Pyrotechnic Shock Test Development

Midterm report

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Table of Contents

Table of Figures

Table of Tables

Abstract

A fundamental goal of this project is to facilitate the testing of electronic components subject to high frequency, high acceleration 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 in a test environment is then in 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 SRS shock. At the completion of the project a functional prototype as well as a tailored modeling system is expected.

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 lost by their current test procedures. Their desire is for development of test procedures and modeling methods to accurately replicate pyrotechnic shock loading. 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 was developed for this deliverable as well as resource allocation and tentative time schedules. This serves to keep the project moving forward and progressing steadily.

2 Project Definition

2.1 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].

2.2 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 is lacking in terms of the quality of results, efficiency, accuracy, and repeatability.

2.3 Goal Statement & Objectives

Design a test apparatus and modeling system for Harris Corp. with a clear and concise method for accurately simulating shock responses.

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.

2.4 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, the primary issue faced by Harris is not that the current hammer blow test is not an effective means of generating the desired pyrotechnic shocks, but that it is currently inefficient due to required trial and error time beforehand. Therefore, if we were to focus our efforts on better modeling the current system and finding ways to reduce the number of necessary trial runs, our constraints are then limited only to the current models used for testing. The two suggested and used by Harris Corp., according to Mr. Wells, are a hammer drop test and an air hammer test [4]. We were provided the links to the exact patents detailing each method of testing. For the hammer drop test [6] and the air hammer test [7], the overlapping constraints requested by Harris are:

- Device capable of testing unit between 5-50 lbs
- Must accommodate a parcel of dimension up to 16" L x 16" W x 12" H
- Must generate SRS pyrotechnic shock responses of up to 5000g peak and 10kHz (max levels for mid field range shocks)
- Response must be captured by an analysis system
- Test parameters must be controllable through accessible software tool (MATlab)
- Project expenses must stay within allotted budget ($4000)

In regards to the budget, we were told there is the chance that if an acceptable business case were made to demonstrate the necessity for extra funding, the project could be recommended for a continuance in future projects. Other typical constraints regarding the size of the machine, the required material used, and so forth, are not included in this section because to this point, no such constraints exist. We are planning to make use of sensors and software available at the school to the highest extent we can. The material choice, for example, is purposefully not a constraint as it represents a variable of the shock generation process that we are able to explore as a way to better control the parameters of shock testing.

		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	

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

3 Design and Analysis:

3.1 Functional Analysis

This pyrotechnic shock testing machine will consist of multiple parts. These include, but are not limited to:

- Mechanical
  - Square tube steel frame construction frame
  - Pneumatic air piston
    - Airtec Pneumatic XL series
    - Bimba Pneumatic MFD Extruded Thrusters
    - SMC Pneumatics
  - 200psi capable air compressor
  - 145psi+ compressed air tank
  - Removable test fixture
- Electrical
  - Accelerometer
    - Anti-aliasing filter (if necessary)
  - Electronic release valve (if necessary)
- Computing
  - PC with Windows XP or newer
    - MATLab
    - LabView
    - PTC Creo

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.

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

Table 2 - Material Selection matrix for structure/framing material

In addition we have researched off-the-shelf pneumatic cylinders that are available from three different providers. Off-the-shelf components were explored due to the time savings associated with not having to manufacture a pneumatic cylinder, as well as the ability to purchase a packaged assembly that includes a release valve. At Airtec, they range from 1 to 10 bar in pressure ratings, and from 32mm to 125mm in piston diameter. The force ratings for these particular piston diameters range from 430N to 6630N when using 6 bar pressures [9]. In addition from Bimba Manufacturing Company, diameters range from 12mm to 63mm and operating pressures range from 1.2 to 10 bar [14]. SMC was explored for possible pneumatic cylinders, however they operate at different specifications and have been sidelined for the time being [13]. Further analysis is required in regards to generating necessary forces and contact durations in order to to perform a final selection process on the pneumatic cylinder that will be used.

In pneumatic systems, an air compressor as well as a compressed air tank is required. These are widely available and off-the-shelf components. The Airtec specifications note a maximum of 10 bar, [9] and the Bimba brochure also notes a maximum operating pressure of 10 bar [14]. Therefore, 10 bar will stand as our maximum operating pressure at this time. SMC was also considered as a viable option should a suitable product not be available from Airtec or Bimba. Air compressors and compressed air tanks valid for these ranges are widely available, possibly even available for use at the AME facility [8].

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. This part of our design is currently undergoing a material selection process to identify the ideal material, or whether multiple test plates of different materials will better suit the test environment. Our ideal materials exhibit a predictable and constant natural frequency, impact resistance to provide longevity, are easily machine-able to allow multiple fixture placements, cost effective, and readily available. In addition, should the budget allow, multiple test fixtures may become a more feasible option. 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). Table 3 below details some of these specific material properties considered.

