FINAL DESIGN PROJECT: ACTUATED HAND

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ENGR3330 Mechanical Design Olin College of Engineering Dec. 12, 2018

Grade:	________\ 100
Exec Summary:	_________\2
Preliminary Design:	_________\10
FBDs:	_________\10
CAD Models:	_________\20
FEA/FOS:	_________\10
Optimize Parts:	_________\15
Manufacture DWGs:	_________\20
Assembly DWGS:	_________\10
BOM:	_________\3

Executive Summary:

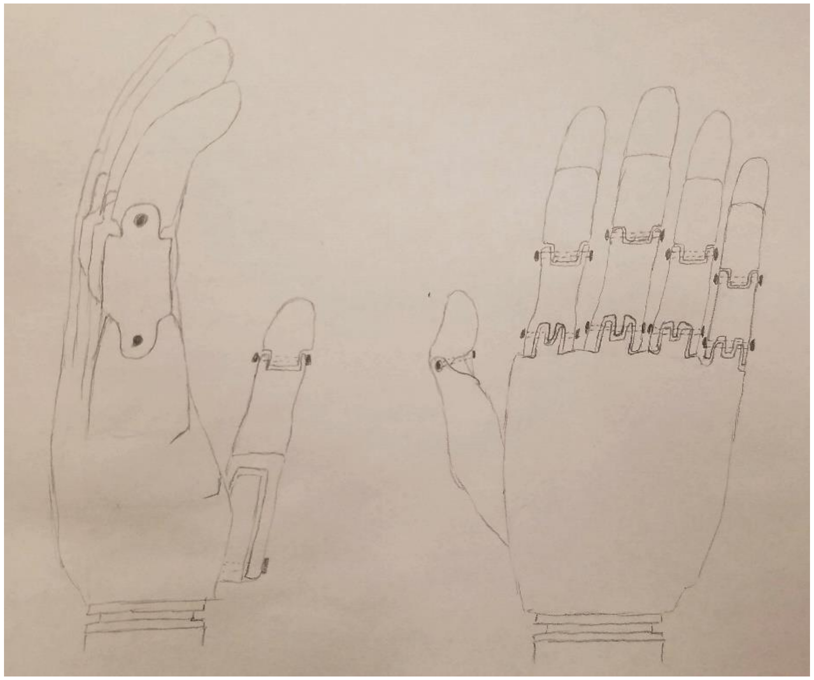
For the final Mechanical Design project I chose to create a mechanically actuated hand. This design was inspired by the Bebionic prosthetic hand created by Ottobock. It has four fingers and one thumb, each individually actuated with two joints on each of the fingers and one on the thumb. It's designed with both function and aesthetics in mind so that it would have a wide range of capabilities as well as have a cohesive and sleek design. A large amount of time on this project went into making sure part and motion geometries were both accurate and appealing.

Because of the small scale and complex geometry, many of the pieces are 3D-printed and this allows for more complex designs such as the pin-slot mechanism and internal wire routing channels in the palm pieces. This also means that many parts were designed to be made out of ABS plastic material. Generally this isn't a very strong material choice as compared to many metals or carbon fibers, so future iterations should consider other manufacturing methods or more advanced metal or carbon-infused 3D-printers.

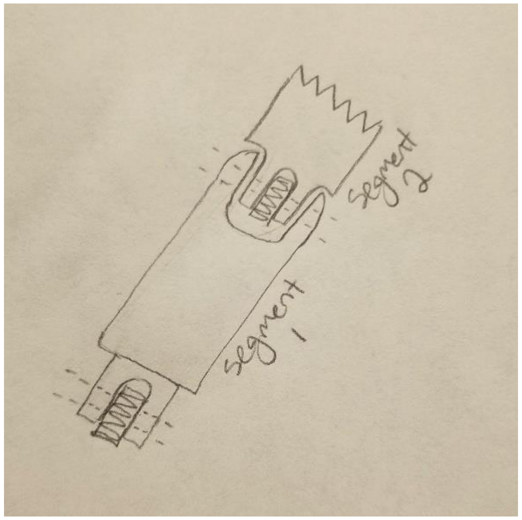
Future versions should consider improving work on more discrete integration of mechanical components. Additionally, attachment methods could be designed and incorporated to allow the hand to connect to a larger prosthetic system.

Preliminary Design Sketch and Product Description:

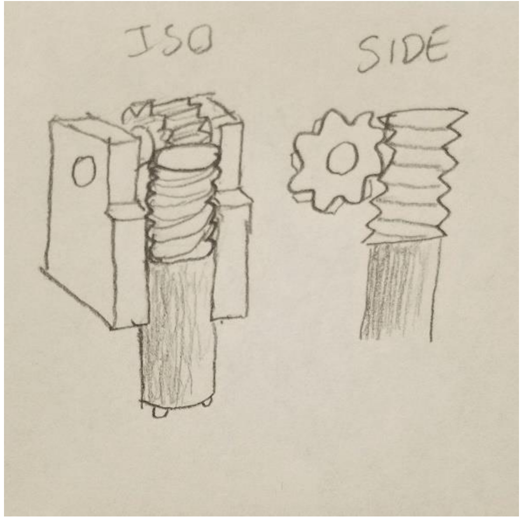
This design is a mechanical hand with individually actuated fingers. Overall, system is designed to be easily manufactured and assembled. The hand is made of two palm pieces that sandwich together, four double-jointed fingers attached to the top part of the palm, and one single-jointed thumb that attaches to the side.



The fingers consist of two pieces that fit into each other and are fixed around a worm gear wheel. The second segment is the outermost part of the finger. This part is fixed to a gear through tight press fit and fits around an axle that runs through both segments. The first segment houses a motor and worm gear that connects to the second segment. It also includes a joint fixed to a worm gear wheel at the lower end, where it connects to the base piece on the hand.

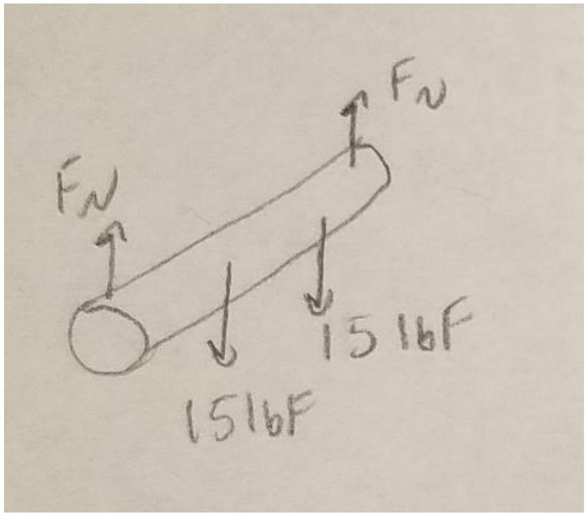


This joint is fixed to the palm and also houses a motor and worm gear. Five of these base pieces connect to the palm and allow the fingers to rotate. The worm gears and motor are small plastic gears as might be used in a small toy. The worm gear wheel is sintered in order to withstand higher forces.

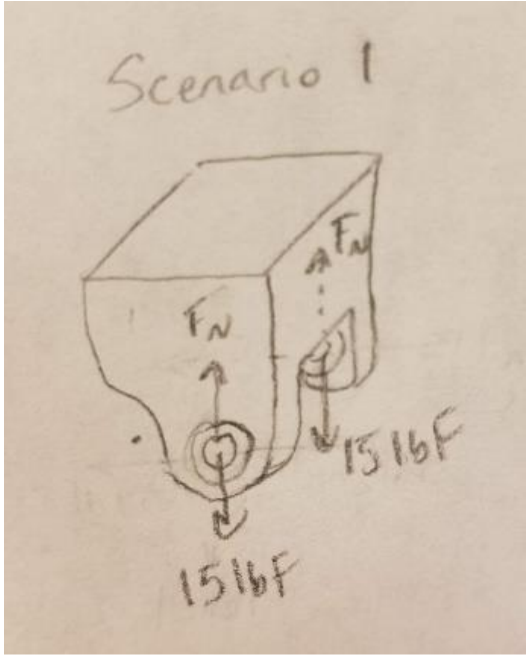


Free Body Diagrams of all Critical Parts:

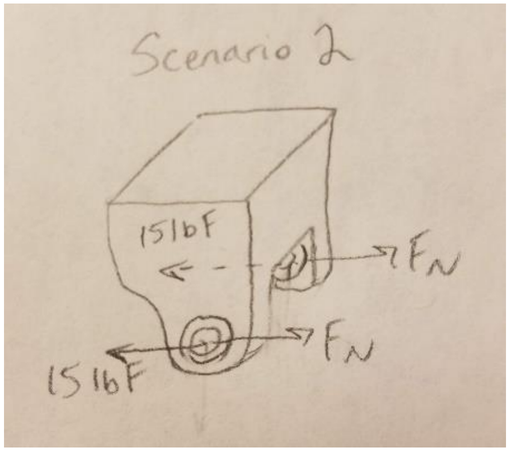
The main parts of concern in this model are the base piece, the axle, and the gears. These were looked at from the case of three main scenarios that could happen to the hand: **(1) the hand is oriented with the fingers down and curled such as when it is trying to life a heavy bag, (2) the hand is oriented fingers down and curled and hits an object such as dropping down onto a surface, and (3) the hand is oriented with the fingers down and straight such as when a finger hits an object while extended (see FEA section for model image representation).** Each of these load cases were tested for an expected 30 lbF or when distributed, 15 lbF on either side. The 30lb or 15lb weights are approximate estimates based on either a case where a weight of 60 pounds is evenly distributed across the four fingers or 30 lbF hits an object such as a hard surface. The general case for the axle distributes the 30 lb weight on either side and experiences 15 lbF offset from the center. This is counteracted by the normal force on either end where the axle contacts the base piece.



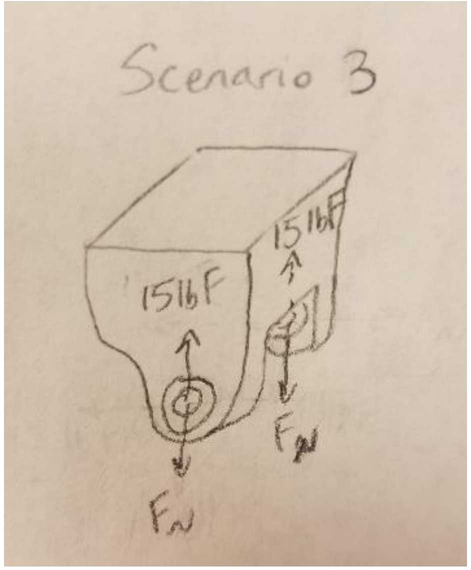
In scenario one a downwards force of 30 lbs is exerted on the finger and therefore the base piece as well. The forces are measured at the surface where the axles contact the base piece. This is counteracted with normal forces in the opposite directions.

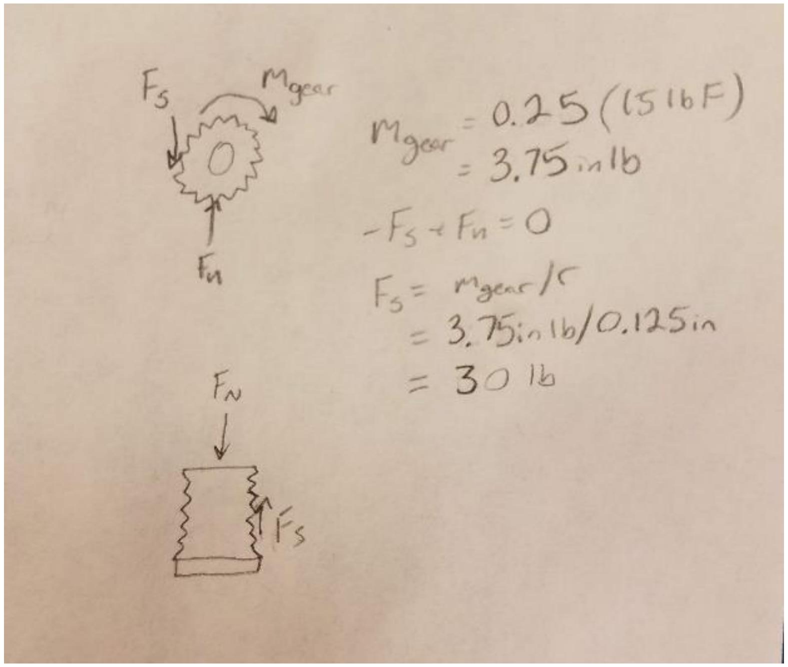


The same goes for scenario two where the finger is hit straight-on and the base piece receives a force in the leftwards direction as shown in this orientation.



