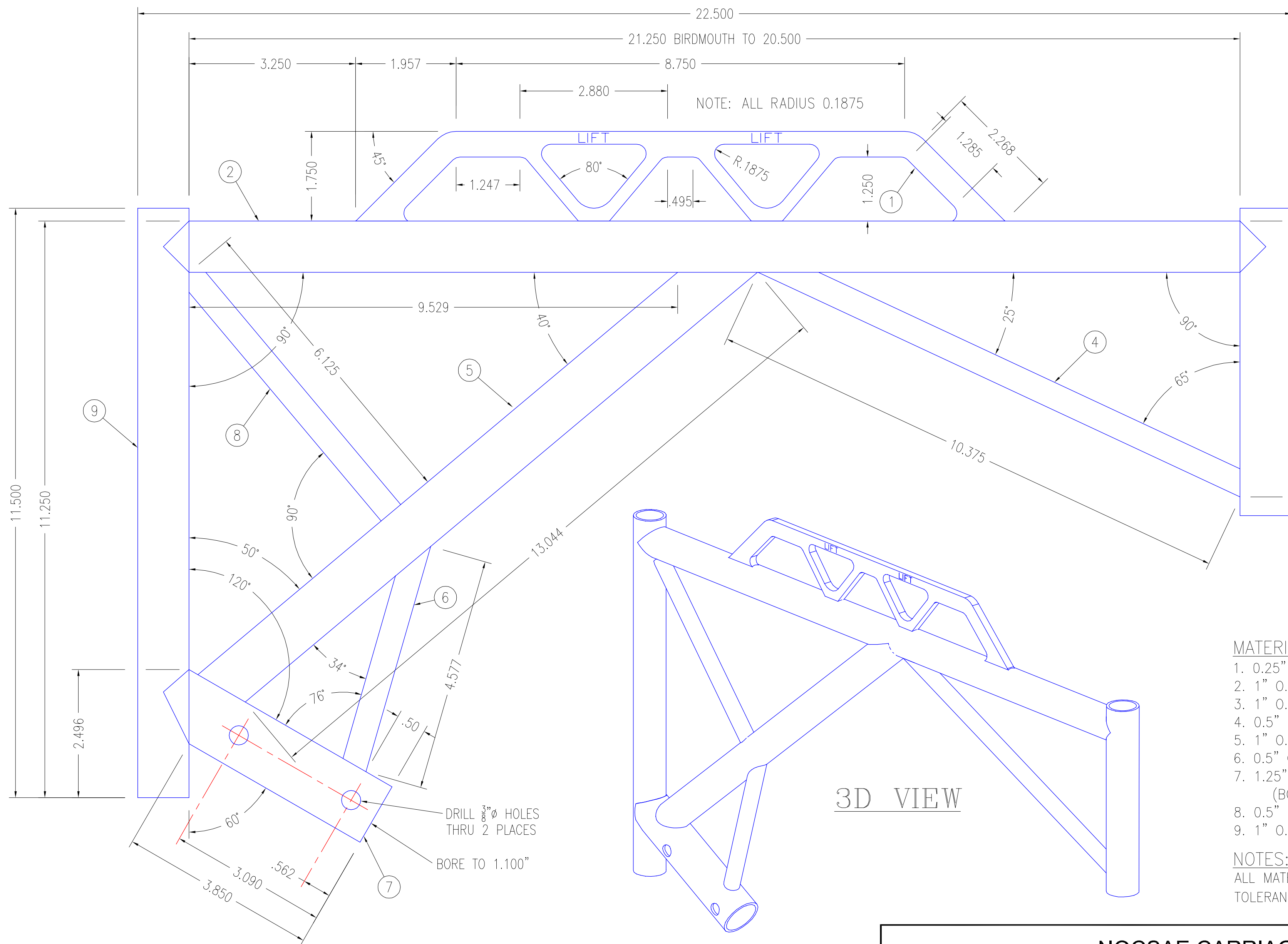

MATERIAL LIST:

1. 0.25" PLATE
2. 1" O.D. TUBE X .083 WALL
3. 1" O.D. TUBE X .083 WALL
4. 0.5" O.D. TUBE X .083 WALL
5. 1" O.D. TUBE X .083 WALL
6. 0.5" O.D. TUBE X .083 WALL
7. 1.25" O.D. TUBE X .083 WALL (BORE TO 1.10" I.D.)
8. 0.5" O.D. TUBE X .083 WALL
9. 1" O.D. TUBE X .083 WALL

NOTES:

ALL MATERIAL ALUMINUM T-6061
TOLERANCE = $\pm\frac{1}{32}$"

NOCSAE CARRIAGE

DATE: 8/3/13	SCALE: 1:2	SIZE: B	SHEET 1 OF 1	DWG No. NHPA-00

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ROCKFORD, TN 37853
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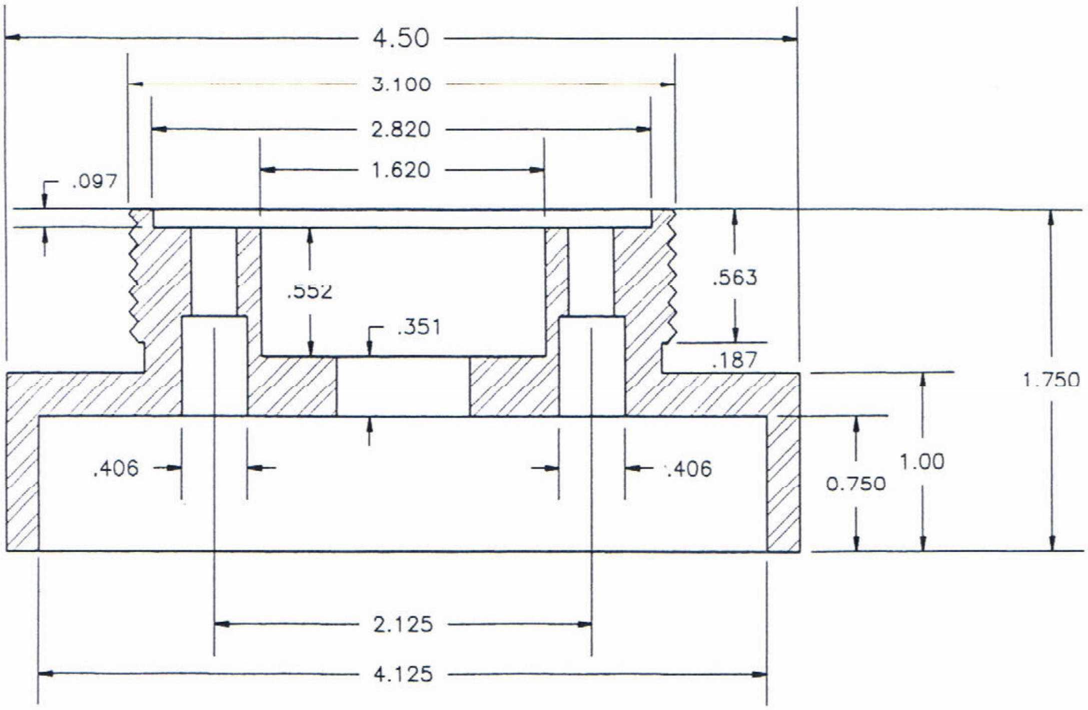

SECTION B–B

NOTES:

1. MATERIAL: 2024 T–351
2. PINS: .375 DOWEL PIN x 3/4" LONG
3. THD. SIZE: 3 1/8" – 10 TPI
4. TOLERANCE: 3 PLACES ±.005   2 PLACES ±.010
5. FINISH: √125
6. DEBURR: BREAK ALL SHARP EDGES

HEADFORM COLLAR	
DATE: 11/1/97	SCALE: 1:1

SIRC

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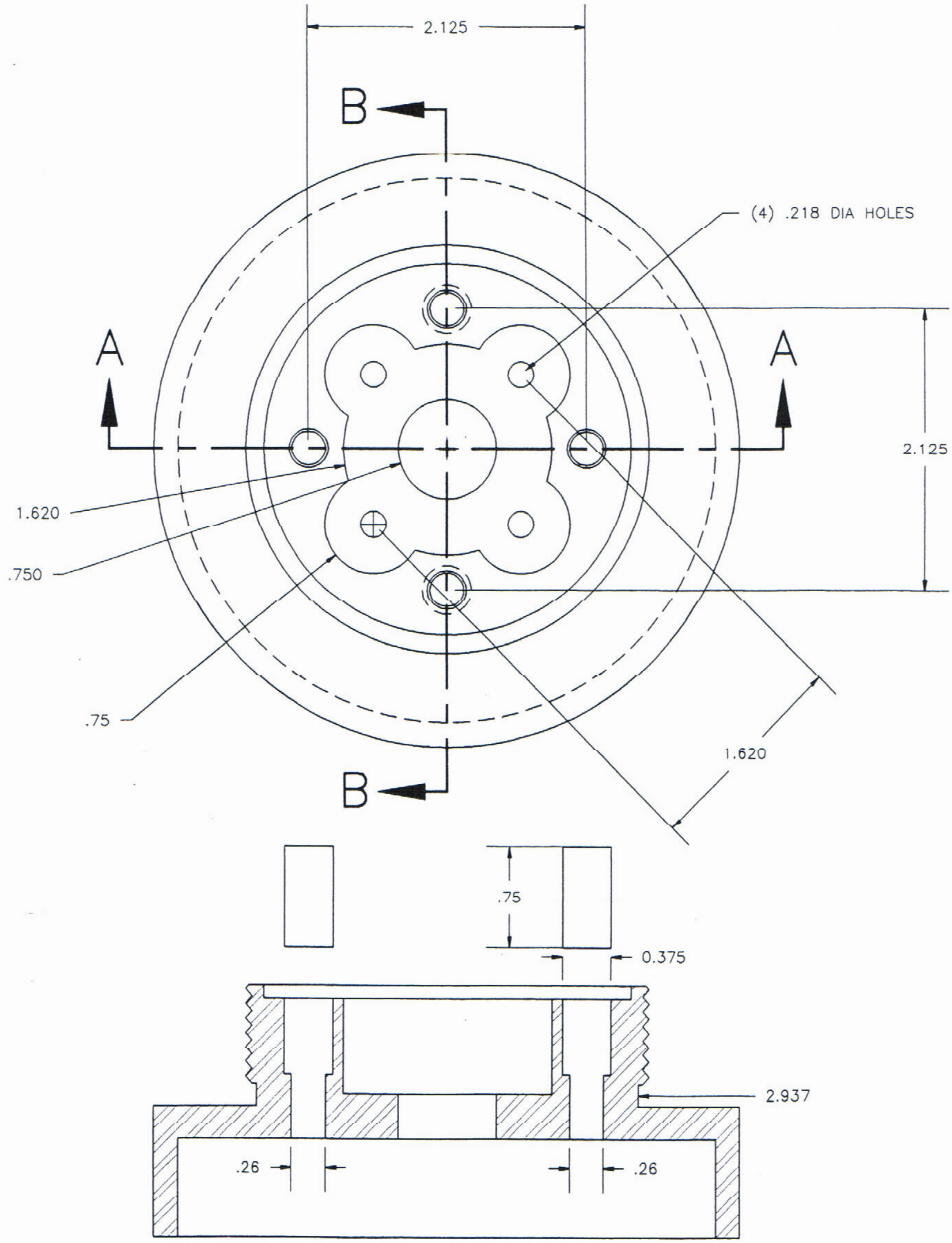
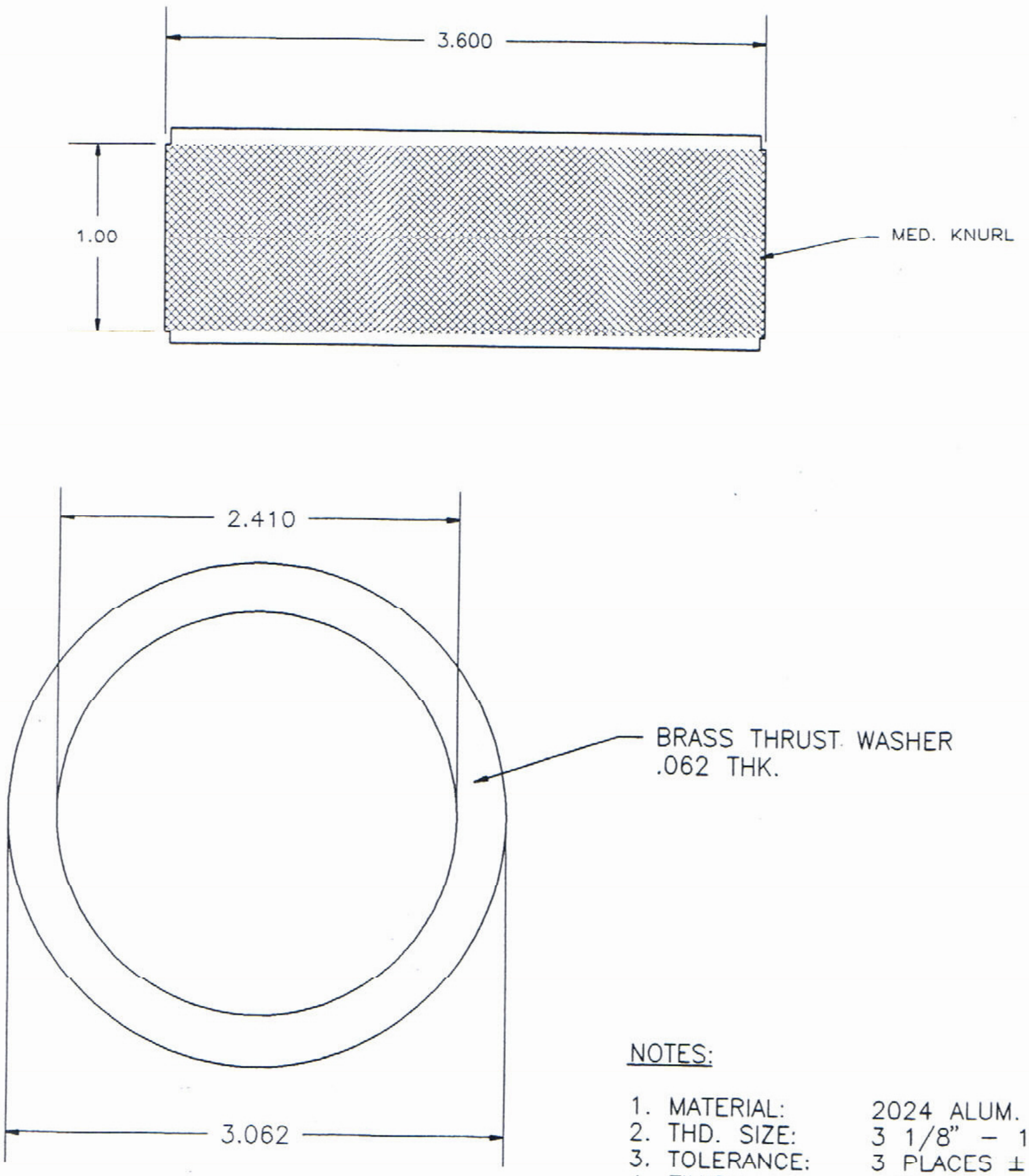

2.125
B
(4) .218 DIA HOLES
A
A
2.125
1.620
.750
.75
1.620
B
.75
0.375
2.937
.26
.26

SECTION A–A



NOTES:

1. MATERIAL: 2024 ALUM.
2. THD. SIZE: 3 1/8" – 10
3. TOLERANCE: 3 PLACES ±.005
4. FINISH: √125
5. DEBURR: BREAK ALL SHARP EDGES

HEADFORM THREADED LOCK RING

DATE: 11/2/97	SCALE: 1:1

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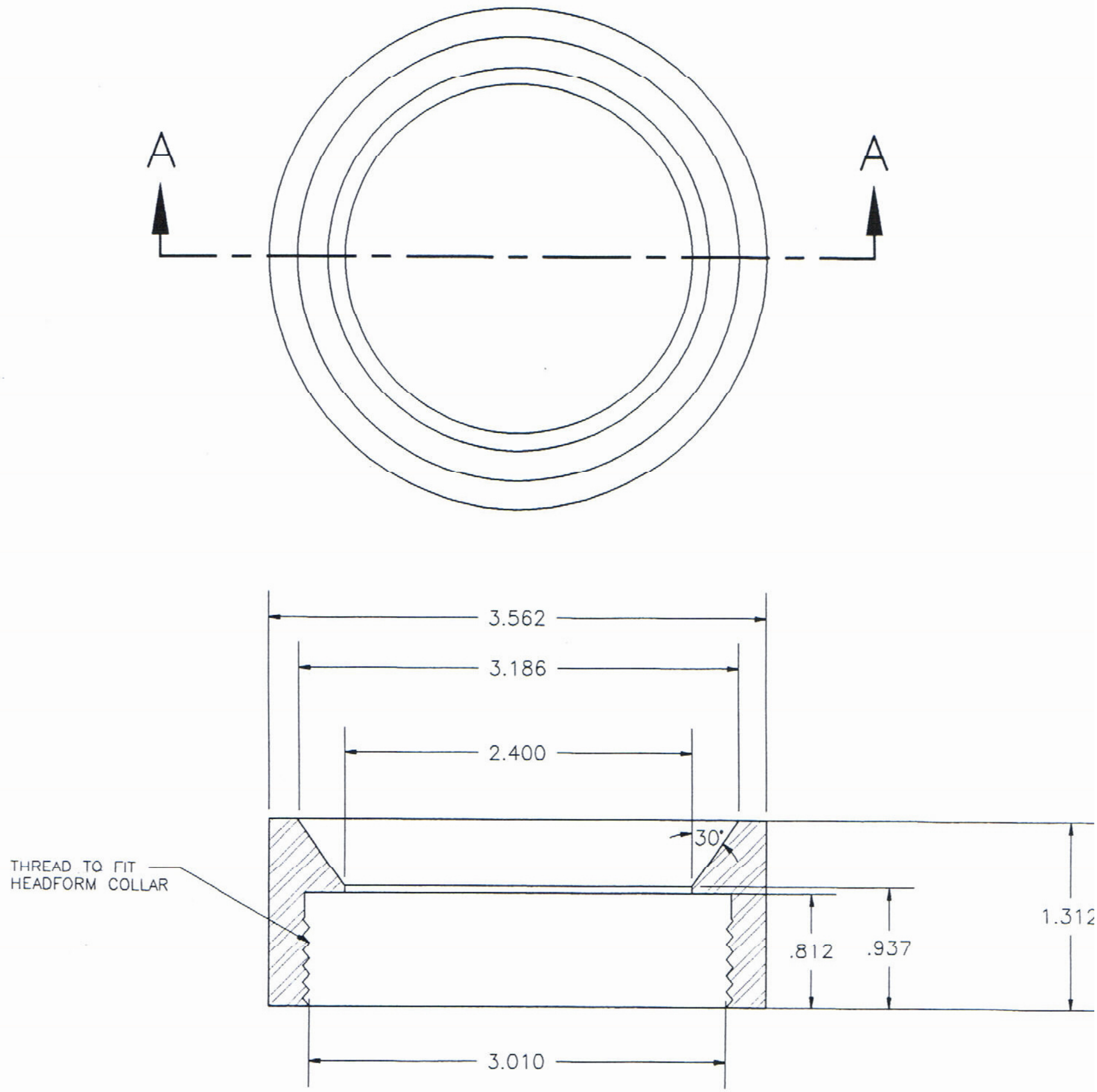
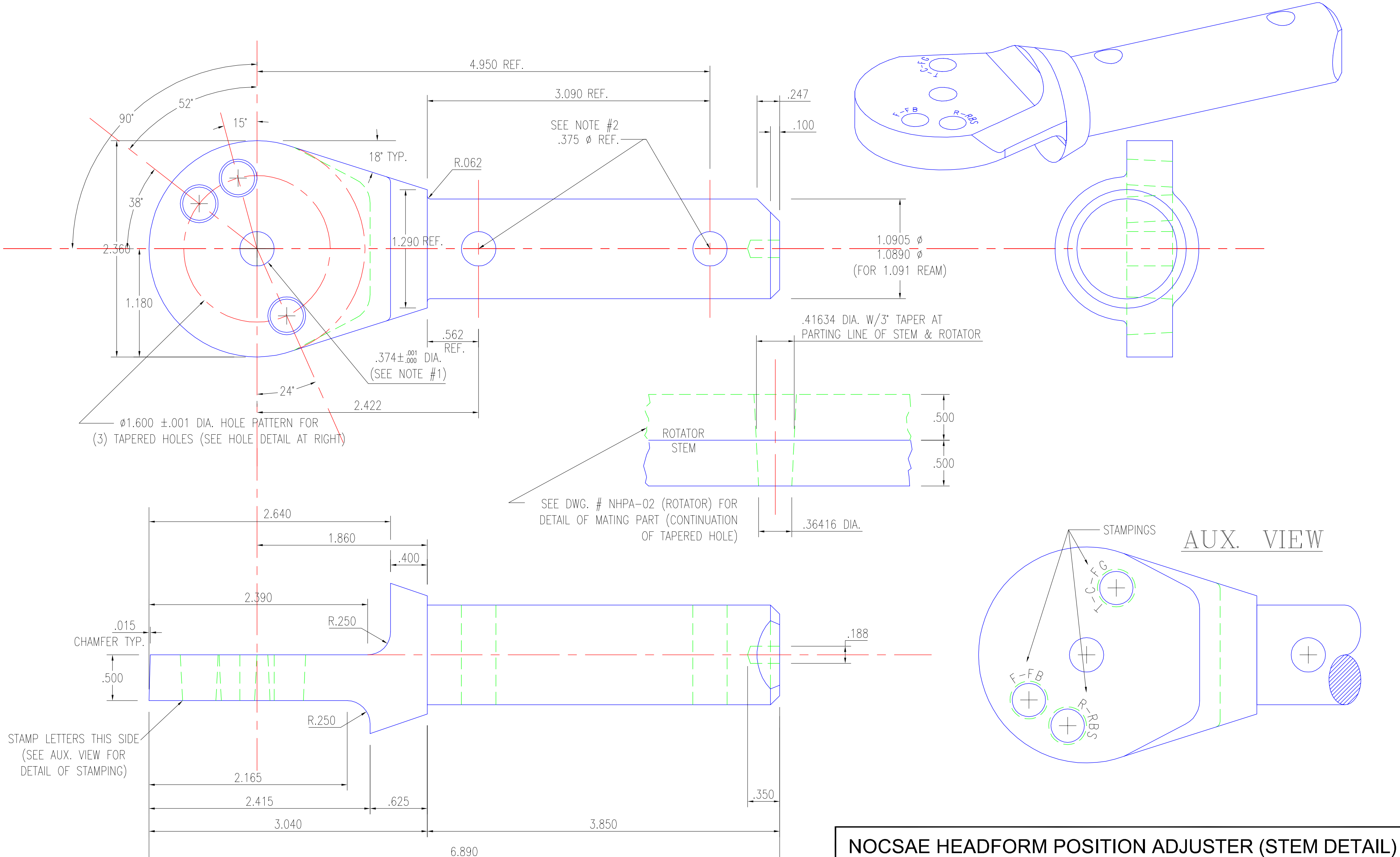

