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Prosthetic Hand: Articulation

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Prosthetic Hand: Articulation

By

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Abstract

This group project objective was about developing a low cost articulated prosthetic hand. This project was developed in two parts: articulation and body. The development of the articulation started as a simple system that has developed into a more complex system push and pull system. The development cycle helped define the systems used in the prosthetic. The movement/articulation system needed to not only move parts of the hand but also hold objects with the appropriate gripping power. The finger also has to be able close in a reasonable amount of time. The articulation is driven by motors attached to small gearboxes. The gearbox was developed to withstand the holding forces and movements within the gearbox. The boxes and gears were designed for continuous use over time. Gears were designed to be small and light allowing speed of movement. The gearbox was developed to be made with a commonly 3D printer. The gearbox was developed to be lightweight and be easily replicated. The development cycle helped to modify the parts for better operations. The developed parts where changed in size to make the gearbox 25% smaller then original design. The rack was built to hand the linier motion and pressure from the gears. The gears hold up to 20% more pressure than the gearboxes should handle. The hand held 5 lbs. per finger, moved faster than 3.5ft/s. , and had constant repeatability.

Introduction

Description:

This project is being designed as a low-cost replacement prosthetic.

Motivation:

As costs of components have lowered and more technology has become available prices of prosthetics have not come down. The ability of robotic prosthetics has stagnated in large and expensive design programs with little ability of a common person acquiring a mechanically articulating hand that can replace a hand for many daily tasks.

Function Statement

This object must provide a grip replacement of a hand for a person. This prosthetic device fingers must articulate like fingers. The movement of the fingers should be smooth and functional.

Design Requirements

The device will meet the following requirements:

- Finger curls 270 degrees
- Hold 20 lb to 30 lb worth of grip force
- Liner driven finger movement at 1.25 feet/second
- Fingers must close within 2 seconds.
- Connecting rods that can handle a 100 lb. impact

Engineering Merit

The engineering merit to this project is that a device needs to be constructed to replace a lost hand. Due to the overall design, all aspects of the machine will need to be able to withstand normal use of a hand. The manipulating of fingers will have to produce the calculated grip force and movement.

1. Sizing the gear box
2. Determine gear size, spacing, and appropriate material.
3. Determine appropriate motors and drivers.
4. Size push rods for length and strength
5. Determine proper cam size and appropriate center pin size
6. Design finger to close in 2 seconds

Scope of Effort

The goal of this project will only include operations that will make the hand articulation function. The hand will not offer any more functionality then a real hand. Designing the mechanical linkages to hand the load of movement and resist impacts. This will require the design of a working combination of mechanical linkages, motor mounts, and gearboxes.

Success Criteria

1. This hand should mimic the functionality and provide the ability to grip objects with ease.
2. Hold 25 lbs. in hand
3. Grip with 5 to 7 lbs. of force per finger

Design & Analysis

Proposed Solution

Normal prosthetics are either nonfunctional or have some functionality to them but cost a large amount to produce. There are several compromises that are made when building a prosthetic that are dependent on cost. With the advent of 3D printing the cost of producing complex parts has become cheaper. The challenge of developing a lightweight and cost effective prosthetic that is available to everyone.

Design Description

The design for this articulated hand is being developed as a replacement that is lightweight and has simple to produce parts. The tools required should only be a 3D printer and simple hand tools. The form of the hand should be functional and have a range of movement that allows the user most of the functionality of a hand.

Benchmark

The most comparable product available to the general public is the either the 3D printed hand that is being distributed by designers through NIH (National institute of health). This product cost around $40 to $100 to print off on a 3D printer depending on the material that is used. This prosthetic is not assisted by the use of motor and is the simplest to use. The least expensive mechanical prosthetic with motors available to the public has a rough cost of between $3000 to $30,000 depending on functionality and materials. The produced product will be tested against a 3D printed base model.

Benchmark Summary:

Product	Capability	Cost (USD)
Raptor Hand	20 lbs.	$45 (Printed Solid)
BeBionic Hand	40 lbs.	$30,000

Performance Predictions

1. The prosthetic will be able to lift 25 lbs.
2. The prosthetic will be able to close its fingers in less than the predicted time of 2 seconds
3. The whole mechanical system will weigh less than 2 lbs.

Descriptions of Analysis

The articulation of this project is relying on the single discipline of mechanical design. The production of this product is being developed so that a person with limited skills and tools can produce the parts that can either be built or purchased. This limits the design factors and also keeps the cost down. The factors that are calculated in the analysis section are helping define what kind of parts can be used or what might fail too quickly.

1. Appendix A-1: Deflection of a small rod
   This data was calculated to find out how much a small rod or pin might deflect under a direct loading that was determined to be a maximum loading. The data shows that a short rod would only deflect .00020”. This tells us that while there will be some movement but that it wouldn’t be significant enough to make an adjustment in the design.

2. Appendix A-2: Rotational pressure and angle of rotation of a small rod
   This data is going to be used to know how much a short rod might twist under a determined max loading. The data shows that a short rod would not deflect 0.034 degrees of twist. This data will help in the design of the pins needed for connecting the cam and longer rods.

3. Appendix A-3: Column Analysis for a short rod
   This data is being use to understand if the rod will collapse or deform if we put it under a maximum loading. The data shows that the pin would only bend and break under a loading of 517 psi which is a factor of safety of 5.

4. Appendix A-4: Max Angle of rotation for 5.5” rod
   The data calculated here is to show the amount of twist in a longer rod. This data shows that there is less than a degree of rotation. This data helps in the design of the rod and how much rotation there might be between the rack on the gear drive and the cam in the fingers. This is calculated as if there is a load on the rod and no stiffness or resistance provided by the structure of the body.

5. Appendix A-5: Column Analysis for 5.5” rod
   The data here is being calculated to find if the maximum loading pushing down on the rod. This data is needed to find if the rod will bend if it is being put under load compressing the rod. This data is helpful in figuring out if the material will break or bend. It also helps to understand how the rod will react under a load.

6. Appendix A-6: Endurance limit for 1018 Steel
   The data calculated here allows the designer know what the maximum stress allowed on this material for repeatability. The material is being used as connecting rods between the gear drive and the cams.

7. Appendix A-7: Endurance limit for Brass
   The data calculated here allows the designer know what the maximum stress allowed on this material for repeatability. The material is being used as pins.

8. Appendix A-8: Endurance limit for ABS
   The data calculated here allows the designer know what the maximum stress allowed on this material for repeatability. This material is being used as frame, pins, cams, and the gearbox.

9. Appendix A-9: Endurance limit for Nylon
   This data is needed as some parts may need to be stronger then ABS. Nylon is available as either a 3D printed material or as a liquid for a liquid diffusion printer.

10. Appendix A-10: Minimum Needed SFM of Rack
    This data is needed to find the minimum speed needed to close the fingers on the hand.

11. Appendix A-11: Initial Metal Gear Design
    This data is calculated to find the forces on the gear teeth of the pinion and gear. The data calculates the ratio of reduction. It also gives us data that helps to choose the right material for the gears. The data also tells us the forces that might cause issues. The data shows that the initial choice of gearing had too much stress on the teeth and they would have broken.

12. Appendix A-12: Final Metal Gear Design
    This final design incorporates all of the data that was gathered in the initial design. The gears chosen are larger and have more teeth. The minimum RPM was raised to reduce the stress on the teeth. The data shows that a simple RC car gears can handle the stresses as long as they are hardened material.

Due to the changes involved in design the data has been updated to reflect the changes in design. Some of the data presented here is still relevant to the project as we may still need to use the data if we change parts or materials. The current project is being done using the same data plus some of the part production is using 3D printer. The data shows that PLA can be used as a substitute for printing less integral parts. The printed parts are also have been modified from the original form and optimized for size.

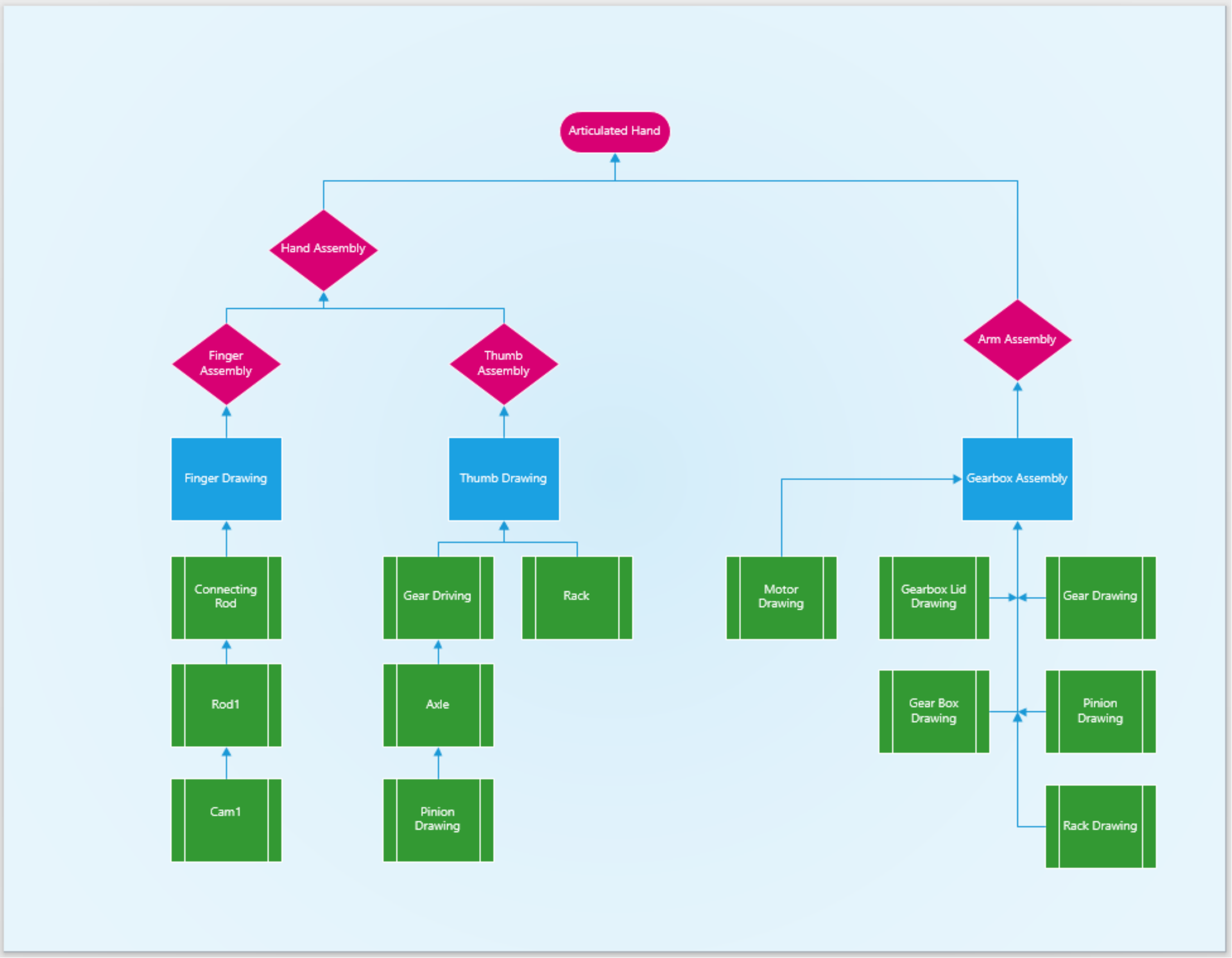
Scope of Testing & Evaluation:

The scope of this project is limited to the moving parts of the hand controlled by the developed This will be conducted for a period of time test the construction of the gearbox and rack. The articulation part of the project will be tested for movement and speed.

Evaluation will be conducted with several test to evaluate the motor/gearbox setup. The initial test will be that the gearbox can run without breaking or having issues with the gears. The second test will be running at nominal load (hand attached) or a period of time. The third test will be the fingers lifting a 5 lb load. The last test will be conducted as a pass/fail of the hand grabbing and holding a can.

Methods & Construction

The part was developed from the ground up to be a part that a person can simply produce on any 3D printer. The parts for the motor gearbox and articulated hand piece are being produced by a team. The parts should be easy to produce and use a limited amount of tools that should be accessible to any person.



The parts built for the gearbox are the adapter plate, gearbox, lid, and rolling rack. These parts will need to be built to specification and hold a certain tolerance to make it a functioning gearbox. The parts that are being purchased for the gearboxes are parts that require too much machining or cost too much to produce in house. The intention is to turn the rotational force into linier force.

Adapter Plate

This part was built after the gearbox was shrunk to better use space. The benefit of this part is that it allows multiple different motors to be mounted to the gearbox. The draw backs are that it is another part to produce and it takes up more space. The ability to adapt the new or different motors helps with a constantly changing product that might have newer and better motors installed. Currently this part is being 3D printed to allow for speed of production. The screw holes are drilled out to the specified size and tapped as needed. Currently the gearboxes are printed in PLA. This has the advantages of being cheaper to make and since there is a limited need for the plate currently to handle large loads.

Gearbox

The Gearbox is currently at revision D. The initial gearbox was larger and had the rack placed at the end. With changes that made it smaller and lighter also increased the need for accuracy in production section. With 3D printing depending on the print quality the box has been very close to being in specification or if it's a lower quality print it can be massively out of specification. Getting the design to it medium print quality has taken a lot of time. If the gearbox is out of specification, then the gears wont mesh or the rack won't have enough space to move. The current material used in construction of the gearbox is PLA. Initially the box was designed with ABS in mind but printers with PLA where only available to us. Some changes to the wall thickness and how many screw holes used to hold the lid on were added to provide additional stability and strength. The screw holes are drilled out to the specified size and tapped as needed. Fit and finish is done by hand with sandpaper and files. The latest design requires less hand smoothing and test fitting.

Gearbox Lid

This part was originally designed as a flat part but issues came up when actually assembling the gearbox assembly. The gears require a hex nut to hold them to the shaft. These are not easily accessible to tighten and caused issues trying to test fitment. One of the other problems was the rack assembly was rotating in the space that was around it. Another problem in development was the rack was flexing the wall of the gearbox causing changes to the side depth and long screws to help keep the lid and body together. This product is produced using a 3D printer. The test parts were printed in PLA as it was the available material. While this was not the first choice it was available and free. The design and production of the lid changed with the different material. Fit and finish was done with sand paper and a file. Holes where drilled to the right size using the correct drill bits.

Rack

The rack is integral to the construction of the linier gearbox setup. The rack must withstand the push and pull of the motors. The initial construction was to be of purchased rack material and some sort of backing. During the design process it was found to be to hard to procure the particular size and adapt it to the project. The material available was fairly expensive and also came in long lengths that could not be used in this project. It was eventually decided to actually produce the needed part by 3D printing. The part includes a rack section along with guides built in. The rack also had to have an attachment point for the linkage to the fingers. This was originally going to be drilled but in subsequent designs it was implemented as a printed hole. This allowed the part to be produced with limited fit and finish.

Gears

Originally designed with the plan to use 3D printed gears the choice was made to move over to metal gears when the calculations for plastic gears showed that the teeth would rip or shred due to the pitting forces. The resulting calculations showed that if we wanted to not heat treat the gears we would have to have a extremely hard metal and be able to cut it. The machine shop available didn’t have that capability. Currently since this object is in the design process it was decided to procure the gears. It was found that RC car gears that have been hardened will exceed the design specifications of the gearboxes. These gears do not require any extra finishing and can be simply installed in the gearbox.

Shafts

The shafts where originally designed to be 3mm to fit the gears. The only available material was stainless steel shafts for RC cars. The material was strong enough to be used but was overkill for the low loads that were being put on the shafts. The time it took to produce one shaft was about 10 minutes using a grinder at slow speed to not work harden the material. When testing the fit it was found that 1/8th rod fits well in the gears. This change has a positive effect o speeding up the production of the part. This part can be produced with a saw and some minimal sanding.

Testing Methods

The testing for this project is going to be completed in multiple parts. The first test is to see if the product will be able to function as intended. The motors should be able to reasonably move the fingers and provide the amount of holding torque needed to move the fingers open and closed. The hand will be tested by running the motors for a certain amount of time and look at the effects of running the motors. Currently the body of the gearbox is printed in PLA. This is a material that is not as strong as the original proposed material of ABS. The next step will be to test the how strong the hand can grip something. The test will use common household objects that require grip. The data with this will allow us to tailor the device more too specific needs. The data will also help us create a better program to use the prosthetic. The testing should also test how much stress they can hold. The testing will also include the drive shafts and the material used in the gears. The testing will be a long term movement simulation

Discussion

The design of this project has been interesting from the start. Several different design philosophies were tested. Initially it was though that two designs could be developed at the same time. One being the prosthetic used by a human subject and one that might be used for heavy industry. After several different proposals including both hands it was decided that with the limited time the group should invest its time in a single prototype and if time allowed the other built and tested.

The initial design called for the use of push/pull rods pulling a cam to rotate the hand. This design was initially attempted in solidworks. The assembly showed that there was going to be an issue with using the push rod method. One the issues was that there was more parts that where required to be designed to fix the problems. This would require a lot more design time then the team had available for the production cycle. Another issue with this design was the delicate nature of the parts that were designed. This design hand many small parts and a lot of extra design features.

The problems that were in the initial design still persistent with the second iteration of the design using cams to rotate the joints. The using push rods attached to cams caused issues with movement and causing further problems with movement. Initially a internal part was designed to help move the finger using a rack and pinion setup. This design was initially placed in the fingers to spread out as the finger bent to smooth the movement. This part of the project got removed as it was over engineered and would have been a large time sink trying to get it to work.

The final design was initially simple gearboxes with motors attached to them pulling a wire to initiate movement. During the design process it was decided that to initiate the movement with a linear drive. Several different types where looked at before the decision was made to build the system in house. The problem with acquiring several online or instore was that either they were very expensive or underpowered.

After it was decided to build the linear system inhouse several things happened. The initial gear reduction was calculated. This allowed for size requirements to be decided. Due to the space and size requirements it was decided to directly mount the gearbox and stepper motor together. This design was intentional as it was designed for ease of mounting and replacement. The initial gearbox was a simple design with two gears and a rack forming a T. This design was initially 3D printed but never attached to a motor. The size proved to be too large for the project and unwieldly when functioning. One of the major problems was the size of the plastic gears needed to run the gearbox. Due to the stresses on the teeth of the gear it required rather large gears.

The next several iterations of the gearbox changed several initial features of the original gearbox. Initially the gearbox was built to be driven by a small stepper motor that produced 16 N-cm of power. Since there was limited power being pushed through the system plastic gears where initially tried but where too large for the space allowed. During development it was found that steel gears could be used if they where hardened. Initially it was looked into to see if they could be produced in house but the cost was such that it was cheaper to buy through a vendor. After several sets of calculations it was decided to go with 48 pitch gears and rack for movement.

Initially the design called for a steel shaft for the production of the gearbox. This was due to cost and initial availability. After the design phase concluded it was found that the 5mm size rod was a special order item and was twice as expensive as stainless steel shafts for RC cars. After procuring the drive shaft material it was found to be extremely hard to machine and time consuming to build. After talking with an advisor it was found that 1/8” aluminum rod would also work within the loading parameters.

The rack was initially designed to be attached to a push pull rod and function as the linear slide. During the development phase it was initially built as just a rack and nothing more. After some testing with the first iteration of the rack it was found that it needed a way to hold itself against the wall of the gearbox. This redesign allowed for some parts of the gearbox to be removed and several parts to be deleted from the construction process.

The gearbox and lid went through several changes in the production process. Several redesigns were required to reduce size and weight. After testing the gearbox assembly alone it was found that a simple adapter plate would solve most of the mounting issues cause by the limited size of the box. After a adapter plate was developed it made it much faster for testing and the assembly process.

One of the major problems with this project was the electronics to run the hand. Initially due to the simplistic nature of our design it was though that a simple program and drivers would be needed. Use of an Arduino Uno helped limit the amount of work needed to develop programs. This also needed to be programed which ended up taking more time then initially planned. The physical drivers for the stepper motors were purchased online due to time constraints and ability to produce them. Some issues persist in the design that will have to be addressed in the future.

After testing it was found that the gearbox design held up under loading and functioned properly. The motors still have some work left to make it as strong as needed. Stepper motors are very good for initial design, but they are loud and take a lot of space. When testing it was concluded the next step would be to find similar strength servo motors and mount them to the gearbox.

Conclusion

This project is a mechanical marvel. The project should meet or exceed the calculated values that were given. The data shows that there are some items that that need to be improved to make the articulation to be smoother and have better functionality. During testing it was found that some of the initial design problems could be resolved by printing with a better 3D printer or simplifying the design. While some design issues still persist in the design it does function as expected and due to the shortened development cycle, many of the small issues were ignored that will have to be addressed in the future. Some of the breakthrough in this design happened when fixing other problems. After being developed as a single hand it is still might be developed into two different iterations. One would be a normal use prosthetic and the other being something of a heavy use arm that can possibly attach to some sort of robot. The data gathered for the simple arm will help in the development of the heavy arm. The data shows that the gearing allowed the finger to grip/pull closed with a normal speed and the strength to move a 5lb weight continually. This shows that after some development the hand will have a similar grip strength as a normal hand. The development of the gear drive also allows for different gears to be used allowing the hand a more controlled speed of movement. This data shows that the fingers will close in under two seconds. The data also shows that all of the material used will be subjected to far less than the maximum endurance loading. All of these items combine to make the final product a much stronger than required with the possibility of making an awesome hand. The gearbox and hand combo also showed that it could be developed into many other objects as needed.

