Impact Testing & Pyrotechnic Shock Modeling

Final Report

Due 4/10/2015 4pm

Written by: Charles DeMartino (cd10h@my.fsu.edu)
Chad Harrell (crh11g@my.fsu.edu)
Chase Mitchell (cwm11@my.fsu.edu)
Nathan Crisler (nrc11b@my.fsu.edu)

Sponsor: Harris Corporation, Mr. Robert Wells, Mr. Giann Cornejo, Ms. Sarah Cooper

Advisors: Dr. Rajan Kumar

Instructors: Dr. Nikhil Gupta, Dr. Chiang Shih

Contents

Table of Figures iii

Table of Tables iv

Abstract i

Acknowledgements ii

Introduction 1

  Need Statement 2

  Objectives 2

  Constraints 3

    Given Requirements 3

    Derived Requirements 3

Background Review 4

Concept Generation 5

  Shock Generation Concepts 5

  Design Evaluation 10

    Selection 10

Final Design 15

Experimental Design 17

  Testing Methods 18

  Results Processing 18

Environmental, Safety, and Ethical Considerations 20

Project Management 21

  Communications 21

  Timeline 21

  Resource Assignment 21

  Critical Tasks 22

  Procurement 23

Conclusion 24

References 25

Appendix A: Gantt Chart 26

Appendix B: Critical Part CAD Drawings 27

Team Bio 31

Table of Figures

Figure 1 - Simple schematic of a shock tube [7] 6
Figure 2 - Example of a drop table [9].......... 7
Figure 3 - Airtec pneumatic piston/cylinder with attached valve [12] 8
Figure 4 - Pendulum shock testing apparatus [10] 9
Figure 5 - First design utilizing a swing hammer.......... 12
Figure 6 - T-slotted aluminum bars and example joint assembly [15] 13
Figure 7 - Second design iteration after T-slot aluminum bars selected 14
Figure 8 - Final design iteration for manufacturing 16
Figure 9 - Flowchart depicting the data transformation process of refining test results.......... 19
Figure 10 - Comparison of damped vs undamped SRS curves.......... 20
Figure 11 - Budget Allocation.......... 23

Table of Tables

Table 1 - Weighted decision matrix for impact method 11
Table 2 - Weighted decision matrix for framing material 12
Table 3 - Material properties considered in test fixture selection [13, 14] 13
Table 4 - Failure Mode Effect Analysis of Physical Test Rig 17
Table 5 - Sensitivity schedule for Dytran 3086A4T accelerometer 19
Table 6 - Bill of materials 24

Abstract

The difficulties and inefficiencies in simulating pyrotechnic shock on varying components was conceived as a capstone project by Harris Corporation. These shocks are quantified by calculating a shock response spectrum (SRS) from the resulting acceleration time history of a shock or simulated shock impulse. After multiple design iterations, Team 15 selected an adjustable swinging hammer setup to simulate shock loadings. The t-slotted aluminum chassis holds a rectangular and tunable plate that is struck by the hammer swing. This impact is realized as an acceleration by a test article and further processed from time history to frequency domain data. Testing of the setup has shown consistency with regards to input and output SRS. The input parameters of interest include: hammer head size, strike location, test article location, plate fixture boundary conditions, and modally tuning the large plate. Specifically the goal is to correlate and identify trends when varying the input parameters and producing SRS curves. This will simplify future testing of pyrotechnic shock at Harris Corporation by providing the documentation and insight needed to achieve specific simulated pyrotechnic shock outputs. The final result will include documentation of the tests performed as well and setup procedures.

Acknowledgements

The work Senior Design 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, Mr. Giann Cornejo, and Ms. Sarah Cooper 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. Additionally we would like to thank the graduate student teaching assistants, Samuel Botero, Ricardo Aleman, and Yuze Liu for their time and advice concerning assignments. We also wish to acknowledge the help we received in the field of data acquisition and setup from Mr. Strike and staff of the FCAAP Polysonic tunnel. Finally, we would like to thank our senior design instructors Dr. Gupta and Dr. Shih for having provided assistance in both project planning, scheduling, and technical communications.

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. The project was extended by our Harris sponsors and Dr. Shih toward the end of the fall semester to two years of senior design work. With this change, the scope of the work to be accomplished over the course of this year was changed to more manageable goals with emphasis on developing a solid understanding of pyrotechnic shock testing, develop working physical and computational models, and create a solid groundwork for the next year's team. Mr. Wells, the Harris sponsor, sent a revised list of expectations for the project pertaining to each year individually [1].

The new scope for the first year involves creating working systems for the two core components of the project: a physical testing rig and computer modeling software. The testing rig will be completed at least through the prototyping phase, with concept refinement and design reviews guiding its creation [2]. The software modeling will be completed using two software packages available at the school, Matlab, PTC Creo, and Abaqus. The team found two reliable ways to use Matlab to process the raw testing data, the Smallwood recursive method and Kelly-Richman method, to generate the desired final form of SRS curves. The Creo Parametric modeling and analysis as well as the Creo Simulate simulations will provide a reference for our initial testing conditions, as well as what results to expect. Both the physical and computer models will employed in feedback loop to better tailor the results. Abaqus is being used to evaluate the modal response of the plate for proper placement stiffening bands to be used as the final variable of interest.

Concerning the first year of the project, over the coming semester the team will construct a 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 the team will adjust variables one at a time to determine the effect of the variable on the test results. While these tests are being done the team will begin programming in MATLab to create a function based off the test results with the goal of creating a program that will analytically model the experimental results 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 shock.

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.

Objectives

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

- ✓ 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
- ✓ Test by varying adjustable fixture parameters
    - o Fixture plate boundary conditions
    - o Test article location
    - o Hammer impact location
    - o Hammer tip shape
    - o Tuning bands
- ✓ Tabulate testing results for future reference

The final two objectives pertain to final testing which has not concluded yet due to delays in assembly. Testing will be done with constant values for all variables in order to determine an accurate baseline result. Once these results have been tabulated the team will adjust variables one at a time to determine the effect of the variable on the test results. Each set of test data from these runs will be processed through a verified MATLAB code which was designed to take raw data and output usable SRS curves.

Constraints

The primary issue faced by Harris is not that the current hammer blow test is repetitive in nature, rather its inherent nature to be time consuming in tailoring test setup for generating the desired pyrotechnic shocks [3]. 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:

Given Requirements

Mr. Wells and his colleagues at Harris Corp. have required some basic requirements for the newly specified project scope [1]. These are smaller scaled from the previous requirements to emphasize the focus on developing correlations between varying the selected parameters and the effects on the resulting SRS curve. These updated requirements are listed below:

- Test article size – up to 8”x 8” x 6”
- Test article weight – up to 10 lbs
- SRS response up to 500g acceleration and 10 kHz
  - Stay within tolerances set by MIL-STD-810 G, Method 517.2, Proc III
- Software allowing varied inputs to predict SRS response
- Accelerometer(s) specs must adhere to Nyquist Sampling Theorem (2.5x minimum)
- Project expenses must stay within allotted budget ($4000)
- Acceleration data acquisition that covers generated force ranges
- Software conversion for raw data to usable SRS curves
- Test measurement documentation and storage

Derived Requirements

Derived requirements stem from the team’s observations throughout the course of product development. These are specifications that arise out of a need to abstain from making the project overly complex and the need to remain on schedule. Many of these derived requirements evolved throughout the current phase of the project when deemed necessary by the team, sponsor, or advisor. These requirements are listed below:

- Use of a sacrificial striking plate to preserve integrity of the more costly fixture plate
- Employing the Smallwood Recursive Method for generating SRS curves to preserve continuity of information when provided to Harris Corp. for validation
- Documentation throughout project to be provided for year two.
- Consistent force generation to minimize margin of error
- Adjustable fixture parameters
    - Fixture plate boundary conditions
    - Test article location
    - Hammer impact location
    - Hammer tip shape
    - Modal tuning bands

Background Review

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 [4]. Computer simulations of pyrotechnic shock are computationally intensive, in particular finite element analysis has difficulty modeling the high frequency characteristics of pyrotechnic shock. Computational methods often yield much more conservative results due to the sacrifice in processing power [1].

Not only is this shock difficult to recreate in a testing situation, it is also difficult to study in the time domain. Irvine recommends the use of the Shock Response Spectrum, or SRS, [5] 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 respond to a certain shock [5].

The rapid decay, transient nature, and extreme frequencies are difficult to simulate using a mechanical 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 [1]. 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 [5, 3]. High acceleration shock loadings are more accurately created by explosives; however, this is rarely done in practice due to the obvious dangers [1].

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 [6]. Replicating the pyrotechnic shock mechanically, as opposed to simulating with real pyrotechnics, can potentially solve any issues encountered with acceleration data acquisition.

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 [6]. Findings by The Harris Corporation agree with Luhrs in that the drop test was overestimating the shock accelerations [3].