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

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

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 our maximum theoretical frequency is 10 kHz, an accelerometer with the capability of 20 kHz sampling rate is required in hopes to avoid the effects of aliasing. This requirement serves to provide a true reconstruction of the signal without the need for an anti-aliasing filter. Dr. Kumar has informed us that the AME facility has accelerometers that meet this requirement on hand, and even suggests two and a half times this maximum frequency as a requirement [8]. 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.

An electronic release valve has been elected as a more preferable choice for operating the pneumatic cylinder. In comparison to a mechanical dump valve, electronic valves have shorter response times which allow for a more uniform and repeatable disbursal of air into the pneumatic cylinder. In addition, electronic valves can be remotely operated and increase the safety of the device during operation. Lastly, mechanical dump valves are subject to the user's input in turning the valve and may not provide uniform and repeatable pressure release.

As far as computing goes, both MATLab and LabView are widely used programs in the field of data acquisition and data processing. Our sponsor, Mr. Wells, explicitly requested MATLab for producing the SRS curves, which has become an added constraint. LabView is a widely used data acquisition software package that is relatively simple to configure with basic knowledge. If LabView is unavailable, the accelerometer data will have to be further processed into usable information before it can be put into MATLab. This should not be an issue however, since LabView is currently available on the College of Engineering lab computers.

PTC Creo Parametric will be used to develop solid models of the individual components. Once these components have been designed and finalized, PTC Creo also afford us the ability to perform simulations within the program itself. This multi-faceted tool will prove to be very useful when tailoring the responses of individual components and aide in producing a natural frequency for the system as a whole. This 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.

In terms of manufacturing considerations, the FSU-FAMU Engineering School has access to two machine shops with many fabrication tools ranging from full sets of hand-held hardware to water-jets and lathes. These will almost certainly be utilized in the fabrication of the apparatus frame and potentially the modification of purchased parts. Given the complexity of many of our force generating considerations, as well as the ample project budget, it will be a better use of resources to pursue the procurement of market tools such as pneumatic pistons or shock tubes.

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 required article testing size (32" L x 32" W x 24" H) to allow for interchanging of the force delivery and fixture 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 is 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 use of a close range piston shock generation or room for kinetic energy use in the form of swinging hammers.

The issues arising from Harris' current test apparatus is the need for multiple iterations of trial-and-error testing for each shock qualification. 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 design of the frame is currently in-process. However, it is known that the frame will have to be made such that it can house a variety of testing sample sizes and potentially different shock generators. Therefore, the evaluation of shock generating tools in order to decide on a preliminary setup is crucial for this stage of the project.

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. These aspects will be explored further in future analysis. As for shock generation, section 3.2 details the three design concepts that have been explored.

3.2 Design Concepts

Design 1: Shock Tube

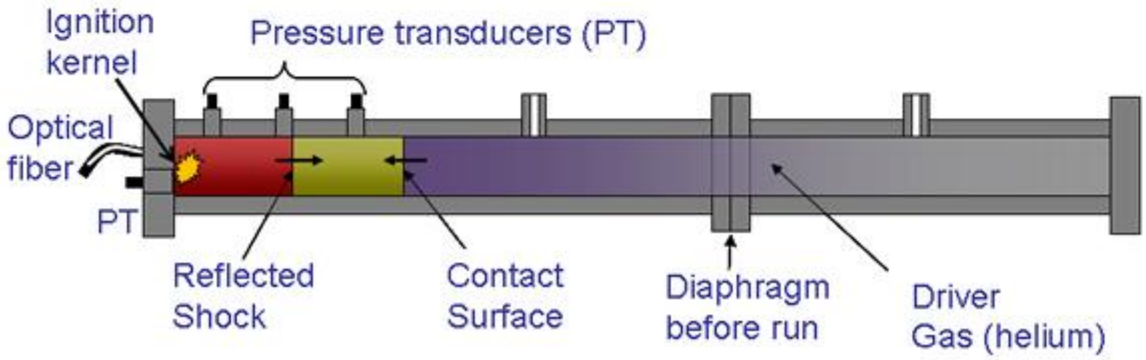

Figure 1 - Example of a Shock Tube [10]

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

Figure 2 - Example of a Drop Table [12]

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

Figure 3 - Airtec Pneumatic Piston/Cylinder with attached valve [9]

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.