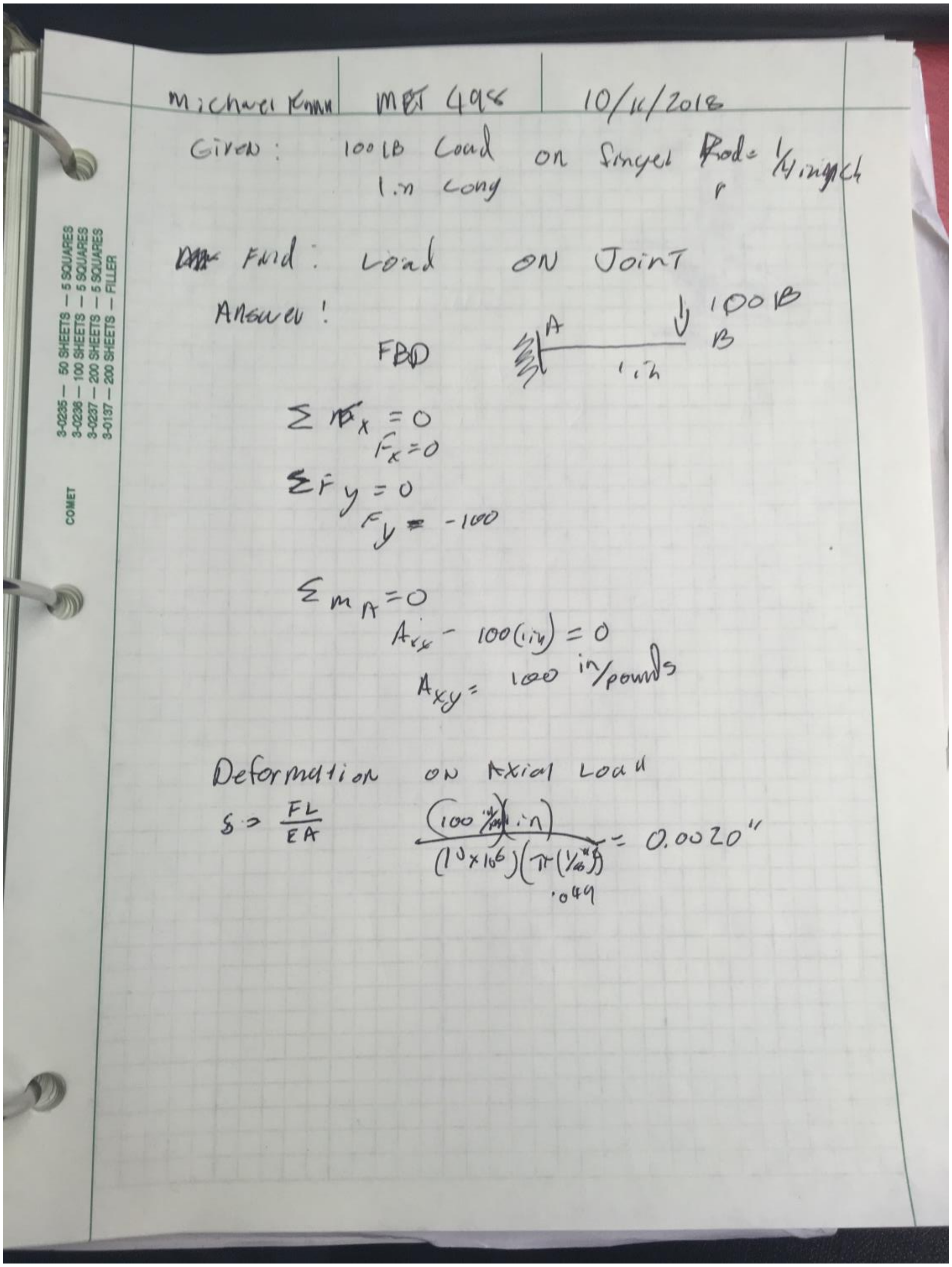
Acknowledgements

Thank you to Riley Smith for being an excellent partner and always having a positive attitude even in the face of the extensive hardships during this project. Michael and Riley would also like to thank Central Washington University for their assistance in making this project a reality. Without the efforts of the MET Faculty, this could not have been possible. Thank you to Matt Burvee and Ted Bramble for allowing full use of the machine shop which was essential for completing this project. Finally, a special thanks to Professors Roger Beardsley, Craig Johnson, and Charles Pringle for answering all questions that this team had throughout the year.

APPENDIX A:

Appendix A: Analysis

A-1 Deflection of a small rod



Michael Kann | MET 498 | 10/11/2018

Given: 100 LB Load on Singel Rod = 1/4 inch

1 in Long

~~DA~~ Find: Load ON JoinT

Answer!

FBD

A

100 LB

B

1 in

$\Sigma F_x = 0$

$F_x = 0$

$\Sigma F_y = 0$

$F_y = -100$

$\Sigma M_A = 0$

$A_{xy} - 100(1\,in) = 0$

$A_{xy} = 100$ in/pounds

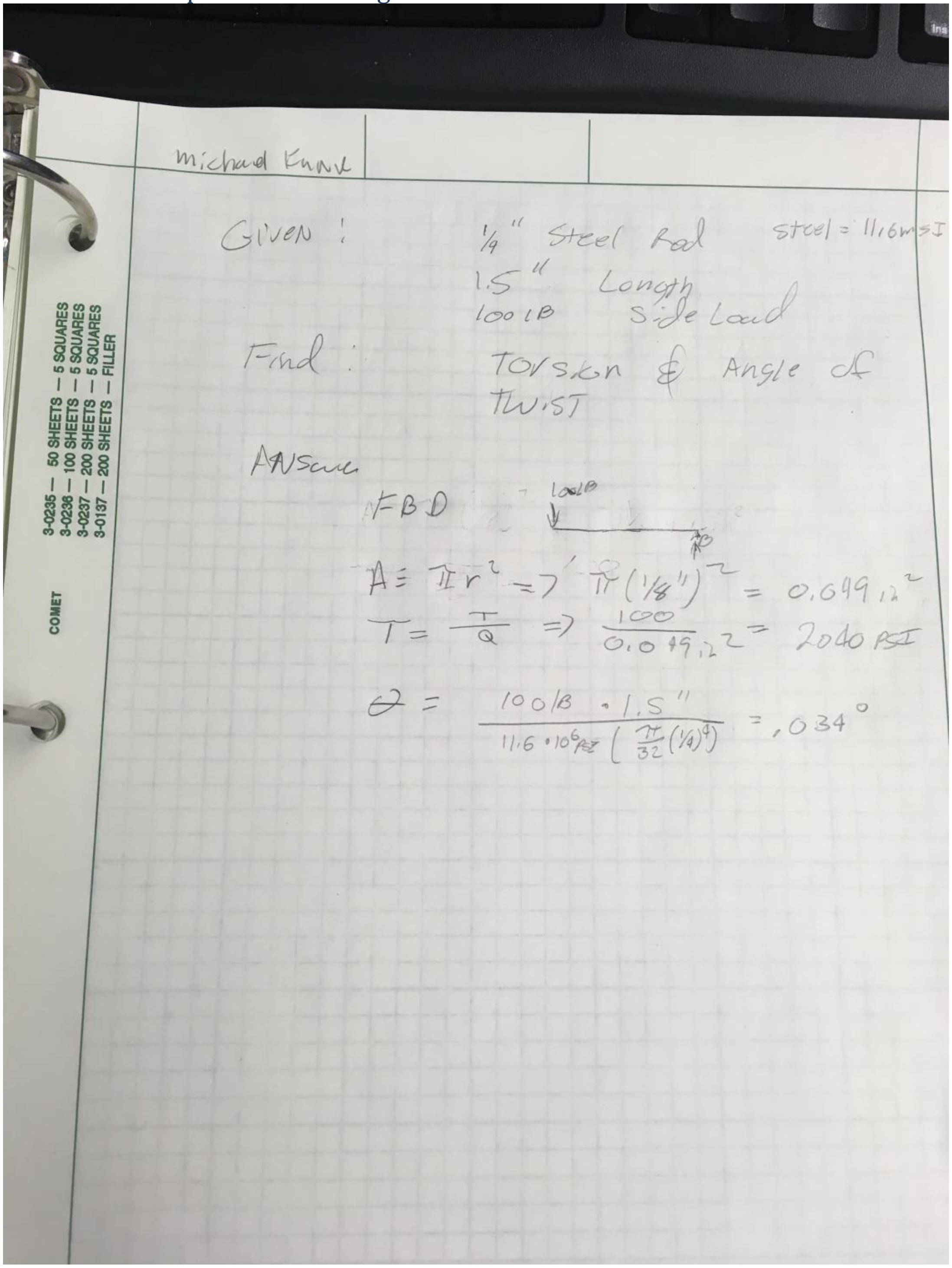
Deformation on Axial Load

$\delta = \frac{FL}{EA}$

$$\frac{(100\ in/lb)(in)}{(10\times10^6)(\pi(1/8")^2)} = 0.0020"$$

.049

A-2: Rotational pressure and angle of rotation of a small rod



michael Knack

GIVEN : 1/4" Steel Rod steel = 11,6 mSI
1.5" Length
100 LB Side Load

Find : Torsion & Angle of TWIST

ANSwer

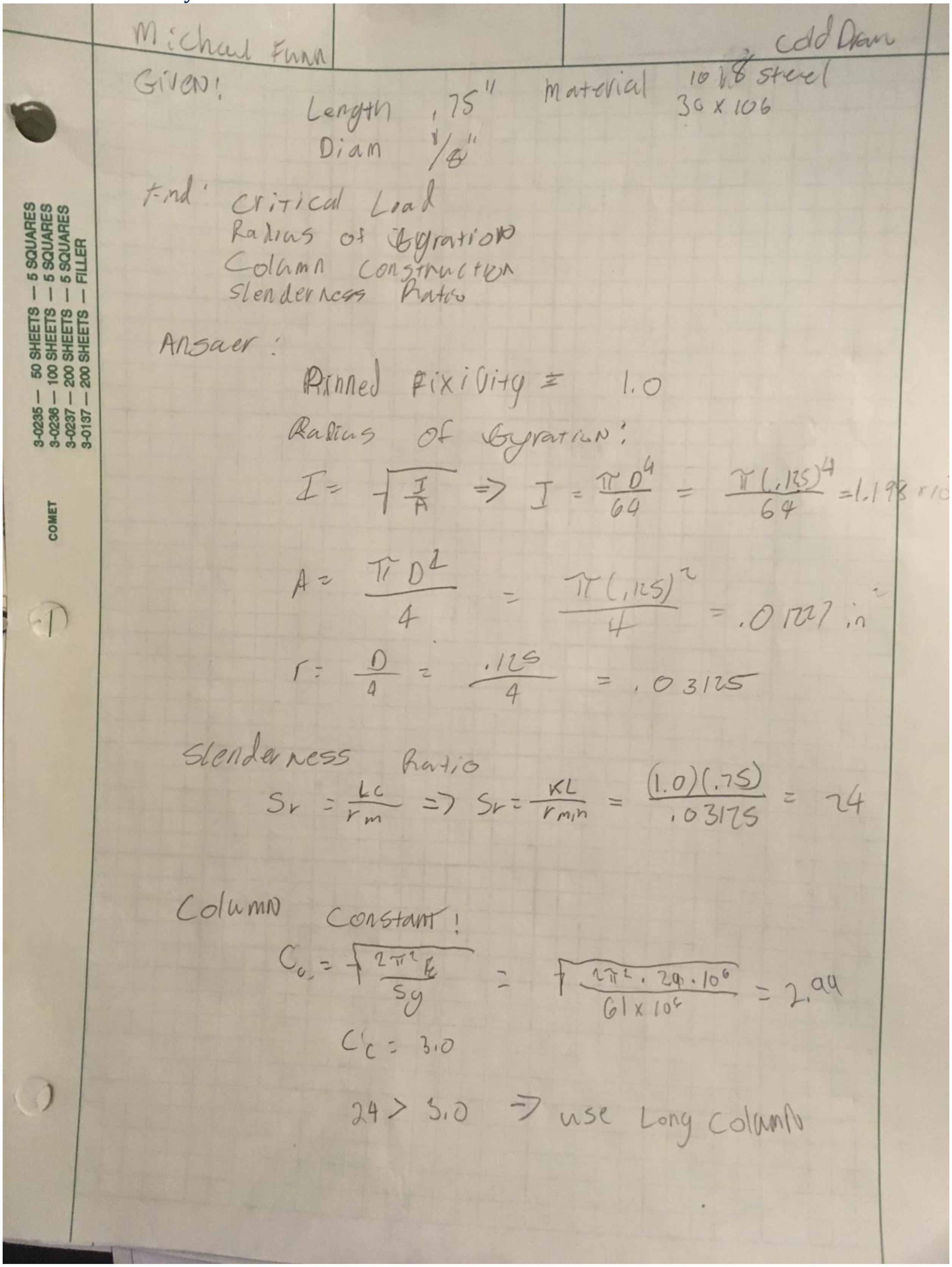
FBD

$A = \pi r^2 \Rightarrow \pi(1/8")^2 = 0,049 \text{ in}^2$

$T = \frac{T}{Q} \Rightarrow \frac{100}{0,049 \text{ in}^2} = 2040 \text{ PSI}$

$\theta = \frac{100 \text{ lB} \cdot 1.5"}{11.6 \cdot 10^6 \text{ PSI} \left(\frac{\pi}{32} (1/4)^4 \right)} = ,034°$

A-3: Column Analysis for a short rod



Michael Funn

cold Drawn

Given!

Length .75" Material 1018 steel

Diam 1/8" 30 x 106

Find: Critical Load

Radius of Gyration

Column Construction

Slenderness Ratio

Ansaer:

Pinned Fixivity = 1.0

Radius of Gyration:

$$I = \sqrt{\frac{I}{A}} \Rightarrow I = \frac{\pi D^4}{64} = \frac{\pi(.125)^4}{64} = 1.198 \times 10$$

$$A = \frac{\pi D^2}{4} = \frac{\pi(.125)^2}{4} = .01227 \text{ in}^2$$

$$r = \frac{D}{4} = \frac{.125}{4} = .03125$$

Slenderness Ratio

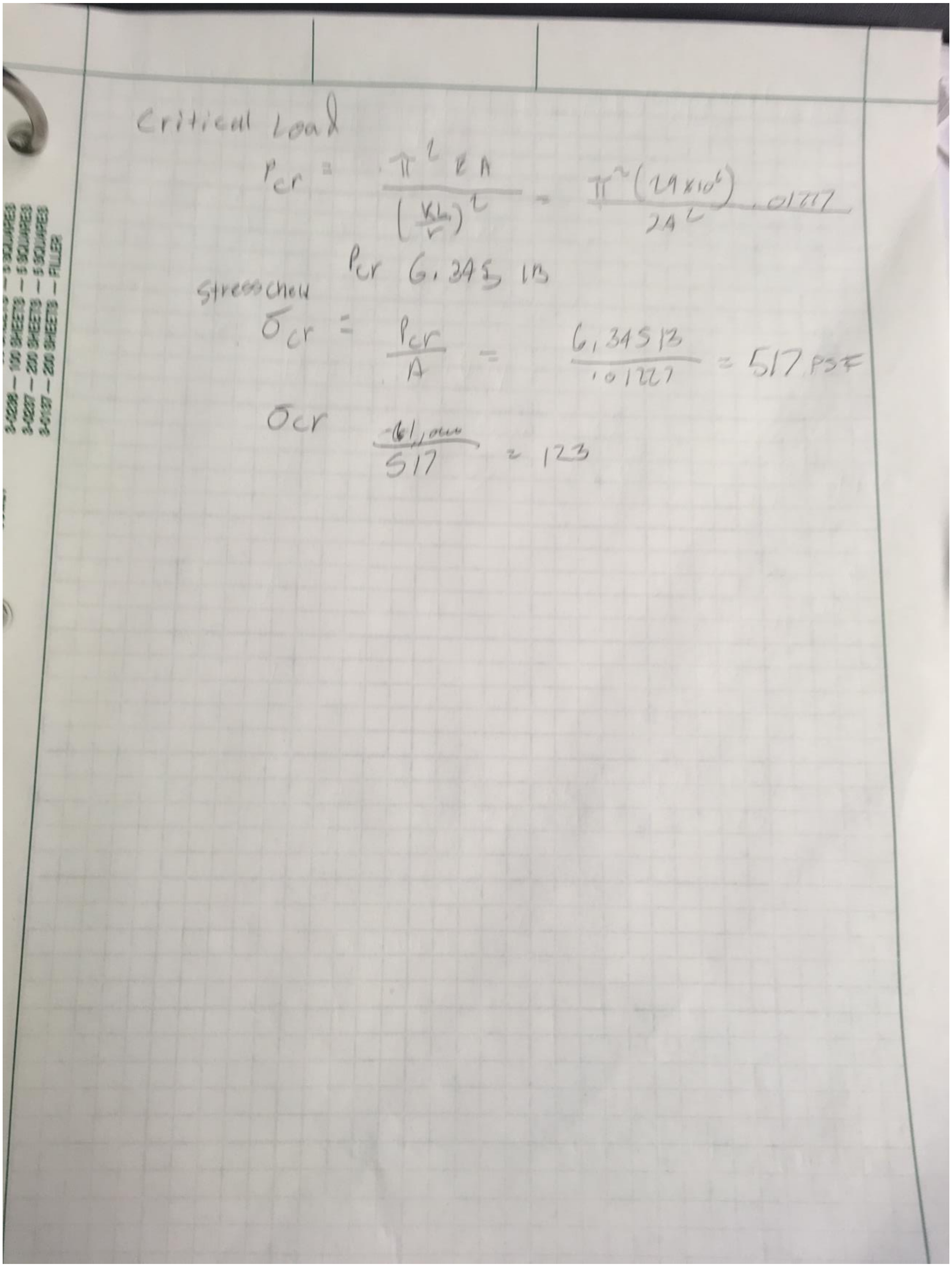
$$S_r = \frac{L_c}{r_m} \Rightarrow S_r = \frac{KL}{r_{min}} = \frac{(1.0)(.75)}{.03125} = 24$$

Column Constant!

$$C_c = \sqrt{\frac{2\pi^2 E}{S_y}} = \sqrt{\frac{2\pi^2 \cdot 29 \cdot 10^6}{61 \times 10^6}} = 2.94$$

$$C'_c = 3.0$$

$24 > 3.0 \Rightarrow$ use Long Column



Critical Load

$$P_{cr} = \frac{\pi^2 E A}{\left(\frac{KL}{r}\right)^2} = \frac{\pi^2 (29\times10^6) .01727}{24^2}$$

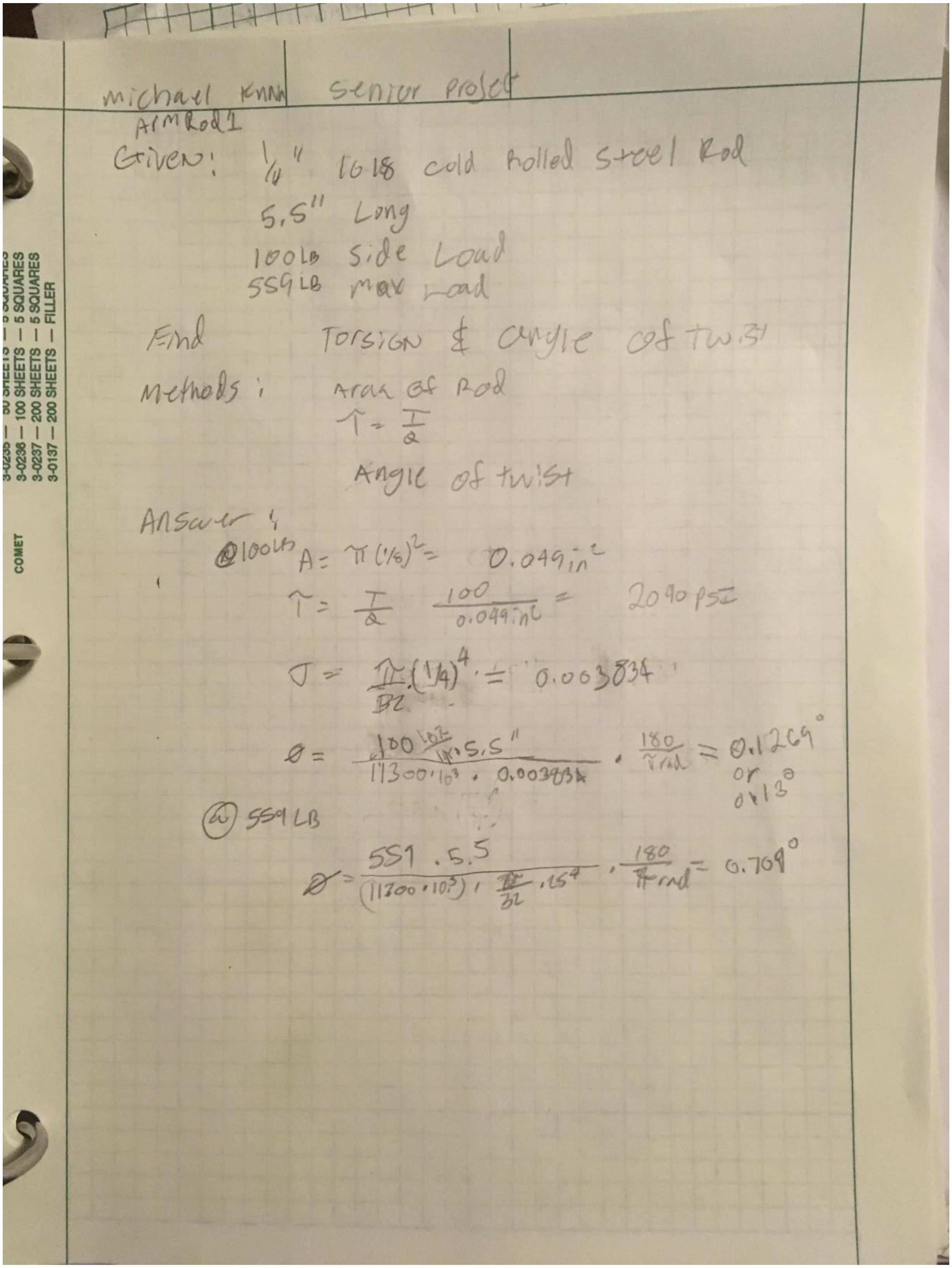
P_{cr} 6,345 lB

Stress check

$$\sigma_{cr} = \frac{P_{cr}}{A} = \frac{6,345 \text{ lB}}{.01227} = 517 \text{ PSF}$$

$$\sigma_{cr} \quad \frac{-61,000}{517} = 123$$

A-4: Max Angle of rotation for 5.5” rod



michael Kunn senior project

AimRod1

Given: $\frac{1}{4}$" 1018 cold Rolled steel Rod

5.5" Long

100LB side Load

559LB max Load

Find Torsion & angle of twist

methods: Area of Rod

$\tau = \frac{T}{Q}$

Angle of twist

Answer:

① 100Lb $A = \pi (1/8)^2 = 0.049 in^2$

$\tau = \frac{T}{Q} \quad \frac{100}{0.049 in^2} = 2090 psi$

$J = \frac{\pi}{32} (1/4)^4 \doteq 0.003834$

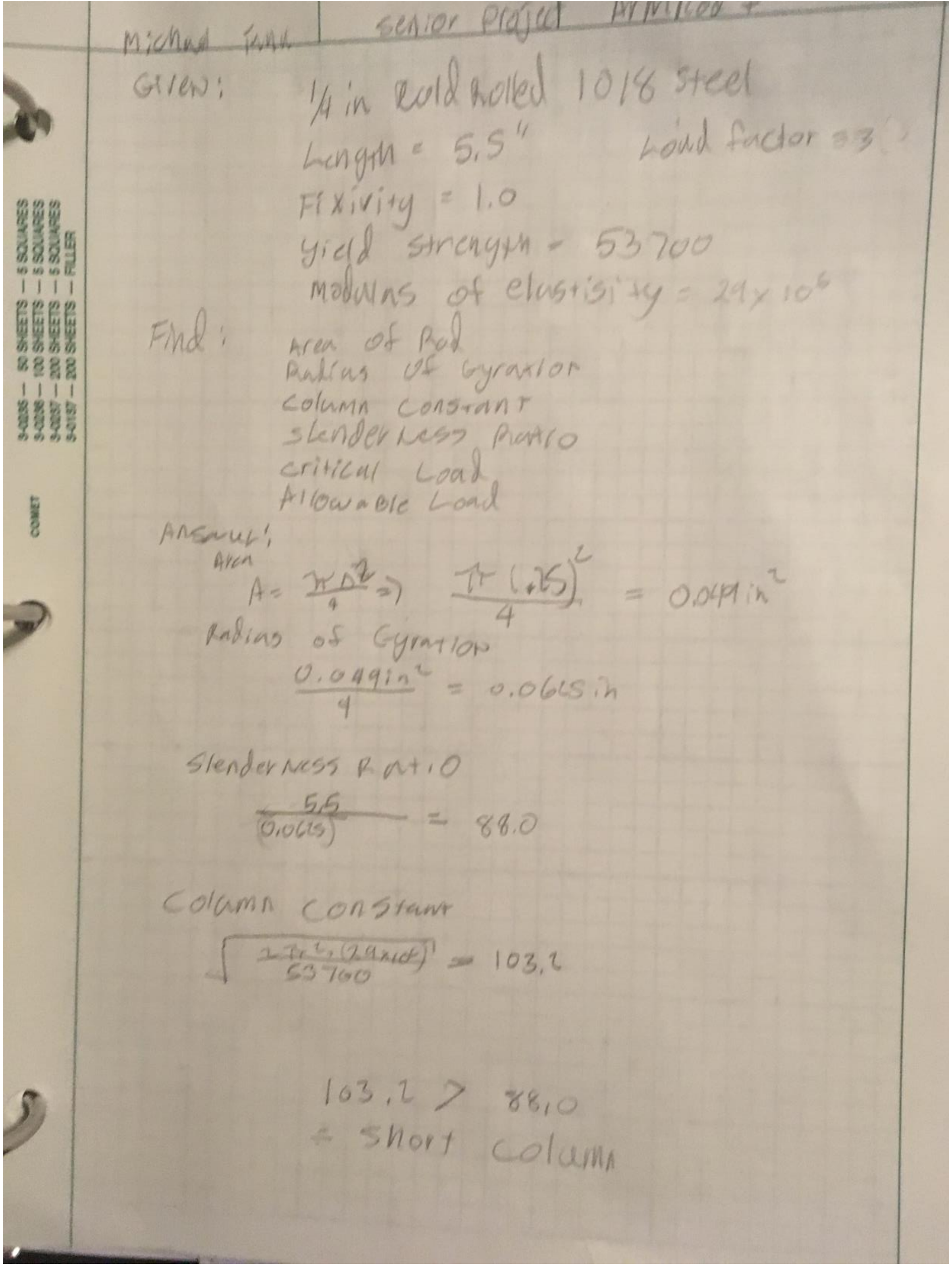
$\theta = \frac{100 \frac{lb}{in} \cdot 5.5"}{11300 \cdot 10^3 \cdot 0.003834} \cdot \frac{180}{\pi rad} = 0.1269°$

or 0.13°

② 559 LB

$\theta = \frac{551 \cdot 5.5}{(11300 \cdot 10^3) \cdot \frac{\pi}{32} \cdot .25^4} \cdot \frac{180}{\pi rad} = 0.709°$

A-5: Column Analysis 5.5” rod



Michael [illegible] | Senior Project [illegible]

Given: 1/4 in cold rolled 1018 steel

Length = 5.5"   Load factor = 3

Fixivity = 1.0

yield strength = 53700

modulus of elastisity = 29×10^6

Find:
Area of Rod
Radius of Gyration
Column Constant
Slenderness Ratio
Critical Load
Allowable Load

Answer:

Area

$$A = \frac{\pi D^2}{4} \Rightarrow \frac{\pi(.25)^2}{4} = 0.049\ in^2$$

Radius of Gyration

$$\frac{0.049 in^2}{4} = 0.0625\ in$$

Slenderness Ratio

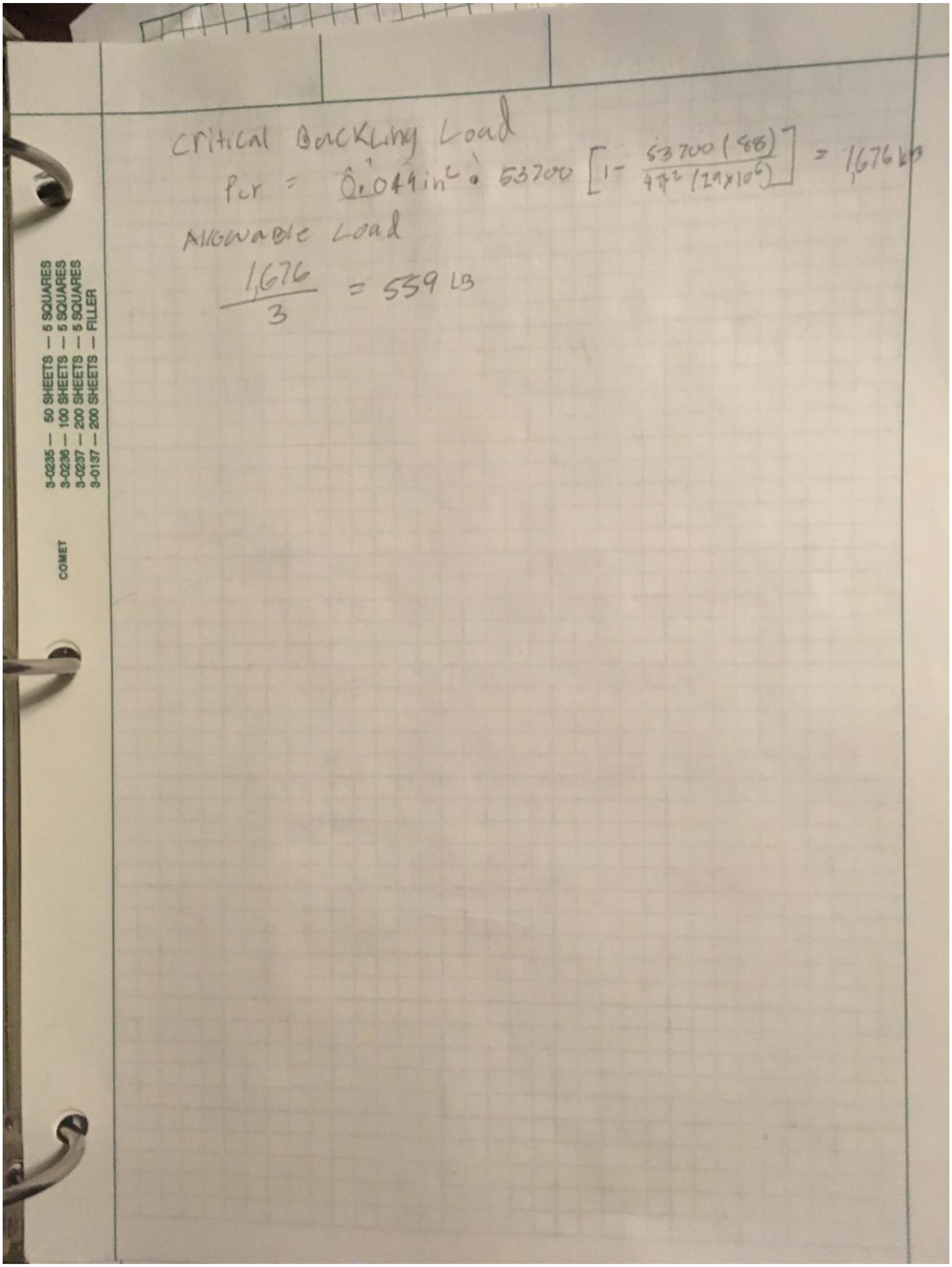
$$\frac{5.5}{(0.0625)} = 88.0$$

Column Constant

$$\sqrt{\frac{2\pi^2(29\times10^6)}{53700}} = 103.2$$

103.2 > 88.0

∴ Short Column



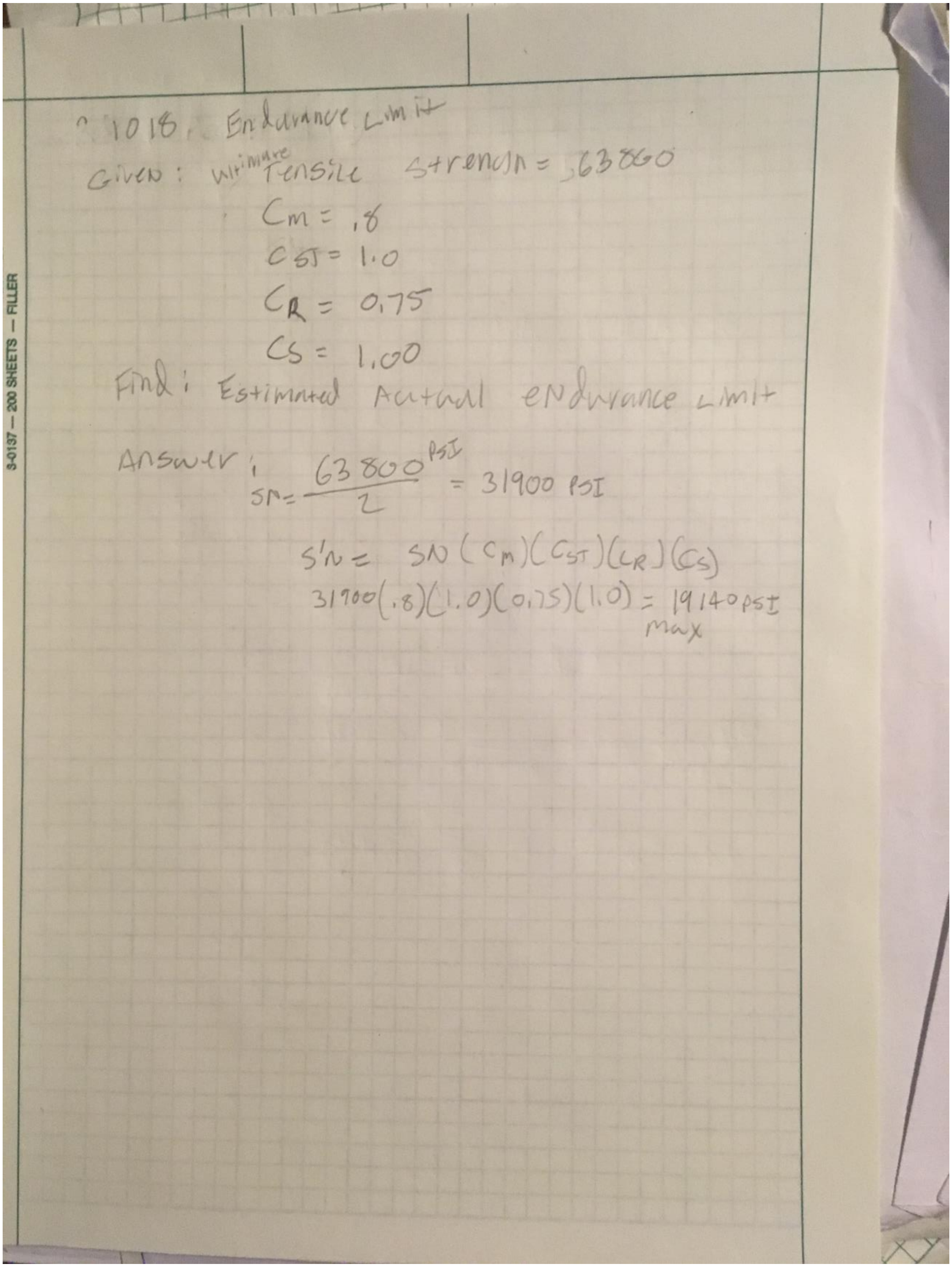
Critical Buckling Load

$$P_{cr} = 0.049\,in^2 \cdot 53700\left[1 - \frac{53700(88)}{4\pi^2(29\times10^6)}\right] = 1{,}676\,lb$$

Allowable Load

$$\frac{1{,}676}{3} = 559\ LB$$

A-6: Endurance limit for 1018 steel



1018 Endurance Limit

Given: ultimate Tensile Strength = 63800

$C_m = .8$

$C_{ST} = 1.0$

$C_R = 0.75$

$C_S = 1.00$

Find: Estimated Actual endurance Limit

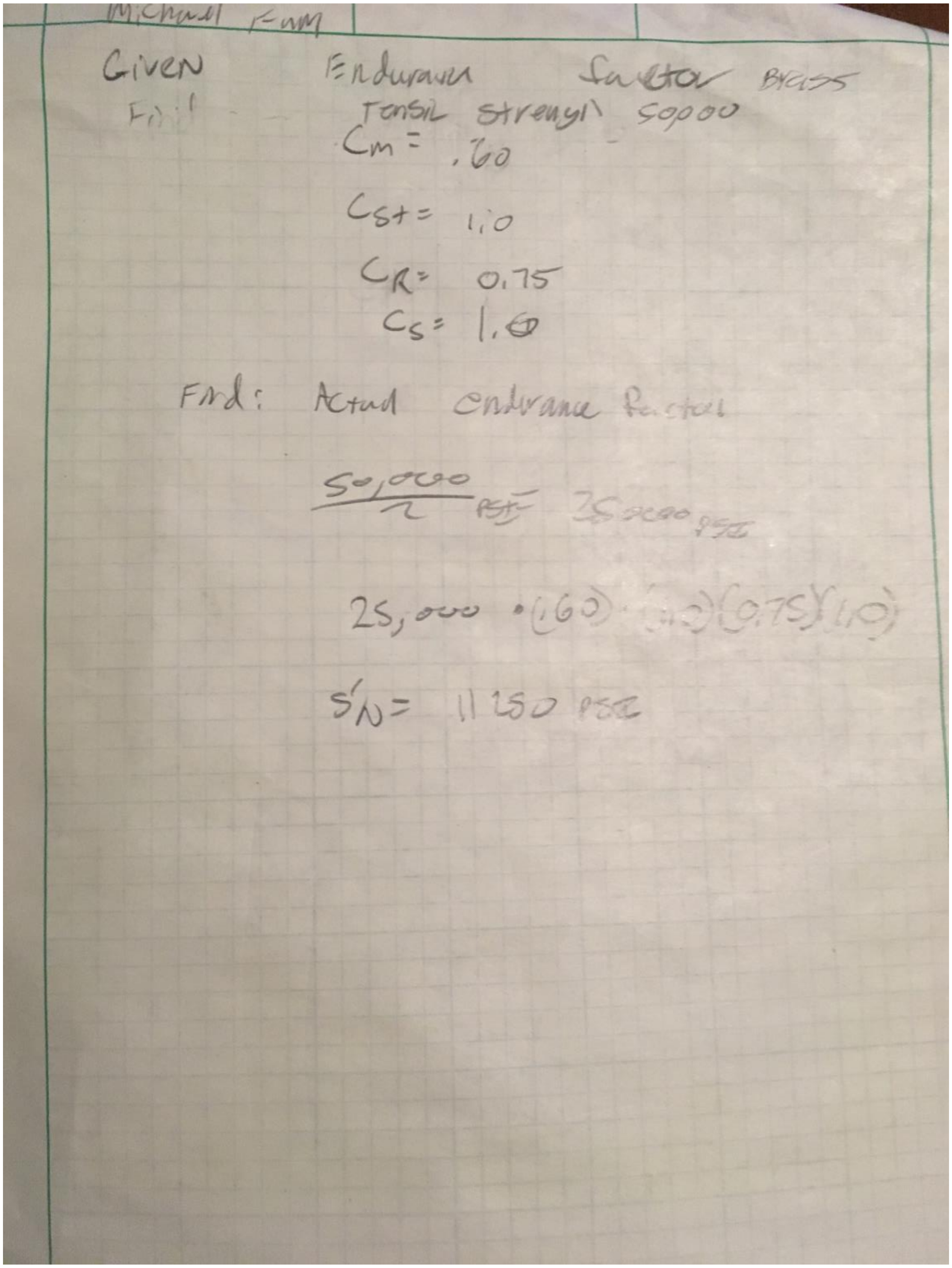
Answer:

$$S_n = \frac{63800 \text{ PSI}}{2} = 31900 \text{ PSI}$$

$$S'_n = S_n (C_m)(C_{ST})(C_R)(C_S)$$

$$31900(.8)(1.0)(0.75)(1.0) = \underset{\text{max}}{19140 \text{ PSI}}$$

A-7: Endurance limit for Brass



Michael Fum

Given Endurance factor Brass

Find

Tensil strength 50000

$C_m = .60$

$C_{st} = 1.0$

$C_R = 0.75$

$C_s = 1.0$

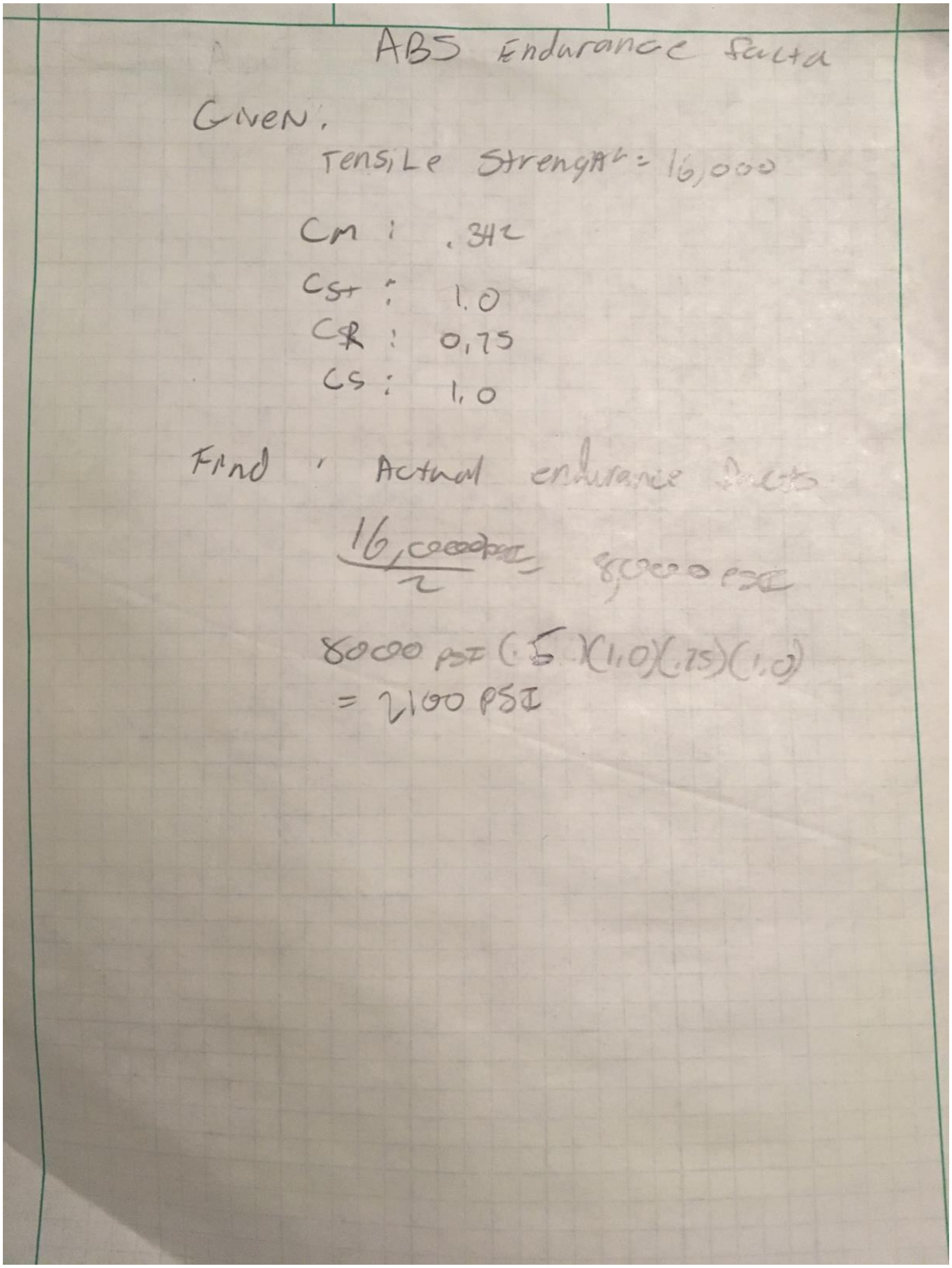
Find: Actual endurance factor

$\frac{50,000}{2}$ psi = 25,000 psi

$25,000 \cdot (.60) \cdot (1.0)(0.75)(1.0)$

$s'_N = 11250$ psi

A-8: Endurance limit for ABS



ABS Endurance facta

Given:

Tensile Strength = 16,000

Cm : .342

Cst : 1.0

CR : 0.75

Cs : 1.0

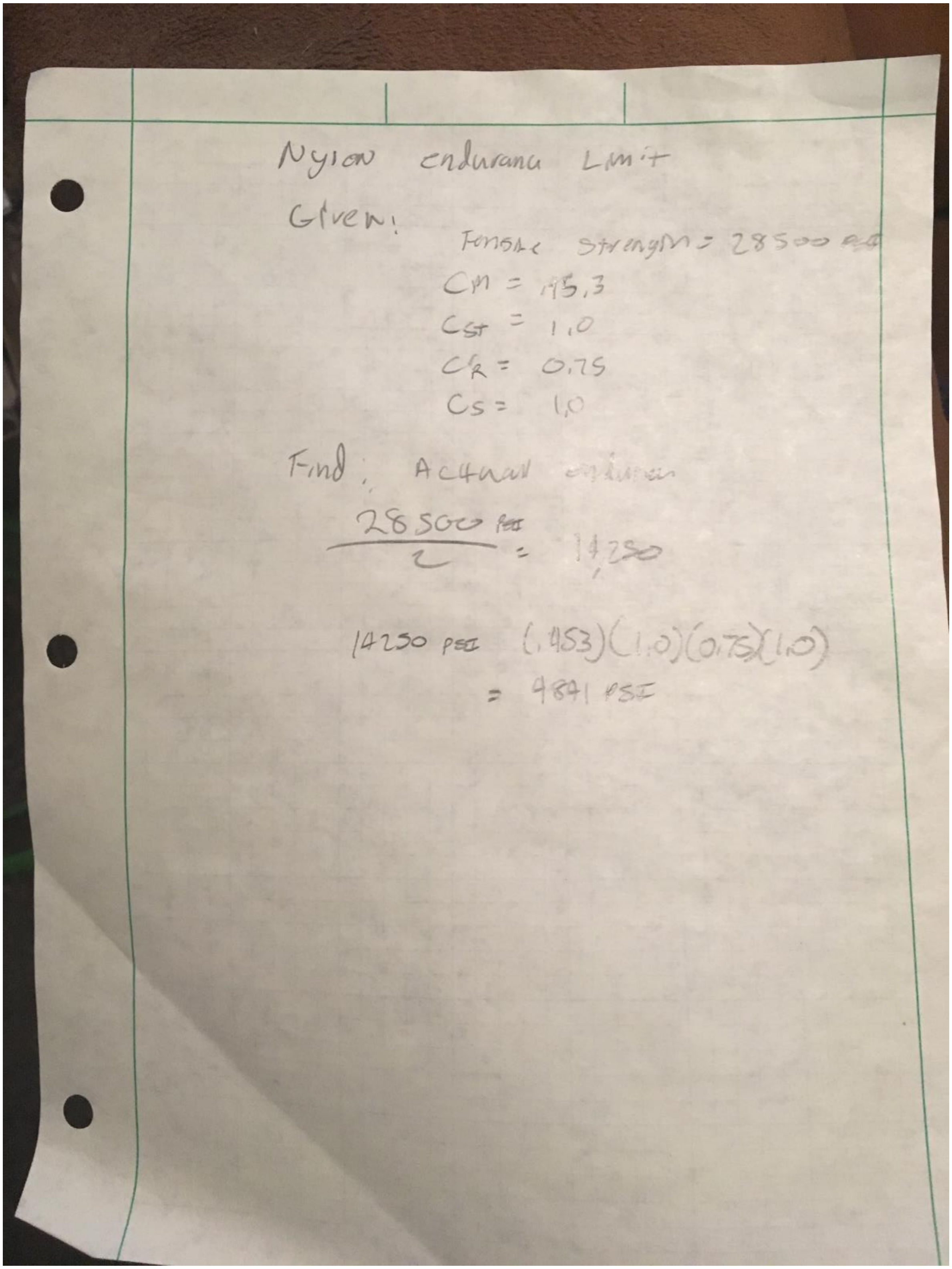
Find: Actual endurance facts

$$\frac{16,000\,psi}{2} = 8,000\ psi$$

8000 psi (.5)(1.0)(.75)(1.0)