A
A
3.562
3.186
2.400
30°
THREAD TO FIT
HEADFORM COLLAR
.812
.937
1.312
3.010

SECTION A–A



NOTES:

1. CTR, HOLE TO BE REAMED FOR .375" X 1" ALLEN-HEAD SH BOLT.
2. HOLES AT .562 REF & 3.09 REF. TO BE DRILLED & REAMED WHEN ASSEMBLED INTO CARRIAGE (SEE DWG NHPA-00).
3. MATERIAL: ALUMINUM (2024 T-351). STOCK REQUIRED: 2⅝" DIA. X 7" LONG.

NOCSAE HEADFORM POSITION ADJUSTER (STEM DETAIL)				
DATE: 8/3/13	SCALE: 1:1	SIZE: B	SHEET 1 OF 1	DWG No. NHPA-01

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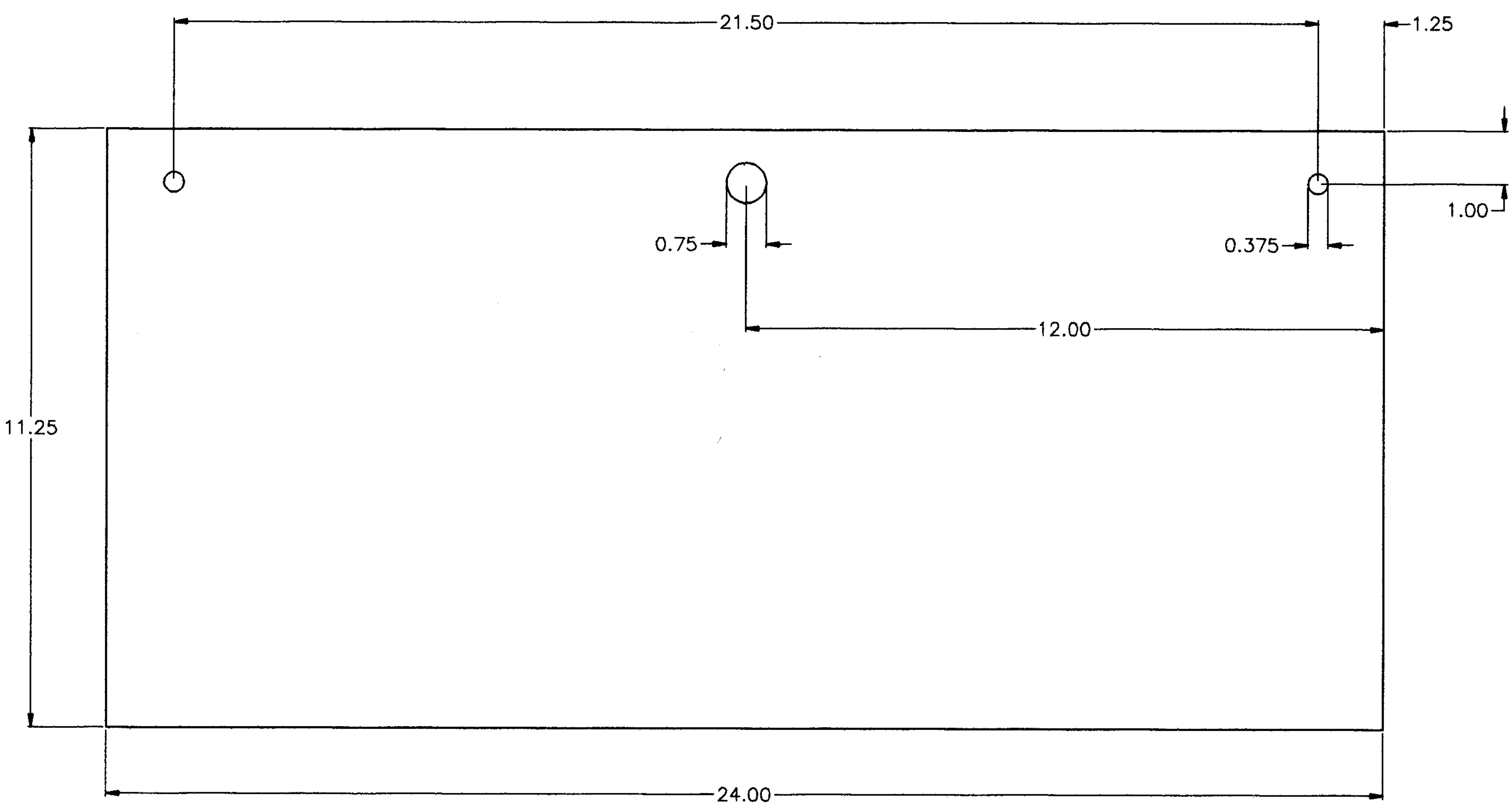
ROCKFORD, TN 37853

PHONE 865-523-1662
FAX 865-523-1233



NOTE:

MATERIAL: 3/8" THICK ALUM.-6061

TOP PLATE			
2-14-98	SCALE: 1:3	SHEET 1 OF 1	DRAWING: TA-01

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Knoxville, TN 37919
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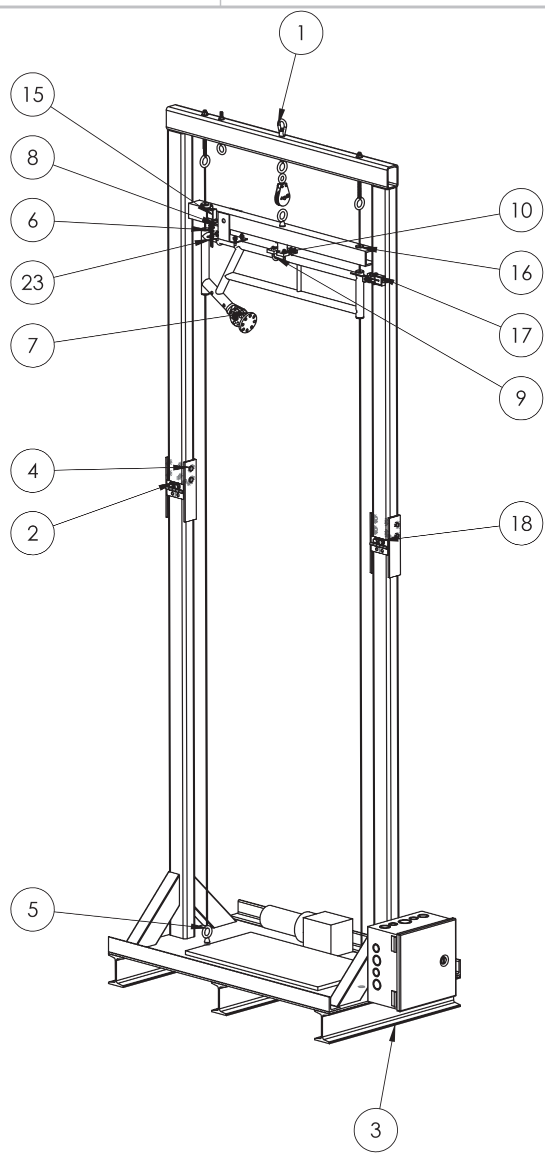
APPENDIX D: HELMET DROP TOWER ENGINEERING DRAWING



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	DT005A	UPPER FRAME	1
2	16175A61	HINGE	2
3	DT004A	LOWER FRAME	1
4	97245A442	CLEVIS PIN	4
5	N/A	STEEL CABLE	2
6	N/A	CARRIAGE	1
7	N/A	HEADFORM ROTATOR	1
8	DT013P	SAFETY BRACKET	1
9	3035T12	U - BOLT	4
10	DT012P	MAGNET PLATE	1
11	90670A029	1/4-20 HEX NUT	2
12	91259A624	SHOULDER SCREW	1
13	95462A030	5/16-18 HEX NUT	1
14	90850A150	5/16 WASHER	1
15	aem2g21z11-3	LIMIT SWITCH	1
16	DT006A	LIFT BAR ASSEMBLY	1
17	aem2g71z11-3	LIMIT SWITCH	1
18	91236A636	3/8-16 CAP SCREW	4
19	98023A031	3/8 WASHER	4
20	91113A031	3/8 LOCK WASHER	4
21	90473A031	3/8-16 HAX NUT	4
22	92627A216	QUICK RELEASE PIN	1
23	93306A550	1/4-20 CAP SCREW	1

	NAME	DATE
DRAWN	MJS	5/30/16
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

DO NOT SCALE DRAWING

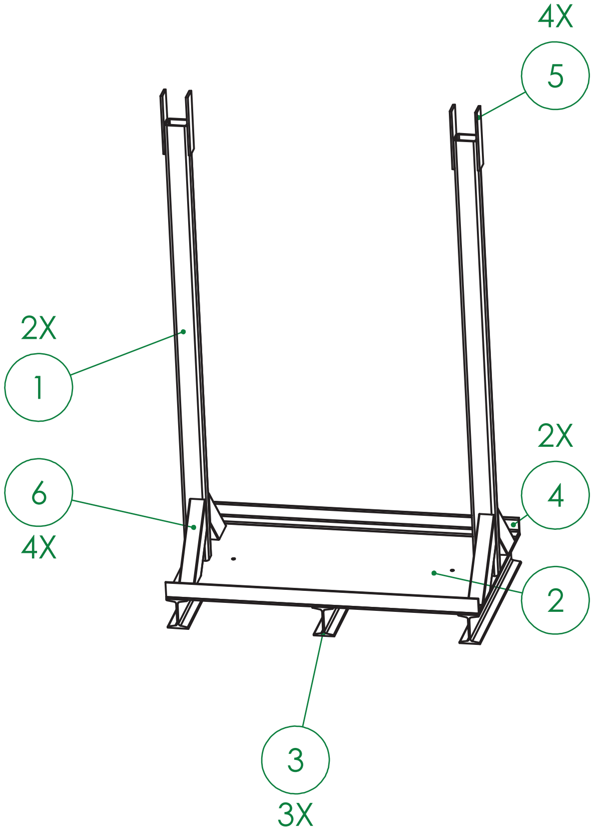
TITLE:

DROP TOWER

SIZE **B** DWG. NO. DT001A REV

SCALE: 1:32 WEIGHT: SHEET 1 OF 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	DT002P	UPRIGHT	2
2	DT001P	BASEPLATE	1
3	DT007P	BASE	3
4	DT006P	STIFFENER	2
5	DT015P	SIDE PLATE	4
6	DT008P	SUPPORT	4



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.03 THREE PLACE DECIMAL ±.003	DRAWN	M. SCHUSTER	5/26/16
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	Q.A.		
MATERIAL	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING	NEXT ASSY:		

CAL POLY

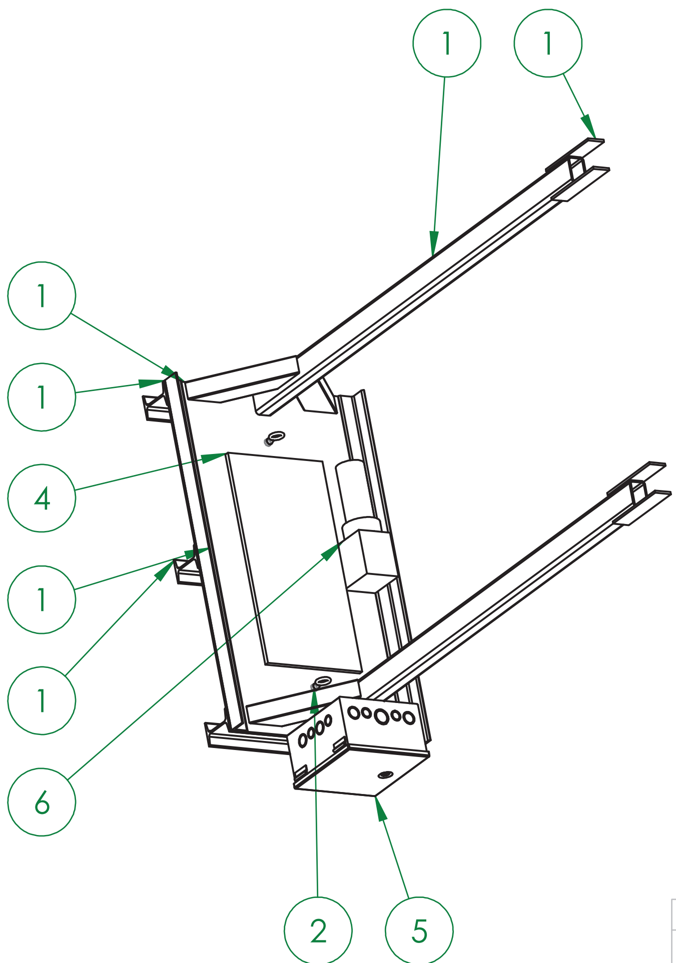
TITLE:

LOWER FRAME

SIZE	DWG. NO.	REV
A	DT002A	

SCALE: 1:24 WEIGHT: SHEET 1 OF 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	DT002A	LOWER FRAME	1
2	3014T956	EYEBOLT	2
3	96282A103	3/8-16 LOCKNUT	2
4	N/A	IMPACT PAD	1
5	75065K66	ENCLOSURE	1
6	N/A	WINCH	1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.03 THREE PLACE DECIMAL ±.003	DRAWN	M. SCHUSTER	5/30/16
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	Q.A.		
MATERIAL	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING	NEXT ASSY:		

CAL POLY

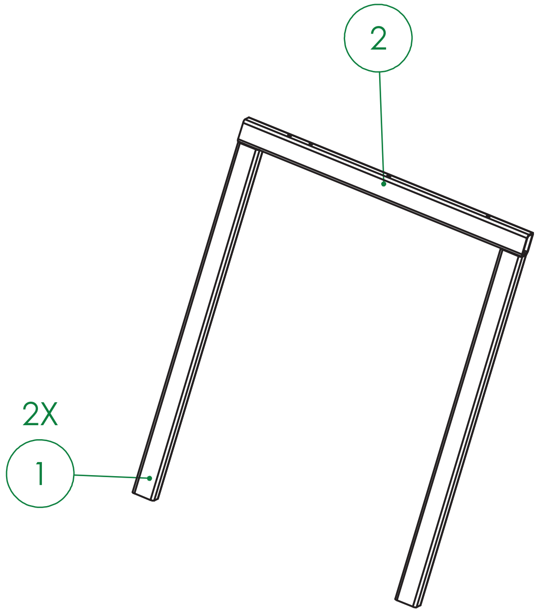
TITLE:

LOWER FRAME WITH RIGGING

SIZE	DWG. NO.	REV
A	DT004A	

SCALE: 1:32 WEIGHT: SHEET 1 OF 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	DT003P	Rect. Tube	2
2	DT004P	TOP BEAM	1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.03 THREE PLACE DECIMAL ±.003	DRAWN	M. SCHUSTER	05/26/16
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	Q.A.		
MATERIAL	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING	NEXT ASSY:		

CAL POLY

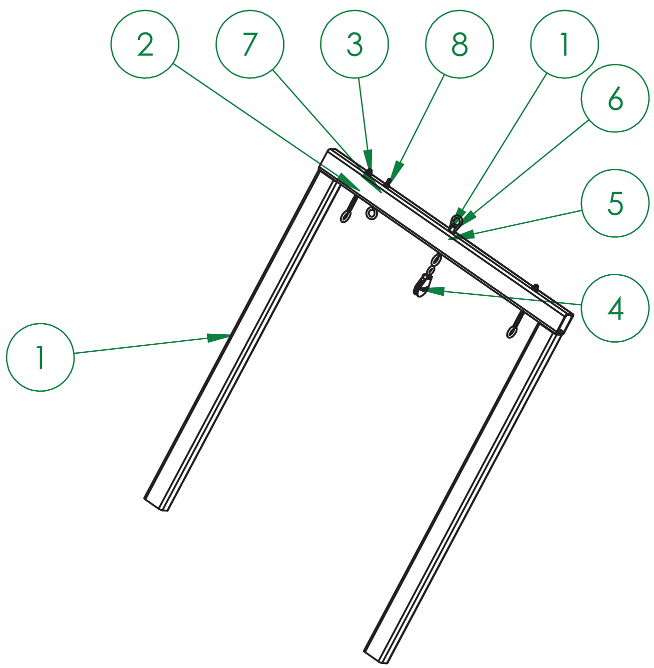
TITLE:

UPPER FRAME

SIZE	DWG. NO.	REV
A	DT003A	

SCALE: 1:24 WEIGHT: SHEET 1 OF 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	DT003A	UPPER FRAME	1
2	3013T969	EYEBOLT	2
3	93298A130	3/8-16 LOCKNUT	2
4	3099T13	PULLEY	1
5	3014T906	EYEBOLT	1
6	3274T41	EYE NUT	1
7	3014T905	EYEBOLT	1
8	93298A120	5/16-18 LOCKNUT	1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.03 THREE PLACE DECIMAL ±.003	DRAWN	M. SCHUSTER	5/30/16
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	Q.A.		
MATERIAL	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING	NEXT ASSY:		

CAL POLY

TITLE:

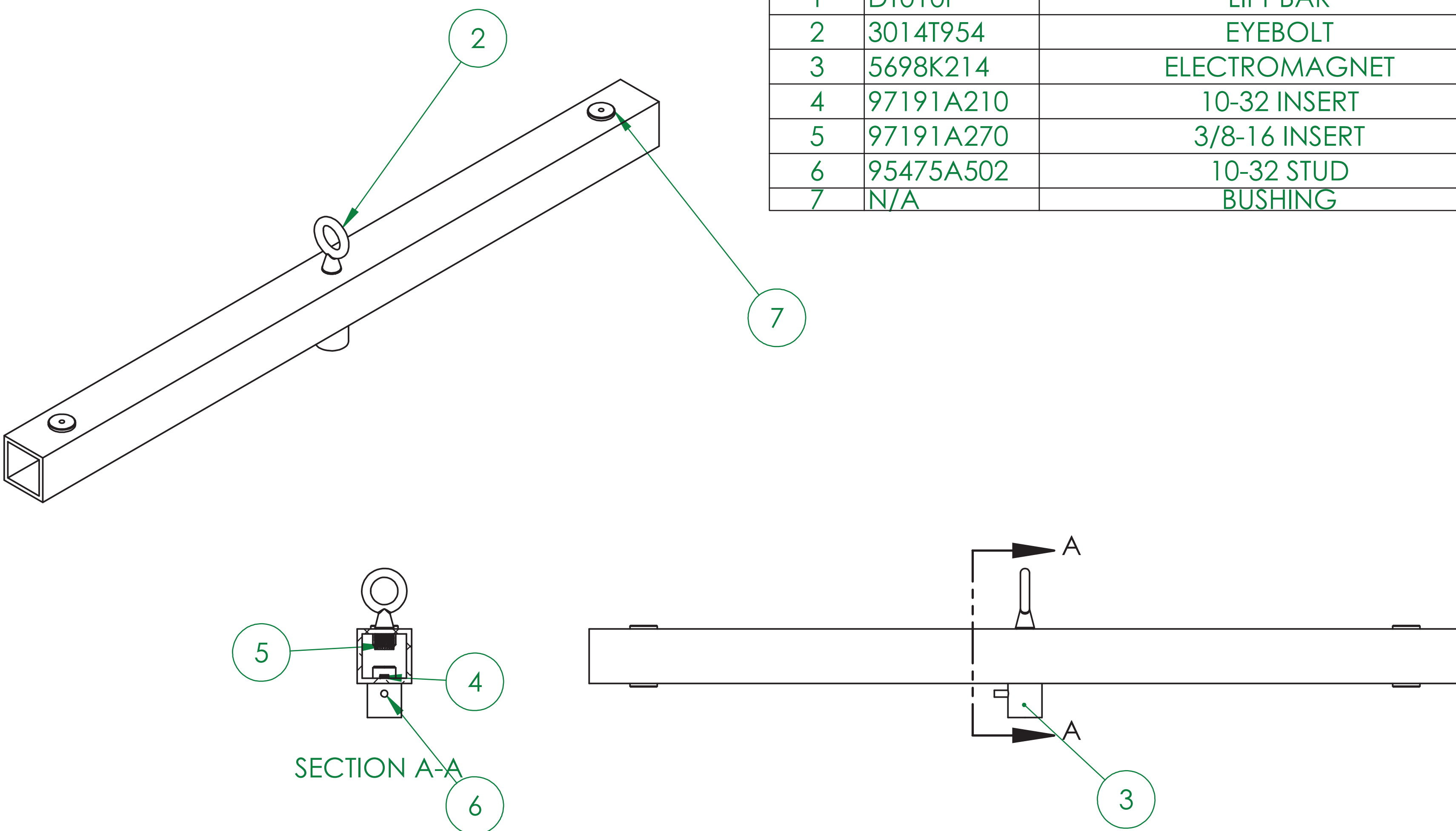
UPPER FRAME WITH RIGGING

SIZE: **A** | DWG. NO. DT005A | REV

SCALE: 1:24 | WEIGHT: | SHEET 1 OF 1

2 1 B A

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	DT010P	LIFT BAR	1
2	3014T954	EYEBOLT	1
3	5698K214	ELECTROMAGNET	1
4	97191A210	10-32 INSERT	1
5	97191A270	3/8-16 INSERT	1
6	95475A502	10-32 STUD	1
7	N/A	BUSHING	4



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.03
THREE PLACE DECIMAL ±.003

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	M. SCHUSTER	3/2/16
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

NEXT ASSY:

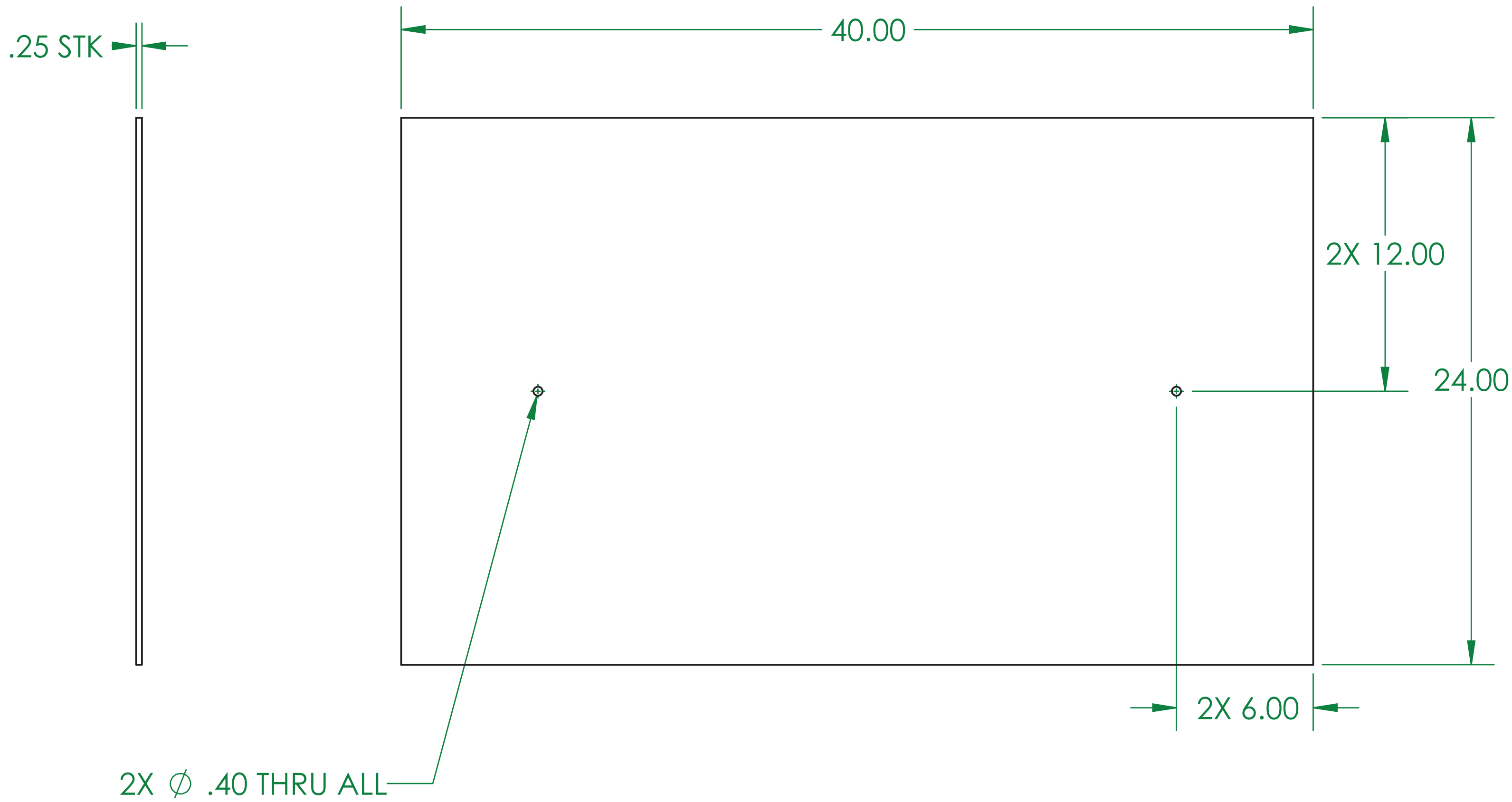
CAL POLY

TITLE:

LIFTER

SIZE A | DWG. NO. DT006A | REV

SCALE: 1:6 | WEIGHT: | SHEET 1 OF 1



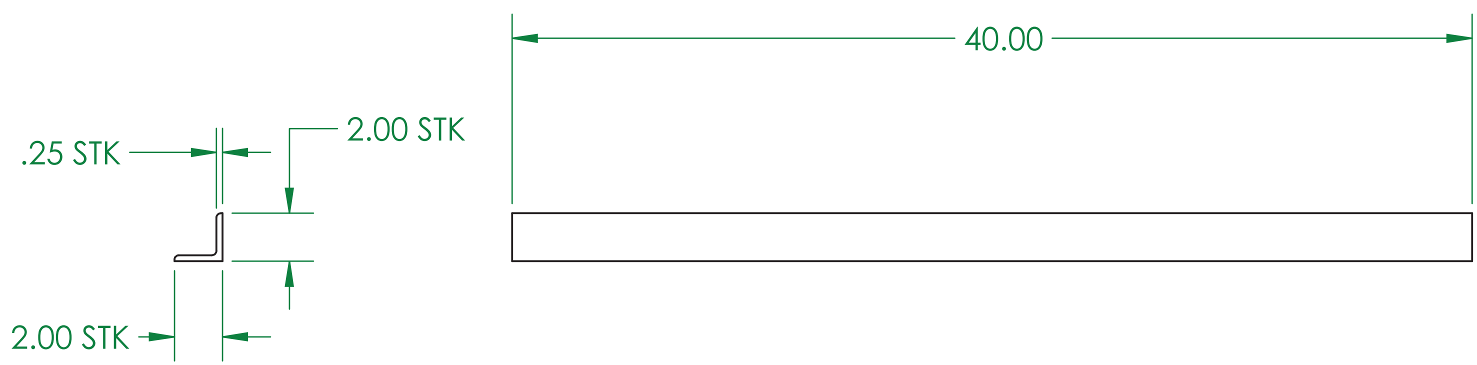
UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.03 THREE PLACE DECIMAL ±.003	DRAWN	M. SCHUSTER	3/2/16
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	Q.A.		
MATERIAL STEEL	COMMENTS:		
FINISH MACHINED			
DO NOT SCALE DRAWING	NEXT ASSY:		

CAL POLY

TITLE:

BASE PLATE

SIZE	DWG. NO.	REV
A	DT001P	
SCALE: 1:8	WEIGHT:	SHEET 1 OF 1



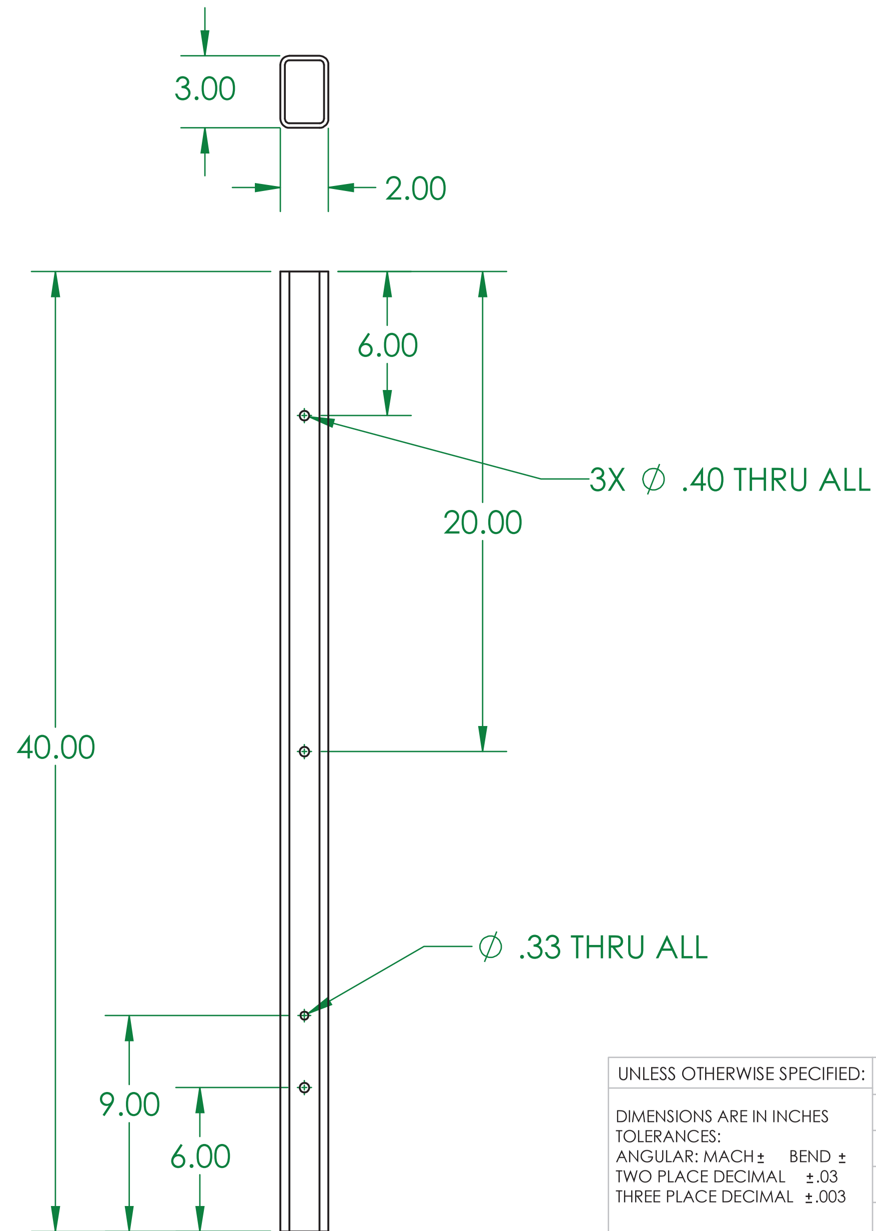
UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.03 THREE PLACE DECIMAL ±.003	DRAWN	M. SCHUSTER	3/2/16
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	Q.A.		
MATERIAL STEEL	COMMENTS:		
FINISH AS RECEIVED			
DO NOT SCALE DRAWING	NEXT ASSY:		

CAL POLY

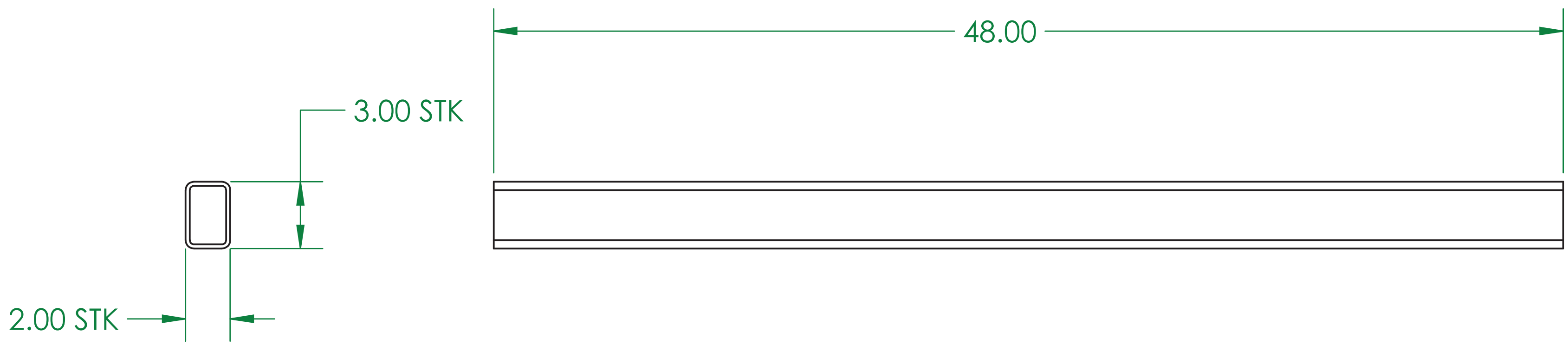
TITLE:

BASE STIFFENER

SIZE	DWG. NO.	REV
A	DT006P	
SCALE: 1:8	WEIGHT: 10 LB	SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	CAL POLY
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.03 THREE PLACE DECIMAL ±.003	DRAWN	M. SCHUSTER	3/2/16	TITLE: TOP TUBE
	CHECKED			
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	Q.A.			
MATERIAL: STEEL	COMMENTS:			SIZE: A / DWG. NO.: DT004P / REV
FINISH: AS RECEIVED	NEXT ASSY:			SCALE: 1:8 / WEIGHT: 18 LB / SHEET 1 OF 1
DO NOT SCALE DRAWING				

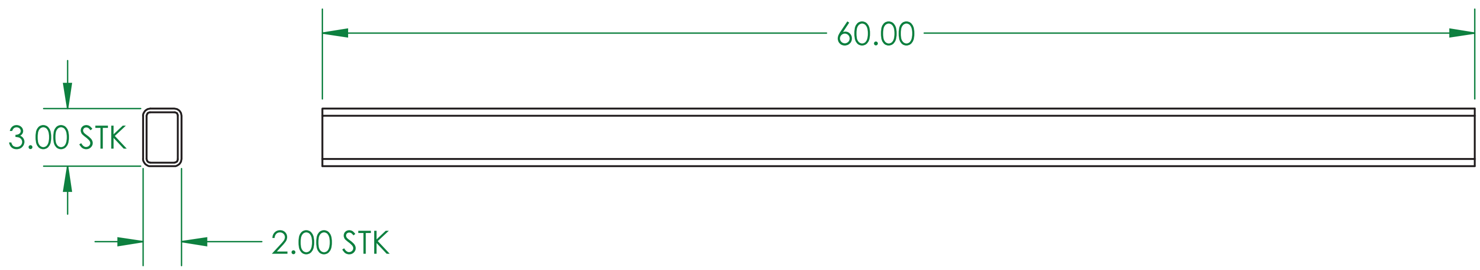


UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.03 THREE PLACE DECIMAL ±.003	DRAWN	M. SCHUSTER	3/2/16
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	Q.A.		
MATERIAL STEEL	COMMENTS:		
FINISH AS RECEIVED			
DO NOT SCALE DRAWING	NEXT ASSY:		

CAL POLY

TITLE: RECT. TUBE

SIZE	DWG. NO.	REV
A	DT003P	
SCALE: 1:8	WEIGHT: 22 LB	SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.03 THREE PLACE DECIMAL ±.003	DRAWN	M. SCHUSTER	3/2/16
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	Q.A.		
MATERIAL STEEL	COMMENTS:		
FINISH AS RECEIVED			
DO NOT SCALE DRAWING	NEXT ASSY:		