Scenario three receives a force similar but opposite to scenario one as the force is now exerted up on the backside of the finger.





The interaction between the gears at the base point takes these forces into account by means of an exerted moment on the worm gear wheel. This is measured considering a 15 lbF applied (as when lifting a 60 lb object across four fingers) at a quarter inch distance from the pivot. This can allow for calculations of the applied force on the teeth of the worm gear wheel and the worm gear. Usually the worm gear has a more complex formula due to its angled teeth, but this custom worm gear has an angle of only 5 degrees so the closest approximation is used along with the large over-estimations for weight to allow for physical-error as compared to calculations. It was calculated that the force applied to the tooth face would be 30 lbF.

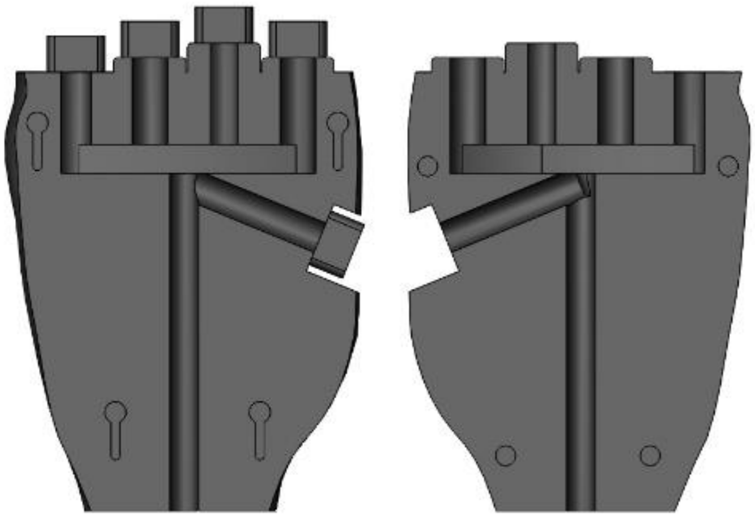
CAD Models (annotated summary of major parts):

The actuated hand includes four finger subassemblies and a thumb subassembly (each with a base connection), in addition to a two-piece palm that includes tunnels for wire routing as well as connection pins.

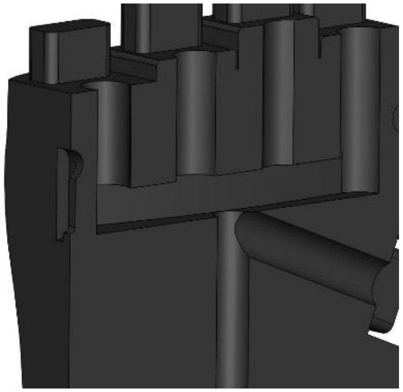
The base design consists of a small piece with a bottom pocket that allows it to fit snugly onto each of the palm connection extrusions and remain fixed in place with two small bolts. A motor and worm gear are press fit into the palm and held by the base piece such that the worm gear and worm gear wheel mesh. The worm gear wheel is freely spinning on the axle and is held in place with its extrusions on either side along with two small retaining rings on the axle itself. The axle is rotating freely inside the press fit journal bearings.

This piece then connects to the first finger joint through an interference fit with the first segment and the worm gear wheel, achieved by heating the 3D-printed plastic when assembling. The finger segment houses the motor and worm gear internally, again with a heated interference fit, and includes pass thrus for the motor wires. This segment connects to the second segment in a similar fashion. The second segment has a fixed angled geometry in order to allow for fine motor control without over powering or over constraining the fingers.

The palm assembly itself consists of two pieces of 3D-printed form that come together to allow for easy assembly. The form was carefully designed to mimic that of a real hand and give the visual appearance of texture and muscle. The inside shows the channels provided for routing the wires down and out the base of the hand.



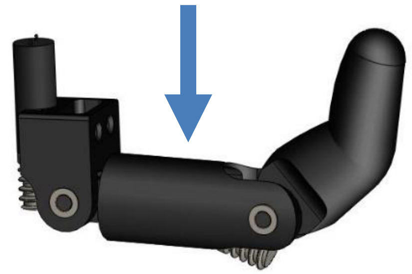
Additionally, the two pieces come together and slide to lock into place with a pin and lock mechanism (one side shown below in a cross-sectional view on the left side of the part).



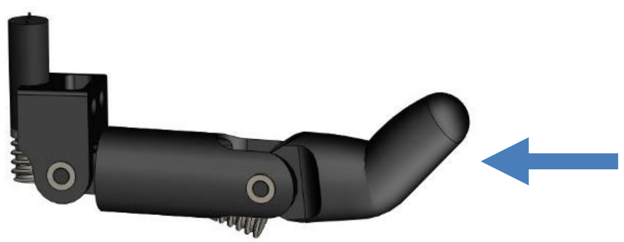
FEA/Factor of Safety Analysis of all Critical Parts:

As discussed in the FBD section, the elements were analyzed according to three main scenarios:

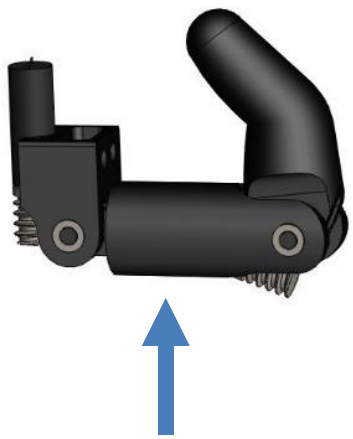
Scenario 1 in which the finger is bent and receives a force from the top (such as when lifting an object).



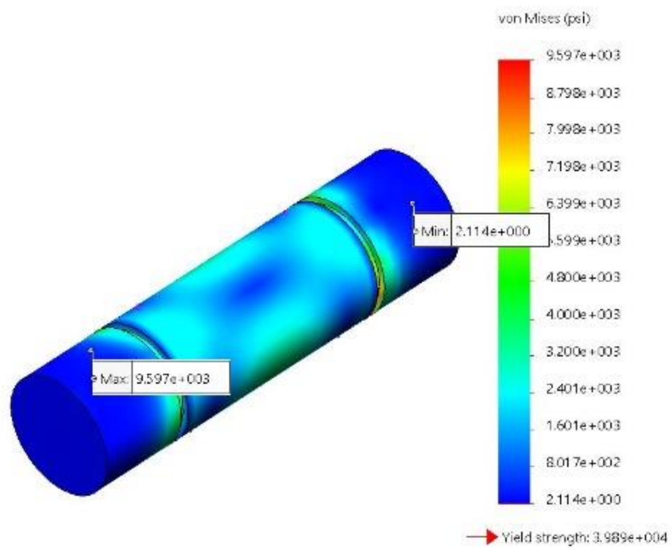
Scenario 2 in which the finger is straight and receives a force head-on (such as in an object collision).



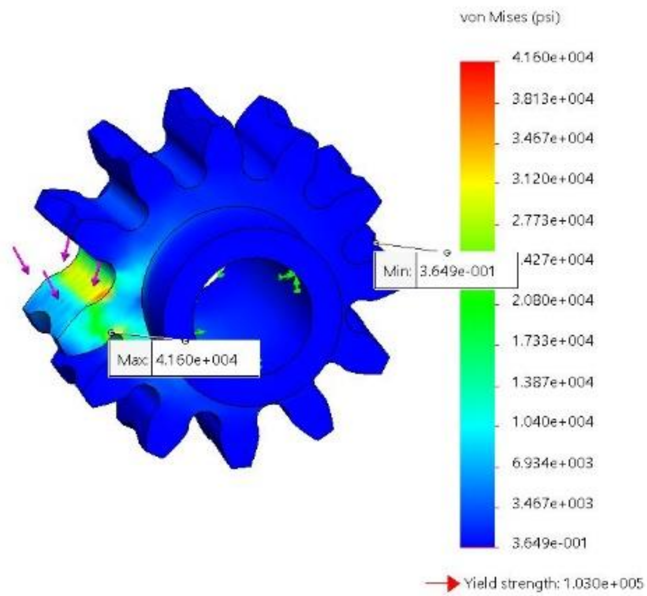
Scenario 3 in which the finger in bent and received a force from the bottom (such as in a surface collision).



First we look at the performance of the central axle under these loads. The axle can be taken as a general case where two forces are applied offset from the center in a linear direction. Taking two 15 lb forces, this axle has minimal stress and maintains a factor of safety of 4.2.

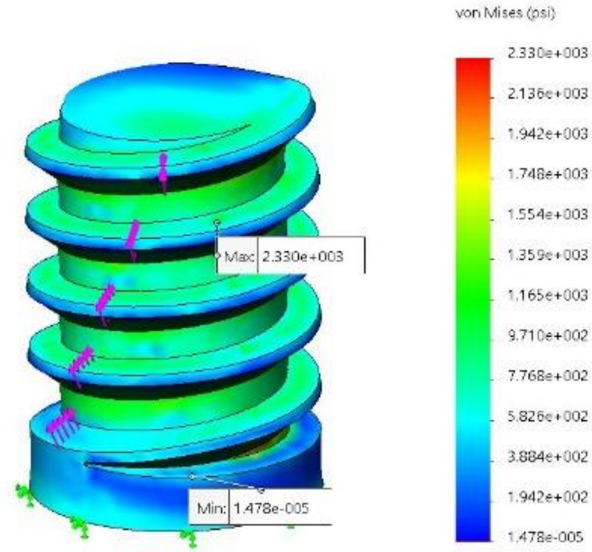


Next we look at the worm gear wheel for this general case where the pressure on an individual tooth was previously calculated in the FBD section. This gear, on first pass, had a factor of safety of 2.5, so the redesign and new FOS will be discussed in the optimization section.

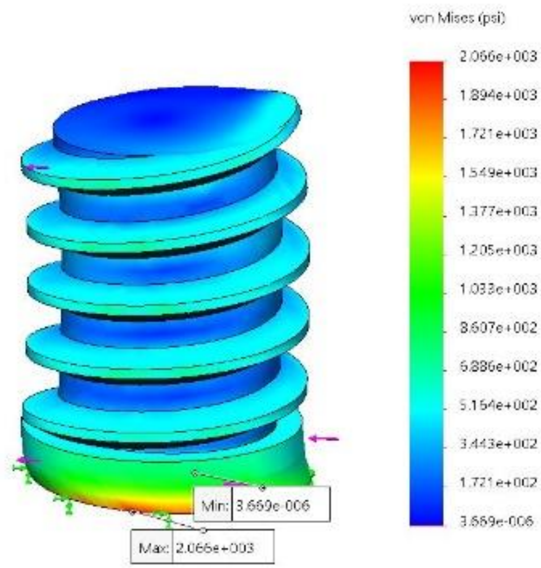


The worm gear itself is analyzed for each of the scenarios. In scenario 1, it receives the calculated force in an upwards direction. This still maintains a FOS of 3.2. Note: Both the worm gear and base piece are base of ABS plastic, which was found to have a Yield Strength of approximately 7400 psi (Source:

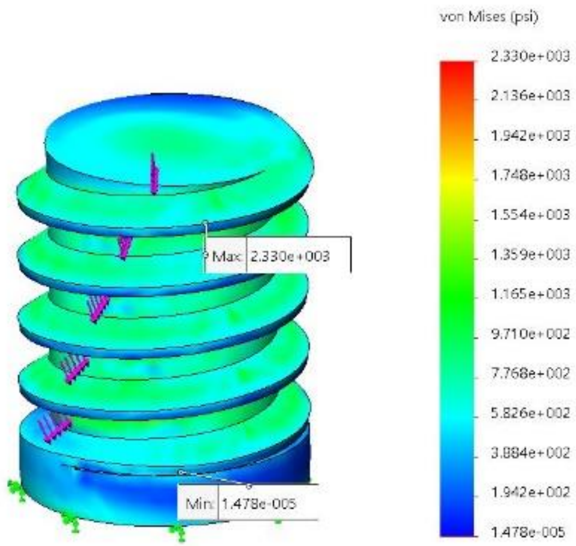
http://www.dielectriccorp.com/downloads/thermoplastics/abs.pdf).