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. 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 3, the air/pneumatic hammer achieved the highest scores. This design represents the best overall testing package 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 are going to move forward with the design of an air hammer apparatus for testing with the goal to design an apparatus that we can operate using alternative methods such as adding a kinetic hammer, or adapting the system from pneumatic to hydraulic if timing and budget allows. This serves to give us a concrete design goal that can be modified after preliminary testing if the initial results are inadequate. In addition, the ability to modify the setup easily will present an added bonus to its usability.

	Decision Matrix					
Apparatus	**Accuracy**	**Durability**	**Assembly**	**Cost**	**Adaptability**	**Total**
Air/Pneumatic Hammer	4	4	2	2	4	3.3
Drop Table	2	2	4	3	2	2.5
Shock Tube	1	5	5	3	2	2.8
Weight Factor	.3	.15	.15	.2	.2	

Table 4 - Decision matrix: Design Selection

4 Methodology

The methodology of this 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 show to be very useful. 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, a SRS, or shock response spectrum can be obtained.

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. Figure 4 shows the flow of data in the creation of the SRS curve.

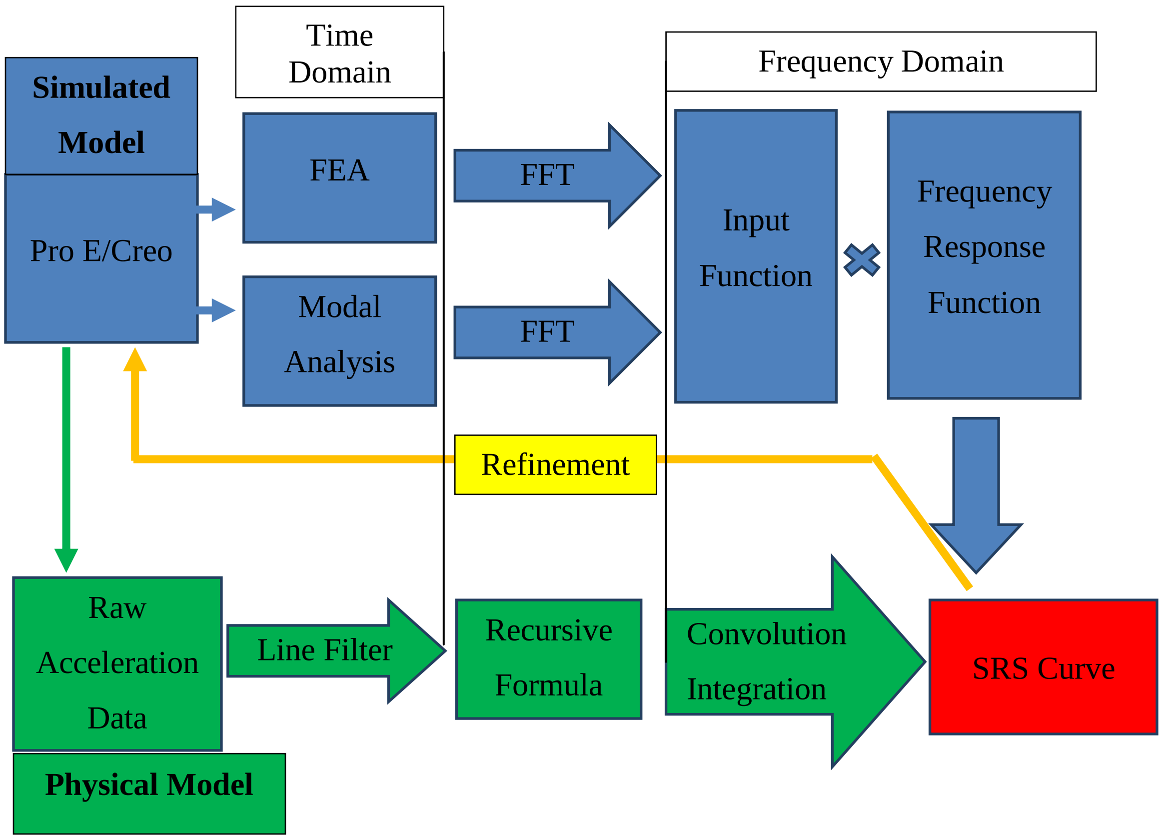

Figure 4- Flowchart depicting the methods of data processing

4.1 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.

4.2 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 4 below tabulates projected costs for materials required in this build that are known to not be available from within the AME or CoE facilities.