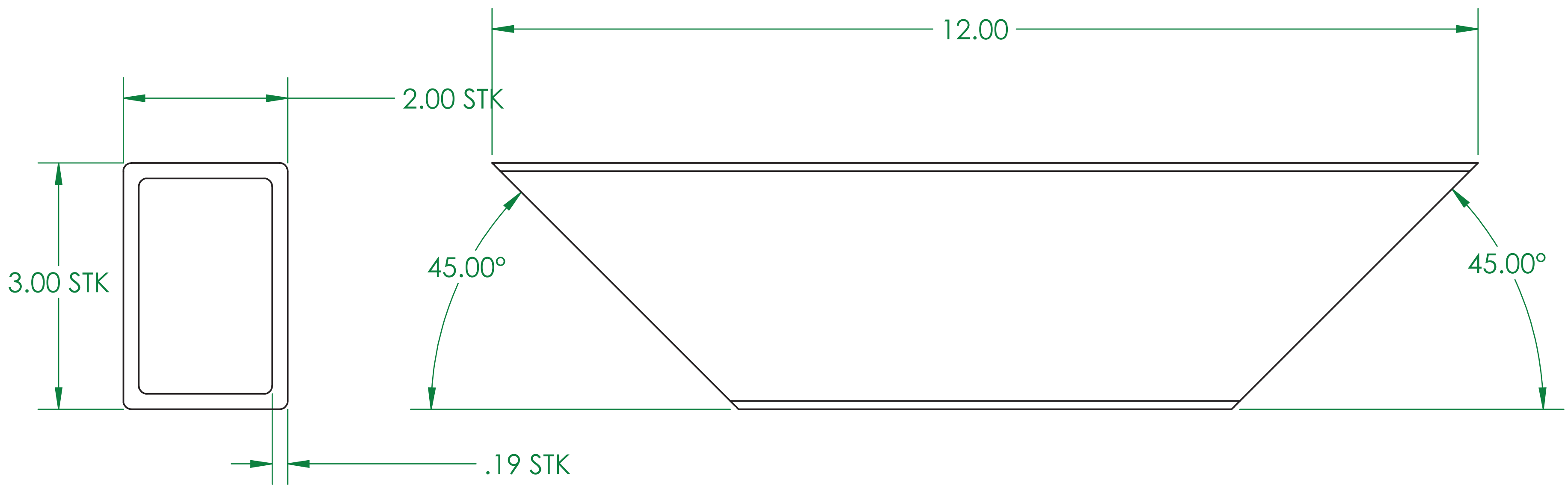
CAL POLY

TITLE:

LONG RECT. TUBE

SIZE	DWG. NO.	REV
A	DT011P	

SCALE: 1:10 WEIGHT: 28 LB SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.03 THREE PLACE DECIMAL ±.003	DRAWN	M. SCHUSTER	3/2/16
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	Q.A.		
MATERIAL STEEL	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING	NEXT ASSY:		

CAL POLY

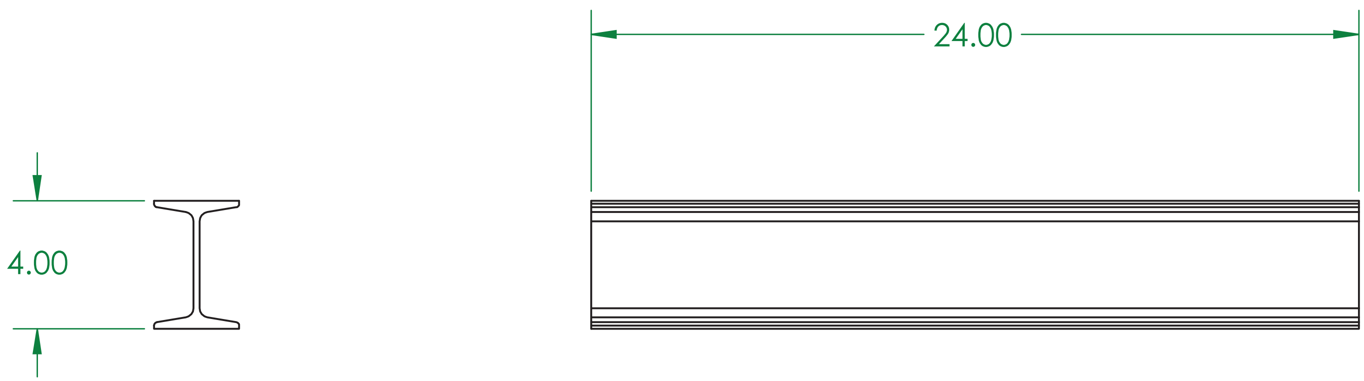
TITLE:

ANGLE SUPPORT

SIZE	DWG. NO.	REV
A	DT008P	

SCALE: 1:2 | WEIGHT: 0.5 LB | SHEET 1 OF 1

NOTES:
1. S 4X7.7 I BEAM



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.03 THREE PLACE DECIMAL ±.003	DRAWN	M. SCHUSTER	3/2/16
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	Q.A.		
MATERIAL STEEL	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING	NEXT ASSY:		

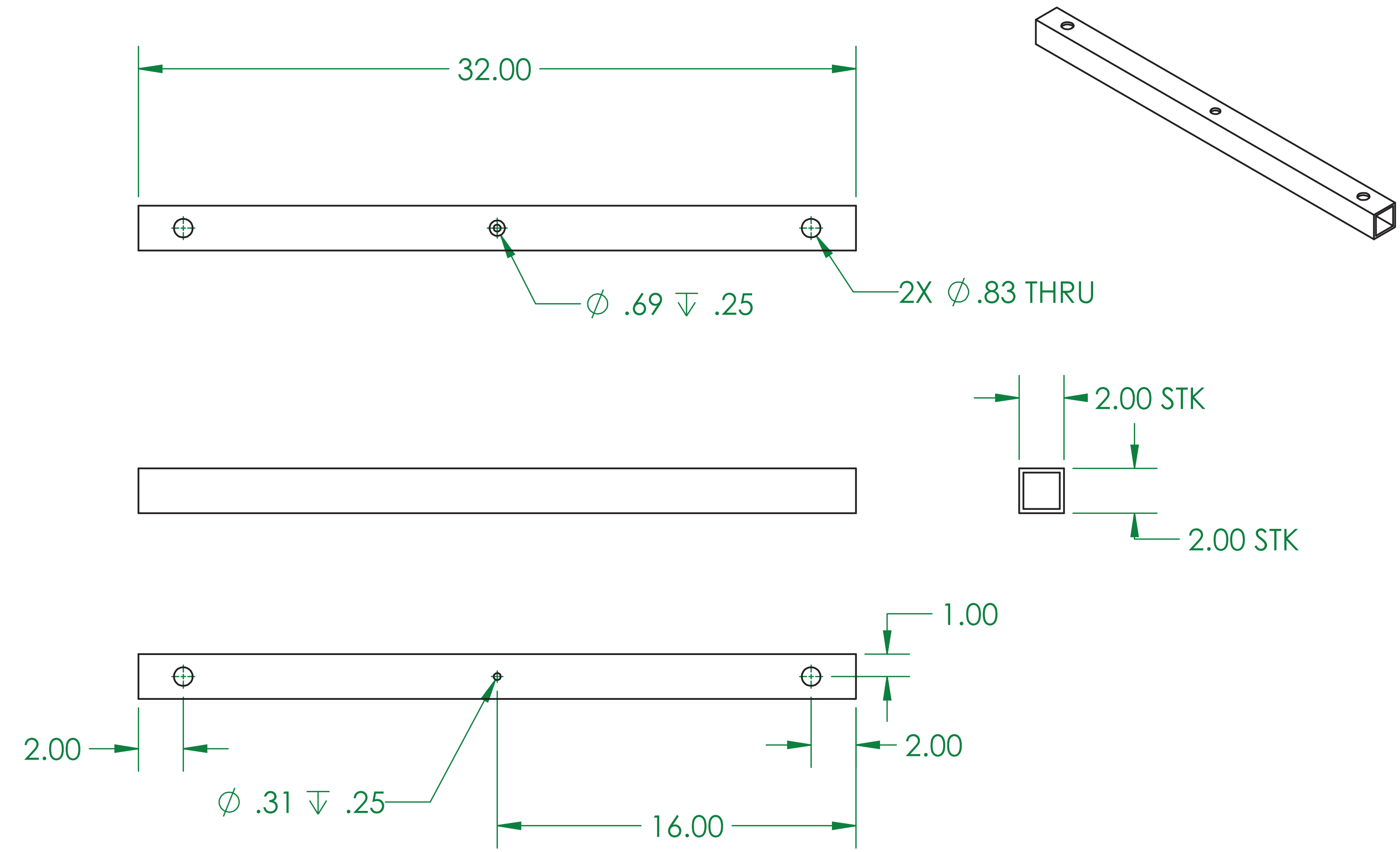
CAL POLY

TITLE:

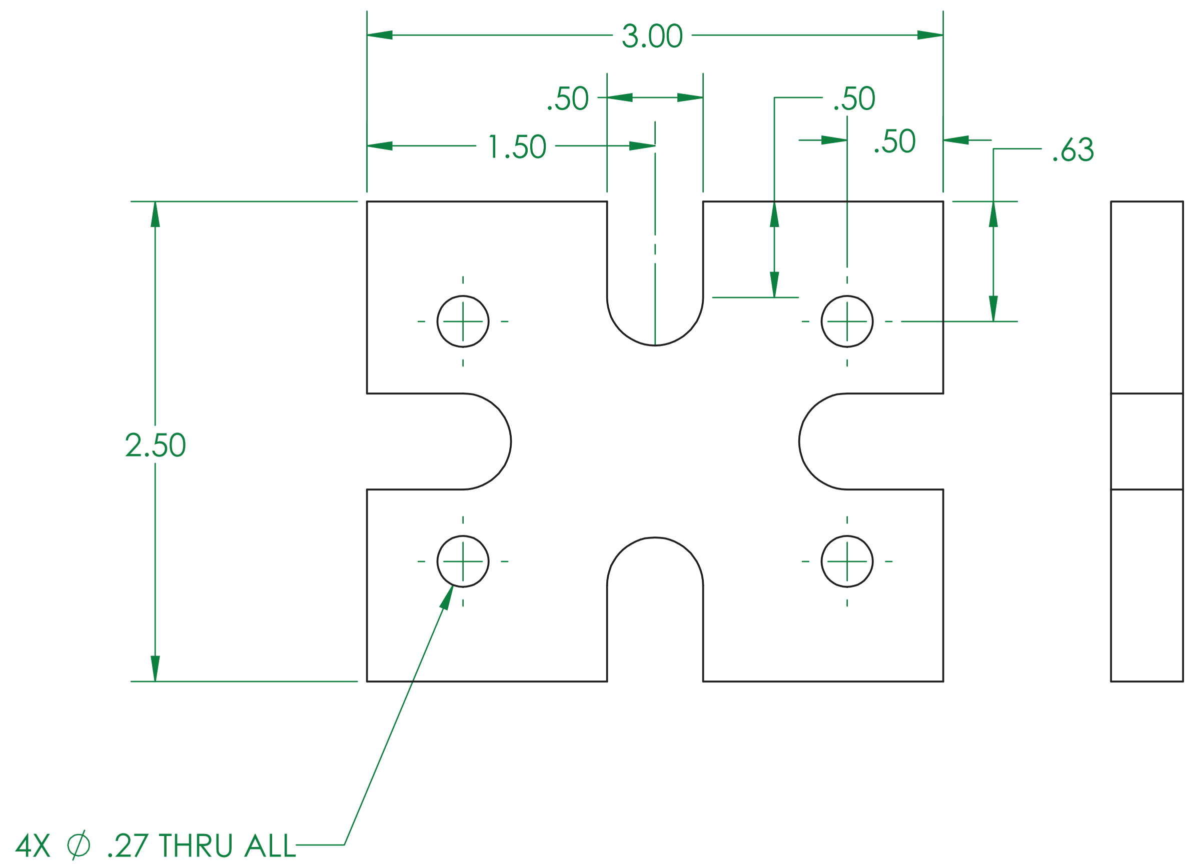
BASE I BEAM

SIZE	DWG. NO.	REV
A	DT007P	

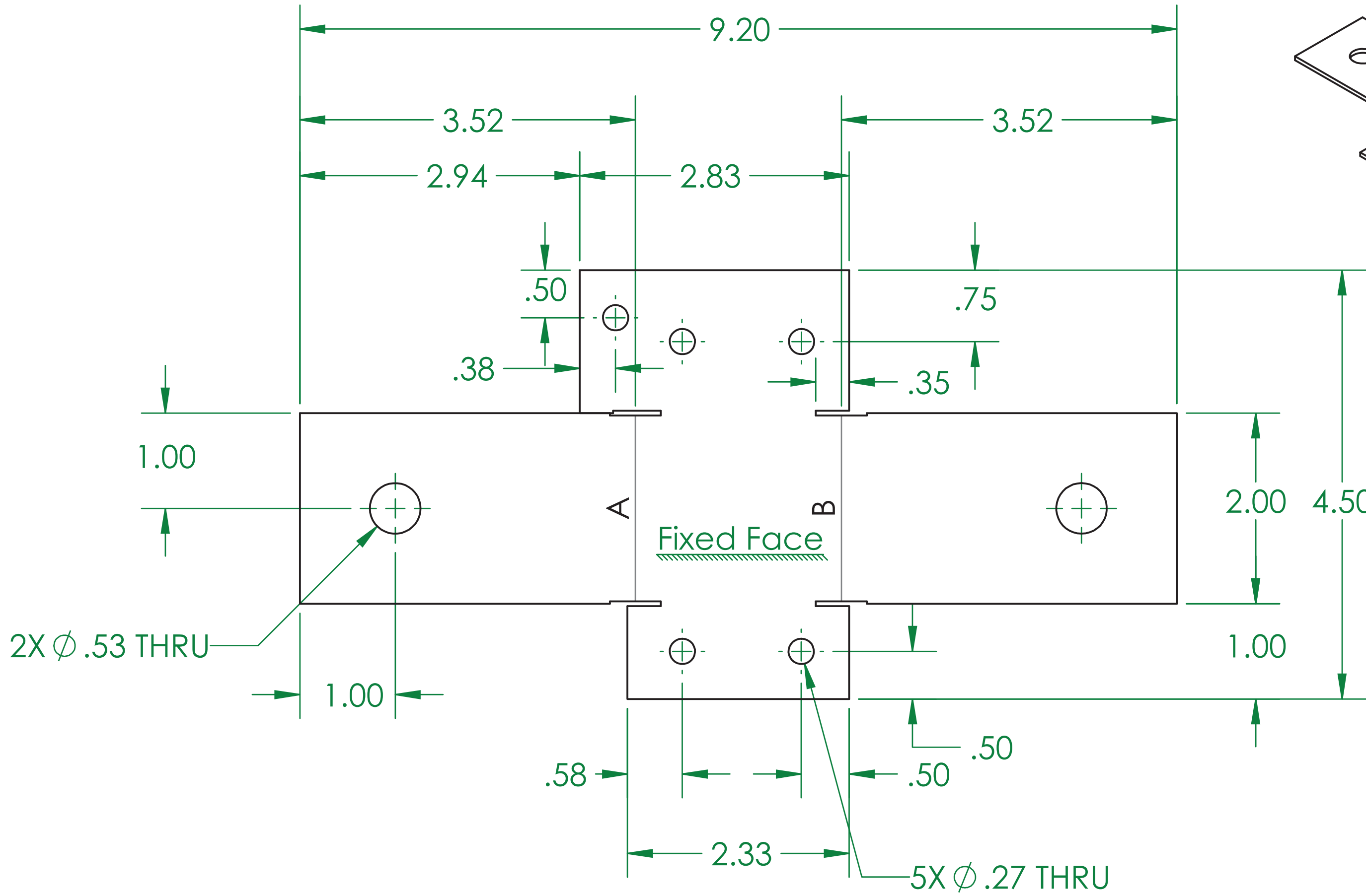
SCALE: 1:6 | WEIGHT: 16 LB | SHEET 1 OF 1

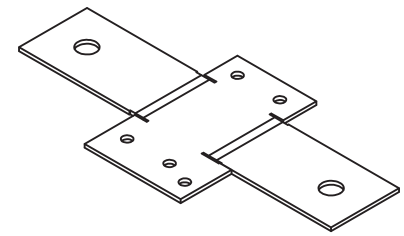


UNLESS OTHERWISE SPECIFIED:		NAME	DATE	CAL POLY
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.03 THREE PLACE DECIMAL ±.003	DRAWN	M. SCHUSTER		TITLE: LIFT BAR
	CHECKED			
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	Q.A.			
MATERIAL AL 6061-T6	COMMENTS:			SIZE A · DWG. NO. DT010P · REV
FINISH	NEXT ASSY:			SCALE: 1:8 · WEIGHT: · SHEET 1 OF 1
DO NOT SCALE DRAWING				



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	CAL POLY
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.03 THREE PLACE DECIMAL ±.003	DRAWN	M. SCHUSTER		TITLE: MAGNET PLATE
	CHECKED			
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	Q.A.			
MATERIAL STEEL	COMMENTS:			SIZE A | DWG. NO. DT012P | REV
FINISH	NEXT ASSY:			
DO NOT SCALE DRAWING				SCALE: 1:1 | WEIGHT: | SHEET 1 OF 1





Tag	Direction	Angle	Inner Radius
A	UP	90°	0.1
B	UP	90°	0.1

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.03
THREE PLACE DECIMAL ±.003

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL: AL 6061

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	M. SCHUSTER	
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

NEXT ASSY:

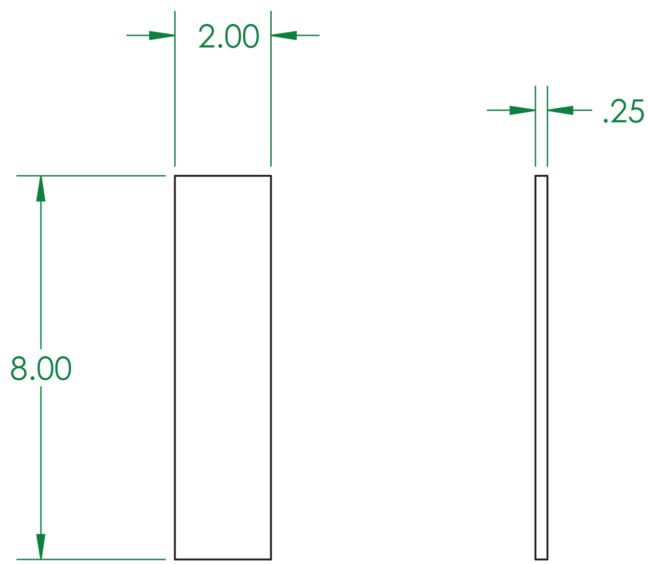
CAL POLY

TITLE: SAFETY BRACKET

SIZE: A | DWG. NO. DT013P | REV

SCALE: 1:4 | WEIGHT: | SHEET 1 OF 1

NOTES:
HOLES TO BE DRILLED WHEN INSTALLED
ON FULL ASSEMBLY



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.03 THREE PLACE DECIMAL ±.003	DRAWN	M. SCHUSTER	5/30/16
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	Q.A.		
MATERIAL STEEL	COMMENTS:		
FINISH AS MACHINED	NEXT ASSY:		
DO NOT SCALE DRAWING			