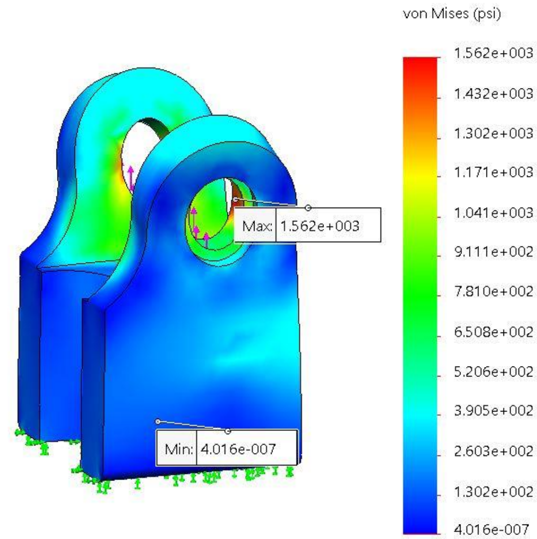
In scenario 2, the worm gear receives a linear horizontal force, providing a FOS of 3.6.



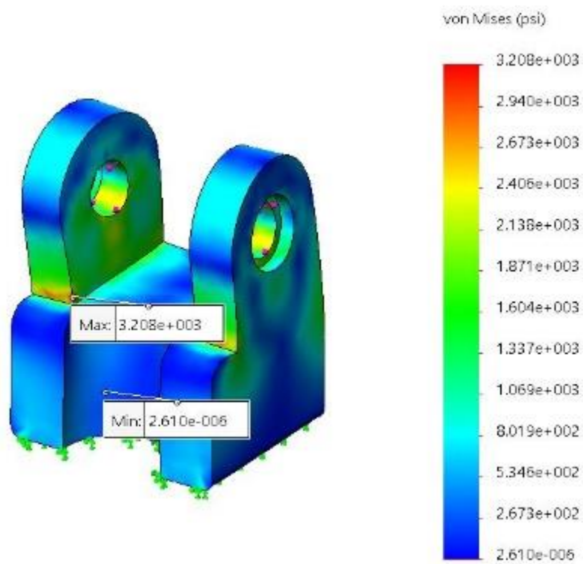
In scenario 3, the worm gear again received a force on the tooth face, this time in a downwards direction, providing a FOS again of 3.2.



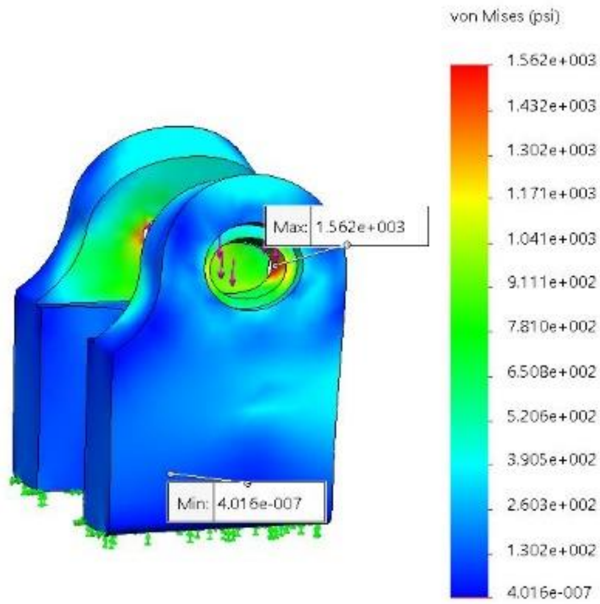
The base piece shown here is receiving a downwards force of 15 lbs on either face of the axle hole. This provides a FOS of 4.7. Note: This is the FEA of the piece post-optimization that will be discussed in the optimization section.



The base piece here is pre-optimization, and receives a linear force that creates a FOS of 2.3. The part was then optimized to increase this, as discussed in optimization.

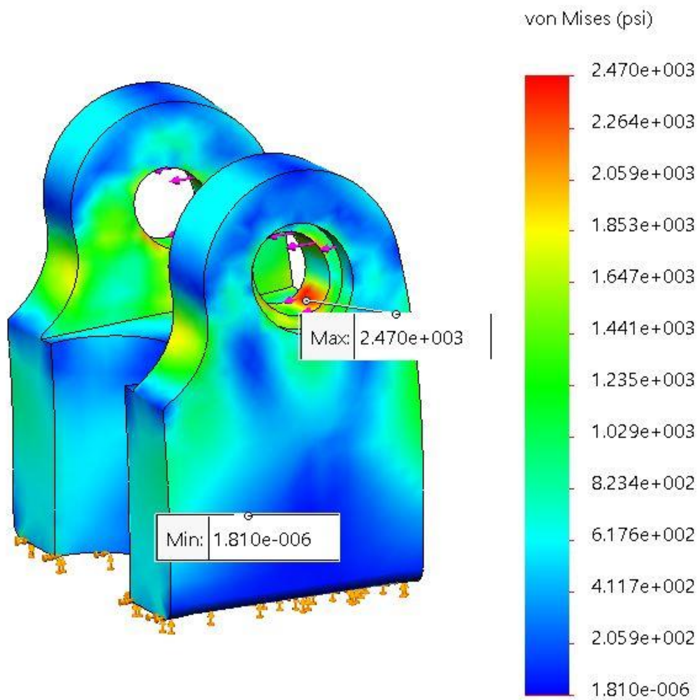


The final configuration of the post-optimized base piece receives a downwards force and provides an FOS of 4.7.



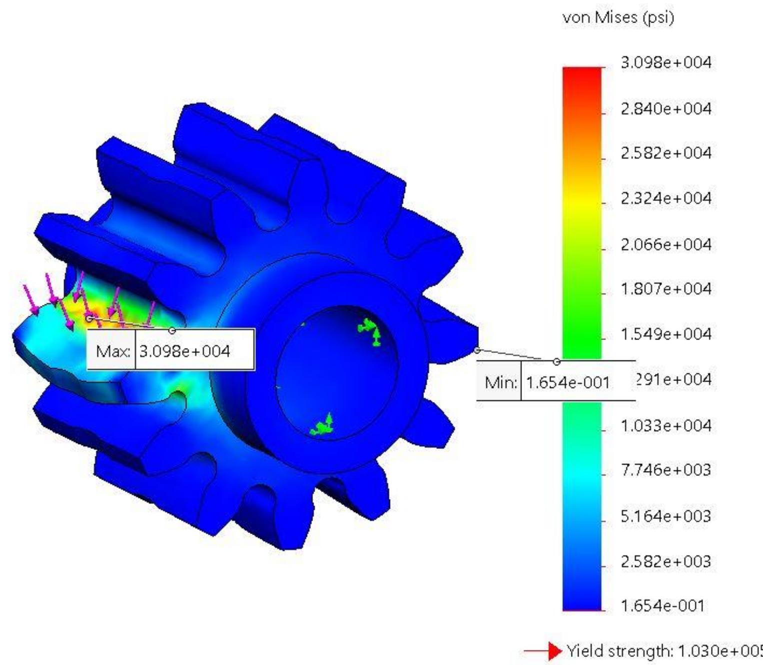
Optimization of Key Critical Parts:

Two of the heavily loaded parts were unable to meet the minimum factor of safety of 3.0 in initial FEA testing. The base piece was then modified by adding more material between the top flat surface ant the bottom of the hole as well as a large fillet to support the hole under linear face forces. This provided a new factor of safety of 3.0, which is sufficient considering the loads are overestimated.



The gear was easily modified because of its custom geometry to allow for a larger area to apply the force on, lowering the force on any one point. This provided a new factor of safety of 3.3.

1



Manufacturing Detailed Drawings:

As follows are the manufacturing drawings for major, non-COTS parts.

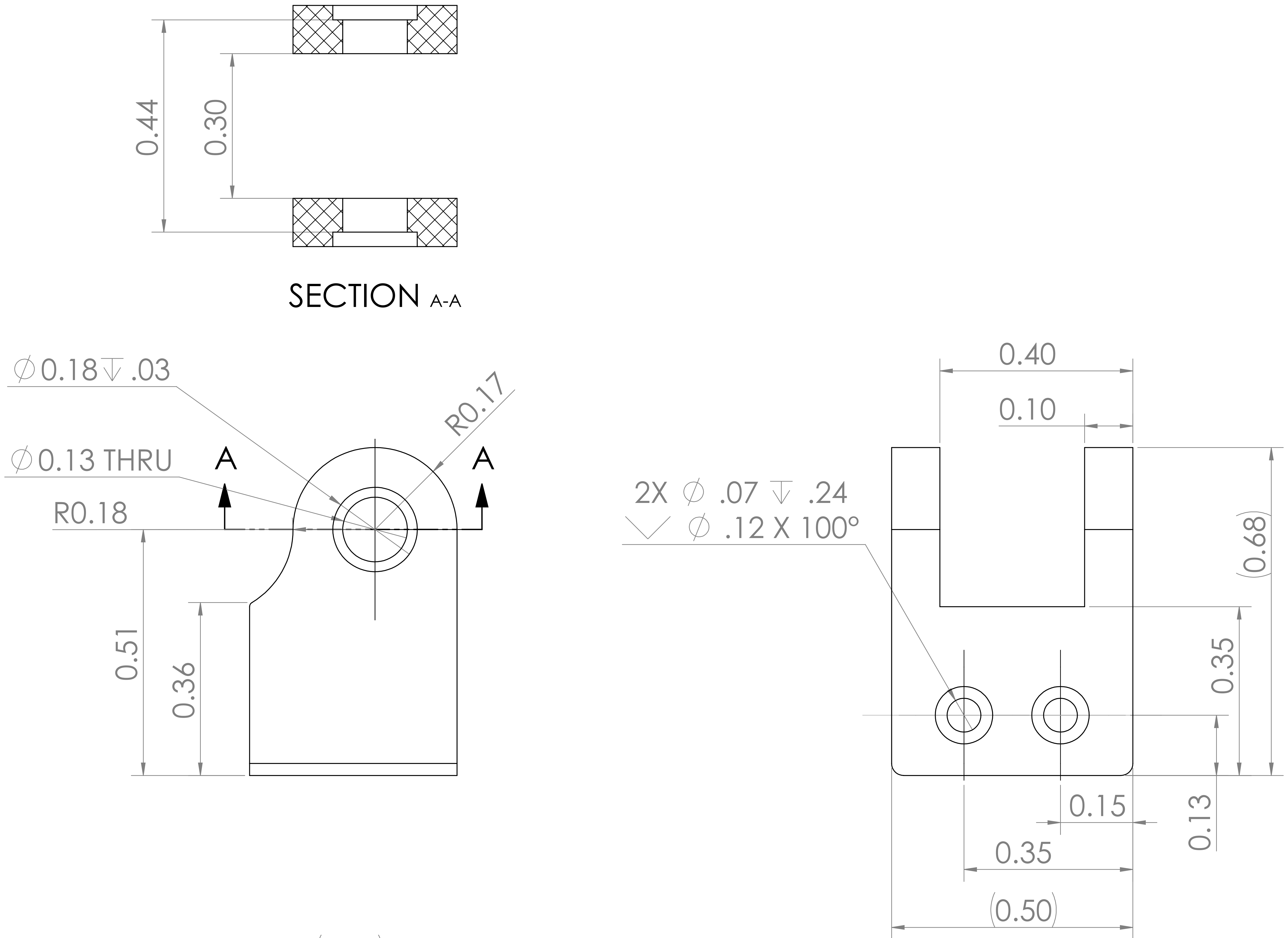
Complete Assembly Drawings:

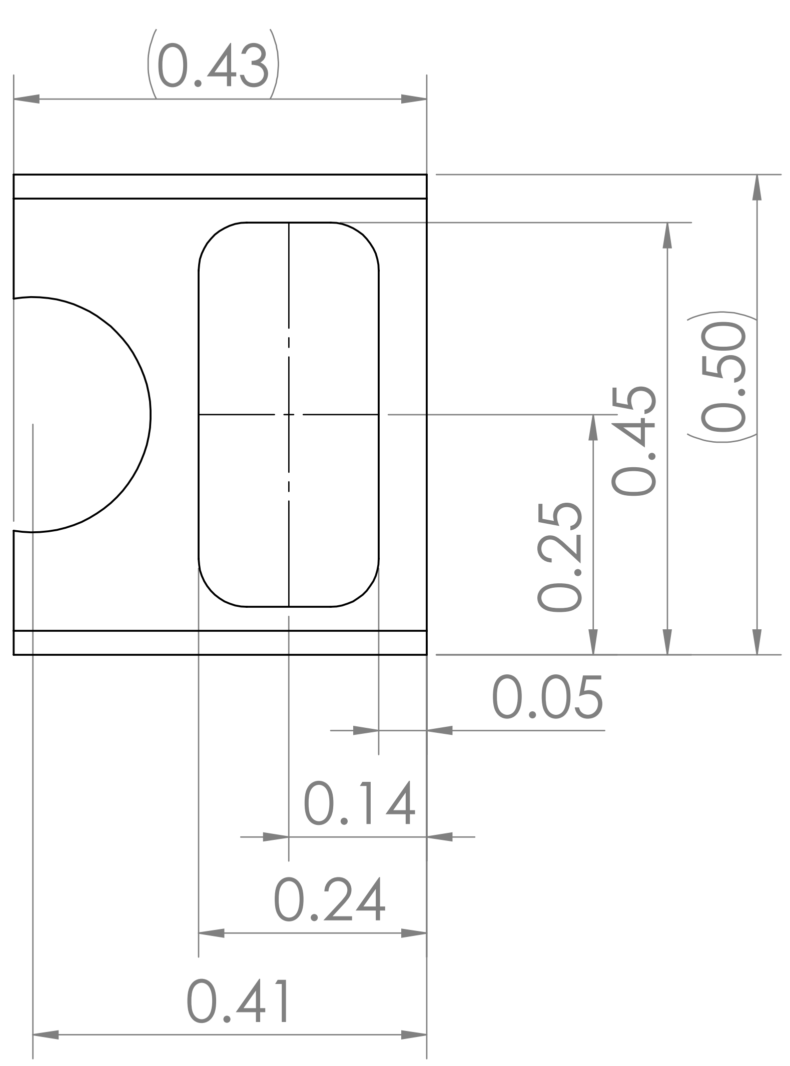
As follows are the subassembly and assembly drawings for this project.

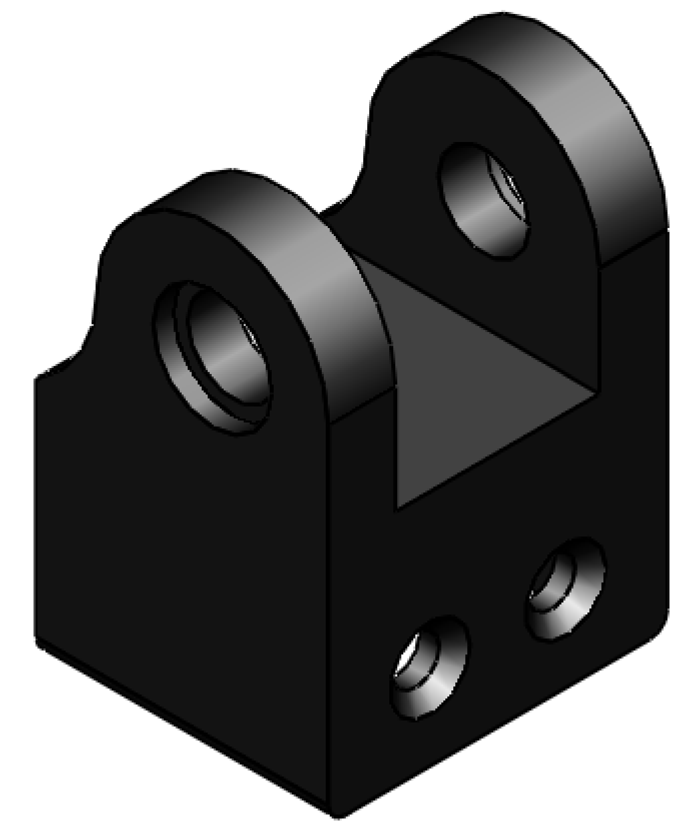
Bill of Materials:

As follows is the Bill of Materials for the main assembly. Many parts are 3D-printed due to complex geometry and scale.

Item	Part Name	Description	Quantity	Source	Price Per ($)	Total Price ($)	P/N	Link
1	finger_seg2	Thumb segment	1	3D Printing	N/A	N/A	N/A	
2	finger_base1	Base connection	5	3D Printing	N/A	N/A	N/A	
3	mainAxle	Axle	9	Stock	N/A	N/A	N/A	
4	wormGearCustom	Worm wheel	9	3D Printing	N/A	N/A	N/A	
5	wormGear	Worm gear, pack of 100	9	Amazon.com	2.5	2.5	N/A	https://www.amazon.com/50pcs-6x8mm-Aperture-Plastic-Accessories/dp/B01MA0UFBO/ref=sr_1_25?s=industrial&ie=UTF8&qid=1543259833&sr=1-25&refinements=p_n_feature_seven_browse-bin%3A5485604011
6	smallMotor	Toy motor 6mm, pack of 5	9	Alibab.com	1	2	TGPP06-C	https://www.alibaba.com/product-detail/6mm-micro-planetary-gear-motor-for_60223004425.html?spm=a2700.details.maylikever.15.1c09cad4DoGhXf
7	sleeveBearing	Sleeve bearing	18	McMaster	12.21	219.78	6338k324	https://www.mcmaster.com/6338k324
8	finger_segment1	Finger joint	4	3D Printing	N/A	N/A	N/A	
9	finger_segment2	Finger segment	4	3D Printing	N/A	N/A	N/A	
10	SCHCSCREW...	#0 SHCS 0.06-80, pack of 25	10	McMaster	8.88	88.8	91253a031	https://www.mcmaster.com/91253a031
11	palm_front	Front palm	1	3D Printing	N/A	N/A	N/A	
12	palm_back	Back palm	1	3D Printing	N/A	N/A	N/A	
Total Purchase: 313.08								







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DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.03 THREE PLACE DECIMAL ±.01	DRAWN	C.SEGAR 12/10/18
	CHECKED	
	ENG APPR.	
	MFG APPR.	
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.	
MATERIAL ABS	COMMENTS:	
FINISH		
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NEXT ASSY	USED ON
APPLICATION	

TITLE:

finger_base

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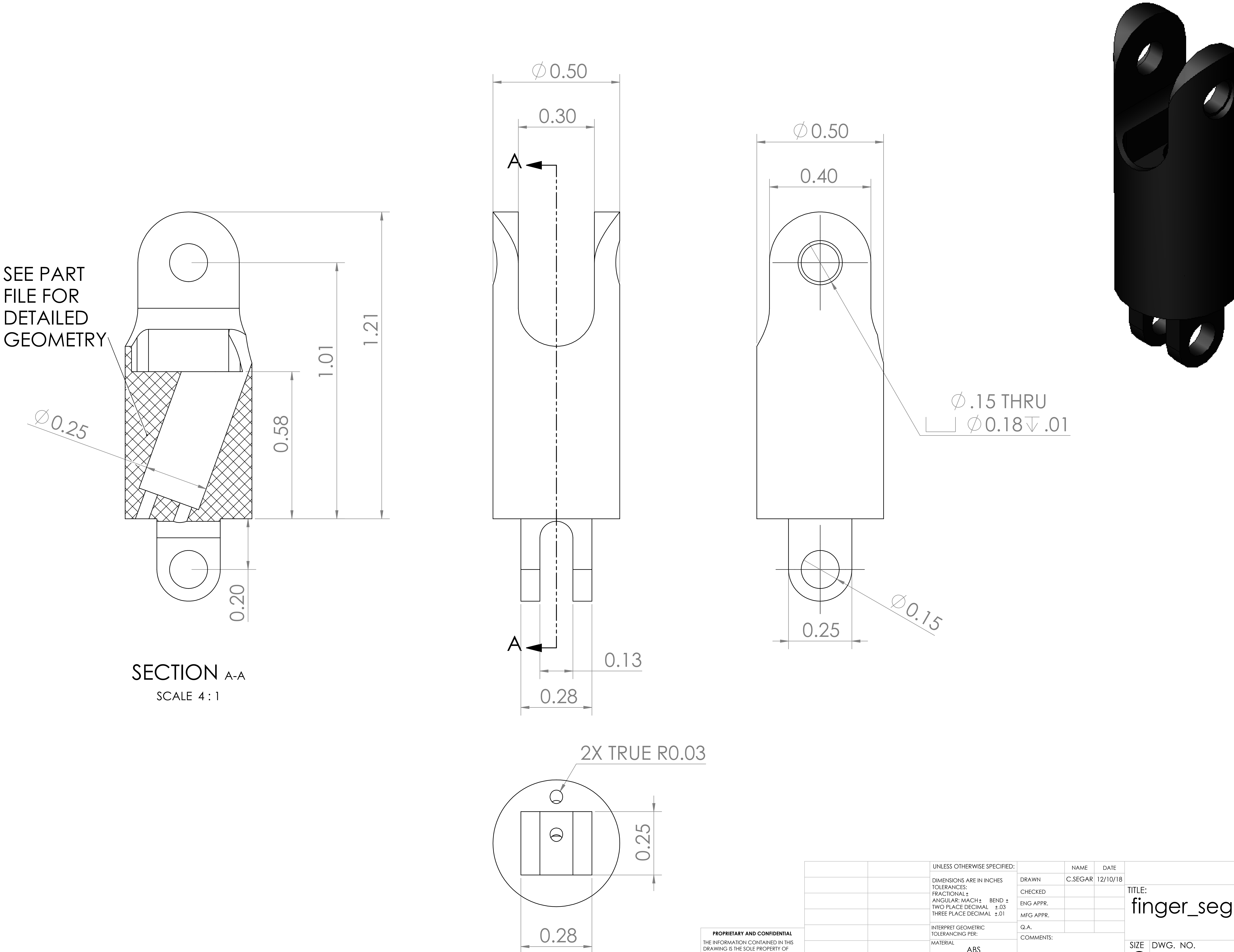