Item	**Description**	**Qty**	**Cost**
Square Steel Tube [21] *CAD Appendix 3*	Structural (A500) steel 1.25" x 1.25" x 24' ---- 3/16" wall	2	$276.96 + Shipping
Pneumatic Cylinder [13] *SMC - CAD N/A*	NC-G-G-N-32-1200-U07US 32mm bored, 304.8mm stroke	1	TBD
Pneumatic Cylinder [14] *Bimba - CAD N/A*	MTCL-32X250-S-T 32mm bore, 250mm stroke	1	TBD
Pneumatic Cylinder [9] *Airtec - Appendix 3*	XLVK-032-01-XXX-0320 32mm diameter, 320mm stroke	1	TBD
Test Fixture Plate [21] *CAD Appendix 3*	Aluminum (6061-T651) plate 32" x 32" x 0.5"	1	$443.13 + shipping

Table 5 - Budget allotments for required purchases

5 Conclusion

The hardship of this particular project will be the creation of a program that will determine the test parameters for the shock testing. We will further develop the air hammer test method and associated modeling program. This works well as Mr. Wells is happy with this current test method and is seeking a more efficient means to utilize it. From this point forward the focal point of this project will be material selection, supply acquisition, data acquisition systems and data modeling. Material selection may be reiterated as the project progresses and new information or new requirements unfold. Supply acquisition will occur as needed since some supplies may be available already without needing to incur costs in purchasing them. (I.e. accelerometer, air compressor, compressed air tank.) Data acquisition requires calibration as well as initial setup in order to ensure proper data recording is occurring. Data modeling is an ever-evolving process that will be refined over time based upon the necessary modifications due to material properties changing or new parameters being realized.

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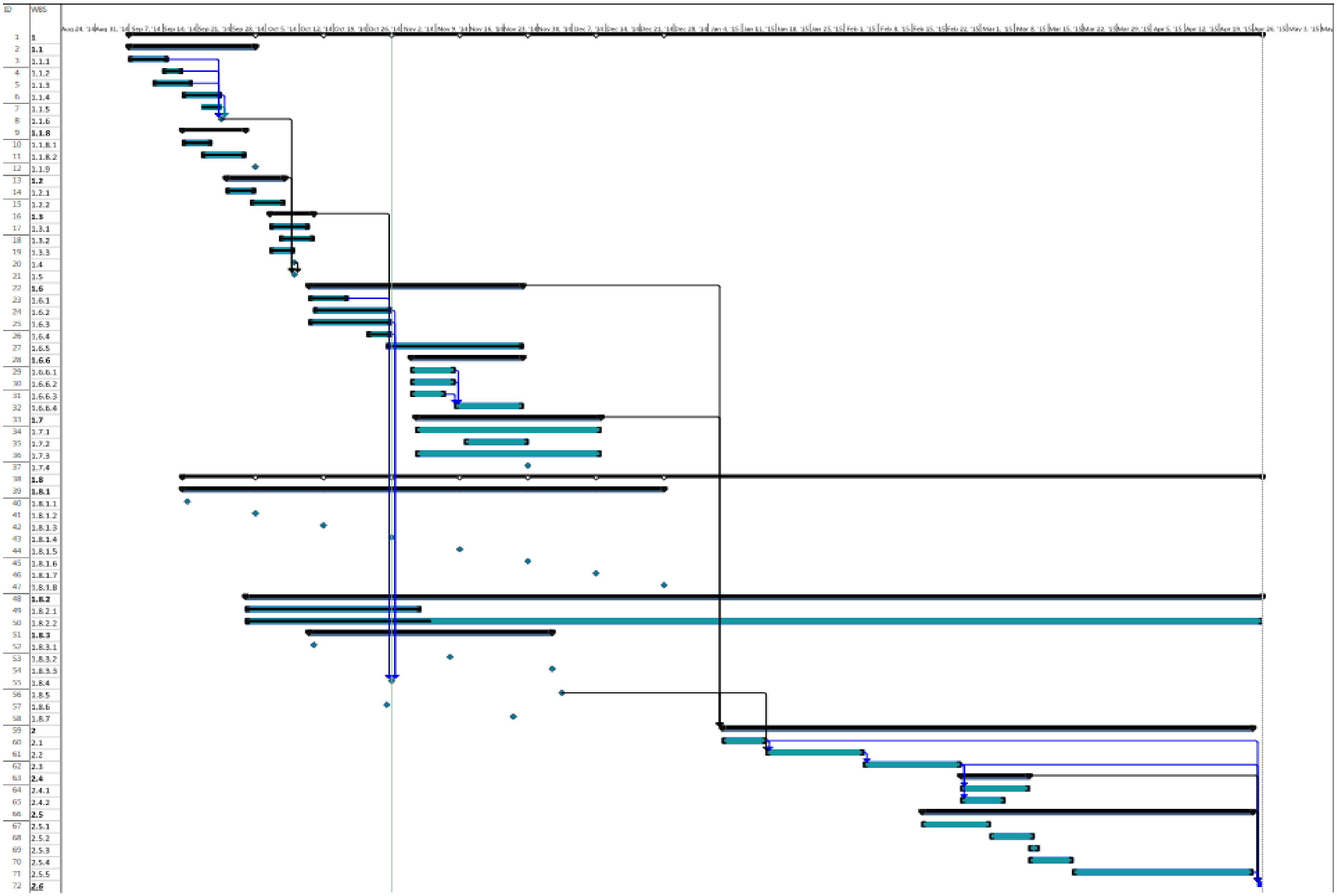
7 Appendix 1 (Task List)