CAL POLY

TITLE: SIDE PLATE

SIZE	DWG. NO.	REV
A	DT015P	
SCALE: 1:4	WEIGHT:	SHEET 1 OF 1

Line	Item	QTY	Pkg QTY	Net Price	Price	Source	Part
1	2x3 Steel Rect Tubing 3/16" Wall (per ft)	22			$ 104.00	B&B Metals	Frame
2	1/4 Inch Steel Plate 24"x48"	1			$ 70.00	B&B Metals	Frame
3	S 4x7.7 Beam (per ft)	6			$ 50.00	B&B Metals	Frame
4	1 x 1 x 1/8 Steel Angle (per ft)	7			$ 15.00	B&B Metals	Frame
5	1" Diameter Aluminum Tubing .083 Wall (per ft)	7			$ 32.52	Online Metals	Carriage
6	1.25" Diameter Aluminum Tubing .083 Wall (per ft)	1			$ 10.05	Online Metals	Carriage
7	0.5" Diameter Aluminum Tubing .083 Wall (per ft)	1			$ 5.72	Online Metals	Carriage
8	1" Diameter Delrin Rod 4" long (8576K21)	1			$ 5.06	McMaster	Bushings
9	Aluminum 2024 2 5/8 Dia x 7" long	1			$ 49.56	Online Metals	Headform Stem
10	Aluminum 2024 3 Dia x 4" long	1			$ 40.40	Online Metals	Headform Rotator
11	16175A61	2	1	$ 4.45	$ 8.90	McMaster	Surface-Mount Hinge
12	97245A442	4	5	$ 7.08	$ 7.08	McMaster	Clevis Pin, 1/2" Dia, 4" Len
13	3014T956	2	1	$ 3.15	$ 6.30	McMaster	Eyebolt with Shoulder, 3/8"-16
14	96282A103	2	50	$ 6.98	$ 6.98	McMaster	Serrated-Flange Locknut, 3/8"-16
15	3013T969	2	1	$ 8.23	$ 16.46	McMaster	Eyebolt without Shoulder, 3/8"-16
16	93298A130	2	50	$ 7.60	$ 7.60	McMaster	Nylon-Insert Flange Locknut
17	3099T13	1	1	$ 11.88	$ 11.88	McMaster	Pulley
18	3014T906	1	1	$ 13.88	$ 13.88	McMaster	Eyebolt with Shoulder, 3/8"-16
19	3274T41	1	1	$ 6.83	$ 6.83	McMaster	Oval Eye Nut
20	93298A110	2	100	$ 7.48	$ 7.48	McMaster	Nylon-Insert Nonmarring Flange Locknut
21	3014T901	2	1	$ 10.22	$ 20.44	McMaster	Eyebolt with Shoulder, 1/4"-20 Thread Size
22	91259A624	1	1	$ 1.54	$ 1.54	McMaster	Shoulder Screw, 3/8" Dia, 5/16"-18
23	95462A030	1	100	$ 6.44	$ 6.44	McMaster	Hex Nut, 5/16"-18
24	90850A150	1	50	$ 8.55	$ 8.55	McMaster	Flat Washer, 5/16" Screw Size
25	3014T905	1	1	$ 13.94	$ 13.94	McMaster	Eyebolt with Shoulder, 5/16"-18
26	93298A120	1	50	$ 5.45	$ 5.45	McMaster	Flange Locknut, 5/16"-18
27	8635K818	1	1	$ 53.45	$ 53.45	McMaster	Rubber, 1/2" Thick, 12" x 24", 40A Duro
28	3461T37 (per ft)	25	1	$ 0.87	$ 21.75	McMaster	Stainless Steel Wire Rope, 1/8" Dia
29	5513T12	4	1	$ 3.53	$ 14.12	McMaster	Wire Rope Clamp
30	3494T11	4	1	$ 0.63	$ 2.52	McMaster	Wire Rope Thimble
31	8494T12	1	1	$ 5.36	$ 5.36	McMaster	Anchor Shackle
32	92375A325	4	10	$ 10.23	$ 10.23	McMaster	Hairpin Cotter Pin
33	6061 2" Square Tube, 3' long	1		$ 27.83	$ 27.83	Online Metals	Lift Bar
34	Headform	1		$ 500.00	$ 500.00		
35	5698K214	1		$ 49.48	$ 49.48	McMaster	24V Electromagnet
36	750R-2C-24D	4		$ 7.75	$ 31.00	Automation Direct	24VDC Coil DPDT Relay
37	750-2C-SKT	4		$ 4.25	$ 17.00	Automation Direct	Relay Socket
38	GCX3330-22	1		$ 14.50	$ 14.50	Automation Direct	3 Pos Knob, Return to Center
39	AEM2G71Z11-3	1		$ 28.00	$ 28.00	Automation Direct	Rod Limit Switch
40	AEM2G21Z11-3	1		$ 26.00	$ 26.00	Automation Direct	Plunger Limit Switch
41	GCX3203-24L	1		$ 14.00	$ 14.00	Automation Direct	Pushbutton
42	GCX3243-24L	1		$ 15.50	$ 15.50	Automation Direct	2 Pos Knob, Mom
43	ECX2055-24L	1		$ 8.50	$ 8.50	Automation Direct	LED Indicator
44	SA110-40SL	1		$ 13.50	$ 13.50	Automation Direct	4 Hole Pushbutton Enclosure
45	PSS24-100	1		$ 30.00	$ 30.00	Automation Direct	24V Power Supply
46	75065K660	1		$ 36.21	$ 36.21	McMaster	Enclosure (Relays and P.S.)
47	61672			$ 149.99	$ 149.99	Harbor Freight	Winch
48	356A02	1		$ 895.50	$ 895.50	PCB PiezoTronics	Triaxial Accel
49	034G25	1		$ 211.50	$ 211.50	PCB PiezoTronics	25' Accel Cable
50	482C05	1		$ 481.50	$ 481.50	PCB PiezoTronics	4-Channel Accel Power Supply
51	McMaster Carr Shipping				$ 50.00		
52	Automation Direct Shipping				$ -		
53	Online Metals Shipping				$ 24.10		
54	PCB Shipping				$ -		
55	Shop Labor (per hr)	20		$ 16.00	$ 320.00		
	TOTALS				**$ 3,583.60**		

APPENDIX E: FULL SCALE TESTING ANALYSIS CODE

Table of Contents

Multi-axis Multi-file SI Analysis

Michael Schuster 5/24/2016

analyses data to determine SI

```
clear all
clc
fprintf('Multi-axis Multi-file SI Analyzer\n')
fprintf('Michael Schuster\n\n')
```

User Inputs

```
fs = 16384;     %Sampling Frequency

maxplot = 3;    %max # of runs which plots will be produced for

fld = 'F:\Full Scale Data\Control\2ft';    %Target Folder
fn = ls(fld);

tbl = 'test.txt';    %Desired Table txt filename

    w = 1;
    pp = 1;
```

Folder Parsing

```
for runnum = 1:40

    filestr1 = ['input1(t) ', num2str(runnum),'.txt'];
    filestr2 = ['input2(t) ', num2str(runnum),'.txt'];
    filestr3 = ['input3(t) ', num2str(runnum),'.txt'];



    sfn = size(fn);
    for q = 1:sfn(1)
        fn2 = fn(q,:);
```

```
        if strcmpi(fn(q,:),filestr1) == 1
```

File Import

```
            fprintf('\n<strong>Run %d:</strong>\n',w)
            data = importfile(strcat(fld,'\',fn2),31);
            data1 = data(:,2);

        elseif strcmpi(fn(q,:),filestr2) == 1

            data = importfile(strcat(fld,'\',fn2),31);
            data2 = data(:,2);


        elseif strcmpi(fn(q,:),filestr3) == 1

            data = importfile(strcat(fld,'\',fn2),31);
            data3 = data(:,2);



    resdata = sqrt(data1.^2 + data2.^2 + data3.^2);

    rdata = resdata;

        if w <= maxplot
            figure(pp)
            plot(data(:,1),rdata)
        end
        hold on

        fprintf('Import Complete\n')
```

Data filtering

```
        fdata = butter16(rdata);
        %fdata = (rdata);

        if w <= maxplot
            plot(data(:,1),fdata)
        end

        fprintf('Filtering Complete\n')
```

Individual SI

```
        for i = 1:length(fdata)
          if fdata(i) <= 4
              fdata(i) = 0;
          end
        end
```

```
h = 0;
while h < 1

    for j = 1:length(fdata)
        if fdata(j) ~= 0
            break
        end
    end

    for k = j:length(fdata)
        if fdata(k) == 0
            break
        end
    end

    pulse = (k - j)/fs;

    if pulse < .003
        h = 0;
        fdata(j:k) = 0;
    else
        h = 1;
    end

end

[m,p] = max(fdata);

if w <= maxplot
    plot(data(:,1),fdata)
    legend('Unfiltered Raw Data','Filtered Raw
Data','Filtered Processed Data')
    ti1 = ['Data ',num2str(w)];
    title(ti1)
    xlabel('Recording Time [s]')
    ylabel('Acceleration [g]')
end

y = fdata(j:k);

hold off
pp = pp+1;
if w <= maxplot
    figure(pp)
    %plot((1/fs)*(1:length(y)),y,'g')
    hh = area((1/fs)*(1:length(y)),y);
    hh.FaceColor = [0 1 0];
    ti2 = ['Single Impulse ',num2str(w)];
    title(ti2)
    xlabel('Pulse Time [s]')
    ylabel('Acceleration [g]')
end
```

```
y = y.^2.5;
SIval(w) = trapz((1/fs)*(1:length(y)),y);
%fprintf('Run %d SI = %0.2f\n',[w SIval(w)])

if SIval(w) > 1200
    pass(w) = 0;
else
    pass(w) = 1;
end
```

Energy Dissipation Coefficient

```
[m2,p2] = max(fdata(k:end));

EDC(w) = m2/m*100;
%fprintf('Energy Dissipation Coefficient = %0.2f%%
\n',EDC(w))

for r = 1:length(fdata)
    if r > p2 && fdata(r) == 0
        break
    end
end

EDCpl = fdata(j:(r+k+100));

pp = pp+1;

if w <= maxplot
    figure(pp)
    plot((1/fs)*(1:length(EDCpl))+((1/
fs)*j),EDCpl,'c')
    hold on
    plot((1/fs)*p,m,'o',(1/fs)*(p2+k),m2,'o')
    plot([(1/fs)*j (1/fs)*(p2+k)],[m m],'b',[(1/fs)*j
 (1/fs)*(p2+k)],[m2 m2],'r')
    %stem((1/fs)*p,m)
    %stem((1/fs)*(p2+k),m2)
    hold off
    ti3 = ['EDC Calculation ',num2str(w)];
    title(ti3)
    xlabel('Recording Time [s]')
    ylabel('Acceleration [g]')
    %mid = mean((1/fs)*p),(((1/fs)*(p2+k)));
    %xxx = [mid mid]./((1/fs)*(r+k+100));
    %xxx = [.5 .5];
    %yyy = [m m2]./m;
    %annotation('doublearrow',xxx,yyy)
end

w = w+1;
pp = pp+1;
```

```
            end
        end
end

SImean = mean(SIval);
EDCmean = mean(EDC);

fprintf('\n\n<strong>Mean SI = %0.2f</strong>\n',SImean)
if min(pass) ~= 1
    fprintf('Helmet Fails\n')
else
    fprintf('Helmet Passes\n')
end

fprintf('<strong>Mean EDC = %0.2f%%</strong>\n\n',EDCmean)
```

Table Creation

```
T = table([1:(w-1)]',SIval',EDC','VariableNames',{'Run','SI','EDC'});
disp(T)
writetable(T,tbl)

disp('DONE')
```

Published with MATLAB® R2016a

Table of Contents

Multi-axis Multi-file SI Analysis Windowed

Michael Schuster 5/24/2016

analyses data to determine SI

```
clear all
clc
fprintf('Multi-axis Multi-file SI Analyzer\n')
fprintf('Michael Schuster\n\n')
```

User Inputs

```
fs = 16384;     %Sampling Frequency

maxplot = 3;    %max # of runs which plots will be produced for

fld = 'E:\THESIS\physical testing\Full Scale Data\exp\2ft';    %Target
 Folder
fn = ls(fld);

tbl = 'test.txt';    %Desired Table txt filename

    w = 1;
    pp = 1;
```

Folder Parsing

```
for runnum = 1:40

    filestr1 = ['input1(t) ', num2str(runnum),'.txt'];
    filestr2 = ['input2(t) ', num2str(runnum),'.txt'];
    filestr3 = ['input3(t) ', num2str(runnum),'.txt'];



    sfn = size(fn);
    for q = 1:sfn(1)
        fn2 = fn(q,:);
```

```
            if strcmpi(fn(q,:),filestr1) == 1
```

File Import

```
                fprintf('\n<strong>Run %d:</strong>\n',w)
                data = importfile(strcat(fld,'\',fn2),31);
                data1 = data(:,2);

            elseif strcmpi(fn(q,:),filestr2) == 1

                data = importfile(strcat(fld,'\',fn2),31);
                data2 = data(:,2);


            elseif strcmpi(fn(q,:),filestr3) == 1

                data = importfile(strcat(fld,'\',fn2),31);
                data3 = data(:,2);



        resdata = sqrt(data1.^2 + data2.^2 + data3.^2);

        rdata = resdata;

            if w <= maxplot
                figure(pp)
                plot(data(:,1),rdata)
            end
            hold on

            fprintf('Import Complete\n')
```

Data filtering

```
            fdata = butter16(rdata);
            %fdata = (rdata);

            if w <= maxplot
                plot(data(:,1),fdata)
            end

            fprintf('Filtering Complete\n')
```

Individual SI

```
            for i = 1:length(fdata)
              if fdata(i) <= 4
                  fdata(i) = 0;
              end
            end
```

```
h = 0;
while h < 1

    for j = 1:length(fdata)
        if fdata(j) ~= 0
            break
        end
    end

    for k = j:length(fdata)
        if fdata(k) == 0
            break
        end
    end

    pulse = (k - j)/fs;

    if pulse < .003
        h = 0;
        fdata(j:k) = 0;
    else
        h = 1;
    end

end

k = j + (.025*fs);

[m,p] = max(fdata);

if w <= maxplot
    plot(data(:,1),fdata)
    legend('Unfiltered Raw Data','Filtered Raw
Data','Filtered Processed Data')
    ti1 = ['Data ',num2str(w)];
    title(ti1)
    xlabel('Recording Time [s]')
    ylabel('Acceleration [g]')
end

y = fdata(j:k);

hold off
pp = pp+1;
if w <= maxplot
    figure(pp)
    %plot((1/fs)*(1:length(y)),y,'g')
    hh = area((1/fs)*(1:length(y)),y);
    hh.FaceColor = [0 1 0];
    ti2 = ['Single Impulse ',num2str(w)];
    title(ti2)
    xlabel('Pulse Time [s]')
```

```
    ylabel('Acceleration [g]')
end

y = y.^2.5;
SIval(w) = trapz((1/fs)*(1:length(y)),y);
%fprintf('Run %d SI = %0.2f\n',[w SIval(w)])

if SIval(w) > 1200
    pass(w) = 0;
else
    pass(w) = 1;
end
```

Energy Dissipation Coefficient

```
[m2,p2] = max(fdata(k:end));

EDC(w) = m2/m*100;
%fprintf('Energy Dissipation Coefficient = %0.2f%%
\n',EDC(w))

for r = 1:length(fdata)
    if r > p2 && fdata(r) == 0
        break
    end
end

EDCpl = fdata(j:(r+k+100));

pp = pp+1;

if w <= maxplot
    figure(pp)
    plot((1/fs)*(1:length(EDCpl))+((1/
fs)*j),EDCpl,'c')
    hold on
    plot((1/fs)*p,m,'o',(1/fs)*(p2+k),m2,'o')
    plot([(1/fs)*j (1/fs)*(p2+k)],[m m],'b',[(1/fs)*j
 (1/fs)*(p2+k)],[m2 m2],'r')
    %stem((1/fs)*p,m)
    %stem((1/fs)*(p2+k),m2)
    hold off
    ti3 = ['EDC Calculation ',num2str(w)];
    title(ti3)
    xlabel('Recording Time [s]')
    ylabel('Acceleration [g]')
    %mid = mean((1/fs)*p),(((1/fs)*(p2+k)));
    %xxx = [mid mid]./((1/fs)*(r+k+100));
    %xxx = [.5 .5];
    %yyy = [m m2]./m;
    %annotation('doublearrow',xxx,yyy)
end
```

```
                w = w+1;
                pp = pp+1;

            end
        end
end

SImean = mean(SIval);
EDCmean = mean(EDC);

fprintf('\n\n<strong>Mean SI = %0.2f</strong>\n',SImean)
if min(pass) ~= 1
    fprintf('Helmet Fails\n')
else
    fprintf('Helmet Passes\n')
end

fprintf('<strong>Mean EDC = %0.2f%%</strong>\n\n',EDCmean)
```

Table Creation

```
T = table([1:(w-1)]',SIval',EDC','VariableNames',{'Run','SI','EDC'});
disp(T)
writetable(T,tbl)

disp('DONE')
```

Published with MATLAB® R2016a

Table of Contents

Multi-axis Multi-file HIC Analysis

Michael Schuster 5/24/2016

analyses data to determine SI

```
clear all
clc
fprintf('Multi-axis Multi-file SI Analyzer\n')
fprintf('Michael Schuster\n\n')
```

User Inputs

```
fs = 16384;     %Sampling Frequency

maxplot = 3;    %max # of runs which plots will be produced for

fld = 'E:\THESIS\physical testing\Full Scale Data\exp\2ft';    %Target
 Folder
fn = ls(fld);

tbl = 'test.txt';    %Desired Table txt filename

    w = 1;
    pp = 1;
```

Folder Parsing

```
for runnum = 1:40

    filestr1 = ['input1(t) ', num2str(runnum),'.txt'];
    filestr2 = ['input2(t) ', num2str(runnum),'.txt'];
    filestr3 = ['input3(t) ', num2str(runnum),'.txt'];



    sfn = size(fn);
    for q = 1:sfn(1)
        fn2 = fn(q,:);
```

```
                if strcmpi(fn(q,:),filestr1) == 1
```

File Import

```
                    fprintf('\n<strong>Run %d:</strong>\n',w)
                    data = importfile(strcat(fld,'\',fn2),31);
                    data1 = data(:,2);

                elseif strcmpi(fn(q,:),filestr2) == 1

                    data = importfile(strcat(fld,'\',fn2),31);
                    data2 = data(:,2);


                elseif strcmpi(fn(q,:),filestr3) == 1

                    data = importfile(strcat(fld,'\',fn2),31);
                    data3 = data(:,2);



                  resdata = sqrt(data1.^2 + data2.^2 + data3.^2);

                  rdata = resdata;

                    if w <= maxplot
                        figure(pp)
                        plot(data(:,1),rdata)
                    end
                    hold on

                    fprintf('Import Complete\n')
```

Data filtering

```
                    fdata = butter16(rdata);
                    %fdata = (rdata);

                    if w <= maxplot
                        plot(data(:,1),fdata)
                    end

                    fprintf('Filtering Complete\n')
```