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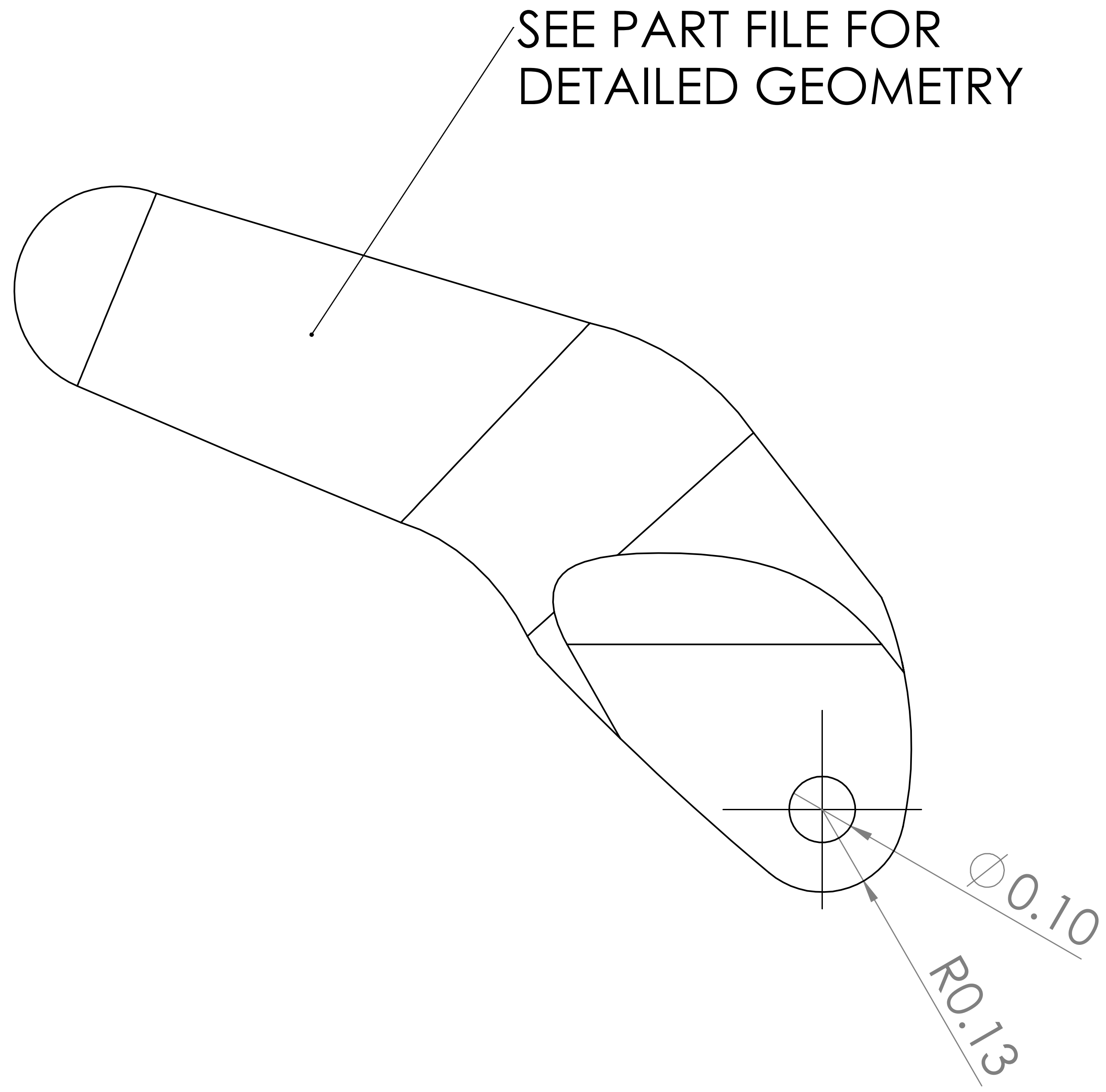

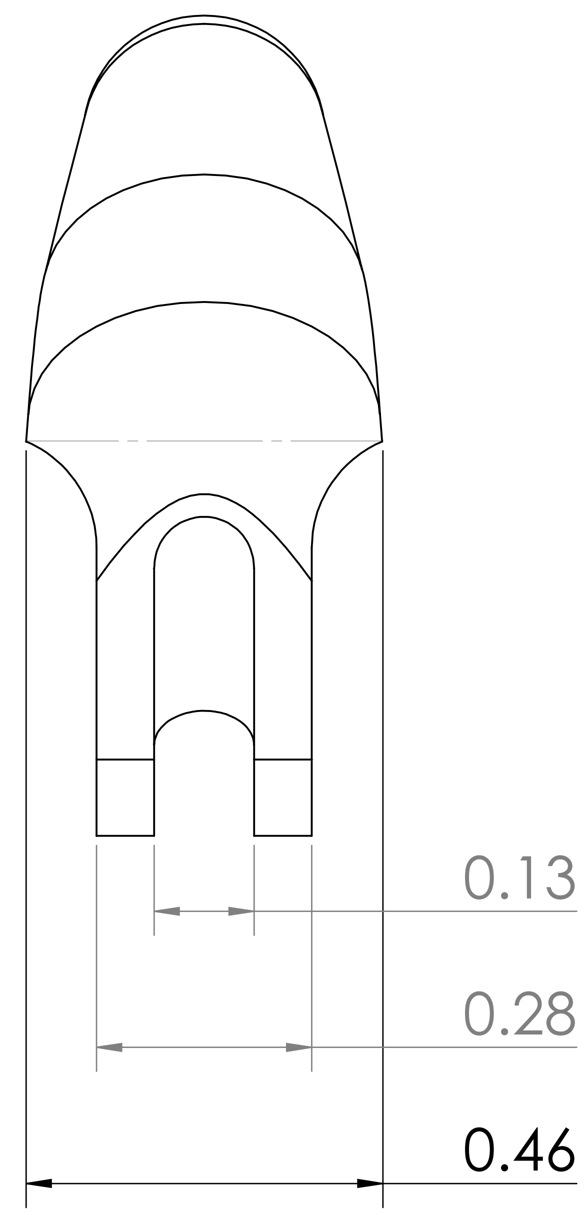

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TITLE:
finger_seg2

SIZE C | DWG. NO. | REV A

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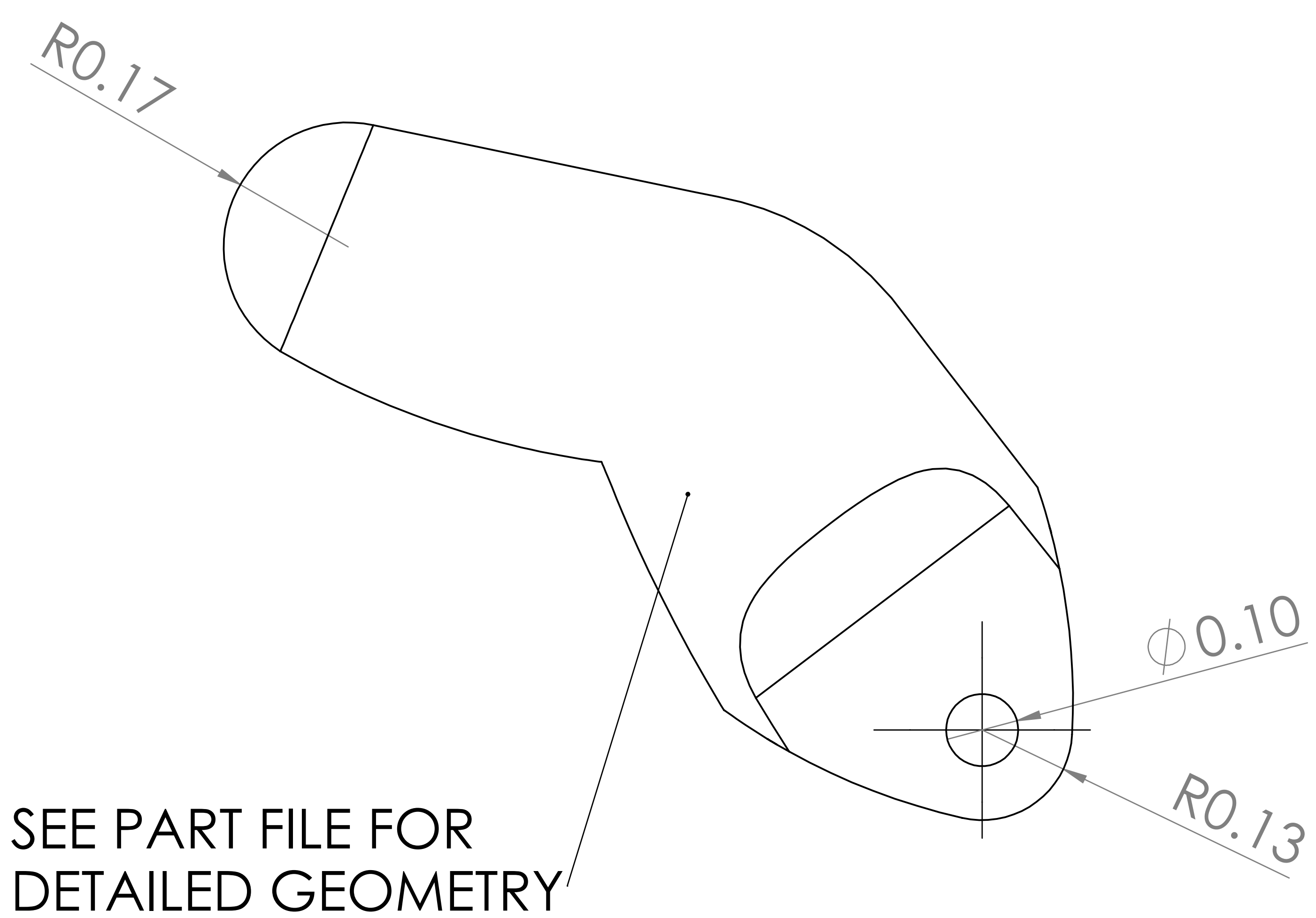

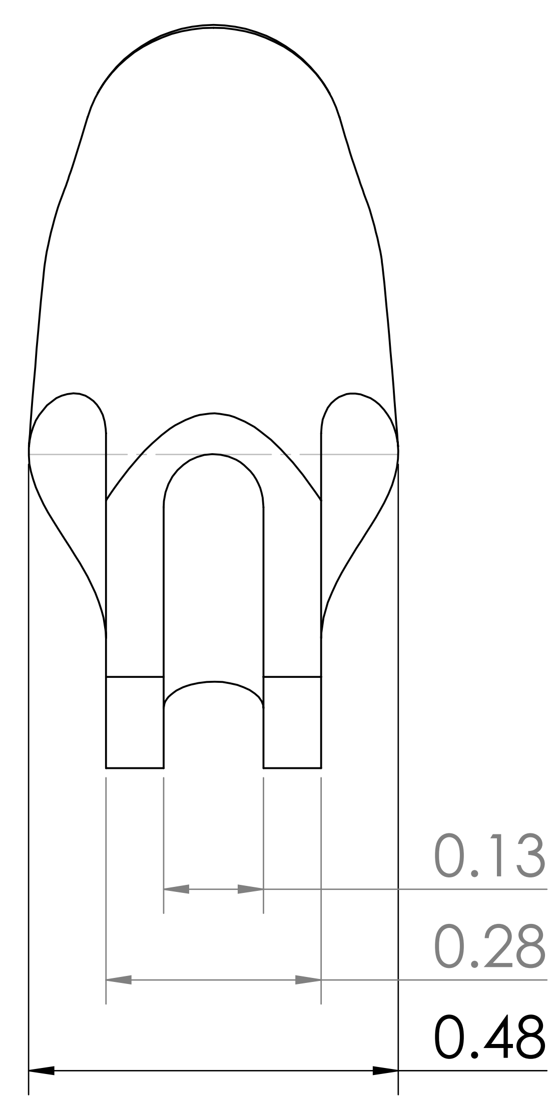

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			Q.A.		
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TITLE: finger_segment2