= 2100 PSI

A-9: Endurance Limit of Nylon



Nylon endurance Limit

Given:

Tensile strength = 28500 psi

$C_m = .453$

$C_{ST} = 1.0$

$C_R = 0.75$

$C_S = 1.0$

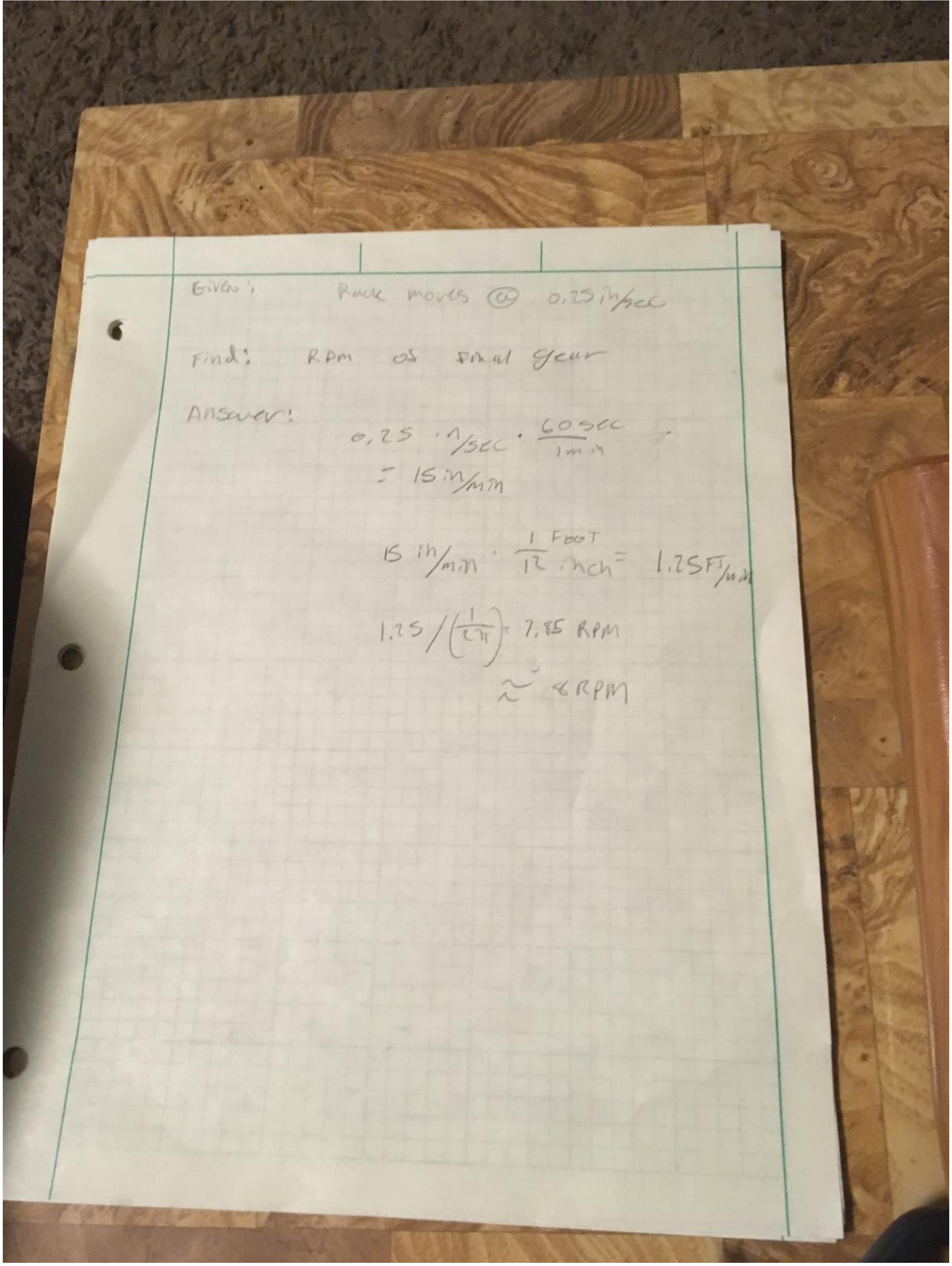
Find: Actual endurance

$$\frac{28500 \text{ psi}}{2} = 14,250$$

$$14250 \text{ psi } (.453)(1.0)(0.75)(1.0)$$

$$= 4841 \text{ psi}$$

A-10: Needed Final Gear RPM/Rack Speed



Given: Rack moves @ 0.25 in/sec

Find: RPM of final gear

Answer:

$$0.25 \text{ in/sec} \cdot \frac{60 \text{ sec}}{1 \text{ min}}$$

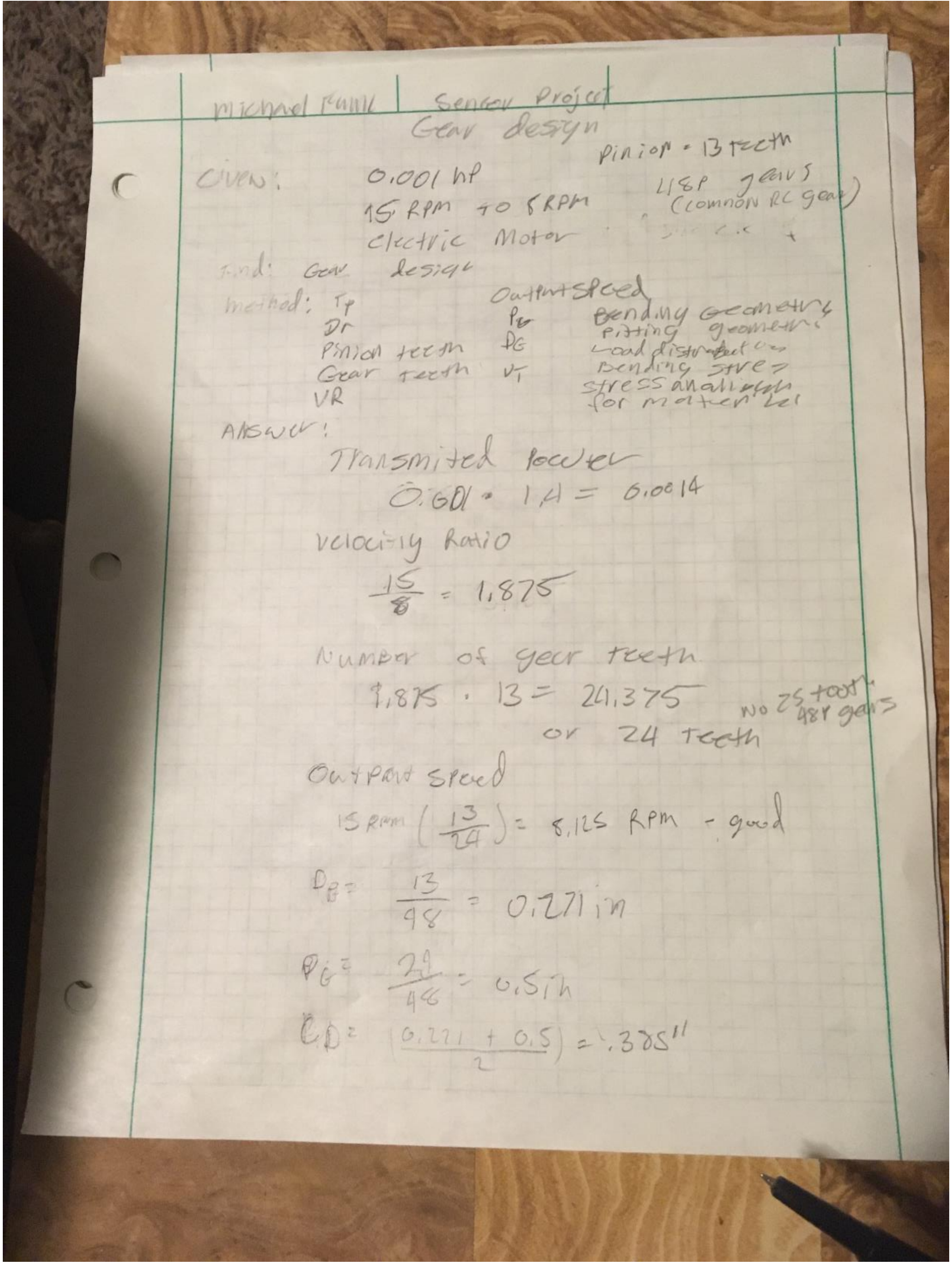
$$= 15 \text{ in/min}$$

$$15 \text{ in/min} \cdot \frac{1 \text{ Foot}}{12 \text{ inch}} = 1.25 \text{ FT/min}$$

$$1.25 / \left(\frac{1}{2\pi}\right) = 7.85 \text{ RPM}$$

$$\approx 8 \text{ RPM}$$

A-11: Initial Metal Gear Design



Michael Funk | Senior Project

Gear design

Pinion = 13 teeth

Given: 0.001 hp
15 RPM to 8 RPM
electric Motor

48P gears
(common RC gear)

Find: Gear design

Method: Tp
Dr
Pinion teeth
Gear teeth
VR

Output speed
P_P
D_G
V_t

Bending geometry
Pitting geometry
Load distribution
Bending stress
stress analysis for material

Answer:

Transmited power

$0.001 \cdot 1.4 = 0.0014$

velocity Ratio

$\frac{15}{8} = 1.875$

Number of gear teeth

$1.875 \cdot 13 = 24.375$
or 24 teeth

no 25 tooth 48P gears

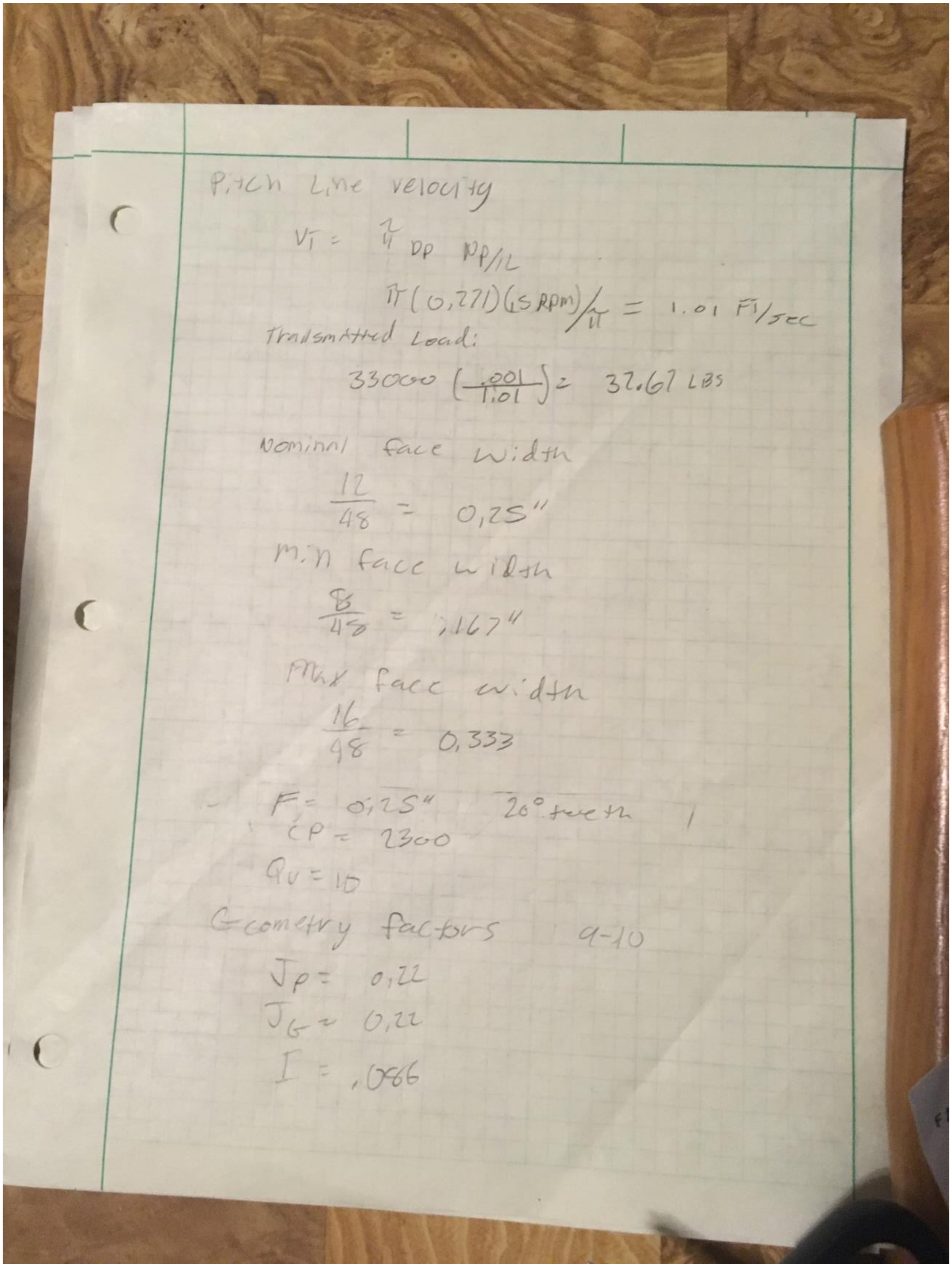
Output speed

$15\text{ RPM}\left(\frac{13}{24}\right) = 8.125\text{ RPM}$ - good

$D_P = \frac{13}{48} = 0.271\text{ in}$

$D_G = \frac{24}{48} = 0.5\text{ in}$

$CD = \left(\frac{0.271 + 0.5}{2}\right) = .385''$



Pitch Line velocity

$V_T = \frac{\pi}{12} D_P \ n_P/12$

$\pi(0{,}271)(15\ \text{RPM})/12 = 1.01$ Ft/sec

Transmitted Load:

$33000\left(\frac{.001}{1.01}\right) = 32.67$ LBS

Nominal face width

$\frac{12}{48} = 0{,}25''$

min face width

$\frac{8}{48} = 0{,}167''$

max face width

$\frac{16}{48} = 0{,}333$

F = 0,25"   20° teeth

CP = 2300

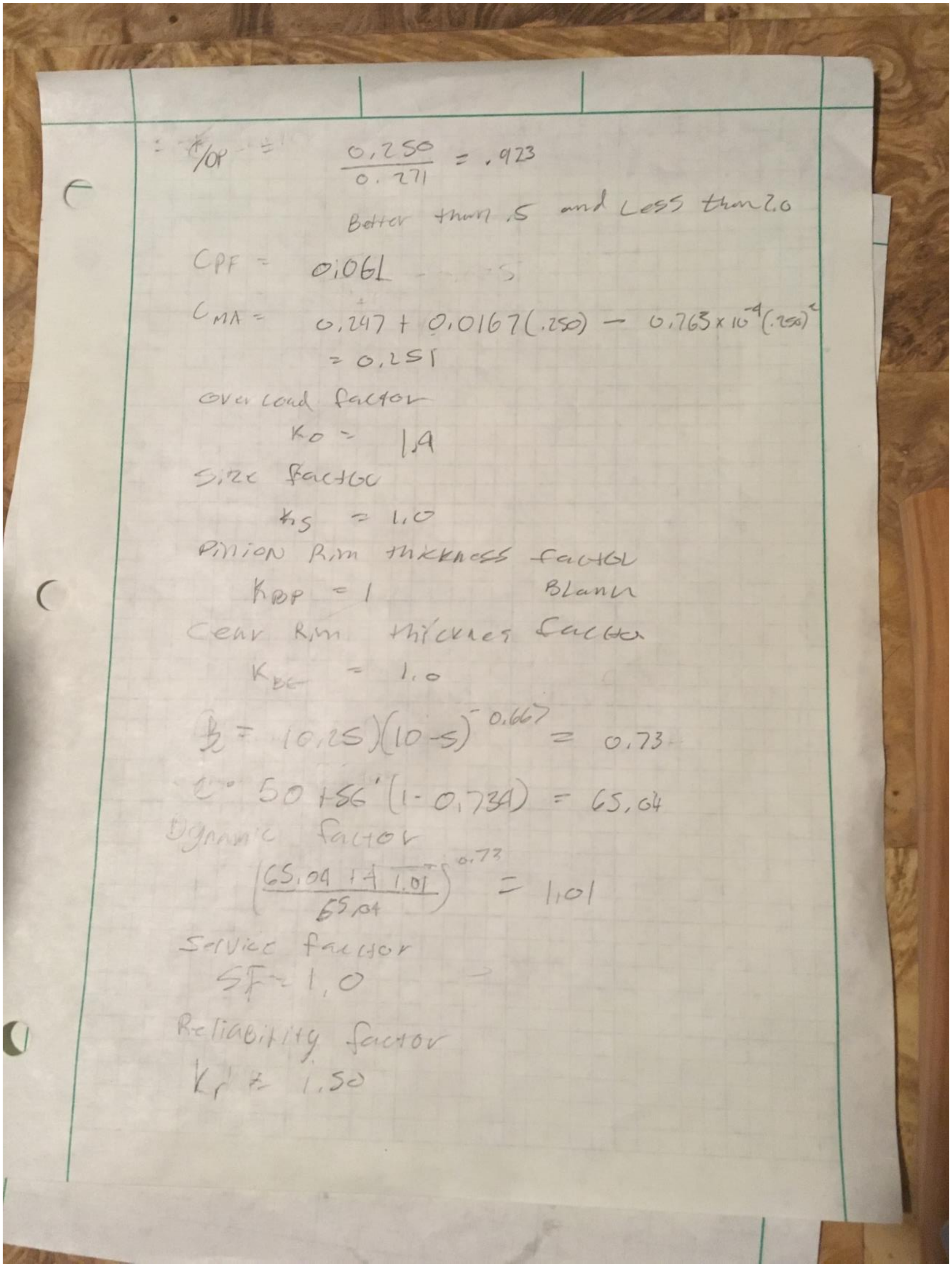
$Q_V = 10$

Geometry factors   9-10

$J_P = 0{,}22$

$J_G = 0{,}22$

$I = .086$



$F/d_P = \frac{0,250}{0.271} = .923$

Better than .5 and Less than 2.0

$C_{PF} = 0,061$

$C_{MA} = 0,247 + 0,0167(.250) - 0,763 \times 10^{-4}(.250)^2$

$= 0,251$

Over Load factor

$K_O = 1,4$

Size factor

$K_S = 1,0$

Pinion Rim thickness factor

$K_{BP} = 1$ Blank

Gear Rim thickness factor

$K_{BG} = 1.0$

$B = (0,25)(10-5)^{0.667} = 0.73$

$C = 50 + 56(1 - 0,734) = 65,04$

Dynamic factor

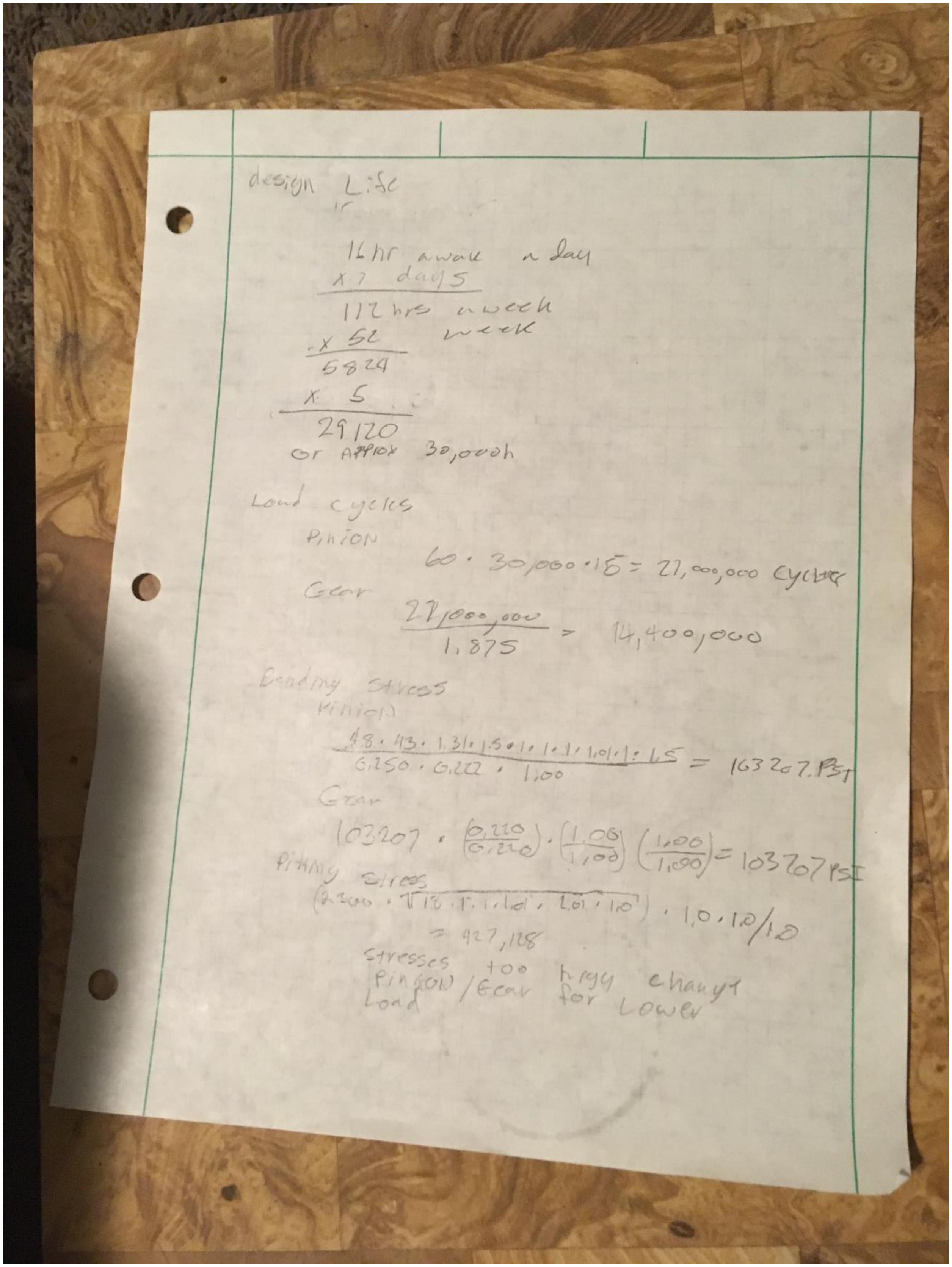
$\left(\frac{65,04 + \sqrt{1,01}}{65,04}\right)^{0.73} = 1,01$