Individual SI

```
                    for i = 1:length(fdata)
                      if fdata(i) <= 4
                          fdata(i) = 0;
                      end
                    end
```

```
h = 0;
while h < 1

    for j = 1:length(fdata)
        if fdata(j) ~= 0
            break
        end
    end

    for k = j:length(fdata)
        if fdata(k) == 0
            break
        end
    end

    pulse = (k - j)/fs;

    if pulse < .003
        h = 0;
        fdata(j:k) = 0;
    else
        h = 1;
    end

end

HICnum = .036;

k = j + (HICnum*fs);

[m,p] = max(fdata);

max_a(w) = m;

if w <= maxplot
    plot(data(:,1),fdata)
    legend('Unfiltered Raw Data','Filtered Raw
Data','Filtered Processed Data')
    ti1 = ['Data ',num2str(w)];
    title(ti1)
    xlabel('Recording Time [s]')
    ylabel('Acceleration [g]')
end

y = fdata(j:k);

hold off
pp = pp+1;
if w <= maxplot
    figure(pp)
    %plot((1/fs)*(1:length(y)),y,'g')
    hh = area((1/fs)*(1:length(y)),y);
```

```
        hh.FaceColor = [0 1 0];
        ti2 = ['Single Impulse ',num2str(w)];
        title(ti2)
        xlabel('Pulse Time [s]')
        ylabel('Acceleration [g]')
    end


    HICval(w) = trapz((1/fs)*(1:length(y)),y);
    HICval(w) = (HICval(w)/HICnum).^(2.5);
    HICval(w) = HICval(w)*HICnum;
    %fprintf('Run %d SI = %0.2f\n',[w SIval(w)])

    if HICval(w) > 1200
        pass(w) = 0;
    else
        pass(w) = 1;
    end
```

Energy Dissipation Coefficient

```
    [m2,p2] = max(fdata(k:end));

    EDC(w) = m2/m*100;
    %fprintf('Energy Dissipation Coefficient = %0.2f%%
\n',EDC(w))

    for r = 1:length(fdata)
        if r > p2 && fdata(r) == 0
            break
        end
    end

    EDCpl = fdata(j:(r+k+100));

    pp = pp+1;

    if w <= maxplot
        figure(pp)
        plot((1/fs)*(1:length(EDCpl))+((1/
fs)*j),EDCpl,'c')
        hold on
        plot((1/fs)*p,m,'o',(1/fs)*(p2+k),m2,'o')
        plot([(1/fs)*j (1/fs)*(p2+k)],[m m],'b',[(1/fs)*j
 (1/fs)*(p2+k)],[m2 m2],'r')
        %stem((1/fs)*p,m)
        %stem((1/fs)*(p2+k),m2)
        hold off
        ti3 = ['EDC Calculation ',num2str(w)];
        title(ti3)
        xlabel('Recording Time [s]')
        ylabel('Acceleration [g]')
        %mid = mean((1/fs)*p),(((1/fs)*(p2+k)));
```

```
                %xxx = [mid mid]./((1/fs)*(r+k+100));
                %xxx = [.5 .5];
                %yyy = [m m2]./m;
                %annotation('doublearrow',xxx,yyy)
            end

            w = w+1;
            pp = pp+1;

        end
    end
end

SImean = mean(HICval);
EDCmean = mean(EDC);

fprintf('\n\n<strong>Mean SI = %0.2f</strong>\n',SImean)
if min(pass) ~= 1
    fprintf('Helmet Fails\n')
else
    fprintf('Helmet Passes\n')
end

fprintf('<strong>Mean EDC = %0.2f%%</strong>\n\n',EDCmean)
```

Table Creation

```
T = table([1:(w-1)]',HICval',EDC','VariableNames',
{'Run','HIC','EDC'});
disp(T)
writetable(T,tbl)

disp('DONE')
```

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```
function input1t1 = importfile(filename, startRow, endRow)

%IMPORTFILE Import numeric data from a text file as a matrix.
%   INPUT1T1 = IMPORTFILE(FILENAME) Reads data from text file FILENAME
 for
%   the default selection.
%
%   INPUT1T1 = IMPORTFILE(FILENAME, STARTROW, ENDROW) Reads data from
 rows
%   STARTROW through ENDROW of text file FILENAME.
%
% Example:
%   input1t1 = importfile('input1(t) 1.txt', 31, 16414);
%
%    See also TEXTSCAN.

% Auto-generated by MATLAB on 2016/02/12 13:54:17
```

Initialize variables.

```
delimiter = '\t';
if nargin<=2
    startRow = 31;
    endRow = inf;
end
```

Format string for each line of text:

```
column1: double (%f)

% column2: double (%f)
% For more information, see the TEXTSCAN documentation.
formatSpec = '%f%f%[^\n\r]';
```

Open the text file.

```
fileID = fopen(filename,'r');
```

Read columns of data according to format string.

This call is based on the structure of the file used to generate this code. If an error occurs for a different file, try regenerating the code from the Import Tool.

```
dataArray = textscan(fileID, formatSpec, endRow(1)-
startRow(1)+1, 'Delimiter', delimiter, 'EmptyValue'
 ,NaN,'HeaderLines', startRow(1)-1, 'ReturnOnError', false);
for block=2:length(startRow)
    frewind(fileID);
    dataArrayBlock = textscan(fileID, formatSpec, endRow(block)-
startRow(block)+1, 'Delimiter', delimiter, 'EmptyValue'
 ,NaN,'HeaderLines', startRow(block)-1, 'ReturnOnError', false);
    for col=1:length(dataArray)
        dataArray{col} = [dataArray{col};dataArrayBlock{col}];
    end
end
```

Close the text file.

```
fclose(fileID);
```

Post processing for unimportable data.

No unimportable data rules were applied during the import, so no post processing code is included. To generate code which works for unimportable data, select unimportable cells in a file and regenerate the script.

Create output variable

```
input1t1 = [dataArray{1:end-1}];
```

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```
function y = butter16(x)
%UNTITLED16 Filters input x and returns output y.

% MATLAB Code
% Generated by MATLAB(R) 8.6 and the Signal Processing Toolbox 7.1.
% Generated on: 17-Feb-2016 22:05:41

%#codegen

% To generate C/C++ code from this function use the codegen command.
% Type 'help codegen' for more information.

persistent Hd;

if isempty(Hd)

    % The following code was used to design the filter coefficients:
    %
    % N    = 4;      % Order
    % F3dB = 1000;   % 3-dB Frequency
    % Fs   = 16384;  % Sampling Frequency
    %
    % h = fdesign.lowpass('n,f3db', N, F3dB, Fs);
    %
    % Hd = design(h, 'butter', ...
    %     'SystemObject', true);

    Hd = dsp.BiquadFilter( ...
        'Structure', 'Direct form II', ...
        'SOSMatrix', [1 2 1 1 -1.62241701874291 0.749495988750496; 1 2
 1 1 ...
        -1.37827832665825 0.486234658545862], ...
        'ScaleValues', [0.0317697425018976; 0.0269890829719025; 1]);
end

s = double(x);
y = step(Hd,s);
```

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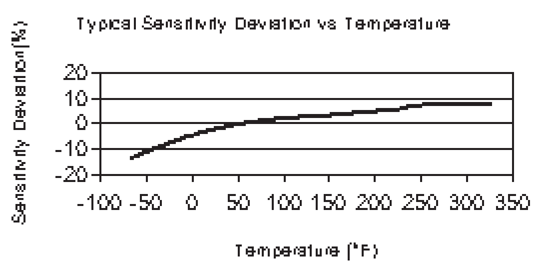
APPENDIX F: SPECIFICATION SHEETS

Model Number 356A02	TRIAXIAL ICP® ACCELEROMETER	Revision: R ECN #: 43905

Performance	ENGLISH	SI	
Sensitivity(± 10 %)	10 mV/g	1.02 mV/(m/s²)	
Measurement Range	± 500 g pk	± 4900 m/s² pk	
Frequency Range(± 5 %)	1 to 5000 Hz	1 to 5000 Hz	
Frequency Range(± 10 %)	0.5 to 6000 Hz	0.5 to 6000 Hz	
Resonant Frequency	≥ 25 kHz	≥ 25 kHz	
Broadband Resolution(1 to 10,000 Hz)	0.0005 g rms	0.005 m/s² rms	[1]
Non-Linearity(400 g, 3920 m/s²)	≤ 1 %	≤ 1 %	[4]
Non-Linearity(500 g, 4900 m/s²)	≤ 2 %	≤ 2 %	[4]
Transverse Sensitivity	≤ 5 %	≤ 5 %	
Environmental			
Overload Limit(Shock)	± 7000 g pk	± 68,600 m/s² pk	
Temperature Range(Operating)	-65 to +250 °F	-54 to +121 °C	[3]
Temperature Response	See Graph	See Graph	[3][1]
Base Strain Sensitivity	0.001 g/με	0.01 (m/s²)/με	[1]
Electrical			
Excitation Voltage	20 to 30 VDC	20 to 30 VDC	
Constant Current Excitation	2 to 20 mA	2 to 20 mA	
Output Impedance	≤ 200 Ohm	≤ 200 Ohm	
Output Bias Voltage	8 to 12 VDC	8 to 12 VDC	
Discharge Time Constant	0.6 to 2.0 sec	0.6 to 2.0 sec	
Settling Time(within 10% of bias)	<5 sec	<5 sec	
Spectral Noise(1 Hz)	150 μg/√Hz	1472 (μm/sec²)/√Hz	[1]
Spectral Noise(10 Hz)	25 μg/√Hz	245 (μm/sec²)/√Hz	[1]
Spectral Noise(100 Hz)	10 μg/√Hz	98 (μm/sec²)/√Hz	[1]
Spectral Noise(1 kHz)	5 μg/√Hz	49 (μm/sec²)/√Hz	[1]
Physical			
Sensing Element	Ceramic	Ceramic	
Sensing Geometry	Shear	Shear	
Housing Material	Titanium	Titanium	
Sealing	Hermetic	Hermetic	
Size (Height x Length x Width)	0.55 in x 0.80 in x 0.55 in	14.0 mm x 20.3 mm x 14.0 mm	
Weight	0.37 oz	10.5 gm	[1]
Electrical Connector	1/4-28 4-Pin	1/4-28 4-Pin	
Electrical Connection Position	Side	Side	
Mounting Thread	10-32 Female	10-32 Female	
Mounting Torque	10 to 20 in-lb	113 to 225 N-cm	



[5]

All specifications are at room temperature unless otherwise specified.
In the interest of constant product improvement, we reserve the right to change specifications without notice.

ICP® is a registered trademark of PCB Group, Inc.

OPTIONAL VERSIONS

Optional versions have identical specifications and accessories as listed for the standard model except where noted below. More than one option may be used.

HT - High temperature, extends normal operation temperatures

Frequency Range(± 5 %)	1 to 5000 Hz	1 to 5000 Hz	
Frequency Range(± 10 %)	0.7 to 6000 Hz	0.7 to 6000 Hz	
Broadband Resolution(1 to 10,000 Hz)	0.0008 g rms	0.008 μm/sec² rms	
Temperature Range(Operating)	-65 to +325 °F	-54 to +163 °C	
Excitation Voltage	22 to 30 VDC	22 to 30 VDC	
Output Bias Voltage	7 to 15 VDC	7 to 15 VDC	[2]
Discharge Time Constant	0.5 to 1.5 sec	0.5 to 1.5 sec	
Spectral Noise(1 Hz)	400 μg/√Hz	3920 (μm/sec²)/√Hz	
Spectral Noise(10 Hz)	50 μg/√Hz	490 (μm/sec²)/√Hz	
Spectral Noise(100 Hz)	25 μg/√Hz	245 (μm/sec²)/√Hz	
Spectral Noise(1 kHz)	6 μg/√Hz	58.8 (μm/sec²)/√Hz	

RH - RoHS Compliant

T - TEDS Capable of Digital Memory and Communication Compliant with IEEE P1451.4

TLA - TEDS LMS International - Free Format

TLB - TEDS LMS International - Automotive Format

TLC - TEDS LMS International - Aeronautical Format

TLD - TEDS Capable of Digital Memory and Communication Compliant with IEEE 1451.4

Temperature Range	-65 to +250 °F	-54 to +121 °C
Output Bias Voltage	8.5 to 13.0 VDC	8.5 to 13.0 VDC

NOTES:
[1]Typical.
[2]TEDS option adds 1.0 VDC to bias voltage.
[3]250° F to 325° F data valid with HT option only.
[4]Zero-based, least-squares, straight line method.
[5]See PCB Declaration of Conformance PS023 for details.

SUPPLIED ACCESSORIES:
Model 080A109 Petro Wax (1)
Model 080A12 Adhesive Mounting Base (1)
Model 080A90 Quick Bonding Gel (1)
Model 081B05 Mounting Stud (10-32 to 10-32) (1)
Model ACS-1T NIST traceable triaxial amplitude response, 10 Hz to upper 5% frequency. (1)
Model M081B05 Mounting Stud 10-32 to M6 X 0.75

Entered: AP	Engineer: DK	Sales: WDC	Approved: BAM	Spec Number:
Date: 3/10/2015	Date: 3/10/2015	Date: 3/10/2015	Date: 3/10/2015	**10927**

PCB PIEZOTRONICS
3425 Walden Avenue, Depew, NY 14043

Phone: 716-684-0001
Fax: 716-684-0987
E-Mail: info@pcb.com

10324

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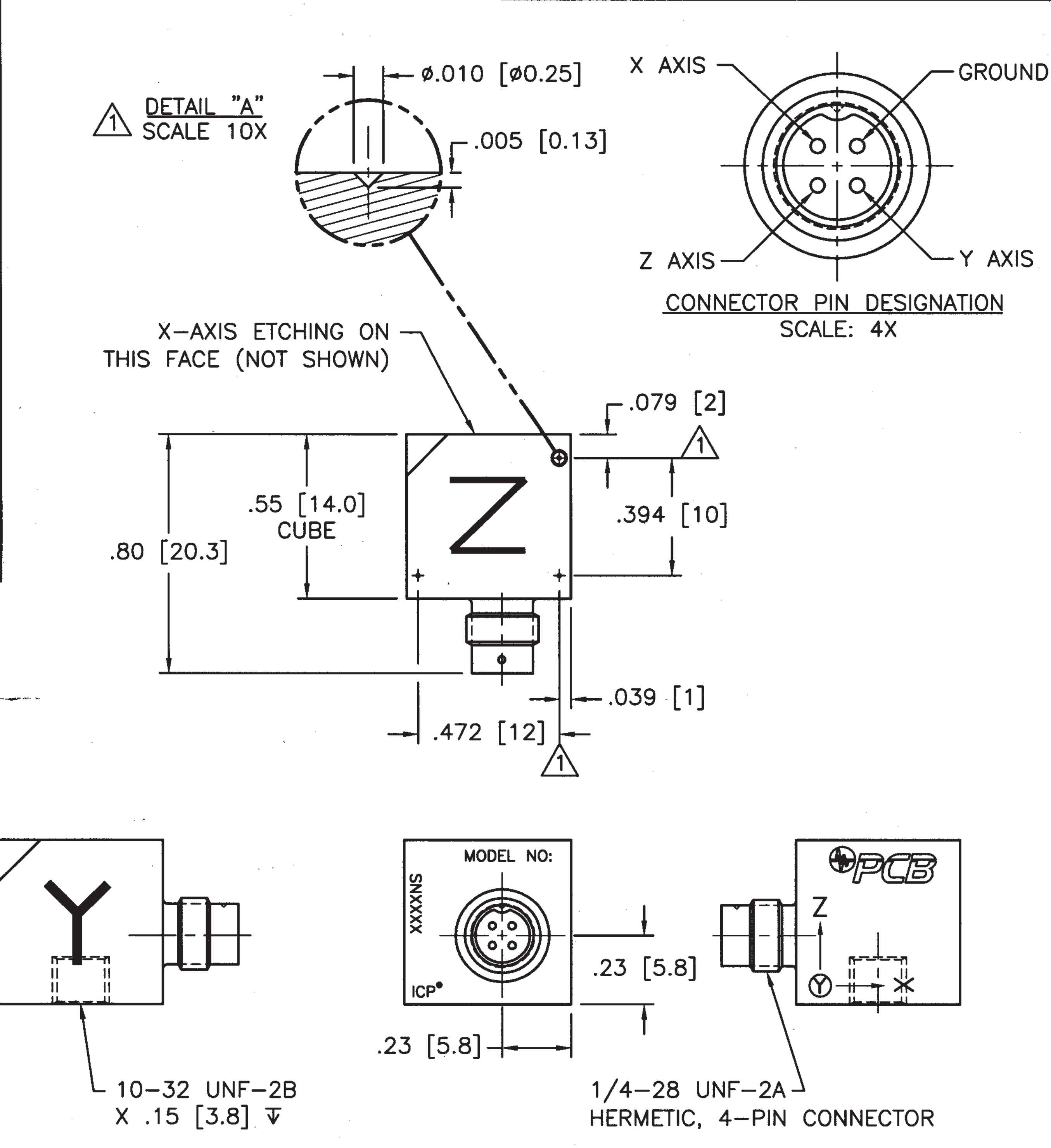
APPLICATION		
NEXT ASS'Y	USED ON	VAR

REVISIONS				
REV	DESCRIPTION	ECN	DATE	APP'D
C	UPDATED ETCHING	14909	3/6/02	
D	ADDED TEDS OPTION	19290	2/18/04	



△1 TEDS OPTIONS ONLY

UNLESS SPECIFIED TOLERANCES	
DIMENSIONS IN INCHES	DIMENSIONS IN MILLIMETERS [IN BRACKETS]
DECIMALS XX ±.01 XXX ±.005 ANGLES ±2 DEGREES	DECIMALS X ±0.3 XX ±0.13 ANGLES ±2 DEGREES
FILLETS AND RADII .003 - .005	FILLETS AND RADII [0.07 - 0.13]
DD011 REV. C 01/21/03	

DRAWN		2/18/04	MFG		2/18/04
CHK'D		2/18/04	ENGR		2/18/04
APP'D		2/18/04	SALES		2/18/04

TITLE OUTLINE DRAWING
14mm CUBE W/ $\frac{1}{4}$-28 4-PIN CONNECTOR
TRIAXIAL ACCELEROMETER

PCB PIEZOTRONICS™
3425 WALDEN AVE. DEPEW, NY 14043
(716) 684-0001 EMAIL: SALES@PCB.COM

CODE IDENT. NO.	DWG. NO.
52681	10324
SCALE: 2X	SHEET 1 OF 1

Model Number 482C05

FOUR-CHANNEL, ICP® SENSOR SIGNAL CONDITIONER

Revision: J
ECN #: 43617

	ENGLISH	SI	
Performance			
Channels	4	4	
Sensor Input Type(s)	ICP®	ICP®	
Output Range(Maximum)	± 10 V	± 10 V	
Low Frequency Response(-5 %)	<0.1 Hz	<0.1 Hz	[2][3]
High Frequency Response(-5 %)	>1000 kHz	>1000 kHz	
Phase Response(at 1 kHz)	± 1 °	± 1 °	
Cross Talk(maximum)	-72 dB	-72 dB	
Fault/Bias Monitor/Meter(LED)	Open/Short/Overload	Open/Short/Overload	
Environmental			
Temperature Range(Operating)	+32 to +120 °F	0 to +50 °C	
Electrical			
Power Required(for supplied AC power adaptor)	AC Power	AC Power	
Power Required(direct input to unit)	DC power	DC power	
AC Power(47 to 63 Hz)	100 to 240 VAC	100 to 240 VAC	
AC Power	≤ 0.7 Amps	≤ 0.7 Amps	
Excitation Voltage(± 1 VDC)(To Sensor)	+26 VDC	+26 VDC	
DC Offset	<20 mV	<20 mV	
DC Power	+32 to 38 VDC	+32 to 38 VDC	
DC Power	<0.25 Amps	<0.25 Amps	
Constant Current Excitation(To Sensor)	2 to 20 mA	2 to 20 mA	[1]
Overload Threshold(± 1.0 Vpk)	± 10 Vpk	± 10 Vpk	
Discharge Time Constant(0 to 50 %)	>5 sec	>5 sec	[2][3]
Broadband Electrical Noise(1 to 10,000 Hz)	3.5 µV rms	3.5 µV rms	[4]
Spectral Noise(1 Hz)	1.30 µV/√Hz	1.30 µV/√Hz	[4]
Spectral Noise(10 Hz)	0.10 µV/√Hz	0.10 µV/√Hz	[4]
Spectral Noise(100 Hz)	0.08 µV/√Hz	0.08 µV/√Hz	[4]
Spectral Noise(1 kHz)	0.07 µV/√Hz	0.07 µV/√Hz	[4]
Spectral Noise(10 kHz)	0.07 µV/√Hz	0.07 µV/√Hz	[4]
Physical			
Electrical Connector(ICP® Sensor Input)	BNC Jack	BNC Jack	
Electrical Connector(Output)	BNC Jack	BNC Jack	
Electrical Connector(DC Power Input)	5-socket DIN (female)	5-socket DIN (female)	
Size (Height x Width x Depth)	3.2 in x 8.0 in x 5.9 in	8.1 cm x 20 cm x 15 cm	
Weight	1.25 lb	567 gm	

CE [5]

All specifications are at room temperature unless otherwise specified.
In the interest of constant product improvement, we reserve the right to change specifications without notice.
ICP® is a registered trademark of PCB Group, Inc.