SIZE	DWG. NO.	REV
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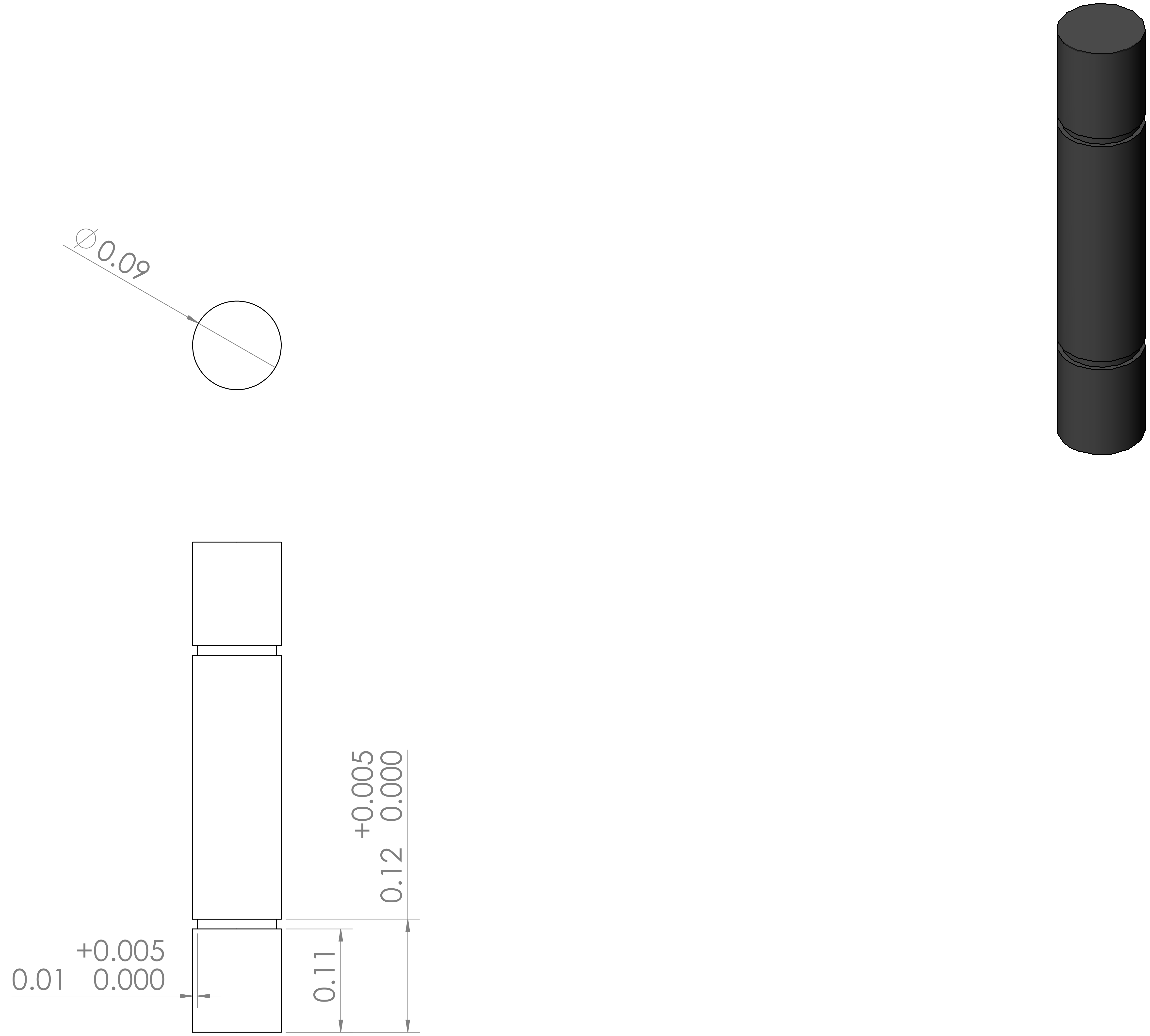

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			ENG APPR.			
			MFG APPR.			
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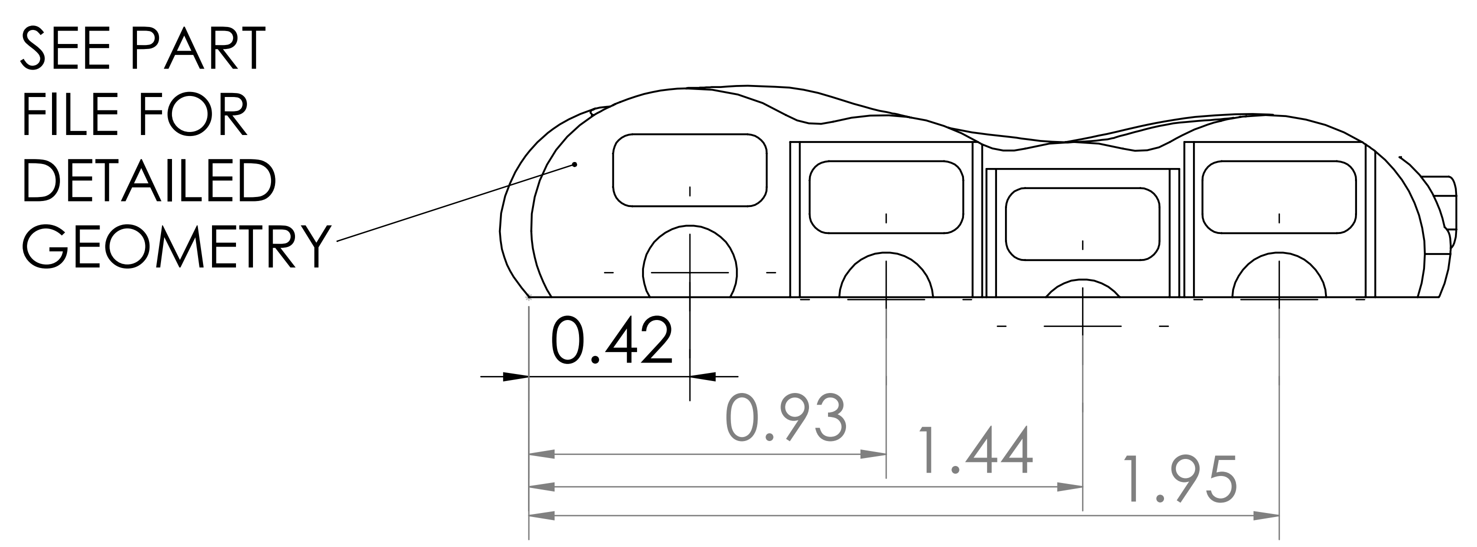

