Interim Design Report

Pyrotechnic Shock Test Development

Team Number: Team 15

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Abstract

The fundamental goal of this project is to facilitate the testing of electronic components subject to high frequency, high acceleration pyrotechnic induced shock loadings. These shock loadings are often difficult to recreate in a test environment due to the complex acceleration time history of the pulse. Commonly, these shock loadings are experienced during staging events in spacecraft and satellite operations. Since the shock time history is quite complex, it is easier to describe how a structure responses to the pulse rather than to describe the shock motion. This response is captured in a Shock Response Spectrum (SRS) which plots the peak acceleration response of a large number of single degree of freedom systems excited by the pulse under an assumed damping. The primary hurdle is generating a suitable shock response spectrum equivalent to that of the pyrotechnic shock. This project seeks to develop a standardized method of modeling and testing, in a reliable manner, electronic components to a specified pyrotechnic shock. At the completion of the project a functional prototype, as well as a tailored modeling system, is expected.

Acknowledgements

The work Team 15 has done, and hopes to accomplish, is only possible with the help from our sponsor, Harris Corporation, and the FSU-FAMU College of Engineering faculty. We would like to thank Mr. Robert Wells and his colleagues at Harris for providing this project and for their contributions of both time and resources to help point us in the right direction. We would also like to acknowledge our faculty advisor. By assisting in securing critical resources as well as a testing location, Dr. Kumar has proven to be an invaluable asset to our team and project. His words of wisdom have also served to keep us on track and driven to complete the project. Lastly, our senior design instructors Dr. Helzer, Dr. Gupta, and Dr. Shih for helping us with the planning and execution of this design task.

Team Biographies

Charles DeMartino, Team Leader:

Charles DeMartino is a senior in the undergraduate BSME program at the FAMU-FSU College of Engineering. His educational focus is on material science and design. He enjoys diving into problems that require analytical solutions as well as those involving new technology. After completing his degree he hopes to find employment within his field.

Chason Mitchell, Treasurer:

Chason Mitchell is a senior at the FAMU-FSU College of Engineering and a native resident of Tallahassee, FL. Chason enjoys involving himself in many different areas of study, but he is particularity interested in fluid power, hydraulics, and powertrain engineering. Upon graduation, Chason plans to obtain experience in the industry and before pursuing further education.

Nathan Crisler, Webmaster:

Nathan Crisler is a senior at the FAMU-FSU College of Engineering pursuing a Bachelor of Science in Mechanical Engineering. He is focusing his senior year on Aeronautics, a new program at the College of Engineering. He enjoys problem solving and find new solutions to difficult problems.

Chad Harrell, Secretary:

Chad Harrell is a senior in mechanical engineering at the FAMU-FSU College of Engineering. He is on the thermal fluids track for senior year. He is the secretary for the engineering honor society Pi Tau Sigma, and is a member of ASME and SAE. He appreciates a challenge and enjoys watching football, swimming, and reading. He is seeking a full time, entry level position in the mechanical engineering field after graduation in Fall 2015.

1 Introduction

The project for the development of a hammer blow test device to simulate pyrotechnic shock was brought to the university by the Harris Corporation. Pyrotechnic shock testing is used to determine the effect of shock on electronic equipment. This testing is done to verify that products can sustain any shock they may encounter during their life. Harris has brought this project forward due to the time and money expended by their current test procedures. Their desire is the development of a clear and documented analysis of controlling test parameters to affect a change on the Shock Response Spectrum (SRS) curve generation. Ultimately, the end product will allow for a more precise test setup and elimination of trial and error methods used in the current test procedures. A schedule has been developed, as well as resource allocation and tentative time schedules, which serve to keep the project moving forward and progressing steadily.

2 Project Overview

This section discusses the project's origins and scope, background information, needs and goals statements, and how they will be met.

2.1 Scope

The scope of this project was recently extended from a single design year to two. This decision was made both by the Harris sponsors and the senior design faculty at the college. The reason for this was to allow time for the creation of a working test apparatus with supporting modeling and system documentation in the first year (2014-2015), with follow on improvements to the testing rig and modeling in the second year (2015-2016) to achieve the goal of a concrete methods to reduce the trial and error of shock testing.

Concerning our year of the project, over the coming semester we will construct our test apparatus and begin testing. Testing will be done with constant values for all variables in order to determine an accurate baseline result. Once these results have been tabulated we will adjust our variables one at a time to determine the effect of the variable on our results. While these tests are being done we will begin programming in MATLab to create a function based off our test results with the goal of creating a program that will analytically model what we find experimentally and generate appropriate SRS curves. This project requires collaborative efforts in order to re-design and produce a suitable testing apparatus and modeling system. This is required to reduce inefficiencies of the current trial and error method employed by Harris for testing electronic components in regard to high load, high frequency shocks.

2.2 Background research

Pyrotechnic induced shock can potentially be devastating to electronic equipment. Increasing use of pyrotechnics as a means for mechanical actuation warrants increasing need to validate the effects they have on system components. These shocks were often ignored, yet further work by Moneing has shown critical failures induced by pyrotechnic shock [1]. Mathematical and computational models have difficulty with the computational resources required. In particular the FEM analysis has difficulty modeling the high frequency characteristics of pyrotechnic shock. The requirement of a large number of tests has proven to be an inefficient method of modeling these shock responses. Computational methods often yield much more conservative results due to the sacrifice in processing power [4]. Not only is this shock difficult to recreate in a testing situation, it is also difficult to model particularly as a function of time. Irvine recommends the use of the Shock Response Spectrum, or SRS, [3] to estimate the damage potential a shock may have. The SRS facilitates the analysis of shock on the component, rather than trying to analyze the extremely short duration, transient shock in the time domain. The SRS shows peak acceleration of a pre-determined series of natural frequencies that would be imparted by a certain shock [3]. The rapid decay, transient nature, and extreme frequencies are difficult to simulate using a shaker to induce vibrations. Mechanical shock inputs such as pneumatic and hammer blow tests can yield optimal results, yet are time consuming in their tuning [4]. Additionally, the shock imparted often cannot be subjected directly to the component in testing, but through a mounting which could have substantially different mechanical properties thereby hindering the accuracy of the results [3]. High acceleration shock loadings are more accurately created by explosives; however, this is rarely done in practice due to the obvious dangers [4].

Works by Chu and others have noted significant sources of error in accelerometer measurements in pyrotechnic shock. Actual pyrotechnic explosions can excite piezoelectric accelerometers at their natural frequency [5]. Replicating the pyrotechnic shock mechanically, as opposed to simulating with real pyrotechnics, can potentially solve any issues encountered with accelerometer measurements.

Tests done to electronic components by Luhrs have focused mostly on using a drop test to simulate pyrotechnic shock. He notes the discrepancies between using a drop test and shaker test as opposed to identical testing on a simulated spacecraft structure with a shock induced by pyrotechnics. No equipment failures occurred, until 2500g peak acceleration was reached, where crystal oscillators began to fail. On the other hand, a simulated spacecraft structure test setup experienced no failures until upwards of 7000g peak acceleration [5]. Findings by The Harris Corporation agree with Luhrs in that the drop test was overestimating the shock accelerations [2].

2.3 Need Statement

This project requires collaborative effort in order to re-design and produce a suitable testing apparatus and modeling system. This is required to reduce the inefficiencies of the current trial and error methods employed by Harris Corp for testing electronic components in regards to high load, high frequency shocks [2].

The current shock testing method lacks adaptability, requiring too much trial and error and expenditure of resources.

2.4 Goal Statement & Objectives

The goal is to design an adaptable test apparatus and modeling method to test, evaluate, and tabulate the measured effects that varying test parameters has on SRS curve generation.

Objectives:

- Research and explore alternative testing methods
- Devise systematic approach to maximize repeatability
- Develop computational modeling method for test standardization
- Find suitable shock load sensors for hands-on testing
- Explore possible apparatus designs; Material selection
- Design selection based upon feasibility, budget, and constraints
- Produce prototype and modeling method.

2.5 Constraints

In order to clarify the project and highlight key factors, the team's first contact via teleconference with Robert Wells at Harris Corp. was spent reviewing the initial information he sent and defining the project to develop a clear problem statement and corresponding goals. Both from the conversation and the parameters of the project laid out in the launching presentation, an extensive constraints list does not seem viable. Rather than creating an entirely new testing apparatus for shock testing, we will use a simplified approach to generate the shock itself. The primary issue faced by Harris is not that the current hammer blow test is ineffective in generating the desired pyrotechnic shocks, but that it is lacking efficient transitioning from one test's requirements to the next. This is due to the trial and error approach in tuning the apparatus prior to the actual testing procedure. Therefore, if we were to focus our efforts on better test parameter control and modeling for the current system, we can seek ways to reduce the number of necessary trial runs. The following list of constraints and considerations was developed based on both sponsor suggestions and as a result of team discussion:

- Proven consistency in shock generation
- Reliable release mechanism
- Model simulations
- Acceleration data acquisition that covers generated force ranges
- Software conversion or raw data to usable SRS curves
- Adjustable fixture and test parameters
- Test measurement collection and storage
- Project expenses must stay within allotted budget ($4000)

We have focused our efforts on the ability to accurately model the systems response, as well as provide methods for adjusting the apparatus for specified parameters. Typical constraints regarding the test rig itself are discussed in Section 3 and not declared here, as they can be modified as needed. Table 1 shows a house of quality matrix created from communications with Mr. Wells, and Harris Corp.

Table 1 - House of Quality Matrix: Engineering Requirements vs. Customer Requirement

		Engineering Requirements						
Customer Requirements	Weight factor	Material Selection	Size	Accuracy	Cost	Programming	DAQ	
Minimal Cost	2.5	9	9	3	9	1	3	
Ease of use	5			1	3	9	9	
Durable	5	9			3	3		
Accurate	5	1	1	9	3	9	9	
Size	2		9		9			
Software	5			9	3	9	9	
	Raw Score	72.5	45.5	102.5	101	152.5	142.5	616
	Relative Wt %	11.77	7.39	16.64	16.31	24.76	23.13	
	Rank	5	6	3	4	1	2	

2.6 Communications

Effective communication has a substantial effect on the success of our group and meeting the goals of our project. Our group consists of four team members, making it one of the smaller senior design groups. This makes coordinating meetings easier using email and group texting applications. These forms of communication have the added benefit of quickly sharing and documenting thoughts or suggestions for use later if necessary.

Team rapport also has a substantial impact on the effectiveness of the team. Our team has been able to work well without setting stringent boundaries on responsibilities. This makes it easier for all team members to be able to contribute, and learn, different aspects of the project without feeling regulated to only one part of the project.

