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Repurposing Carbon Fiber Composite Through Mechanical Means

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ABSTRACT

Composite waste from the 777 aircraft is a growing concern for Boeing and amounts to an excess of 600,000 pounds of highly valuable carbon fiber being thrown away. Reclaiming this material has been a long sought-after goal of Boeings as the current solution is ever expanding landfills. The two current methods of recycling composite waste are chemically and mechanically processing. The focus of this paper will be demonstrating the feasibility of mechanically processing composite waste to increase storage efficiency before chemically treating to reclaim the actual carbon fibers. This paper provides a two-stage solution for the recycling question. The first stage involves the composite passing through a device with a series of rollers and a cam. The cam causes bending and localized fracture/delamination in the composite. The rollers and cam rotate at a rate of 88 revolutions per minute at a feed rate of 100 inches per minute. The device is powered by a 5 horsepower motor, a gear speed reducer and a series of chains and shafts. The second stage involves the damaged composite entering a second device which cuts the composite into strips to enable bulk storage. Testing will consider the feasibility of the system working to process the composite at a continues rate of 100 inches per minute. These results will enable improvements to the design and determine if the current model is feasible to fulfill the processing rate of 100 inches per minute.

Keywords: Composite, Recycling, Carbon Fiber, Mechanically

1: INTRODUCTION

1a: Description:

Boeing has a surplus of composite waste from the 777-9 aircraft wingskin and has a need to find a solution to recycle or repurpose the waste due to the highly valuable carbon fiber imbedded in the resin matrix. Currently there is an excess of 600,000 pounds of composite waste being thrown into landfills which is very likely millions of dollars being thrown away. Boeing would like to find a means to minimize this revenue loss. A device to conduct small scale delamination and shredding of composite samples was engineered to generate hard data for upscaling and future processing of the shredded composite.

1b: Motivation:

This project was motivated by a need for a device that would recycle waste composite and retrieve as much viable carbon fiber as possible. Boeing does not want to throw the composite scrap into a landfill due to the environmental impact as well as the enormous loss of revenue for not reusing the expensive carbon fiber. A later objective which was not pursued in this project was to determine practical applications for the recycled carbon fiber.

A secondary motivation was to enable more efficient storage of the composite before chemical processing by reducing the composite from long unwieldy strips to small pieces. These small pieces will be stored in bins before chemical processing commences.

1c: Function Statement:

Delaminate carbon fiber composite sample through bending.

1d: Requirements

- Require roller speed to be under 100 RPM
- Cannot cost more than 2500 dollars for materials and manufacturing

- Device cannot weigh more than 75 pounds

1e: Engineering Merit

The merit for this project was developing a means to reduce the volume of composite waste donated from 4 to 5 feet lengths to chips that can be stored in a storage bin before being processed chemically. All current methods for recycling long fiber carbon fiber composites involve chemical means. This will allow for repurposing in aerospace applications. For other applications such as strengthening laptop cases chips of carbon fiber will suffice.

1f: Scope of Effort

The scope of this project will focus solely on delaminating the composite layers and attempting to crush the resin matrix. Typical industrial processing of carbon fiber composite involves chemically removing the epoxy resin to preserve as much of the original length of the fiber as possible. For mechanical crushing the typical method in industry involved a large multi bladed cutting device which chips the composite into pieces. The device which was built was a small scale version of these industrial devices.

1g: Success Criteria

Success for this project will be measured by two main methods. First is being able to crush the resin matrix and second is the level of damage to the carbon fiber.

For being able to crush the resin matrix this mainly lies in developing calculations that show the required load and stress can be achieved using available equipment and staying with budget. If it can be demonstrated the resin matrix can be crushed to the extent the carbon fiber can be retrieved this method will be deemed a success.

For being able minimize damage to the carbon fiber through crushing is the second criteria for determining success of this project. The goal is extract carbon fiber in a condition that it can eventually be reused.

2: DESIGN & ANALYSIS

2a: Approach: Proposed Solution

This project was conceived as a holding device for collecting the bend and crush data for the composite specimens. Figure 1 below shows the first general outline for this project.

The general idea for this holding device is to support the specimen while using a machine press. The shape of the device is for easy machinability to keep the cost down.

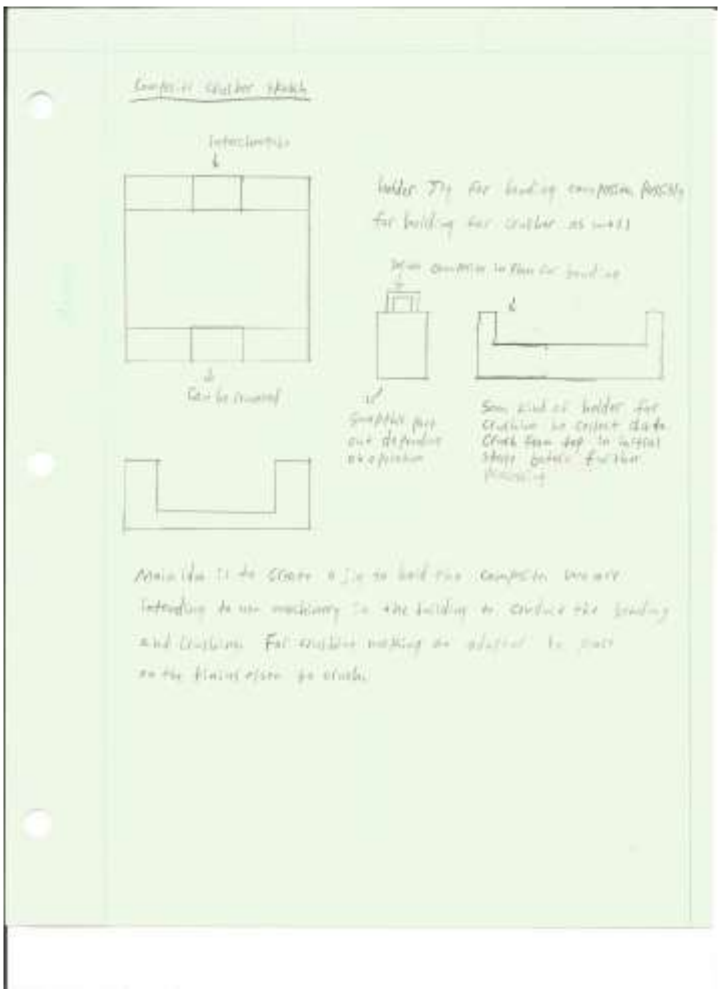


Figure 1: Initial drawing of holding device

Figure A.1 and A.2 in Appendix A show preliminary dimensions and force loading of the composite holder. The load to bend the beam on the initial beam test conducted by Dr. Craig Johnson was calculated to be 25,740 pounds. The machine used to bend the composite has a maximum loading of 60,000 pounds. The load on the beam arms was also calculated to be 30,000 pounds each. The next step will be to determine the material used in construction of the holder. The project has morphed from these original ideas to a device in which the composite will enter and be crushed using a camshaft with a system of gears and a motor. Appendix A.1 through Appendix A.9 are considered obsolete due to the changes in the project over time.

2b: Design Description

Appendix B houses the general outline of the design. The design involves four walls connected together with bolts to form a housing. Two sets of roller on each side of the housing provide a means to contain and advance the composite. A camshaft in the center will provide the bending force to fracture the composite.

2c: Benchmark

Current benchmarks are based on industrial machines used to chop scrap material. One example is listed below.

The Model 55033 XHD is a commercial scrap chopper designed for use with metal, plastic and fiberglass. It is a vertical gravity fed chopper.

Figure 2c: Benchmark scrap machine

Source: http://compactorsinc.com/scrap-chopper-model-5503-xhd/

2d: Performance Predictions

The performance of this device will depend almost entirely on having access to a powerful enough motor. The horsepower and torque requirements are going to have to be sufficient enough to provide 9000 pounds of force to fracture the composite. If this force is met there is no reason to believe the device will not perform its job of fracturing the composite.

The expected feed rate of the composite sample in the device is 100 inches per minute

2e: Description of Analysis

The analysis focused primarily on calculating the torque requirement to fracture the composite using a camshaft. The device had changed for several times over this process and the final form is an enclosed device which will have gears to turn rollers and the camshaft.

2f: Scope of Testing and Evaluation

The scope of testing will be running a piece of composite through the device to determine if it successfully fractured the composite to the level it can be shredded in the follow up device. Evaluation will be focused on the success of the fracture and shredding and the feed rate of the material in how much it can process over a to be determined period of time.

2g: Analyses

Two analysis presented in the Requirements, Analysis, Design and Documentation format will be presented below.
The first example is in Appendix A.12. The procedure is as follows.

1. Requirement
The requirement for this example is to determine the load when the composite fails and begins to delaminate.

2. Analysis
To conduct the analysis a test was conducted using a 6 inch by 3 inch piece of composite. This was loaded onto a three point bend jig and using the Tinius Olsen hydraulic press a load was slowly applied until the composite delaminated. This load was around 9,000 pounds. Once the delamination started the composite lost nearly all its strength and continued delamination occurred as the composite was slowly split in half. The loading never reached more than 1,000 pounds after the composite fractured.

3. Design

The data gathered from the analysis was used to determine the method of delamination. An elliptical shaft was chosen which would exert the required torque to bend and delaminate. Figure 3 below shows the torque and torsional shear stress calculation for three sample elliptical sizes. It was a challenge finding equations for this specific shape because the general shape is circular. These torques are best guesses based on the ability to find usable equations.

4. Documentation
Figures 1, 2 and 3 will be documented in A.10, A.11 and A.12 of Appendix A in the proposal and will be discussed in sections 2b and 2g of the proposal. Figure 4 will be documented in B.7 of Appendix B

The second example is in Appendix A.13. The procedure is as follows.

1. Requirements
The requirement is to determine if aluminum is suitable for use in the housing to keep the weight requirement below 50 pounds.

2. Analysis
The primary analysis is focused on the shafts and how they interact with the gears and bearings. As shown in Appendix A.13 the housing itself will not directly interface with the camshaft or the rollers but any loading placed on the rollers and camshaft will be shifted over the gears through the bearing.

3. Design
Through the analysis the design decision to use 6061 and 2024 Aluminum was chosen. This was essentially a requirement because the housing would have weighed over 70 pounds if steel was used and Titanium is not a cost effective solution.

4. Documentation
The documentation for this R.A.D.D. sample is in Appendix A.13.

i: Design Issues

The most glaring design issue is the motor and gearing. It was calculated that around 9000 inch-pounds of torque are required to fracture the composite based on the current camshaft design. If this torque is not easily achievable upon further exploration of possible motor sources and gearing setups a review of the camshaft would occur.

ii: Calculated Parameters

The primary calculated parameter of issue is the 9,000 pound force requirement to fracture the composite and the required 9,000 inch pounds of torque that needs to be generated by the motor and gear system to transmit to the camshaft onto the composite sample.

iii: Best Practices

Best practices for the project primarily deals with standardizing all of the holes and picking bushings and fasteners in a uniform size.

2h: Device: Parts, Shapes and Conformation

Appendix B lists the principle components of the project. The primary parts of the assembly are the top, side, bottom, roller and camshaft. Additional parts will be the gear and motor setup once these are determined. Fasteners and bearings are support items. The shape of the assembly will essentially be a box with the rollers and camshaft on the inside. The fasteners will screw into pre drilled holes in the bottom, sides and top. The gear and motor will be on the external part of the assembly. The assembly will conform to standard sizes for the roller, camshaft and fasteners. A standard motor and gearing mechanism will also conform to a standard speed reduction.

2i: Device Assembly, Attachments

Appendix B.4 shows an exploded view of the assembly. The motor and gearing will be on the outside in some configuration.

2j: Tolerances, Kinematics, Ergonomics

The tolerance requirement is not critically tight on this project. This is a trial and error project and it is likely adjustments to placements of the rollers and camshaft will have to take place so it is likely a sliding raid will eventually be installed. The main kinematics will be the rollers, camshaft, gears and motor. The housing will be stationary. The housing to expected to weigh close to 50 pounds without a motor or gears. This was reduced from almost 80 pounds by replacing the steel with aluminum.

2k: Technical Risk Analysis, Failure Mode Analyses, Safety Factors, Operation

The primary technical risk analysis involves failure to acquire the required motor. The machine will not operate without this and thus is the largest risk that has to be mitigated. This will be mitigated by seeking out knowledgably staff who either have access to the required motor or know where to go to get additional assistance.

Failure Mode Analyses is primarily of use if the camshaft and/or the gearing fails while it is attempting to fracture the composite. The rollers should not experience a high enough force to fail. The safety factor selected for the camshaft is 1.3, this was the largest value given the required one inch diameter on the camshaft. The operation of the device will involve a motor connected to gears rotating two front rollers. These will draw in the composite to a spinning camshaft. Two rollers behind the camshaft will provide extra stability for the camshaft to fracture the composite.

2L: Analysis Modifications During Construction

There were several modifications made necessary during the construction phase. The first major requirement was the dimensions not being correct on ordered material. Primary examples being the camshaft and the sides. The camshaft was designed to be one foot in length, but the ordered material was closer to eleven inches. In retrospect two feet of material should have been ordered. The original side height was eight inches, but six inches was erroneously ordered. This turned out to be better for the design as a more compact shape was determined to be more desierable.

Besides material issues a major analysis that took place was not using gears to drive the two front rollers but instead connecting the gearbox directly to the top roller and using a chain to drive the camshaft. Figure A.14 and A.15 in the appendix demonstrate the calculations made to determine if a belt or chain would be appropriate. Due to the low RPM of 88 as per requirement a belt cannot be used. The calculation for the chain was limited in large part to the relatively small size of the device. A 100 pitch chain was chosen due to the sprocket size being smaller as per the calculation. Near the end of the project it was determined that this chain is well beyond the torque requirements of the device and a smaller chain and sprocket will be chosen when further refinement of the device takes place.

The last major change made in the analysis was creating slots in the slides so the shafts could be adjusted. This was determined necessary because the thickness of the composite waste is not uniform and applicable tension needs to be maintained on the composite waste to allow for the rollers to move the material forward. The second reason for this change was the chain. It was deemed necessary to allow for adjustment of the chain tightness by physically moving the shaft into place and securing it in place with a custom machined wedge.

3: METHODS & CONSTRUCTION

3a: Construction

i: Description

This project was conceived as a joint venture with Boeing to develop a prototype to recycle composite waste. The analysis and design were done entirely at CWU with assistance from Dr. Craig Johnson and John Lockleer from Boeing. Funding was generously given by the Joint Center for Aerospace Technology Innovation. Currently tube bending machinery is being looked at to delaminate the composite into strips and possibly chopping up the stripes. A device will be made to house the blades for chopping. Removing the carbon fiber from the resin will be the final step.

The final construction of the device will work as follows. The composite waste is loaded into the device so it is sitting between the front and rear rollers. A spring loaded set of rollers will drive the material forward while rotating cams bend the composite. The composite will be damaged to some degree and exit the device. From here it will enter into the cutter counterpart and be cut into strips. Due to communication issues between this device and the cutting device there is some difficulty in how the material will feed from this device to the cutting device. These issues will be discussed in the testing sections below.

ii: Drawing Tree, Drawing ID's

The drawing tree is located in Appendix B.1. It provides a breakdown of the assembly to the sub-assembly and the sub-assembly to the individual components to those sections. The Drawing ID's are Appendix B.2 to B.31 and provide each individual component as well as the disposables (fasteners and bearings).

A large number of revisions were made during the construction phase as unexpected errors and issues came up. Most than half of the drawings are obsolete and have been marked as such.

iii: Parts list and labels

Appendix C gives the parts list and labels required for the assembly. It was fortunately discovered some of the material could be used for multiple parts which helped reduce the cost of materials. The sides and bottom were the most expensive because they are the thickest.

More material was ordered than was needed due to changes made at the last minute to the project. There was very little waste of the actual material used to construct the housing but the gears and possibly the couplings are not needed due to different possibilities of mounting during the testing phase.

iv: Manufacturing issues

Unforeseeable manufacturing issues involve not having the right equipment to or size to drill or tap a hole. This is unlikely to be an issue.

Manufacturing issues are divided into two fundamental areas. The first is material sizing error and the second is error in machining.

The material sizing error was parts being under the required dimensions and causing a change in the design. The camshaft was the biggest culprit of this. The ordered length was supposed to be one foot but it arrived at closer to eleven inches and this caused some issues with alignment. In retrospect two feet should have been ordered to prevent this from happening. Other material had to be milled to size but this was not a primary issue.

Errors in machining make up the bulk of the problems with the device. There were substantial machining errors which is largely in part of the inexperience of the operator. The sides, top and bottom making up the housing were not machined in an optimal order which caused a large amount of misalignment. The top was drilled first because it was assumed the sides would line up properly. There was an error in cutting the length of the sides and this caused them to not be even in length. A workaround was made by aligning the sides up in a manner so the holes for the bottom plate would line up. These holes were then drilled because the CNC mill was not utilized from the start. The large number of holes that needed to be drilled should have all been done at once to allow for optimal alignment and additional material should have been ordered earlier so the lengths of the sides would line up.

This project would not have been completed without the machining expertise of Matt Burvee and Ted Bramble. These two should have been consulted from the beginning of the manufacture process to streamline the machining from the beginning and ending with a better project.

v: Discussion of assembly, sub-assemblies, parts, drawings

The assembly is made up of two side pieces, a top and a bottom piece. These will be connected via fastener and are located in Appendix B.5 through Appendix B.7. Four rollers will provide advancement for the composite material. This is located in Appendix B.8. The camshaft that will be doing the actual fracturing is located at Appendix B.9

The final assembly consists of the top, two sides and bottom pieces to make the assembly. These are connected by fasteners. Inside the assembly are four shafts used as rollers, a camshaft and three cams secured in place by keys. On the outside of the cam and the top roller of the input side are chain sprockets with a chain attached. The current chain was selected is well above the torque requirement and so this is likely to be reduced to smaller chain.

Figures B.1 to B.31 show the entire inventory of components for the device. There were multiple revisions to most of the components due to either unforeseen changes in the design or change in requirement due to material not meeting the specified requirements.

4: TESTING METHOD

i: Introduction

The testing of the composite recycling device involves delaminating the composite in the bending device and cutting the delaminated composite into strips with the cutting device. The RPM was set to 88 by using a 20:1 gear speed reducer and the final torque was calculated to be 3,580 in-lbs. Actual testing was not conducted because of the complexity of building a mounting device to hold the motors and delamination devices but a detailed plan to do so in the future will be discussed below.

ii: Method

The composite repurposing was tested in two stages. The first stage was to delaminate the composite into individual layers. This was done by feeding the composite through a delamination device. Two motors power the devices, one for the delamination device and one for the cutting device. The motors cause a camshaft to rotate which causes bending and delamination of the composite as it is being fed through. The cutting action is in the second device which will cut the devices into strips. Tests were conducted in November of 2017 on the Tinius Olsen and it was fond a load of 10,000 pounds is required to delaminate. This gives a baseline for how much force the camshafts will have to generate to cause delamination

The proposed testing setup has a yet unresolved issue of mounting. There are two motors, a crushing device, a speed reducing gearbox and a cutting device that need to be mounted onto a solid surface that will ideally be mobile. A further issue is the vertical nature of the cutting device. One proposed solution is to have an inclined plane to aid in the movement of the composite waste through the crusher. The motor will be mounted to the solid surface and connected to the gearbox by two shafts and a coupler. The gearbox would be mounted in alignment with the motor and have two shafts and coupler connected in alignment with the crushing device. This proposed setup will be difficult because there is little room for error in alignment.

A second proposed setup is using a series of steps and chains/sprockets. The motor would be on the top step with a chain/sprocket connected to a sprocket and shaft on the gearbox on the next step below. From the exit side of the gearbox a chain and sprocket would connect to the crushing device on the step below. This setup is unrealistic to develop in the time span and can be treated as a project in itself. It is advised to consider this option for future updates on this projects.

It was determined that due to the major safety concerns that need to be built into any mounting device it was not practical to develop it for this specific project. A future project continuing the construction of mounting using the already completed devices would be ideal.

iii: Test Procedure description

The testing itself will be straightforward once the mounting issues are resolved. A sample of composite waste will be loaded into the front of the device and fed through it. The cams will damage the composite to make it easier for the cutting device to cut the composite into strips. How the cutting device will do this is outside the scope of this project.

The weight of the mounting assembly and all components is expected to be around 500 pounds so the entire assembly will not be mobile. There are also considerations of supplying enough power to two 13 amp motors without blowing out circuit breakers. Another consideration is airborne particles of carbon fiber and resin plastic so adequate ventilation must be present.

A full description of the testing procedure can be found in Appendix H.

iv: Deliverables

Expected deliverables were detailed reports on expectations of tests vs real outcomes of tests.

Improvements to the design of the composite recycler will be the primary deliverables after testing is concluded. There are many improvements that can be made to this design and it is a viable option for future projects.

5: Budget/Schedule/Project Management

5a: Proposed Budget

Proposed Budged is $5000 courtesy of the JTATI. This is divided up into $2500 between the two partners for this project. Additional self-funding is an option depending on the requirements of what needs to be purchased. The final budget along with all purchased components can be found in Appendix C.

i: Discuss part suppliers, substantive costs and sequence or buying issues

The entirety of the frame, rollers and camshaft can be manufactured in house with material from McMaster-Carr. Total costs for this parts is under $500. The primary issues will be obtaining a powerful enough motor without going over budget. It would be ideal to have access to a powerful enough one in house.

The original proposed budget had the majority of the housing along with the cam, camshaft, rollers, screws and bearings. The motor, gears and gearbox had not yet been decided. The total cost at this point was $441.74. The motor and gearbox which were being looked at were projected at $738.23 and $372.95 respectively. The JCATI funding of $5000.00 is more than sufficient to account for the cost of these components.
The parts that have been ordered will be broken down into two categories. Parts that have been ordered and arrived and parts which have been ordered and not yet arrived.

The parts that have been ordered have worked as intended with a few exceptions. The screws are too long due to an error with the dimensions in the side but are cheap enough that they can be easily replaced. The bearings for the rollers are also wrong because the roller diameter was adjusted when determining the requirements for the chain. These are again cheap enough that they do not propose a problem with reordering.
Parts left to be bought are the keyed shafts connecting the motor to the gearbox and the gearbox to the roller shaft. Also a mounting for the motor, gearbox and composite crusher will be constructed likely from scrap obtained from the machine shop. In addition a cover for the exposed gears on the outside of the device will be made for user protection. A final order will

need to be compiled within the next week and placed based on what is available to use in the scrap section of the machine shop.

There was some waste due to parts being ordered and frequent changes in the design not requiring these parts. The allotted budget was $2500 and of that $2320.31 was spent. Additionally $71.42 of private money was spent on largely last minute items. Upon review there are many areas were significant savings could have taken place. Many disposable items such as bushing should have been ordered at the end due to changes in shaft diameters as the machining process

ii: Determine labor or outsourcing rates & estimate costs

All labor is planned to be done in house. The machining is simple enough with minimal help. If changes to any part of the project occur this would change the possibility of outsourcing.

All labor was conducted by the operator, Ted Bramble and Matt Burvee. All labor costs were typical salary costs. No work was outsourced.

iii: Labor

Labor will primarily be done by the principal student working on this aspect of the project. It is estimated Friday will be spent conducting extra work in the machine shop.

Roughly 60% of the labor was conducted by the principal operator. The remaining 40% was from direct assistance by Ted Bramble and Matt Burvee.

iv: Estimate total project cost

The higher end estimation for this project is near $1000. This is mainly due to the gears which will have to be ordered once the motor is determined. If the motor needs to be purchased this value will jump up depending on the price of the motor.

The total cost of the project was $2,391.73 and additional components are expected to be ordered in the final phase of the project. The budget itself was under the allotted amount although some of components were purchased by the principal student directly.

v: Funding source(s)

The primary funding source is JTATI which graciously donated $5000 for the project.

5b: Proposed schedule

The proposed schedule is listed in Appendix E. The manufacturing steps were added in due to the vastly added time these will create.

The schedule assumes material would be obtained on time. There was an initial delay of two weeks of starting the manufacturing due to a misunderstanding of how the JCATI funding was to be distributed. Once the material arrived it was a relatively steady process of manufacturing with delays due in large part to scheduling time for Matt Burvee to assist with cutting keyways into the cams and shafts and Ted Bramble with multiple CNC lathe and mill operations.

i: High level Gantt Chart

The high level gantt chart involves the proposal as a whole, analyses, documentation, proposal mods, part construction, device construct, device evaluation and 489 deliverables.

The Gantt chart in Appendix E will be broken down. The estimated time to completion was 529 hours minus the estimated 100 hours for the testing phase. The computed time to completion was 553 hours. It was expected this project would take longer to complete than what was expected. The major causes of this were multiple revisions of designs. Material would be ordered and the dimensions would not match what was planned for. This would cause a redesign in solidworks and creating new drawings. In cases where machining had taken place this would result in having to decide if the part was acceptable as is or having to be scrapped. Options for scrapping pieces were minimal mainly due to the time constraint to finish the project.

ii:Define specific tasks, identify them, and assign times

These are listed in Appendix E. Each task is identified and times have been assigned.

The times were tracked as the project progressed. The drawings took much longer to finish than what was initially expected because of the multiple revisions that took place with nearly all of them. The machining generally took less time than what was expected because of the rapid ability of CNC machining

iii: Allocate task dates, sequence and estimate duration

Dates were listed for the proposal phase in Appendix E. All aspects have been noted with green boxes.

Each subsection is identified with its own color. The estimated dates of completion were not accurate because of multiple delays in material shipping as well as delays in machining due to availability of Matt Burvee/Ted Bramble for specific machining tasks. One notable delay was keying the cams. This was planned for the end of February but was not completed until the first week in March. These delays did not impede the completion of the project but required a shuffling around of priorities.

iv: Specify deliverables, milestones

These are specified in Appendix E.

v: Estimate total project time

The estimated time was over 500 hours. This is likely excessively high but takes into account all of reworking on the proposal.

The actual time so far is 553 hours so this estimate was not too far off. The planned time will likely exceed 600 hours due to mounting and other requirements in the testing phase.

vi: Gantt Chart

The Gantt Chart is in Appendix E

5c: Project Management

i: Human Resources: You are the most important human resource. Other HR may include mentors, staff, faculty, etc.

Primary HR is the ETSC and MET staff at CWU as well as John Lockleer from Boeing.

ii: Physical Resources: Machines, Processes, etc.

The Tinius Olsen hydraulic press was critical to determine the specifications needed for the camshaft. Additional hardware may also be found in determining the motor.

iii: Soft Resources: Software, Web support, etc.

Primary soft resources are the internet for finding information on carbon fiber and McMaster-Carr for supply needs.

iv: Financial Resources: Sponsors, Grants, Donations

JTATI is the sole source of financial assistance for this project.

6: Discussion

6a: Design Evolution / Performance Creep

The design evolved from a mounting device to hold composite to an enclosed structure in which a rotating camshaft would fracture the composite. Performance will depend primarily on the motor that is obtained and upon the gear reduction that is utilized.

The final design has some significant changes compared to when the initial design was completed. This was mainly due to the addition of a chain and sprocket and the requirements of adding slots to adjust for the tightness of said chain. In addition it was determined the rollers needed to be adjustable because the composite waste is not uniform in thickness and a spring system was set to maintain proper tension.

6b: Project Risk analysis

Project Risk will be analyzed using six criteria. Feasibility, cost, schedule, environment, resources and interest. These will be explored below.

1. Feasibility

The feasibility of this project is defined by the ability to fracture carbon fiber composite and cut the fractured pieces. Experimentation has shown the composite will fracture at a bending load of 9000 pounds. The key to the feasibility then is to translate this bending load into a torque and design a motor and gear system that will generate the required torque utilizing a camshaft to fracture the composite.

2. Cost

Cost is typically the most important aspect in risk analysis. External funding for a project is typically the preferred method. This specific project has been funded graciously by the Joint Center for Aerospace Technology Innovation (JTATI) and should supply sufficient funding to complete the project.

3. Schedule

Schedule is a very important aspect and a time table has to be developed to ensure the project is completed successfully. This was accomplished through use of the GANTT chart. A detailed weekly schedule was completed which shows what has to be done and when. This will specifically become important during the construction phase to ensure parts are ordered and/or manufactured in time to put the design together.

4. Environment
The environment of the school prohibits explosives and building anything too big. For this project these conditions do not apply.

5. Resources
Resource requirements for this project will involve material costs and manufacturing. As noted above the entirety of material cost should be handled by funding. Manufacturing will range from outside contracting to in house work.

6. Interest
The topic of composite recycling is of big interest due to the nature of the industry in becoming more green. The project itself has the potential to grow in future years and can become a fully functional machine.

6c: Success

Success will be determined by how damaged the composite is as it exists the bending machine and enters the cutting machine. From there success will be determined in how the strips are cut it specified strips

6d: Project Documentation

The documentation will be handled in a notebook for the manufacturing and testing sections. For manufacturing this will help to track how purchases are going, when products arrive and how long it is taking to machine the parts. In addition, machine makeup sheets will be made to track the exact processes that will be used in machining. For the testing section the tests will be tracked on sheets and analyzed to see how they performed.

6e: Next phase

The next phase is to begin construction. This will commence in January.

The construction phase has been completed, the next phase is testing which will begin near the end of March.

7: Conclusion

7a: Design title

The project is to repurpose carbon fiber composite through mechanical means. This will be done by delaminating the composite using a rotating camshaft. The delaminated composite will then be fed into a cutting device which will cut the composite into strips for storage and later processing

7b: Analysis

Analysis focused around determining the required load to fracture the composite. Once this was determined the next step was to determine the required horsepower and torque required to generate that loading. This will be conducted upon further investigation during the manufacturing process.

7c: Design predictions

Design predictions are with the correct motor and gearing system the composite will fracture without difficulty and advance through to the cutting machine at the other end.

The composite waste will be inserted into the composite crusher. The device will be turned on and cause some level of damage to the composite. The damaged composite will then exit the composite crusher and enter the composite cutter where it will be cut into strips. How the waste will be collected is outside the scope of this report.

7d: Results

The primary purpose of this project is to investigate the possibility of recycling a large volume of composite waste by crushing and cutting. There are a number of indications which could determine how successful this task was. The nature of this project proved to be highly experimental and will likely require further refinement once the first round of testing is completed. It is expected this will be a multi year project where each subsequent year will build upon knowledge gained from the previous year(s)

The first of these is will the device be able to crush to the composite to some level. This can be measured by the durability of the device to handle the stresses of bending the composite waste. There were some fundamental issues with alignment due to construction errors that may affect the durability of the device. Initial testing of the composite involved using a three point bend with a 3 inch by 3 inch sample. The final composite waste piece will be a several foot long piece that is unknown in how it will bend and damage. Any amount of damage to the composite piece will result in a successful test.

The second indication will be the integration of the crushing component and the cutting component. Logistics of mounting aside the whole process of recycling involves the composite running through the crushing device and directly into the cutting device. This accomplishment will demonstrate the ability to feed composite into two separate machines doing two separate actions.

The final indication is the ability to modify and improve the design. The final design ended up being modification friendly and based on the tests conducted it can be readily improved. Once data is collected it will be easier to determine what possible medications need to be made The slits cut into the device allow for adjustments to be made in terms of the chain and sprocket and the rollers.

8: Acknowledgements: For gifts, advisors and other contributors

Joint Center for Aerospace Technology Innovation for the generation $5,000 donation, John Lockleer and Boeing for the opportunity to work on this composite recycling project and Dr. Craig Johnson for assistance and submitting the research for publication. In addition Ted Bramble and Matt Burvee for future assistance during the construction phase and all the additional ESTC staff and faculty.

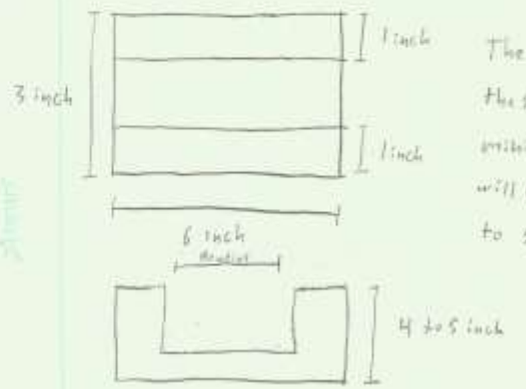
Matt Burvee and Ted Bramble were instrumental in machining the project as well as providing advice for how to possibly mount the device. The use of the CNC lathe/mill without having prior experience would have been impossible without Ted Brambles assistance. Dr. Craig Johnson and Charles Pringle were instrumental in analysis calculations as well as general improvements to the design as the process went on.