Service factor

$SF = 1,0$

Reliability factor

$K_r = 1,50$



design Life

16 hr awake a day

x 7 days

112 hrs a week

x 52 week

5824

x 5

29120

or Approx 30,000h

Load cycles

Pinion

$60 \cdot 30{,}000 \cdot 15 = 27{,}000{,}000$ cycles

Gear

$$\frac{27{,}000{,}000}{1.875} = 14{,}400{,}000$$

Bending Stress

Pinion

$$\frac{48 \cdot 43 \cdot 1.31 \cdot 1.5 \cdot 1 \cdot 1 \cdot 1 \cdot 1.0 \cdot 1 \cdot 1.5}{0.250 \cdot 0.222 \cdot 1.00} = 163207.\text{PSI}$$

Gear

$$103207 \cdot \left(\frac{0.220}{0.220}\right) \cdot \left(\frac{1.00}{1.00}\right) \left(\frac{1.00}{1.00}\right) = 103207\text{PSI}$$

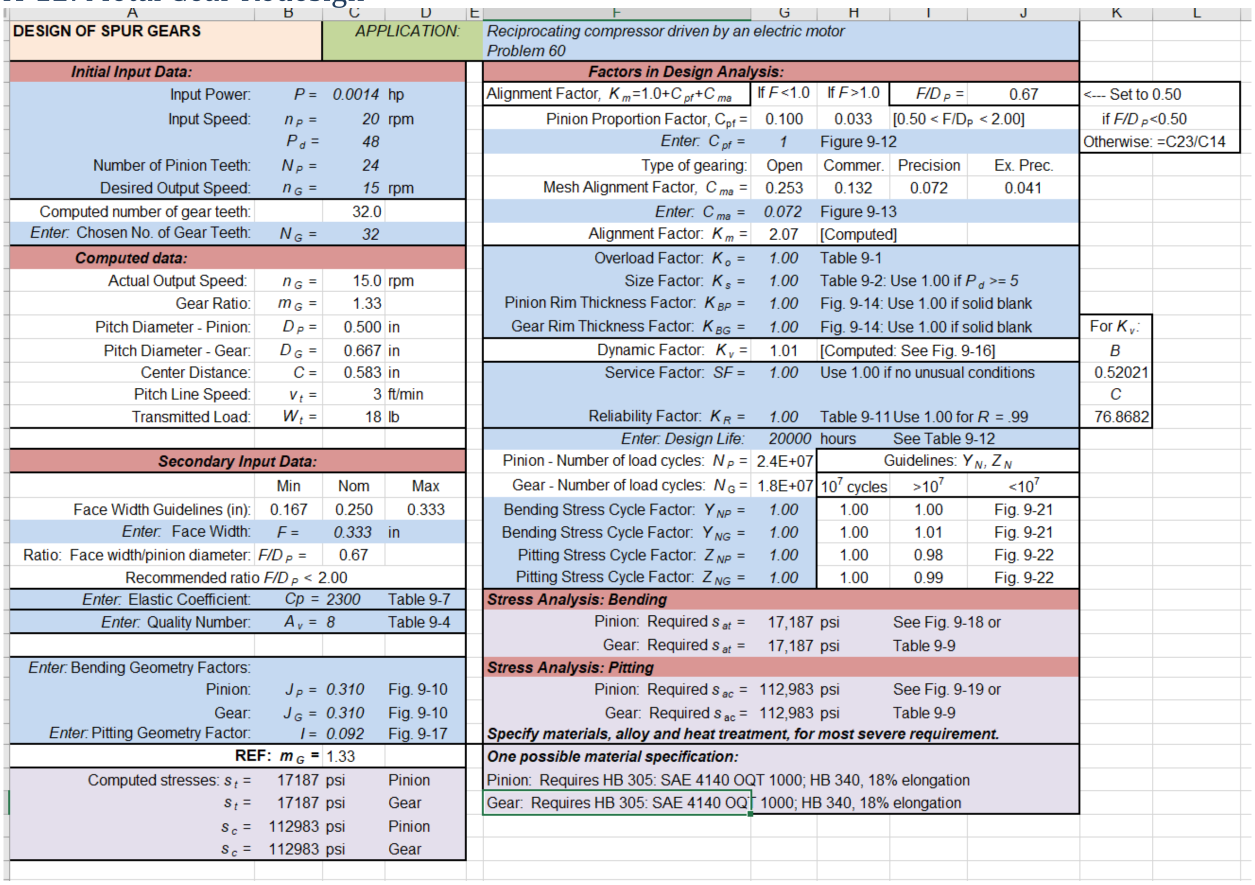
Pitting Stress

$$\left(2300 \cdot \sqrt{18 \cdot 1 \cdot 1 \cdot 1.0 \cdot 1.01 \cdot 1.0}\right) \cdot 1.0 \cdot 1.0 / 1.0$$

$= 427{,}128$

Stresses too high change
Pinion/Gear for Lower
Load

A-12: Metal Gear Redesign

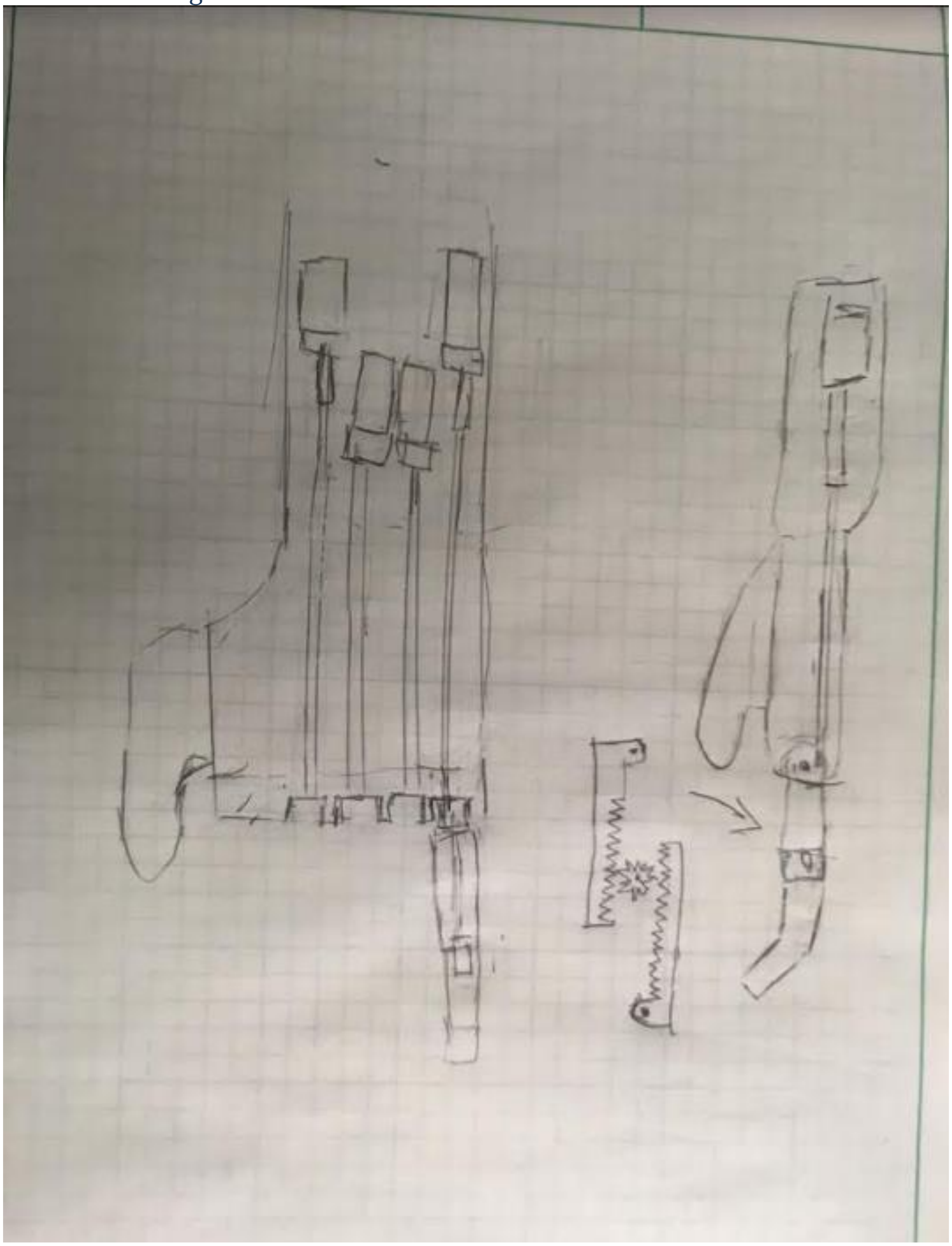


A	B	C	D
DESIGN OF SPUR GEARS		*APPLICATION:*	
Initial Input Data:			
Input Power:	P =	*0.0014*	hp
Input Speed:	n_P =	*20*	rpm
	P_d =	*48*	
Number of Pinion Teeth:	N_P =	*24*	
Desired Output Speed:	n_G =	*15*	rpm
Computed number of gear teeth:		32.0	
Enter: Chosen No. of Gear Teeth:	N_G =	*32*	
Computed data:			
Actual Output Speed:	n_G =	15.0	rpm
Gear Ratio:	m_G =	1.33	
Pitch Diameter - Pinion:	D_P =	0.500	in
Pitch Diameter - Gear:	D_G =	0.667	in
Center Distance:	C =	0.583	in
Pitch Line Speed:	v_t =	3	ft/min
Transmitted Load:	W_t =	18	lb
Secondary Input Data:			
	Min	Nom	Max
Face Width Guidelines (in):	0.167	0.250	0.333
Enter: Face Width:	F =	*0.333*	in
Ratio: Face width/pinion diameter:	F/D_P =	0.67	
Recommended ratio F/D_P < 2.00			
Enter: Elastic Coefficient:	Cp = *2300*		Table 9-7
Enter: Quality Number:	A_v = *8*		Table 9-4
Enter: Bending Geometry Factors:			
Pinion:	J_P = *0.310*		Fig. 9-10
Gear:	J_G = *0.310*		Fig. 9-10
Enter: Pitting Geometry Factor:	I = *0.092*		Fig. 9-17
REF:	m_G =	1.33	
Computed stresses: s_t =	17187	psi	Pinion
s_t =	17187	psi	Gear
s_c =	112983	psi	Pinion
s_c =	112983	psi	Gear

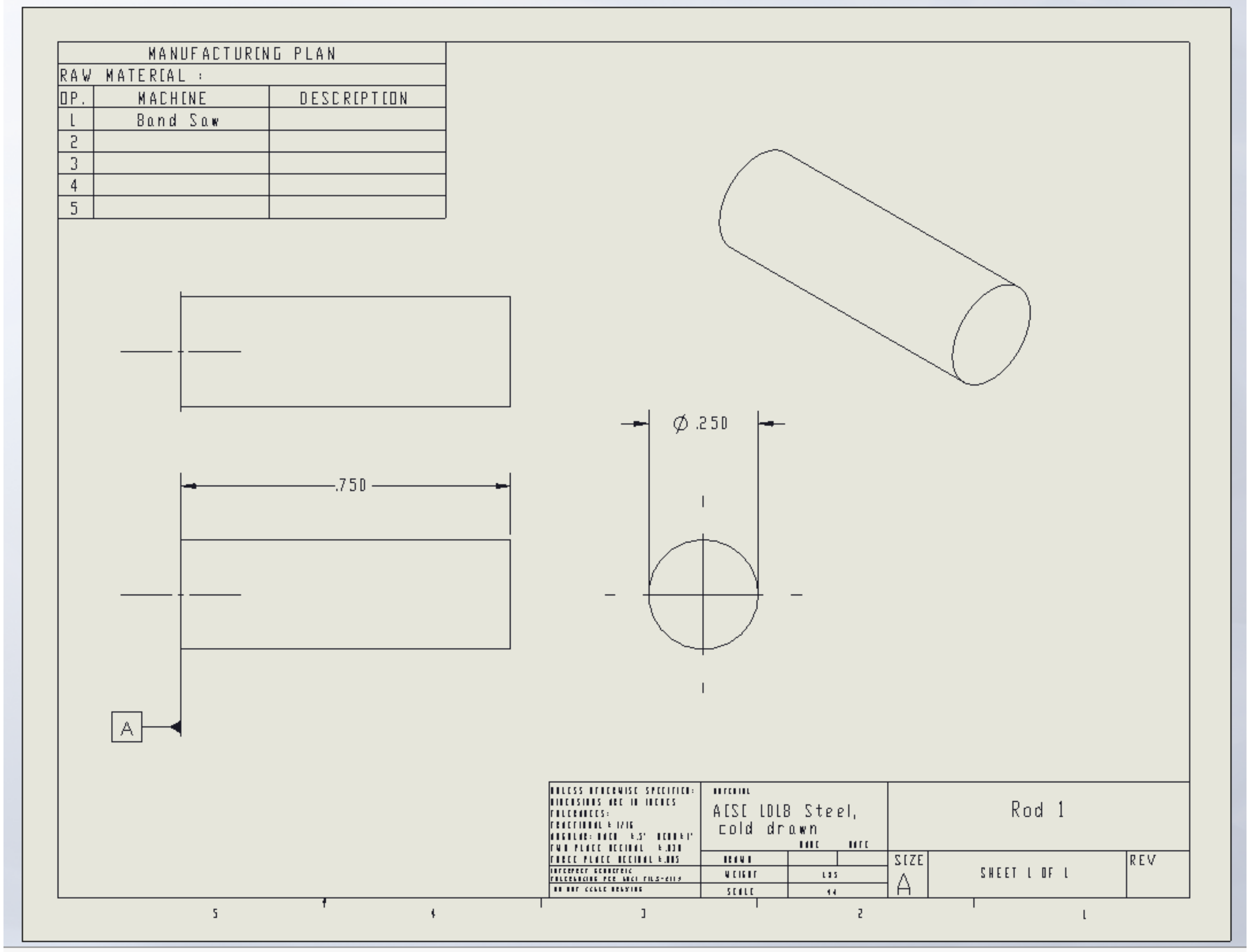
F	G	H	I	J	K	L
Reciprocating compressor driven by an electric motor *Problem 60*						
Factors in Design Analysis:						
Alignment Factor, K_m=1.0+C_{pf}+C_{ma}	If F<1.0	If F>1.0	F/D_P =	0.67	<--- Set to 0.50	
Pinion Proportion Factor, C_{pf} =	0.100	0.033	[0.50 < F/D$_P$ < 2.00]		if F/D_P<0.50	
Enter: C_{pf} =	*1*	Figure 9-12			Otherwise: =C23/C14	
Type of gearing:	Open	Commer.	Precision	Ex. Prec.		
Mesh Alignment Factor, C_{ma} =	0.253	0.132	0.072	0.041		
Enter: C_{ma} =	*0.072*	Figure 9-13				
Alignment Factor: K_m =	2.07	[Computed]				
Overload Factor: K_o =	*1.00*	Table 9-1				
Size Factor: K_s =	*1.00*	Table 9-2: Use 1.00 if P_d >= 5				
Pinion Rim Thickness Factor: K_{BP} =	*1.00*	Fig. 9-14: Use 1.00 if solid blank				
Gear Rim Thickness Factor: K_{BG} =	*1.00*	Fig. 9-14: Use 1.00 if solid blank			For K_v:	
Dynamic Factor: K_v =	1.01	[Computed: See Fig. 9-16]			*B*	
Service Factor: SF =	*1.00*	Use 1.00 if no unusual conditions			0.52021	
					C	
Reliability Factor: K_R =	*1.00*	Table 9-11	Use 1.00 for R = .99		76.8682	
Enter: Design Life:	*20000*	hours	See Table 9-12			
Pinion - Number of load cycles: N_P =	2.4E+07	Guidelines: Y_N, Z_N				
Gear - Number of load cycles: N_G =	1.8E+07	10^7 cycles	$>10^7$	$<10^7$		
Bending Stress Cycle Factor: Y_{NP} =	*1.00*	1.00	1.00	Fig. 9-21		
Bending Stress Cycle Factor: Y_{NG} =	*1.00*	1.00	1.01	Fig. 9-21		
Pitting Stress Cycle Factor: Z_{NP} =	*1.00*	1.00	0.98	Fig. 9-22		
Pitting Stress Cycle Factor: Z_{NG} =	*1.00*	1.00	0.99	Fig. 9-22		
Stress Analysis: Bending						
Pinion: Required s_{at} =	17,187	psi	See Fig. 9-18 or			
Gear: Required s_{at} =	17,187	psi	Table 9-9			
Stress Analysis: Pitting						
Pinion: Required s_{ac} =	112,983	psi	See Fig. 9-19 or			
Gear: Required s_{ac} =	112,983	psi	Table 9-9			
Specify materials, alloy and heat treatment, for most severe requirement.						
One possible material specification:						
Pinion: Requires HB 305: SAE 4140 OQT 1000; HB 340, 18% elongation						
Gear: Requires HB 305: SAE 4140 OQT 1000; HB 340, 18% elongation						

Appendix B: Drawings

B-1: Initial Design



B-2: Rod1 Drawing



MANUFACTURING PLAN		
RAW MATERIAL :		
OP.	MACHINE	DESCRIPTION
1	Band Saw	
2		
3		
4		
5		

MATERIAL

AISI 1018 Steel, cold drawn

Rod 1

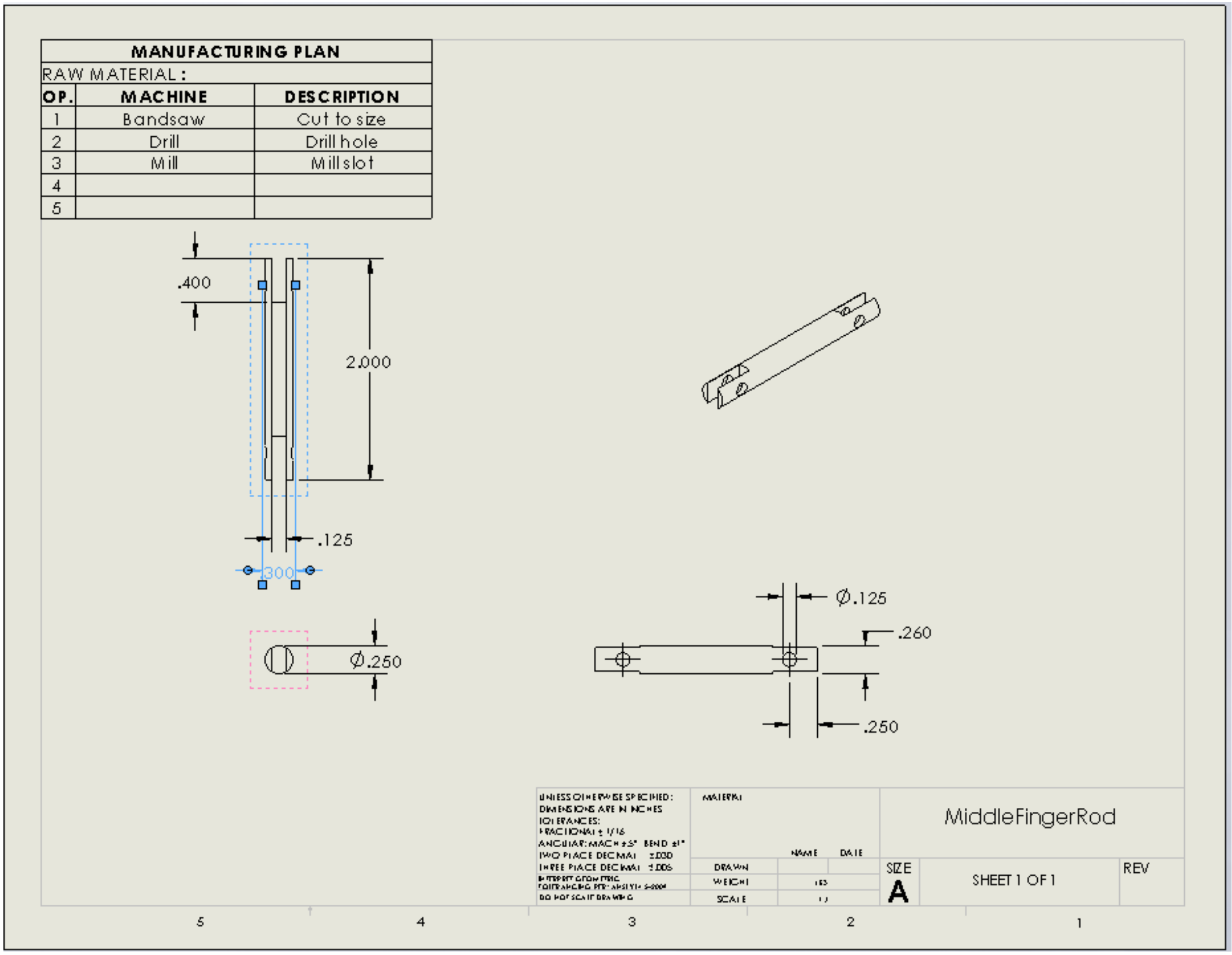
SIZE A

SHEET 1 OF 1

REV

Figure B-1

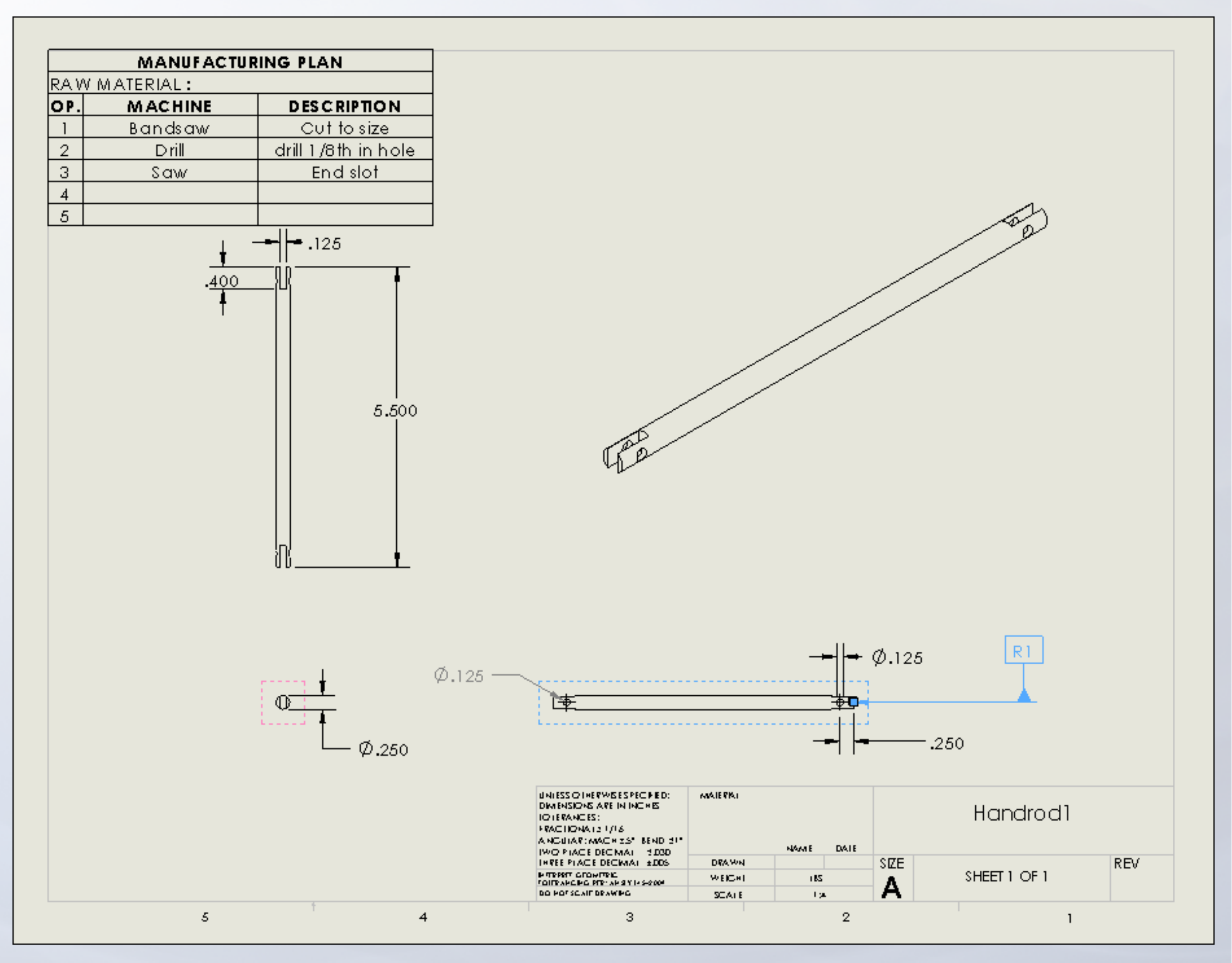
B-2: Middle Finger Rod Drawing



MANUFACTURING PLAN		
RAW MATERIAL:		
OP.	MACHINE	DESCRIPTION
1	Bandsaw	Cut to size
2	Drill	Drill hole
3	Mill	Mill slot
4		
5		