Due to our team's inexperience with the technical details of this project, initial progress was slowed as we became more familiar with the subject of shock testing. This was overcome as we were able to share our gained knowledge with each other over report writing and project planning. The flow of information was facilitated by both our project sponsors and faculty advisor. In particular, the early semester teleconferences with Mr. Wells and later additionally his colleagues has helped each team member to stay on the same page.

Our website will be used extensively in the following semester and all later work performed. This allows us to maintain one central location of data and information about the project that is accessible anywhere that the internet is available. In addition, it is both easily and readily updateable. In addition we can make finished reports available to all personnel without having to send emails with attachments and rather an email with a web link or a simple notification that the website has been updated.

3 Design and Analysis:

The design and analysis section shows our progression of ideas and ideological analysis of proposed concepts. This section has been updated recently to reflect the change in project scope and the change in selected design concept.

3.1 Functional Analysis

This pyrotechnic shock testing machine will consist of two key components. First, the physical testing rig must be built, and therefore requires mechanical systems and analysis. Second, there will be extensive use of software systems for both modeling and data processing. Functional analysis then must consider both the mechanical and computational sides of the project and how they will interact, which is detailed in the methodology segment (section 7) of this report.

Mechanical:

In the mechanical section of our function analysis we have proposed the use of a square tube steel constructed frame that is rigid and strong. The weight of this material also serves to help keep the test apparatus sturdy before, during, and after the test impact is made. It is also cheap, easy to assemble, and readily available. The decision matrix in Table 2 details this selection.

Table 2- Material selection matrix for structure/framing material

Material	Durability	Cost	Availability	Assembly	Total
Wood	1	5	4	4	3.0
Plastic	2	3	3	3	2.6
Composites	4	2	2	1	2.6
Steel	5	3	4	3	4.0
Aluminum	4	3	3	2	3.2
Weight Factor	0.4	0.2	0.2	0.2	1.0

When it comes to the removable test fixture, there are a lot of considerations. This part is necessary to allow for standardization across multiple test attempts, as well as variability in test subject placement and shock response tailoring. Our ideal materials exhibit a predictable and constant natural frequency are easily machine-able to allow multiple fixture placements. They are also cost effective and readily available. In addition, should the budget allow, multiple test fixtures may become a more feasible option to allow the adaptability of testing it is our goal to achieve.

The material choice for the level of testing we will be conducting for this project does not require high levels of material analysis for two main reasons. First, the purpose of the test fixture plate in pyrotechnic shock testing is to have established, predictable reactions to shocks and the transfer of them to test articles. Therefore, the materials shown in Table 3 are all plausible materials due to the wealth of readily available material properties and their metallic consistency. Second, because adaptability is of high importance, the machinability of our material choice is likewise crucial. We know for certain that local fabrication shops and the school machine shops have the capability and expertise in working with these materials regularly, so these materials lead to higher precision and quicker machine times.

At the current time, we have elected to use 6061-T651 Aluminum due to considerations involving machine-ability (hardness), weight (density), and energy absorption (yield strength).

Other variations of aluminum were excluded for their lack of availability in the necessary size and/or excessive costs. Table 3 below details some of these specific material properties considered. These properties are not weighted due to the relative nature of their comparison. Additionally, in discussions with Harris personnel, the aluminum alloy of choice should give us comparable material properties, and thus testing result correlations, to the testing material they use.

Table 3- Material properties considered in test fixture selection [19, 20]

Material	Density	Hardness Rockwell B-Scale	Yield Strength
A36 Steel Plate	7850 kg/m^3	81	250 MPa
6061-T6 Aluminum	2720 kg/m^3	60	276 MPa
Yellow Brass	8670 kg/m^3	57	83 MPa

The device will be constructed of an all steel frame that houses an aluminum test fixture plate. This plate will be removable for the purpose of replacement or maintenance. Square tube steel will be used for the outer shell structure to provide an easier method of manufacturing versus using a round steel tube. In addition, square tube was used to cut costs as well as excessive weight versus solid bar.

In terms of manufacturing considerations, the FSU-FAMU Engineering School has access to two machine shops with many fabrication methods ranging from full sets of hand-held tools to water-jets machines and lathes. These will be utilized in the fabrication of the apparatus frame and potentially the modification of purchased parts. Given the ongoing nature of tuning this testing machine, the budget will be reserved as much as possible for any advantageous or necessary changes that may be needed.

The frame will be constructed from square steel tube which was chosen over the other highly weighted option, aluminum alloys, due to the higher strength as well as ease of machinery. Although machining aluminum is not necessarily more difficult than steel, the ability to easily weld support additions to the steel frame gives it an edge and helps with maintaining variability in case of modifications. We have decided to make the first build twice the size of the average article testing size (32” L x 32” W x 24” H) to allow for interchanging of the force delivery and test article location; initial testing will reveal any weaknesses or necessary alterations. The construction, as mentioned above, will be done in the available machine shops using drawings and specifications provided by the team after procurement of materials on the schedule provided below. Anything that cannot be done within the machine shops will be outsourced to local businesses on an as-needed basis.

The intent was to leave the option open to switch in and out different shock generation tools so that if affordable options arise, both with respect to time and budget, we can make use of the same setup to assess our modeling software given different testing conditions. For example, starting with a larger frame allows for the future use of a close range piston shock generator.

Electrical:

In the electronic section of our design analysis, we considered three different parts. First was the accelerometer to be used in capturing the impact and acceleration data. In examining the requirements for an accurate reading, care must be used in selecting an appropriate accelerometer. The Nyquist Sampling Theorem states that in processing a limited bandwidth signal, the sampling rate must be two times the maximum frequency of the signal [11]. Since the maximum theoretical frequency for our project scope is 10 kHz, an accelerometer with the capability of 20 kHz sampling rate would be required to avoid the effects of aliasing. Although the final design for the testing rig (discussed in Secion 3.4) will not produce such high frequency levels, our faculty advisor, Dr. Kumar, has informed us that the AME facility has accelerometers that meet this requirement on hand. At this time, we foresee no need for an anti-aliasing filter, given the correct accelerometers being available for use. However after preliminary tests and data analysis, it may become necessary in order to obtain the correct signal data. The electrical components necessary for this build also include a DAQ system. Within the data acquisition system there are several components which we have been informed are available for use at the AME Low Speed Wind Tunnel facility [8] and include some signal processing and capturing equipment.

Computing:

MATLab, LabView, Creo Parametric, and Creo Simulate will be used throughout our project to assist in data processing and testing design. Our sponsor, Mr. Wells, explicitly requested the use of MATLab for producing the SRS curves, which has become an added constraint. Many MATLAB codes for data conversion to SRS curves are readily available online, but will be tailored to our specific needs. LabView is a widely used data acquisition software package that is relatively simple to configure with basic knowledge. We have confirmed that we will be able to make use of the available LabView licensing already loaded onto the College of Engineering lab computers. PTC Creo Parametric will be used to develop solid models of the individual components. These component drawings will be used in the machining of the test rig. When the parts and the assembly are finalized, our testing will be modeled using the test fixture part in Creo Simulate. PTC Creo's multi-faceted tool will prove to be very useful when tailoring the responses of individual components and aide in identifying the natural frequency for the system as a whole. The natural frequency of the system is very important when testing because it differs from the natural frequency of each individual component and must be considered in the modeling calculations for our final resulting SRS curve.

3.2 Design Concepts

In order to evaluate the different options, our decision will be based on accuracy, durability, assembly, adaptability, and cost. Certain parameters, namely the accuracy, may be affected by more than just the shock generating apparatus itself. For example, the sensors used play a huge role in determining the final accuracy and precision of measurements.

Design 1: Shock Tube

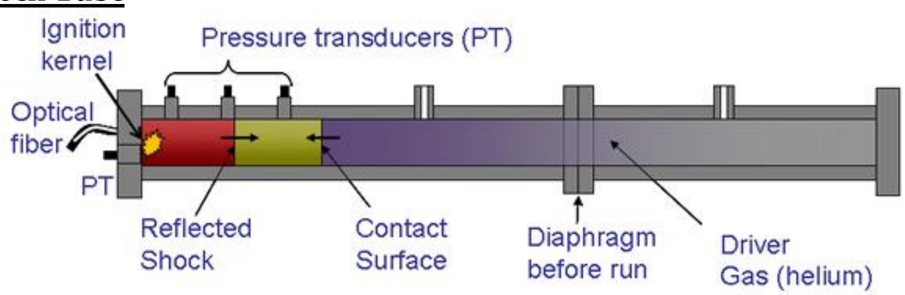

Fig. 1 - Simple schematic of a shock tube [10]

Fig. 1 depicts the cross section of shock tube used for shock testing.

Accuracy: Due to the very controllable nature of shock tube testing, it is capable of high accuracy values. This comes at higher costs, however, and relies heavily on initial investment. It is more than capable of creating the necessary shock strengths required for this project's testing. The drawbacks, however, arise from the shock tube's additional parameters that must be controlled in order to maintain high accuracy and efficiency during testing. Because shock tubes use pressurized gas regions, one high pressure area blocked by a diaphragm leading to the long directional low pressure region, it becomes very important to consider higher level gas dynamics and their interaction with the flow's enthalpy and compressibility[8]. As Harris Corporation is not concerned in this project with these additional flow conditions, it simply adds complexities at no real task value.
Durability: Shock tubes, after the initial investment, are sturdy and experience little degradation due to testing. There is, however, losses to the burst discs or diaphragm after every test that must be considered.
Assembly: Assembly of a shock tube, including pre-testing pressurization, loading of a burst disc, control of initial conditions in the two pressure regions, can be a complex process.
Adaptability: Although the added variables to consider make shock tubes harder to setup for testing, they do offer a wide scope of possibilities that make it a very adaptable method.
Cost: Shock tubes are large construction and require many different variable controllers from pressure to temperature pretest to the chosen materials and scoring of the burst discs or other valve features. Therefore, they tend to be a sizable initial, with the added downside of having sacrificial parts for each testing.
Adaptability: When considering the adaptability of a shock tube it requires quite a different mount, as well as much different parameters in the post-test mode (enthalpy and compressibility considerations). This makes the shock tube setup less physically adaptable should changes need to be considered after preliminary tests. The shock tube setup is also quite large as compared to a pneumatic cylinder and does not offer the ability to change individual parts in order to better tailor the test. For this reason, the adaptability score is low.