9: References:

Primary reference was the Machine Elements in Mechanical Design textbook by Robert L. Mott and Statics and Mechanics of Materials by R.C. Hibbeler

APPENDIX A - ANALYSIS

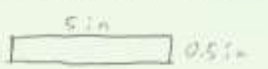
Composite holder dimensions and expected loading:



The goal is to minimize the size of the device to minimize cost. The device will need to be strong enough to support the loading

The 156 ksi will change once data is collected.

A standard specimen size will be cut and a test will be conducted to determine the load and stress needed to begin delamination. Once this data is gathered the holding device can be specified to include material of sample



Template size for composite specimen

Load calculation to bend composite $\sigma = \frac{P}{A}$

$156{,}000 \text{ psi} = \frac{P}{A}$ Area of die to bend is $0.055 \text{ in} \times 3 \text{ inch} = 0.165 \text{ in}^2$

$= 156{,}000 \text{ psi} = \frac{P}{0.165 \text{ in}^2} \Rightarrow P = 156{,}000 \text{ psi} \cdot 0.165 \text{ in}^2 = \boxed{25{,}740 \text{ lbs}}$

minimum support on arms

Figure A.1: Preliminary dimensions and load calculation on original composite test

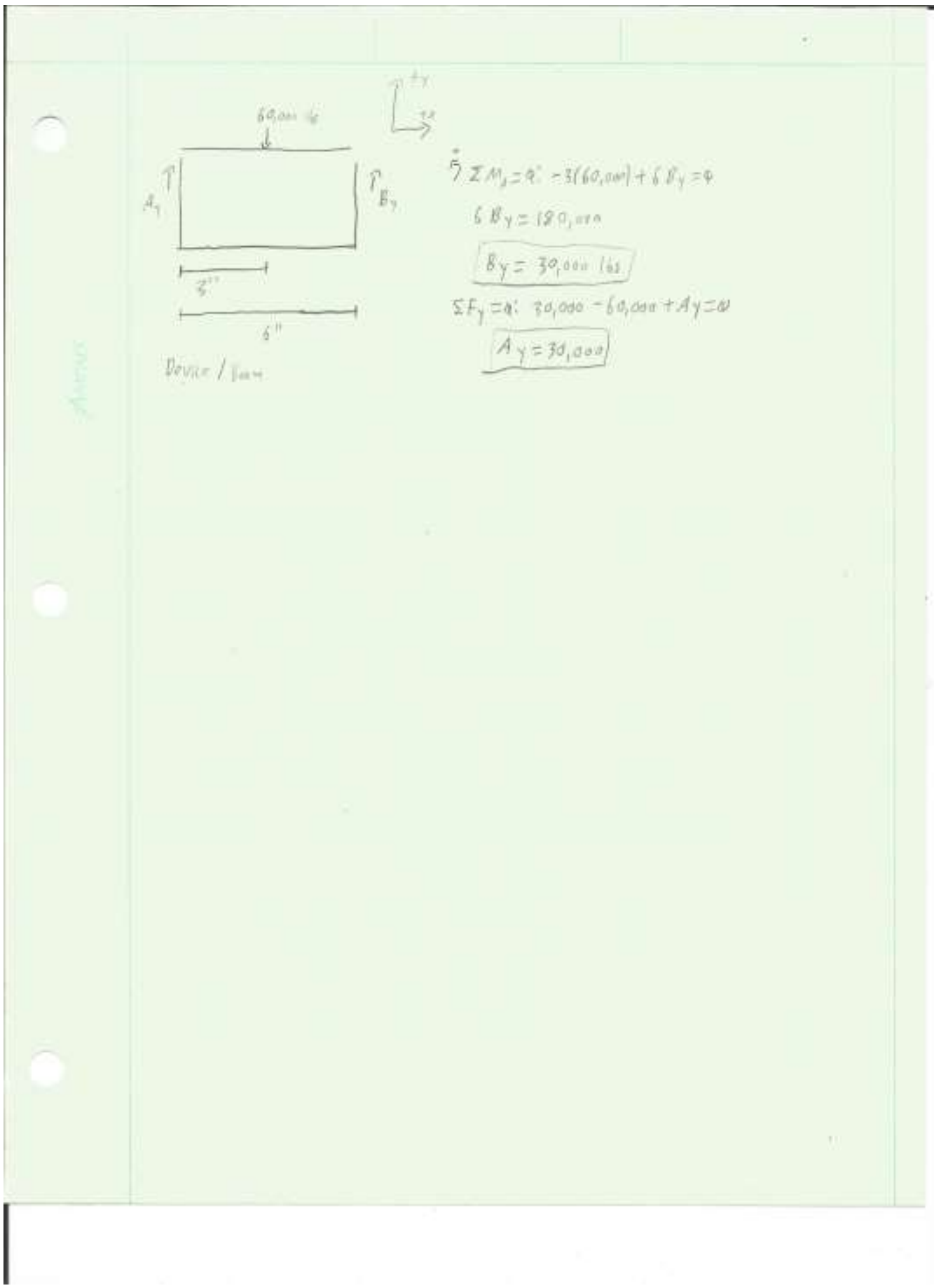


Figure A.2: Load calculation on composite jig arm

$\frac{1}{3}$

Requirement

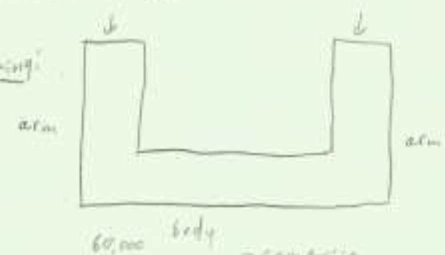
Device to hold composite sample during three point crush testing. Device has to be strong enough to withstand a maximum of 30 tons of loading. The actual loading will be less but wanted to spec the holder to maximum load for unforeseen future events.

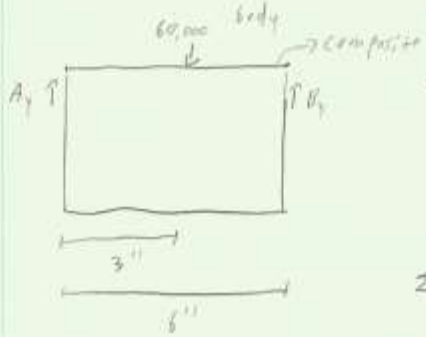
Analysis:

Assumption: using some form of steel / displacement of .001 inch (one-thousandth)

use $\delta = \frac{NL}{AE}$ and solve for L to find height of the arms and middle section. Set

Drawing:





$\circlearrowleft \Sigma M_A = 0: \; -3(60{,}000) + 6B_y = 0$

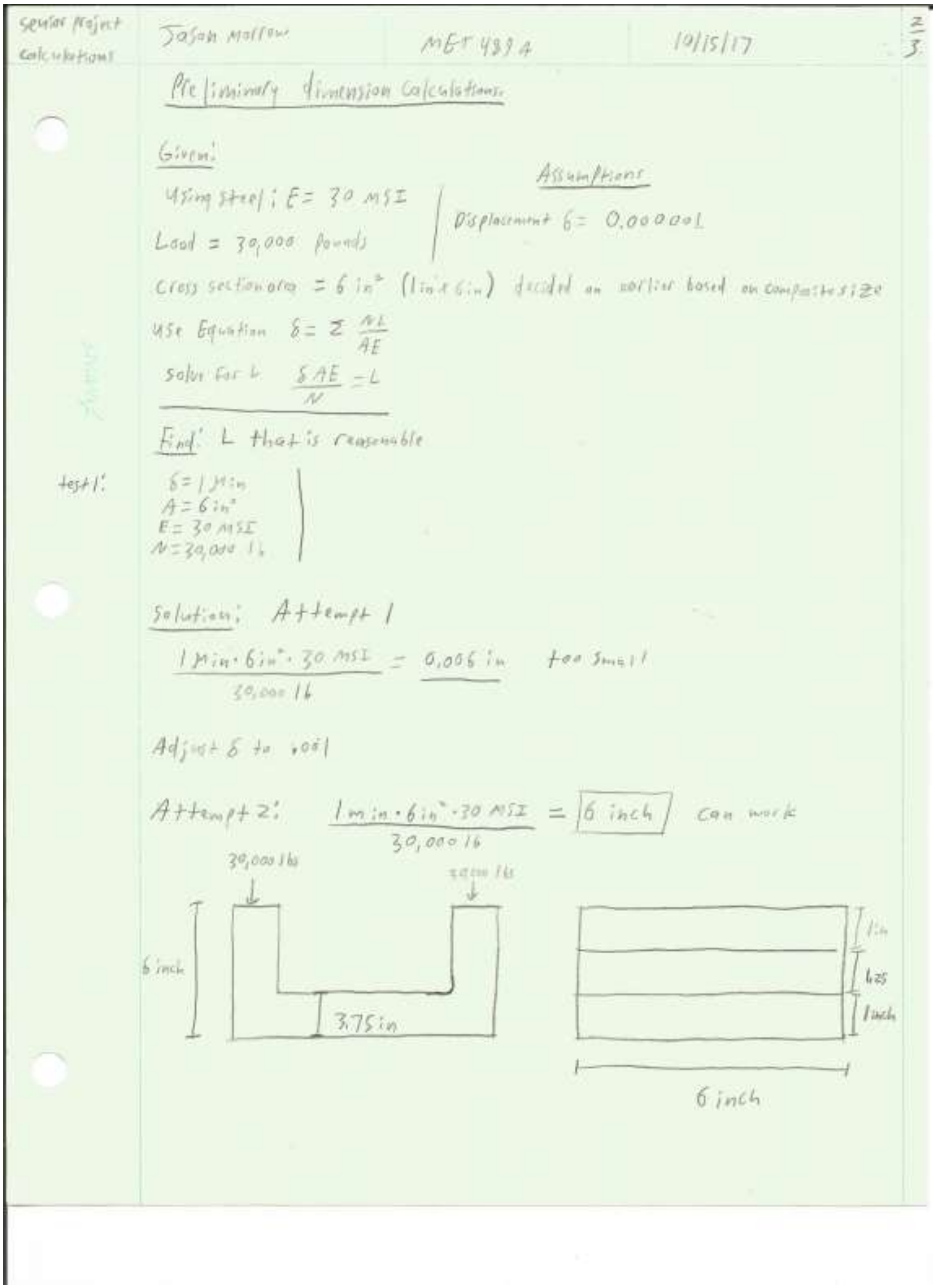
$6B_y = 180{,}000$

$\boxed{B_y = 30{,}000 \text{ lbs}}$

$\Sigma F_y = 0: \; 30{,}000 - 60{,}000 + A_y = 0$

$\boxed{A_y = 30{,}000 \text{ lb}}$

Figure A.3 Requirement and Analysis for composite holder



Senior Project Calculations | Jason Mollow | MET 489 A | 10/15/17 | 2/3

Preliminary dimension Calculations

Given:

Using steel; E = 30 MSI

Load = 30,000 pounds

Assumptions

Displacement δ = 0.000001

Cross section area = 6 in² (1in x 6in) decided on earlier based on composite size

Use Equation δ = Σ NL/AE

Solve for L δAE/N = L

Find: L that is reasonable

test 1:

δ = 1 μin
A = 6 in²
E = 30 MSI
N = 30,000 lb

Solution: Attempt 1

1 μin · 6 in² · 30 MSI / 30,000 lb = 0.006 in too small

Adjust δ to .001

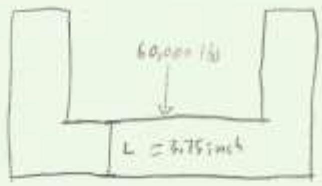
Attempt 2: 1 min · 6 in² · 30 MSI / 30,000 lb = 6 inch can work

Figure A.4 Continuation of Analysis for composite holder

Senior Project Calculations

Jason Morrow | MET 489 A | 10/15/17 | 3/3

Preliminary dimension calculations part 2



Given: Using steel: $E = 30$ MSI

$N = 60{,}000$ lbs

$A = 7.5\,in^2$ (1.25 in × 6 in)

Find: L for base

Solution:

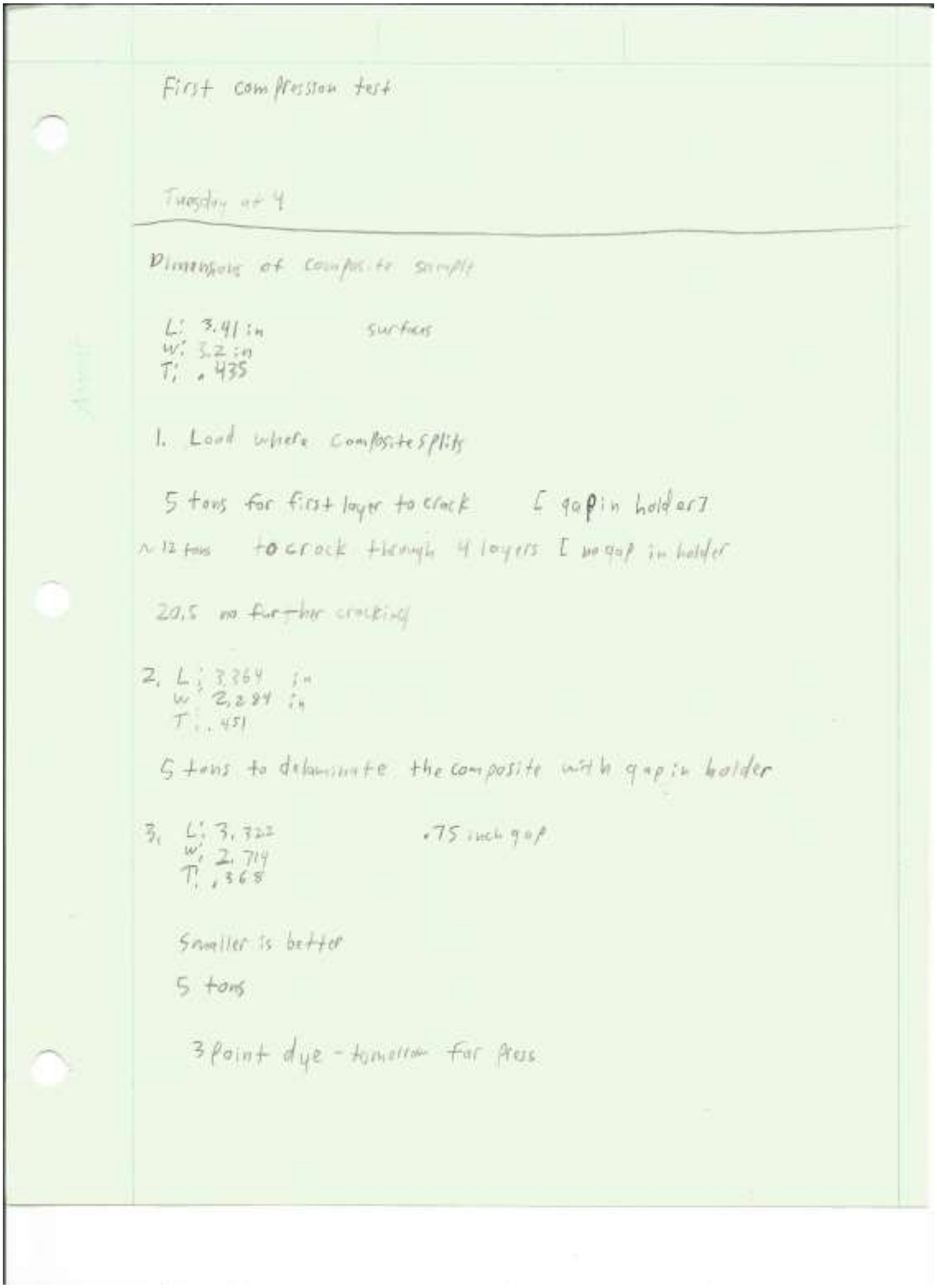
$$\delta = \Sigma \frac{NL}{AE} \rightarrow NL = \delta AE \rightarrow L = \frac{\delta AE}{N}$$

$$= \frac{1\times10^{-7}in \cdot 7.5\,in^2 \cdot 30\,MSI}{60{,}000\,lb} = \boxed{3.75\,inch}$$

Design:

Based on analysis a prototype 3D module is created. This will serve as a base for future additions involving a roller system with gears

Figure A.5 Conclusion of Analysis and Design for composite holder



First compression test

Tuesday at 4

Dimensions of composite sample

L: 3.41 in   surfaces
W: 3.2 in
T: .435

1. Load where composite splits

5 tons for first layer to crack   [gap in holder]

~12 tons to crack through 4 layers [no gap in holder

20.5 no further cracking

2. L: 3.364 in
W: 2.284 in
T: .451

5 tons to delaminate the composite with gap in holder

3. L: 3.322   .75 inch gap
W: 2.719
T: .368

Smaller is better

5 tons

3 point dye - tomorrow for press

Figure A.6 First crush test data

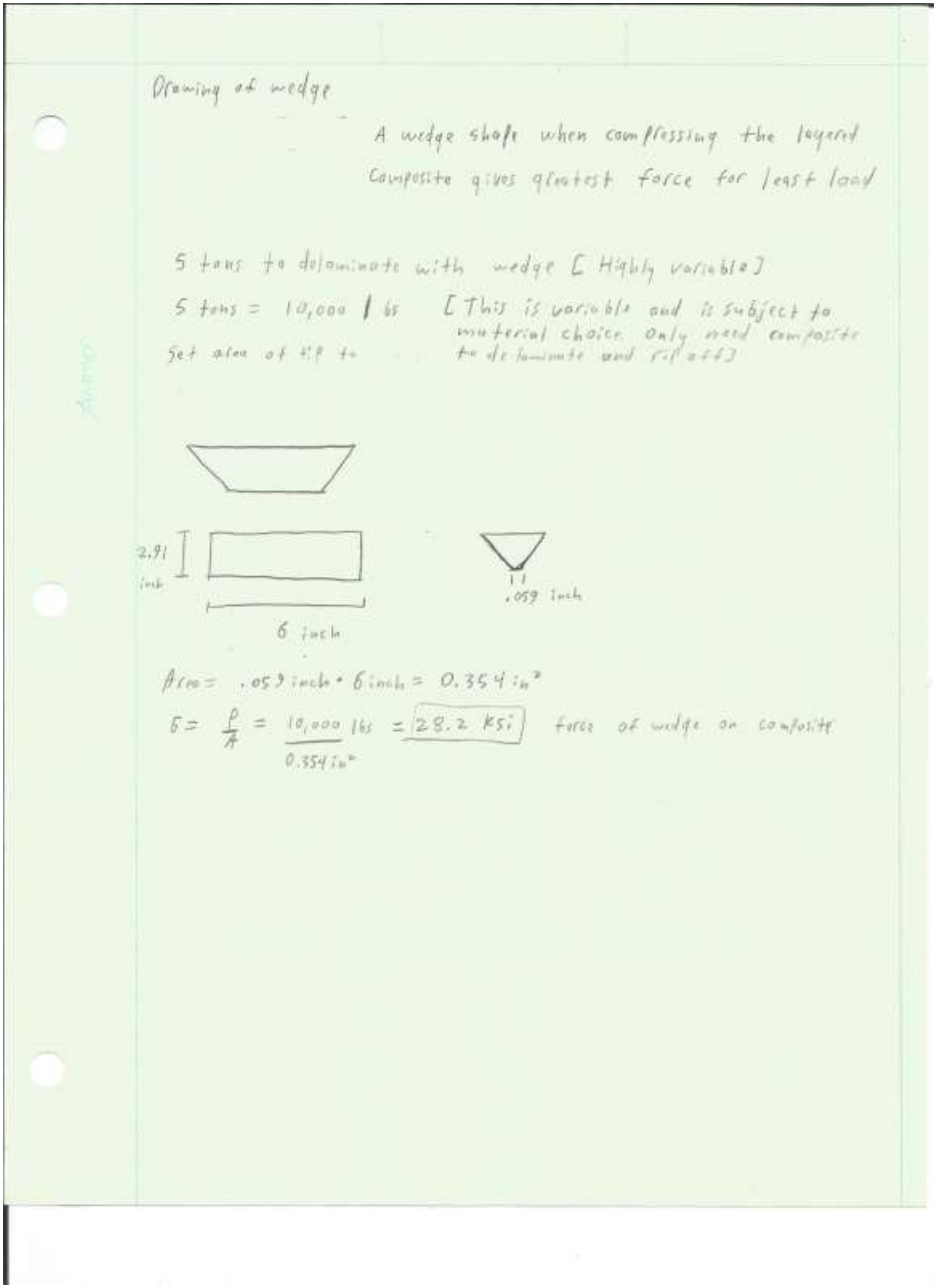
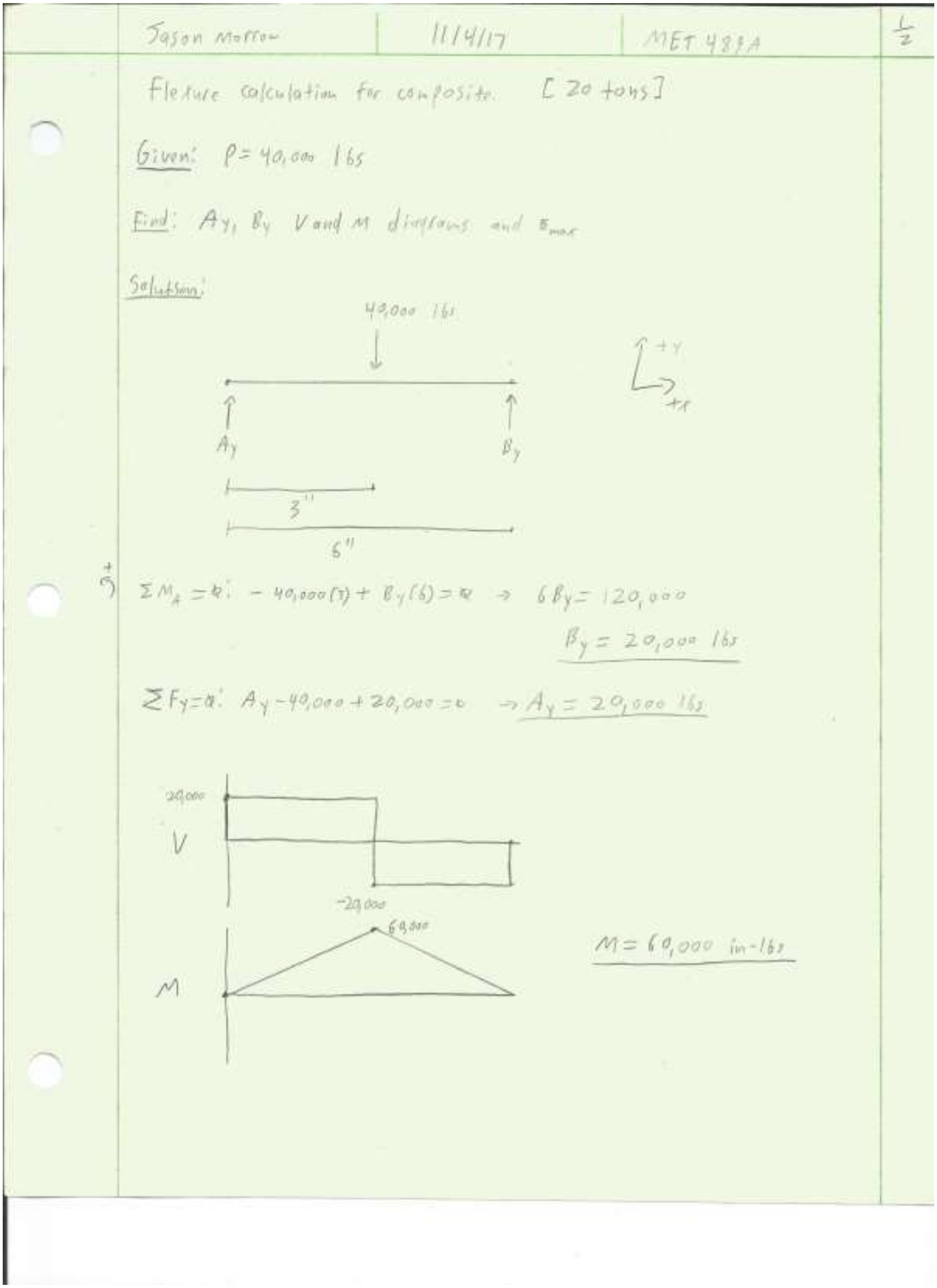


Figure A.7. Sketch and analysis of wedge for crush test



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Flexure calculation for composite. [20 tons]

Given: $P = 40{,}000$ lbs

Find: A_y, B_y, V and M diagrams and σ_{max}

Solution:

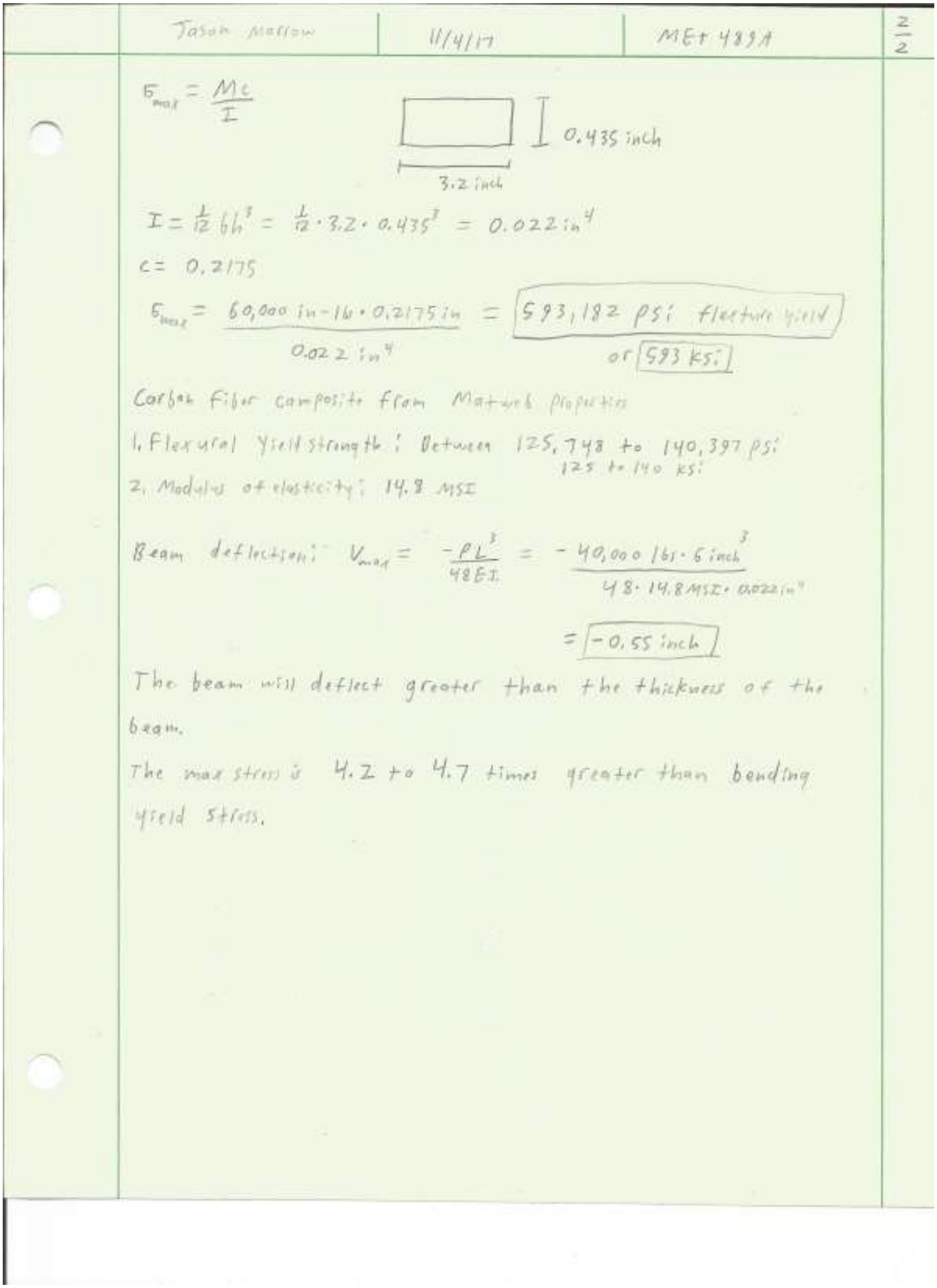
$\circlearrowleft^{+}$ $\Sigma M_A = 0$: $-40{,}000(3) + B_y(6) = 0 \rightarrow 6B_y = 120{,}000$

$B_y = 20{,}000$ lbs

$\Sigma F_y = 0$: $A_y - 40{,}000 + 20{,}000 = 0 \rightarrow A_y = 20{,}000$ lbs

$M = 60{,}000$ in-lbs

Figure A.8: Sheer and moment diagram for stress calculation for hydraulic press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$\sigma_{max} = \frac{Mc}{I}$

$I = \frac{1}{12} bh^3 = \frac{1}{12} \cdot 3.2 \cdot 0.435^3 = 0.022 \, in^4$

$c = 0.2175$

$\sigma_{max} = \frac{60{,}000 \text{ in-lb} \cdot 0.2175 \text{ in}}{0.022 \text{ in}^4} = 593{,}182 \text{ psi}$; flexture yield or 593 ksi

Carbon Fiber composite from Matweb properties

1. Flexural yield strength: Between 125,748 to 140,397 psi
125 to 140 ksi
2. Modulus of elasticity: 14.8 MSI

Beam deflection: $V_{max} = \frac{-PL^3}{48EI} = -\frac{40{,}000 \text{ lbs} \cdot 6 \text{ inch}^3}{48 \cdot 14.8 \text{ MSI} \cdot 0.022 \text{ in}^4}$

$= -0.55$ inch

The beam will deflect greater than the thickness of the beam.

The max stress is 4.2 to 4.7 times greater than bending yield stress.