WBS	Task Name	Duration	Start	Finish	Resource Names	% Complete	Predecessors
1	**Design**	**166 days**	**9/7/14**	**4/27/15**	**All**	**46%**	
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%	3,4,5,6,7
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%	13,8,20
1.6	**Development**	**32 days**	**10/14/14**	**11/26/14**		**65%**	
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	Resonance Response	5 days	10/26/14	10/30/14	Chase	91%	
1.6.5	Preliminary CAD Drawings	20 days	10/30/14	11/26/14		100%	

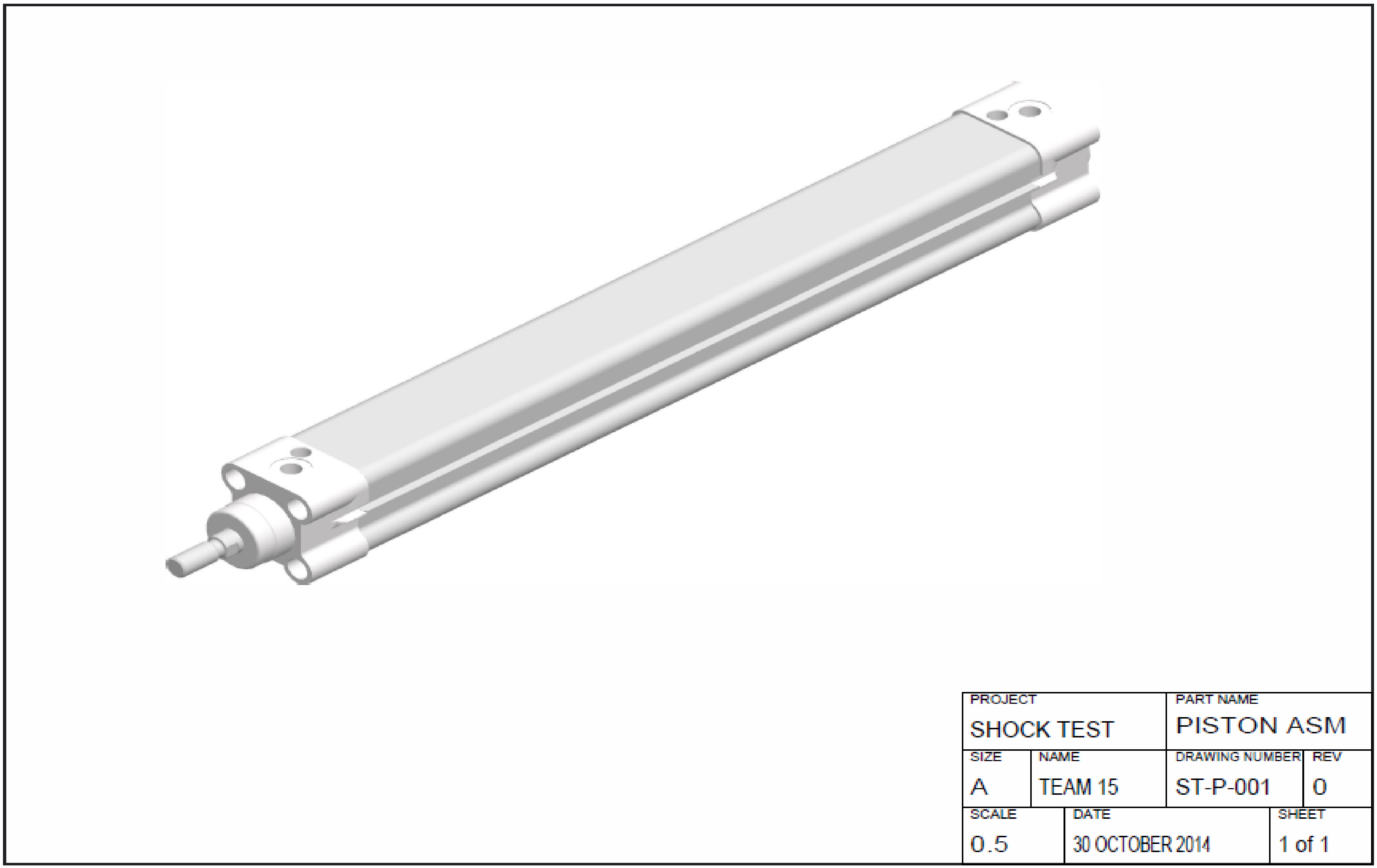
1.6.6	**Modeling**	**17 days**	**11/4/14**	**11/26/14**		**0%**	
1.6.6.1	Tuning Methods	7 days	11/4/14	11/12/14	Chase	0%	
1.6.6.2	Pulse Generation Inputs	7 days	11/4/14	11/12/14	Chad,Nathan	0%	
1.6.6.3	Response Spectrum Generation	5 days	11/4/14	11/10/14	Charles	0%	
1.6.6.4	Program Development	10 days	11/13/14	11/26/14	Chase,Charles	0%	29,30,31
1.7	**Procurement**	**28 days**	**11/5/14**	**12/12/14**		**0%**	
1.7.1	Pneumatics	28 days	11/5/14	12/12/14	Charles,Nathan	0%	
1.7.2	D.A.Q	10 days	11/15/14	11/27/14	Chase,Advisor,Chad	0%	
1.7.3	Structural	28 days	11/5/14	12/12/14	All	0%	
1.7.4	Submit Purchase Orders	0 days	11/28/14	11/28/14	All	0%	
1.8	**Reporting**	**158 days**	**9/18/14**	**4/27/15**		**32%**	
1.8.1	**Staff Meetings**	**71 days**	**9/18/14**	**12/25/14**	**All**	**50%**	
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		0%	
1.8.1.6	Staff Meeting 6	1 day	11/27/14	11/27/14		0%	
1.8.1.7	Staff Meeting 7	1 day	12/11/14	12/11/14		0%	
1.8.1.8	Staff Meeting 8	1 day	12/25/14	12/25/14		0%	
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**		**33%**	
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	0%	
1.8.3.3	Final Presentation	1 day	12/2/14	12/2/14	All	0%	
1.8.4	Midterm Report	0 days	10/31/14	10/31/14	All	100%	16,23,24,25,26
1.8.5	Final Report	0 days	12/5/14	12/5/14	All	0%	
1.8.6	Peer Evaluation I	0 days	10/30/14	10/30/14		100%	
1.8.7	Peer Evaluation II	0 days	11/25/14	11/25/14		0%	
2	**Prototyping**	**79 days**	**1/7/15**	**4/25/15**	**All**	**0%**	**22,33,56**