Design 2: Drop Table

Fig. 2 - Example of a drop table [12]

Fig 2 depicts a drop table.
Accuracy: The drop table test is an effective way to simulate pyrotechnic shock by dropping platform holding the test specimen in a controlled release to remain as close to one dimensional as possible. It also has the added benefit of generating shocks that distribute in a pattern more closely resembling that which would be felt by pyrotechnic shockwaves across an area. The primary drawback for drop tables is that they yield overly conservative results [2].
Durability: Drop testing apparatus has to be durable by nature, but will also require the method of holding the test specimen in place to be tough enough to withstand the same forces used for testing multiple times over.
Assembly: The assembly of a drop table test is quite simple to fabricate, as it relies heavily on gravitational forces and free falling governing equations.
Cost: The drop table testing setup is simple enough to be a cheap construction, with most of the monetary investment going toward quality strength materials to ensure repeated use does not wear down the guiding arms or table and end up skewing the results.
Adaptability: If the table top holding the test apparatus is built large enough, then it is a very versatile method of testing as it can hold many different sizes and weights of test specimen. The test can then be adjusted again to find the same levels of desired shocks just by adding or subtracting initial values such as weights and height dropped.

Design 3: Air/Hydraulic Hammer

Fig. 3 - Airtec pneumatic piston/cylinder with attached valve [9]

Fig 3 depicts a pneumatic piston used for shock testing.
Accuracy: Using a pneumatic hammer is an efficient way to test differing levels of shock generated by striking a panel with a test subject secured to the other side. Because the force imparted to the panel can be controlled through either air pressure or other means of linear actuation, it can consistently provide accurate shock generation for data acquisition.
Durability: The durability of a pneumatic hammer testing setup is highly dependent on the frame and support structures and since it is using direct force application to generate shocks, material selection is also a primary factor. In our testing, however, the forces generated should not be so large as to cause great concern for the wearing of a hammer head for example. Also, if pressurized air is used to generate the driving force, pressure containment also becomes an issue.
Assembly: Creating a testing scenario for using a pneumatic hammer is relatively easy, requiring only a secure holding mechanism for the hammer and the test specimen to be effective.

Cost: Pneumatic hammers are generally inexpensive with respect to our allotted budget, and will work well without needing much more than the initial investment to purchase one that fits the required specifications.
Adaptability: Due to the impact location and size being controllable by changing out the mass and shape of the striking face, the pneumatic hammer setup is very adaptable to different testing requirements. It also is useful for finding the effects of using theses controllable variables to generate different shock responses.

Design 4: Kinetic Hammer

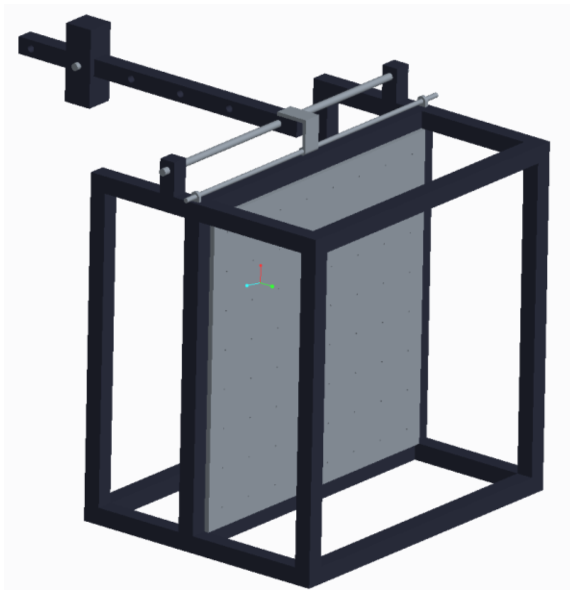

Fig. 4 - CAD solid model of our kinetic hammer apparatus

Fig 4 shows a kinetic hammer variation of shock testing.
Accuracy: Due to the crude set up of the drop hammer it does not offer the highest accuracy out of the available test methods. User controlled setting and release of the hammer introduces additional variables that may affect the returned results. While this human interaction with the machine will affect results it will not play a large enough role to deter it from being used to generate baseline shock generation results. The main issue is the repeatability of the test. The machine must be set up in a way that it can be returned to the same position for each test and offer the same results. This precision is of the machine that must be optimized.
Durability: The durability of the kinetic hammer is dependent on the frame structure and test fixture. The forces generated for our test will be scaled down for the kinetic hammer test. With this in mind the steel structure of the test apparatus should be fully capable of withstanding the repeated tests without any fear of failure.
Assembly: The assembly of a kinetic hammer is relatively simple to produce. The hammer will be operated relying on gravity, and be governed by pendulum equations. The only additional requirement is a frame that will hold the test fixture onto which the hammer can be mounted.
Cost: The kinetic hammer is the cheapest test apparatus to create. The entire structure, hammer, and test plate will be made of steel and aluminum.
Adaptability: There are many interchangeable aspects to the kinetic hammer. After baseline testing, the shape, weight, and size of the hammer can all be adjusted to tailor results. Additionally

testing can be done with different test fixtures. This use of multiple controllable variables will provide for a test that can be fine-tuned for results.

3.3 Evaluation of Designs

The issues arising from Harris' current test apparatus is the need for trial and error. This can be due in fact to lack of a procedure in their test or an inaccurate test apparatus. With this in mind we must choose which test apparatus we would like to test with so we can move forward. The selection will be between an air or pneumatic hammer, drop table, or shock tube. Our decision will be based on accuracy, durability, assembly, cost, and adaptability. Each apparatus is rated on a scale of one to five on their performance in each area. One represents the worst where five represents the best. Total scores are calculated by multiplying the performance factor by the weight factor. The weight factor indicates the importance of each of our criteria compared in our matrix.

3.3.1 Selection Method and Criteria

Our selection method involved discussing and researching the different methods of administering the impact. Accuracy is the highest weighted criteria as it is most important both to our sponsors and our team. Accuracy is the reason this project was brought to our team and involves the ability to repeat tests and achieve the same results. Durability represents the ability for a device to perform multiple tests with little to no maintenance necessary in order to ensure repeatable tests, as well as prolong the overall life of the testing machine. Durability on this small scale is not our biggest concern, we want something that will last through our small scale testing and can later be adapted in large scale to prolong the life of the machine. Assembly is of moderate importance to us, as we are still sourcing parts. The possibility of an in-house build is priority, therefore we have to make sure it is something we are capable of constructing. Adaptability is our need to adapt the apparatus to achieve our desired output. Since we would like to use a standalone structure that will house the different components of the design, adaptability is retained in the essence that the force generation method can be changed, either slightly or completely, should we need to go that route after preliminary testing. In addition the test plate we've elected to use allows for shifting of the mass location or addition of damping to different locations in order to modify the response. Our final criteria is cost, we have a finite budget we are working with so we must make sure our apparatus is cost efficient, and does not utilize our entire budget lest we need the funds for another aspect of testing or design.

3.3.2 Selection

Based on our decision matrix in Table 4, the kinetic hammer achieved the highest scores. This design represents the best overall testing package for this portion of the project scope based upon our research and brainstorming sessions. As previously stated the drop table tends to over test the specimen, and the shock tube also tests thermal properties; both of these are undesirable situations. It is for these reasons we have ruled these two apparatus' out due to their less than sufficient means of generating a controlled shock. We have moved forward with the design of a kinetic hammer apparatus for testing with the goal to design an apparatus that we can operate using alternative methods such as adding an air hammer, if timing and budget allows. This serves to give us a concrete design goal that can be modified after preliminary testing (or in the following year of project scope) if the initial results are inadequate. In addition, the ability to modify the setup easily will present an added bonus to its usability.

Table 4- Weighted decision matrix for testing method

Apparatus	Accuracy	Durability	Assembly	Cost	Adaptability	Total
Air/Pneumatic Hammer	4	4	2	2	4	3.4
Kinetic Hammer	3	4	4	4	4	3.7
Drop Table	2	2	4	3	2	2.4
Shock Tube	1	5	5	3	2	2.5
Weight Factor	*0.3*	*0.1*	*0.1*	*0.2*	*0.3*	

3.4 Final Design

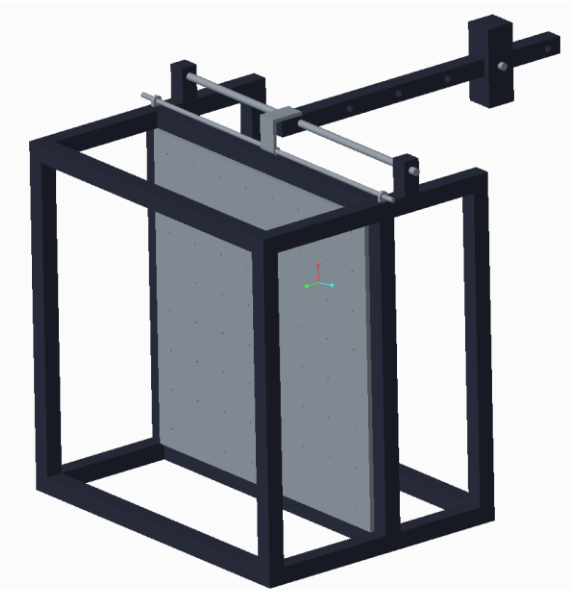

Fig. 5 - Final design in CAD utilizing a swing hammer

As the decision matrix in Table 4 above shows, our final design will make use of a kinetic hammer as the shock generator. The advantages of this design stem from both its simplicity, cost, and adaptability. The simple kinetic hammer allows for quick and easy test set up, while affording many different possibilities for test variations. These variations include changing the hammer dimensions, the impact location, the weight of the hammer, the response characteristics of the fixture plate, and many more as shown in Fig 5. In order to keep the test repeatable we will be limiting the variables that are modified while reserving the ability to modify almost any facet of this design in the future. The materials discussed previously to build this rig are fairly inexpensive and machining friendly to allow for versatility in the future should design changes be required. The largest benefit of our design lies within the schools local machine shop being able to perform the majority, if not all, of the required fabrication.

4 Risk and Reliability Assessment

There is inherent risk going forward in the initial design of the swing hammer. Although our sponsor has approved and advised the method of using a hammer impact, a significant cost is still incurred in material purchase and assembly; additionally, it is difficult to predict the degree of adaptability of the design will be given the loose constraints of the testing application. A preliminary physical model is not possible and jumping straight into constructing the design brings risk, yet the risk has been significantly lowered moving the planned design from the pneumatic hammer due to the cost of the pneumatic hammer alone. Nevertheless, a hammer test remains the mainstay of simulated pyro-shock testing.