Figure A.9: Flexural Stress calculation for composite beam

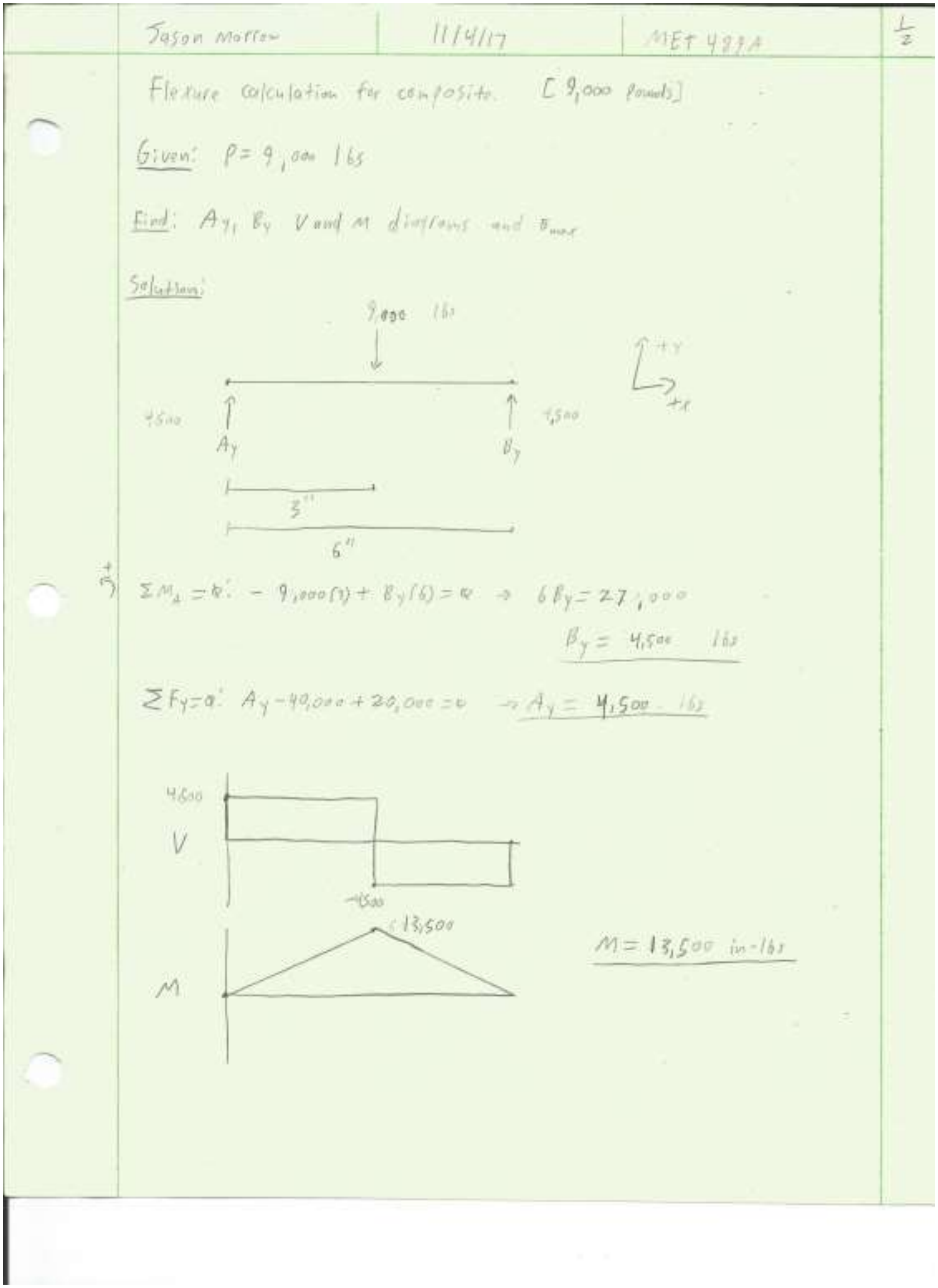
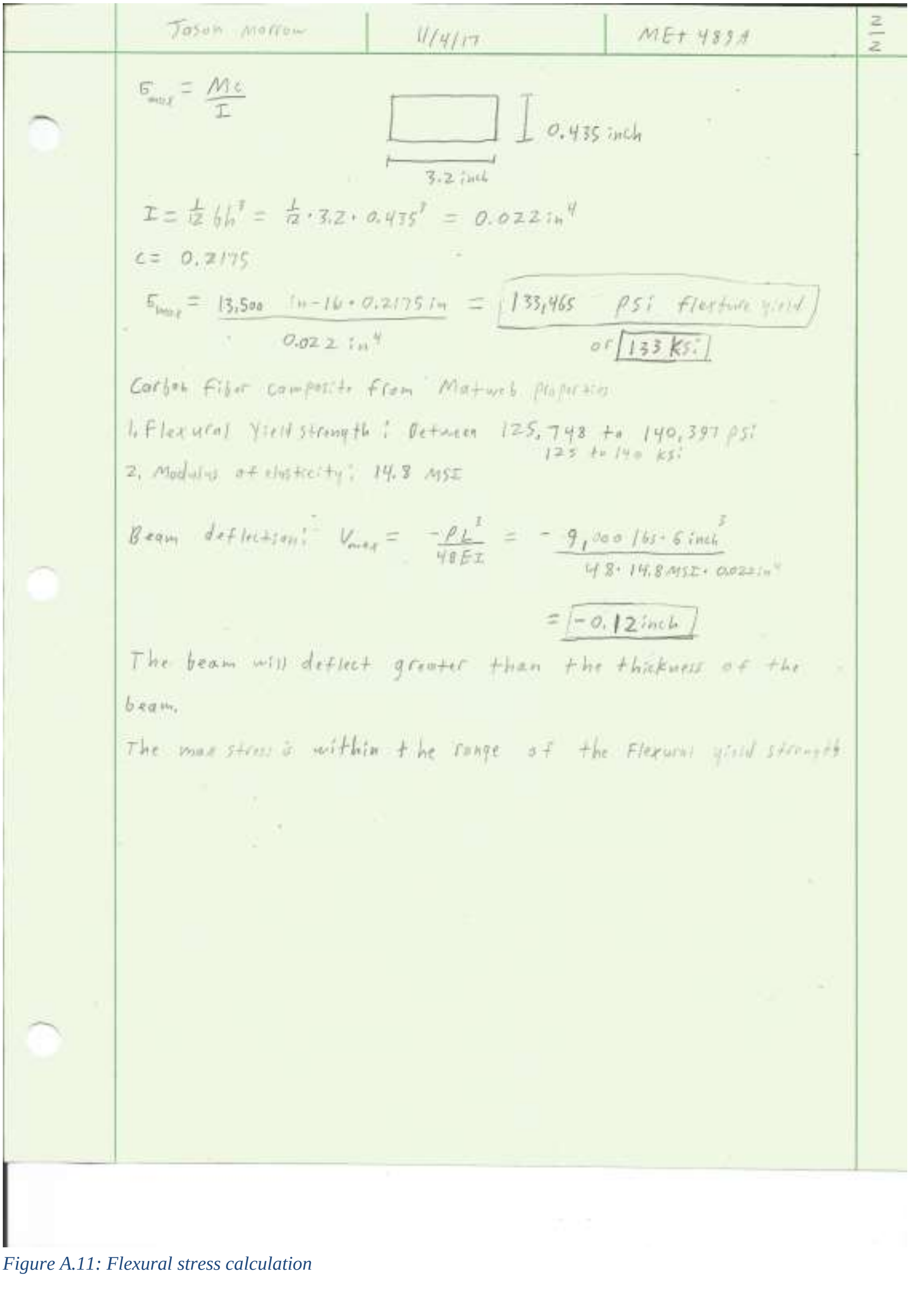


Figure A.10: Updated shear and moment diagrams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$\sigma_{max} = \frac{Mc}{I}$

$I = \frac{1}{12} bh^3 = \frac{1}{12} \cdot 3.2 \cdot 0.435^3 = 0.022 \, in^4$

$c = 0.2175$

$\sigma_{max} = \frac{13{,}500 \text{ in-lb} \cdot 0.2175 \text{ in}}{0.022 \text{ in}^4} = 133{,}465$ psi flexture yield or 133 ksi

Carbon fiber composite from Matweb properties

1. Flexural yield strength: Between 125,748 to 140,397 psi
125 to 140 ksi

2. Modulus of elasticity: 14.8 MSI

Beam deflection: $V_{max} = \frac{-PL^3}{48EI} = -\frac{9{,}000 \text{ lbs} \cdot 6 \text{ inch}^3}{48 \cdot 14.8 \text{ MSI} \cdot 0.022 \text{ in}^4}$

$= -0.12$ inch

The beam will deflect greater than the thickness of the beam.

The max stress is within the range of the Flexural yield strength

Figure A.11: Flexural stress calculation

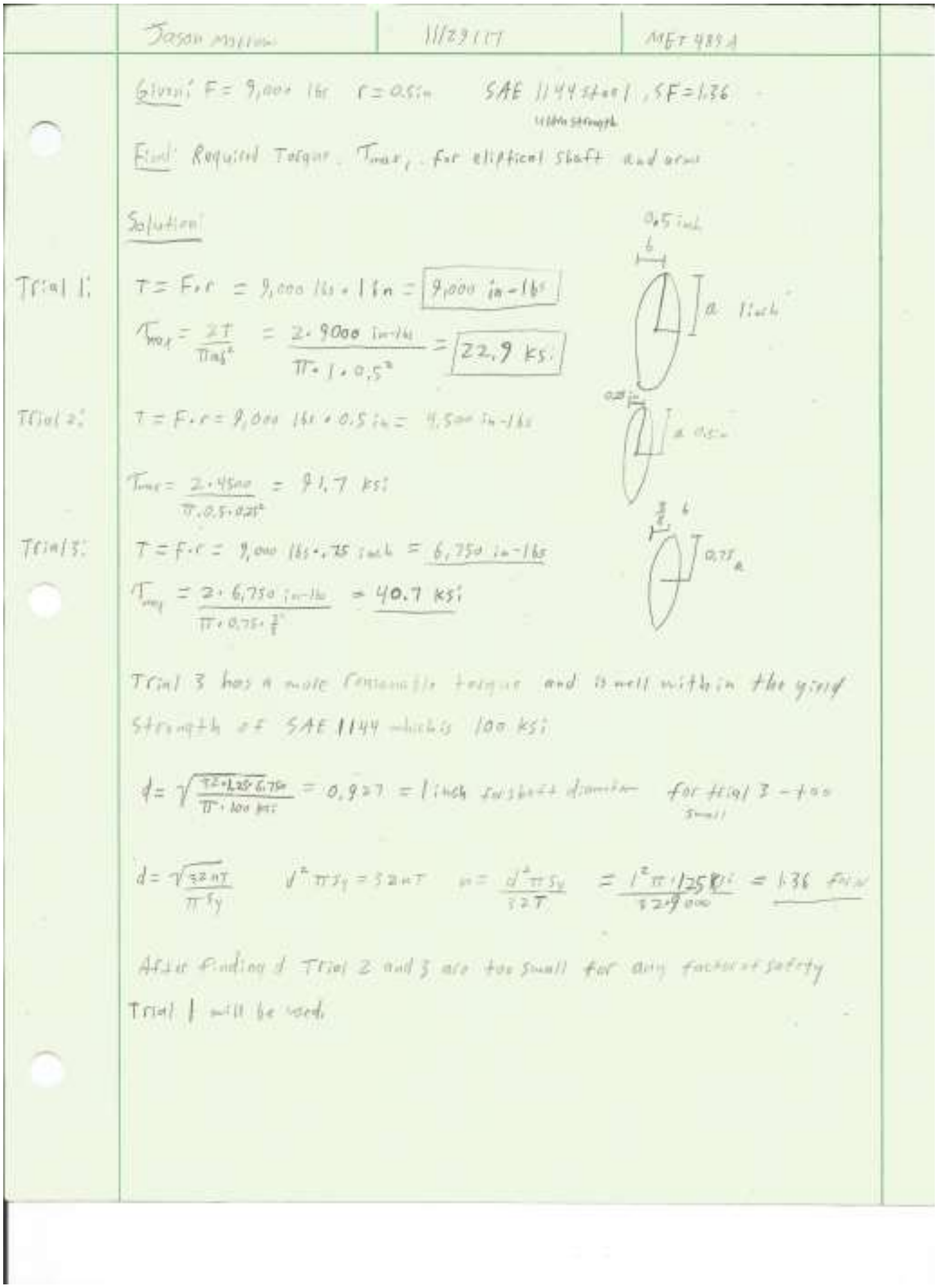
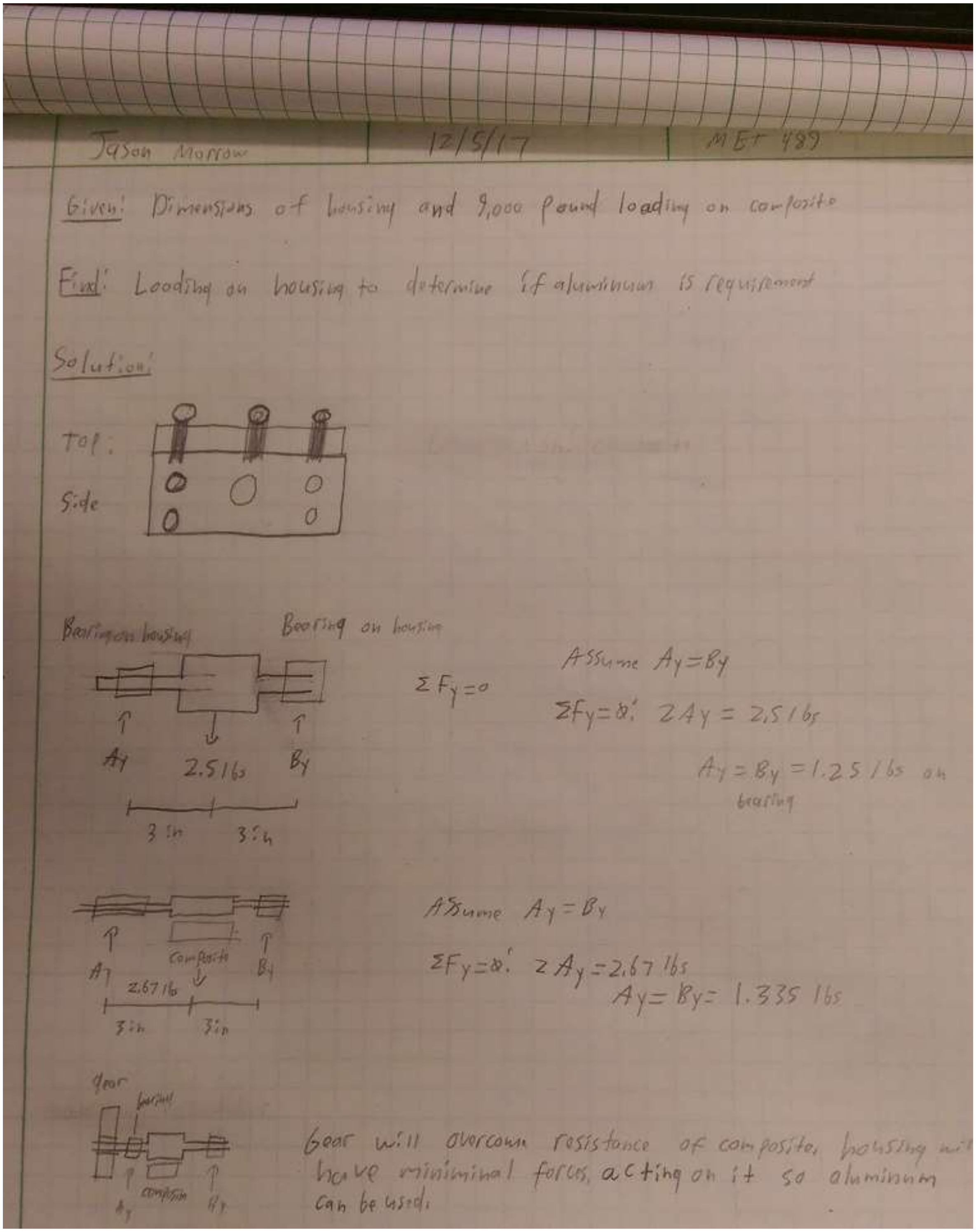


Figure A:12 Torque and Torsional stress calculation



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Given: Dimensions of housing and 9,000 pound loading on composite

Find: Loading on housing to determine if aluminum is requirement

Solution:

$\Sigma F_y = 0$

Assume $A_y = B_y$

$\Sigma F_y = 0$: $2A_y = 2.5$ lbs

$A_y = B_y = 1.25$ lbs on bearing

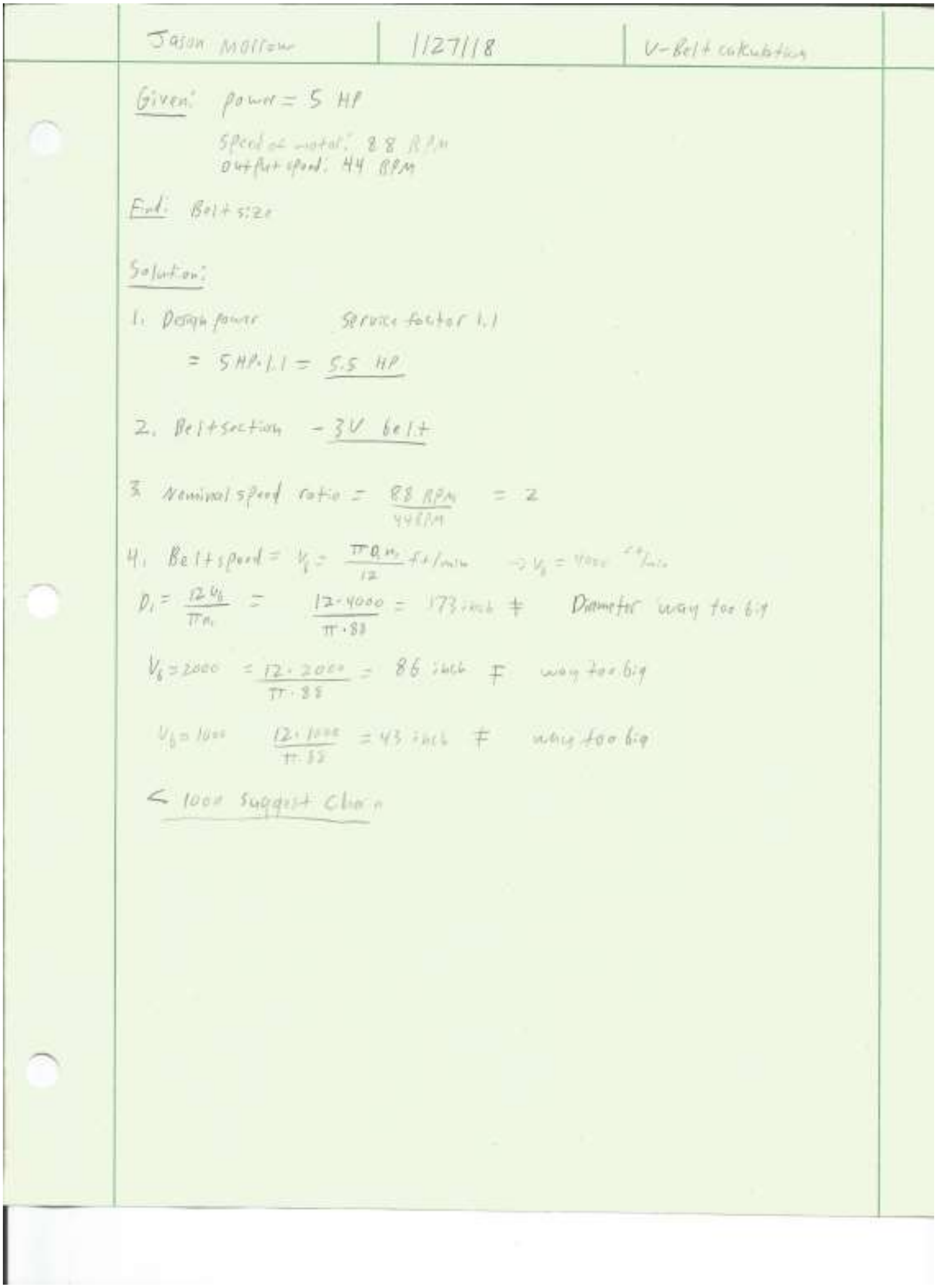
Assume $A_y = B_y$

$\Sigma F_y = 0$: $2A_y = 2.67$ lbs

$A_y = B_y = 1.335$ lbs

Gear will overcome resistance of composite, housing will have minimal forces acting on it so aluminum can be used.

Figure A.13: Housing material selection


Jason Morrow | 1/27/18 | V-Belt calculation

Given: power = 5 HP

Speed of motor: 88 RPM

Output speed: 44 RPM

Find: Belt size

Solution:

1. Design power   service factor 1.1

= 5 HP · 1.1 = 5.5 HP

2. Belt section - 3V belt

3. Nominal speed ratio = 88 RPM / 44 RPM = 2

4. Belt speed = $V_b = \frac{\pi D_1 n_1}{12}$ ft/min → V_b = 4000 ft/min

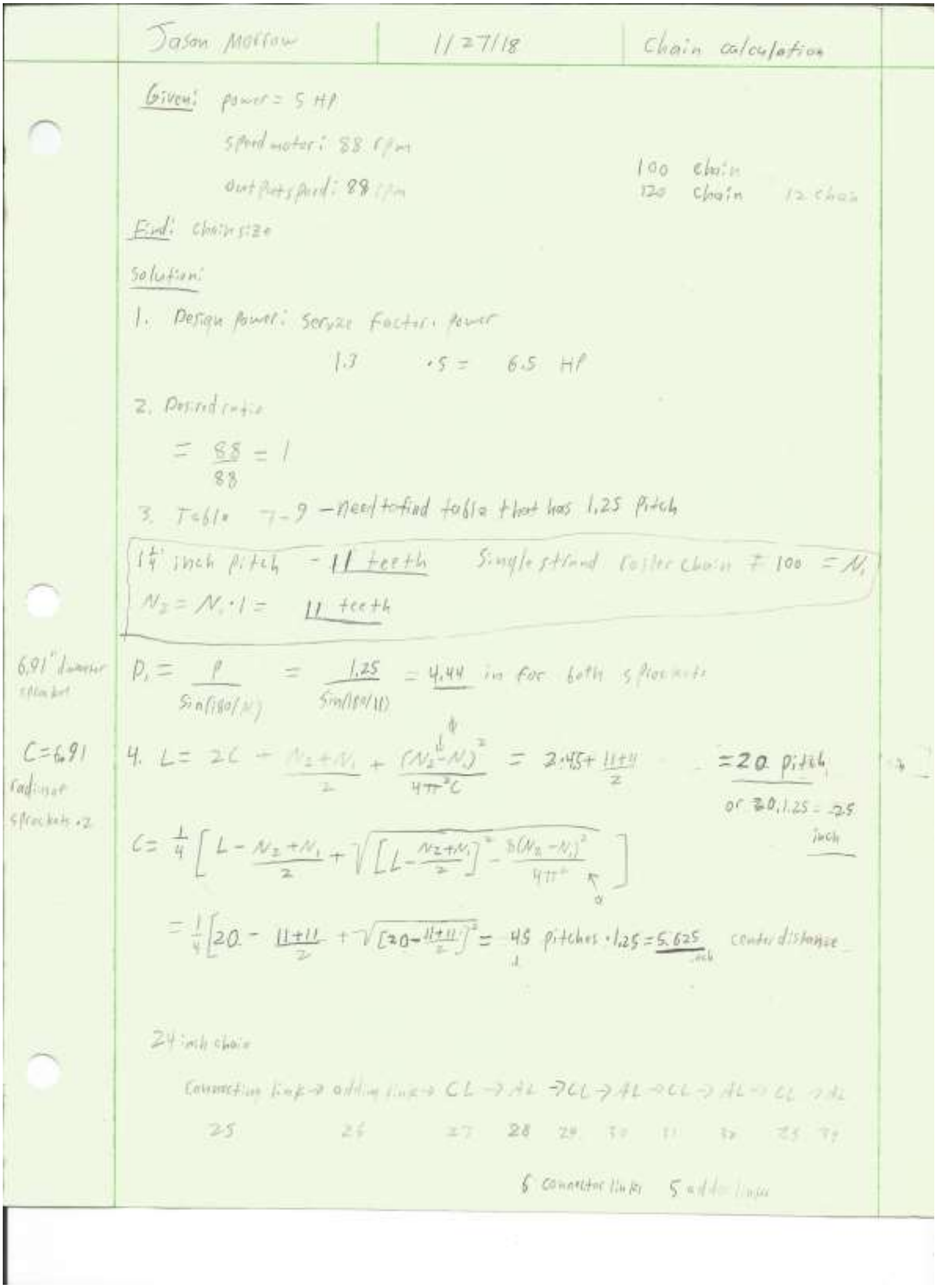
$D_1 = \frac{12 V_b}{\pi n_1} = \frac{12 \cdot 4000}{\pi \cdot 88}$ = 173 inch ≠ Diameter way too big

V_b = 2000 = $\frac{12 \cdot 2000}{\pi \cdot 88}$ = 86 inch ≠ way too big

V_b = 1000 $\frac{12 \cdot 1000}{\pi \cdot 88}$ = 43 inch ≠ way too big

< 1000 suggest Chain

Figure A.14: Belt calculation



Jason Morrow | 11/27/18 | Chain calculation

Given: power = 5 HP

speed motor: 88 rpm

output speed: 88 rpm

100 chain
120 chain 12 chain

Find: chain size

Solution:

1. Design power: service factor · power

$1.3 \cdot 5 = 6.5$ HP

2. Desired ratio

$= \frac{88}{88} = 1$

3. Table 7-9 — need to find table that has 1.25 pitch

$1\frac{1}{4}$" inch pitch - 11 teeth Single strand roller chain # 100 = N_1

$N_2 = N_1 \cdot 1 =$ 11 teeth

6.91" diameter sprocket

$D_1 = \frac{p}{\sin(180/N_1)} = \frac{1.25}{\sin(180/11)} = 4.44$ in for both sprockets

C=6.91 radius of sprockets ·2

4. $L = 2C + \frac{N_2+N_1}{2} + \frac{(N_2-N_1)^2}{4\pi^2 C} = 2 \cdot 4.5 + \frac{11+11}{2}$ = 20 pitch

or $20 \cdot 1.25 = 25$ inch

$C = \frac{1}{4}\left[L - \frac{N_2+N_1}{2} + \sqrt{\left[L - \frac{N_2+N_1}{2}\right]^2 - \frac{8(N_2-N_1)^2}{4\pi^2}}\right]$

$= \frac{1}{4}\left[20 - \frac{11+11}{2} + \sqrt{\left[20 - \frac{11+11}{2}\right]^2}\right] = 4.5$ pitches $\cdot 1.25 = 5.625$ inch center distance

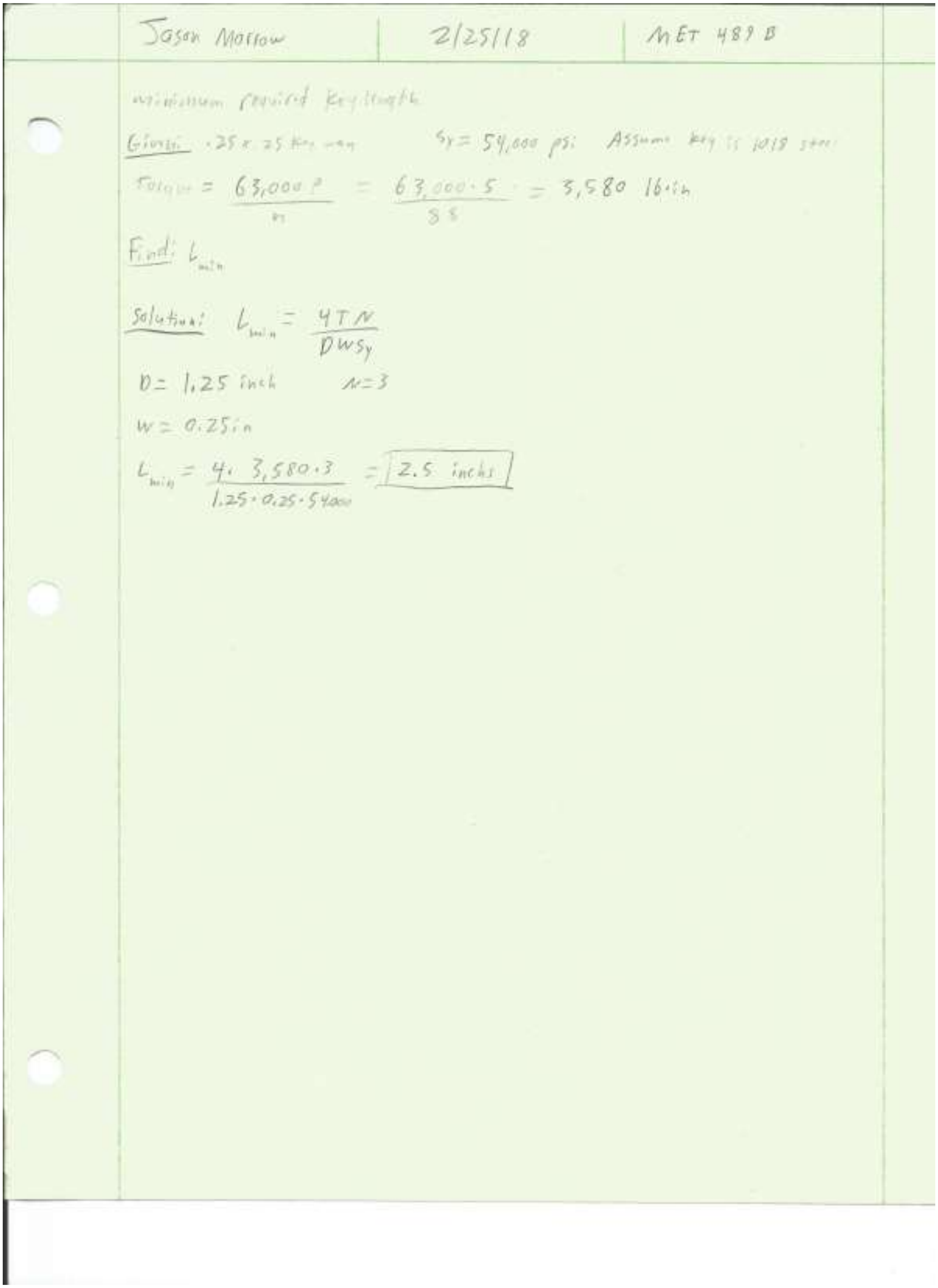
24 inch chain

Connecting link → adding link → CL → AL → CL → AL → CL → AL → CL → AL

25 26 27 28 29 30 31 32 33 34

6 connector links 5 adding links

Figure A.15: Chain calculation


Jason Morrow | 2/25/18 | MET 489 B

minimum required key length

Given: .25 x .25 key ... S_y = 54,000 psi Assume key is 1018 steel

Torque = $\frac{63{,}000 P}{n} = \frac{63{,}000 \cdot 5}{88}$ = 3,580 lb·in

Find: L_{min}

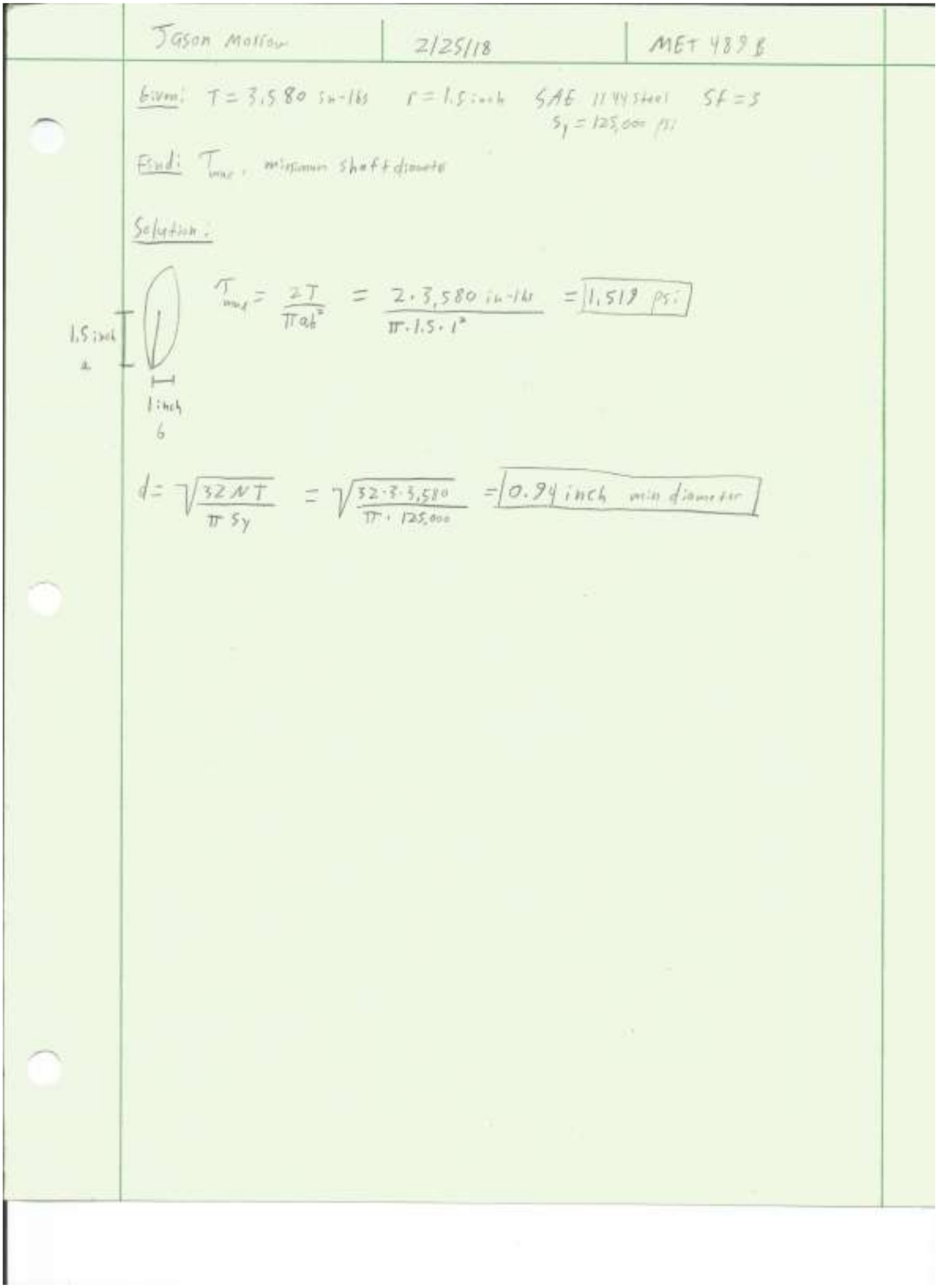
Solution: $L_{min} = \frac{4TN}{DWS_y}$

D = 1.25 inch N = 3

W = 0.25 in

$L_{min} = \frac{4 \cdot 3{,}580 \cdot 3}{1.25 \cdot 0.25 \cdot 54000}$ = 2.5 inchs

Figure A.16: Key calculation



Jason Mollow | 2/25/18 | MET 489B

Given: $T = 3{,}580$ in-lbs $r = 1.5$ inch SAE 1144 steel $SF = 3$
$S_y = 125{,}000$ psi

Find: τ_{max}, minimum shaft diameter

Solution:

$$\tau_{max} = \frac{2T}{\pi a b^2} = \frac{2 \cdot 3{,}580 \text{ in-lbs}}{\pi \cdot 1.5 \cdot 1^2} = 1{,}519 \text{ psi}$$

1.5 inch a
1 inch b

$$d = \sqrt{\frac{32NT}{\pi S_y}} = \sqrt{\frac{32 \cdot 3 \cdot 3{,}580}{\pi \cdot 125{,}000}} = 0.94 \text{ inch min diameter}$$

Figure A.17: Minimum shaft diameter calculation

APPENDIX B – Sketches, Assembly drawings, Sub-assembly drawings, Part drawings, Manufacture pictures

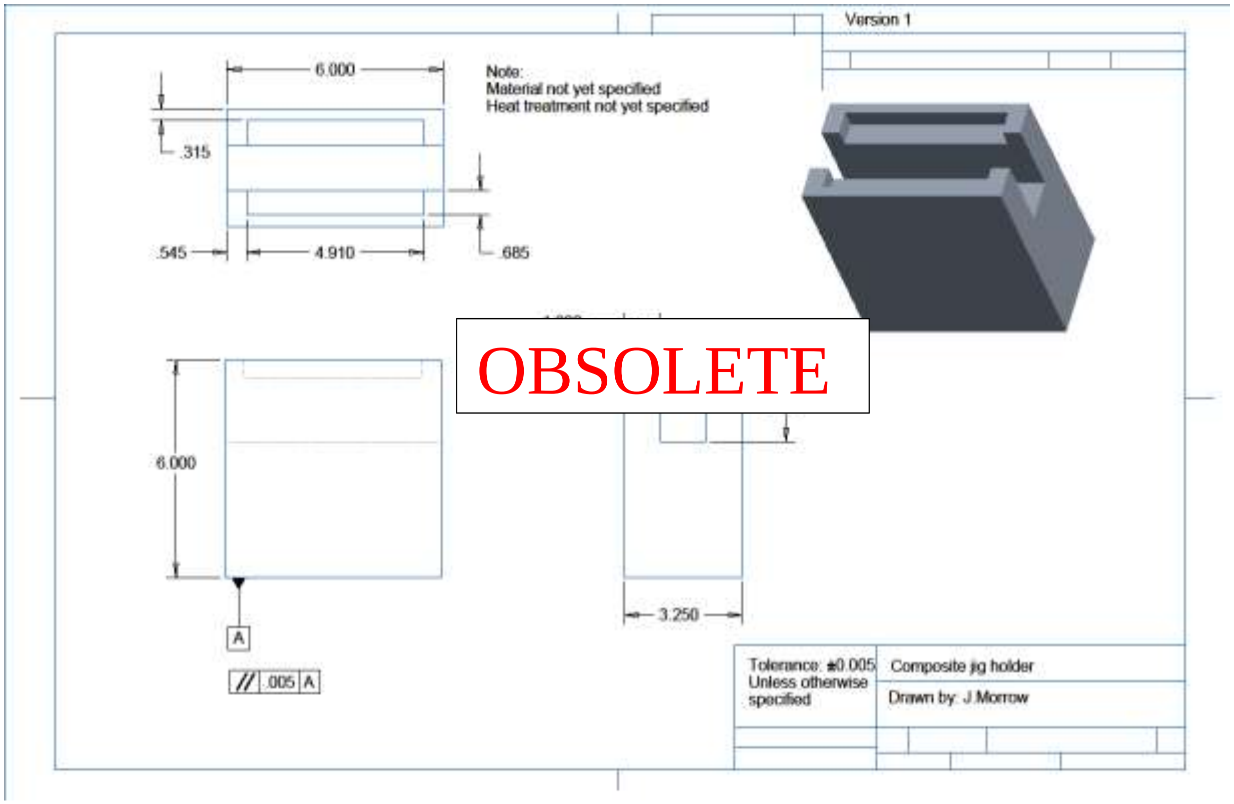


Figure B.1: First conceptual drawing of composite holder.