Figure B-2

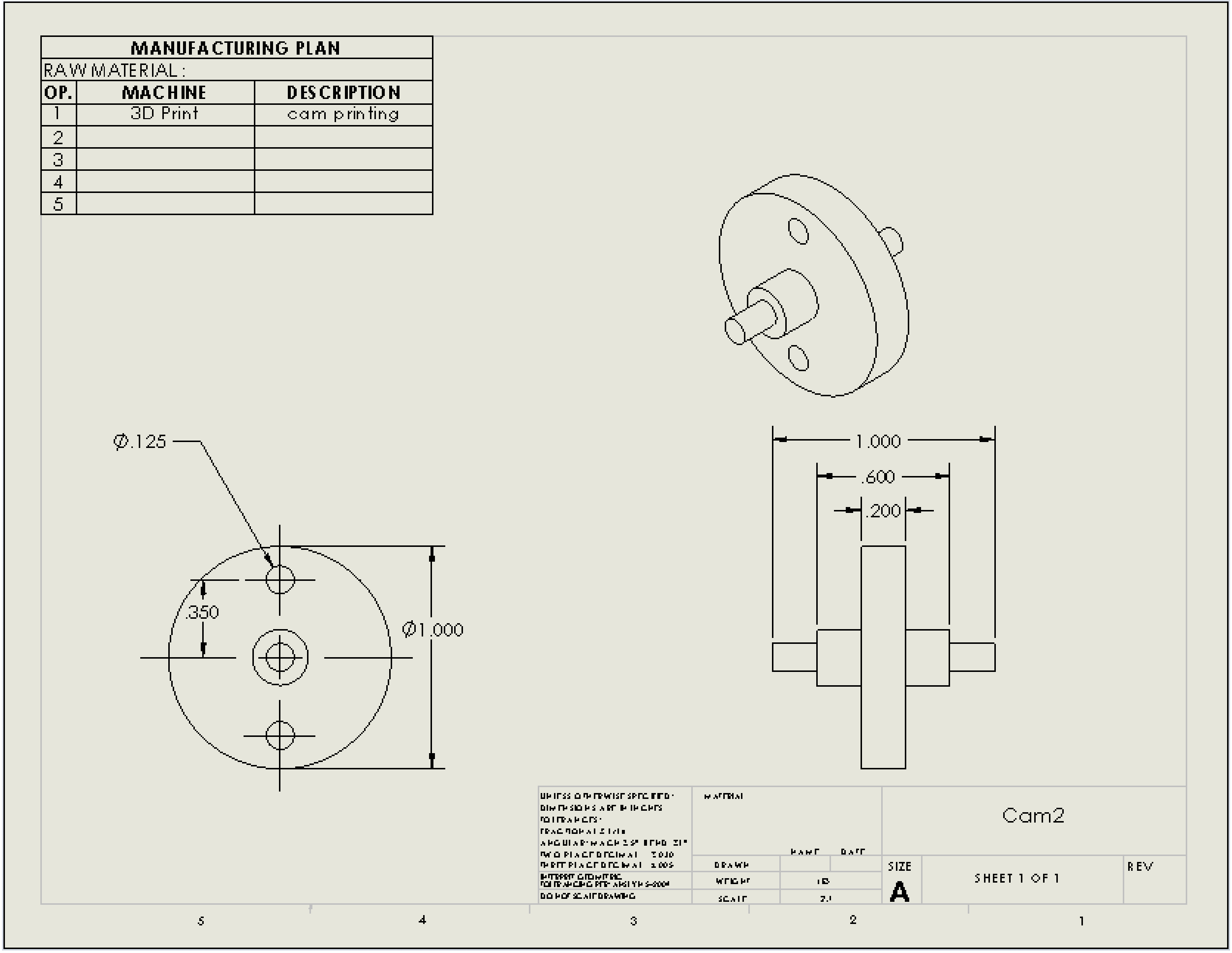
B-3: HandRod1 Drawing



MANUFACTURING PLAN		
RAW MATERIAL :		
OP.	**MACHINE**	**DESCRIPTION**
1	Bandsaw	Cut to size
2	Drill	drill 1/8th in hole
3	Saw	End slot
4		
5		

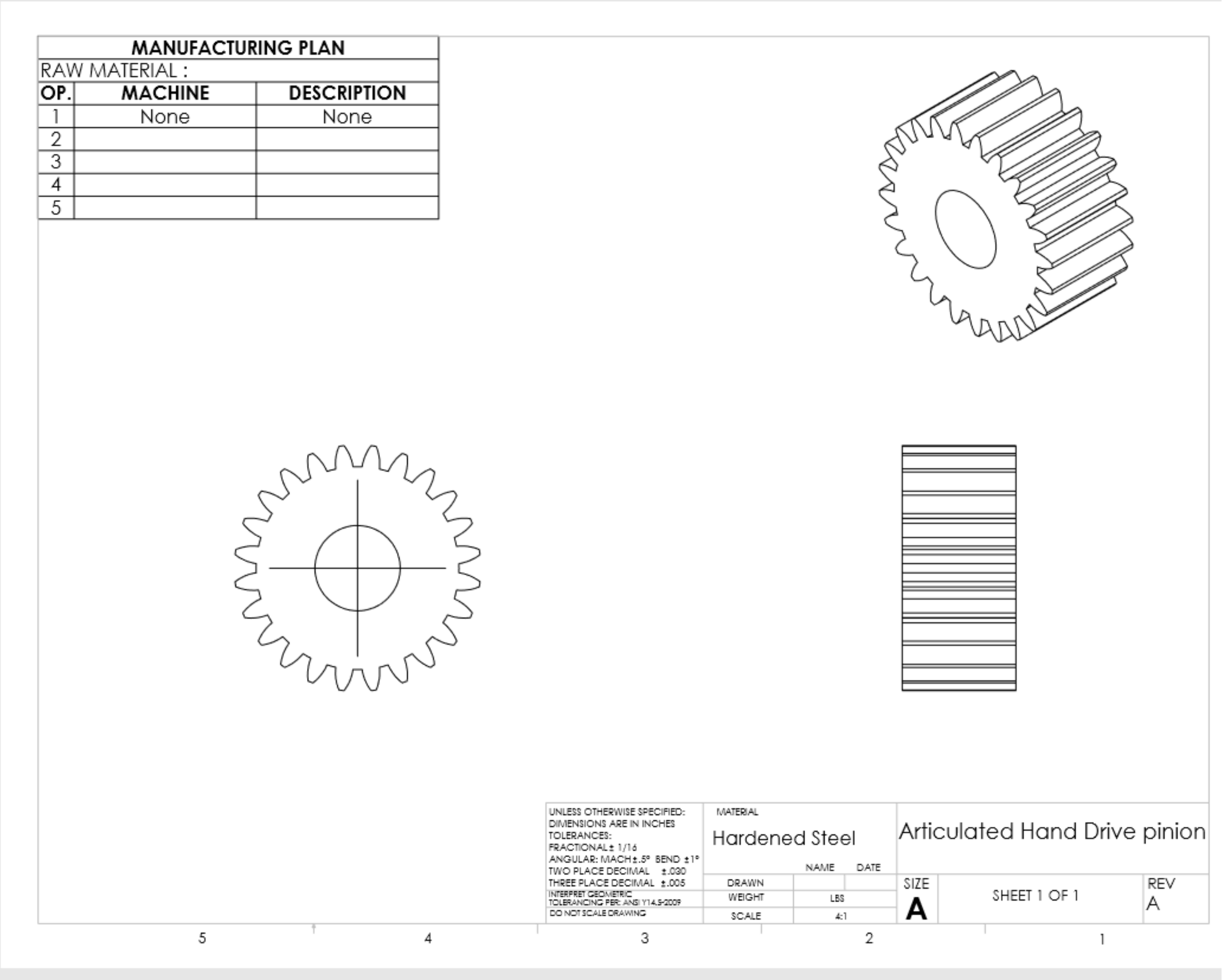
Figure B-3

B-4: Cam Drawing



MANUFACTURING PLAN		
RAW MATERIAL :		
OP.	**MACHINE**	**DESCRIPTION**
1	3D Print	cam printing
2		
3		
4		
5		

B-5: Pinion Drawing



MANUFACTURING PLAN

RAW MATERIAL :

OP.	MACHINE	DESCRIPTION
1	None	None
2		
3		
4		
5		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16
ANGULAR: MACH ± .5° BEND ± 1°
TWO PLACE DECIMAL ±.030
THREE PLACE DECIMAL ±.005
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14.5-2009
DO NOT SCALE DRAWING

MATERIAL
Hardened Steel

	NAME	DATE
DRAWN		
WEIGHT	LBS	
SCALE	4:1	

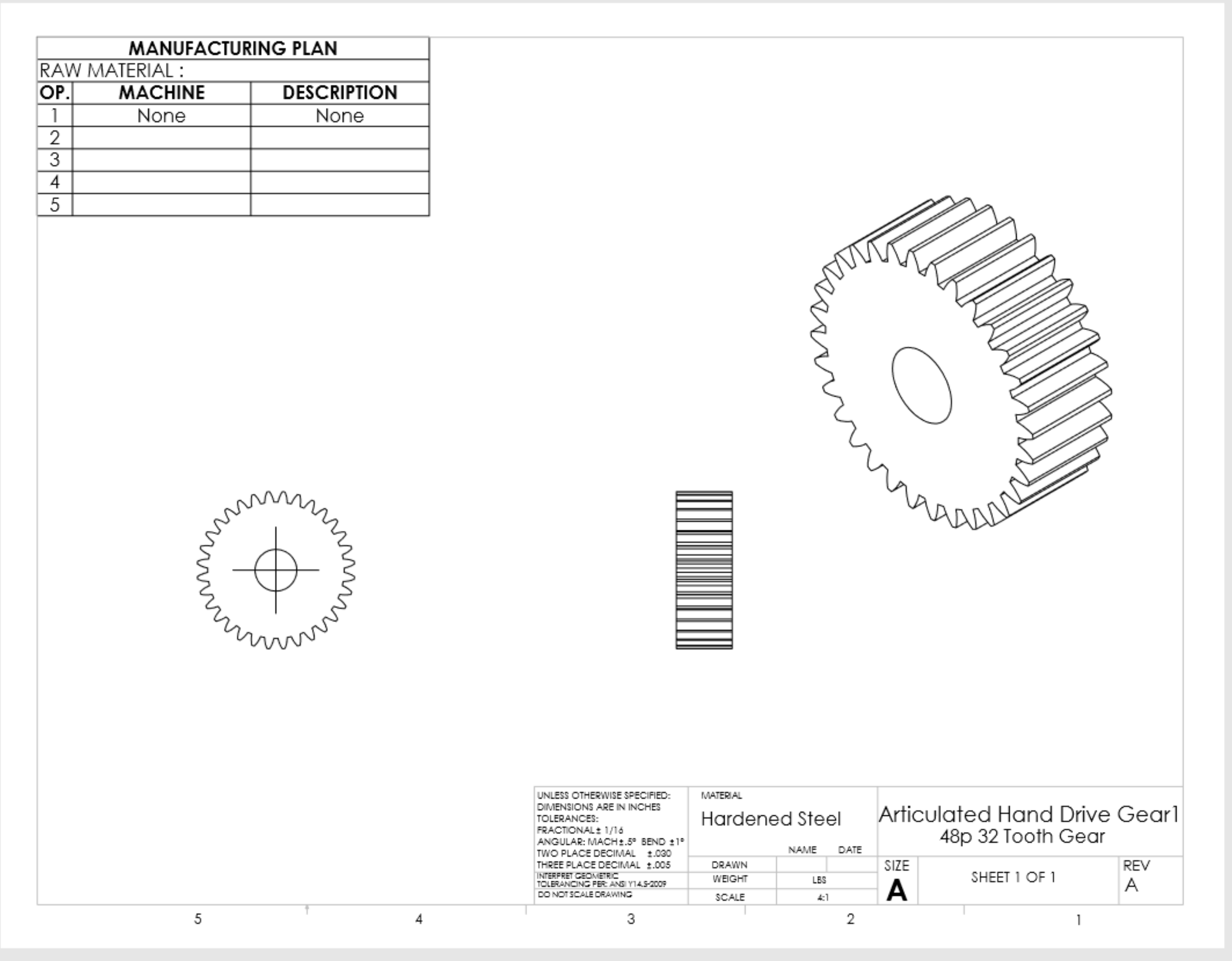
Articulated Hand Drive pinion

SIZE A

SHEET 1 OF 1

REV A

B-6: Gear Drawing



MANUFACTURING PLAN

RAW MATERIAL :

OP.	MACHINE	DESCRIPTION
1	None	None
2		
3		
4		
5		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL± 1/16
ANGULAR: MACH±.5° BEND ±1°
TWO PLACE DECIMAL ±.030
THREE PLACE DECIMAL ±.005
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14.5-2009
DO NOT SCALE DRAWING