Concept Generation

Pyrotechnic shock testing consists of two primary systems: first, a physical testing rig, which will generate safe and consistent shock; and second, a data acquisition system (DAQ) which includes methods to capture the physical test data and subsequently analyze with software. Choosing a design for the physical testing rig had to be conducted first as the method of shock generation can impact the necessary DAQ tools.

Shock Generation Concepts

There are many viable ways used in industry to generate high levels of shock to model as pyrotechnic shock. Four of the options with potential application in this project were researched and are discussed below. As discussed in the objectives and goal statement, the main areas of focus for the final test rig were its adaptability and repeatability. In order to evaluate the different designs, they were graded based on accuracy, durability, assembly, cost, and adaptability.

Design 1: Shock Tube

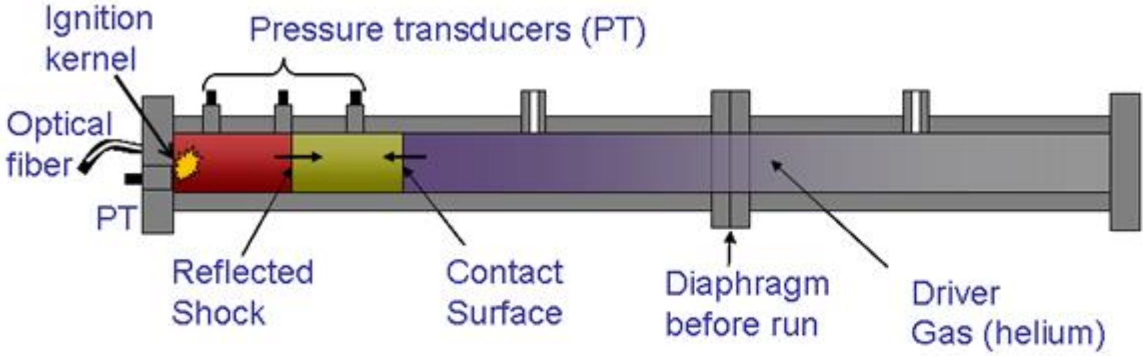


Figure 1 - Simple schematic of a shock tube [7]

Accuracy: Shock tube testing is capable of high accuracy due to extensive research and understanding of shock control. This comes at higher costs, however, and relies heavily on initial investment. Shock tubes are 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 considering and controlling these additional flow conditions for this project, it 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, testing losses due to burst discs being sacrificial parts and needing to be replaced after every test.

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. Additionally, the testing space required for a shock tube is large compared to the other designs.

Cost: Shock tubes are large constructions 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 investment, 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 many 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

Figure 2 - Example of a drop table [9]

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, which necessitates additional considerations during data processing [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. This design has a greater chance to breakdown from cyclical and impact fatigue.

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 a simple and 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

Figure 3 - Airtec pneumatic piston/cylinder with attached valve [12]

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

Figure 4 - Pendulum shock testing apparatus [10]

Accuracy: The drop hammer does not offer the highest accuracy out of the available test methods due to having to rely on swinging mass and consistent impact dynamics. 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 precise positions for each test and offer the same results.

Durability: The durability of the kinetic hammer is dependent on the frame structure and test fixture. With this in mind the materials selected to construct the test apparatus needs to be fully capable of withstanding the repeated tests without fear of growing inconsistencies or failures.

Assembly: The assembly of a kinetic hammer is relatively simple to produce. The hammer can be operated by either relying on gravity or using augmented force with the addition of motor rotation. The only additional requirement is a frame that will hold a test fixture onto which the hammer can be mounted.

Cost: The kinetic hammer has the potential to be the cheapest test apparatus to create. The entire structure, hammer, and test plate can be made of uniform pieces of raw materials.

Adaptability: There are many interchangeable aspects to the kinetic hammer, which is one of the strengths of a simple design. 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.

Design Evaluation

Selection

The selection method involved discussing and researching the different methods of administering the impact. Accuracy, which encompasses the repeatability, was the highest weighted criteria as it was one of the most important both to the sponsors and the team. Durability represented 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 was not a large concern; the goal was to create something that would last through the smaller scale testing the project called for and could later be adapted in large scale. Assembly was of moderate importance, as extra machine time or lengthy setup times for the test would limit testing capability. As with all projects, cost also had to be considered. The team did have a finite budget, discussed later in the report, and as such had to also consider the financial viability of the different designs and assess if an apparatus is cost efficient, particularly in light of still requiring DAQ components. The final point of evaluation, adaptability, was the second most important criteria. It represented the need to have an adaptable apparatus to tailor to desired outputs by changing controlled variables.

Each apparatus was rated on a scale of one to five on their performance in each area. One represented the worst, five the best. Total scores were calculated by multiplying the performance factor by the weight factor. The weight factor indicates the importance of each of the criteria and compared in the matrix. Based on the decision matrix below in Table 1, the kinetic hammer achieved the highest scores. This design represented the best overall testing package for this portion of the project scope based upon the above research and results from communication with advisors, sponsors, and team brainstorming sessions. As previously stated, the drop table tests tend to over test the specimen, and the shock tube also tests thermal properties; both of these are undesirable situations. It was for these reasons we ruled out those possibilities. The team then moved forward with the design of a kinetic hammer apparatus for testing with the goal to design an apparatus that could be operated using alternative methods such as adding an air hammer. The advantages of using a kinetic hammer stemmed from both its simplicity, cost, and adaptability, allowing for quick and easy test set up while affording many different possibilities for test variations.

Table 1 - Weighted decision matrix for impact 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*	

The initial design shown in Figure 5 was a brute force approach to the design problem. With a major focus on structural rigidity, the ideas was to use an all-steel construction that required a lengthy welding process and even more in depth manufacturing. Although this build met the team's metrics for selection, it also proved to be less than ideal. The strength of the structure, simplistic approach, ease of modeling, and over-simplified hammer head made this design appealing. Conversely, the extensive manufacturing processes required as well as the lack of adaptability caused the team to rethink and redesign the physical structure while retaining the same general foundation to design around. An important lesson learned in this first iteration was to always explore the materials available rather than selection materials from what is common.

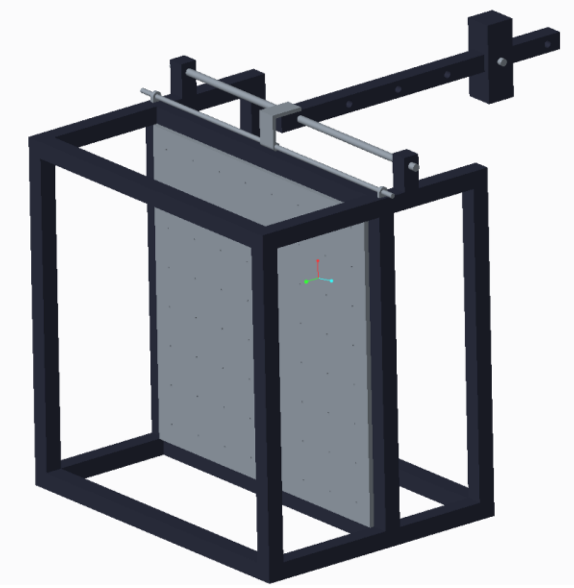


Figure 5 - First design utilizing a swing hammer

The decision matrix in Table 2 details the selection of the material for the frame. This process occurred after the realization that the original selection of material was not truly justified nor fully explored.

Table 2 - Weighted decision matrix for framing material

Material	Durability	Cost	Availability	Assembly	Total
Wood Beams	1	5	4	4	3
Plastic Rods	2	3	3	3	2.6
Composites	4	2	2	1	2.6
Steel Tubing	5	3	4	2	3.8
Aluminum T-slot	4	3	4	5	4
Weight Factor	0.4	0.2	0.2	0.2	

The T-slotted aluminum was brought to the team's attention by project faculty advisor, Dr. Kumar, and was selected for the building of the frame. The appropriate durability of these bars was confirmed by both Dr. Kumar and the Harris sponsors as they are used in many other trying testing conditions by the school's research teams. In addition to being nearly the same price as many other viable materials, namely steel, the t-slot extrusion bars were ordered in appropriate sizes very easily from McMaster-Carr, an approved school vendor [11]. Perhaps the greatest advantage of this material choice was its effect on assembly. The team had originally laid out plans to use steel square tubing to construct the frame and hammer swinging arm. These pieces, however, would all require machining and therefore add to downtime before the assembly could be built. Additionally, the T-slot bars can easily be fitted together using end-fed nuts and bolts fastened through frame plates, as shown in Figure 6.