While the danger of testing with actual pyrotechnics is an obvious danger, simulating with a hammer swing can also present a danger. Care will need to be taken in preparing the test setup for a swing as the hammer has a significant amount of energy to cause injury. Noise is also a factor and cannot be mitigated, so the team will need to take this into consideration when testing the setup

The financial risk is also seriously reduced due to the team’s ability to leverage the school resources. We will have access to accelerometers and any additional data acquisition equipment needed for accurate data recording from the FSU Aero-Propulsion, Mechatronics, and Energy (AME) facility. This will give us much needed preliminary data to refine the experimental model without incurring the cost of an accelerometer or data acquisition equipment. This will substantially lower the cost of the setup, as an accelerometer and equipment can be purchased later on.

In terms of reliability an attempt was made to quantify any possible failure points, and their associated rate of failure. We examined the components individually and together as a whole and found seven points of concern. The most obvious possibility of failure comes from the point of impact (hammer to plate contact). The least obvious would likely be the pivot points for the quick release and the hammer arm.

A failure mode effect analysis was performed on the points of concern and can be found below in table 5. Here, an attempt to quantify the possibility of component failure is tabulated for review. The team has realized the most likely source of failure is in the pivot rod for the hammer arm, and this can be combatted by both pre-test and post-test inspections as well as pre-test dynamics calculations.

The possibility for injury is present, however it is minimized by using safe practices as well as a quick release mechanism with a pull cord long enough to allow the test administrator to be out of any danger. Most, if not all, of our failure modes are easily avoidable and easily monitored.

Table 5 - FMEA Table for risk analysis

Input	Failure Mode	Failure Effects	SEV	Poss. Cause	OCC	Controls	DET	RPN	Action
Hammer	fracture	partial force generation, delay in future testing	6	inadequate material	1	pre/post test inspection, material selection	9	54	replacement-new material
Hammer arm	bending, fracture	partial force generation, delay in future testing	6	off center	1	pre/post test inspection, material selection	9	54	replacement-larger diameter
Arm pivot	bending, fracture	delay in testing, skewed results	6	cyclical fatigue	3	pre/post test inspection, material selection	6	108	replacement-new material
Quick release	premature or failure to release	no results, injury if premature	5	cyclical fatigue	3	pre/post test inspection, material selection	7	105	replacement-redesign
Mount size	sliding, rolling	partial force generation, damage to components, injury	7	incorrect size	2	pre/post test inspection, material selection	3	42	modification/replacement
Fixture plate	bending, fracture	skewed results, delay in testing, damage to accelerometer	7	off center	1	pre/post test inspection, material selection	4	28	replacement-new material/size

5 Methodology

The methodology of our project is best outlined in our project task list, showed in Appendix 1. The project is broken down into summaries, or containers that are descriptive of the tasks required in that area of the project. The primary two summaries are (1) Design and (2) Prototyping.

The design container consists of background, specifications, brainstorming, scheduling, project plan, development, modeling, and reporting. Within each of these containers are specific tasks to be accomplished in order to complete the associated summary task. Once all of these summaries are completed, the design phase will be finished and the prototyping phase may begin.

When it comes to programming a model to accurately display the results of each test, MATLab will be used. The particular method used in our approach requires a substantial impact to be made, causing a shock in the form of an acceleration vs. time data plot or table. Using this information and modeling the system as a single degree of freedom dynamic system will result in the ability to plot the desired SRS curve.

The generation of a Shock Response Spectrum is limited in that that input data measured is not continuous. As noted previously a sufficient sampling rate from an accelerometer will be required for accurate data that will not be continuous in nature. Tumi and Koci have recommended an approach, based from the ISO 18431-4 standard for shock testing, to discretize the analytical methods of modeling the single degree of freedom oscillators to theorize a structures' response to a specified shock [16]. A signal analysis software would be ideal to deal with the high frequency sampling of the input acceleration data. However, MATlab is easily available and the users are most familiar with its operation. Also MATlab is the program of choice in technical computation within Harris Corp.

To achieve a desired SRS, a systematic approach to analyzing the input data is needed. Simulated models in the approach can be used, yet to contribute their effects to the response of the system, they will need to be analyzed in the frequency domain. Creo Parametric offers simplified modal analysis that can be used to model the fixture. The results of this model can be transformed to the frequency domain using the Fast Fourier Transform (FFT). A Frequency Response Function (FRF) can then be used to calculate the response. Work by Aizawa and Avitabile have shown this to be a reliable method [17].

For the physical model, the raw acceleration data measured can be pre filtered to avoid error in acquisition as noted previously. Smallwood has found a recursive formula method that minimizes the errors brought about by an insufficient sampling rate [18]. This method can then be used to calculate a SRS from the measured raw data. Fig 6 shows the flow of data in the creation of the SRS curve.

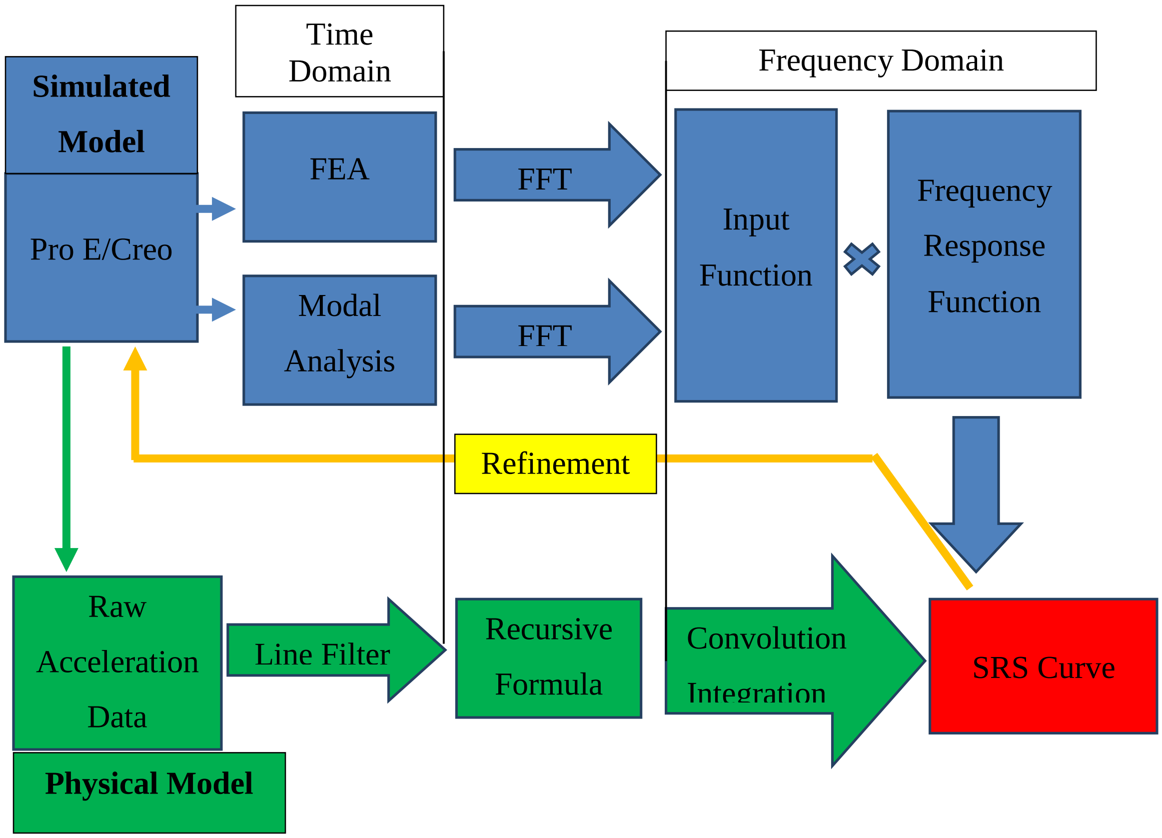

Fig. 6- Flowchart depicting the methods of data processing

5.1 Schedule

The schedule for this team project can be found in Appendix 2. This schedule should be considered tentative after the end of 2014, as it is very difficult to predict project modifications that far into the future. Up until the end of 2014, the schedule is mostly concrete with the exception of presentation dates that are subject to availability. In addition, tasks may be shuffled around within their respective summary containers based on the availability of personnel and resources.

5.2 Resource Allocation

Resource allocation was broken down to each team member and their elected and assigned tasks. These allocations can also be seen in the project task list shown in Appendix 1. Many tasks require all team members to contribute; these are indicated with "All" in the resource column. In addition, any tasks requiring our *Sponsor* - Mr. Wells, *Advisor* - Dr. Kumar, or *Professors* - Dr. Gupta & Dr. Helzer, are labeled as such.

Aside from personnel, considerations must now be taken for budget allocation. Table 6 below tabulates projected costs for materials required in this build that will be used in the fabrication of the testing rig. While we believe this to inclusive of all materials necessary to build the test apparatus, changes on-the-fly may be made if they are deemed related to safety, accuracy, or durability and to preserve the fidelity of the testing process.

5.3 Procurement

The purchase orders for the following material will be submitted by end of day on 12-8-14. This should allow for processing time and shipping to be done over school's winter break. With procurement done before break we should be able to begin work building our test apparatus as soon as the spring semester begins. The total cost of the raw materials is under a fourth of our allotted budget, this will give us flexibility for potential adaptations or changes to the test rig design once initial testing has been completed. This will also allow us to change our parameters throughout testing without fear of going over budget.

Table 6 – Test build raw materials and costs

Item	Description	Unit Price	Quantity	Total	Source		
Steel Tube	1.75"x1.75"x24' 14ga	$54	2	$108	md		
	A513 Steel						
Steel Bar	1.75"x1.75"x4' 14ga	$20	1	$20	md		
	A513 Steel						
Test Plate	32"x32"x0.19"	$184.69	1	$185	md		
	al6061						
Hammer	3"x3"x24"	$137.70	1	$138	md		
	A-36 hot rolled						
Sacrificial plate	1'x1'x0.19"	$23.16	1	$23	md		
	al6061						
Mounting	2'x2'x3/8"	$97.20	1	$97	md		
	A36 steel						
Threaded rod	1/2-20x6'	$25.95	1	$26	grainger	item number	4FGZ5
	carbon steel						
Threaded rod	3/4-16x6'	$59.70	1	$60	grainger	item number	4RDE7
	carbon steel						
Nuts	1/2-20	$10.09	1	$10	grainger	item number	2FY43
	package of 50						
Nuts	3/4-16	$12.43	1	$12	grainger	item number	2FY55
	package of 20						
Machine Screw	1/4-20x3/4"	$25.25	1	$25	grainger	item number	5JB65
	package of 100						
			Total	**$704**			

5.4 Future Plans

The goal in the spring is to complete the building of the test rig as quickly and accurately as possible to allow for testing to begin. One major reason for this is to allow us more time to gain knowledge and experience with the available data acquisition systems at the school that we will be using. Our team is comprised entirely of undergraduate mechanical engineers, so learning to efficiently set up and run our tests will require both extra time spent with our own amount of trial and error and enlisting the help of more experienced students and school faculty. Additionally, we plan to schedule regular teleconference meetings with Harris Corp. to seek continuous feedback and maintain a clear direction. This will also serve to target our efforts towards a specific goal.