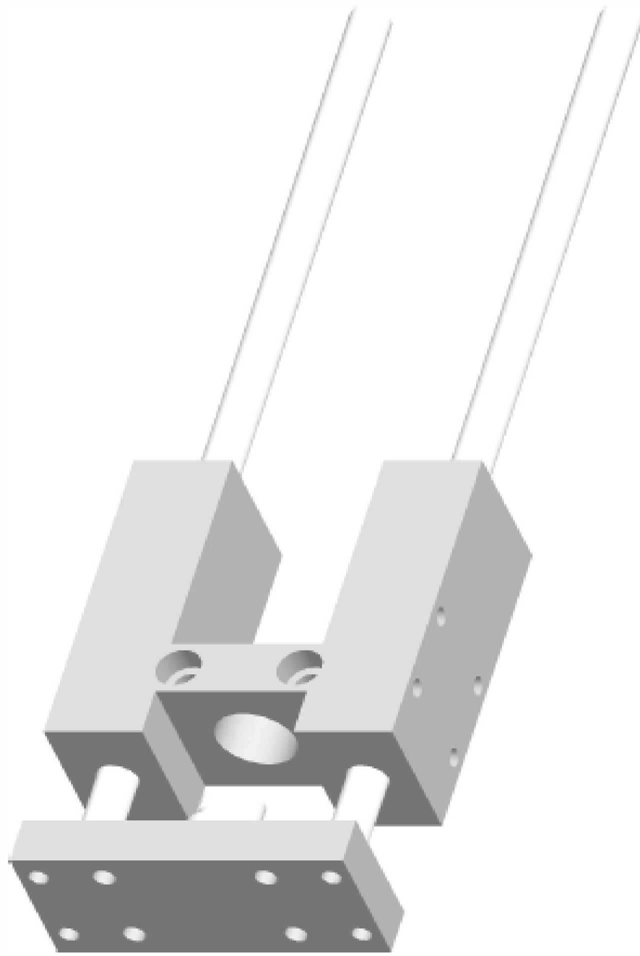
2.1	Finalize CAD Model Drawings	7 days	1/7/15	1/15/15	Charles,Chad	0%	
2.2	Scale Model	14 days	1/16/15	2/4/15	All	0%	56,60
2.3	Preliminary Testing	14 days	2/5/15	2/24/15	All	0%	61
2.4	**Analytical Methods**	**10 days**	**2/25/15**	**3/10/15**		**0%**	
2.4.1	MATLAB Model Refinement	10 days	2/25/15	3/10/15	Chase,Charles	0%	62
2.4.2	MathCAD Analysis Check	7 days	2/25/15	3/5/15	All	0%	62
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%***	***66,63,60,62,71***