Figure 6 - T-slotted aluminum bars and example joint assembly [15]

The team elected to use 6061-T651 Aluminum for the fixture plate 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 [13, 14]

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

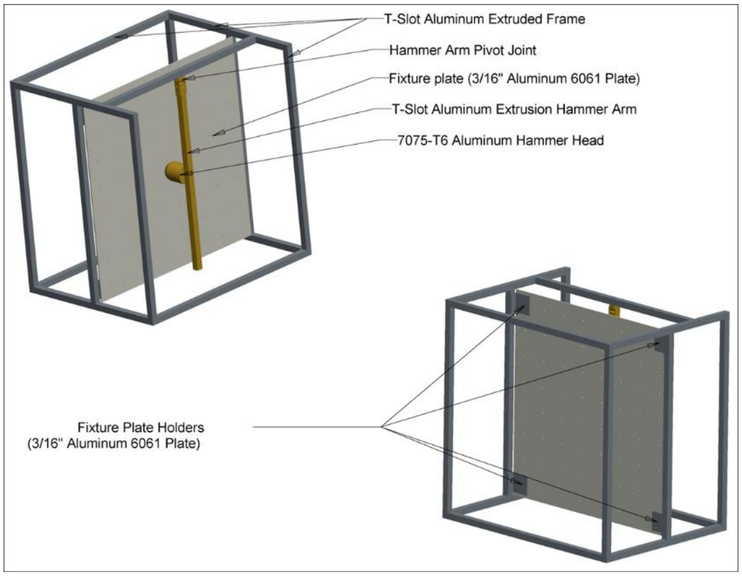


Figure 7 - Second design iteration after T-slot aluminum bars selected

The main difference between the initial test rig design and the second design, shown in Figure 7, was the quick release mechanism. After constructing the entire apparatus the team was able to inspect the apparatus and realize the current design for the quick release would not work. It was later determined they would use excess material purchased to construct a quick release that would be both simple to implement and meet their needs. While it is not shown in this rendering it can be seen in the final design in Figure 8.

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 [12]. 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 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. Given the nature of the project and the two year scope time and money was spent on appropriate hardware that can also be used in year two. This included Dytran model 3086A4T accelerometer and 4110C power supple, while signal conditioner, BNC cables, and a DAQ card were borrowed from the AME. 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.

MatLab, LabView, Creo Parametric, Creo Simulate, and Abaqus 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. In addition Abaqus was used to model the mass and modal participation of the plate as it reacted to impacts. This allows the team to visualize the frequency and modal response of the plate to determine where the tuning bands should be placed during testing. 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.

Final Design

T-slotted aluminum was chosen for the construction of the frame due to its adjustability. It allows adjustment of the location of the fixture plate, hammer swing arm, and hammer tip and weight locations on the swing arm. Portability was also an issue as the t-slotted aluminum and aluminum fixture plate weighs significantly less than a comparable steel setup as aluminum has a density of 0.0975 vs. 0.284 pounds per inch cubed for steel. However, aluminum has a lower strength and fatigue life than comparable steel [15].

Steel was chosen as the material for the mounting brackets. This was chosen to isolate the impact to only excite the plate rather than the entire frame due to the higher elastic modulus of steel vs aluminum. As suggested by Harris, the test article was made from steel since it would meet the weight requirement and also allow a stronger material to thread the accelerometer into. For consistent transmission of force the same material aluminum as the fixture plate was chosen for the sacrificial plate. Harris also indicated from previous experience that there would be significant plastic deformation on the aluminum sacrificial plate from the steel hammer tip; therefore, a specific sacrificial plate is used for each hammer tip size. The final design iteration is shown in Figure 8.

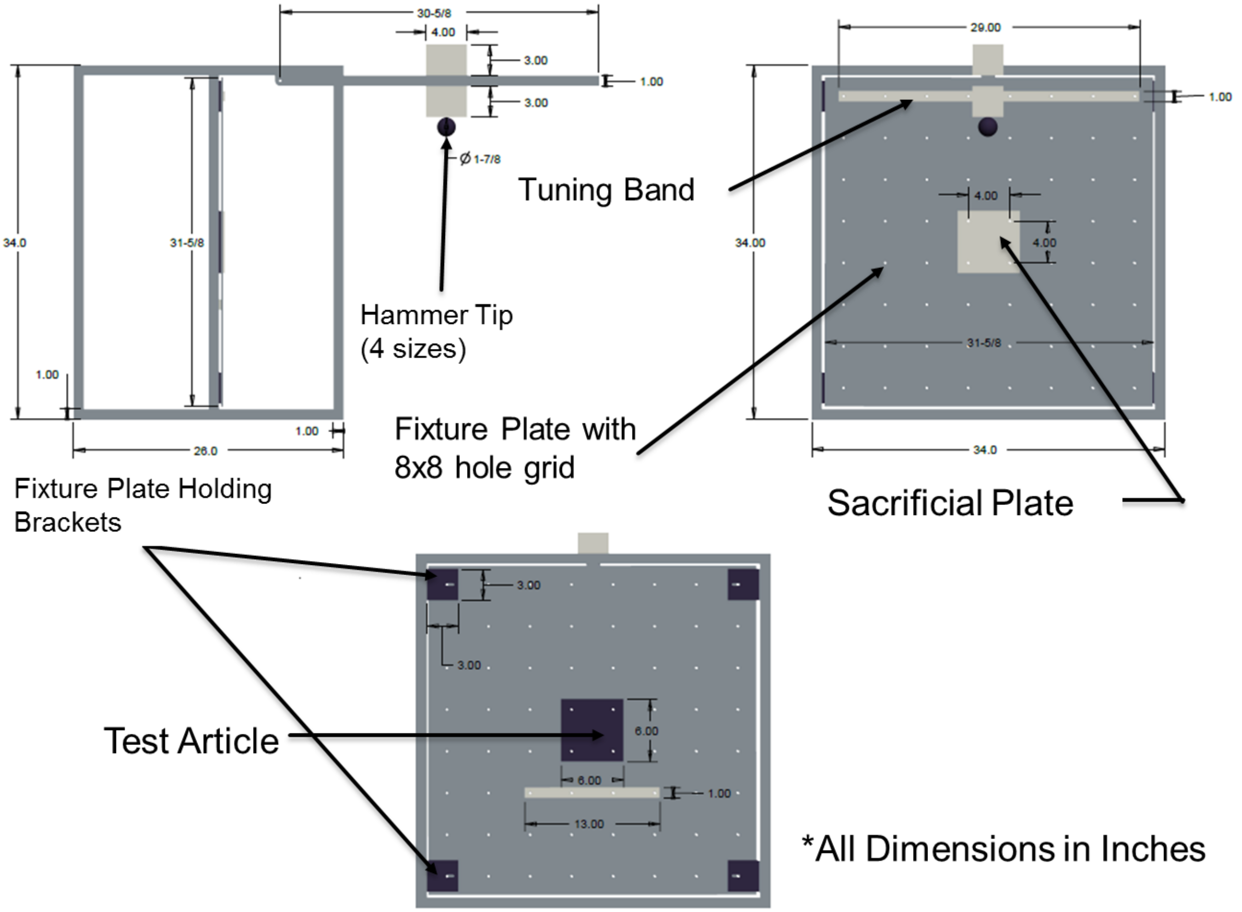
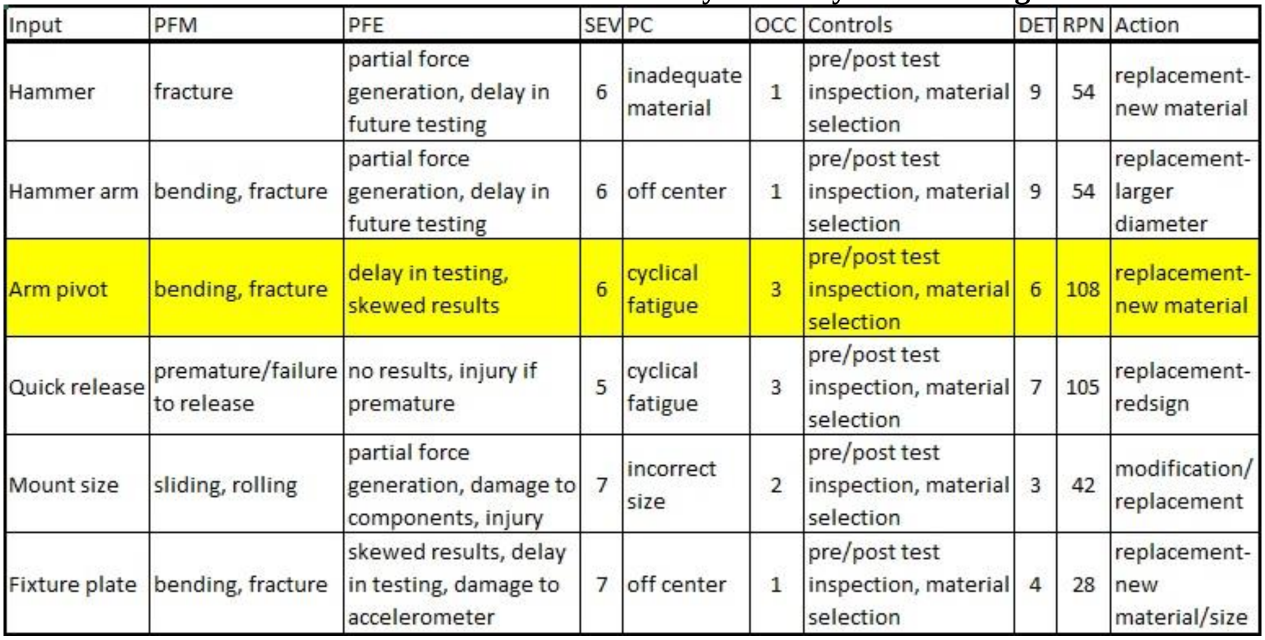


Figure 8 - Final design iteration for manufacturing

With proper maintenance including ensuring proper torqueing of the hardware the test rig will function the duration of this and the following years testing. No problems have been noted from the initial tests conducted thus far. Additionally, a small amount of plastic deformation has been noted on the sacrificial plate as expected; consequently, it will be important to have the hammer swing correctly positioned for each test.