Another potential challenge that may arise after the building of the rig is developing and using the MATLAB code necessary to take our testing data and transform it into the required SRS curves the our project goal needs. Additionally, further steps will be taken to model the shock testing fixture in Creo Simulate to assist in the setting of test parameters. The development of these codes and models does not require the rig to begin, however, so the work on the software component of our project will be ongoing at the beginning of the spring semester. Once the rig is built, our current testing method is as follows:

Step 1) Evaluate the test plate alone
Step 2) Determine viable testing parameters through modeling
Step 3) Systematically isolate test variables
Step 4) Analyze resulting SRS curves
Step 5) Tabulate test results
Step 6) Refine test method
Step 7) Confirm results with computer models

The goal of step 5 is to ease the burden on the second year of this project by providing well documented testing results that can be used to seek correlations between the testing parameters and develop better testing methods. We will be conducting this testing in a school facility, the Aero-propulsion, Mechatronics, and Energy (AME) building, which has a low-speed wind tunnel that has enough space to set up our testing and easy access to a computer set up for our data acquisition.

6 Conclusion

Because pyrotechnic shocks are highly transient and difficult to analytically model, an experimental method must also be employed. Generating shock levels of equivalent magnitude to Harris' testing is no longer required, as instead the focus will be on finding ways to impart adaptability to the shock testing procedure and seek correlations between varying different testing parameters and the resultant effect on SRS curves. To accomplish this, a simple test rig using a kinetic swing hammer was designed and the materials found to adequately fulfill the testing requirements. The focal points of this project in the spring will be manufacturing and assembly, supply acquisition, data acquisition systems, and data modeling.

Some major challenges the team will face in the spring will be growing accustomed to data acquisition and signal processing, as well as efficient modeling using computer software to generate SRS curves from raw testing data. In order to help ease this learning curve, extensive communication with faculty advisor Dr. Kumar, Harris sponsors, and graduate students will be sought. Once the test rig is built, simple testing will be conducted first to confirm predictions based on modeling and establish a good understanding of the test fixture's response to shock impulses. From there, further testing of the effects of changing isolated variables can be completed and the results documented.

7 References

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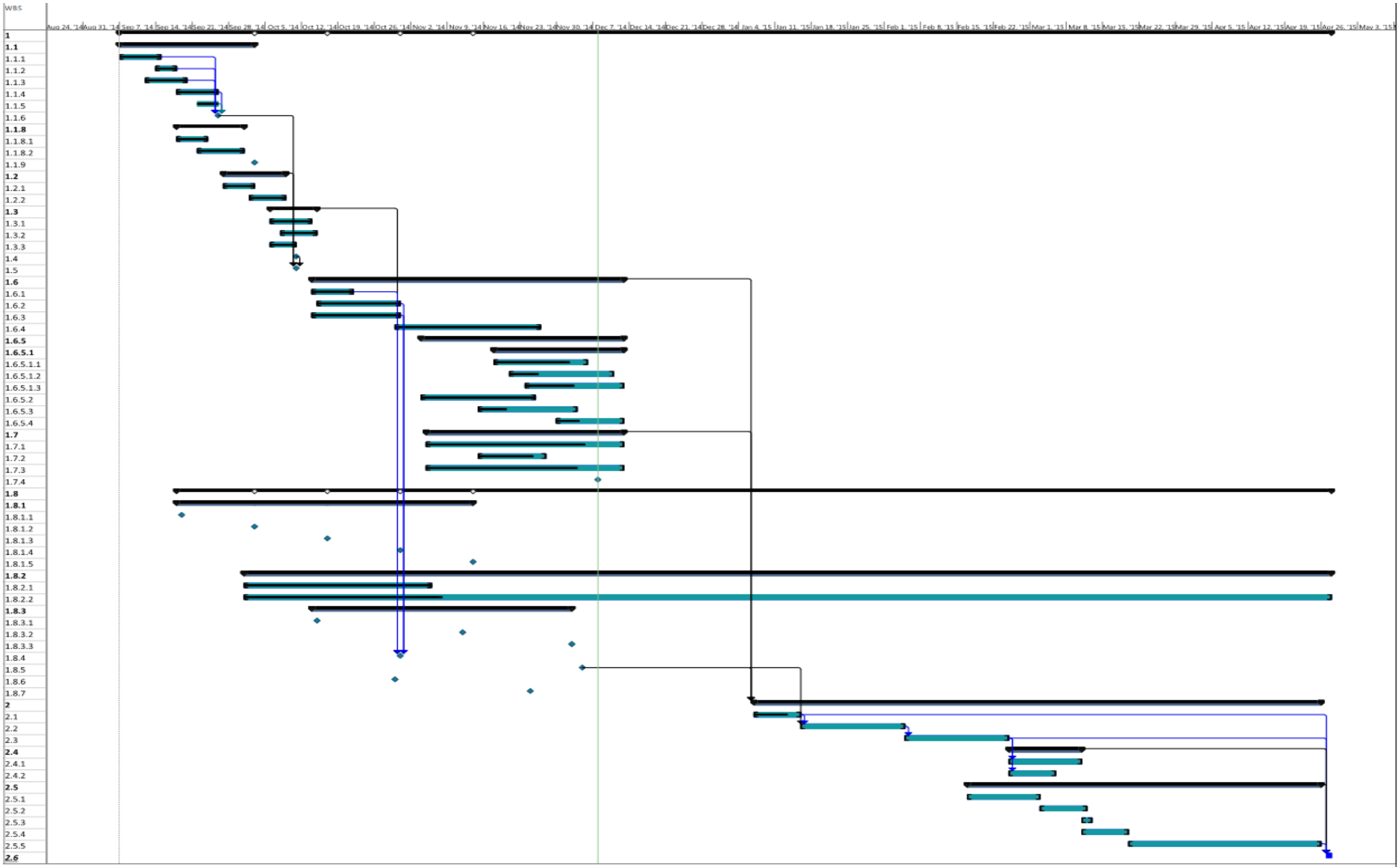
8 Appendix 1 (Task List)

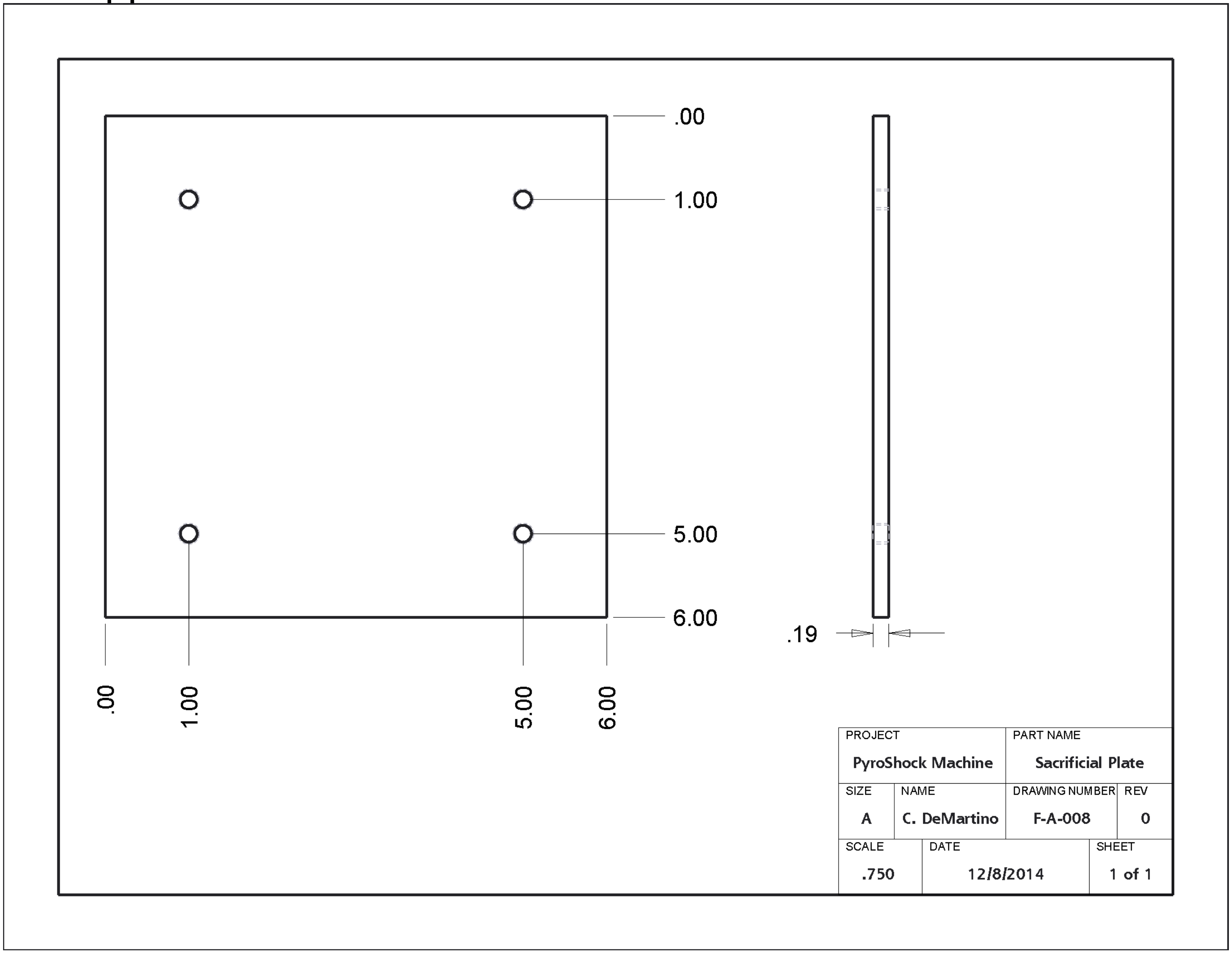
WBS	Task Name	Duration	Start	Finish	Resource Names	% Complete
1	**Design**	**166 days**	**9/7/14**	**4/27/15**	**All**	**62%**
1.1	**Background**	**20 days**	**9/7/14**	**10/2/14**	**All**	**100%**
1.1.1	SRS Pulses	7 days	9/7/14	9/14/14	Chase,Chad,Sponsor	100%
1.1.2	Standards	4 days	9/14/14	9/17/14	Charles,Nathan,Sponsor	100%
1.1.3	Resonance	6 days	9/12/14	9/19/14	All	100%
1.1.4	Tuning (SDM)	6 days	9/18/14	9/25/14	Charles,Chase	100%
1.1.5	Current Methods	4 days	9/22/14	9/25/14	All	100%
1.1.6	Needs Assessment	0 days	9/26/14	9/26/14	All	100%
1.1.8	**Modeling**	**9 days**	**9/18/14**	**9/30/14**	**All**	**100%**
1.1.8.1	Analytical (Computer)	5 days	9/18/14	9/23/14	Charles,Nathan	100%
1.1.8.2	Experimental (D.A.Q.)	7 days	9/22/14	9/30/14	Chad,Chase	100%
1.1.9	Code Of Conduct	0 days	10/3/14	10/3/14	All	100%
1.2	**Specifications**	**9 days**	**9/27/14**	**10/8/14**		**100%**
1.2.1	Design Specs	5 days	9/27/14	10/2/14	Chad,Nathan	100%
1.2.2	Performance Specs	5 days	10/2/14	10/8/14	Chad,Nathan	100%
1.3	**Brainstorming**	**7 days**	**10/6/14**	**10/14/14**		**100%**
1.3.1	Apparatus Builds	7 days	10/6/14	10/13/14	Chase,Nathan	100%
1.3.2	Measurement Methods	6 days	10/8/14	10/14/14	Chase	100%
1.3.3	Programming	5 days	10/6/14	10/10/14	Charles,Chase	100%
1.4	Initial Schedule	5 days	10/6/14	10/10/14	Charles	100%
1.5	Project Plan	0 days	10/10/14	10/10/14	All	100%
1.6	**Development**	**44 days**	**10/14/14**	**12/12/14**		**72%**
1.6.1	Dimension & Physical setup	6 days	10/14/14	10/21/14	Charles	100%
1.6.2	Test Apparatus Selection	12 days	10/15/14	10/30/14	All	100%
1.6.3	Material Selection	13 days	10/14/14	10/30/14	All	100%
1.6.4	Preliminary CAD Drawings	20 days	10/30/14	11/26/14	Charles,Nathan	100%
1.6.5	**Modeling**	**29 days**	**11/4/14**	**12/12/14**		**54%**
1.6.5.1	**FEM Modeling**	**19 days**	**11/18/14**	**12/12/14**		**49%**
1.6.5.1.1	Structural Simulations	14 days	11/18/14	12/5/14	Charles,Nathan	75%
1.6.5.1.2	Modal Simulations	14 days	11/21/14	12/10/14	Chase	25%
1.6.5.1.3	Frequency Domain Simulations	15 days	11/24/14	12/12/14	Chad	48%
1.6.5.2	Force Generation	16 days	11/4/14	11/25/14	All	100%
1.6.5.3	Response Spectrum Generation	14 days	11/15/14	12/3/14		30%
1.6.5.4	Program Development	11 days	11/30/14	12/12/14		38%
1.7	**Procurement**	**28 days**	**11/5/14**	**12/12/14**		**77%**
1.7.1	Raw Materials	28 days	11/5/14	12/12/14		80%
1.7.2	D.A.Q	10 days	11/15/14	11/27/14		75%
1.7.3	Specialty Parts	28 days	11/5/14	12/12/14		75%
1.7.4	Submit Purchase Orders	0 days	12/8/14	12/8/14		100%