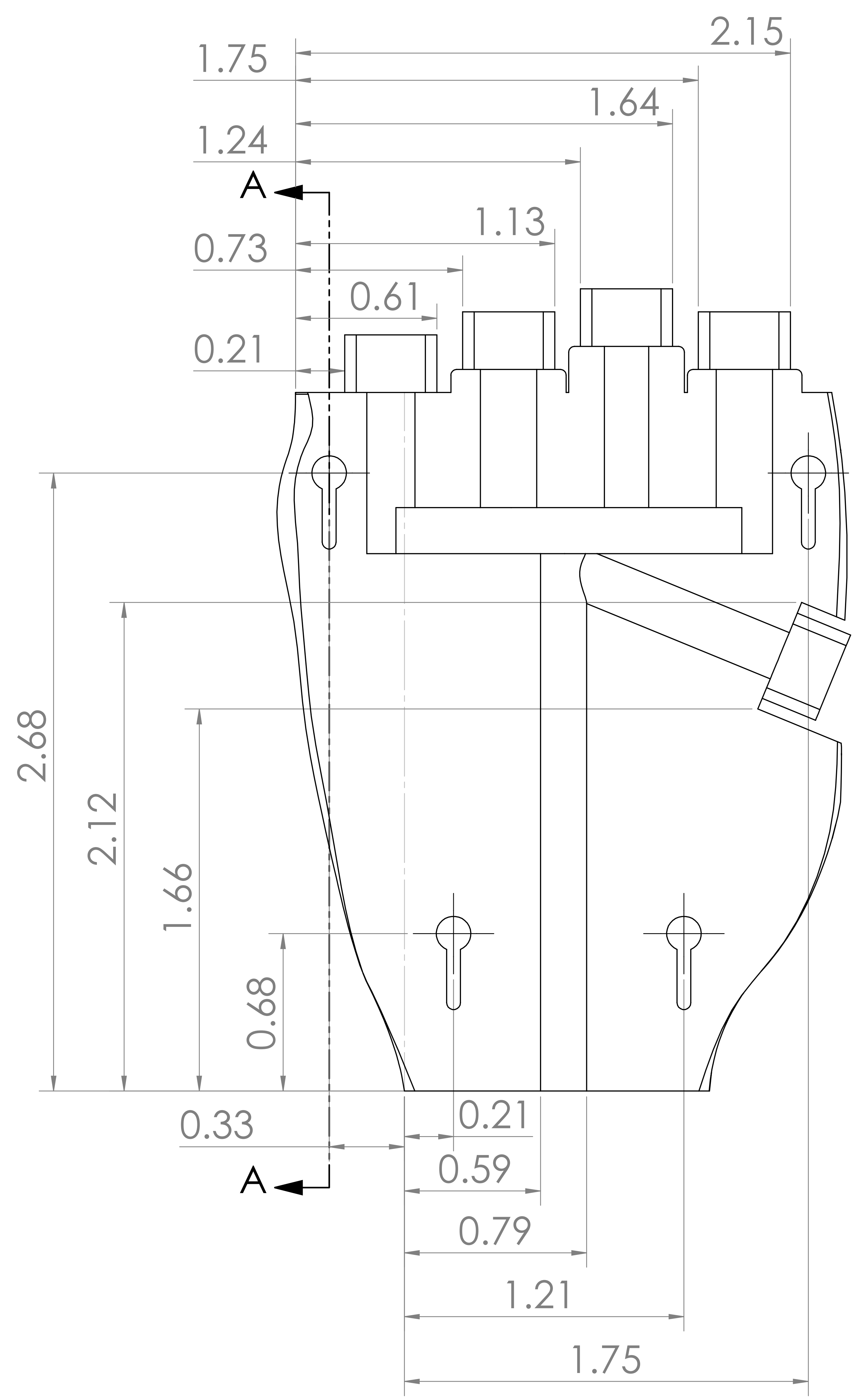

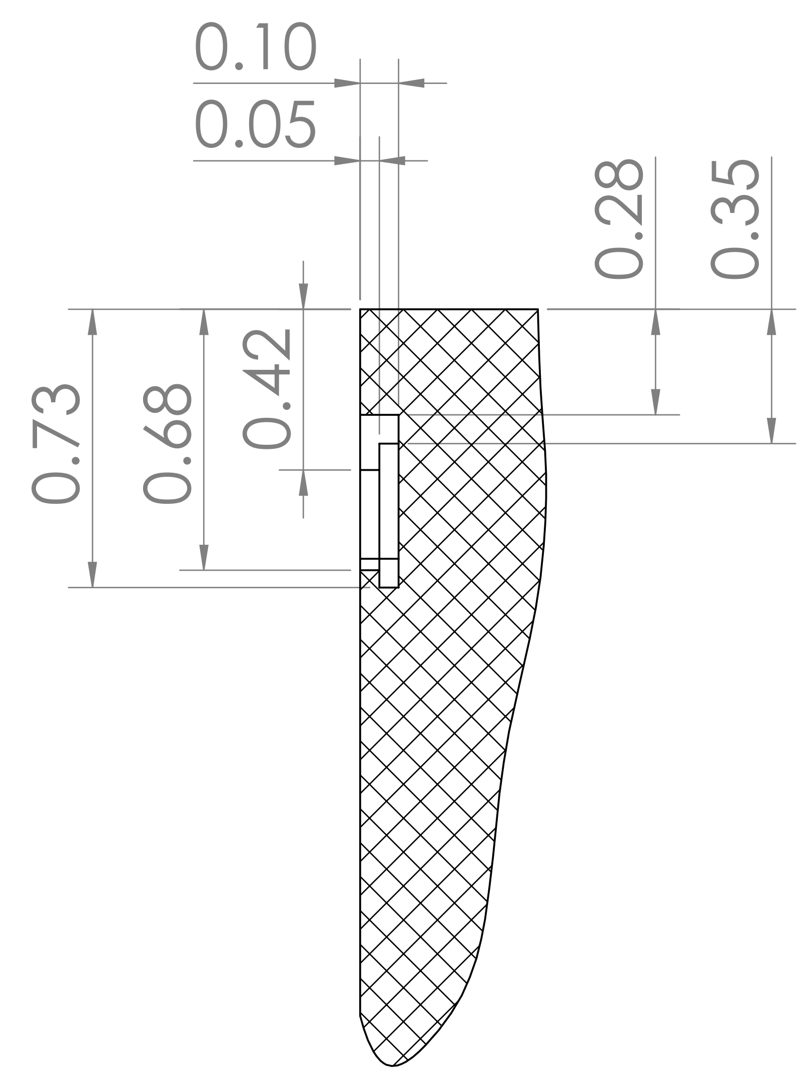

SECTION A-A
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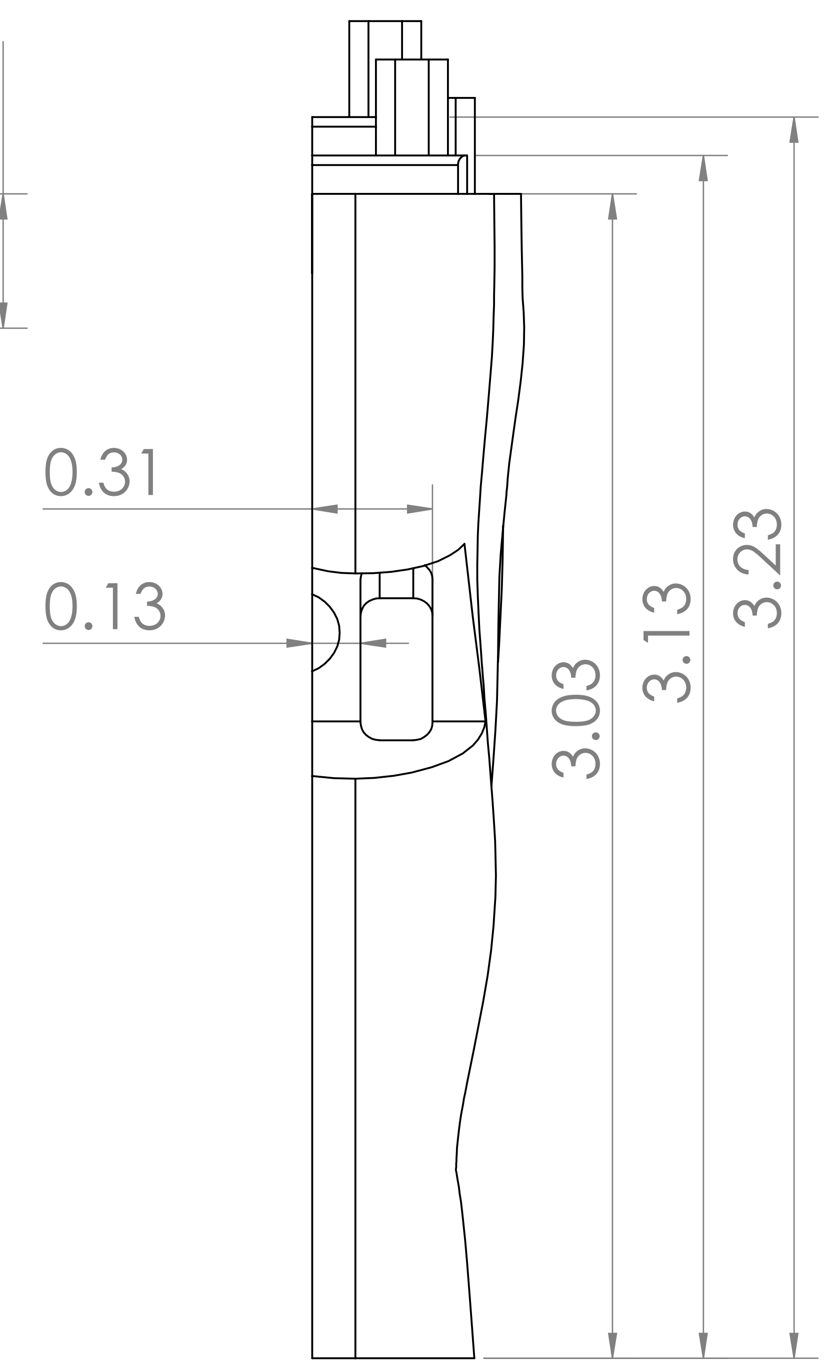

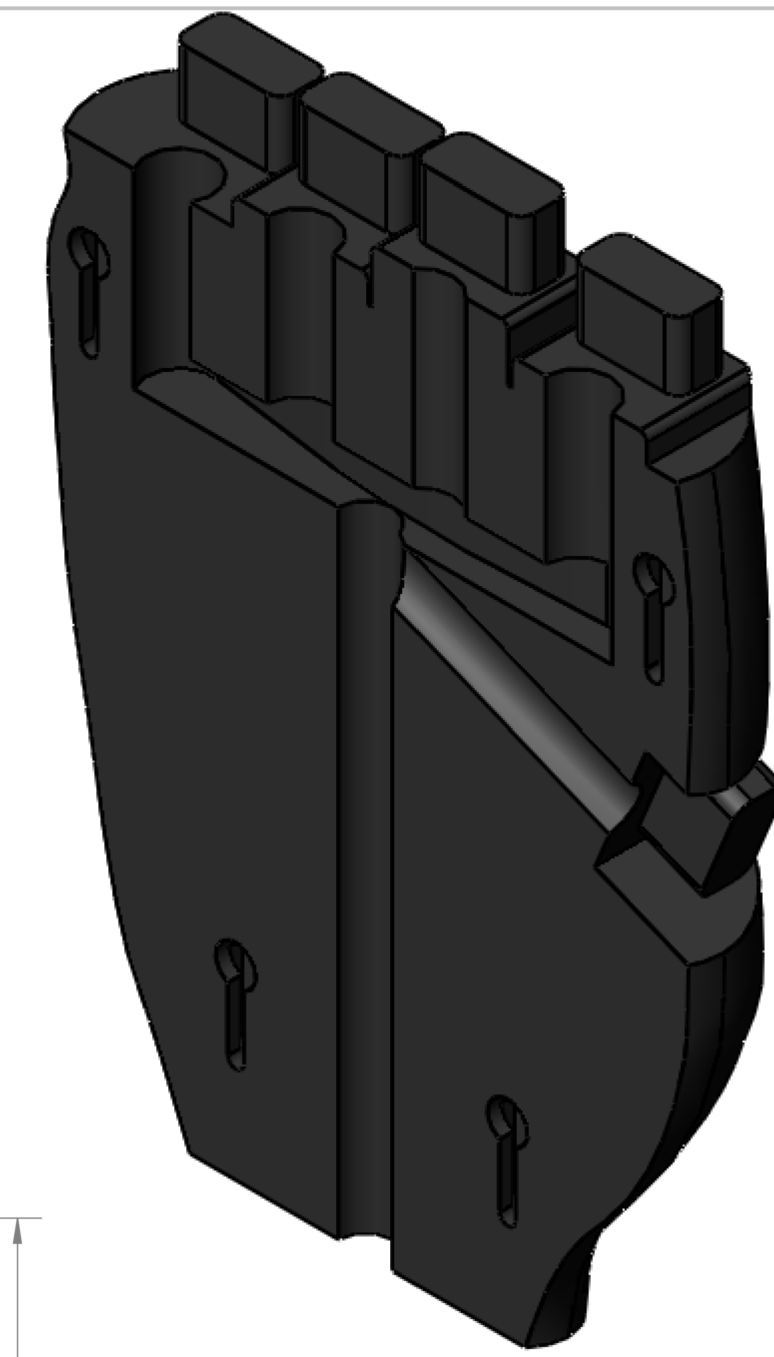

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UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
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TWO PLACE DECIMAL ±.03
THREE PLACE DECIMAL ±.01
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
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	NAME	DATE
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TITLE:
palm_back

SIZE C | DWG. NO. | REV A
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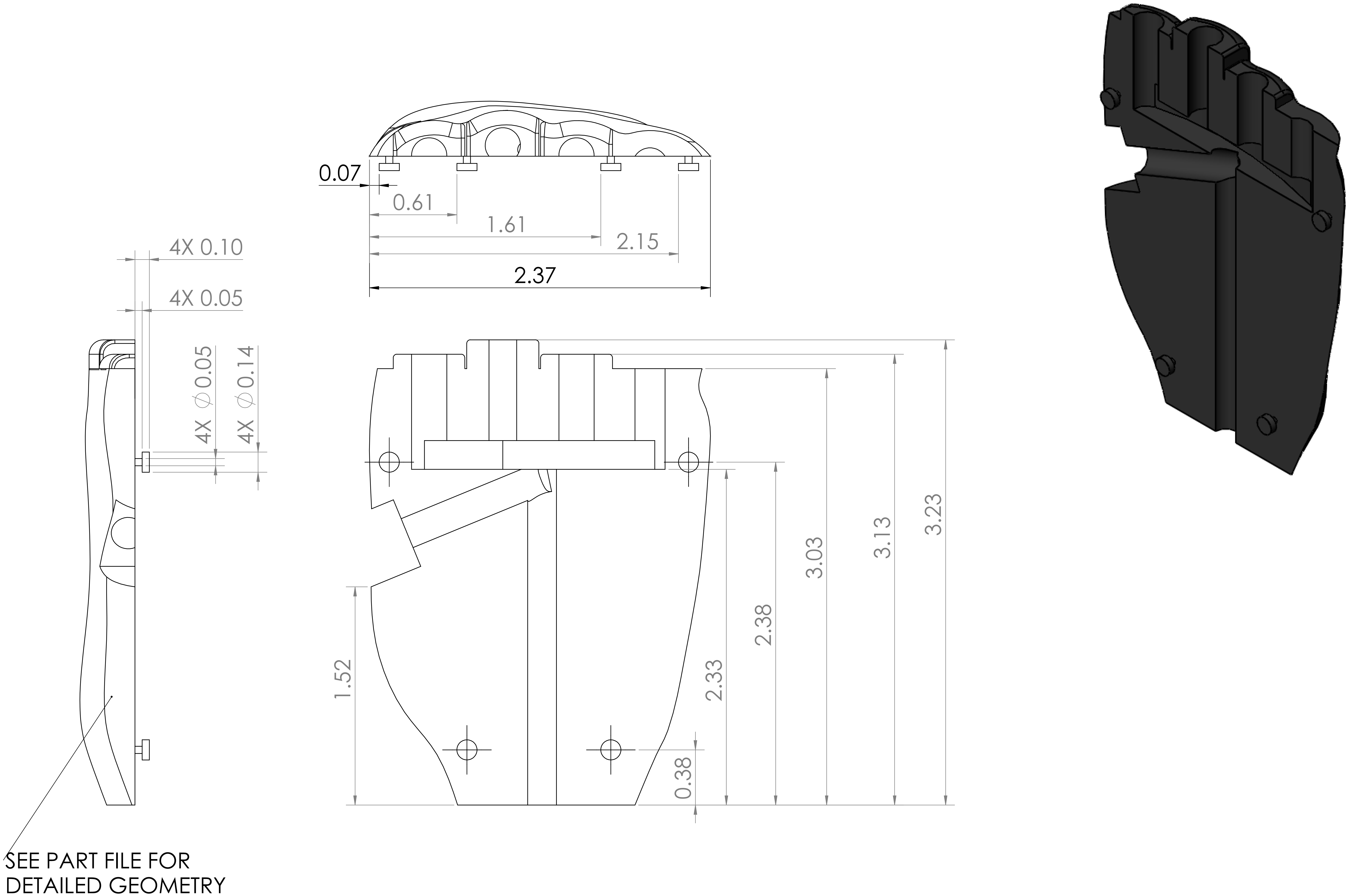