Table 4 - Failure Mode Effect Analysis of Physical Test Rig



Input	PFM	PFE	SEV	PC	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/failure to release	no results, injury if premature	5	cyclical fatigue	3	pre/post test inspection, material selection	7	105	replacement-redsign
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

Table 4 shows many mechanical failures which could occur. Arm pivot failure would be the worst potential physical failure that could happen, but given the part's three bolt design, only extensive testing or improper loading would cause this failure. Significant movement was noticed in the hammer swing arm. Washers were inserted in between to mitigate the movement; yet, it will still be important to check the torque on the connection screws with each run. Interference to the accelerometer signal was also mentioned and was a problem for the area where the testing occurs. After the signal conditioner was added to the DAQ setup, it eliminated the noise in the accelerometer signal noted before. The signal noise could still present a problem in the future due to the dynamic environment where the testing occurs.

Experimental Design

This project was accepted as being primarily research based and therefore involves a lot of unknowns as well as very little conclusive reference material. With that in mind, the team opted to focus on documentation heavily in order to provide the most background information for future projects on this topic. The primary goal of this experimental project was to gain insight as to what effects would be realized by altering specific parameters of the testing setup. After conversations with our sponsor, five major parameters were selected as the variables we would isolate and alter. These five include the hammer head size, the hammer strike location, the location an acceleration is extracted from, fixture plate boundary conditions, and modal stiffening. These five variables represent the bulk interest of this project and provide the groundwork for future exploration into additional variables. Detailed below is the testing method and data processing methods in order to consistently produce results that can be compared for further analysis.

Testing Methods

This testing apparatus was designed to deliver an impact to a large metal plate. In doing so, this impact is absorbed by a test article attached to the large metal plate, and the acceleration of the test article is measured by an accelerometer connected to a DAQ system. To perform tests, a procedure must be followed. Here, it is assumed the apparatus is already assembled.

1. Locate impact location for test
2. Attach sacrificial plate
3. Locate test article location for test
4. Attach test article (assuming accelerometer is already threaded onto plate)
5. Adjust hammer pivot location to be centered on sacrificial plate
6. Select hammer head for test
7. Attach hammer head to corresponding hammer weight.
8. Attach both hammer weights to hammer arm
    a. Hammer weight with attached head faces metal plate
9. Adjust hammer head location to align with center of sacrificial plate
10. Relocate quick release frame mount to align with hammer arm
11. Raise hammer and lock in place with quick release pin
12. One or more persons must operate test apparatus, one person must operate DAQ system
13. The data acquisition and hammer release via pin must occur simultaneously

Once the data is confirmed to be accurate, further processing is done using MatLab in order to obtain the desired output, an SRS curve.

Results Processing

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. For the physical model, the raw acceleration data measured can be filtered to avoid error in acquisition. Smallwood has found a recursive formula method that minimizes the errors brought about by an insufficient sampling rate [16]. This method can then be used to calculate a SRS from the measured raw data. Figure 9 shows the flow of data in the creation of the SRS curve and how the data is processed in order to refine the end results.

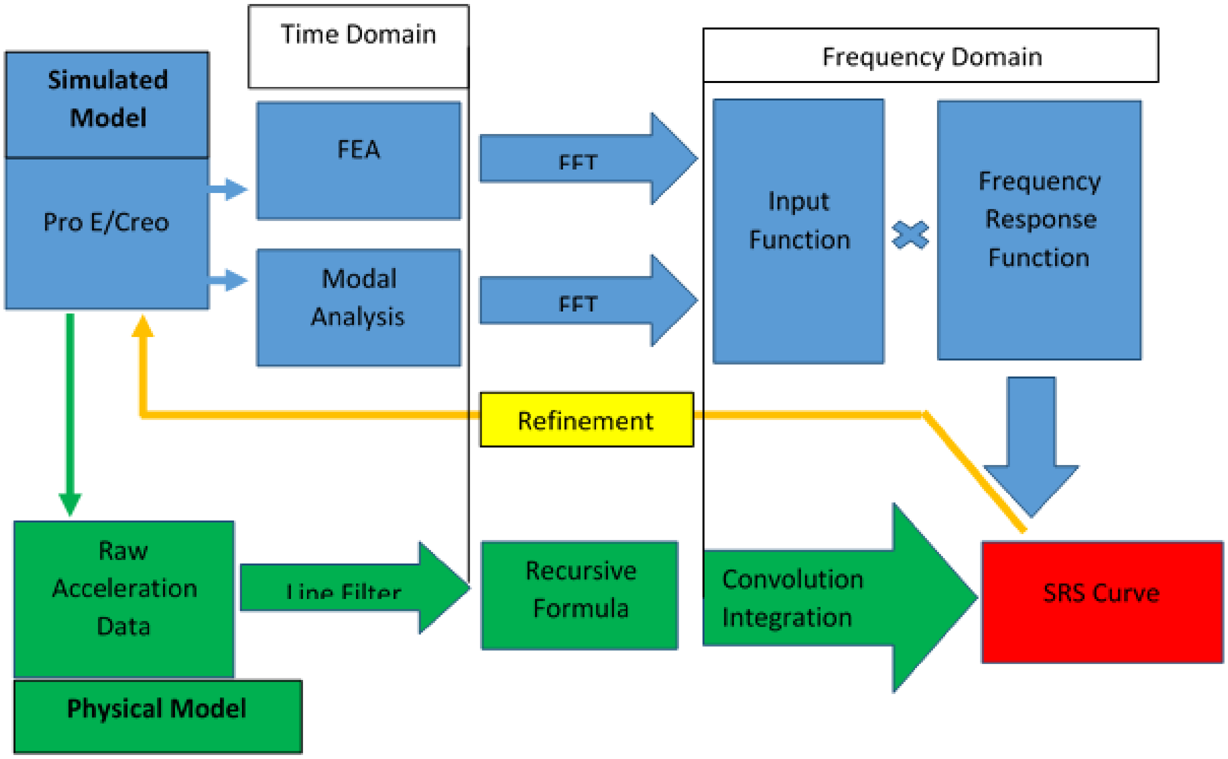


Figure 9 - Flowchart depicting the data transformation process of refining test results

Post-processing of data occurs with both Microsoft Excel and MatLab. Microsoft excel is used to consolidate and organize data from matching test runs. In addition conversions are done within Excel to produce files that can be used as input to MatLab by using the accelerometer outputs produced by LabView and the calibration data for the physical accelerometer. The parameter of interest is the sensitivity of the accelerometer as it relates the voltage output to an acceleration value. Table 5 shows the sensitivity values as calibrated by Dytran, the company that supplied the accelerometer.

Table 5 - Sensitivity schedule for Dytran 3086A4T accelerometer

Acceleration (g's)	Sensitivity (mV/g)
1000	0.521
2000	0.522
3000	0.523

The key to producing data that is both usable and conclusive is to isolate individual variables for each test. For example, when performing tests for the different size hammer heads, checks need to be performed to ensure no other changes have occurred in between tests. This allows for greater accuracy and a more solid comparison between resulting data sets. Figure 10 is the resulting comparison plot for one particular variable.