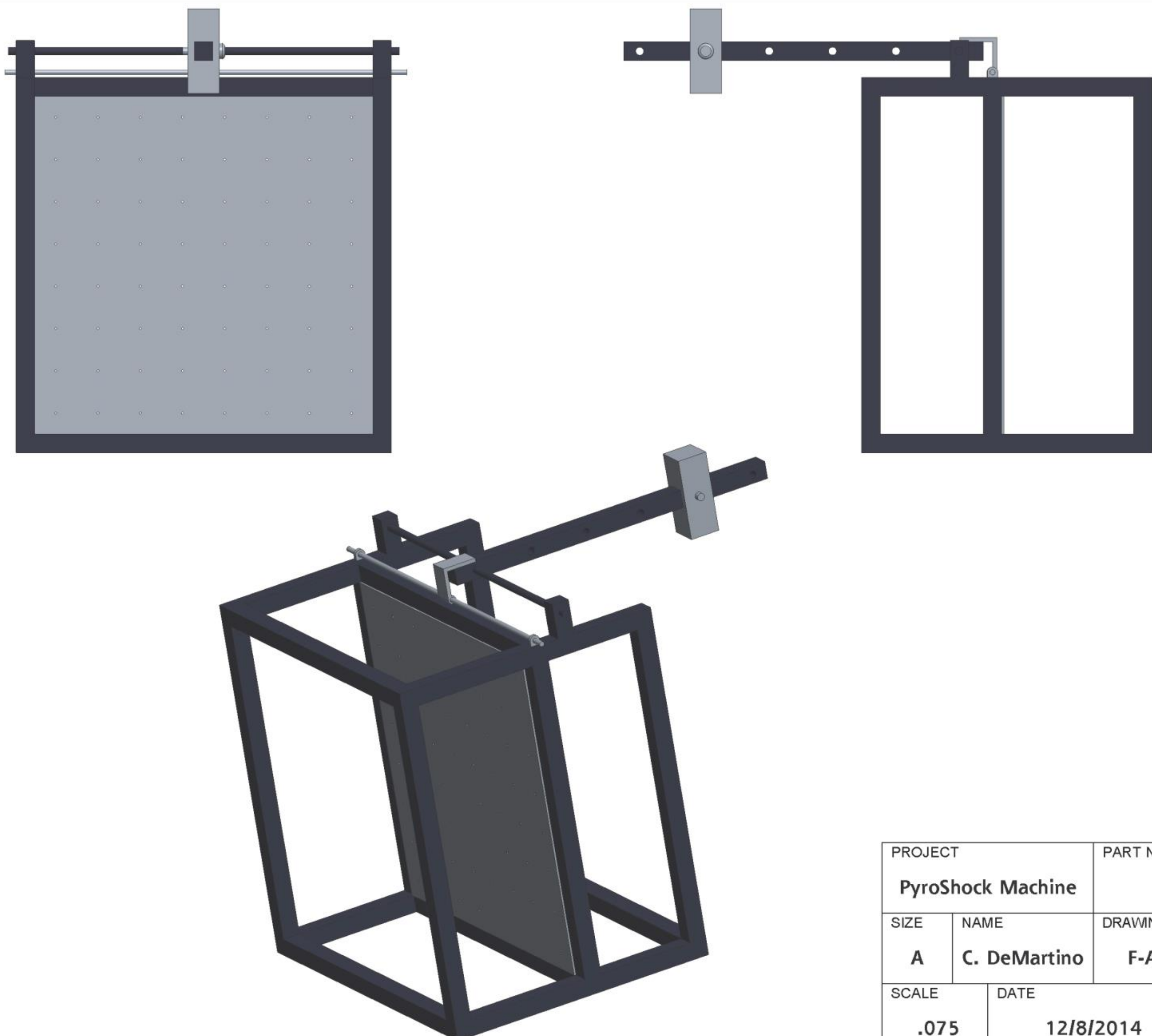
1.8	**Reporting**	**158 days**	**9/18/14**	**4/27/15**		**34%**
1.8.1	**Staff Meetings**	**41 days**	**9/18/14**	**11/13/14**	**All**	**99%**
1.8.1.1	Staff Meeting 1	1 day	9/18/14	9/18/14		100%
1.8.1.2	Staff Meeting 2	1 day	10/2/14	10/2/14		100%
1.8.1.3	Staff Meeting 3	1 day	10/16/14	10/16/14		100%
1.8.1.4	Staff Meeting 4	1 day	10/30/14	10/30/14		100%
1.8.1.5	Staff Meeting 5	1 day	11/13/14	11/13/14		100%
1.8.2	**Website**	**149 days**	**10/1/14**	**4/27/15**	**Nathan**	**31%**
1.8.2.1	Initial Design	26 days	10/1/14	11/5/14		100%
1.8.2.2	Final Design	149 days	10/1/14	4/27/15		19%
1.8.3	**Presentations**	**36 days**	**10/14/14**	**12/2/14**		**100%**
1.8.3.1	Midterm I Presentation	1 day	10/14/14	10/14/14	Charles,Nathan	100%
1.8.3.2	Midterm II Presenation	1 day	11/11/14	11/11/14	Chad,Chase	100%
1.8.3.3	Final Presentation	1 day	12/2/14	12/2/14	All	100%
1.8.4	Midterm Report	0 days	10/31/14	10/31/14	All	100%
1.8.5	Final Report	0 days	12/5/14	12/5/14	All	100%
1.8.6	Peer Evaluation I	0 days	10/30/14	10/30/14	All	100%
1.8.7	Peer Evaluation II	0 days	11/25/14	11/25/14	All	100%
2	**Prototyping**	**79 days**	**1/7/15**	**4/25/15**	**All**	**4%**
2.1	Finalize CAD Model Drawings	7 days	1/7/15	1/15/15	Charles,Chad	60%
2.2	Scale Model	14 days	1/16/15	2/4/15	All	0%
2.3	Preliminary Testing	14 days	2/5/15	2/24/15	All	0%
2.4	**Analytical Methods**	**10 days**	**2/25/15**	**3/10/15**		**0%**
2.4.1	MATLAB Model Refinement	10 days	2/25/15	3/10/15	Chase,Charles	0%
2.4.2	MathCAD Analysis Check	7 days	2/25/15	3/5/15	All	0%
2.5	**Production**	**50 days**	**2/17/15**	**4/25/15**		**0%**
2.5.1	Parts Refinement	10 days	2/17/15	3/2/15		0%
2.5.2	Reassemble Apparatus	7 days	3/3/15	3/11/15		0%
2.5.3	Setup D.A.Q.	2 days	3/11/15	3/12/15		0%
2.5.4	Final Assembly	7 days	3/11/15	3/19/15		0%
2.5.5	Test & Refine	27 days	3/20/15	4/25/15		0%
2.6	***Final Product***	***1 day***	***4/27/15***	***4/27/15***		***0%***