Figure B.1 is modified from the drawings in appendix A. It was decided an indent will help better secure the composite test piece. After considerations of developing a machine to fracture the composite this model was no longer considered for the project.

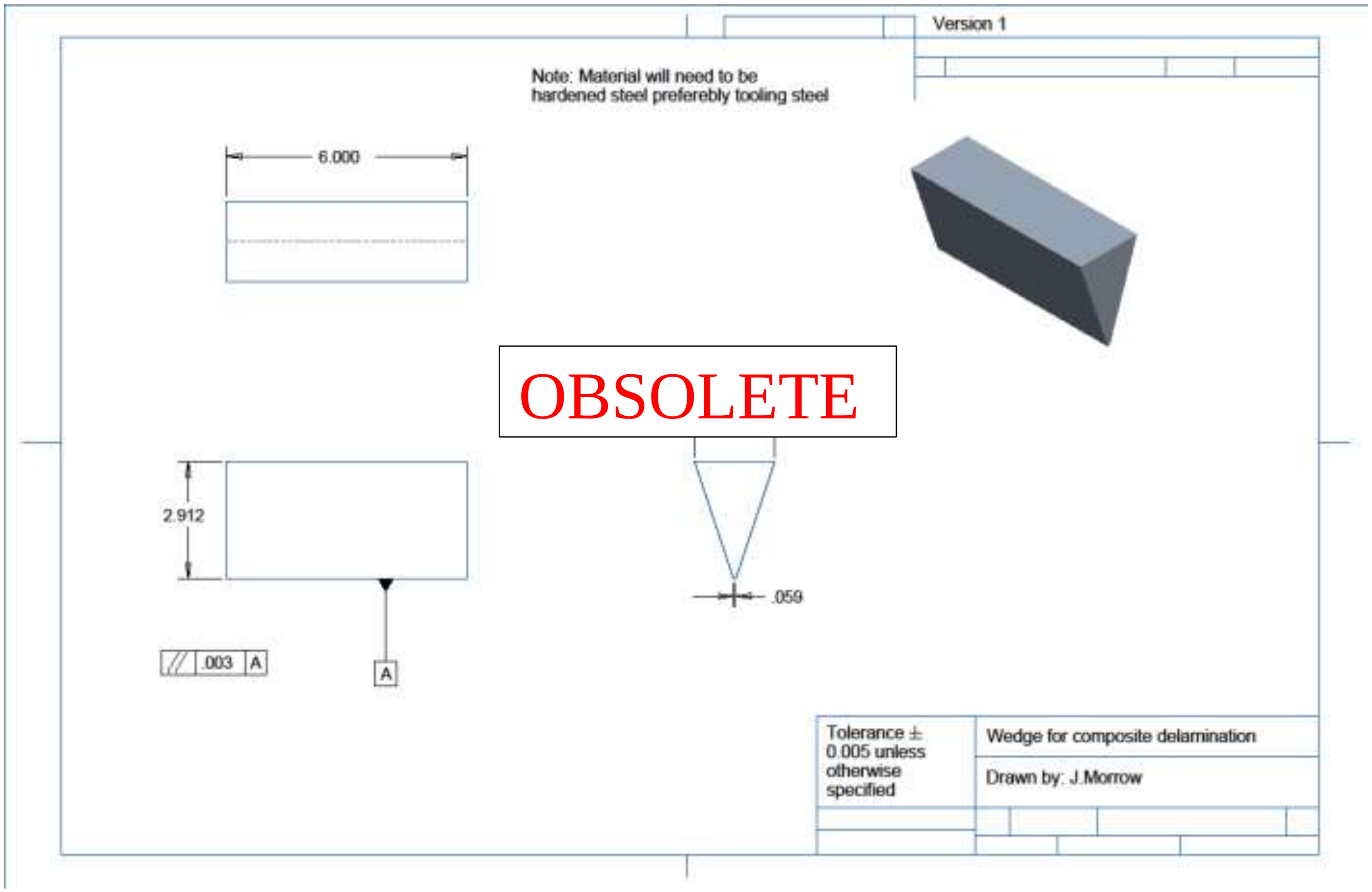


Figure B.2: Wedge for delaminating composite

Figure B.2 is a wedge used in one part of the composite breakdown process. The material will most likely be a hardened steel to survive the multitude of planned future tests. After considerations of developing a machine to fracture the composite this model was no longer considered for the project.

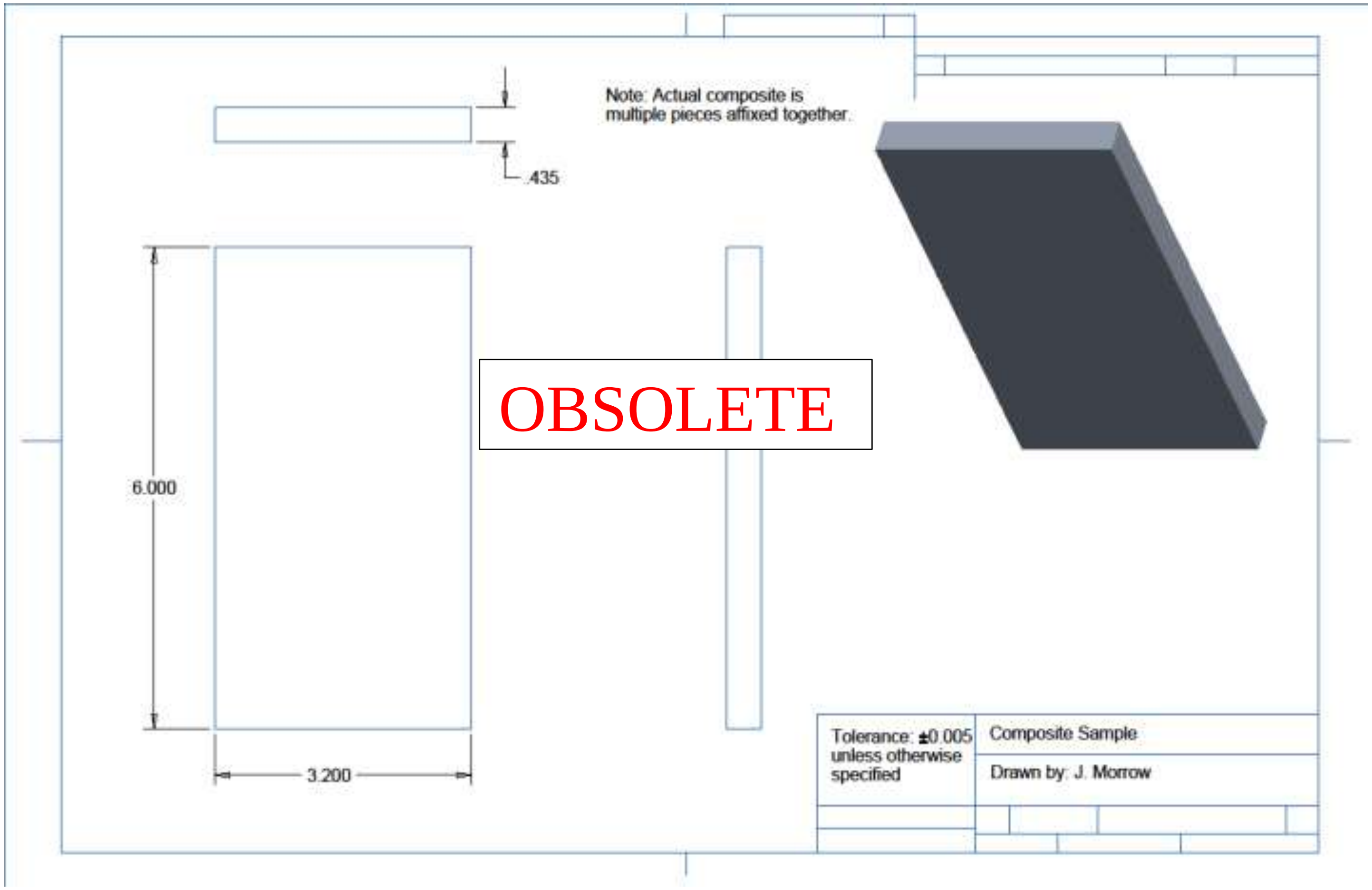


Figure B.3: Standard size for composite sample piece

Figure B.3 shows a standard size for the composite sample piece used when conducting the bending to delaminate. The full length of the composite will be fed into the crushing machine and this figure is no longer required.