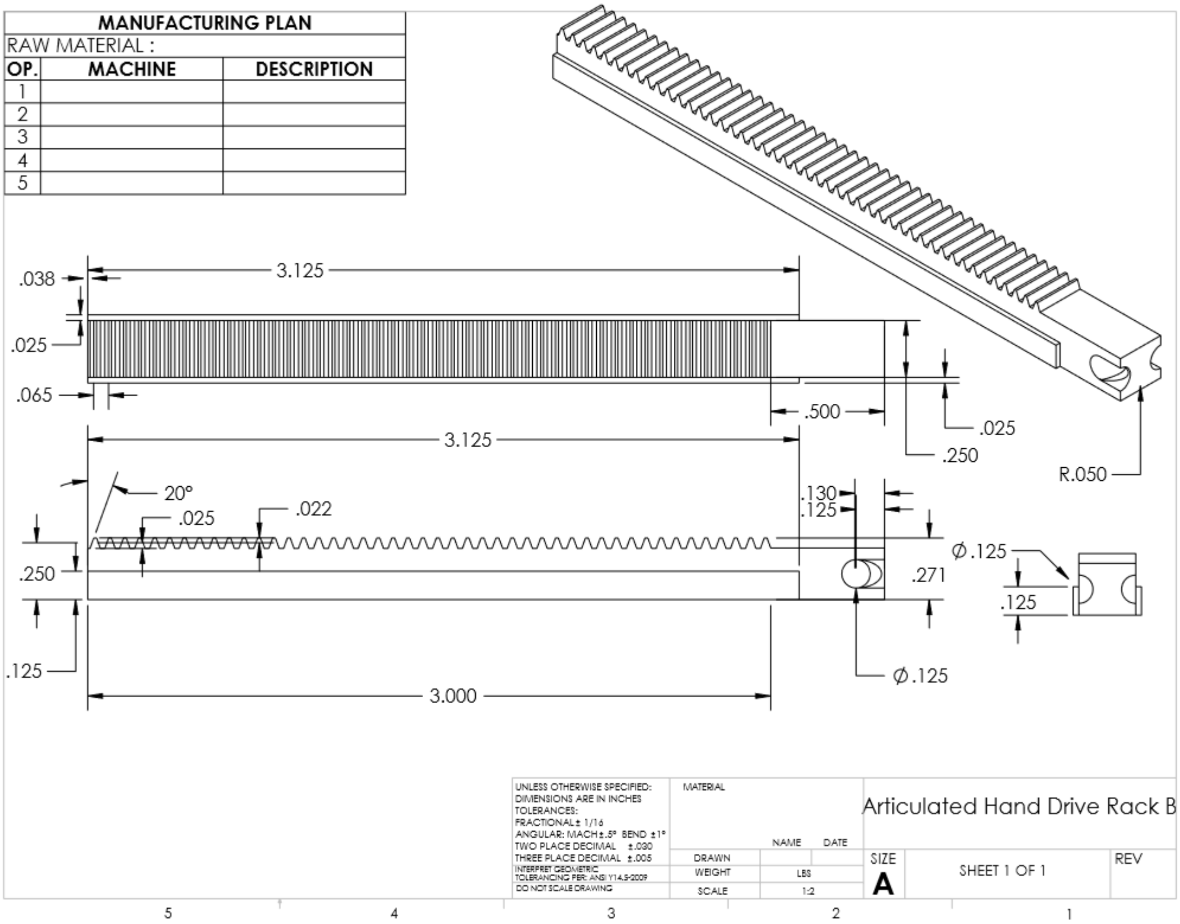
MATERIAL
Hardened Steel

	NAME	DATE
DRAWN		
WEIGHT	LBS	
SCALE	4:1	

Articulated Hand Drive Gear1
48p 32 Tooth Gear

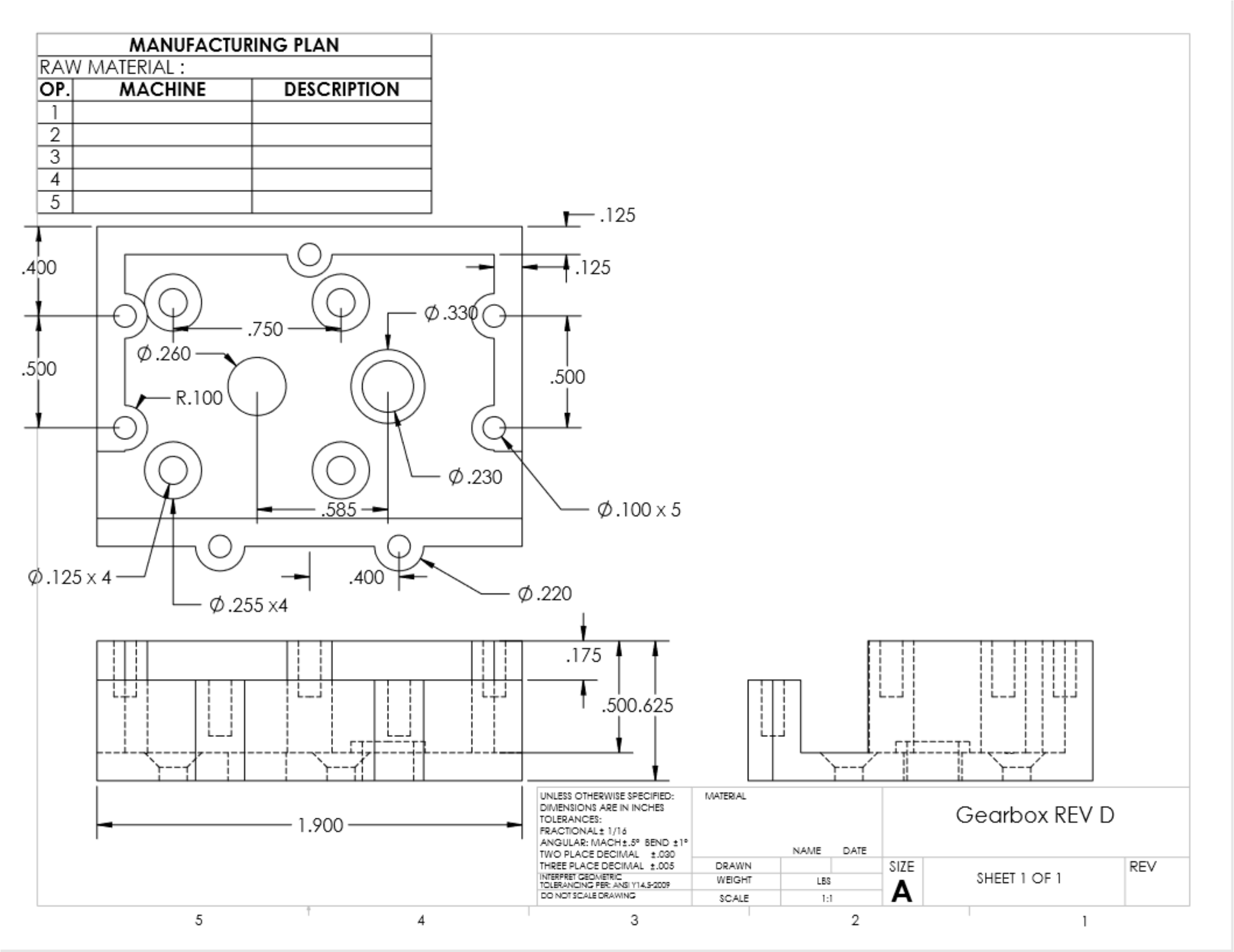
SIZE A
SHEET 1 OF 1
REV A

B-7: Rack Drawing



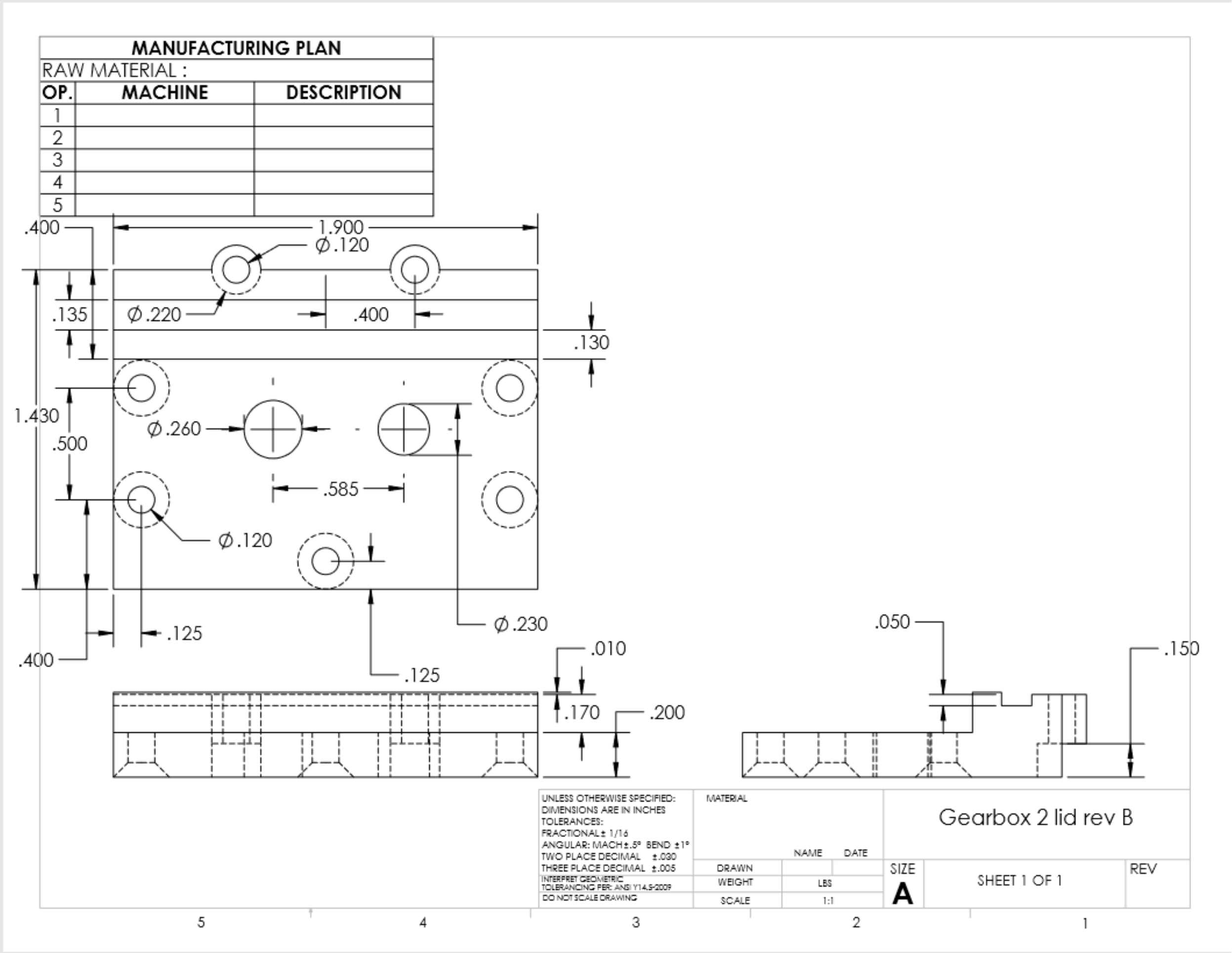
MANUFACTURING PLAN		
RAW MATERIAL :		
OP.	MACHINE	DESCRIPTION
1		
2		
3		
4		
5		

B-8: Gearbox Case Rev D



MANUFACTURING PLAN		
RAW MATERIAL :		
OP.	MACHINE	DESCRIPTION
1		
2		
3		
4		
5		

B-9: Gearbox Lid Rev B



MANUFACTURING PLAN		
RAW MATERIAL :		
OP.	MACHINE	DESCRIPTION
1		
2		
3		
4		
5		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL± 1/16
ANGULAR: MACH±.5° BEND ±1°
TWO PLACE DECIMAL ±.030
THREE PLACE DECIMAL ±.005
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14.5-2009
DO NOT SCALE DRAWING

MATERIAL			
	NAME	DATE	
DRAWN			
WEIGHT	LBS		
SCALE	1:1		

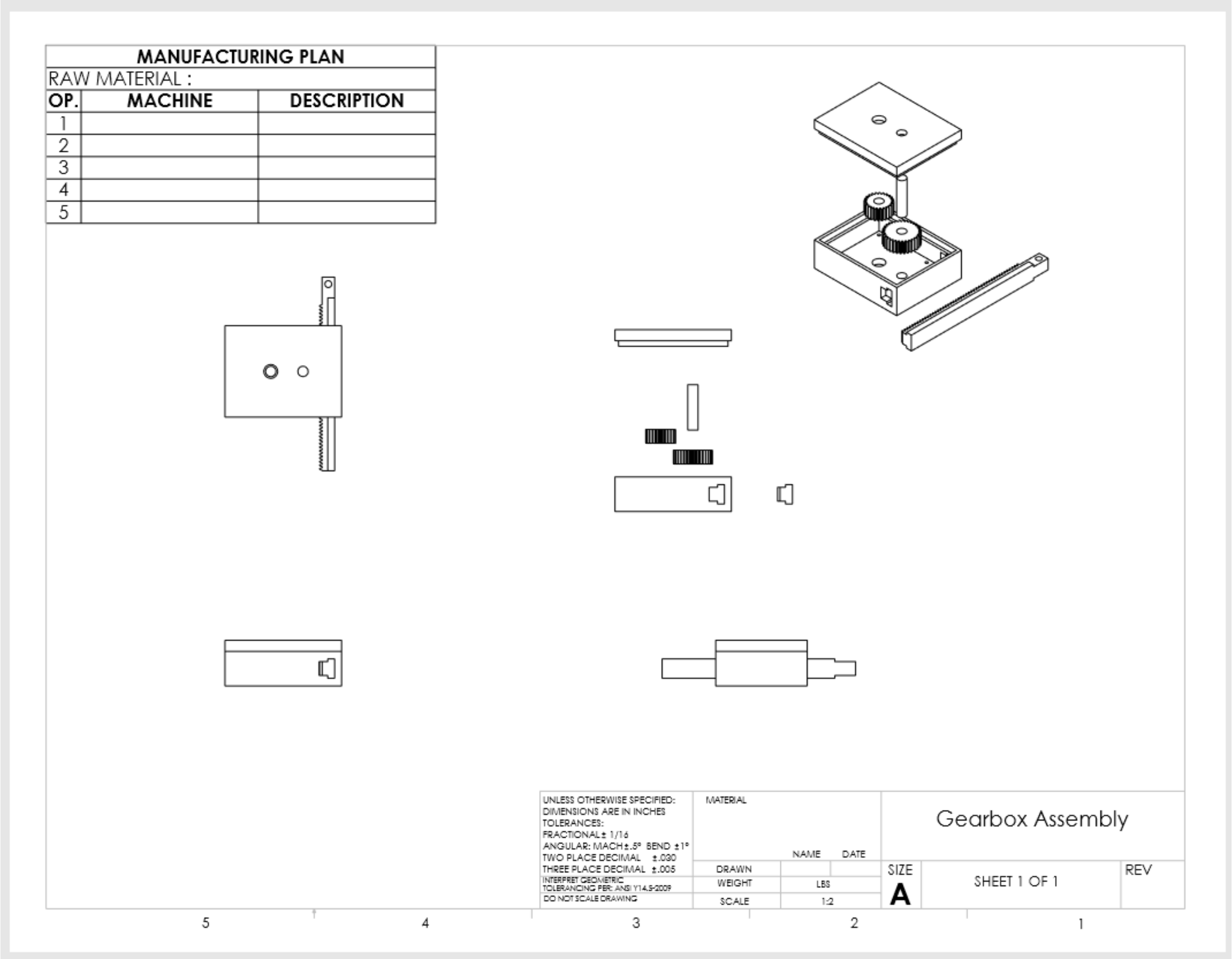
Gearbox 2 lid rev B

SIZE A

SHEET 1 OF 1

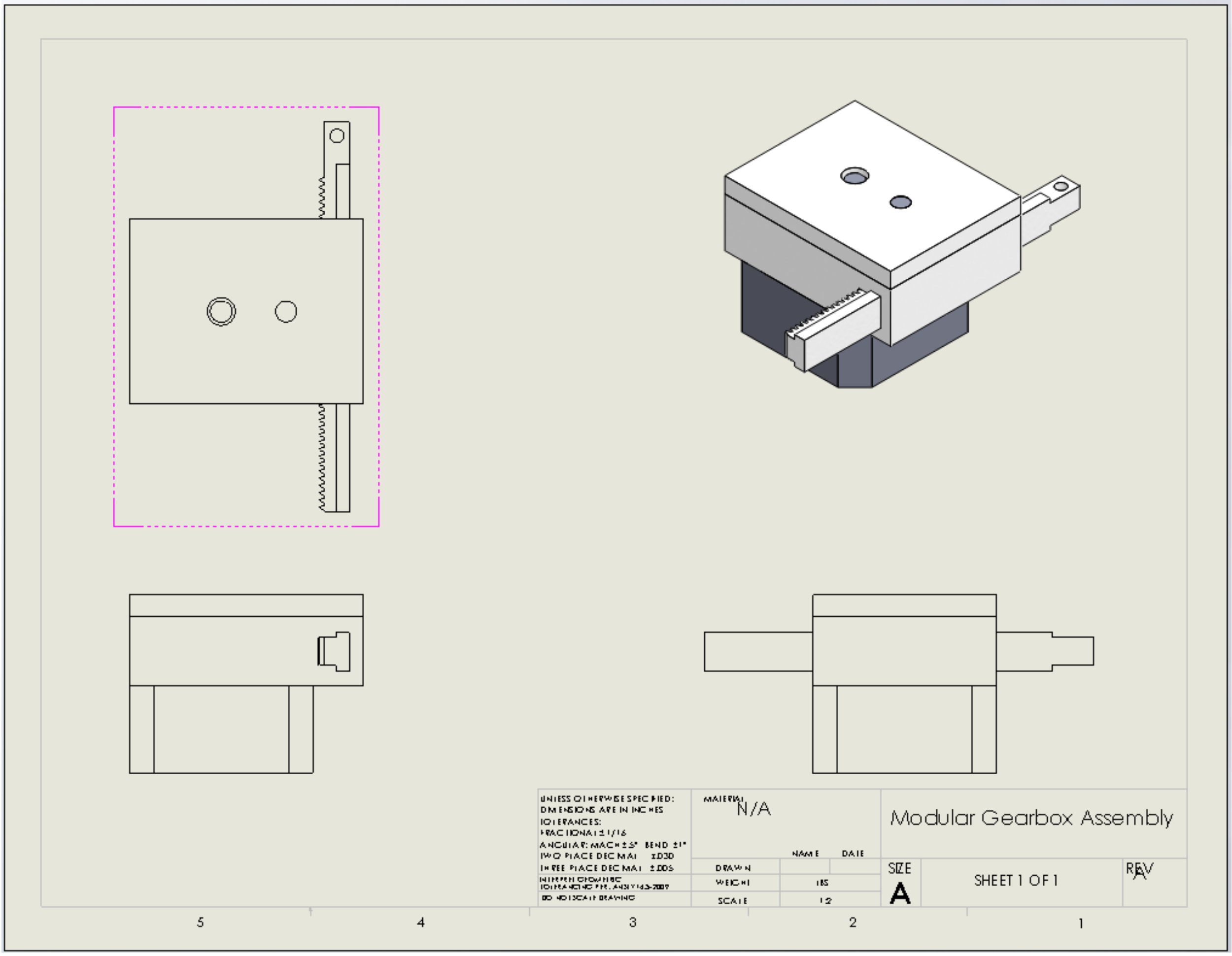
REV

B-10: Gearbox Assembly

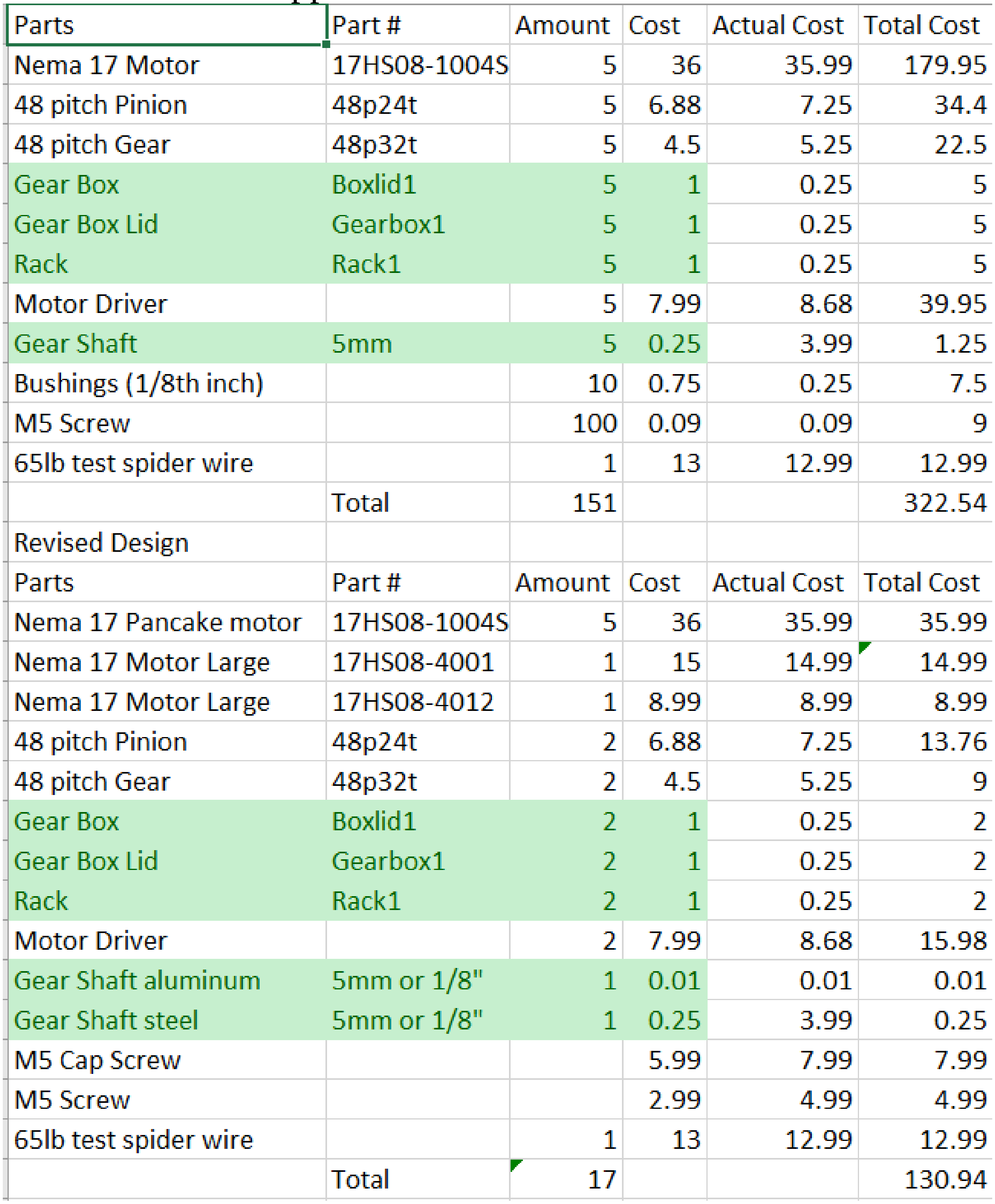


MANUFACTURING PLAN		
RAW MATERIAL :		
OP.	MACHINE	DESCRIPTION
1		
2		
3		
4		
5		

B-11: Modular Motor Assembly



Appendix C: Parts List & Cost



Parts	Part #	Amount	Cost	Actual Cost	Total Cost
Nema 17 Motor	17HS08-1004S	5	36	35.99	179.95
48 pitch Pinion	48p24t	5	6.88	7.25	34.4
48 pitch Gear	48p32t	5	4.5	5.25	22.5
Gear Box	Boxlid1	5	1	0.25	5
Gear Box Lid	Gearbox1	5	1	0.25	5
Rack	Rack1	5	1	0.25	5
Motor Driver		5	7.99	8.68	39.95
Gear Shaft	5mm	5	0.25	3.99	1.25
Bushings (1/8th inch)		10	0.75	0.25	7.5
M5 Screw		100	0.09	0.09	9
65lb test spider wire		1	13	12.99	12.99
	Total	151			322.54
Revised Design					
Parts	Part #	Amount	Cost	Actual Cost	Total Cost
Nema 17 Pancake motor	17HS08-1004S	5	36	35.99	35.99
Nema 17 Motor Large	17HS08-4001	1	15	14.99	14.99
Nema 17 Motor Large	17HS08-4012	1	8.99	8.99	8.99
48 pitch Pinion	48p24t	2	6.88	7.25	13.76
48 pitch Gear	48p32t	2	4.5	5.25	9
Gear Box	Boxlid1	2	1	0.25	2
Gear Box Lid	Gearbox1	2	1	0.25	2
Rack	Rack1	2	1	0.25	2
Motor Driver		2	7.99	8.68	15.98
Gear Shaft aluminum	5mm or 1/8"	1	0.01	0.01	0.01
Gear Shaft steel	5mm or 1/8"	1	0.25	3.99	0.25
M5 Cap Screw			5.99	7.99	7.99
M5 Screw			2.99	4.99	4.99
65lb test spider wire		1	13	12.99	12.99
	Total	17			130.94

Appendix D: Budget

The cost of parts has exceeded the amount of predicted costs. The initial costs were built around the original design would use more but less expensive stepper motors. The costs come from having to acquire new motors and drivers that can handle the power required. Some of the cost changes are offset by the cheaper parts that can be purchased for the project. The stepper motors that were chosen are very small and have limited holding power. During the project there were several redesigns including one that changed from using 5 motors to 2 motors. This is a significant change in need for motor capabilities. The decision to get new motors pushed over the given budget for the project. A cost saving for the project was the ability to get some of the parts needed for the project for free through the Electrical Engineering Technology program. This helped reduce the cost for Arduino Uno and some of the electrical parts. Parts were also provided from one of the team member's home in the form of electrical power sources for the Arduino and stepper motor drivers. Some changes also included the cut shaft being made out of aluminum and not stainless steel.

Gearbox:

The Gearbox's cost less than originally predicted. The printing was completed with the help of the EET Department 3D printer. The cost was also reduced for printing by redesigning the internal structure of the box. The size of the original box was approx. 25% larger than the final product. Printing time was reduced by approximately 20 minutes. The redesign helped reduce the amount of overhang and larger hole sizes reduced printing requirements. As the development cycle progressed the cost to make one full gearbox dropped from $3 to $2.50 due to the reduced print time and less materials used.

Stepper Motor:

In the initial design of the prosthetic hand there was a motor for each finger. The motors initially purchased had limited power and had a slim design that helped with space. Due to a redesign to help limit weight and streamline production it was decided to go with two motors instead of 5. Due to the changes replacement motors had to be ordered to compensate for the hand to function. This raised the total cost of the whole project but lowed the cost of a hand.

Screws:

The screws used in the project didn't change much from initial design to final design. Each bag of screws was 100 count and cost around 2.99 per bag. Some of the less common cost more than 5.99 a bag. When redesigning the gearbox, the cost of the screws was taken into account and a common screw was chosen to be used. There two cap screws that are slightly more expensive used in the design to hold the gearbox slide together. They cost $3.99 for 25. This was chosen because the head is capable of holding the pressure of the rack pressing on the sidewall.

Gears:

With the small size of the gearbox it was decide to use small gears for movement. Initially the build was attempted with plastic gears but due to size and pressure requirements. The gears required had to standup to the pressure on the gear teeth. The data helped find the required gears. After carful consideration hardened steel RC car gears where chosen. Each of the gears cost $ 6.99 and $ 8.99 respectively. Buying gears was cheaper then making and hardening the gears in the machine shop.

Shafts:

The shafts for the gearbox where originally designed to fit gears with a 5mm shaft. The only shafts this size where stainless steel. This cost $2.99 for 2 rods approximately 350mm long. The shafts were easy to acquire but hard to manufacture. The metal was much stronger then needed for the project. Due to the issues with production with stainless steel it was decided that 1/8th in round aluminum rod. This replacement material is still stronger then needed. Each small shaft made with aluminum cost around $0.25 cents. This saved at least .$0.25 per shaft in production and time needed.

Electronics:

All electronics used in this project were off the shelf parts. The Arduino was free to the group. The drivers for the motors were 7.99 apiece. Cost and time was cut down by buying prebuilt stepper motor drives online. All other electronic cables and power sources were provided by the team at no cost.

Appendix E: Schedule

The schedule has changed a lot during the production of the parts. Some parts times where lowered due to the fact they could be purchased instead of being produced. This actually resulted in a current lower time on project then expected going into the testing phase. An attempt to calculate time used for building and making of parts helped us figure out how much time should be allotted to the production of parts. The Gantt chart has been updated to show changes in the time requirements

Gearbox:

This part took the longest at approximately about 20 hours of design work. The initial design was flawed from the start. It had issues with tolerances and fitment. There were issues with the ability to access certain parts from the outside and securing the parts on the inside. Due to the use of 3D printing it was easy to reprint one if some design changes where made but it took about an hour to print one. Other design issued included changing the orientation of the rack to take up less space in the gearbox. Some of the time issues were negated by making the design modular so that only certain dimensions had to be changed on parts.

Gearbox lid:

This part was initially a flat part that required little to no adjustment. As the design of the gearbox evolved it required more changes then expected. Due to the changes a complete redesign of the lid happened. In the initial time planning phase it was thought that there was a chance that it might happen so the design/build was given 20 hours to do it. As it goes it is at less time then it was projected to use.

Gears:

Currently on schedule and within the time allotted. Since it was found out very early on that producing the gears could not happen with the current machinery available the decision was made to order them. Since ordering only took limited time there was little time spent on these parts due to non-production of them. No time was lost due to shipping or ordering.

Shaft:

This took less time to find but longer then anticipated production. Due to the fact that the initial shaft was stainless steel it took several minutes to cut and more time to get rid of burr's. This was accounted for due to the fact that we were going to have to produce five shafts but would not have been viable for a production cycle. It was found that we could use 1/8th aluminum rod as a substitute. This cut down the production of a shaft to just under a minute using a hand saw and some sandpaper. This substitute helped keep our time needs down for each part.

Adapter Plate:

This was an unanticipated need for the project. This part only took around 5 hours to design, produce, and install. The time invested in this allowed me to save time not having to completely redesign the gearbox and lid.