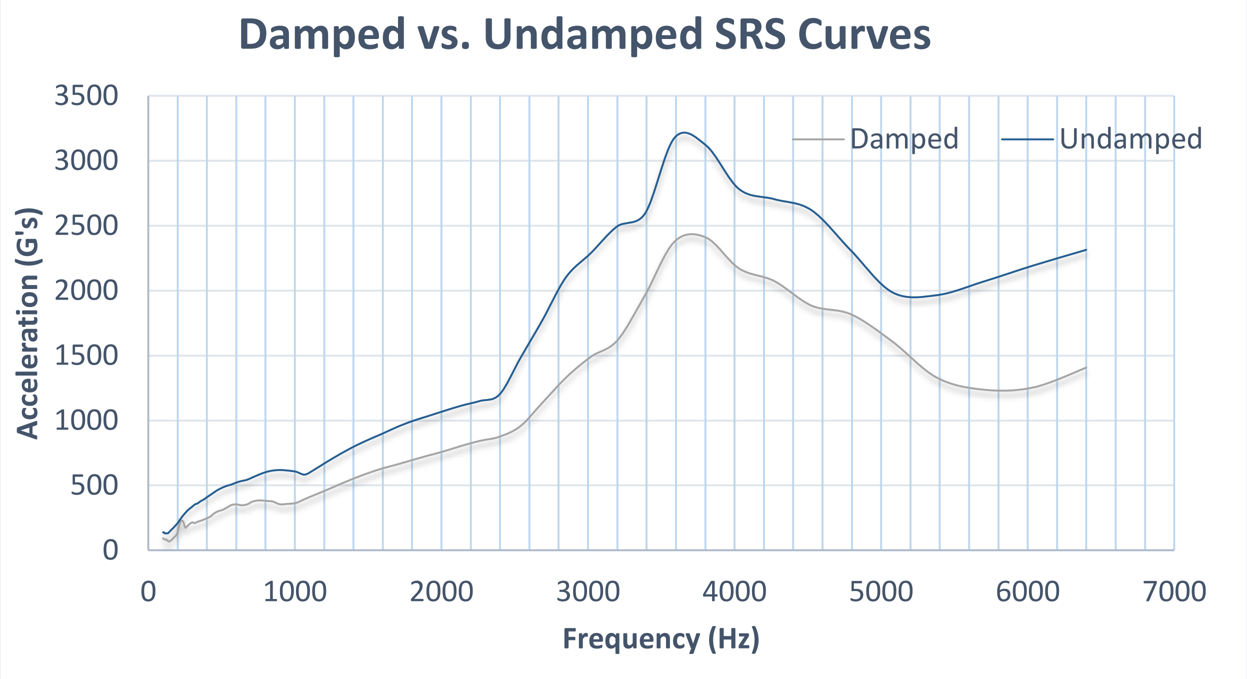


Figure 10 - Comparison of damped vs undamped SRS curves

In this plot, the apparent trend is realized when the amplitudes and frequencies of the two curves are compared. Here, it is distinguishable that the peak acceleration occurs at almost identical frequencies where the damped curve's peak is much lower than the un-damped curve's peak. Plots similar to this are produced for each individual variable that is tested and the results are compiled into an atlas-style reference for future use.

Environmental, Safety, and Ethical Considerations

Due to the nature or our project there are no inherent environmental considerations to take into account. All tests are run indoor in a laboratory setting with no impact on the outside environment. Safety is a concern while testing as our apparatus has heavy moving parts. The main concern for safety is personal injury and noise damage. Our apparatus is a metal hammer that impacts a metal plate. This gives concern for injury from being in the way as the hammer swings, and a concern for hearing from the impact. However with the test protocol we have in place we can significantly reduce the potential for injury, and after initial test runs the noise produced is not as significant as expected and is no longer a concern. After discussions with Harris corp. and filing nondisclosure agreements with the company our ethical considerations air on the side of privacy when dealing with proprietary information provided with Harris. This is to stay in agreement with the NDA's signed and not provide any information held as confidential by Harris.

Project Management

Communications

The primary form of communication for the team will be using the GroupMe app for iPhone and Android. This is a mobile messaging app that provides simple means to set meetings, share ideas, and collaborate on this project. In addition, the team will use e-mail, Google Drive, DropBox, and USB drives to share files. Regular team meetings will be scheduled as needed during regular working hours. After the first semester the team set up weekly teleconferences with the sponsor in order to keep both parties up to date on progress. This was done to keep an open dialogue for any questions that arose during testing phases for the project.

Timeline

At the beginning of the year the team had to gain an understanding of the project they were about to undertake. This had to be done before design could begin. August and September were spent doing background research on the core topic of pyrotechnic shock. October was spent reviewing the literature gathered during background research and gathering an understanding of the project. November and December were spent in discussions with the sponsor as to what exactly they were looking for and the rest was spent designing a test apparatus that would meet these needs. Between semesters the scope of the project was changed, so January was spent quickly redesigning the test structure and procuring the necessary material. February and the first half march were spent constructing the apparatus and building the DAQ system in Labview and verifying the Matlab script. The second half of March and April will be spent testing and compiling data.

Resource Assignment

Resources were an important aspect of completing this project on time. The team sponsor at Harris Corp. brought specialists Giann Cornejo and Sarah Cooper into the communication tree. Mr. Cornejo was invaluable in the selection of the proper type of accelerometer to utilize to collect data, Mrs. Cooper offered her expertise to the analytical modeling providing feedback on both Abuqus modeling and what kind of modal response could be expected. Dr. Kumar offered a facility in which testing could be conducted in the low speed wind tunnel at the AME building. Dr. Kumar also introduced the team to experiment engineer John Strike at the AME Polysonic wind tunnel. Mr. Strike offered insight into the type of data acquisition systems available to the team at the AME facility. Mr. Strike offered his time in helping the team setup and familiarize themselves with LabView, and allowing the team to borrow equipment such as a signal conditioner and modal hammer. Through Dr. Kumar and Mr. Strike the team was able to meet with Tufan Guha, one of Dr. Kumar's graduate students, who was able to help the team in properly using the modal hammer.

The front staff at AME Ashley Cope, Travis Shedrick, and Jackie Kornegay also provided support with securing facilities and filing purchase and travel requests. The machine shops both at the college of engineering and HPMI were essential in manufacturing all of the needed parts in a timely manner. James and Jeremy at the College of engineering shop were able to complete all the necessary work while being overwhelmed with all of the senior design workload they were slammed with, while one part was too big and had to be taken to HPMI. Mr. Horne at HPMI was able to fit this part in between projects and get it back to the team as soon as possible.

Critical Tasks

Procurement was necessary as the team had to take into account what needed to be purchased and how much budget would remain in order to facilitate the purchase of all the necessary equipment and parts. This also had to be done in a timely manner in order to provide time to both machine and assemble the necessary parts of the apparatus. Assembly was done in sections as parts were returned from the machine shop it was important to assemble as we received parts so that once everything was complete testing could begin. As no of the team members had much familiarity with the data acquisition equipment or the lab setup they would be using it was important to start this process early so that the team could utilize the assistance of MR. Strike while not causing him too much hardship or distraction from his own work. With DAQ and assembly done baseline testing began to collect constant test values in order to compare to variable testing which must be done once baseline data is acquired. Documentation is the final critical task to be completed, because the project was extended to a two year project documentation is an ongoing effort. This is to make sure the team next year can pick up where this year's team left off with little to no delay. This will include all of the test data compiled by the team and instructions on how to setup the apparatus and each test to obtain accurate data.

Procurement

The budget for the pyrotechnic shock simulation apparatus was $4,000. After everything for both the device and data acquisition was purchased the total cost of production was $2,093.15. This can be broken down into subsections based on parts of the build. The total cost for the subsections can be seen below is Figure 11. The total for the frame was $537.00, Fixture was $324.21, Hardware was $53.14, Test article was $44.76, Hammer was $173.24, and data acquisition was $960.80. All of this adds up to 52% of our budget. Staying under budget was not the teams main goal with this project, but with how far under budget team 15 stayed they were able to justify the results of the project as financially viable.

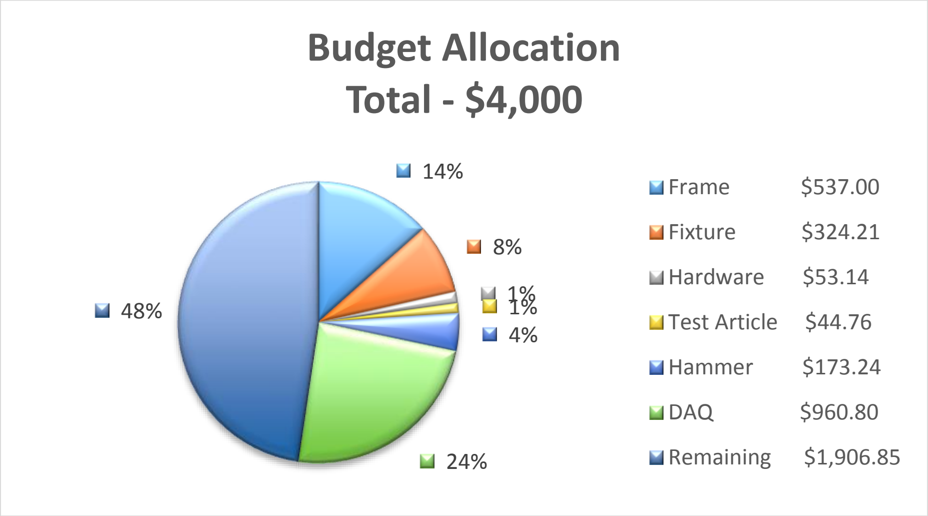


Figure 11 - Budget Allocation

The total budget provided to the team was more than enough after the restructuring of the project scope. The smaller scale testing required a smaller test rig and this in turn led to less use of the budget. As the team expected the largest expenditure was the data acquisition equipment was the most expensive part of the project. But this was a necessity in order to collect the data correctly and make the tests worthwhile. Without the proper data acquisition equipment the project would have been useless. Table 6 below shows the bill of materials for the parts used to construct the test apparatus itself.