8 Appendix 2 (Gantt Chart)



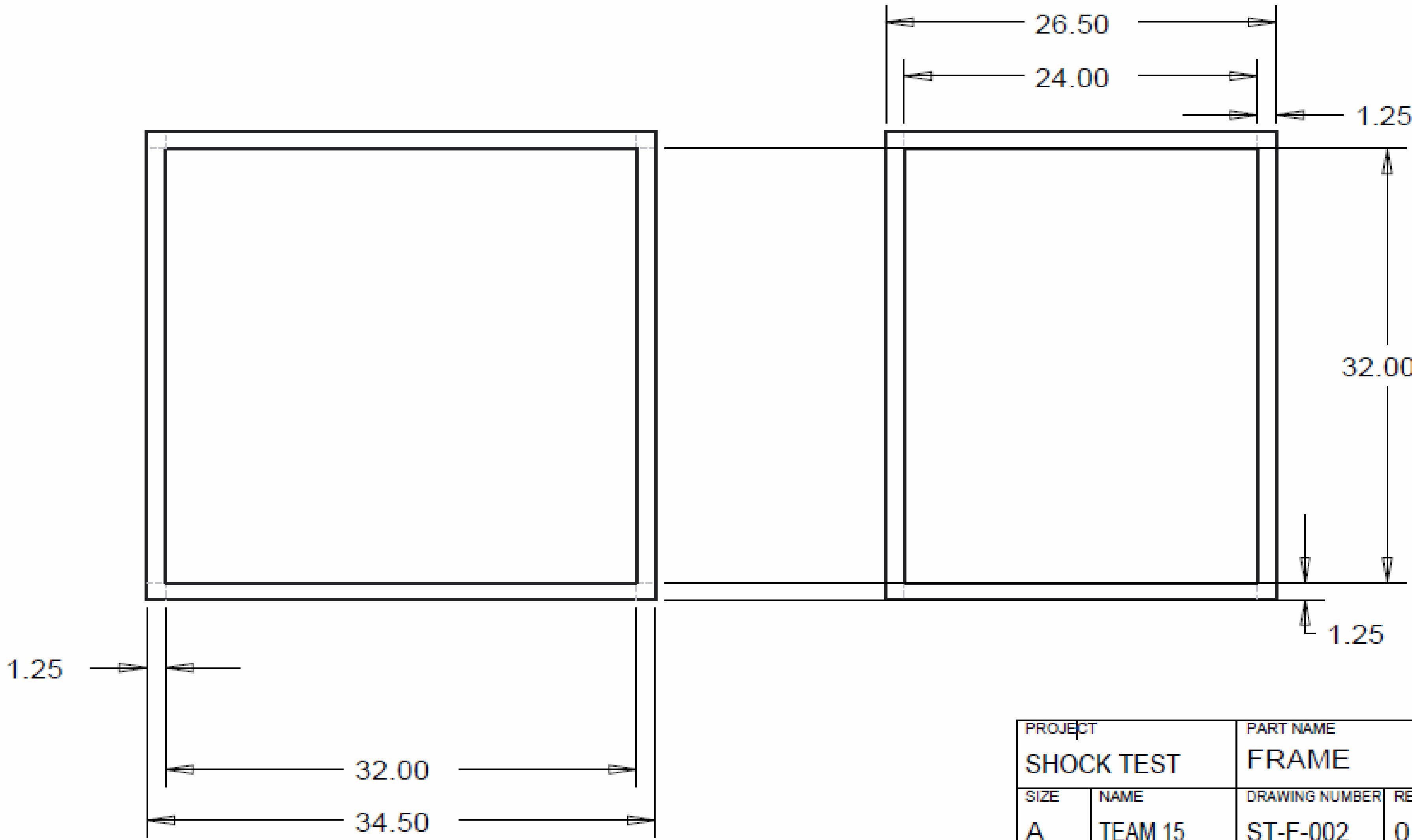
9 Appendix 3 - CAD Models





PROJECT			PART NAME	
SHOCK TEST			LINEAR GUIDE	
SIZE	NAME		DRAWING NUMBER	REV
A	TEAM 15		ST-LG-01	0
SCALE	DATE		SHEET	
0.75	30 OCTOBER 2014		1 of 1	