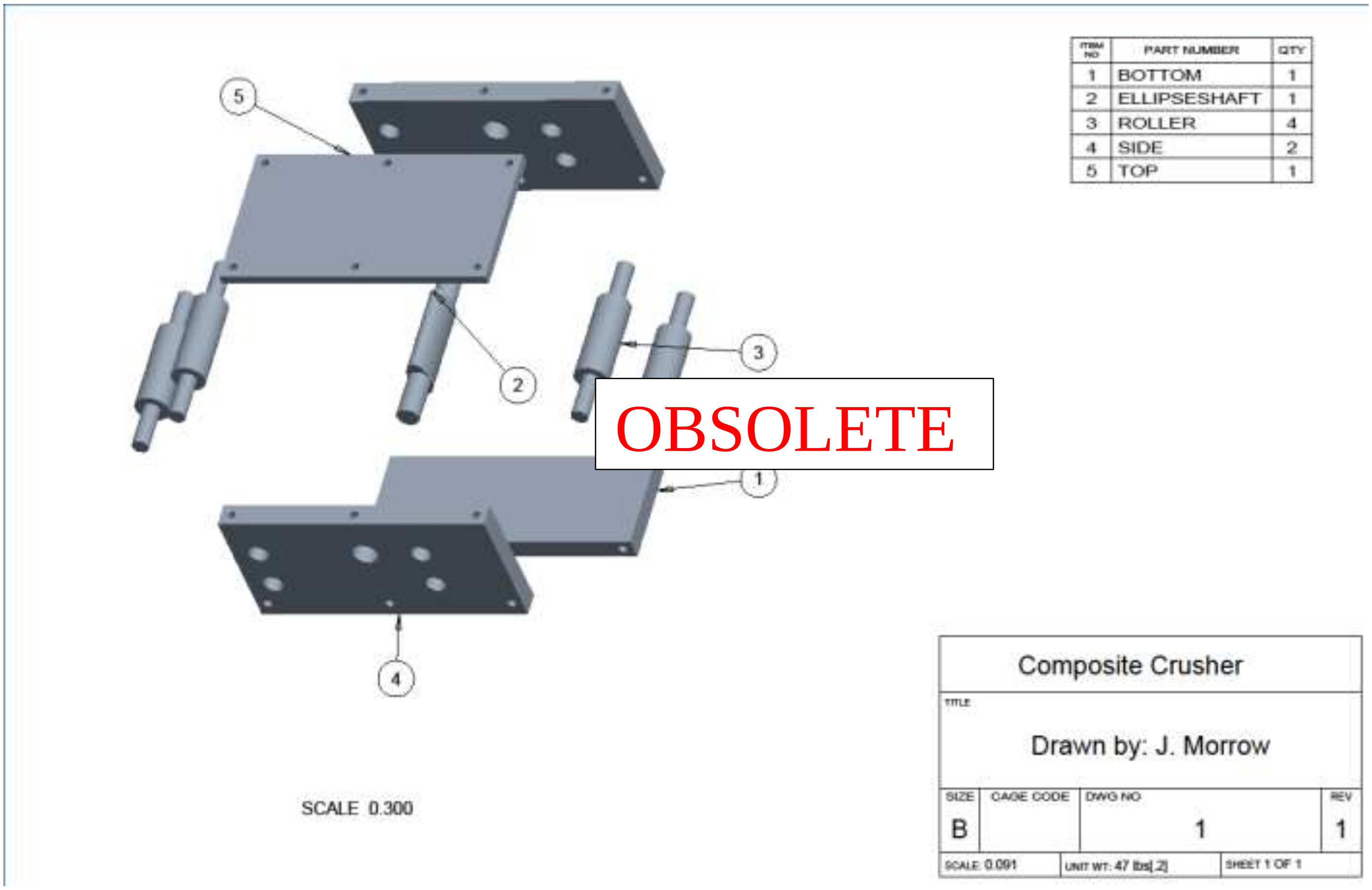


Figure B.4: Exploded view of composite crusher

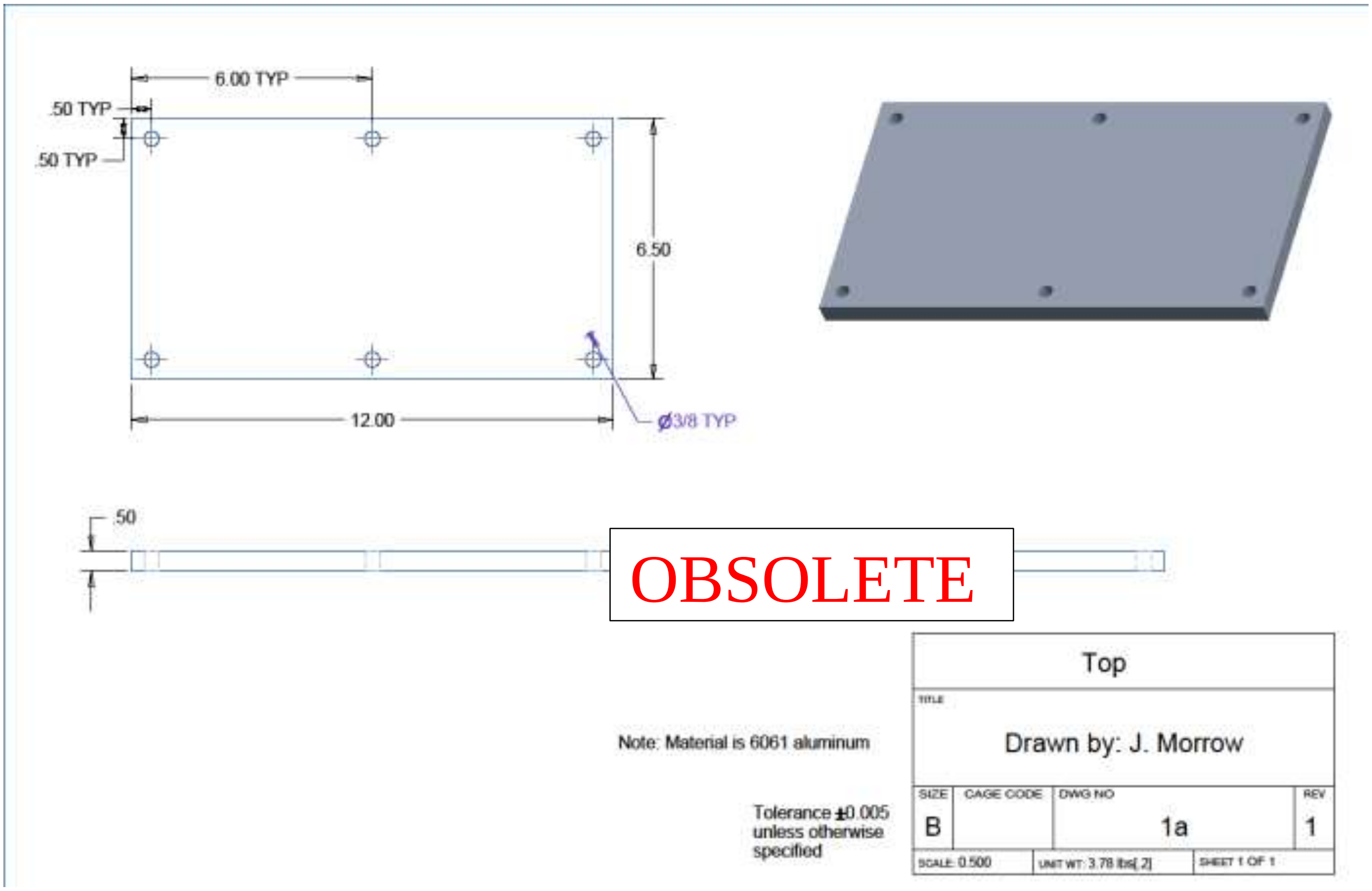


Figure B.5: Top portion of housing unit

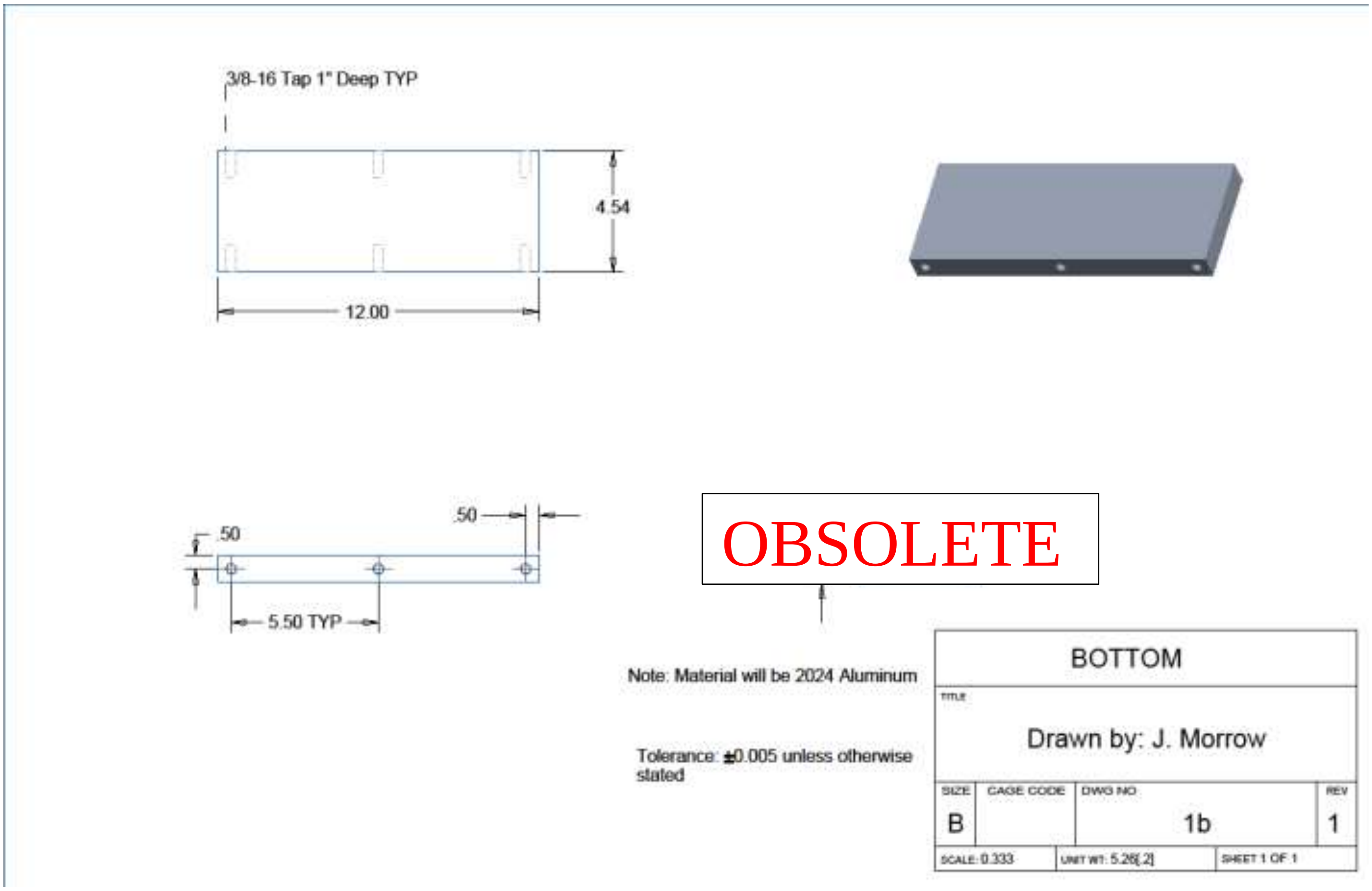


Figure B.6: Bottom portion of housing

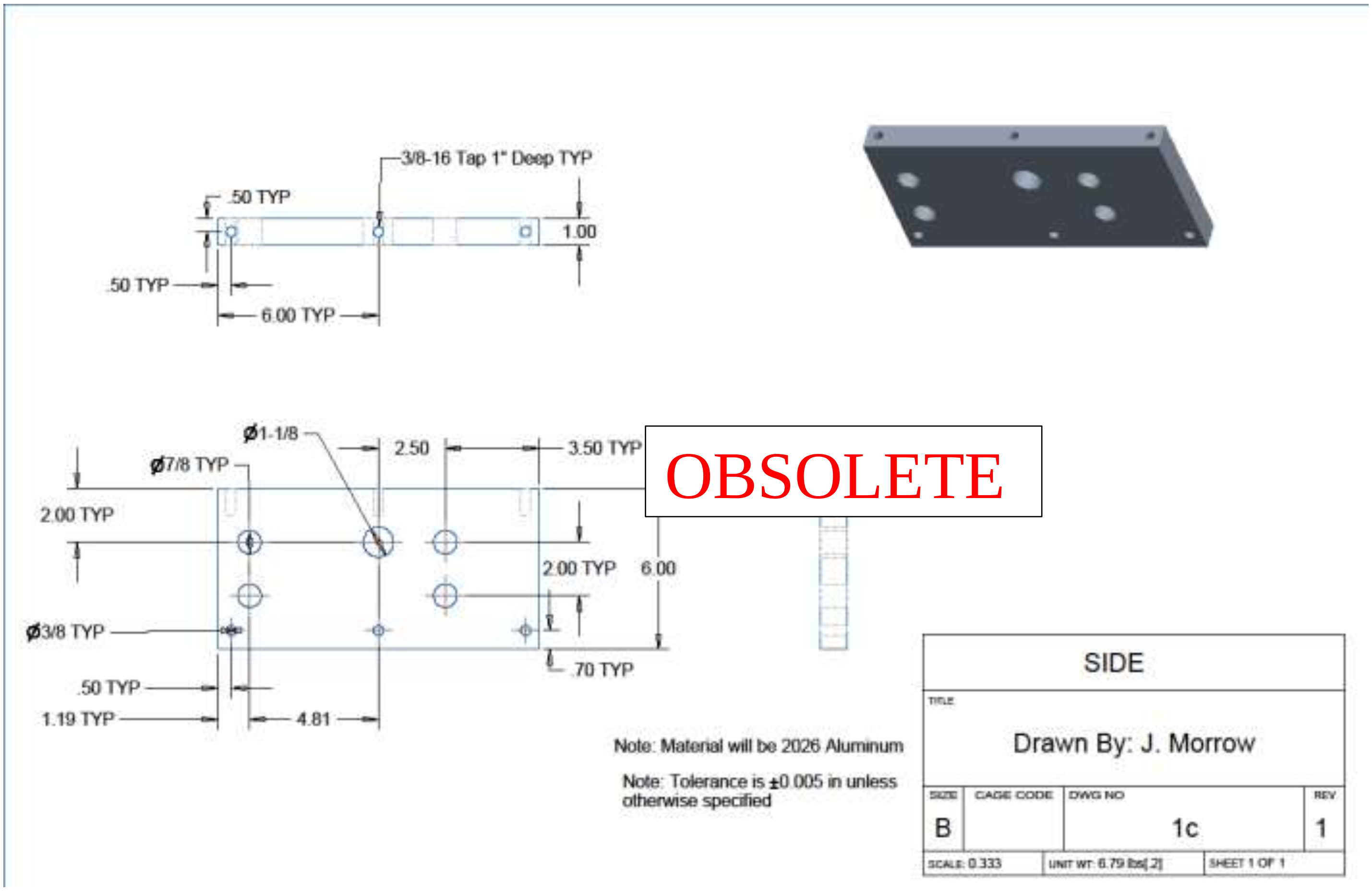


Figure B.7: Side of Housing

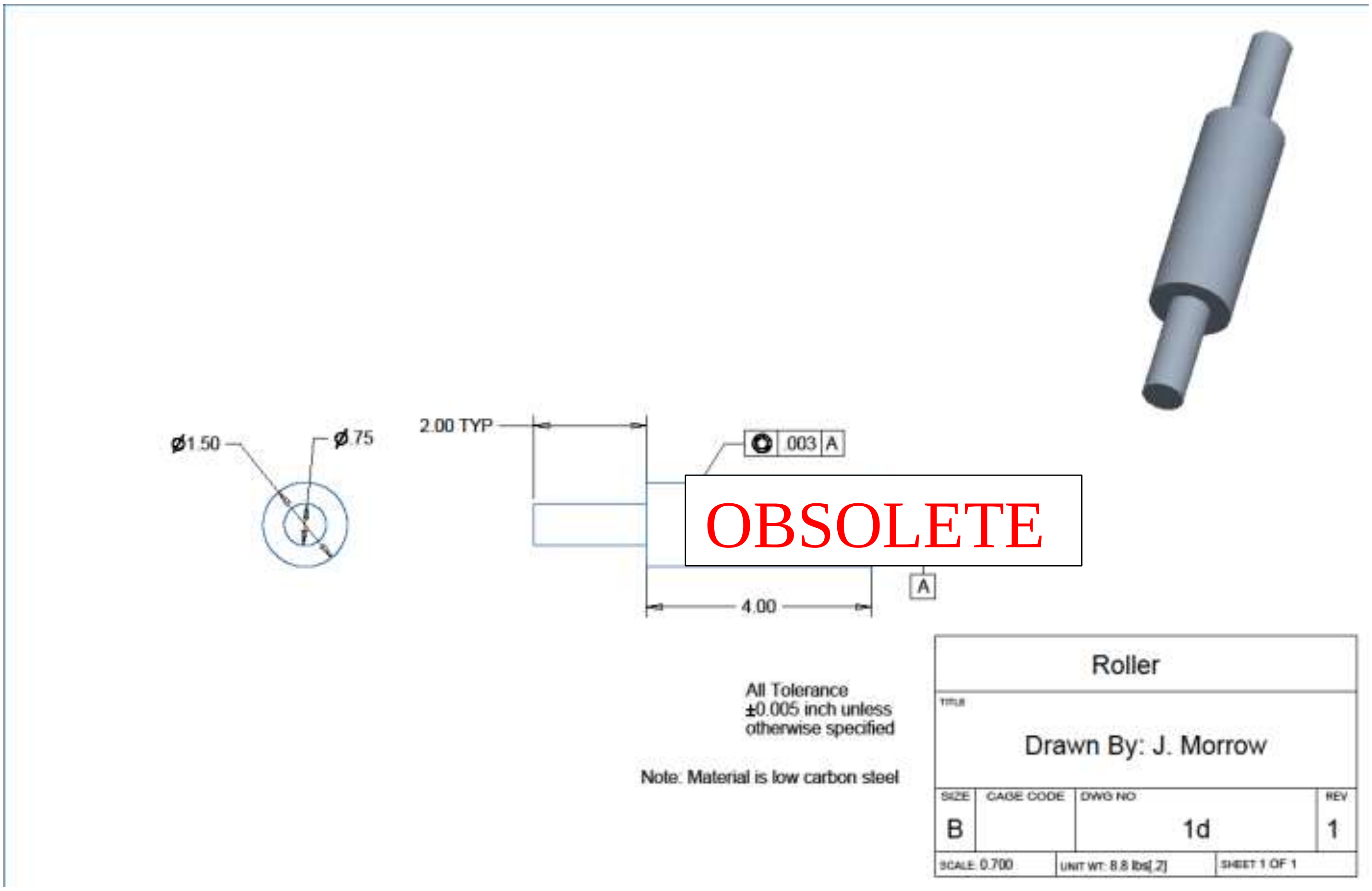


Figure B.8: Roller for Assembly

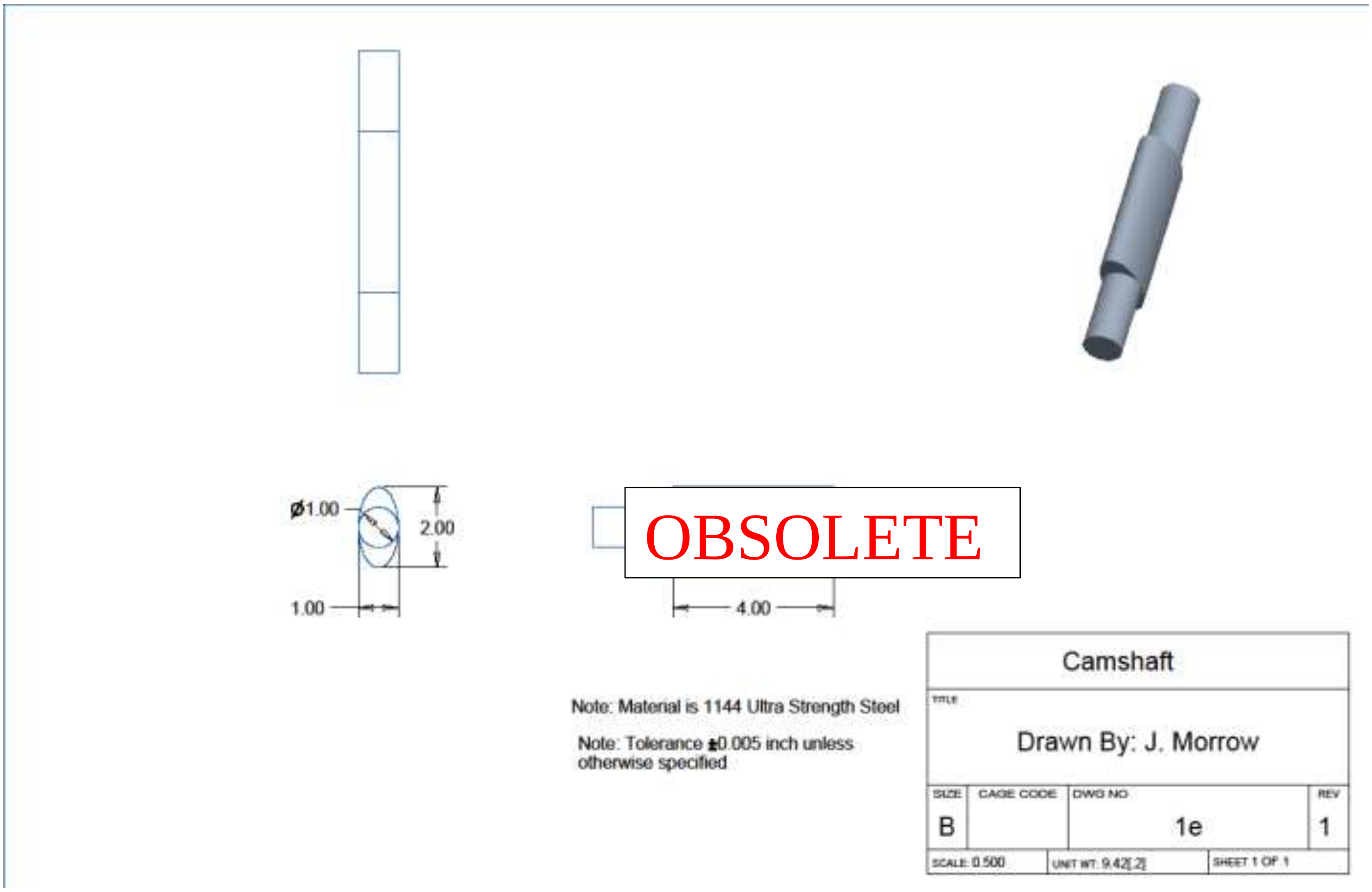
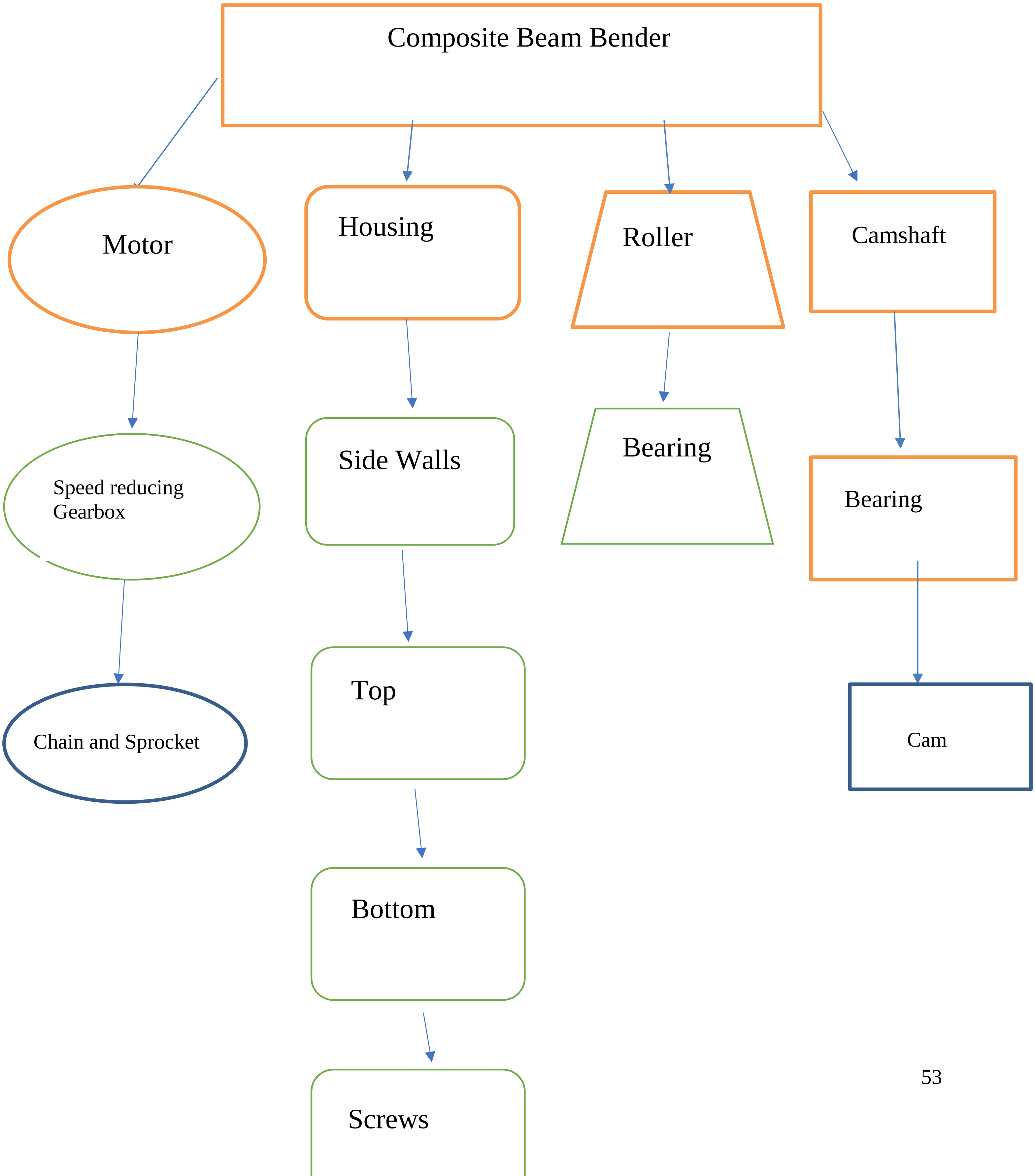