Table 6 - Bill of materials

Part	Quantity	Part	Quantity
24" Aluminum Extrusion	4	1-7/8" Diameter Steel Ball	1
30" Aluminum Extrusion	1	1-3/8" Diameter Steel Ball	1
32" Aluminum Extrusion	6	1" Diameter Steel Ball	1
34" Aluminum Extrusion	5	3/4" Diameter Steel Ball	1
T-Bracket	6	1", 10-32 threaded rod	2
L-Bracket	16	1" 1/4-20 threaded rod	2
180 degree pivot	1	1", 3/8-16 threaded rod	2
Fixture Plate	1	3" x 3" x 4" 7075-T6 Aluminum Block	2
Sacrificial Plate	5	Yoke & Pin Set	2
Test Article	1	Adjustable Length Lanyard	30 feet
Fixture Plate Mounting Bracket	4		

Excess funds were used by the team to facilitate an onsite demo with the sponsors. This will include a critical design review of the test apparatus and the team's findings during testing.

Conclusion

Research has revealed the damage potential of pyrotechnic shock loadings which warrants the need for components to undergo adequate testing. Simulating pyrotechnic shock directly with explosives is highly uncontrollable and unsafe. Consequently, pyrotechnic shock is tested using a variety of methods. However, in attempting to model this scenario using computer applications, a unique set of difficulties and challenges emerged. The lack of a systematic approach to testing shock loadings increases the time and resources spent in the process. Team 15 has set out to develop a testing method to document the effect of input parameters on the output shocks assessed through the SRS outputs. Through multiple design iterations, a hammer swing test was chosen for its adaptability, consistency, and feasibility. Data was gathered varying an individual parameter per test and using guidance from computational simulations to tune the test setup. Difficulties have been encountered such as a need to ensure a rigid frame mounting as well as scheduling delays in machining components. Recommended future includes but is not limited to exploring alternative mounting brackets, additional testing parameters, establishing effective communication with faculty resources, iterative testing and documentation, trend identification, test up-scaling to 5000g's acceleration and 10kHz frequency range, and possibly automated hammer adjustments, impact force sensors and pressure transducers.

References

[1] Robert, Wells. "University Capstone Development of Hammer Blow Test Device to Simulate Pyrotechnic Shock." 19 July 2013. Web. 23 Sept. 2014. <https://campus.fsu.edu/bbcswebdav/pid-6907001-dt-content-rid-38425464_2/xid-38425464_2>.

[2] Wells, Robert. "Conference Call with Robert Wells." Telephone interview. 14 Jan. 2015.

[3] Wells, Robert. "Conference Call with Robert Wells." Telephone interview. 24 Sept. 2014.

[4] Wattiaux, David, Olivier Verlinden, Calogero Conti, and Christophe De Fruytier. *Prediction of the Vibration Levels Generated by Pyrotechnic Shocks Using an Approach by Equivalent Mechanical Shock*. Tech. no. 10.1115/1.2827985. Vol. 130: ASME, 2007. Web. 23 Sept. 2014.

[5] Tom, Irvine. "AN INTRODUCTION TO THE SHOCK RESPONSE SPECTRUM." (2012): 1-3. 9 July 2012. Web. 23 Sept. 2014. <http://www.vibrationdata.com/tutorials2/srs_intr.pdf>.

[6] United States. The Shock and Vibration Information Center. The Under Secretary of Defense for Research and Engineering. *The Shock and Vibration Bulletin*. By Anthony Chu and Henry Luhrs. Washington, D.C.: Naval Research Laboratory, 1987. Print.

[7]"Alternative Fuels Laboratory - Research." *Alternative Fuels Laboratory - Research*. AFL-Graduate Research, 14 Apr. 2013. Web. 21 Oct. 2014.

[8] Kumar, Rajan. “In Office Conference.” Personal interview. 22 Oct. 2014.

[9]"Lansmont Shock Tester (P30M – P60M)." *Lansmont P30M / P60M Shock Tester*. Web. 21 Oct. 2014.

[10] " Pendulum Shock Testing Machine / Shock Machine PST-300." *Pendulum Shock Testing Machine / Shock Machine PST-300*. Web. 3 Apr. 2015.

[11] "McMaster-Carr." McMaster-Carr. Web. 02 Apr. 2015. <http://www.mcmaster.com/#t-slotted-framing/=wonu4r>.

[12]"EFunda: Introduction to Nyquist Sampling Rate." *EFunda: Introduction to Nyquist Sampling Rate*. EFunda, Web. 20 Oct. 2014.

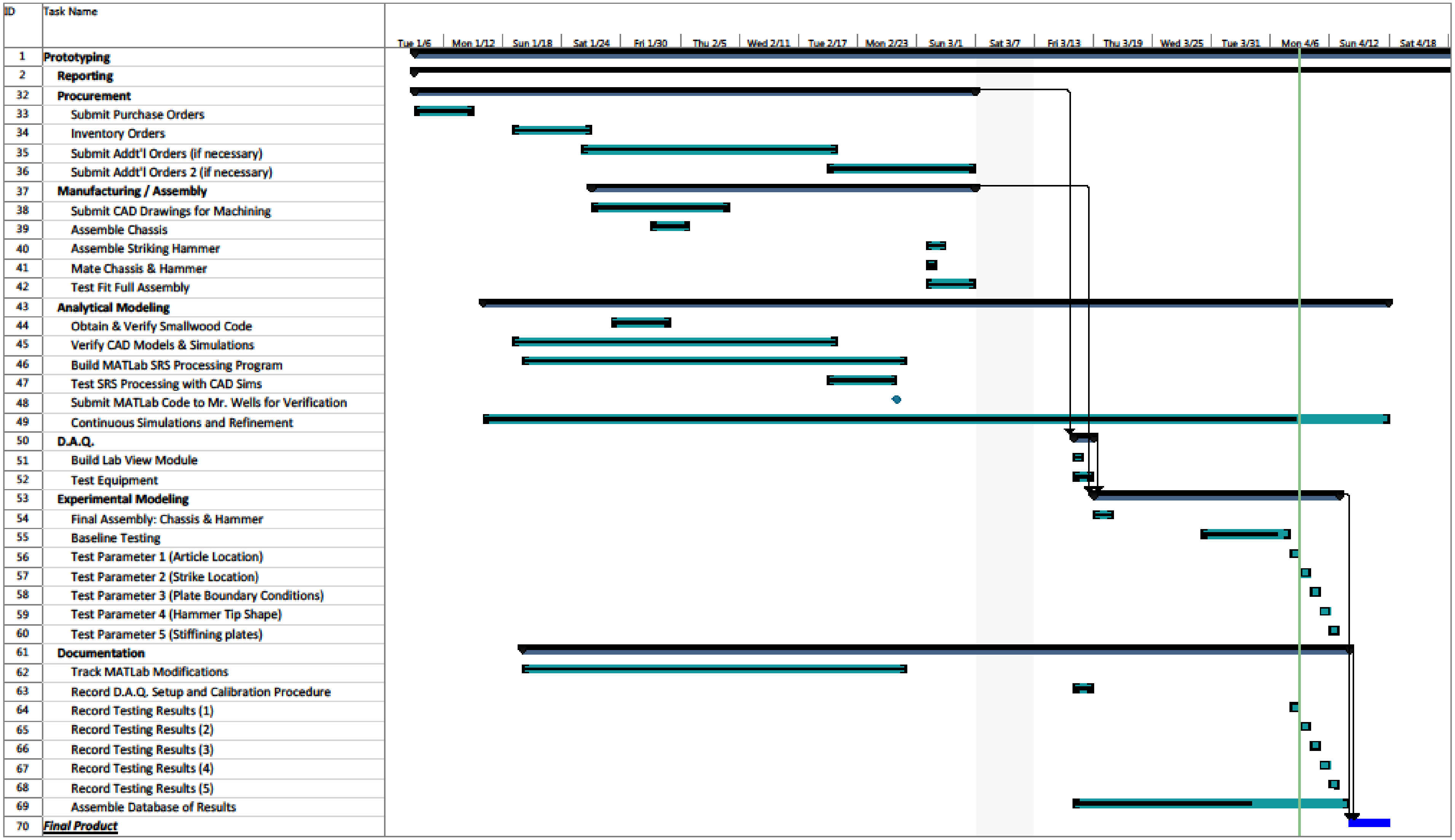
[13] “Online Materials Information Resource - MatWeb." Online Materials Information Resource - MatWeb. MATWeb Online, Web. 20 Oct. 2014. <http://www.matweb.com/>.

[14] "Metals and Alloys - Densities." Metals and Alloys - Densities. Engineering Toolbox, Web. 20 Oct. 2014. <http://www.engineeringtoolbox.com/metal-alloys-densities-d_50.html>.

[15] "ASM Material Data Sheet." *ASM Material Data Sheet*. Aerospace Specification Metals Inc.,Web. 03 Apr. 2015.