OPTIONAL VERSIONS

Optional versions have identical specifications and accessories as listed for the standard model except where noted below. More than one option may be used.

NOTES:
[1]User adjustable, factory set at 4 mA (± 0.5 mA). One control adjusts all channels.
[2]With ≥ 1M ohm input impedance of readout device.
[3]Un-buffered output, read out device input impedance affects discharge time constant and low frequency response of unit.
[4]Typical.
[5]See PCB Declaration of Conformance PS024 for details.

SUPPLIED ACCESSORIES:
Model 017AXX Power Cord
Model 488B04/NC Power Convertor

Entered: AP	Engineer: CPH	Sales: ML	Approved: JWH	Spec Number:
Date: 1/28/2015	Date: 1/28/2015	Date: 1/28/2015	Date: 1/28/2015	35061

PCB PIEZOTRONICS
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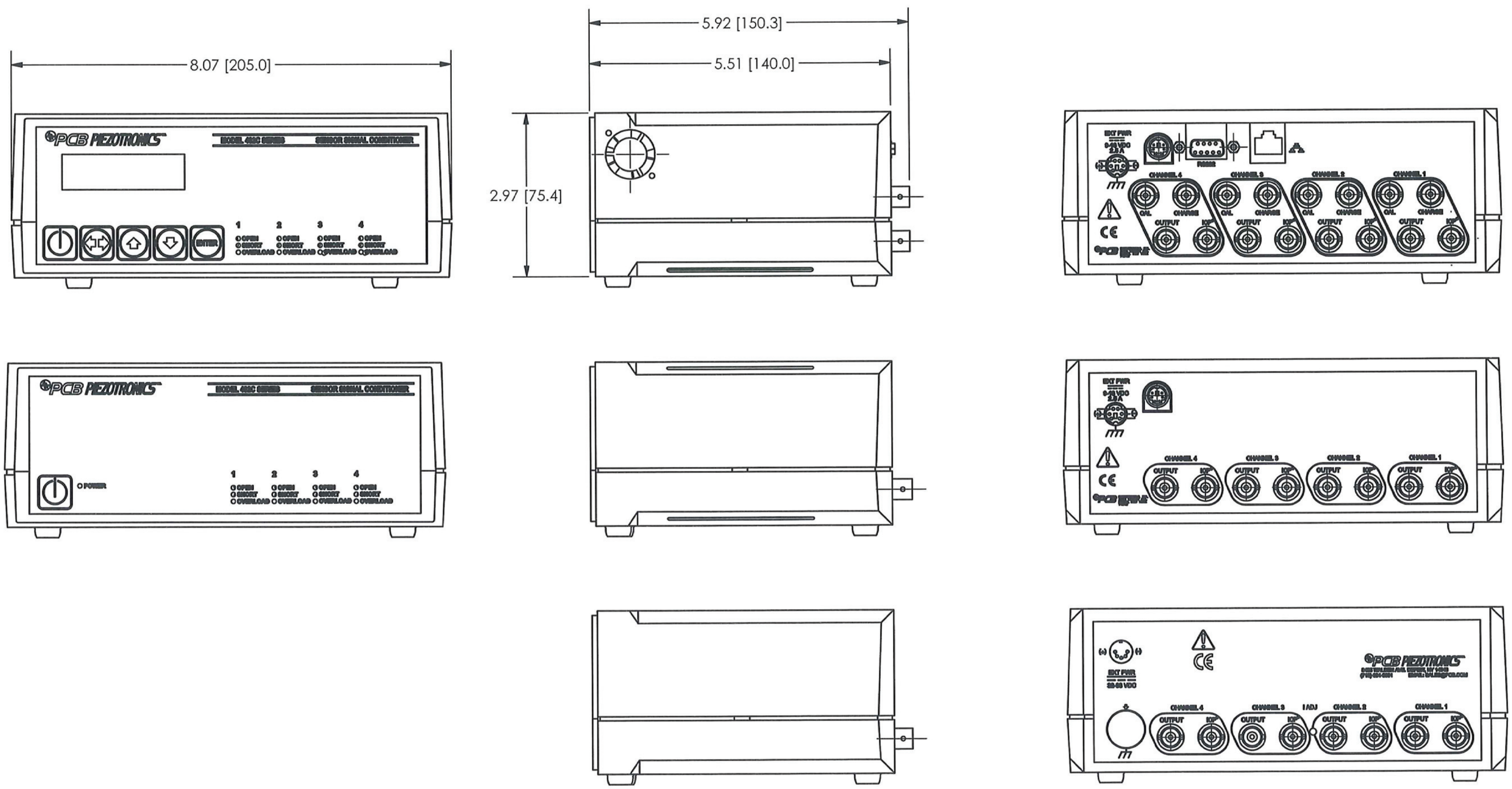
25495

REVISIONS

REV	DESCRIPTION	DIN
E	UPDATED ARTWORK	37737



UNLESS OTHERWISE SPECIFIED TOLERANCES ARE:	
DIMENSIONS IN INCHES	DIMENSIONS IN MILLIMETERS [IN BRACKETS]
DECIMALS XX ±.03 XXX ±.010	DECIMALS X ±0.8 XX ±0.25
ANGLES ± 2 DEGREES	ANGLES ± 2 DEGREES
FILLETS AND RADII .003 - .005	FILLETS AND RADII 0.07 - 0.13

DRAWN		CHECKED		ENGINEER	
SMB	12/16/11	ECB	12/16	KEN L	12/16/11

TITLE

OUTLINE DRAWING
MODEL 482C SERIES 4 CHANNEL
SIGNAL CONDITIONER

PCB PIEZOTRONICS
3425 WALDEN AVE. DEPEW, NY 14043
(716) 684-0001 E-MAIL: sales@pcb.com

CODE IDENT. NO.	DWG. NO.
52681	25495

SCALE: .5X SHEET 1 OF 1

FOCUS II

Real-time Analyzer with High-speed USB 2.0 Interface for Vibration and Noise Analysis

Dynamic Signal Analyzer

Technical Specifications

LDS DACTRON

FOCUS II
Technical Specifications

1

FOCUS II Real-time Signal Analyzer

2

RT Pro Signal Analysis and Waveform Source Software

3

RT Pro Signal Analysis Series
Modal Data Acquisition, Long Waveform Recorder Option, analyze Anywhere Option,
Environmental Data Reduction Option, and Automated Test Option

4

RT Pro Signal Analysis Series
Acoustic Analysis Option, Advance Graphics Option,
RMP Spectrum Processing Option, and Realtiem Order Tracking Option

5

RT Pro Signal Analysis Series
Dactron Rotate Option and Dactron Rotate Plus Option

FOCUS II

FOCUS II Real-time Signal Analyzer

FOCUS II™ makes any PC an instrument-quality analyzer that is a flexible multi-channel analyzer for noise and vibration analysis. Designed for realtime signal analysis, *FOCUS II* offers remarkable performance with a measurement dynamic range of 120 dB and a 42 kHz realtime rate. *FOCUS II* is a USB device that is fully compliant with USB version 2.0, 1.1, and 1.0 specifications.

Signal analysis applications are available for the range of noise and vibration testing – realtime spectrum analysis, modal data acquisition, realtime octave analysis, order tracking and waterfall analysis, transient capture and SRS analysis. *FOCUS II* comes standard with four inputs with ICP® sensor power, all housed in an steel/aluminum case with expansion bays to suport up to twenty inputs, a 6 foot (2.8 meter) USB cable, a user manual (on CD), and a one year warranty.

Inputs

Analog channels	Four standard, expandable to twenty simultaneous channels. All are differential inputs with 220k Ohm impedance. Each input channel has overload detection before both the analog and digital anti-alias filters. Setup allows per channel selection of input voltage range (0.1V, 0.3V, 1V, 3V, 10V), transducer sensitivity, sensor type (e.g., acceleration, force, pressure, etc.), and coupling selections for DC, AC (high pass cutoff at 0.7Hz, 3Hz or 22Hz), ICP and TEDS
Electronics	Differential amplifier, programmable gain amplifier, anti-aliasing filters, and 24-bit Analog to Digital Converter (ADC).
Filtering	An analog filter plus a 160 dB/octave linear-phase digital filter prevent aliasing and phase distortion.
Frequency range	Up to 42 kHz analysis frequency (96k samples per second).
Voltage range	±10 Vpeak
Signal conditioning	Voltage or ICP sensor power (4.7 mA, 30 Vpeak open circuit) and TEDS
Maximum input	±40 V_{peak} without damage
Resolution	24-bit
Dynamic range	120 dBfs 110 dB minimum in FFT mode.
Accuracy	±0.08 dB (1kHz sine at full-scale)
Channel match	
Amplitude	Within ±0.04 dB
Phase	Within ±0.5 degree (from DC to 42 kHz, frequency response measurement, both inputs on the same input range, linear average)
Alias protection	>117 dB stopband rejection
Signal-to-noise	>100 dB (from DC to 1000 Hz measured with half-full-scale sine wave).
Cross-talk	<-110 dB
Total Harmonic Distortion	<-105 dBfs
Frequency accuracy	Within 0.01%

Outputs

Analog channels	Waveform Source with 2 output channels.
Electronics	24-bit Digital to Analog Converter (DAC), with analog and digital anti-imaging filters.
Filtering	A 160 dB/octave digital filter plus an analog filter prevent imaging and phase distortion.
Frequency range	Up to 42 kHz output frequency (96k samples per second)
Voltage range	±10 Vpeak
Resolution	24-bit
Dynamic range	120 dBfs
Total Harmonic Distortion	< -95 dBfs
Output impedance	50 Ω
Maximum current	500 mA peak

Software

Operating system Windows XP/2000/Me/98

Architecture Distributed processing relieves the PC from the burden of realtime processing. True multitasking allows the PC to deliver maximum graphics performance and responsiveness to the user. The software provides both on-line test status and management through text displays, software toggle buttons, and screen displays of multiple time and/or frequency signals.

Applications

- Signal Analysis and Waveform Source
- Modal Data Acquisition
- Acoustic Analysis
- Rotating Machinery Analysis
- Transient Capture and SRS Analysis
- Automatic Pass/Fail Testing
- Waveform Recording
- Data Recording

Features On-line help, consistent management of user defined engineering units, on-line graphics, and test documentation of both measurement parameters and signals through Microsoft Word as printed media or disk files via single click on Icon.

Hardware

Enclosure	Aluminum and steel case encloses low-noise input/output boards with dual 75 MHz 32-bit floating-point DSP processors per board. Rubber corner guards for shock protection and stabilization. Front panel - BNC connectors for inputs and outputs, 2 color status LEDs. Rear panel - sync connector
Input expansion	From four up to twenty total analog inputs. Expansion by four-input modules.
PC configuration	PC with USB connector, Windows XP/2000/Me/98 Operating System, and Microsoft Word are the only requirements.
PC expansion	PC upgrades and peripheral additions do not delay or interrupt data acquisition and realtime processing.

General

Power	9 to 36 Volts DC	
Power consumption	20 to 35 Watts	
Dimensions		
Height	4.5 in.	11.4 cm
Width	11.25 in.	28.6 cm
Depth	10.5 in.	26.7cm
Weight	13.5 lbs	5.85 kg
Temperature	32 to 122°F	0 to 50°C
Humidity	10% to 90% RH non-condensing	

RT Pro Signal Analysis and Waveform Source Software

RT Pro offers powerful data acquisition and realtime signal processing capabilities. "On the fly" changes to the measurement setup allows you maximum flexibility and gives results fast. The Signal Analysis and Waveform Source base package of RT Pro provides comprehensive capabilities for general signal analysis. Optional software packages in the RT Pro Dynamic Signal Analysis Series offer many more application tailored solutions.

Signal Processing Functions

Time domain Time capture, auto-correlation and cross-correlation functions, orbit plots, and statistics.
Frequency domain Realtime spectrum analysis, auto-power spectrum, cross-power spectrum, power spectral density, frequency response function, coherence function, Fourier transforms, impulse responses, and ceptstrum.
Amplitude domain Histogram

Realtime Spectrum Analysis

Realtime rate 42 kHz for tri-spectrum analysis with 20 inputs
Dynamic range 120 dBfs
Frequency range DC to 42 kHz in thirty-six ranges.
Zoom Thirty-two spans from 17 Hz to 10.5 kHz; max. upper frequency of 42 kHz.
Resolution 110, 225, 450, 900, 1800 or 3600 spectral lines*
Windows Hanning, Hamming, Flat-Top, Uniform, Force/Exponential, Kaiser Bessel, Blackman, Blackman Max. Decay, Blackman Min. Sidelobe, Bartlett, Tukey and Welch.

Averaging

Modes Time or Frequency
Types Exponential, linear, peak hold, peak hold for specified number of averages.
Overlap processing User-defined percentage from 0% to 99%. Maximum overlap dependent on sampling rate.
No. of averages 1 to 32767 frames
Frame reject Automatic reject of frames with voltage overloads; manual accept/reject of overloaded frames; manual accept/reject for all frames.

Triggering

Source Input channel, waveform source signal, digital input, time delay, or free run.
Slope Positive, negative or bi-polar
Level Percent of full-scale range or voltage level
Pre/post-trigger User selected number of samples; up to the selected frame size before or up to 65535 samples after the trigger point.
Modes Automatic or manual
Run modes Trigger first frame followed by free run, auto trigger every frame, manual arm every frame.

Transient Capture

Sampling rates Up to 48000 samples per second in twenty-two settings.
Frame size 256, 512, 1024, 2048, 4096 or 8192 samples*. Deep memory capture adds frame sizes of 16384, 32678, 65536,131072 and 262144.
Modes Single frame, multiple frames

Waveform Source

Signals Swept-sine, shaped random, shaped burst random, white noise, pseudo-random, burst random, burst chirp, chirp, sine wave, square wave, and triangle wave, impulse chain, arbitrary waveform, and DC level.

* UP to 1800 lines with all functions enabled for all channels. Higher resolutions dependent on the number of functions and channels active.

Measurement Controls

Measurement and Source Panel toggle buttons and tool bar icons provide easy access to test controls. For added convenience, commonly used commands are accessible via keyboard special function keys.

Controls Start/stop, pause/continue, and next frame buttons.
Requests Time capture, FFT, correlation, spectrum, FRF/coherence, and histogram buttons.
Parameters Spectral lines, frame size, frequency range, sampling interval, spectral window, frames, trigger, average parameters
Waveform source Start/stop, signal selection buttons.
Icons Reset frame averaging, save signals, and quick report.
Status displays Frame number, activity status, and a message box.

Signal Displays

Unlimited number of display windows in tile or cascade format with click & drag zoom, user annotation, and cursors.

Window format Per window choice of single, dual, or four pane formats. Each pane can display single or multiple signals overlaid in either time or frequency. Independent choice of color and texture for signals, grids, tick marks, labels, titles, etc.
Scale format Linear or logarithmic scales for X and Y axes with automatic or manual scaling.
Cursors Single or dual with X, Y, ΔX, ΔY, ΔRMS and Q value readouts; manual peak marks; automatic peak/valley detection and marks; harmonic and sideband cursor.
Frequency signals Auto-spectrum, cross-spectrum, FFT, power spectrum density, frequency response function, coherence.
Signal formats Bode, magnitude, phase, unwrapped phase, polar, vector (Nyquist), real, imaginary.
Engineering units English/SI/Metric/mixed units for acceleration, velocity, displacement, force, and pressure; user defined.
Normalization Engineering Units (EU), EUpeak, EUrms, EU^2, EU^2/Hz, EU/√Hz, EU^2-S/Hz; decibels (dB).
Frequny axis Hz or CPM
Time signals Input time histories, auto and cross correlation, and orbit plots.
Amplitude signals Histograms
Statistics Strip chart output for rms, mean, peak, max and min values of input signals

Signal Calculator

This feature allows you to create customized signals. All signals are calculated and displayed "live" during testing. Operations include add/subtract/multiply/divide and single/double integration or differentiation, A,B,C weighting, square and square root, mobility and admittance.

Data Export

RT Pro provides seamless data interfaces to advanced analysis packages.

Binary file formats Dactron, ME Scope, MATLAB, UFF, WAV, Agilent SDF, MTS ATI/AFU
ASCII file formats UFF, X-Y pair, Y only

Active X Signal Reader

Active X API provide access to Dactron binary data files through programs such as Matlab, Labview, Visual Basic, Visual C, etc.

Post-Test Documentation

Icon for single click generation of data plots and test reports, including measurement parameter listings, test logs, and formatted signal plots, within Microsoft Word. Optional provision for saving documents in Adobe Acrobat PDF format.

RT Pro Dynamic Signal Analysis Series

The RT Pro Dynamic Signal Analysis Series offers application software options to meet tomorrow's needs for noise and vibration analysis. As your test demands grow you can add new RT Pro applications to extend the usefulness and power of your system.

Modal Data Acquisition

(included with RT Pro Signal Analysis and Waveform Source)

FRF & Coherence	Arbitrary assignment of response-excitation pairs from among available inputs. H1 and H2 FRF calculations
Spectrum	Auto-spectra only or auto-spectra and cross-spectra.
Time Capture	Frame size up to 262,144 (using deep memory capture)
Special windows	Force/exponential window with user-set start point, flat top points, and damping factor.
Modal coordinates	Entry of measurement point, axis and sense in Channel Parameters table or via On-line Coordinate Update table.
Auto-incrementing	Automatic updating of roving measurements using pre-set measurement point increment.
Frame reject	Automatic reject of frames with voltage overloads; manual accept/reject of overloaded frames; manual accept/reject for all frames.
Modal package interface	Data interface for popular modal analysis packages.

Long Waveform Recorder Option

This software option enables streaming of long data records. Each record contains gap-free data simultaneously sampled for all active channels. Note that real time signal analysis can be performed during waveform recording.

Max Rate	96k samples per second per 20 channel*
Data formats	Dactron binary, X-Y ASCII, Y-only ASCII, UFF binary, UFF ASCII, WAV, Agilent SDF, MTS ATI/AFU
On-line displays	Input time histories for all inputs; channel status including voltage levels and overloads. FFT, autospectra, cross spectra, FRF, coherence statistics, and waterfall displays are also possible
Post-processing	Via playback in Analyze Anywhere option

* Maximum throughput rate may be limited by the hard disk access time or CPU loading.

Data Recorder Option

The Data Recorder option provides a friendly tape recorder user interface for easy and quick data recording for all active channels and includes voice channel annotation via the PC sound card. Data Recorder also provides a quick and seamless transition to data playback and processing via the Analyze Anywhere option. Note that real time analysis cannot be done while using the Data Recorder.