Figure B.9: Camshaft for fracturing composite

APPENDIX B1: DRAWING TREE



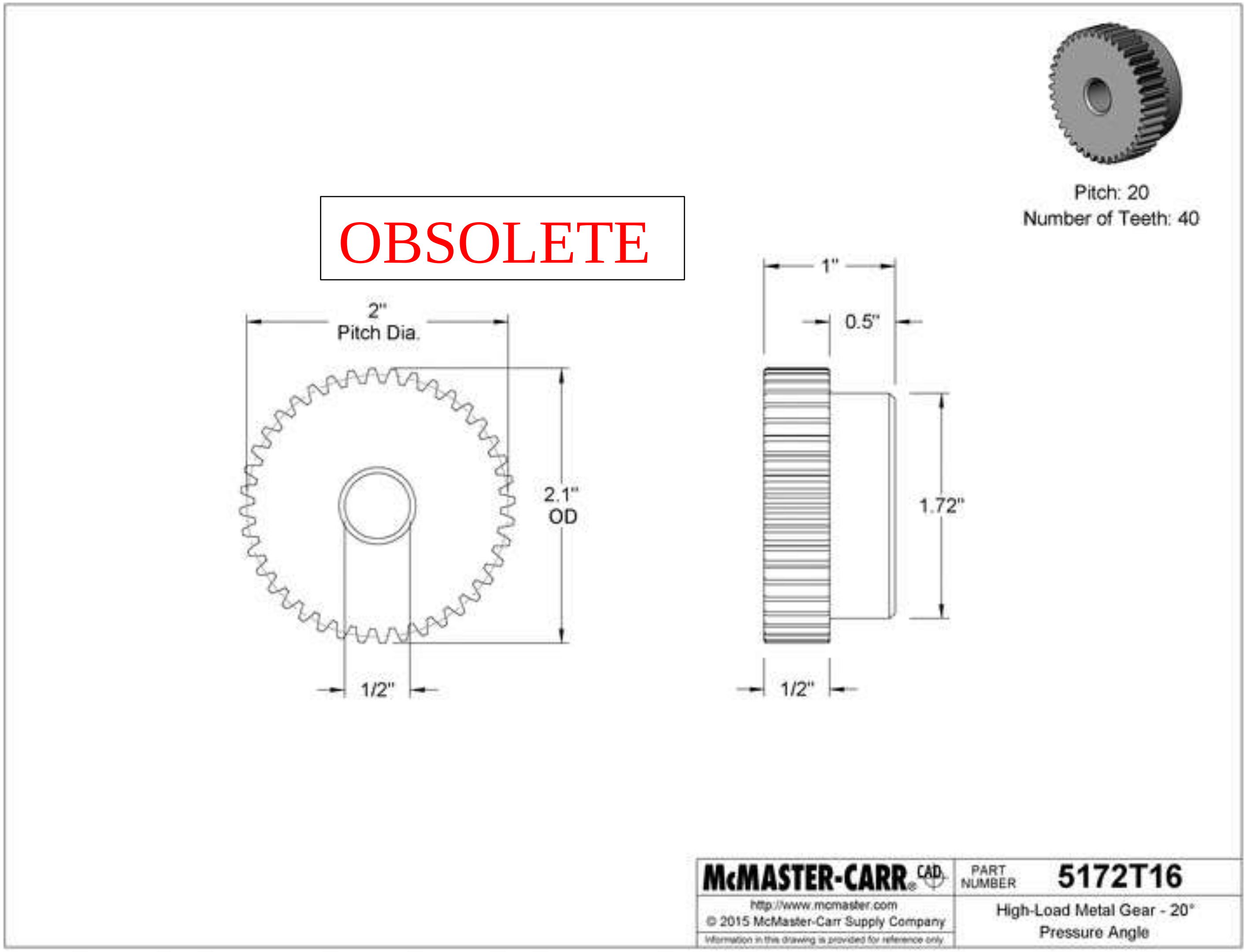


Figure B.10: Roller Gear

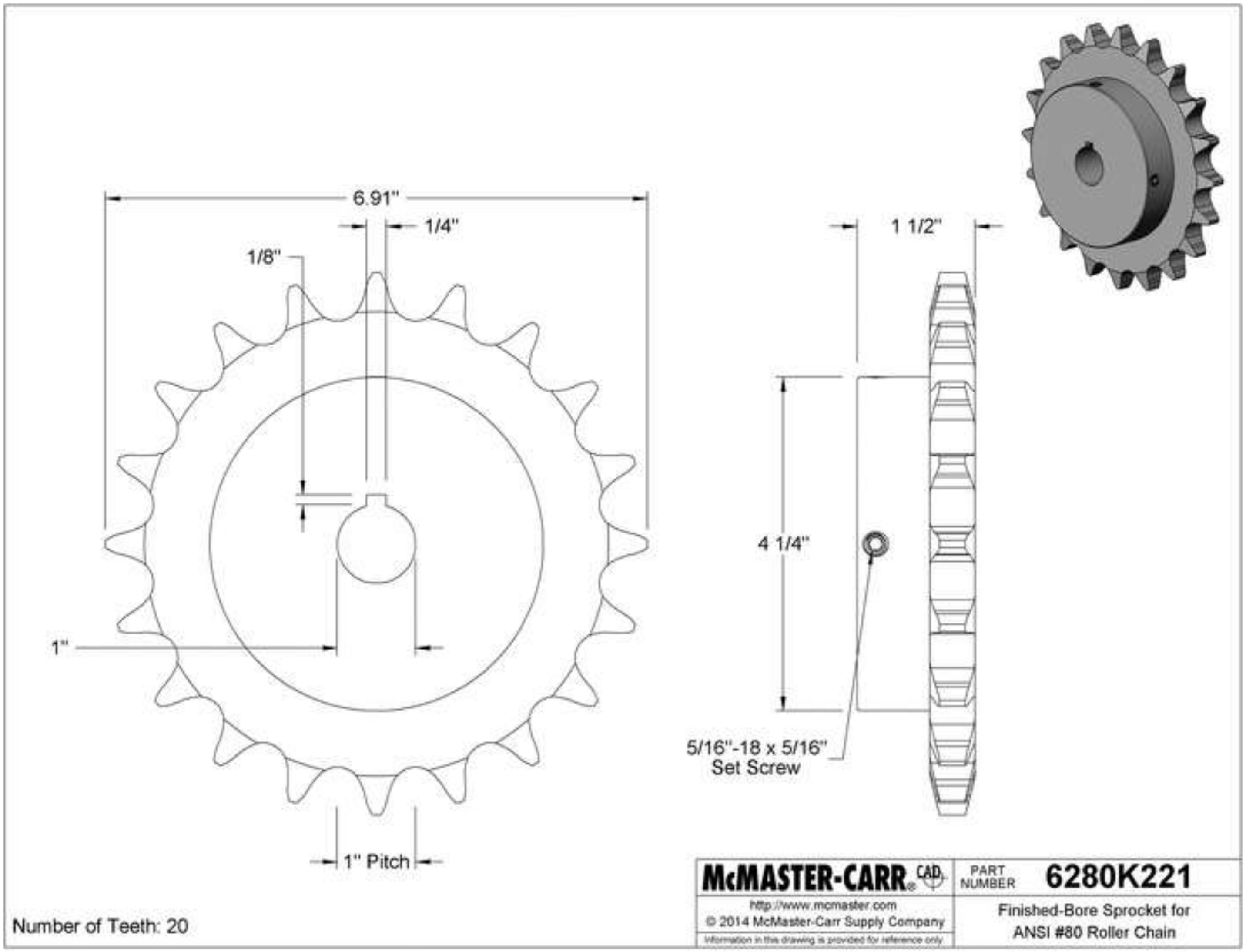


Figure B:11: Chain Sprocket

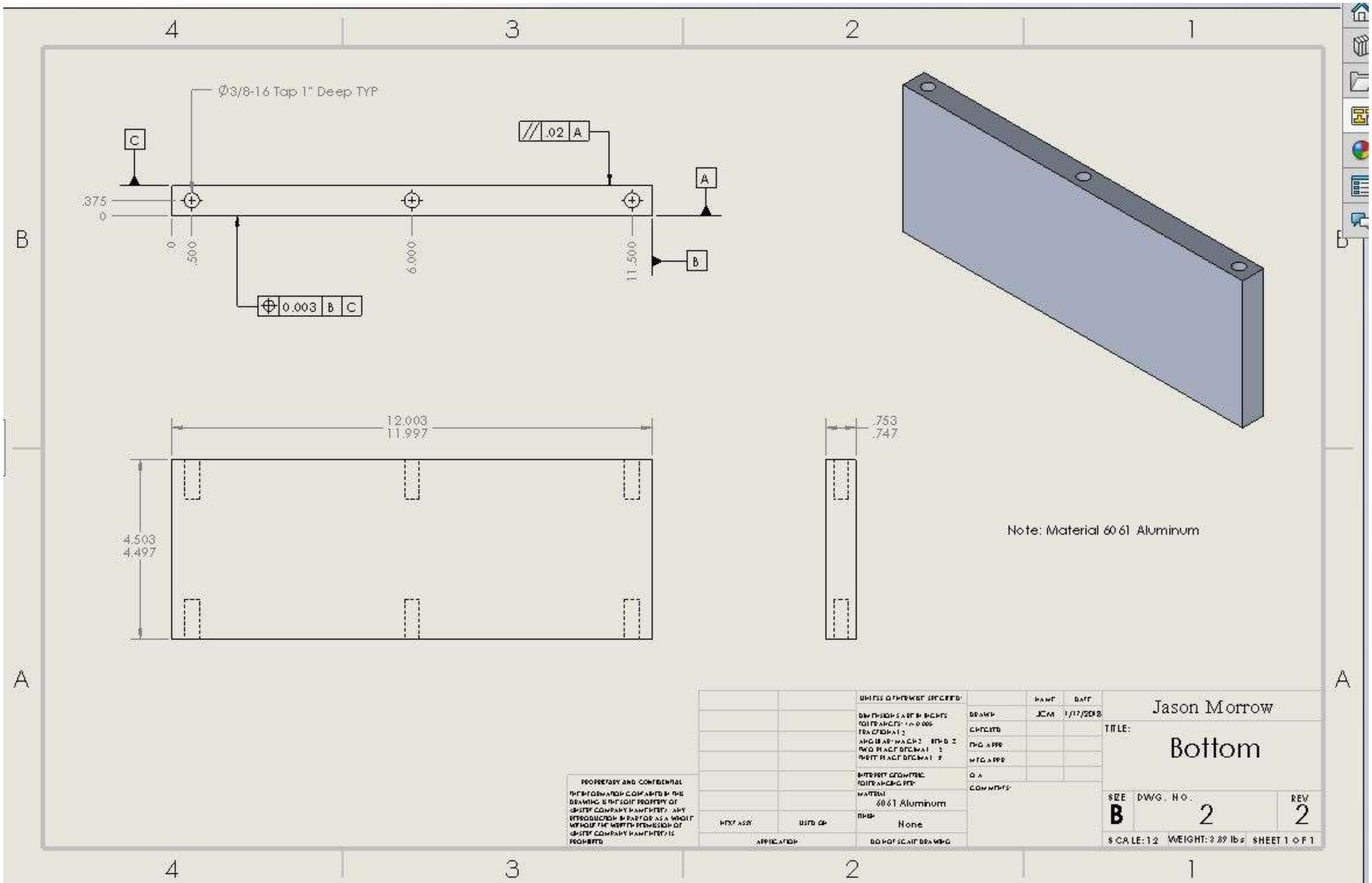


Figure B.12: Bottom

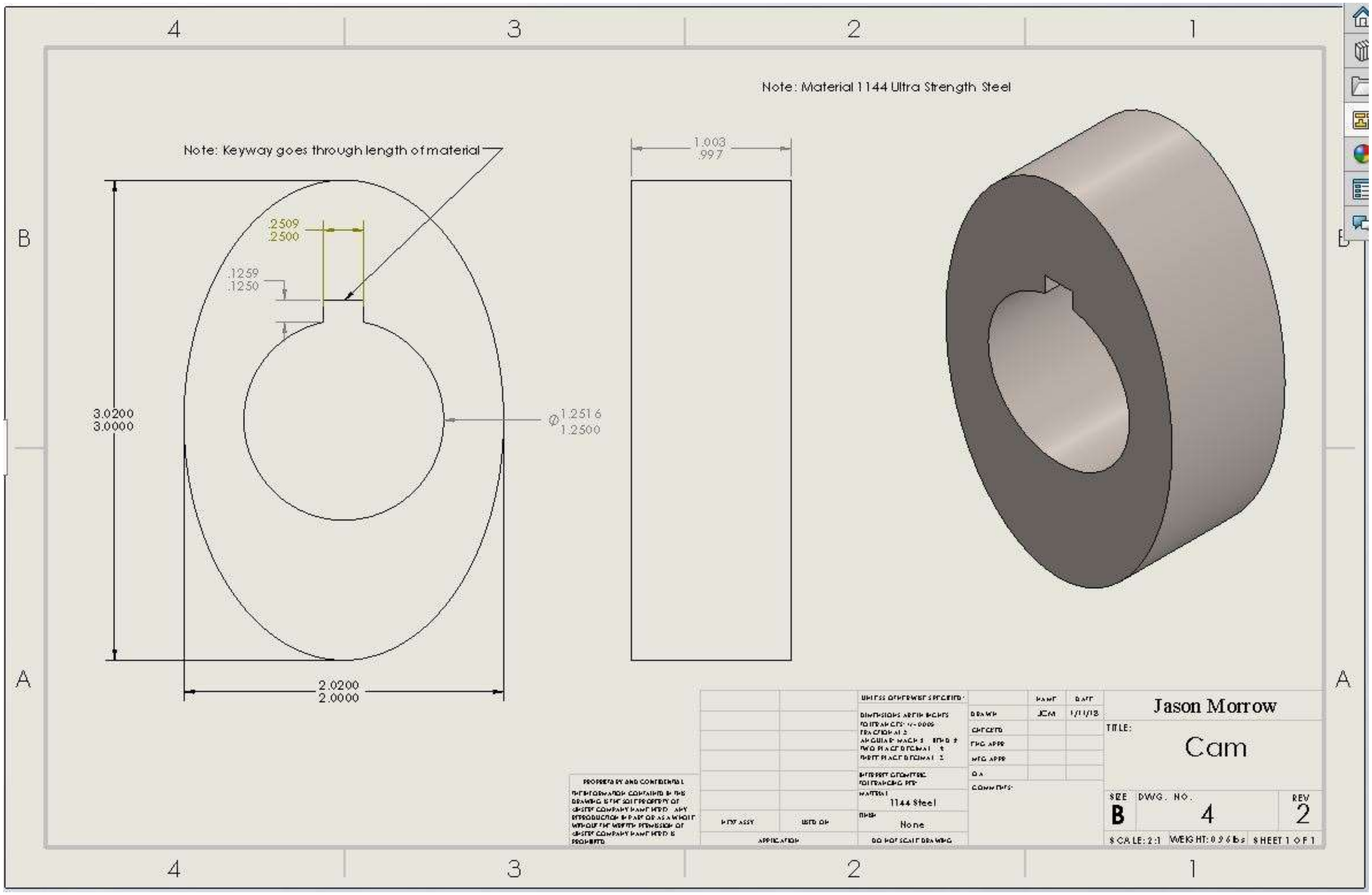


Figure B.13: Cam

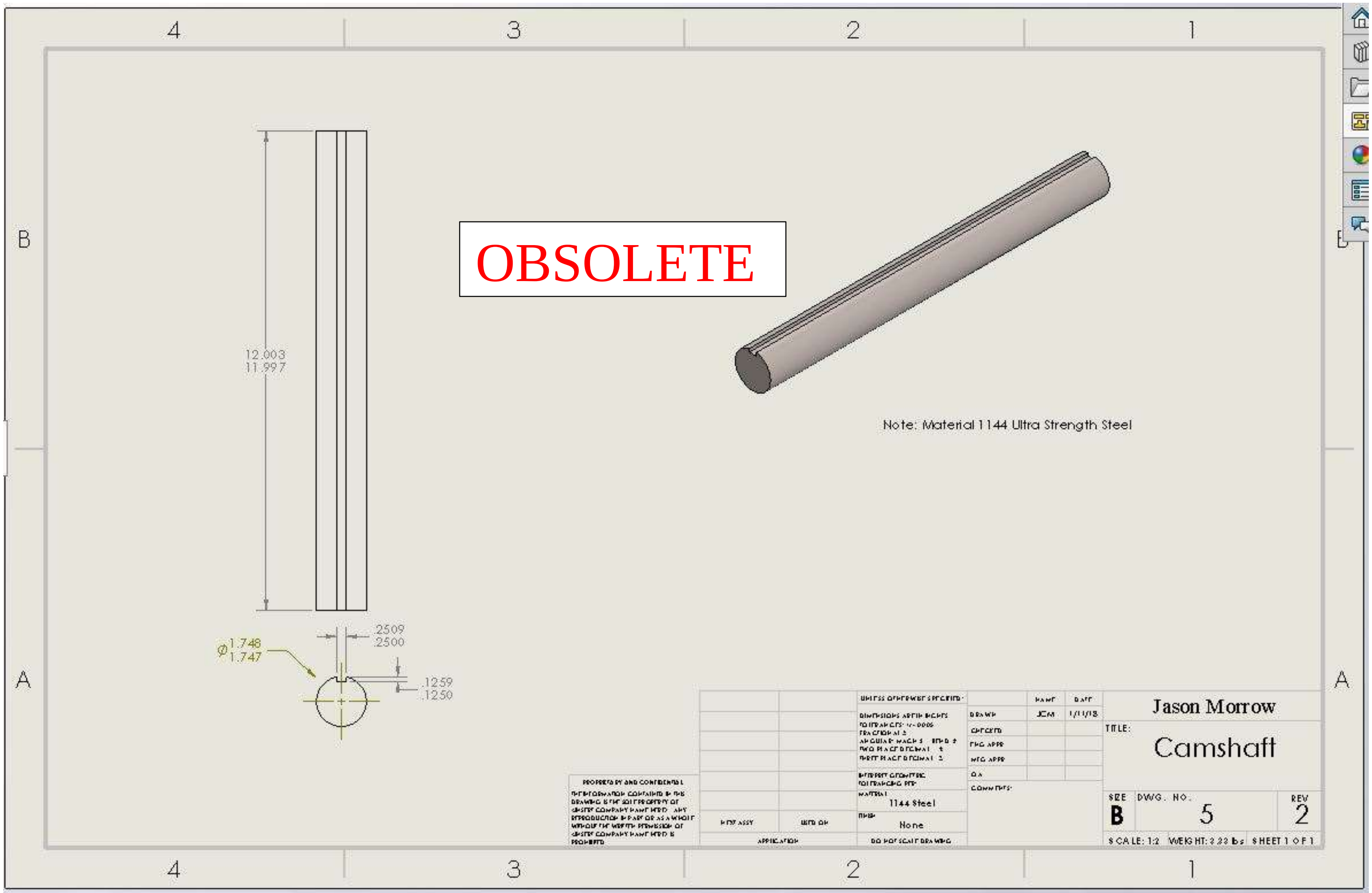


Figure B.14: Camshaft

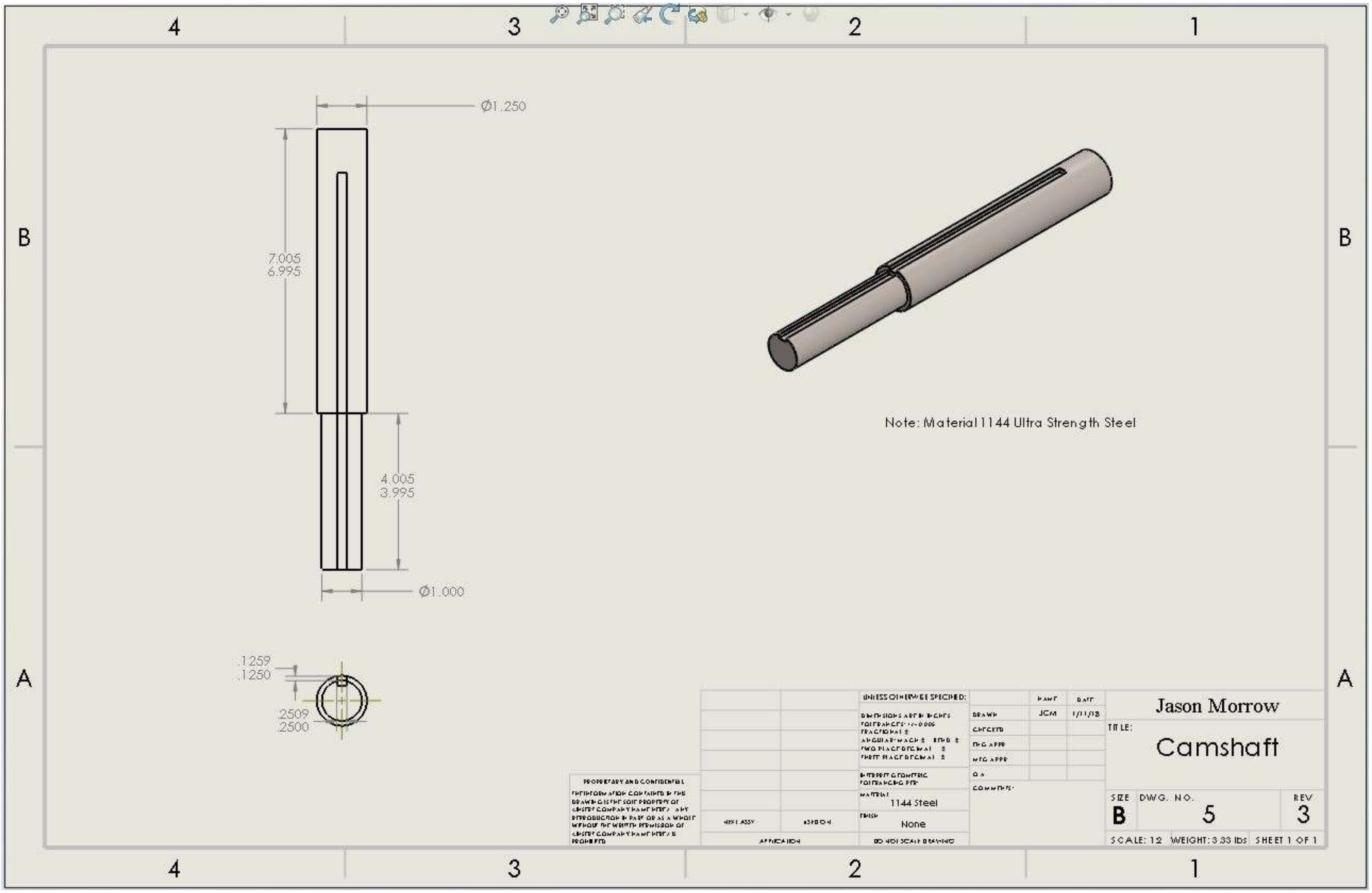


Figure B:15 Camshaft revision

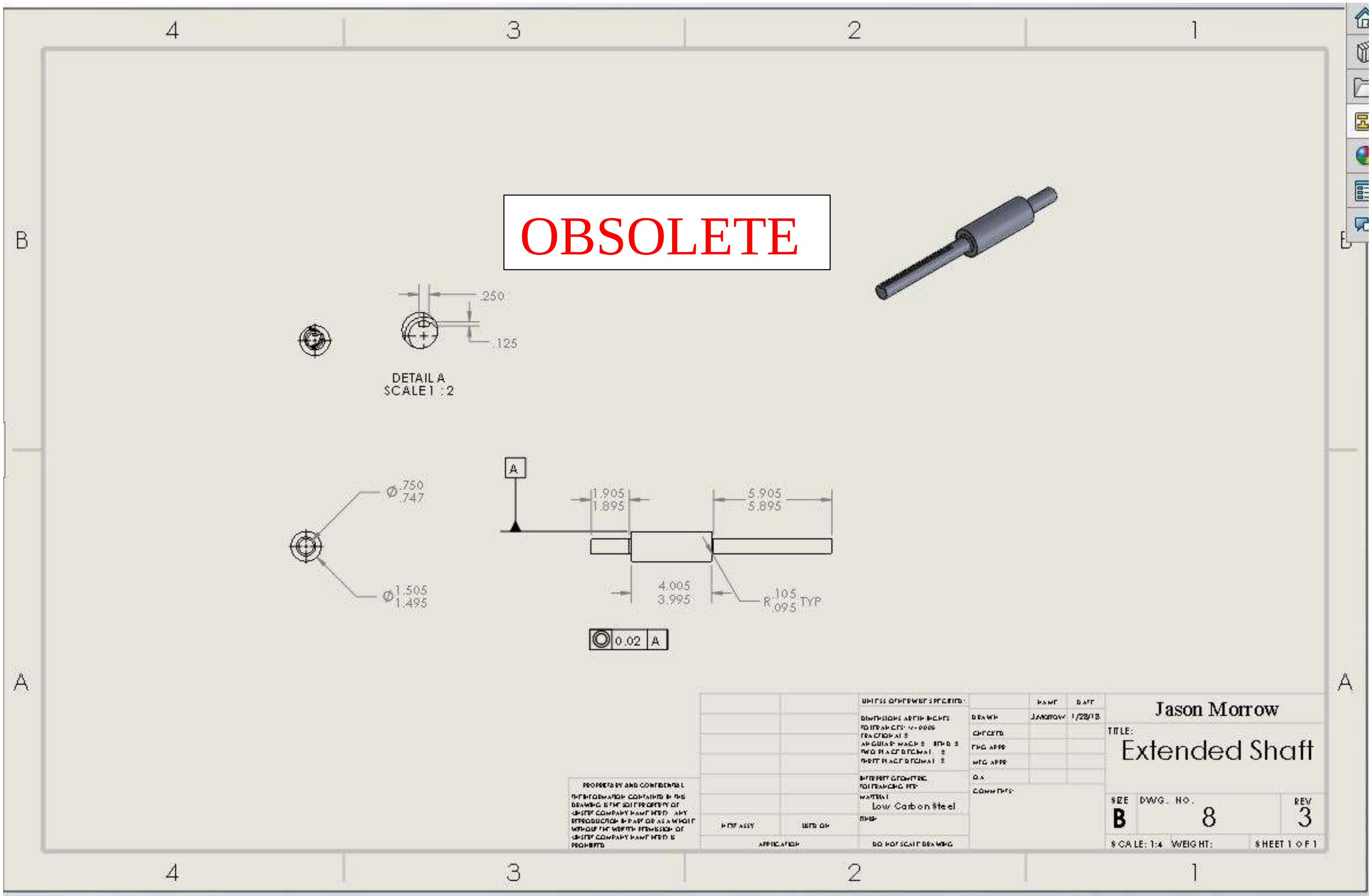


Figure B.16: Extended Shaft

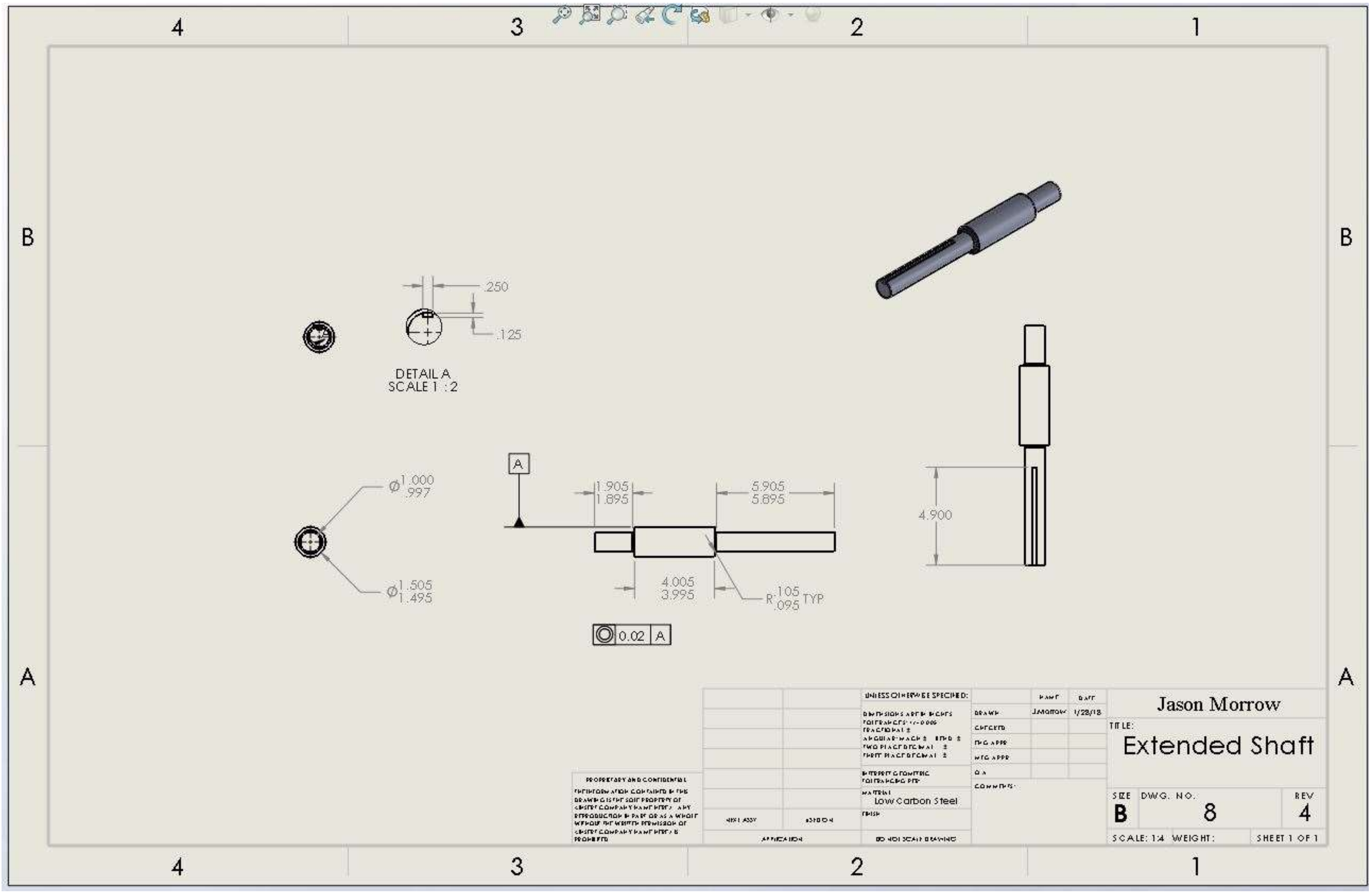


Figure B:17 Revised extended shaft

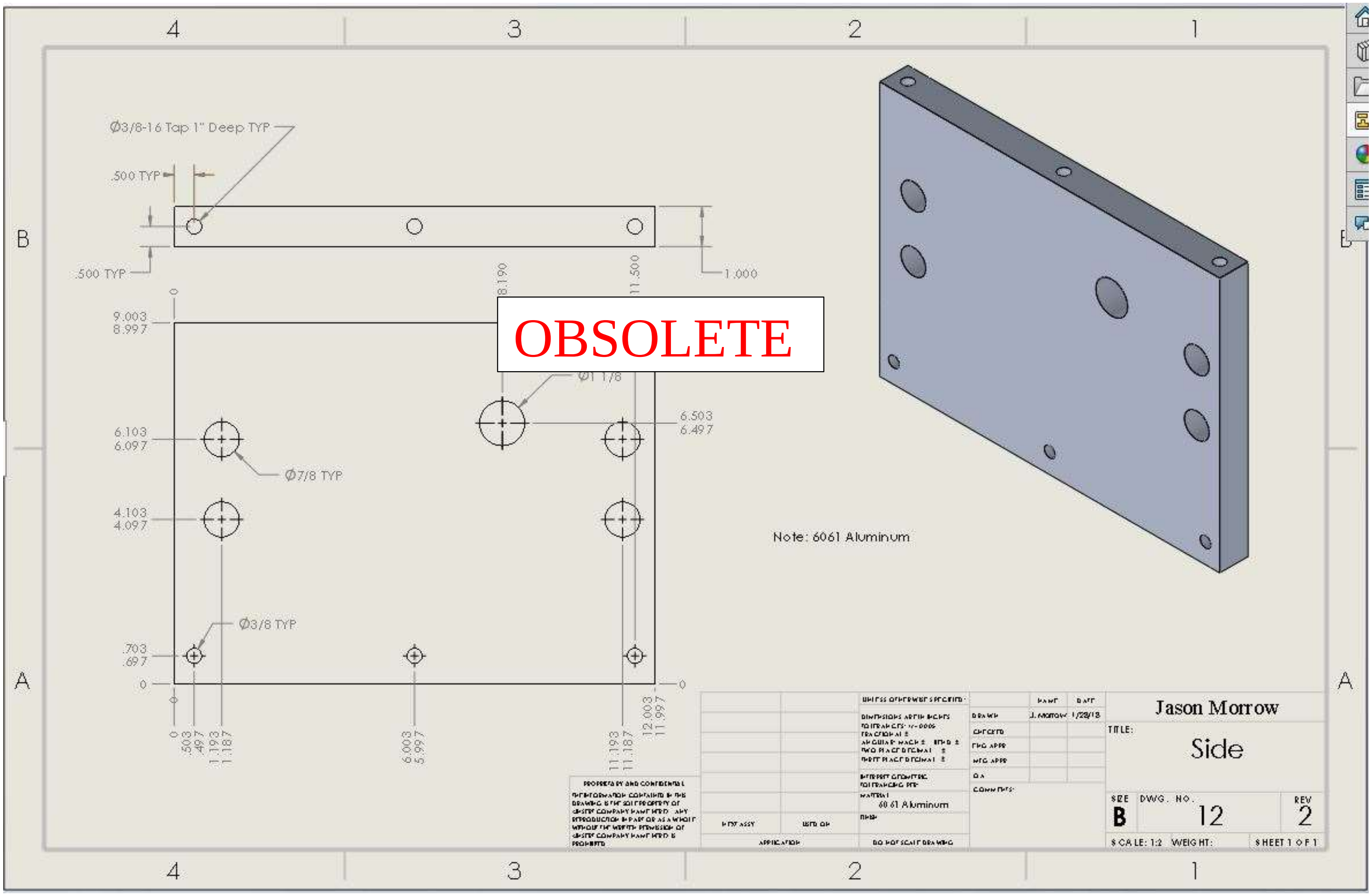


Figure B.18: Side

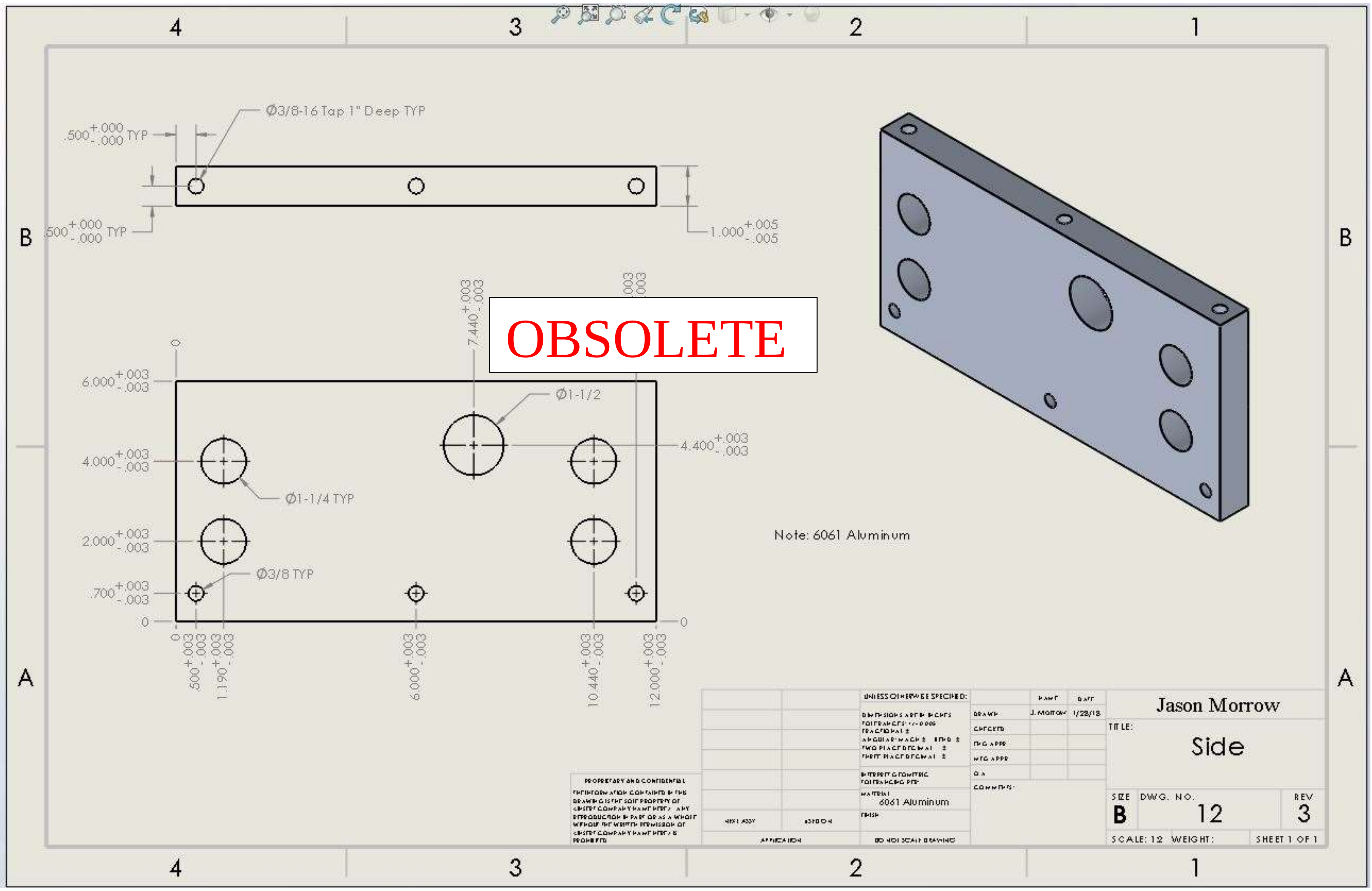


Figure B:19 Revised side

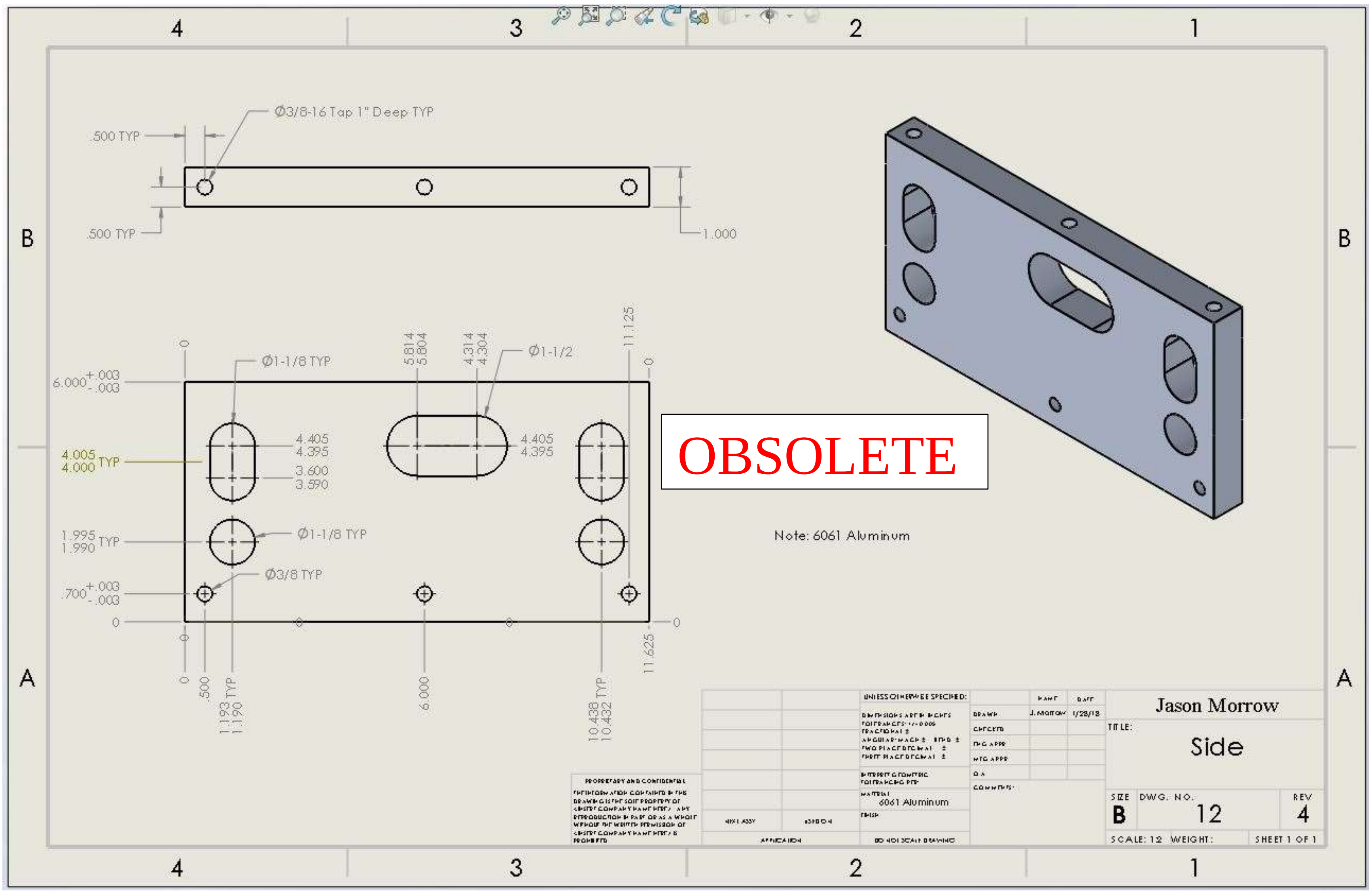


Figure B:20 – second revision of the side part

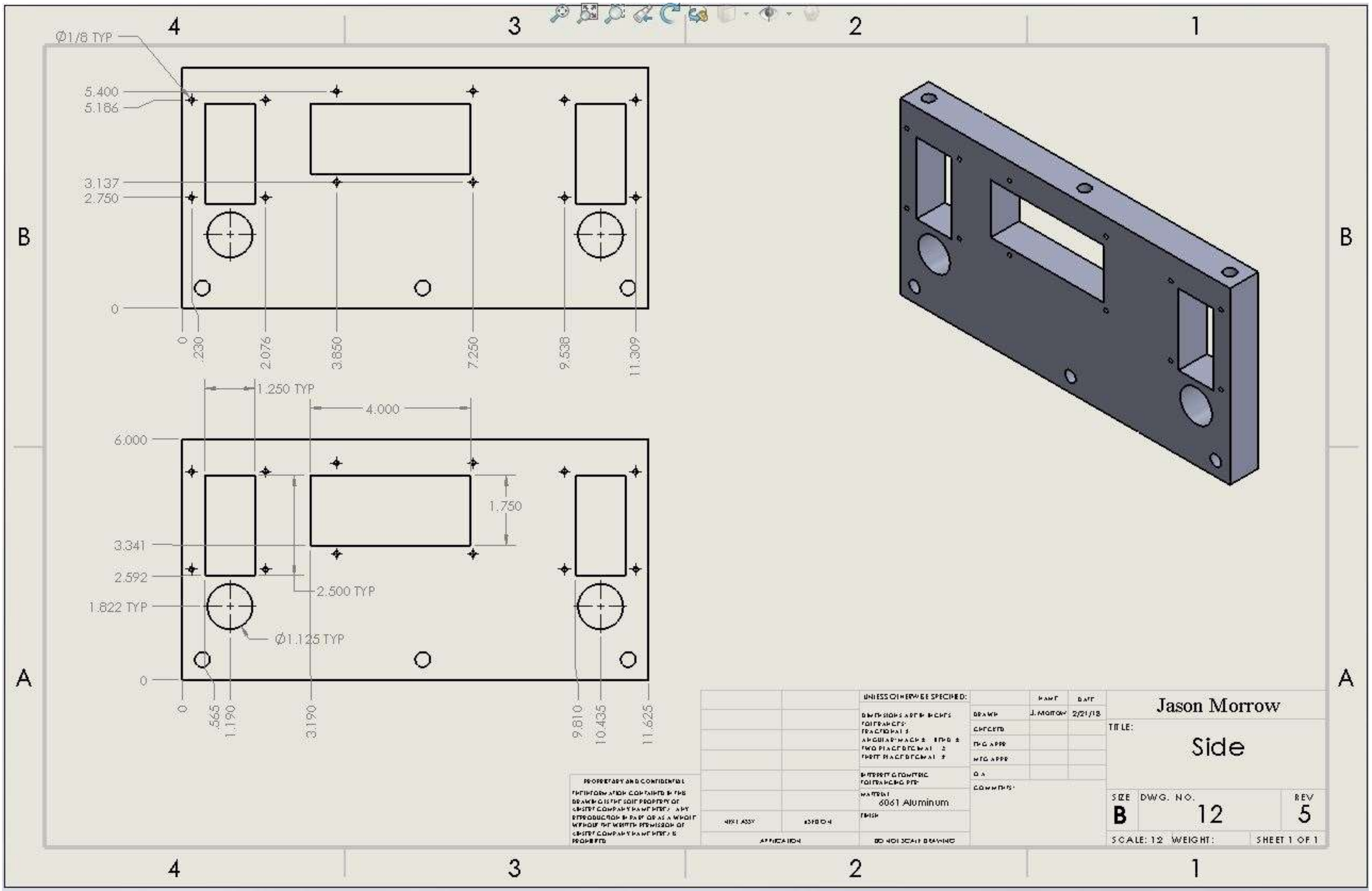


Figure B:21 – final revision of the side part

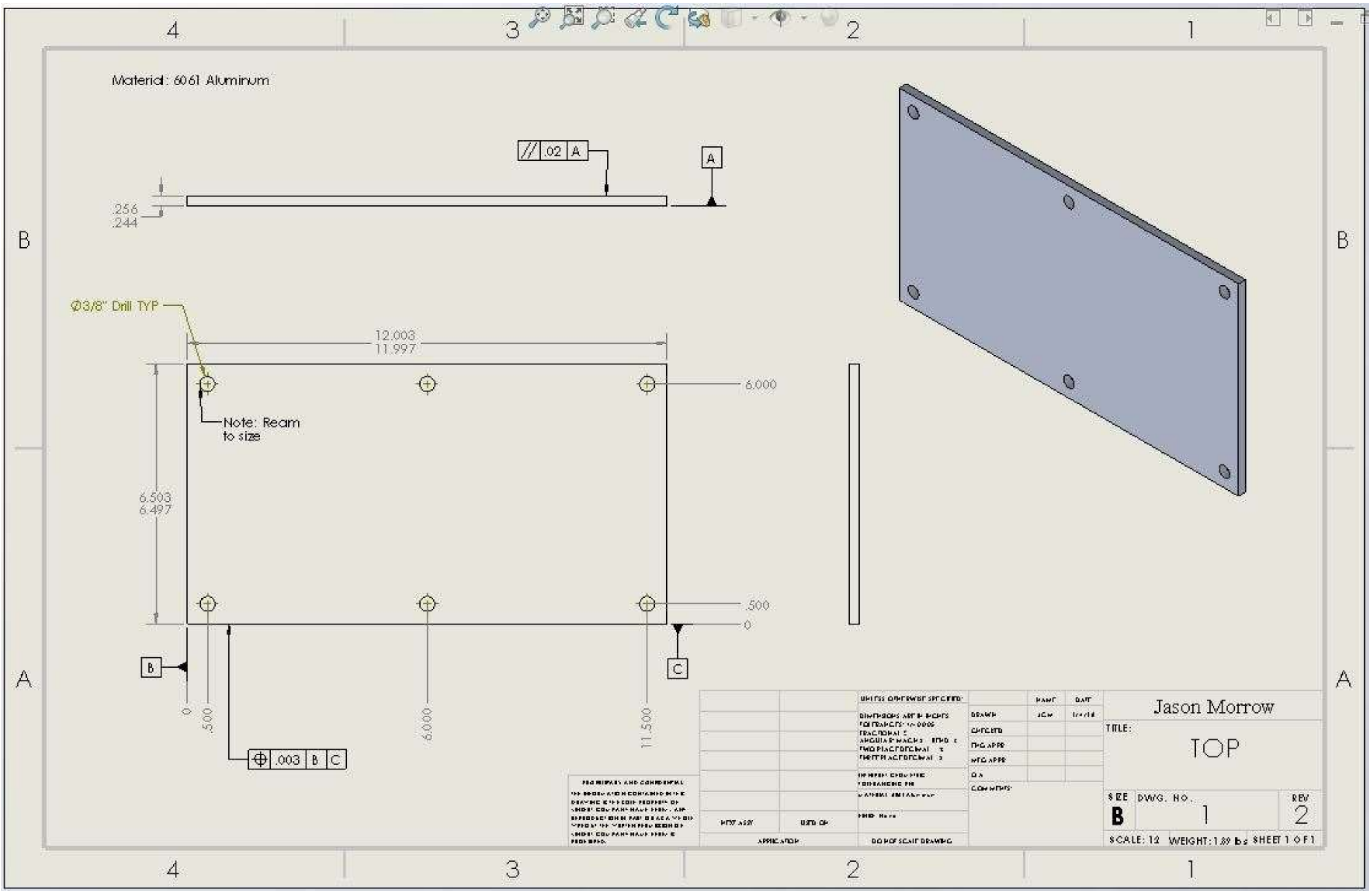


Figure B.22: Top

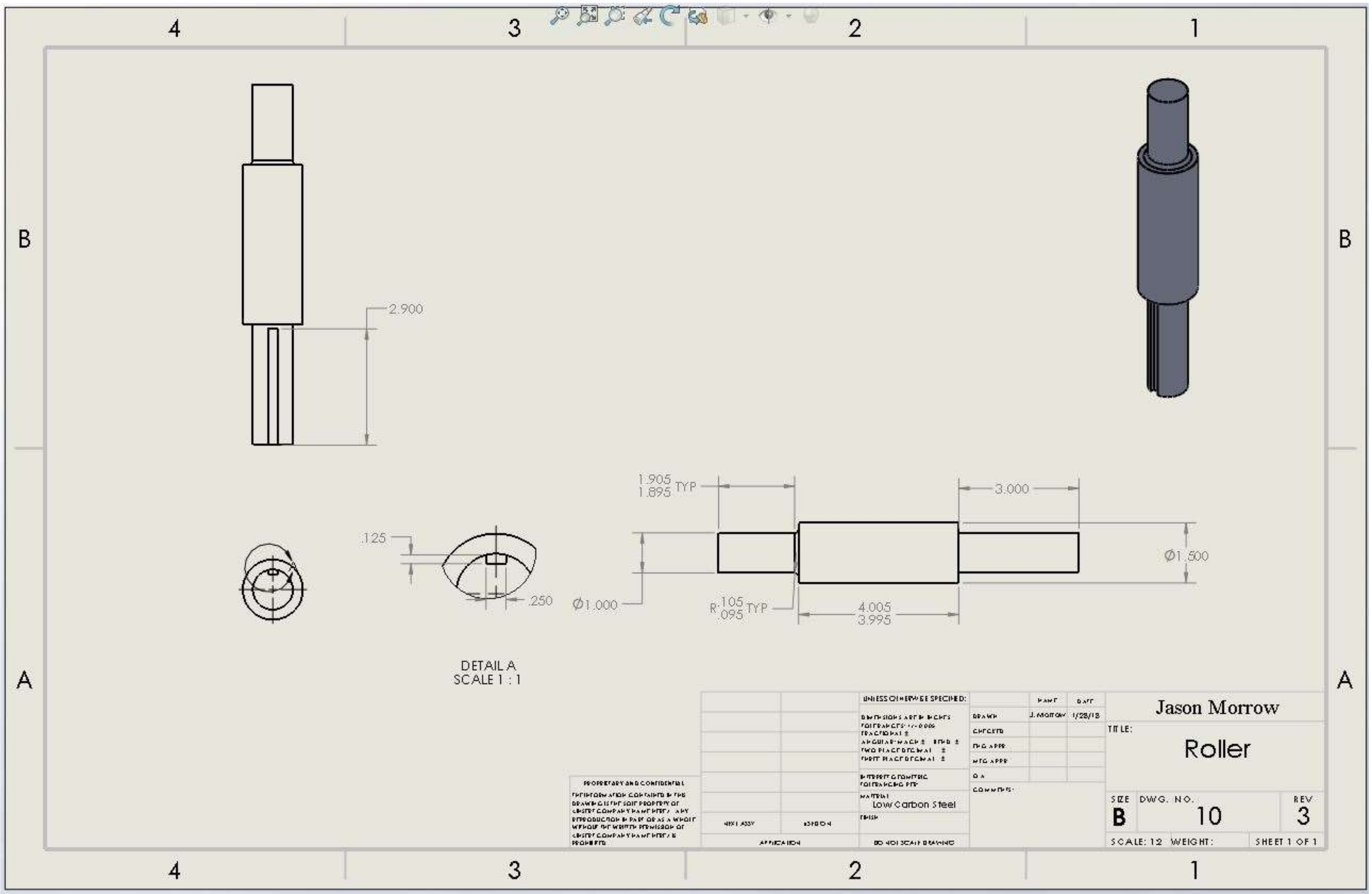


Figure B:23: Revised roller

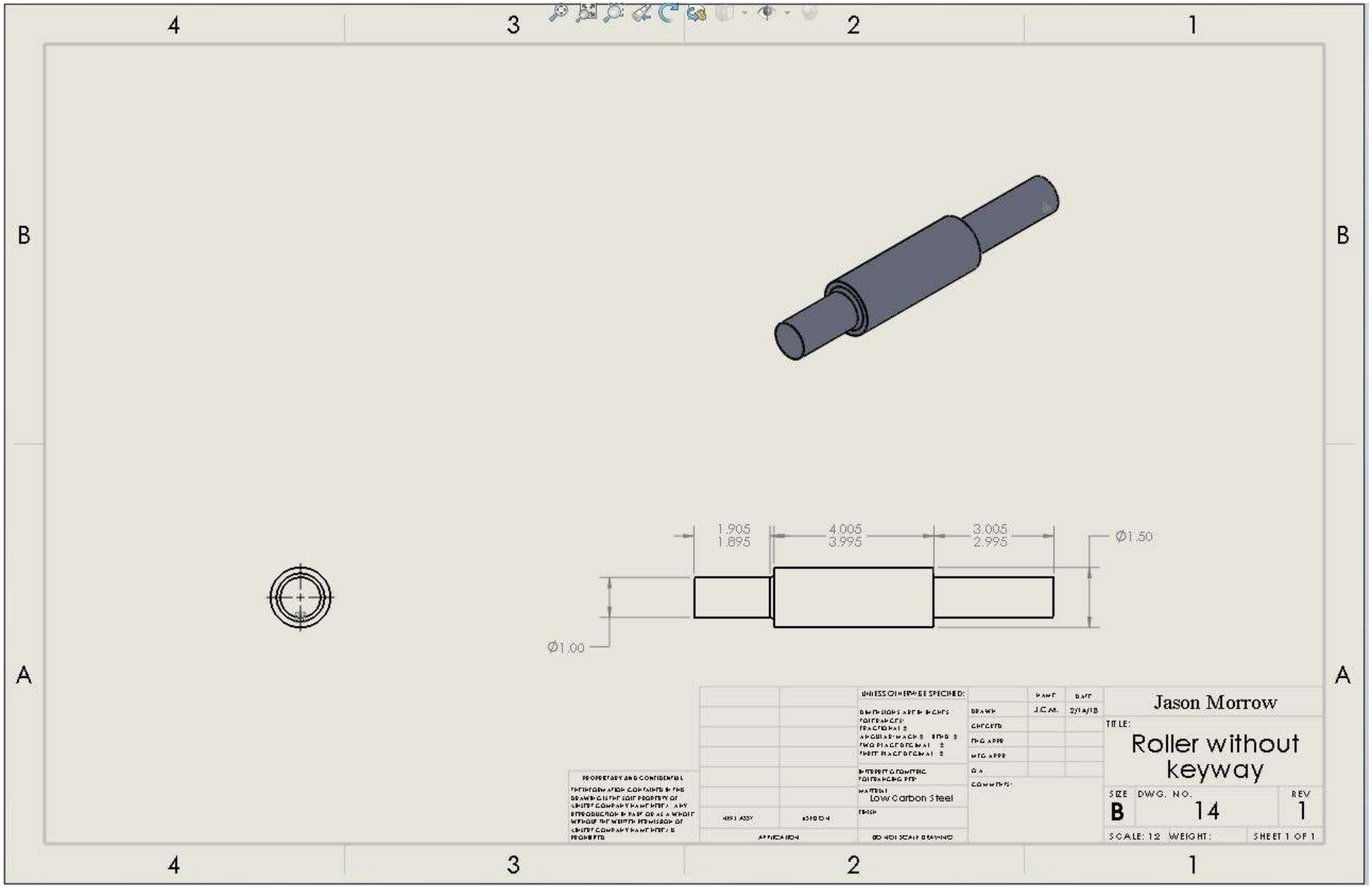


Figure B:24: Revised roller