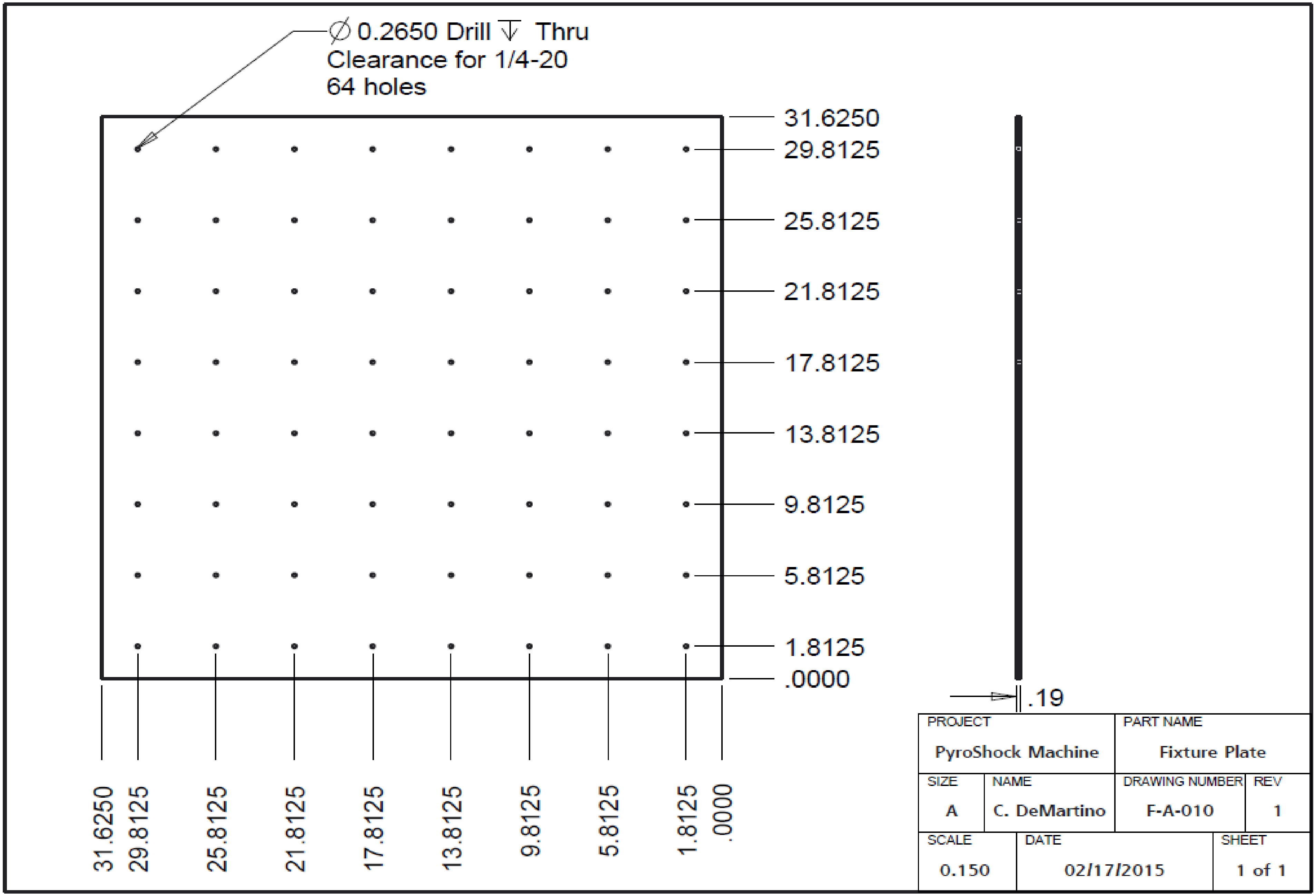
[16]Smallwood, David O. *An Improved Recursive Formula for Calculating Shock Response Spectra*. Sandia National Laboratories, Web. 02 Oct. 2014.

Appendix A: Gantt Chart



ID	Task Name
1	**Prototyping**
2	**Reporting**
32	**Procurement**
33	Submit Purchase Orders
34	Inventory Orders
35	Submit Addt'l Orders (if necessary)
36	Submit Addt'l Orders 2 (if necessary)
37	**Manufacturing / Assembly**
38	Submit CAD Drawings for Machining
39	Assemble Chassis
40	Assemble Striking Hammer
41	Mate Chassis & Hammer
42	Test Fit Full Assembly
43	**Analytical Modeling**
44	Obtain & Verify Smallwood Code
45	Verify CAD Models & Simulations
46	Build MATLab SRS Processing Program
47	Test SRS Processing with CAD Sims
48	Submit MATLab Code to Mr. Wells for Verification
49	Continuous Simulations and Refinement
50	**D.A.Q.**
51	Build Lab View Module
52	Test Equipment
53	**Experimental Modeling**
54	Final Assembly: Chassis & Hammer
55	Baseline Testing
56	Test Parameter 1 (Article Location)
57	Test Parameter 2 (Strike Location)
58	Test Parameter 3 (Plate Boundary Conditions)
59	Test Parameter 4 (Hammer Tip Shape)
60	Test Parameter 5 (Stiffining plates)
61	**Documentation**
62	Track MATLab Modifications
63	Record D.A.Q. Setup and Calibration Procedure
64	Record Testing Results (1)
65	Record Testing Results (2)
66	Record Testing Results (3)
67	Record Testing Results (4)
68	Record Testing Results (5)
69	Assemble Database of Results
70	***Final Product***