ALL DIMENSIONS IN INCHES



PROJECT			PART NAME	
SHOCK TEST			FRAME	
SIZE	NAME		DRAWING NUMBER	REV
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SCALE	DATE		SHEET	
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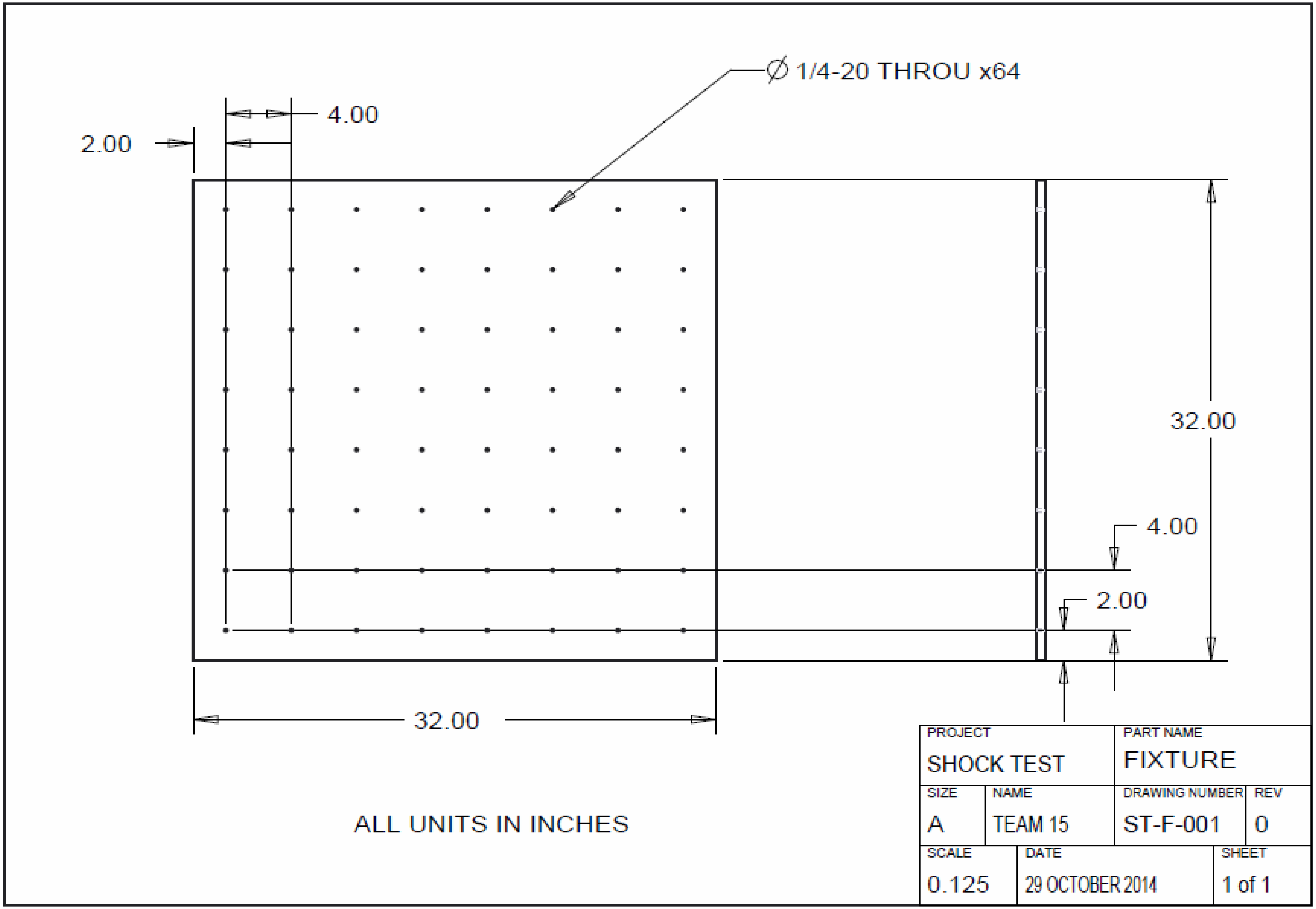
Ø 1/4-20 THROU x64
4.00
2.00
32.00
4.00
2.00
32.00
ALL UNITS IN INCHES
PROJECT
SHOCK TEST
PART NAME
FIXTURE
SIZE
A
NAME
TEAM 15
DRAWING NUMBER
ST-F-001
REV
0
SCALE
0.125
DATE
29 OCTOBER 2014
SHEET
1 of 1