9 Appendix 2 (Gantt Chart)



10 Appendix 3 - CAD Models





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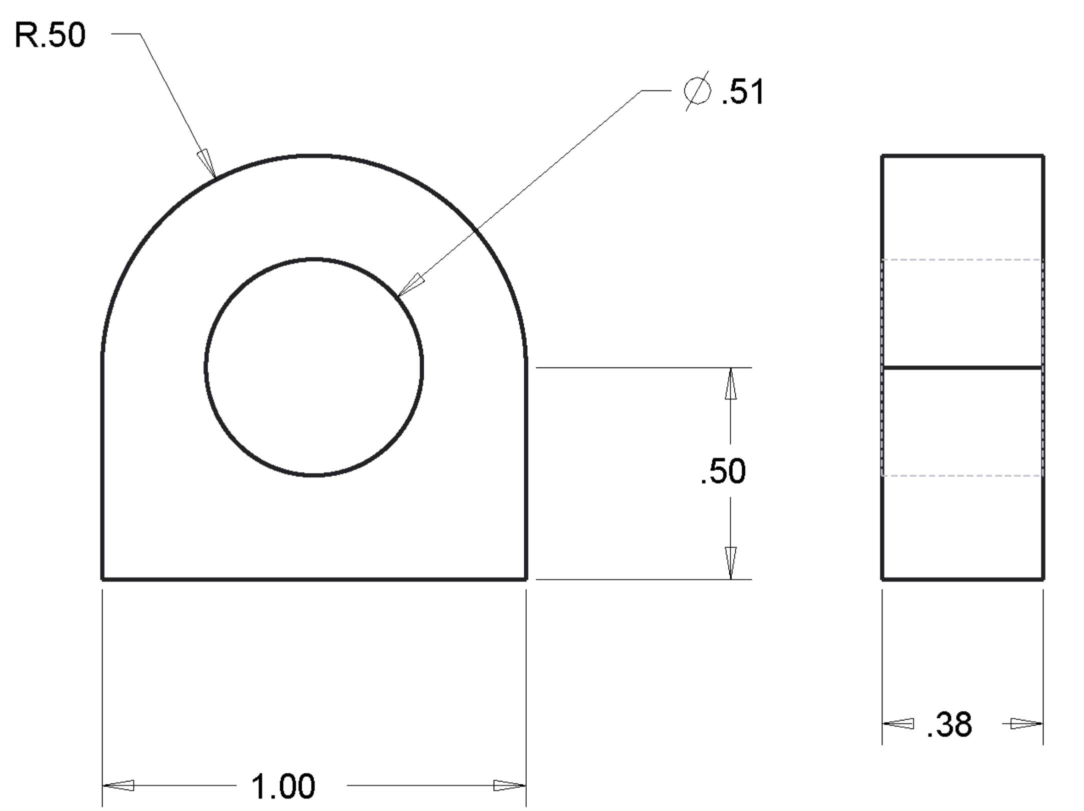