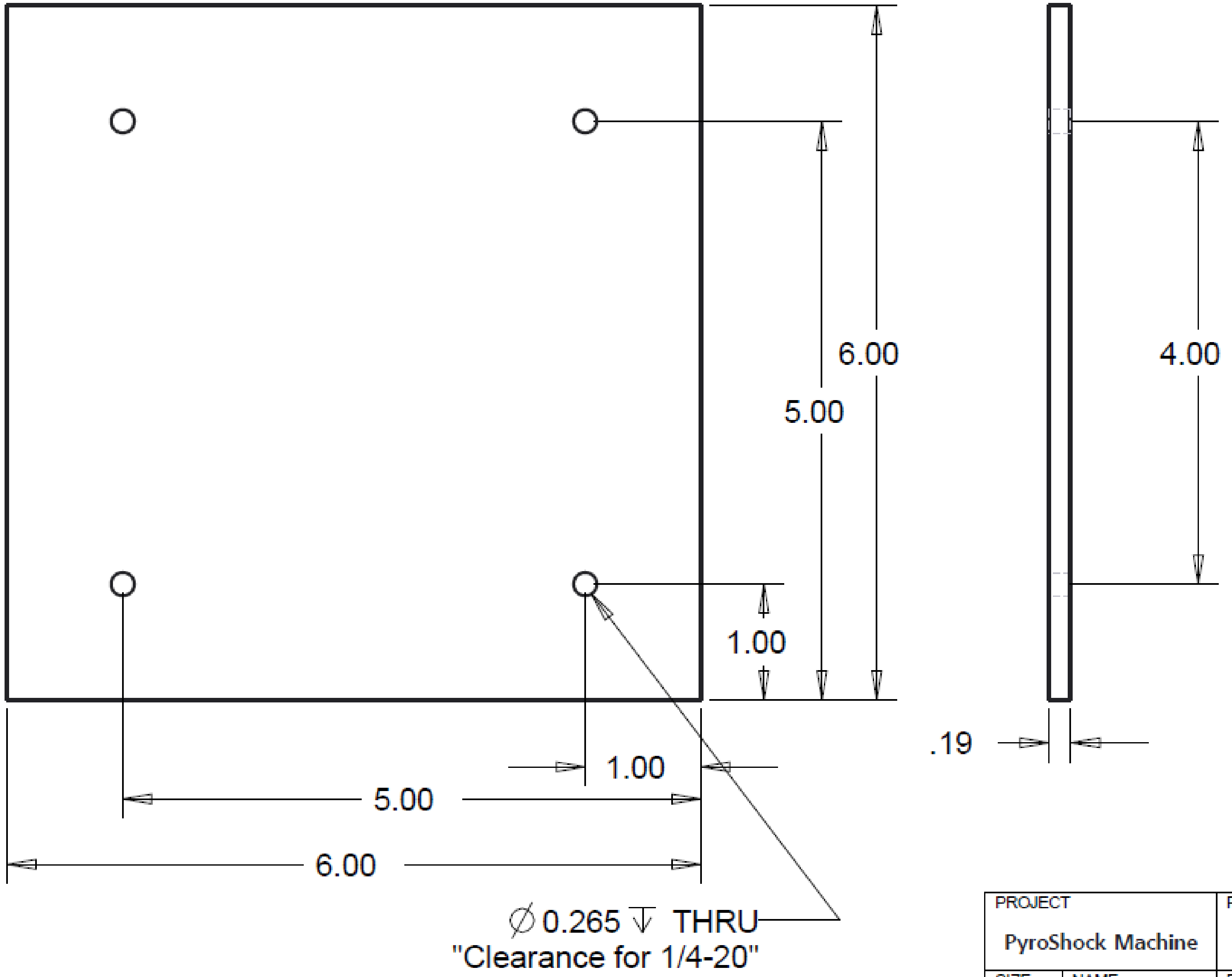
Appendix B: Critical Part CAD Drawings



PROJECT	PART NAME		
PyroShock Machine	Fixture Plate		

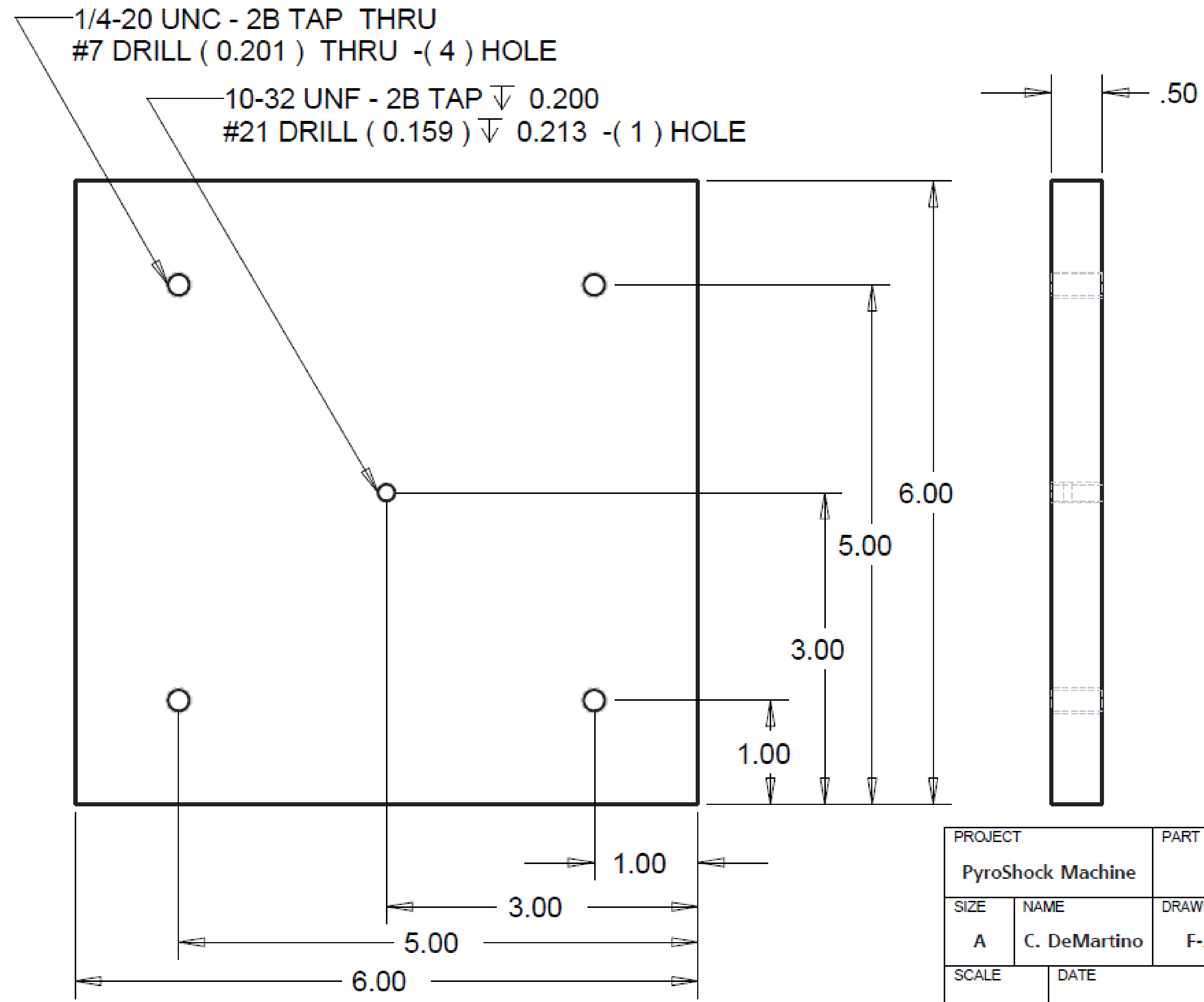
SIZE	NAME	DRAWING NUMBER	REV
A	C. DeMartino	F-A-010	1

SCALE	DATE	SHEET
0.150	02/17/2015	1 of 1

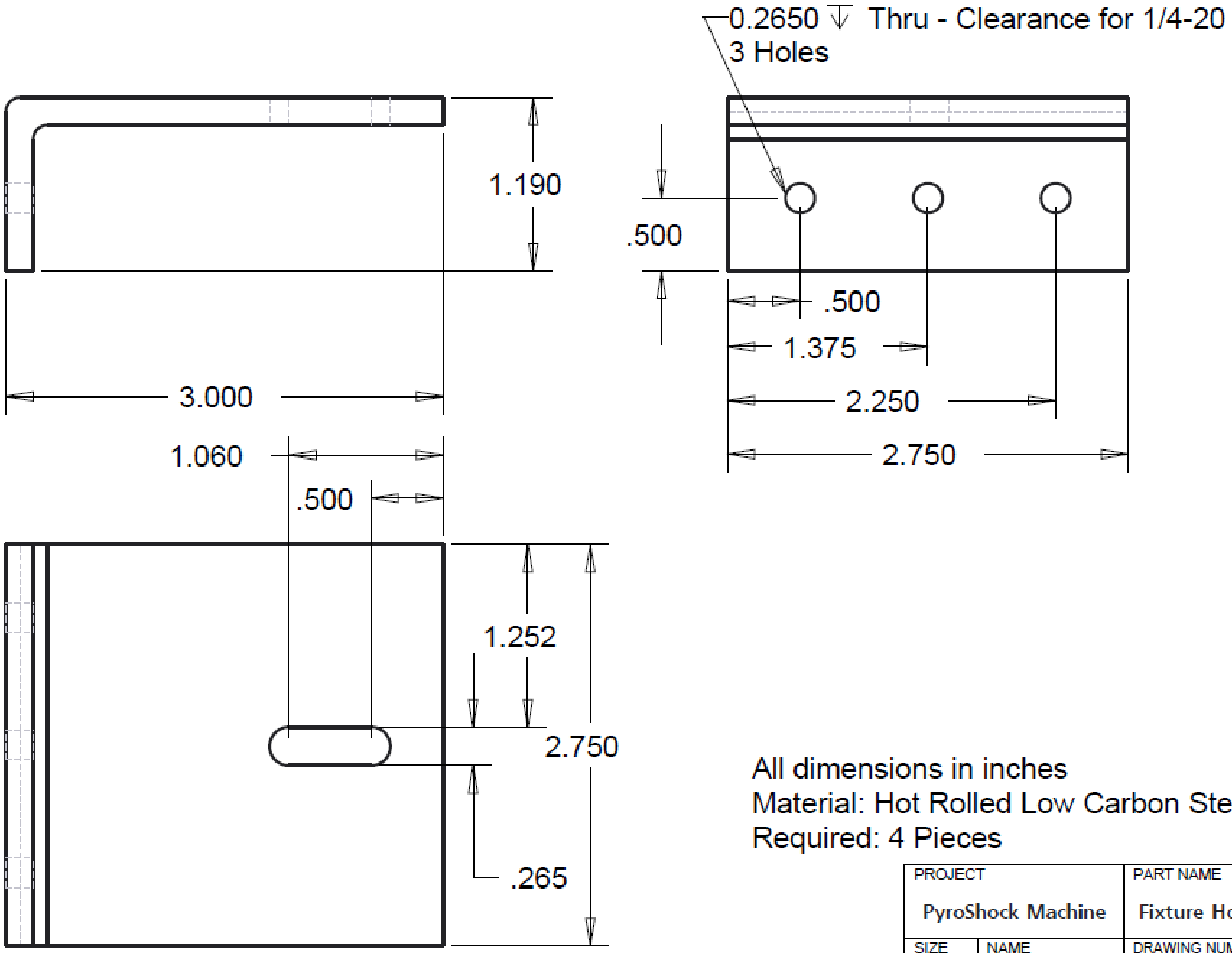


Material: 6061 Aluminum plate
All dimensions in inches

PROJECT PyroShock Machine		PART NAME Sacrificial Plate	
SIZE A	NAME C. DeMartino	DRAWING NUMBER F-A-020	REV 0
SCALE 0.750	DATE 01/23/2015		SHEET 1 of 1



PROJECT PyroShock Machine		PART NAME Test Article	
SIZE A	NAME C. DeMartino	DRAWING NUMBER F-A-025	REV 0
SCALE 0.750	DATE 2/12/2015		SHEET 1 of 1



All dimensions in inches
Material: Hot Rolled Low Carbon Steel
Required: 4 Pieces

PROJECT		PART NAME	
PyroShock Machine		Fixture Holder Steel	
SIZE	NAME	DRAWING NUMBER	REV
A	C. DeMartino	F-A-120	0
SCALE	DATE		SHEET
1.00	2/12/2015		1 of 1

Team Bio

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 Mitchel, 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 finding 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.