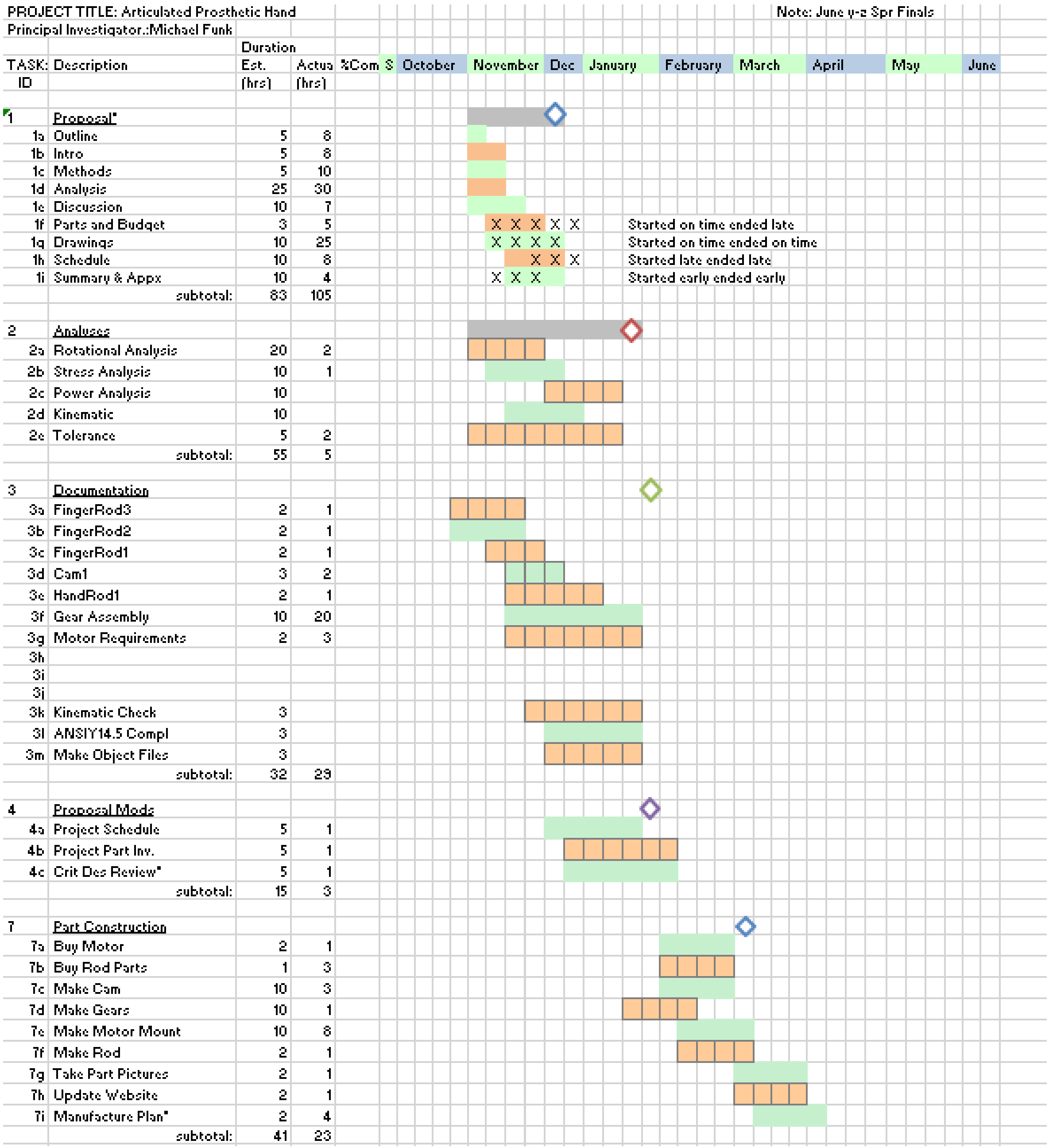
Electronics:

While not initially in the scope of this project this has been used up a lot of time. The electronics used in this project are simple stepper motors and an Arduino. While this should be simple to setup it takes time and parts. Some of the parts where provided by the CWU EET department, some from personal sources, and others were paid for. The cost in time was unexpected due to the time required to build, code, and test. Currently there is no time estimate for this in the Gantt chart.

Stepper Motors:

These parts where known to be only purchasable so time allotted for them was limited. The time used is within the expected parameters even with the need to change out some motors with larger ones. Since we are using uniform style motors the only design changes that need to happen are addressing the length of the motor. Analysis

APENDIX F: Gantt Chart



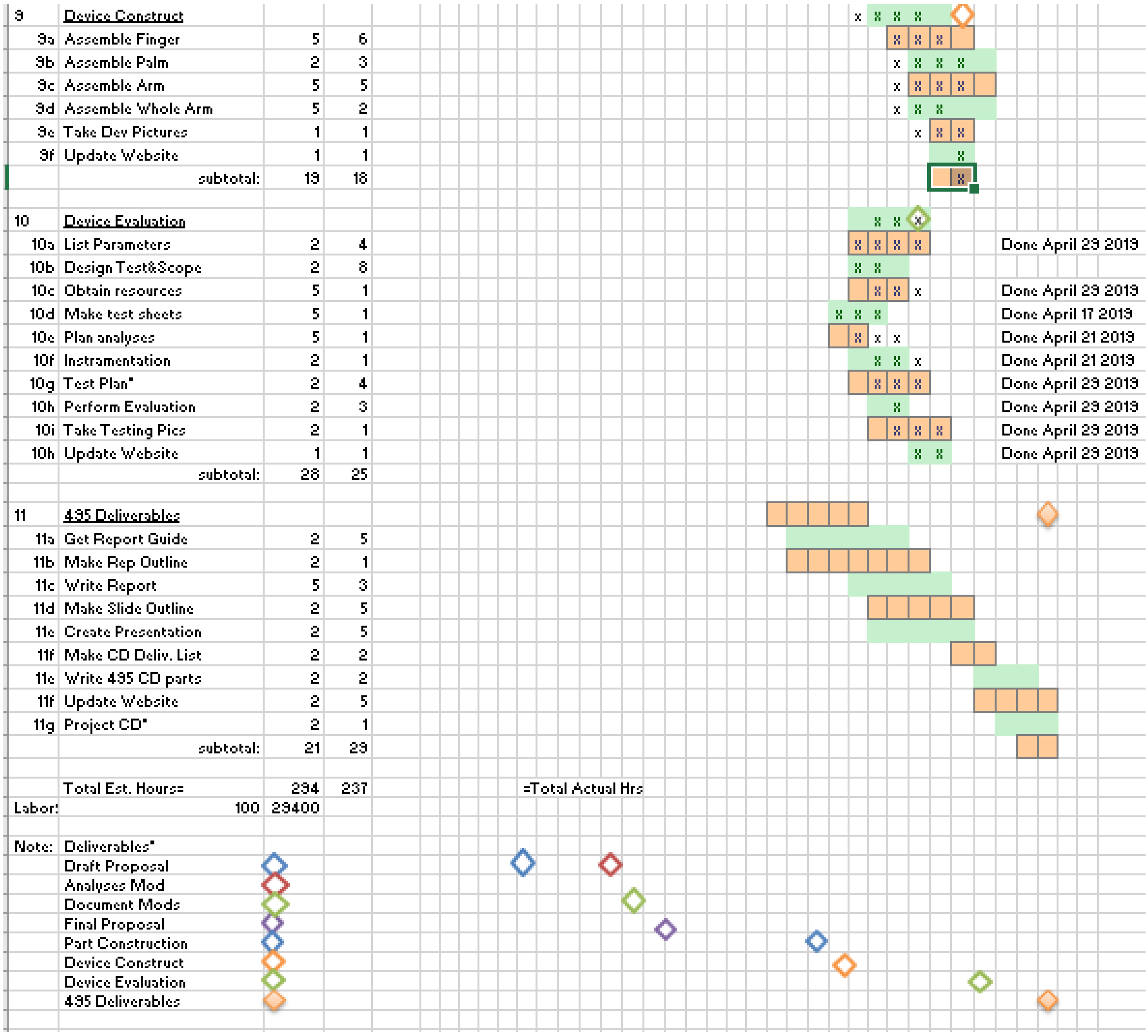
PROJECT TITLE: Articulated Prosthetic Hand

Principal Investigator.:Michael Funk

Note: June y-z Spr Finals

S October November Dec January February March April May June

TASK: ID	Description	Duration Est. (hrs)	Actua (hrs)	%Com	
1	Proposal*				
1a	Outline	5	8		
1b	Intro	5	8		
1c	Methods	5	10		
1d	Analysis	25	30		
1e	Discussion	10	7		
1f	Parts and Budget	3	5		X X X X X Started on time ended late
1g	Drawings	10	25		X X X X Started on time ended on time
1h	Schedule	10	8		X X X Started late ended late
1i	Summary & Appx	10	4		X X X Started early ended early
	subtotal:	83	105		
2	Analyses				
2a	Rotational Analysis	20	2		
2b	Stress Analysis	10	1		
2c	Power Analysis	10			
2d	Kinematic	10			
2e	Tolerance	5	2		
	subtotal:	55	5		
3	Documentation				
3a	FingerRod3	2	1		
3b	FingerRod2	2	1		
3c	FingerRod1	2	1		
3d	Cam1	3	2		
3e	HandRod1	2	1		
3f	Gear Assembly	10	20		
3g	Motor Requirements	2	3		
3h					
3i					
3j					
3k	Kinematic Check	3			
3l	ANSIY14.5 Compl	3			
3m	Make Object Files	3			
	subtotal:	32	29		
4	Proposal Mods				
4a	Project Schedule	5	1		
4b	Project Part Inv.	5	1		
4c	Crit Des Review*	5	1		
	subtotal:	15	3		
7	Part Construction				
7a	Buy Motor	2	1		
7b	Buy Rod Parts	1	3		
7c	Make Cam	10	3		
7d	Make Gears	10	1		
7e	Make Motor Mount	10	8		
7f	Make Rod	2	1		
7g	Take Part Pictures	2	1		
7h	Update Website	2	1		
7i	Manufacture Plan*	2	4		
	subtotal:	41	23		



9	Device Construct			
9a	Assemble Finger	5	6	
9b	Assemble Palm	2	3	
9c	Assemble Arm	5	5	
9d	Assemble Whole Arm	5	2	
9e	Take Dev Pictures	1	1	
9f	Update Website	1	1	
	subtotal:	19	18	
10	Device Evaluation			
10a	List Parameters	2	4	Done April 29 2019
10b	Design Test&Scope	2	8	
10c	Obtain resources	5	1	Done April 29 2019
10d	Make test sheets	5	1	Done April 17 2019
10e	Plan analyses	5	1	Done April 21 2019
10f	Instrumentation	2	1	Done April 21 2019
10g	Test Plan*	2	4	Done April 29 2019
10h	Perform Evaluation	2	3	Done April 29 2019
10i	Take Testing Pics	2	1	Done April 29 2019
10h	Update Website	1	1	Done April 29 2019
	subtotal:	28	25	
11	495 Deliverables			
11a	Get Report Guide	2	5	
11b	Make Rep Outline	2	1	
11c	Write Report	5	3	
11d	Make Slide Outline	2	5	
11e	Create Presentation	2	5	
11f	Make CD Deliv. List	2	2	
11e	Write 495 CD parts	2	2	
11f	Update Website	2	5	
11g	Project CD*	2	1	
	subtotal:	21	29	
	Total Est. Hours=	234	237	=Total Actual Hrs
Labor!	100	23400		

Note: Deliverables*
- Draft Proposal ◇
- Analyses Mod ◇
- Document Mods ◇
- Final Proposal ◇
- Part Construction ◇
- Device Construct ◇
- Device Evaluation ◇
- 495 Deliverables ◇

Appendix G: Evaluation Sheet (Testing)

The articulated hand project						
Data						
	Cycle					Avg
Test 1	1	2	3	4	5	
5min						
30min						
60 min						
Test 2	1	2	3	4	5	
5min						
30min						
60 min						
Test 3	1	2	3	4	5	
5min						
30min						
60 min						

Appendix H: Testing Data

Appendix I: Testing Report

Testing Method: (Introduction)

The articulated hand project has many moving parts. This hand must move in a consistent manor. This test is for functionality of the hand. The test are designed to test if the hand moves and if it functions consistently. The test will be simple use of the gear box unattached to the hand. The functionality of the gearbox is paramount to the movement of the other parts. The gearbox should function in a repeatable nature. This is a simple function test over time. Many of the parts are produced through 3D printing and need to be tested without loading to prove functionality.

The testing of this object is simple and functional. The first test will be that of the motor and gearbox. This will be done to see if there is any challenges or issues caused by the 3D printing. The second will be the nominal loading test. This is just the motor/gearbox assembly attached to the hand and running. Since this might cause something to break this will be done in a open room and clamped to the table. The third test is to run the motor under a given load. Each of these tests will complete a cycle.

Method/Approach:

The testing of this device will be divided into three parts. Each of theses sections are designed to test the capabilities of the product that has been developed. The gearbox is essential to the movement of the hand. The gearbox provides the amount of torque that is needed to move and hold position. Since this is a self-produced gearbox it needs to be tested. The first test is that it can function for a set amount of time and not break. The second test will be to have the motor articulate the fingers for a set amount of time. The last will be ability of the gearbox to handle a load consistently.

The first test of the gearbox is it running under no load for a period of one hour. This should show that the gearbox design can function without any sort of interference or binding. The testing will be conducted by strapping down the motor to a table with it attached to the Arduino Uno running on a constant cycle. The cycle is currently around 4 seconds this will allow the hand to move the fingers at the 3.2 ft/s that was initially calculated as max speed for closing. With it unloaded the gearbox can be tested for general wear on parts. Since the box is specked to handle 10^6 rotations before breaking it should be able to easily handle the time period used at that speed. This should put the gearbox approximately 900 cycles. Since a hand would not full cycle 900 times in an hour normally. This will be filmed to see if there are any changes in movement over time.

The second part of the test is to run the gearbox attached to the hand and articulate the movement. This will be held down to the table with a clamp, so it won't flex off of the table. This will be conducted by attaching the motor to the hand like originally intended and running the motor for the same amount of time as the gearbox run. There should be limited amount of change in functionality or speed. The gearbox should not have any failures but may show some wear. The box should show little wear and function properly.

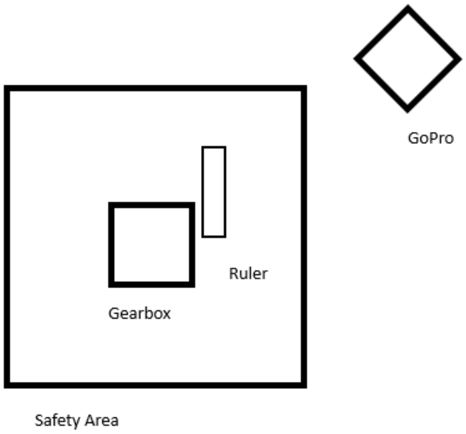
The third test is the same as the second but under load. The hand and motor will hold the same positions. The hand will be clamped to the table. A load of one pound will be placed on the hand or hang from the hand. This will load the hand allowing the testing of movement under load. There should be no issues with the hand pulling a one-pound load. The gearbox is designed to hand a load of 10 pounds regularly.

Test Procedures:

This is a simple procedure is a simple one that test how much repeatability and survivability the gearbox has. The parts are printed and must be stress tested. The box needs to function reliably. The testing of the gearbox will be accomplished by running it through many cycles over time. The gearbox will be closed so that it can replicate normal conditions. The Gearbox will be assembled with the motors that will drive the gears and the linier rack. The parts should be preassembled before the testing.

The place designated for testing is the senior project room. This test requires limited room to test but does require a constant power source to run both the motors and the Arduino. The box is designed to not shoot the rack out so there is a limited amount of space needed around the actual box. This test only requires a ruler and a GoPro. The duration will be a 1 hour run time. The required actions for this testing are:

- Power the Arduino up
- Power the motors
- Place ruler under rack
- Setup the Go Pro
- Start Go Pro
- Set timer
- Start motor cycles
- Stop motor after end of time



Any risk is from the rack coming lose in the testing process, the gears losing contact with each other, or the gearbox losing integrity. This can be mitigated by having a 1 foot box around the gearbox allowing and parts that break to fall in that area. This will allow for safety and stop anything else from happening.

This will be a simple test will help with further design changes and to understand the limitations of the produced item. The data will also help to tell how much longevity the gearbox will have.

Deliverables:

The data that was gathered will help change the design of the gearbox. The data shows that there are some changes that might need to be changed. The data will help the group to change the design of the hand to make it a better product. The prosthetic hand must preform the functions that its designed for. The data gathered is being used to help develop changes that are needed to make the hand have consistent functionality and movement. The hand has had several changes influenced by the data gathered in the testing phase. The hand has proved to be resilient under testing. The data shows that there are several ways to change the design to help production and movement.

When the motor was attached to the testing table and ran data was collected. The data shows that over time the motor does lose power due to heating up. The data shows that over time the motor slows down by .01 seconds. The data also shows that the power produced by the gearbox isn’t diminished by the power creep due to the produced heat. The data shows that the gearbox part of the articulation function as predicted. Due to the data collected some changes have been made to the gearbox to allow for better performance due to some binding issues. The initial data shows that the gearbox loses no speed or performance while unloaded. The gearbox has limited changes during the preloaded cycles. The hand has some speed changes during the weight lifting challenge.

The hand preformed within expectations when lifting/gripping a weight. There are some changes to the design that have been altered in the updated design. The initial design didn’t have enough clearance to deal with the shrink involved in 3D printing. After the initial testing the gearbox was adjusted in size to adapt to the shrink and give proper sizing. The revised gearbox performed much better in performance testing and had little need for modification.

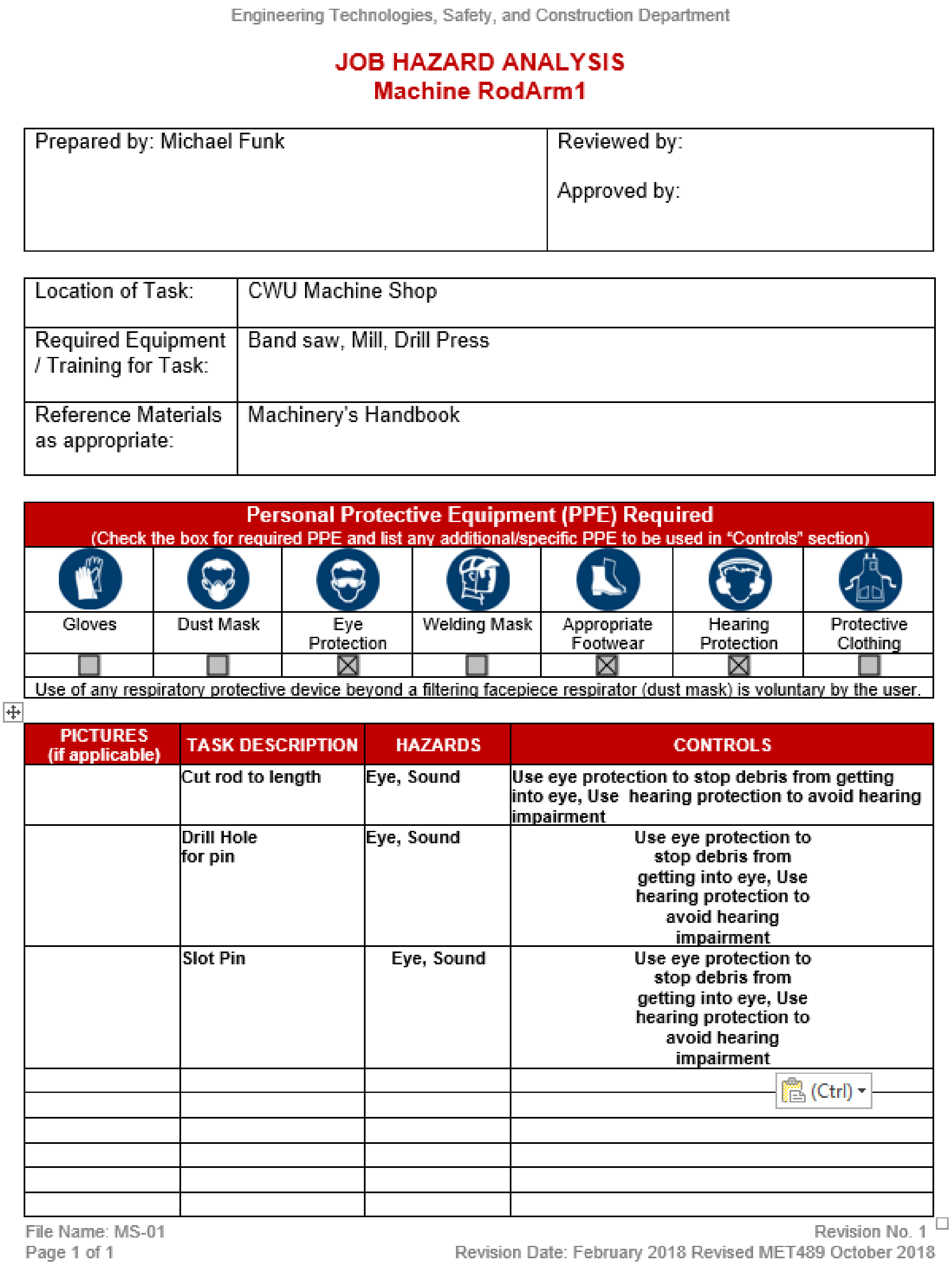
The test with the weight is the most promising for the three tests conducted. This was a 5-pound weight used to test if the gearbox and motor combination would work. This showed that there is enough power to lift the weight and hold it with the current stepper motor configuration. The data shows that there were limited changes in speed due to loading. The changes in the movement speed was around 2%. The video also shows that the hollow body construction of the hand flexes too much to handle much more than the designated value. The holding power shows that there is probable that more weight could be lifted in further testing. The gearbox showed resilience under load and limited degradation of parts.

During testing there where some problems that need to be resolved. Currently due to the testing it was noted that the current attachment to the gearbox does not effectively transfer the pull to the fingers. The pull of the string is at an angle and has caused binding or inefficiency in the pulling motion. The simple solution is to make a bar to spread the loading out to the individual finger lines. The other option is to make a solid connection to the finger lines so that there is limited loss of power due to the string stretching over time.

Over all the test was a success and showed several problems that are simple to fix. The data will also help to make changes that will make the prosthetic hand a much better product. The data is also helping to design much better parts for the hands. The data tells me that there is little change under minor loads. There is still some testing at heavier weights that still needs to be done and all the previous testing is affecting design changes.

APENDIX J: Safety Data Sheet

Safety Data sheet for Arm Rod 1



Engineering Technologies, Safety, and Construction Department

JOB HAZARD ANALYSIS
Machine RodArm1

Prepared by: Michael Funk	Reviewed by: Approved by:

Location of Task:	CWU Machine Shop
Required Equipment / Training for Task:	Band saw, Mill, Drill Press
Reference Materials as appropriate:	Machinery's Handbook

Personal Protective Equipment (PPE) Required
(Check the box for required PPE and list any additional/specific PPE to be used in "Controls" section)

Gloves	Dust Mask	Eye Protection	Welding Mask	Appropriate Footwear	Hearing Protection	Protective Clothing
☐	☐	☒	☐	☒	☒	☐

Use of any respiratory protective device beyond a filtering facepiece respirator (dust mask) is voluntary by the user.

PICTURES (if applicable)	TASK DESCRIPTION	HAZARDS	CONTROLS
	Cut rod to length	Eye, Sound	Use eye protection to stop debris from getting into eye, Use hearing protection to avoid hearing impairment
	Drill Hole for pin	Eye, Sound	Use eye protection to stop debris from getting into eye, Use hearing protection to avoid hearing impairment
	Slot Pin	Eye, Sound	Use eye protection to stop debris from getting into eye, Use hearing protection to avoid hearing impairment

File Name: MS-01
Page 1 of 1

Revision No. 1
Revision Date: February 2018 Revised MET489 October 2018