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PyroShock Machine	Quick Release Mount		
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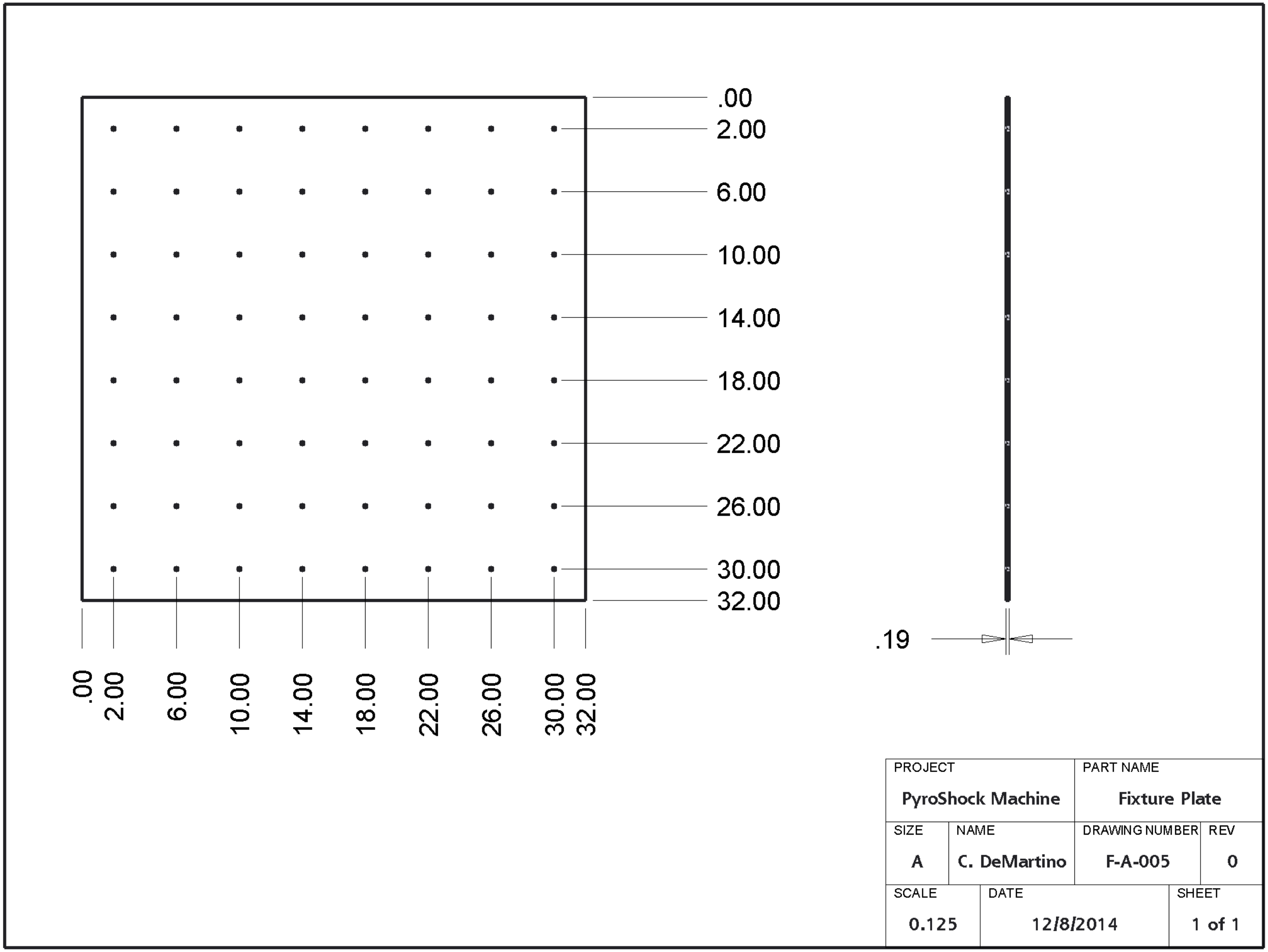
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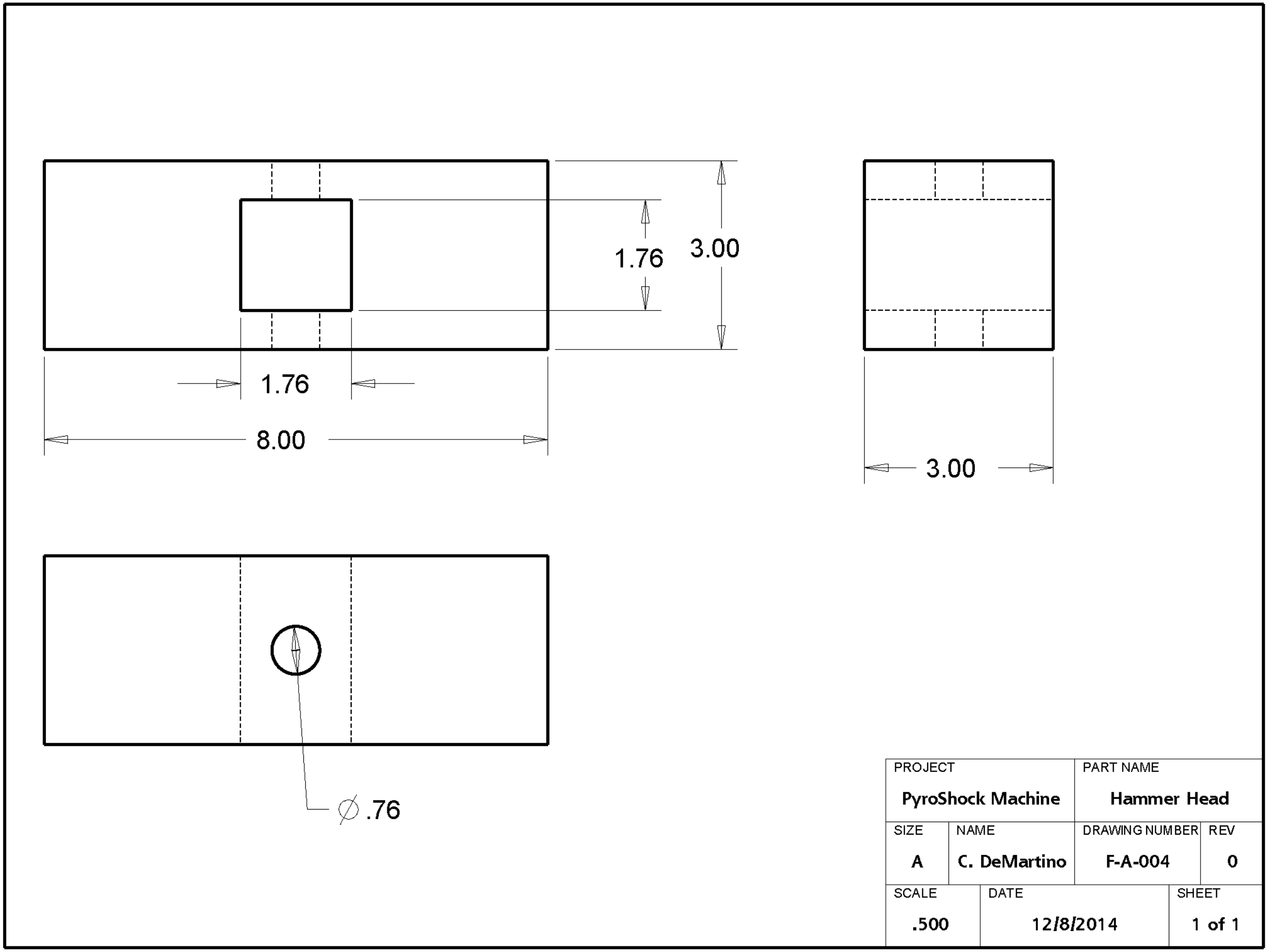
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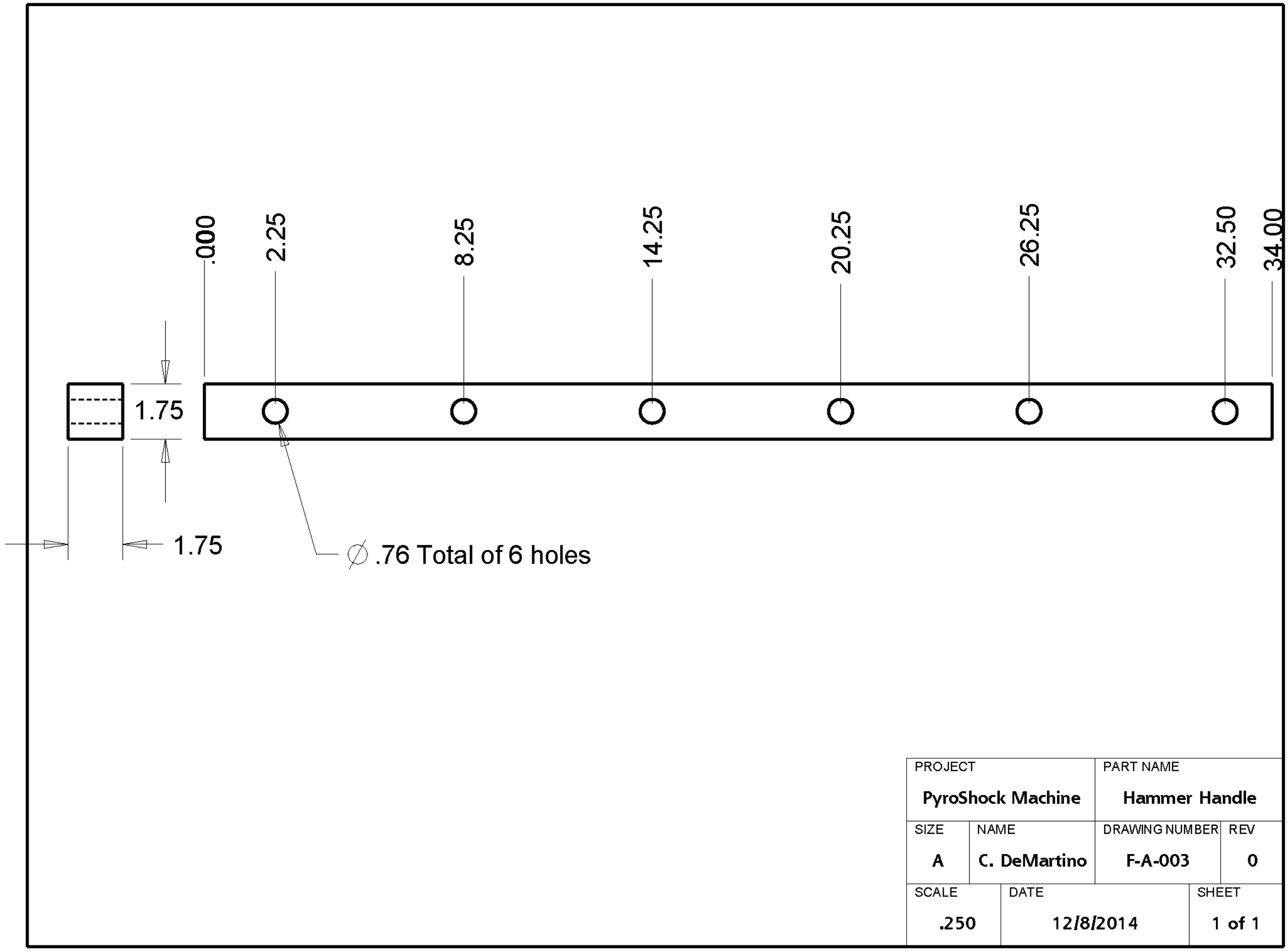
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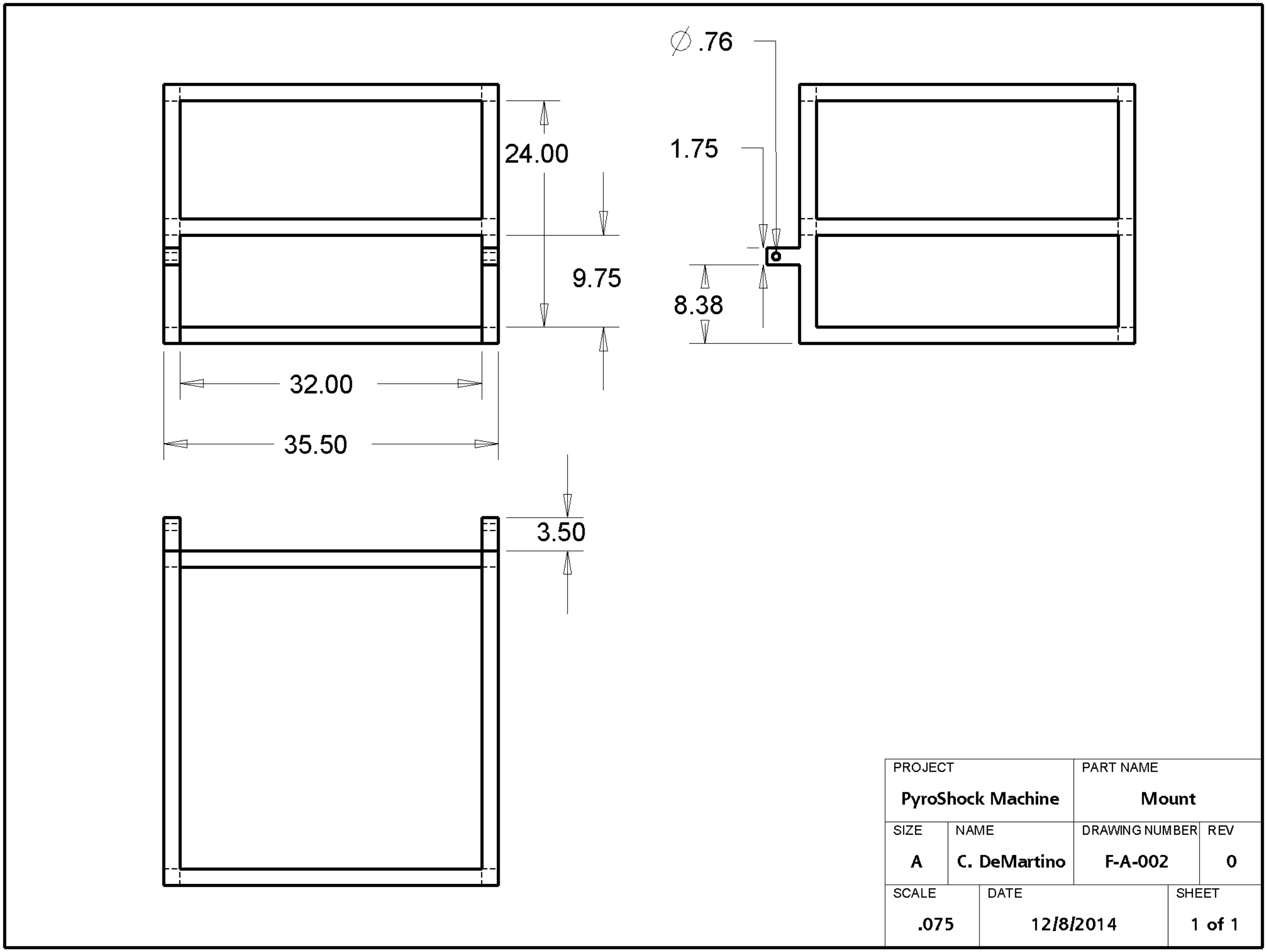
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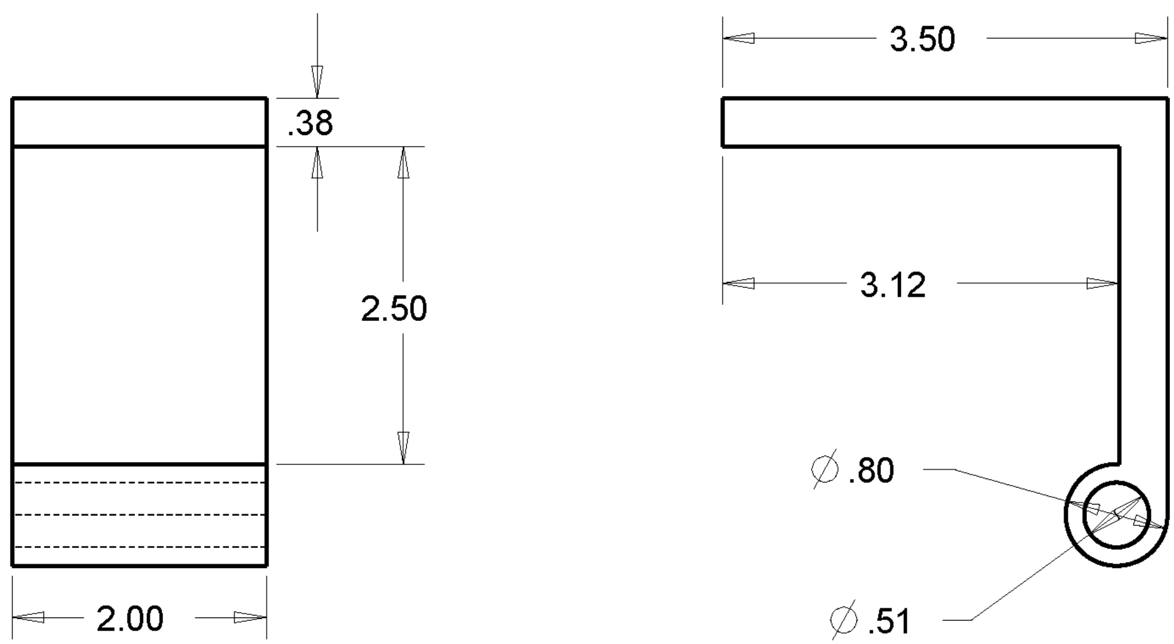
SCALE
.075
DATE
12/8/2014
SHEET
1 of 1



PROJECT		PART NAME	
PyroShock Machine		Quick Release	
SIZE	NAME	DRAWING NUMBER	REV
A	C. DeMartino	F-A-001	0
SCALE	DATE		SHEET
.750	12/8/2014		1 of 1