Max Rate	96k samples per second with 20 channels
Data Formats	Dactron binary, X-Y ASCII, Y-only ASCII, UFF binary, UFF ASCII, WAV, Agilent SDF, MTS ATI/AFU
On-line displays	Input time histories for all inputs; channel status; recording view with summary of index files, recording events and voice records
Post-processing	Via playback in Analyze Anywhere option
Voice Recording	Unlimited number of voice recordings; each voice record up to 10 seconds

Analyze Anywhere Option

Display and review data at your desk by using Analyze Anywhere™. This software can reside on any PC and does not require any Dactron hardware. It offers all of the on-line display features and report generation features available with a Dactron System. Data is easily imported via disk media or across the network.

Data playback allows you to process throughput data collected with Long Waveform Recorder. You can also process data from other data acquisitions systems that export data in either X-Y ASCII, Y-only ASCII, UFF ASCII or UFF Binary format. All of the RT Pro signal processing functions are available for data playback.

Environmental Data Reduction Option

Transient Capture

Sampling rates	Up to 48000 sps in twenty-two settings.
Frame size	256, 512, 1024, 2048, 4096 or 8192 samples*
Modes	Single frame, multiple frames
Averaging	Exponential, linear, peak hold, peak hold for specified number of averages

Shock Response Spectrum

SRS analysis	Up to 14 octave range using maxi-max, negative maximum, and positive maximum analysis techniques. User specifies high and low frequency, reference frequency, damping ratio or Q value, and resolution (1/1, 1/3, 1/6, 1/12, 1/24, or 1/48).

Automated Test Options

Pass/Fail Limits and Criteria

Limits checking	Multiple, simultaneous limit checks on frequency domain, time domain, and amplitude domain signals.
Limits definition	Pass/fail limit criteria may be defined based on: • User created Limit Tables • Measured signals resident in memory • Signals imported from ASCII files • Synthesized signals generated by using RT Pro's Signal Calculator function
Limit tables	High or low limit curves defined based on breakpoint table; interpolation on linear-linear, log-linear, linear-log, or log-log basis.
Limits import	Limit tables seeded from imported ASCII, UFF or Dactron binary file. ASCII files generated by spreadsheets, MATLAB, or other software.
Limit Scaling	Limit curve scaling by using a user entered value as a multiplying constant or offset value.
Limit check range	Sample by sample checking (time domain) or line by line checking (frequency domain); check range may be the whole range or a user specified range.
Limit threshold	User specified percentage of values outside of limits to trigger fail flag.
Overall limits	Fail detection based on the RMS, maximum, mean, minimum, or peak value. (Time and Amplitude Domain only).
Actions on fail flag	Display alarm message, sound PC beep, generate test report, and abort measurement.
User messages	User message strings displayed on test failure.
Frequency domain	Auto and cross spectra, 1/1 and 1/3 realtime octave spectra1, Frequency Response Function and coherence, and Shock Response Spectrum (SRS)[2].
Time domain	Time histories, synchronously averaged time records, and auto and cross correlations (overall value limit checking only for correlations).
Amplitude domain	Histograms (overall value limit checking only).

Test Schedule

User defined sequence of events that are automatically executed during the test.

Events	Measurement duration (hours, minutes, seconds), limit checking on or off, start or stop the source signal, timed pause, save signals, and generate a test report; logic for sequence loop and nested loops.

RT Pro Dynamic Signal Analysis Series

The Acoustic Analysis and Rotating Machinery Analysis options offer advanced on-line processing capabilities. The Acoustic Analysis option provides realtime time-domain octave filtering for 1/1 and 1/3 octave spectra. The Advanced Graphics and RPM Spectrum Processing options provide rpm-based waterfalls, spectrograms, and color contour plots. The Realtime Order Tracking option allows for order analysis of up to 55 orders simultaneously.

Acoustic Analysis Option

Realtime Octave Analysis

Method	Realtime time-domain octave filtering
Standards	
1/1 octave bands	Conform to ANSI Standard S1.11-1986, Order 7, Type 1-D, Extended and Optional Frequency Ranges
1/3 octave bands	Conform to ANSI Standard S1.11-1986, Order 3, Type 1-D, Extended and Optional Frequency Ranges
Frequency ranges	20 inputs
1/1 octave bands	1 Hz - 16 kHz
1/3 octave bands	1 Hz - 20 kHz
Weighting	Linear, A, B and C selectable
Averaging modes	Linear, exponential or peak hold
Sound level detectors	Peak hold, impulse, fast and slow sound level measurements
Measurement period	From 1.3 msec to 48 hours
FFT auto-spectra	Simultaneously measured during realtime octave acquisition.
Averaging	None, exponential, linear, or peak hold
Resolution	225, 450 or 900 spectral lines
Windows	Hanning, Hamming, Flat-Top, Uniform, Kaiser Bessel, Blackman, Blackman Max. Decay, Blackman Min. Sidelobe, Bartlett, Tukey and Welch.
Frequency signals	1/1 and 1/3 octave spectra and auto-spectra
Barchart display	Solid or transparent with multiple signal overlays.
Time signals	Input time histories, overall level (linear or A weighted) versus time, user-selected octave band level versus time.

Advanced Graphics Option

(included with RT Pro Signal Analysis & Waveform Source, Order Tracking and Acoustic Analysis Options)

Quantities	Spectra and time histories versus time
Plot formats	Waterfall (3-D display), waterfall with single pane or dual pane, and spectrograms or color contour (2-D display) plots

W aterfall An alysis

Cursors	
3-D Cursor	Dual axis cursor with trace color highlighted in both axes.
Synching	Synchronized cursor positioning for all cursors in all windows.
Display axes	
X axis	Hertz or CPM; linear or log scale
Y axis	Engineering Units (EU), EU_{peak}, EU_{rms}, EU^2, EU^2/Hz, EU/$\sqrt{Hz}$, EU2-S/Hz; linear, log or dB.
Z axis	Seconds
3-D orientation	Viewing angle interactively set by using the mouse
Slice plot	Selectable as X slice, Z slice

RPM Spectrum Processing Option

Tachometer

Pulses per rev.	1 to 1024
Gear ratio	Ratio of two numbers; each from 0.1 to 10000
RPM range	1 < RPM < 300000
RPM accuracy	100 ppm (typical)
Level range	Programmable from 1V to 10V

RPM Trigger

Level	RPM plus tolerance setting
Slope	Run-up, run-down, absolute value

Run Modes

RPM Waterfall	Low RPM, high RPM, and delta RPM
Frame size	256, 512, 1024, 2048 or 4096 samples*
Spectral lines	110, 225, 450, 900 or 1800 lines*
Averaging	Stable (linear), peak hold, or exponential
Overlap	User specified from 0 to 99%; maximum overlap dependent on sampling rate.
Windowing	Hanning, Hamming, Flat-Top, Uniform, Bartlett, Tukey, Blackman, Blackman (4th) Maximum, Blackman (4th) Minimum, and Welch.
Waterfall plots	Amplitude vs Hertz vs RPM or Seconds; all other attributes as per the Advanced Graphics Option.

Real Time Order Tracking Option

(Includes the Advanced Graphics and RPM Spectrum Processing Options.)

Method 1	Realtime digital resampling technique
Order span	1st up to 320th order tracked; 1 < RPM < 300000
Order resolution	0.025, 0.05, 0.1, 0.125, 0.25, 0.5 and 1.0

Max Order	Order Resolution
20	0.025 to 1
40	0.05 to 1
80	0.1 to 1
160	0.125 to 1
320	0.25 to 1

Number of orders	Up to 55 orders simultaneously tracked online.
Amplitude extraction	Based on DFT frequency domain extraction of order amplitudes.
Run Mode	Run-up, Run-down, and Free run. Selectable number of Runs with automatic rejection of data that violates the Run mode criterion (wrong RPM direction)
Waterfall plots	Amplitude vs Order vs RPM; all other attributes as per the Advanced Graphics Option.
Method 2	FFT based amplitude detection
Order span	1st up to 55th order tracked; 1 < RPM < 300000
Order resolution	0.1 to 200th order in post-process mode. (Maximum useable RPM limited by resolution, tach pulse rate, pulses/rev and averaging used)
Number of orders	Up to 55 orders simultaneously tracked online; unlimited orders in post-process mode.
Amplitude extraction	Selectable based on fixed bandwidth, fixed spectral lines, or frequency rang; additionally, proportional bandwidth (from 1% to 100%) in post process mode.
Waterfall plots	All attributes as per the Advanced Graphics Option.

* Maximum resolution depends on the number waterfall spectra, order tracks defined, and channels active. Up to 3600 lines with two channels, 75 spectra per waterfall, and 20 order tracks per channel.

RT Pro Dynamic Signal Analysis Series

Dactron's Rotate and Rotate Plus options offer advanced and robust post-processing for diagnosing and analyzing noise and vibration problems due to periodic loading from engines, transmissions, drive lines, wheels, belt drives, bearings, turbines, or reciprocating machines such as compressors. All results, both graphics and numeric data, are easily exported to Mircosoft Excel, Word or PowerPoint.

Dactron Rotate Option

Dactron Rotate's fast computations with waterfall and color contour plots make it easy to quickly identify trouble areas while the precision of its computed order tracking and flexible cursors help to immediately pinpoint root causes.

Tachometer Analysis

Tachometer Analysis computes raw or initial estimates of a machine's instantaneous rotating speed from sampled data from a DC or Pulse tachometer signal. A smoothing function fits cubic spline segments to the raw estimate to give a speed curve that is free of tachometer noise and drop out effects.

Tach type	Pulse or DC signal
Tach conversions	
Pulse signal	User specified pulses per revolution
DC signal	User specified RPM per Volt and RPM at zero Volts
Triggering	
Slope	Positive or negative
Level	0 to 10 Volts
Hysteresis	0.01 to 10.0
Hold off	Programmable minimum time between trigger events.
Smoothed RPM	Cubic spline segments provide smoothed estimate of the machine's rotating speed. A unique algorithm removes "outliers" from the raw rpm curve estimate and then re-computes the spline fit. This algorithm makes it possible to generate good speed curve estimates even when using a noisy tachometer signal with pulse dropouts.
Spline segments	1 to 99
Shave %	0% to 20%

Computed Order Track Analysis

Order Tracking digitally resamples based on the smoothed machine speed curve providing alias-free order tracks of amplitude and phase versus RPM.

Order numbers	Simultaneous calculation of multiple orders; fractional or integer orders
Tracking	
Method	RPM, Time or None
Type	Run Down or Run Up
Range and resolution	User specified Min. and Max. RPM or Sec., RPM or Sec. increment, and Max. number of values
Signal Processing	
Filter width	1% to 100%
Weighting	Selectable A, B or C
Signal domain	Single or double Integration/ Differentiation

Torsional Analysis

Based on pulse signals from encoders and flywheels, Torsional Analysis gives an accurate kinematic description of torsional vibrations from single station measurements. This technique processes time domain data, using even relatively coarse measurements, to produce a torsional signature which then is used to make waterfall and order calculations and graphics.

Waterfall Analysis

Waterfall Analysis uses fast Fourier transforms to calculate an array of FFT spectra. Flexible parameter settings and fast computation and display times provide waterfall plots and color contour displays (spectrograms) for the computed FFT arrays.

Quantities	Power Spectral Density (PSD) or Cepstrum
Frame size	128, 256, 512, 1024, 2048, 4096, 8192, 16384 or 32768 samples
Spectral lines	50, 100, 200, 400, 800, 1600, 3200, 6400 or 12800 lines
Averaging	
Number	Selectable from 1 to 500
Type	Stable (linear), peak hold, or exponential
Overlap	User specified from 0 to 50%
Windowing	
Type	Hanning, Hamming, Flat Top, or Uniform
Correction	Narrowband (peak) or Wideband (rms)
Weighting	Selectable A, B or C weighting
Signal domain	Single or double Integration/ Differentiation
Tracking	
Method	RPM, time or none
Type	Run Down or Run Up
Range and resolution	User specified Min. and Max. RPM or Sec., RPM or Sec. increment, and Max. number of spectra
Cursors	
Type	Single, band or harmonic
Axis orientation	Constant frequency, order, RPM or time
Display axes	
X axis	Hertz or orders; linear or log scale
Y axis	Linear, log or dB scale
Z axis	RPM, seconds or number
3-D orientation	Viewing angle interactively set by using the mouse

Dactron Rotate Plus Option

Rotate Plus provides added features for dealing with problems associated with families of harmonics. Re-sampling in the angle domain isolates information vital to diagnosing harmonic problems found in transmissions, bearing and gears.

Millstrum Analysis

This analysis is a variation on Cepstrum analysis and it helps you to identify families of harmonics present in your data. This analysis is particularly powerful in picking out families of harmonics that are obscured by noise or harmonics dominated by the amplitudes of unrelated orders.

Order Normalized Spectra

By resampling data in the angle domain, better order tracking resolution is obtained for data with a large dynamic range and in lower frequency ranges. Resampling in the angle domain at constant intervals maintains the same angle resolution around the governing shaft and gives the same data quality regardless of the shaft speed.

Sideband Cursors

By overlaying Sideband Cursors on your spectra data you can easily identify families of harmonics embedded in your data.

Bearing Cursors

These cursors highlight specific bearing problems such as FTF (Fundamental Train Frequency), BSF (Ball Spin Frequency), BPIR (Ball Pass Inner Race), BPOR (Ball Pass Outer Race), and 2xBSF.

FOCUS II

Technical Specifications

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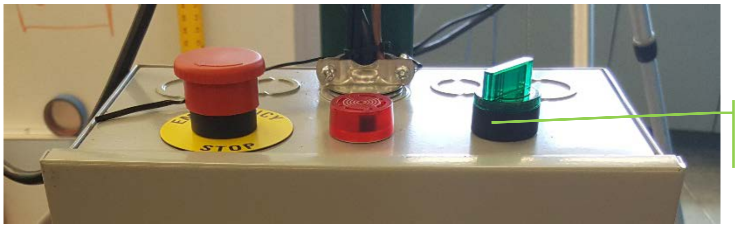
AN SPX COMPANY

APPENDIX G: TEST PROCEDURE

1. Acquire required instrumentation
    a. ICP Signal Conditioner with at least 3 channels
    b. DAQ with sampling frequency of at least 16kHz
    c. High Speed Camera
2. Connect instrumentation to drop tower
    a. Accelerometer cables to signal conditioner
    b. Signal conditioner to DAQ
3. Apply power to drop tower by turning green power switch on top of control box



Power Switch

4. Apply power to instrumentation
    a. Signal conditioner
    b. DAQ
    c. High Speed Camera
    d. Laptops

5. Secure Helmet to headform with chinstrap or duct tape

6. Adjust upper limit switch to correct height for required drop height

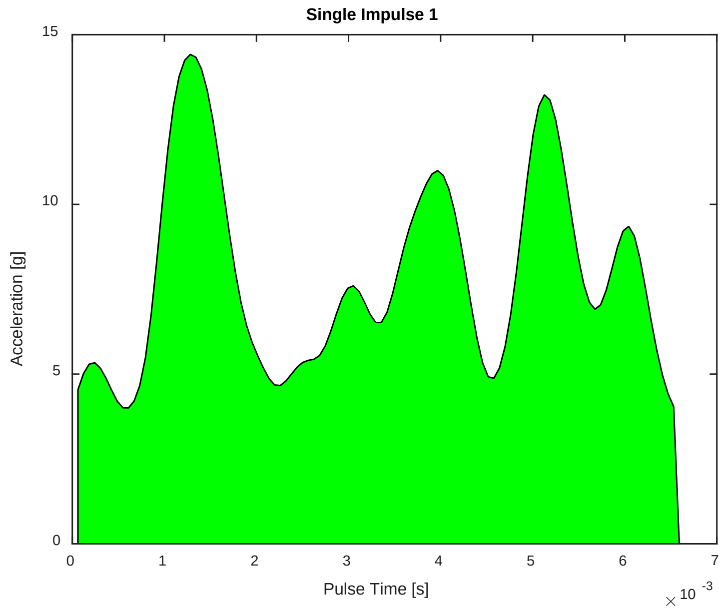
7. Lower lift bar to capture carriage by turning winch control switch to down

position

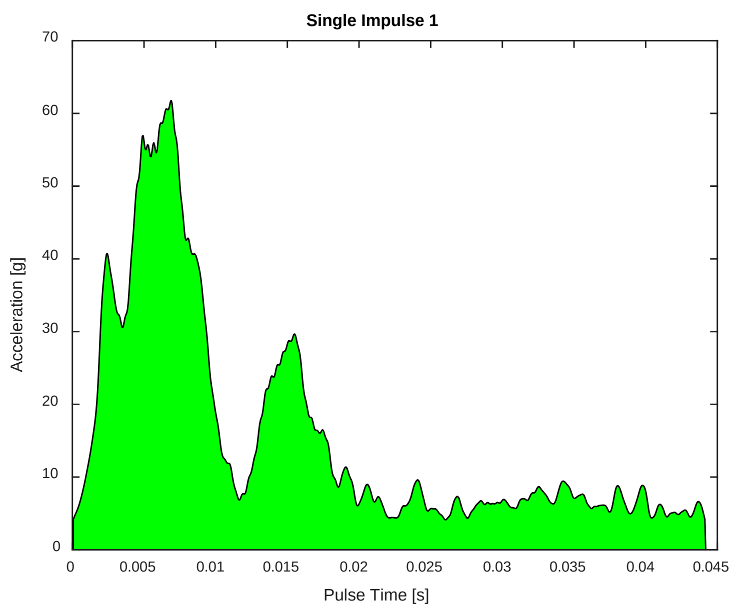
8. Insert safety pin through safety bracket and lift bar
9. Raise lift bar till limit switch activated using winch control switch
10. Measure helmet to impact pad height to ensure correct height is achieved
11. Remove safety pin
12. Retreat safe distance and clear area of unnecessary personnel
13. Pretrigger high speed camera in Phantom Control Software.
14. Start DAQ data recording on DAQ software of choice
15. Turn Safety Switch
16. Release carriage
17. When impact is heard, trigger high speed camera in software
18. Stop DAQ recording
19. Save data and video
20. Readjust helmet
21. Repeat 5-19
22. When testing completed, remove power from all instrumentation and drop tower

APPENDIX H: AXIAL ACCELERATIONS FOR FULL SCALE 2FT DROP TEST

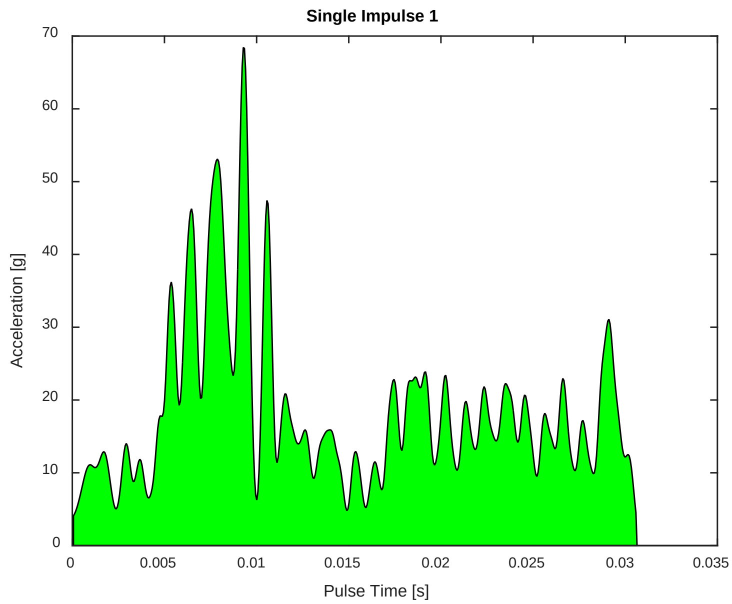
X Axis:



Y Axis:



Z Axis:



Single Impulse 1
Acceleration [g]
0
10
20
30
40
50
60
70
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
Pulse Time [s]