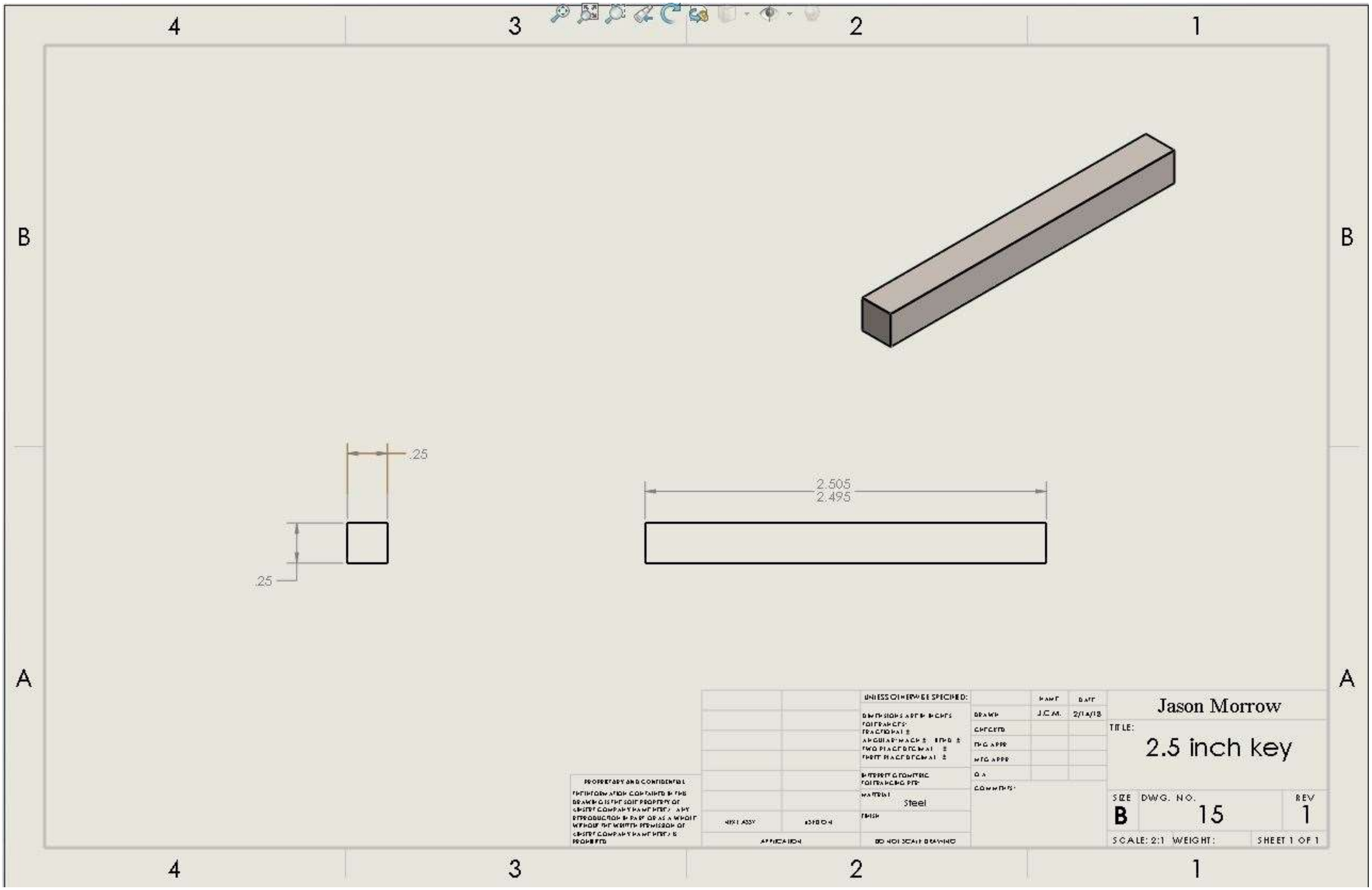


Figure B:25: 2.5 inch key

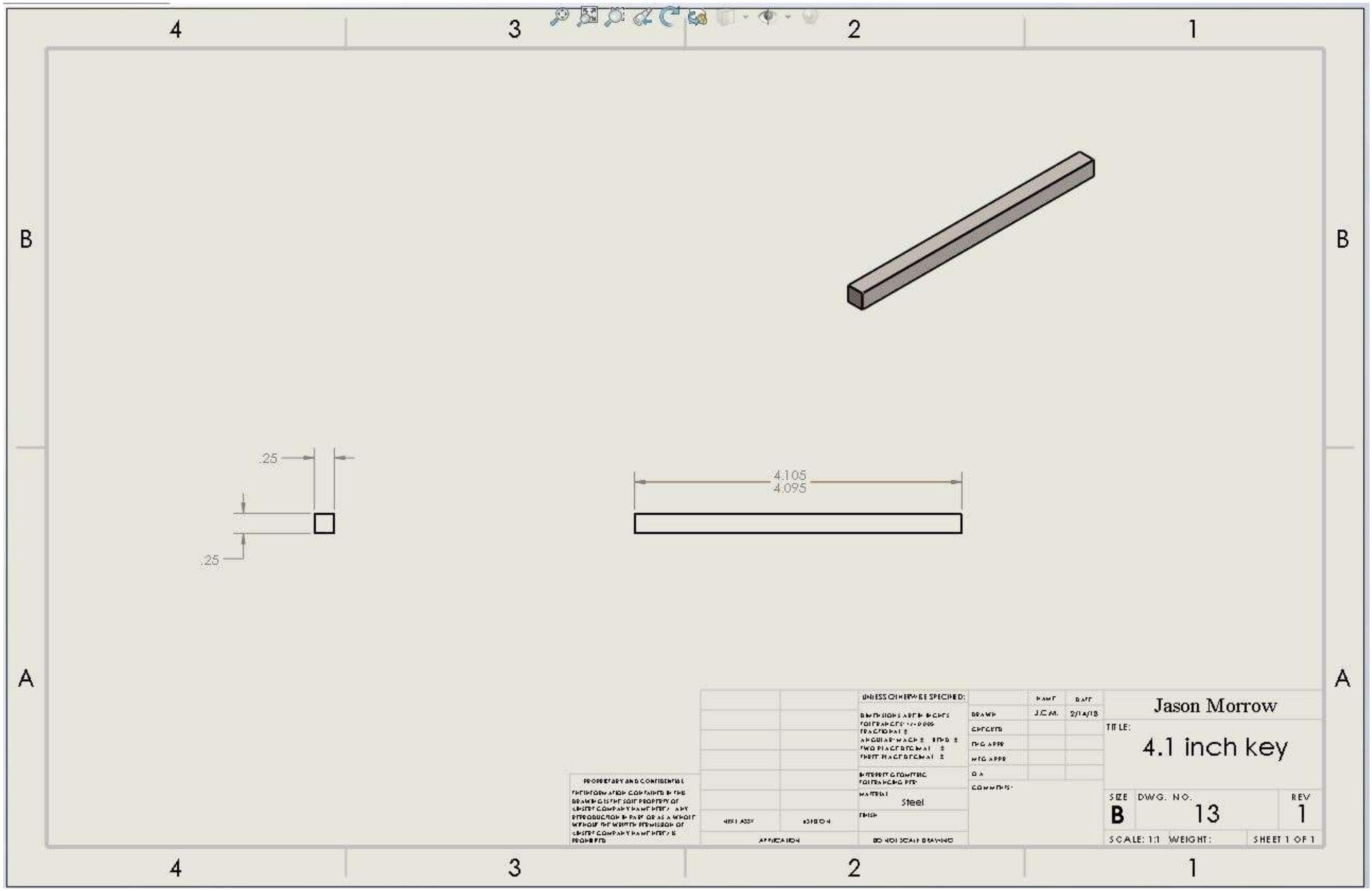


Figure B:26: 4.1 inch key

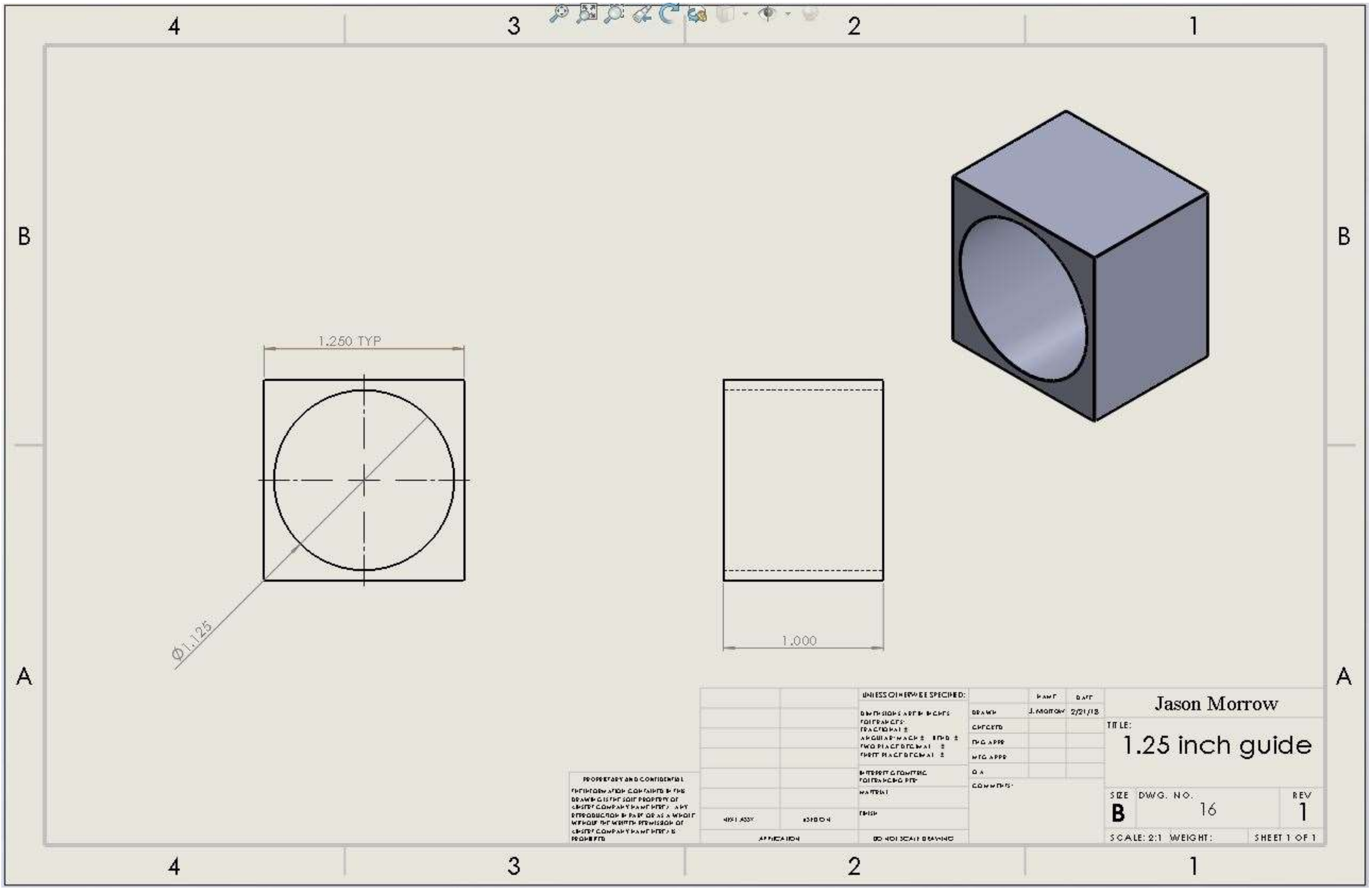


Figure B:27: 1.25 inch shaft guide

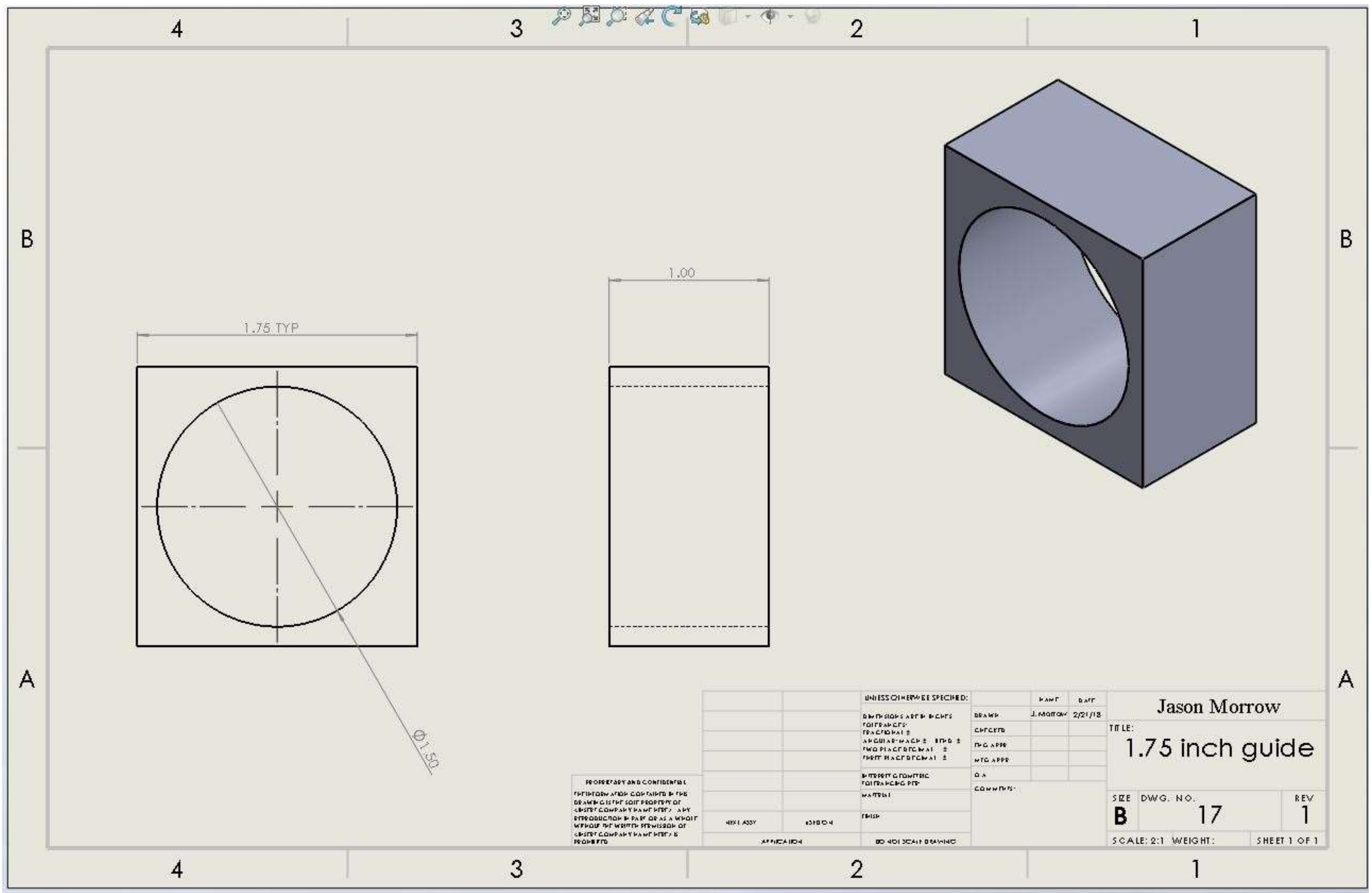


Figure B:28: 1.75 inch shaft guide

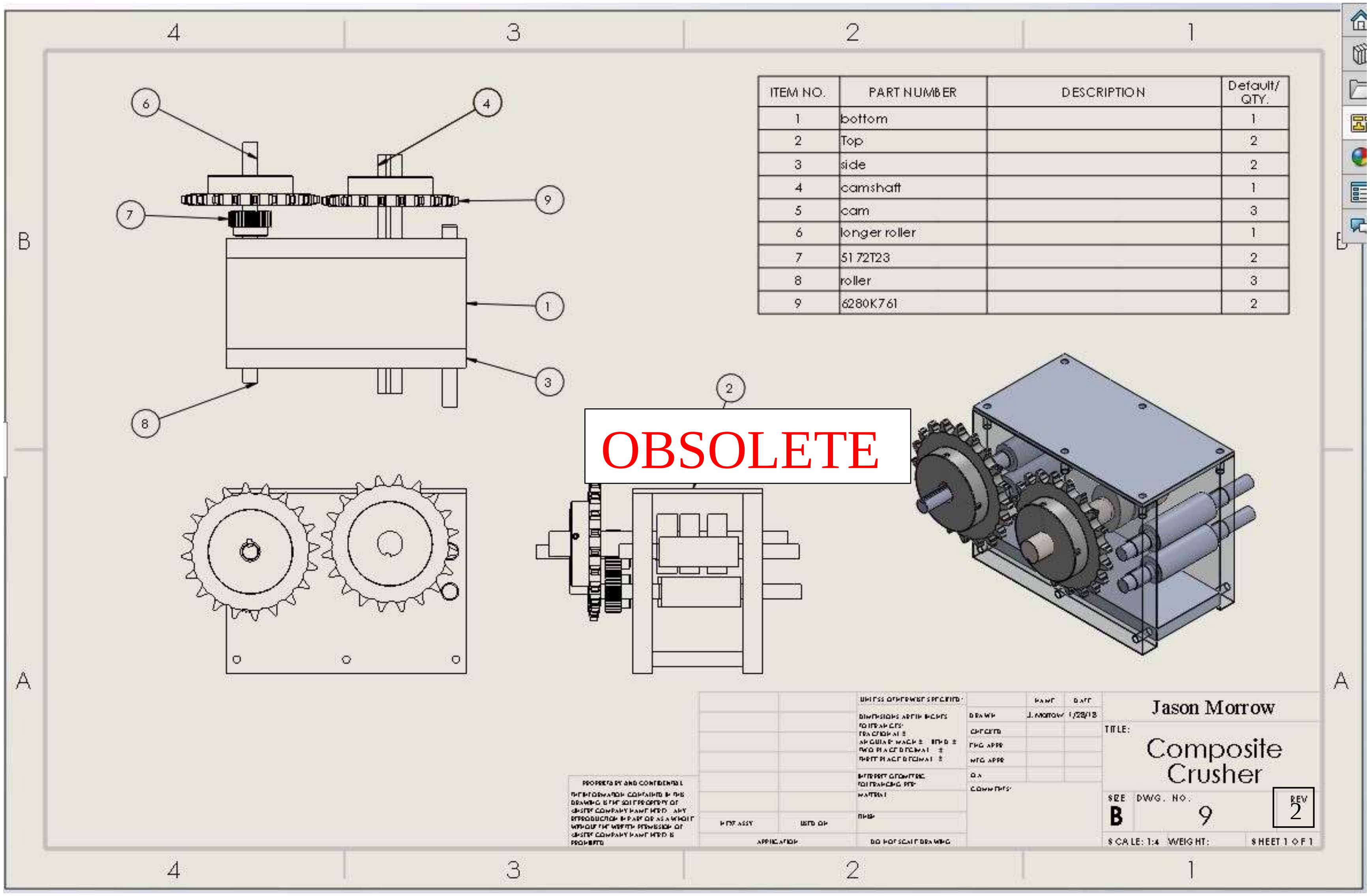


Figure B.29: Composite Crusher

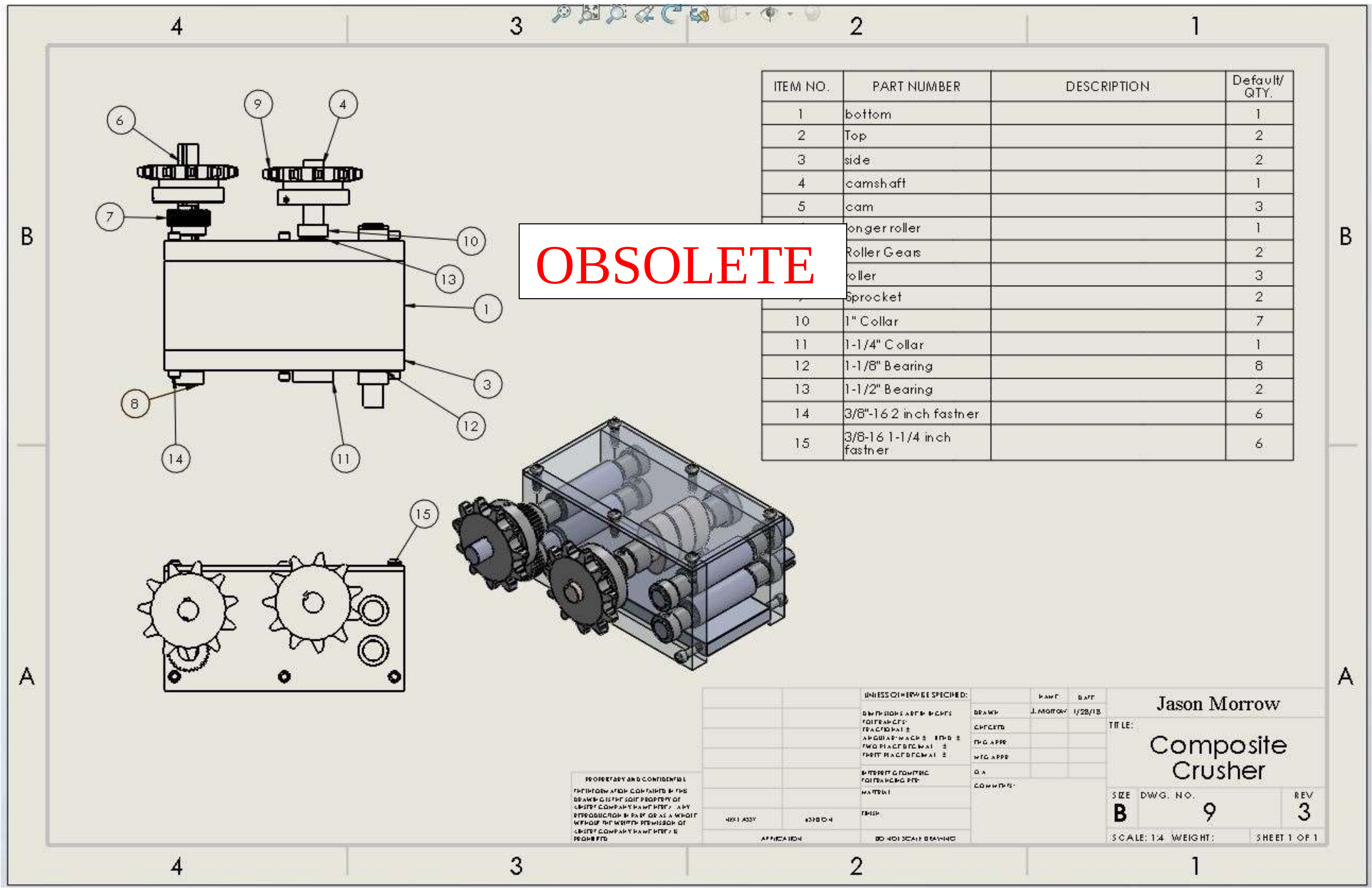
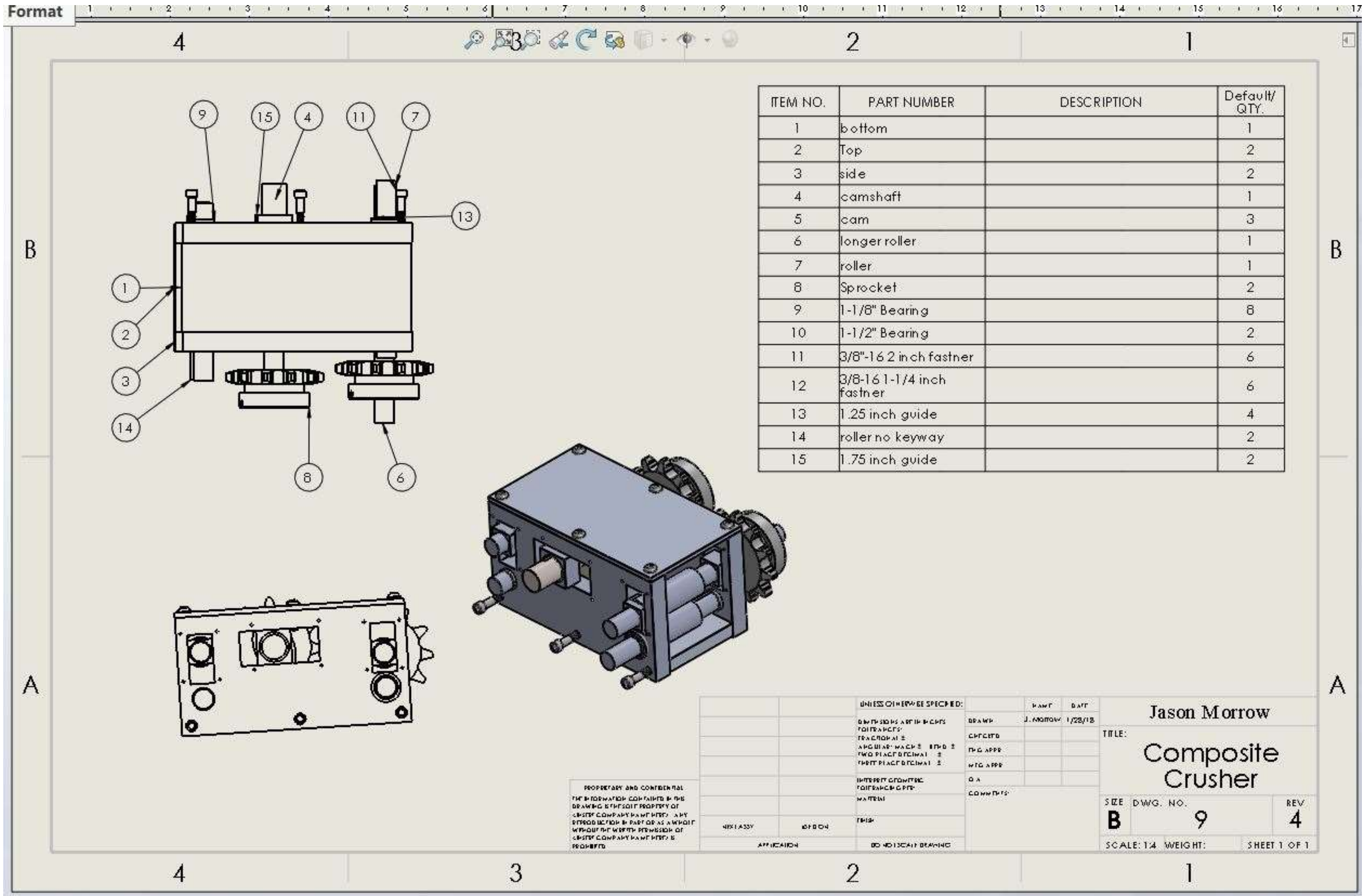


Figure B:30: Revised Composite Crusher



ITEM NO.	PART NUMBER	DESCRIPTION	Default/ QTY.
1	bottom		1
2	Top		2
3	side		2
4	camshaft		1
5	cam		3
6	longer roller		1
7	roller		1
8	Sprocket		2
9	1-1/8" Bearing		8
10	1-1/2" Bearing		2
11	3/8"-16 2 inch fastner		6
12	3/8-16 1-1/4 inch fastner		6
13	1.25 inch guide		4
14	roller no keyway		2
15	1.75 inch guide		2

Figure B:31: Final Composite Crusher

APPENDIX B2: MANUFACTURE PICTURES

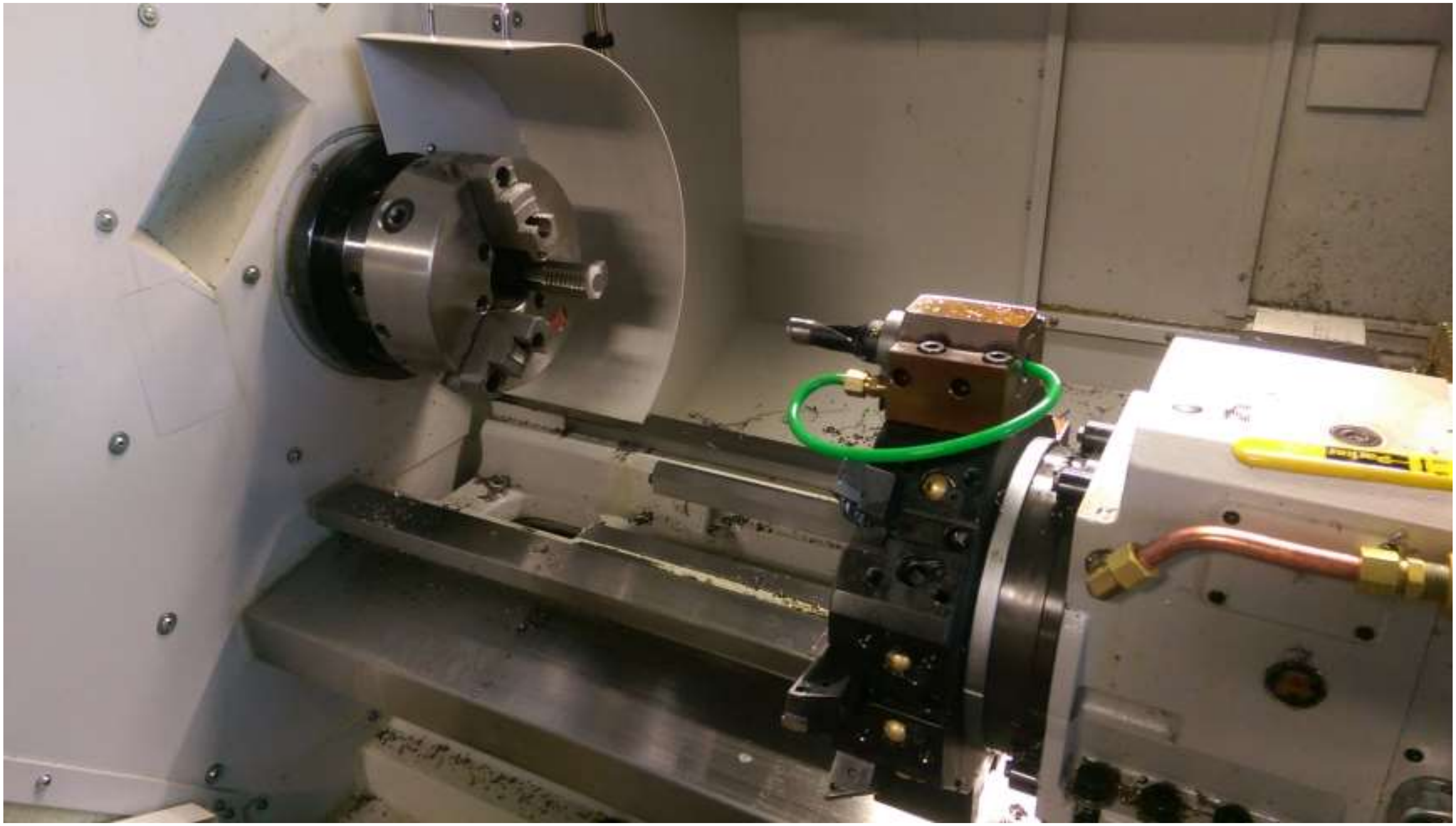


Figure B32: CNC lathe

This was used to bore out the holes for the cams. The entire process was completed with help from Ted Bramble.


Figure B33: Machined Cams

These cams are fresh from the CNC Mill. The excess on the bottom was machined off in the lathe.

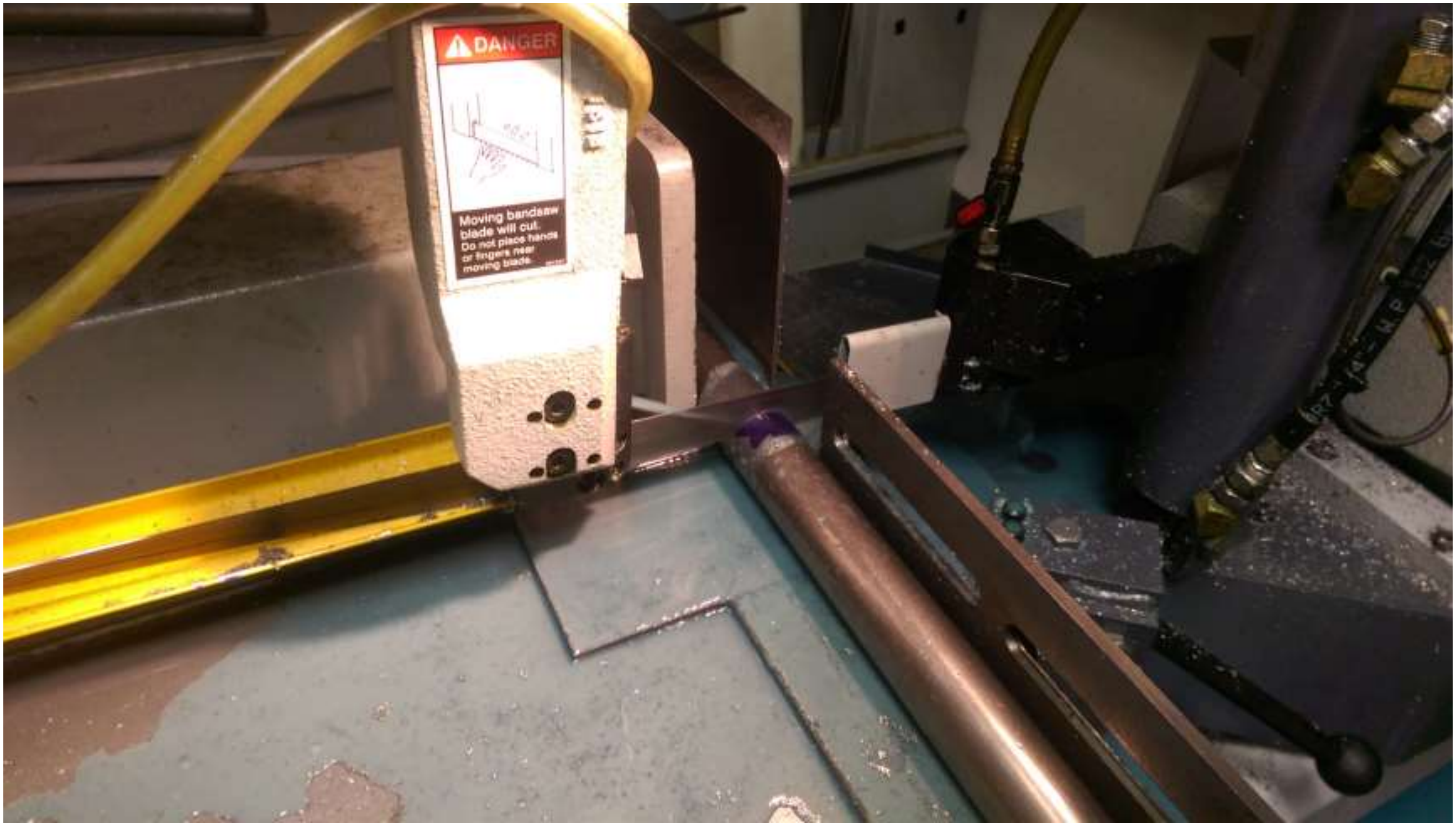


Figure B34: Cutting Rollers

The rollers came in a three foot bar and had to be cut to 12" bars. The bandsaw was set at a lower speed and feedrate due to the rollers being steel compared to aluminum.

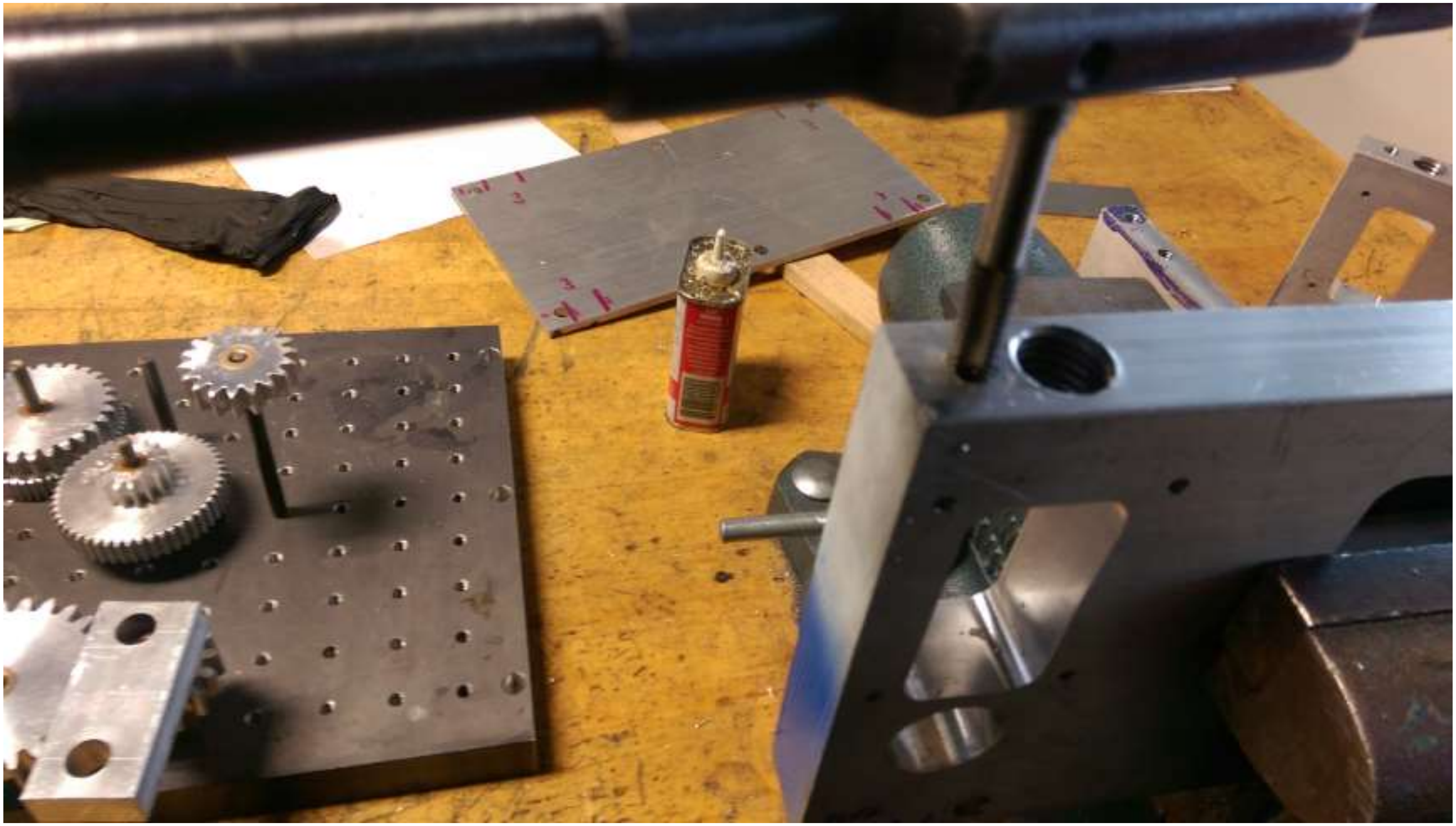


Figure B35: Tapping 3/8"-16 hole

There were numerous holes that needed to drilled and tapped. There were two 3/4"-10 holes that weresubstantially more difficult than the 3/8"-16 holes.

Figure B35: Milling shaft supports

A late stage redesign called for supports for the shaft. This was due to the need for the shafts to be adjustable in the frame of the device The idea of using cubes with a hole bored in the middle was the simplest solution. The material ordered was slightly over-sized so it had to be milled down to size.

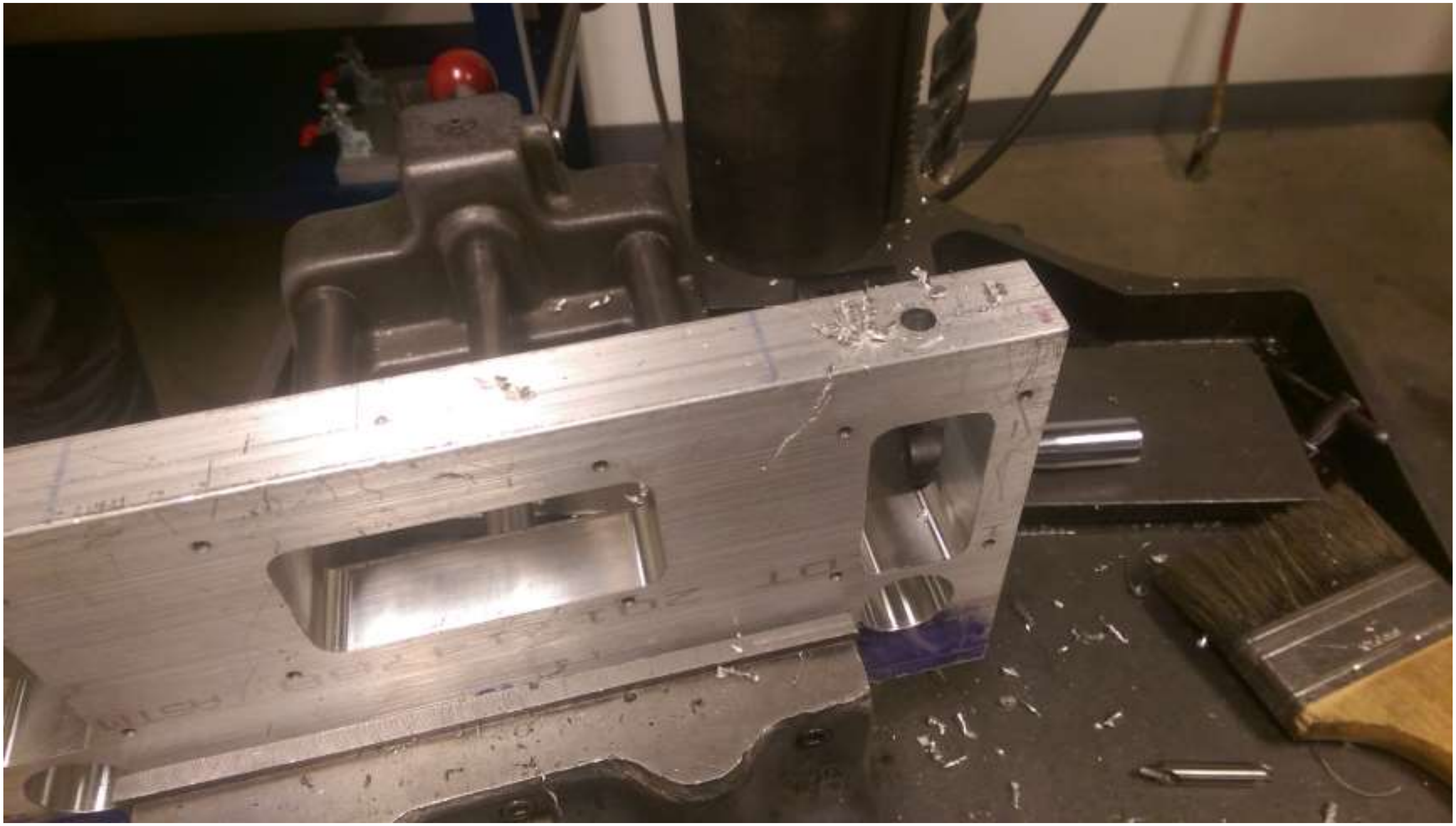


Figure B36: *Drilling for 3/4"-10 tapped hole*

A series of increasingly sized drills is used to drill the hole for tapping.

APPENDIX C/D – Parts List and Budget

Part Ident	*Part Description*	*Source*	*Cost*	*Dispositio*
Side	*6"x 36"x 1" 6061 Aluminum Plate*	*McMaster-Carr https://www.mcmaster.com/#8975k244/=1b2gcr2*	*$113.83*	*Order on web*
Bottom	*5"x24"x 3/4" 6061 Aluminum Plate*	*McMaster-Carr https://www.mcmaster.com/#8975k49/=1b0z8rf*	*$57.99*	*Order on web*
Top	*8"x24"x 1/4" 6061 Aluminum Plate*	*McMaster-Carr https://www.mcmaster.com/#8975k443/=1b0z7i9*	*$33.39*	*Order on web*
Cam	*3" Dia x 12" Steel Rod 1144 Ultra Strength*	*McMaster-Carr https://www.mcmaster.com/#6628k49/=1b20g0o*	*$106.79*	*Order on web*
Camshaft	*1.25" Dia x 12" Steel Rod 1144 Ultra Strength*	*McMaster-Carr https://www.mcmaster.com/#6628k39/=1b22rl4*	*$55.12*	*Order on web*
Rollers (2)	*1.5" Dia x 36" Steel Rod Low Carbon*	*McMaster-Carr https://www.mcmaster.com/#8920k311/=1b22sw6*	*$50.64 ($101.28)*	*Order on web*
Screws (2 packs of ten)	*3/8"-16 Thread size 2" long partially threated*	*McMaster-Carr https://www.mcmaster.com/#92196a632/=1aj4njt*	*$20.26*	*Order on websit*
Bearings for camshaft (2)	*1 1/8 " OD x 1"*	*McMaster-Carr https://www.mcmaster.com/#6391k423/=1b22wej*	*$2.32 ($4.64)*	*Order on websit*
Bearings for rollers (8)	*7/8" OD x 1"*	*McMaster-Carr https://www.mcmaster.com/#6391k259/=1b0ii72*	*$1.94 ($15.52)*	*Order on websit*

			Total	$5
Part Ident	Part Description	Source	Cost	Disposition
Motor	Base-Mount 5 hp 3 phase AC Motor	https://www.mcmaster.com/#5990k314/=1bbaomr	$738.23	Order Online
Roller Gear X2	High Load Metal Gear - 20 degree pressure angle	https://www.mcmaster.com/#5172t23/=1bbxq9t	$39.73 (79.46)	Order Online
Gear Reducer	20:1 Aluminum Right Angle Worm Gear Reducer	https://goo.gl/agMPEy	$372.95	Order Online
Bearing (X2)	Oil-Embedded Sleeve Bearing	https://www.mcmaster.com/#6391k423/=1bby2zu	$2.32 (4.64)	Order Online
Chain Sprocket (X2)	1 1/4 inch shaft sprocket	https://www.mcmaster.com/#2741t231/=1bcb4oc	$97.98 ($195.96)	Order Online
Chain (3 ft)	1 1/4 pitch	https://www.mcmaster.com/#6261k178/=1bcfcum	$66.60	Order Online
Connecting Link (X2)	1 1/4 pitch	https://www.mcmaster.com/#6261k181/=1bcbibr	$3.86 ($7.72)	Order Online
Half Link (X2)	1 1/4 pitch	https://www.mcmaster.com/#6261k271/=1bcbkkx	$8.88 ($17.76)	Order Online
Keystock (X2)	.25 x .25	https://www.mcmaster.com/#98510a136/=1bcbda0	$1.55 ($3.10)	Order Online
Shaft Coupling Hub	7/8" shaft diameter	https://www.mcmaster.com/#6407k43/=1bcfdk6	$26.24	Order Online
Shaft Coupling Hub	1 1/8" shaft diameter	https://www.mcmaster.com/#6407k43/=1bcf70x	$26.24	Order Online
Shaft Coupling Chain (X2)	4000 rpm roller chain	https://www.mcmaster.com/#6407k53/=1bcf7gy	$18.80 (37.60)	Order Online
Shaft Coupling Hub	1" shaft diameter	https://www.mcmaster.com/#6407k43/=1bcf9x6	$26.74	Order Online
Shaft Coupling Hub	1 3/8" shaft diameter	https://www.mcmaster.com/#6407k43/=1bcfagy	$26.74	Order Online
		Total	$1,629.95	Second Round
3/8" -16 Hex Drive Screw	1-1/4" long	https://www.mcmaster.com/#92949a626/=1biz46d	$5.33	Order Online
1" diameter shaft collar (X7)	Black-Oxide 1215 Carbon Steel	https://www.mcmaster.com/#9414t19/=1bizcjc	$2.67 ($18.69)	Order Online
1-1/4" diameter shaft collar	Black-Oxide 1215 Carbon Steel	https://www.mcmaster.com/#9414t24/=1biznfw	$5.42	Order Online
7/8" diameter shaft collar	Black-Oxide 1215 Carbon Steel	https://www.mcmaster.com/#9414t17/=1bj024h	$2.62	Order Online

1-3/8" diameter shaft collar	Black-Oxide 1215 Carbon Steel	https://www.mcmaster.com/#9414t26/=1bj04a9	$6.42	Order Online
External Retaining Ring	1" OD	https://www.mcmaster.com/#91590a133/=1bizptz	$8.54	Order Online
Fixed-Tip Retaining Ring Plier	3/4" to 3-1/2" OD ring	https://www.mcmaster.com/#57805a45/=1bizr65	$20.84	Order Online
7/8" diameter x 12" long keyed rotary shaft	1045 carbon steel	https://www.mcmaster.com/#1497k181/=1bizvw9	$25.17	Order Online
3/16" x 3/16" x 12" key stock	Carbon Steel	https://www.mcmaster.com/#98510a117/=1bizxiz	$0.99	Order Online
1-3/8" diameter x 12" long keyed rotary shaft	1045 carbon steel	https://www.mcmaster.com/#1497k611/=1bizzkz	$39.39	Order Online
5/16" x 5/16" x 12" key stock	Carbon Steel	https://www.mcmaster.com/#98510a150/=1bj0131	$2.29	Order Online
1-1/8" OD Bearing (X6)	Oil-Embedded Sleeve Bearing	https://www.mcmaster.com/#6391k423/=1bby2zu	$2.32 ($13.92)	Order Online
1-1/2" OD Bearing (X2)	Oil-Embedded Sleeve Bearing	https://www.mcmaster.com/#6391k295/=1bj0ez0	$3.16	Order Online
		Total	$152.78	Third Round
1-1/4" x 1-1/4" x 12" Aluminum stock	6061 Aluminum	https://www.mcmaster.com/#aluminum/=1bq9g52	$13.25	Misc
1-3/4" x 1-3/4" x 6" Aluminum stock	6061 Aluminum	https://www.mcmaster.com/#aluminum/=1bq9gzs	$15.51	Misc
		Grand Total	**$2,320.31**	
Ordered by own money				
Compression spring	2.5" long Pack of 6	https://www.mcmaster.com/#9657K422	$7.21	Order Online
5-40 pack of 100	1-1/4" slotted screw	https://www.mcmaster.com/#90276A135	$12.26	Order Online
5-40 Hex Nut	Steel Hex	https://www.mcmaster.com/#90480A006	$1.71	Order Online
3/4"-10 Screw (X2)	Black-Oxide Screw	https://www.mcmaster.com/#91255A061	$18.49 ($36.98)	Order Online
3/8"-16 Screw (pack of 10)	Stainless Steel Button	https://www.mcmaster.com/#92949A628	$6.13	Order Online
Compression spring k = 21 lbs./in.	2.5" long Pack of 6	https://www.mcmaster.com/#9657K421	$7.13	Order Online

Total	$71.42

APPENDIX E – Schedule

SCHEDULE FOR SENIOR PROJECT:

PROJECT TITLE: Composite recycling
Principal Investigator.: Jason Morrow

Note: March x Finals
Note: June x Presentation
Note: June y-z Spr Finals

TASK: ID	Description		Duration Est. (hrs)	Actua (hrs)	November / Dec / January / February / March / April / May / June	Completion
1	Proposal*					
1a	Outline		3	5		100%
1b	Intro		10	15		100%
1c	Methods		10	16		100%
1d	Analysis		15	20		100%
1e	Discussion		15	21		100%
1f	Parts and Budget		10	15		100%
1g	Drawings		5	20		100%
1h	Schedule		5	10		100%
1i	Summary & Appx		10	10		100%
		subtotal:	83	132		
2	Analyses					
2a	Bending Composite		15	20		100%
2b	Torque on shafts		5	10		100%
2c	Required motor		5			100%
2d	Gearing to support motor		5			100%
2e	Housing		5	20		100%
		subtotal:	35	50		
3	Documentation				November / Dec / January / February / March / April / May / June	
3a	Drawing for roller		3	27		100%
3b	Drawing for camshaft		3	27		100%
3c	Drawing for cam		3	21		100%
3c	Drawing for top		3	18		100%
3d	Drawing for side		3	30		100%
3e	drawing for bottom		3	20		100%
3f	drawing for key		3	3		100%
3g	Drawing for Assembly		3	11		100%
3h	Set up sheets		15	6		30%
3i	Drawing for assembly		3	17		100%
3j	ANSIY14.5 Compl		5	3		
		subtotal:	47	183		
4	Proposal Mods					
4a	Project Composite Schedule		20	10		100%
4b	Project Composite Part Inv.		20	15		100%
4c	Crit Des Review*		1	0		
		subtotal:	41	25		
7	Part Construction				January / February / March / April / May / June	
7a	Buy sheet for top/bottom		2	2		100%
7b	Cut 12" piece on side		5	2		100%
	Drill two 1-1/8" holes		5	2		100%
	Drill two 1-3/4" slots		5	2		100%
	Drill 12 1/8" holes		5	2		100%
	Drill 1-1/4" slots		5	2		100%
	Drill 25/64" hole		5	2		100%
	Drill and tap six 3/8" holes		5	3		100%

59	7c	Cut 12" piece on bottom	5	1	100%
60		Drill and tap six 3/8" holes	5	2	100%
61	7d	Buy sheet for top	5	2	100%
62		Cut 12" piece on top	5	1	100%
63		Drill six 3/8" holes	5	1	100%
64	7e	Buy bar for roller	5	3	100%
65		Cut bar stock to 1' length		1	100%
66		Lathe turn roller OD to 1.5"	5	2	100%
67		Lathe turn arms of roller to 0.75"	5	2	100%
68	7f	Camshaft via Ted Bramble assistance	30	15	100%
69	7g	Determine required motor	15	10	100%
70	7h	Buy bearing	2	2	100%
71	7i	Buy screws	2	2	100%
72	7j	Buy gearbox	3	2	100%
73	7k	Build coupling systems	3		
74	7l	Build sprocket and chain system	3		
75	7m	Buy gears	3	2	100%
76	7n	Machine sheet for sides	5	2	
77	7o	Machine sheet for top	5	2	100%
78	7p	Machine sheet for bottom	5		100%
79	7q	Machine sheet for roller	5		
80	7r	Machine keyline cylinder for roller	10	10	100%
81	7s	Machine keyline for camshaft	10	10	100%
82	7t	Machine keyline for cam	10	6	100%
83	7u	Machine and drill 1-1/8" hole in 1-1/4" x 1-1/4" x 1" cube	10	17	100%
84	7v	Machine and drill 1-1/2" hole in 1-3/4" x 1-3/4" x 1" cube	10	2	
85		subtotal:	208	114	
86					
87	9	Device Construct			
88	9a	Assemble Housing	5	6	100%
89		Line up holes in side and top and insert screws	1	3	100%
90	side	Insert bearings into side holes	1	1	100%
91	side	Insert rollers into front and back holes	1	1	100%
92	side	Insert camshaft into middle hole	1	1	100%
93		Line up holes in side and bottom and insert screws	1	2	100%
94	9e	Take Dev Pictures	5	5	
95	9f	Update Website	10	5	
96		subtotal:	25	24	
97					
98	10	Device Evaluation			
99	10a	List Parameters	10	0	
100	10b	Design Test&Scope	10	0	
101	10c	Obtain resources	10	0	
102	10d	Make test sheets	10	0	
103	10e	Plan analyses	10	0	
104	10f	Instrument Robot	10	0	
105	10g	Test Plan*	10	0	
106	10h	Perform Evaluation	10	0	
107	10i	Take Testing Pics	10	0	
108	10h	Update Website	10	0	
109		subtotal:	100	0	
110					
111	11	489 Deliverables			
112	11a	Get Report Guide	10	5	
113	11b	Make Rep Outline	10	5	
114	11c	Write Report	10	15	

115		11d	Make Slide Outline		10	0	
116		11e	Create Presentation		10	0	
117		11f	Make CD Deliv. List		10	0	
118		11e	Write 495 CD parts		10	0	
119		11f	Update Website		10	0	
120		11g	Project CD*		10	0	
121				subtotal:	90	25	
122							
123			Total Est. Hours=		629	553	=Total Actual Hrs
124	Labor$			100	62900		
125							

APPENDIX F – Expertise and Resources

Current benchmarks for recycling composite is industrial sized grinders as seen in section 2C of the main report. The dual crusher/cutting device was envisioned to be a much smaller scale of this grinder. It was expected if the small scale prototype was a success it would be possible to scale up this design to potential industrial scale size.

APPENDIX G – Testing Data

There is no testing data due to the inability to test due to time and resources. Data would have included the feed rate of the rollers as well as the amount of delamination based on counting how many individual layers separated and in how successfully the cutting device cut the delaminated into strips.

APPENDIX H – Data Evaluation Sheets

As stated above there are no data evaluation sheets because no data was collected. Expected sheets would be based on the descriptions in Appendix G.

APPENDIX I – Testing Report

Introduction:

a. Requirements

The primary requirement for testing is determining the feed rate of the composite as it goes through the crusher and the cutter. A secondary requirement related directly to the primary requirement is determining the extent that the crusher delaminates the composite and the ability of the cutter to cut the composite into strips.

b. parameters of interest

The purpose of the device is to delaminate and cut the composite into strips. The primary testing parameters are based around this purpose and thus the test itself has a pass/fail based around the ability to cut to delaminate and cut the composite. Another parameter to monitor is the feed rate of 100 inches per minute.

c. predicted performance

The predicted performance is two fold. The first is the ability of the devices to delaminate and cut the composite into strips. Assuming this is no issue the second predicted performance is the composite feeding through at a rate of 100 inches per minute. This would allow a high level of processing and provide valuable data to begin designing an upscale.

d. data acquisition

The primary source of data acquisition is the output of the cutting device. A success/fail will be given based on if the composited was cut into strips or not.

e. schedule

The testing procedure itself has been hampered with issues involved in mounting. The main factor is time and design requirements of the mounting.

Method/Approach:

a. Resources (hard/soft/external, people, costs)

The primary resource needed is electricity for the motors. This requires professional wiring outside of the expertise of those involved. The construction of the mounting for the devices and the motor require design work and buying material for shelves. Extensive machining will need to occur to mount the devices and there is possibility for welding. Safety concerns must be taken into account for the moving gears and chains.

Matt Burvee, Charles Pringle and Dr. Craig Johnson are the primary advisors for the construction of the mounting as well as for the testing itself.

b. data capture/doc/processing

The data capture boils down to the output condition of the composite. It will be a pass/fail based on if the composite is delaminated in any way and if it is cut. This process is essentially the entire point to the devices, so the documentation will be a simple yes/no checkbox for if the composite was delaminated or not. The RPM can be varied on both the crusher and cutter so different values can be tested to determine if one delaminates or cuts at a better rate than the other.

c. test procedure overview

The test involves sending long strips of composite through the crusher and cutting devices. The motors will be turned on and the material will be fed through the crusher. It will move through the crusher while being delaminated and exit into the cutter. From here it will be cut into strips and exit from the rear into a bin for collection.

d. operational limitations

The primary limitation is the device structure must be in a location where sufficient power can be supplies to the motors. The composite itself is likely to produce airborne debris when being cut so ideally a ventilation system will have to be in place for operator safety.

e. precision and accuracy discussion

Precision and accuracy in the case of this test is how close the feed rate is compared to what was estimated. As for the delamination and cutting there is no specific criteria regarding precision and accuracy as it is a yes/no system of cutting the composite into strips. It either will cut into strips or it won't.

f. data storage/manipulation/analysis

The collected data is essentially the cut material. Analysis will be expecting the state of the processed material and determining what the final feed rate was. Manipulation of the motor speed will allow for various tests to occur. Analysis will be based around the pass/fail of the composite being delaminated or cut.

g. data presentation

The data will be presented in a graph for the various RPMs and determining if a certain RPM is more successful in cutting than another. This can be further charted in how much delamination each RPM causes and the quality of the cuts at each RPM.

Test Procedure

I: Summary and Overview

This project involves taking long strips of composite trimmings from the 777x aircraft and attempting to delaminate and cut these trimmings into strips for bulk storage. This test will involve two devices. The first device will bend the composite causing it to delaminate. The bending action is caused by a rotating cam. Two sets of rollers will cause the composite to run through the device. At the exit of the first device is the entrance to the second device. This device has two sets of cutters which will cut the composite into strips.

II: Time to test

The time to test depends on the true feed-rate of the bending device. The estimated federate is given at 100 inches per minute but this value is likely not correct. This federate goes hand in hand with the length of the composite trimming. They are estimated to be between 6 and 7 feet in length.

III: Location of test

There are limitations to where the testing can take place because of the electrical requirements of the motor. The room has to supply Three phase 230 volts at a 13 amp draw at full load which the motor will be running at. There are a small number of rooms which can supply this power and these are currently being investigated.

IV: Required resources

The primary resources required are electricity and composite trimmings. There is currently an ample supply of composite trimmings and there are available outlets for the electricity requirements of the motor.

V: Risk and Safety Assessment

There are some inherent dangers with this test procedure. There are a number of moving parts to include chains, sprockets and shafts which hair or clothing can be caught in and cause injury. Additionally particles of the composite will become airborne and could be a breathing hazard and eye hazard. Safety glasses and breathing masks will be required. It is unknown how loud the composite being bent will be so hearing protection is recommended but not necessarily required.

VI: Test procedure

On the next page is a mockup of the test procedure. Figure 1 shows the intended set up. There is missing hardware on the gear reducer that is required for proper operation. This is currently being worked on.

The motor/gear reducer and gear reducer/bending device are connected by chains. The whole system is powered by two motors. One for the bending device and one for the cutting device. Figure 1 shows the general location of the entire assembly. There are essentially only 3 steps in this process and they will be listed below. All required connections will be made before the assembly is turned on and all moving components will be covered for safety.

Step 1:

The first step is to insert a strip of composite into the front end of the bending device so it occupies the entire length of the device. The material will be inserted flat as the device is too small to insert it on its side. The composite needs to be fully seated in both ends of the device before it is turned on. This will result in a piece of the composite not being bent. This is required due to the design of the device and insuring both ends are supported in the rollers while the bending occurs.

Step 2:

The second step is to press the start button on the control boxes for both motors as seen in Figure 2. This control box will be wired to the motor in the final assembly. The composite will feed through the bending device through the rollers and the action of the cam. It will continue into the cutting device This should be automated as it was the intention of the design.

Step 3:

The final step is to collect the composite from the end of the cutting device. The specifications of this are outside the scope of this report.

If the device doesn't cut the composite and jams it will have to be removed after the devices are turned off.

VII: Final Discussion

The overall test procedure is simple. The main complications lie in the set up which is outside the responsibility of the tester. The time spent testing depends on the amount of composite scrap desired. The complexity of the devices limits modifications required due to unexpected failures during the test and will require a design overhaul in a future project to complete.

APPENDIX J – Resume

JASON MORROW

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Linkedin: https://www.linkedin.com/in/jasoncmorrow/

Senior mechanical engineering technology student with manufacturing engineering intern experience and Air Force technician experience seeking an entry level engineering position.

EDUCATION

Bachelor of Science, Mechanical Engineering Technology
Expected graduation: June 2018
Central Washington University - Ellensburg, Washington
GPA: 3.65
Bachelor of Science, Space Physics
December 2008
Embry-Riddle Aeronautical University, Prescott, Arizona

INTERNSHIP EXPERIENCE

Red Dot Corporation (June-August 2017) Tukwila, WA

Manufacturing Engineering Intern involved in multiple projects. A sampling will be listed below.

- Utilized Creo to design a backstop to allow for instant placing of a hose fitting into a crimp machine. Design included specifying metal type and required hardness based on the crimp force of the machine. Design model and drawings were created and submitted to machine shop for production.
- Assisted packaging engineer by modifying packaging dividers per customer specification. Modified Creo models and drawings after measuring dimensions to specific specifications.
- Tasked with finding solution to issue of work orders showing erroneous buildable status. Worked with senior software engineer and production lead to identify and correct the issue. Created Excel file and utilized visual basic for application to semi-automate daily work order sorting and graphing of daily buildable and non-buildable trends.
- Gathered one year of sheet metal utilization data from punch presses to determine how to improve nesting of parts to reduce sheet metal waste. Created excel file to allow continued entering of daily punch press reports to track daily utilization. Graphed and presented

data to the lead responsible for nesting.

RELATED EXPERIENCE

United States Air Force (2011-2015) Minot Air Force Base, North Dakota

Verification and Checkout Equipment March 2014 – September 2015

- Led team for preventative maintenance on electronic testing equipment. Increased weapon system pass rate and provided rating of ‘outstanding’ on readiness inspection.

ACTIVITIES

ASME - American Society of Mechanical Engineers - Member

SME – Society of Manufacturing Engineers – President for 2017-2018 school year

SKILLS

AutoCAD, Creo Parametric, SolidWorks, Excel, Powerpoint, Word and Labview