PROPRIETARY AND CONFIDENTIAL

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NEXT ASSY	USED ON	
APPLICATION		DO NOT SCALE DRAWING

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.03
THREE PLACE DECIMAL ±.01

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL: ABS

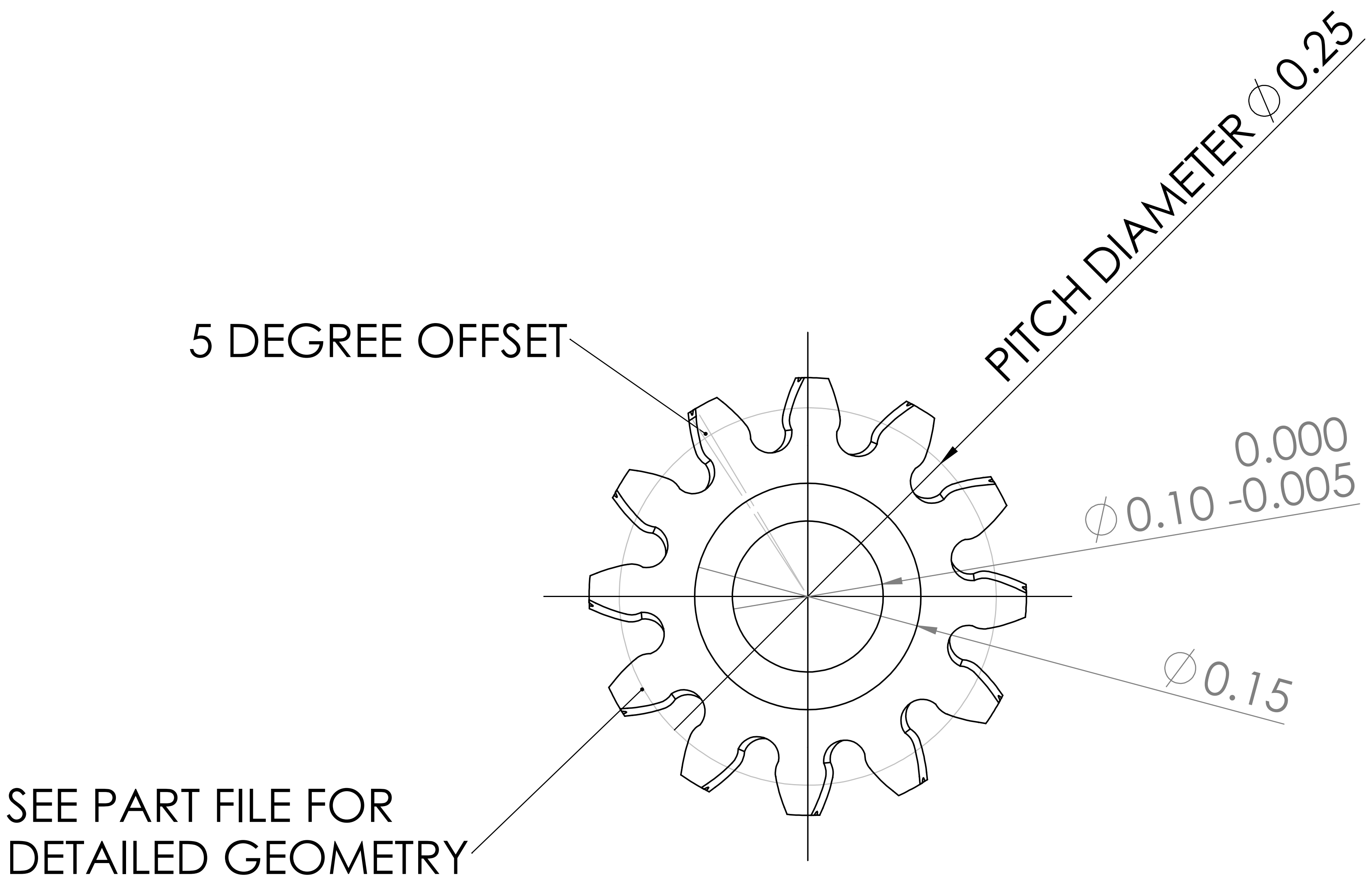
FINISH

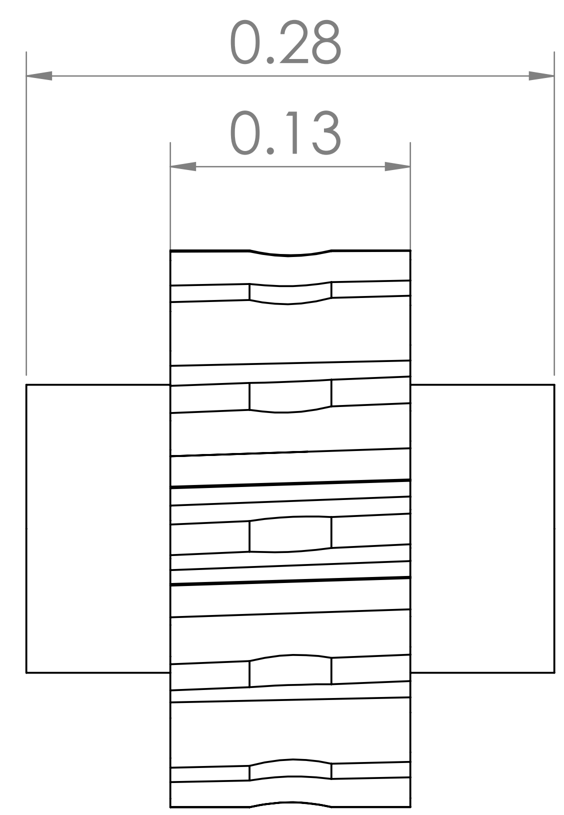
	NAME	DATE
DRAWN	C.SEGAR	12/10/18
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

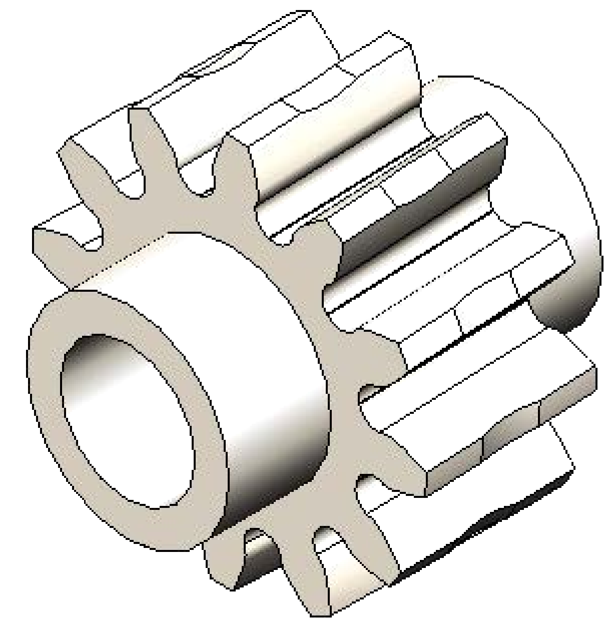
TITLE: palm_front

SIZE: C | DWG. NO. | REV: A

SCALE: 2:1 | WEIGHT: | SHEET 1 OF 1







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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.03
THREE PLACE DECIMAL ±.01

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
4340 STEEL, SINTERED

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	C.SEGAR	12/10/18
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

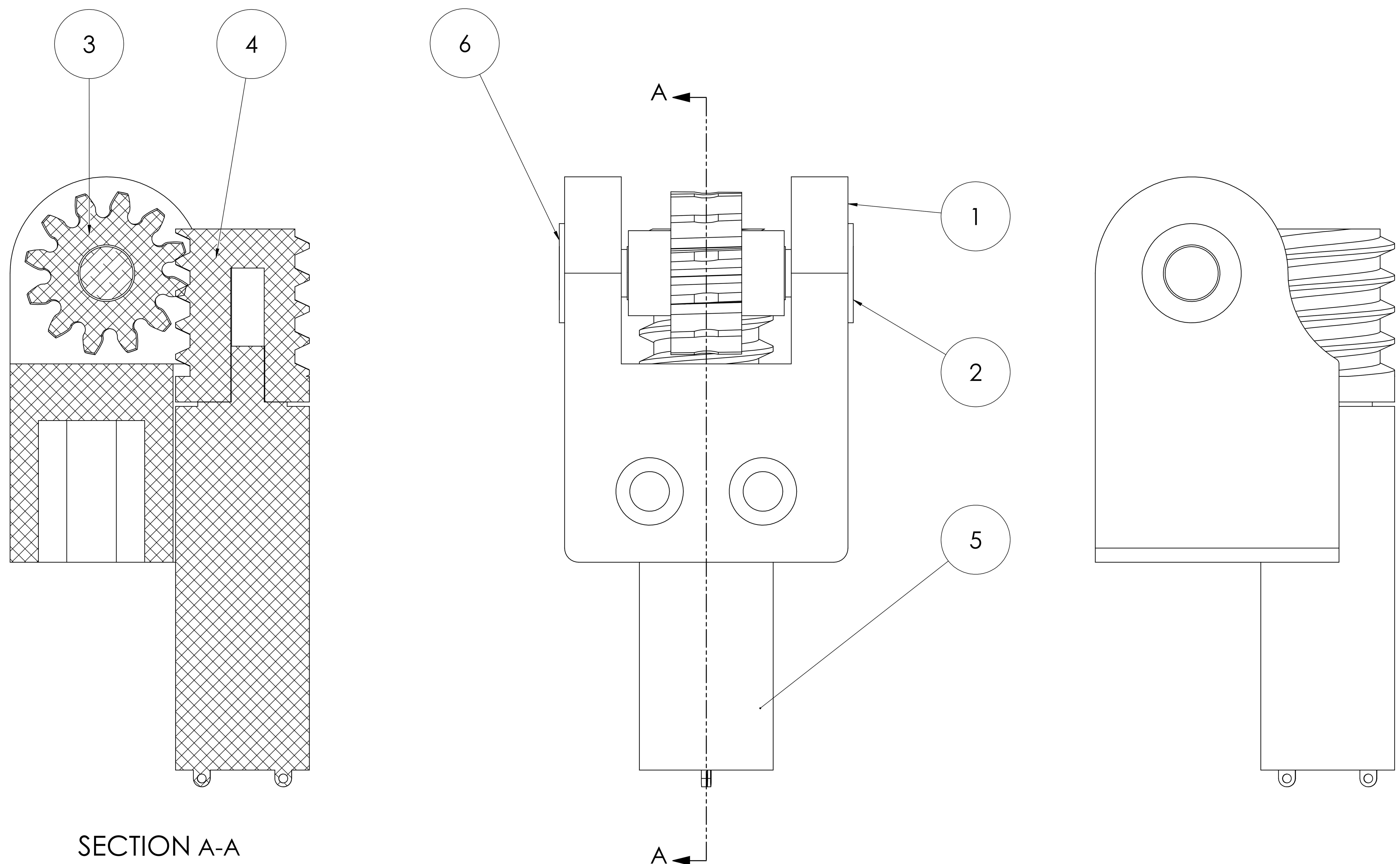
COMMENTS:

TITLE:
wormGearCustom

SIZE	DWG. NO.	REV
C		A

SCALE: 10:1 WEIGHT: SHEET 1 OF 1

ITEM NO.	PART NUMBER	manual explode/QTY.
1	finger_base1	1
2	mainAxle	1
3	wormGearCustom	1
4	wormGear	1
5	smallMotor	1
6	sleeveBearing	2



SECTION A-A
SCALE 8 : 1

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NEXT ASSY | USED ON
APPLICATION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.03
THREE PLACE DECIMAL ±.01

INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	C.SEGAR	12/10/18
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

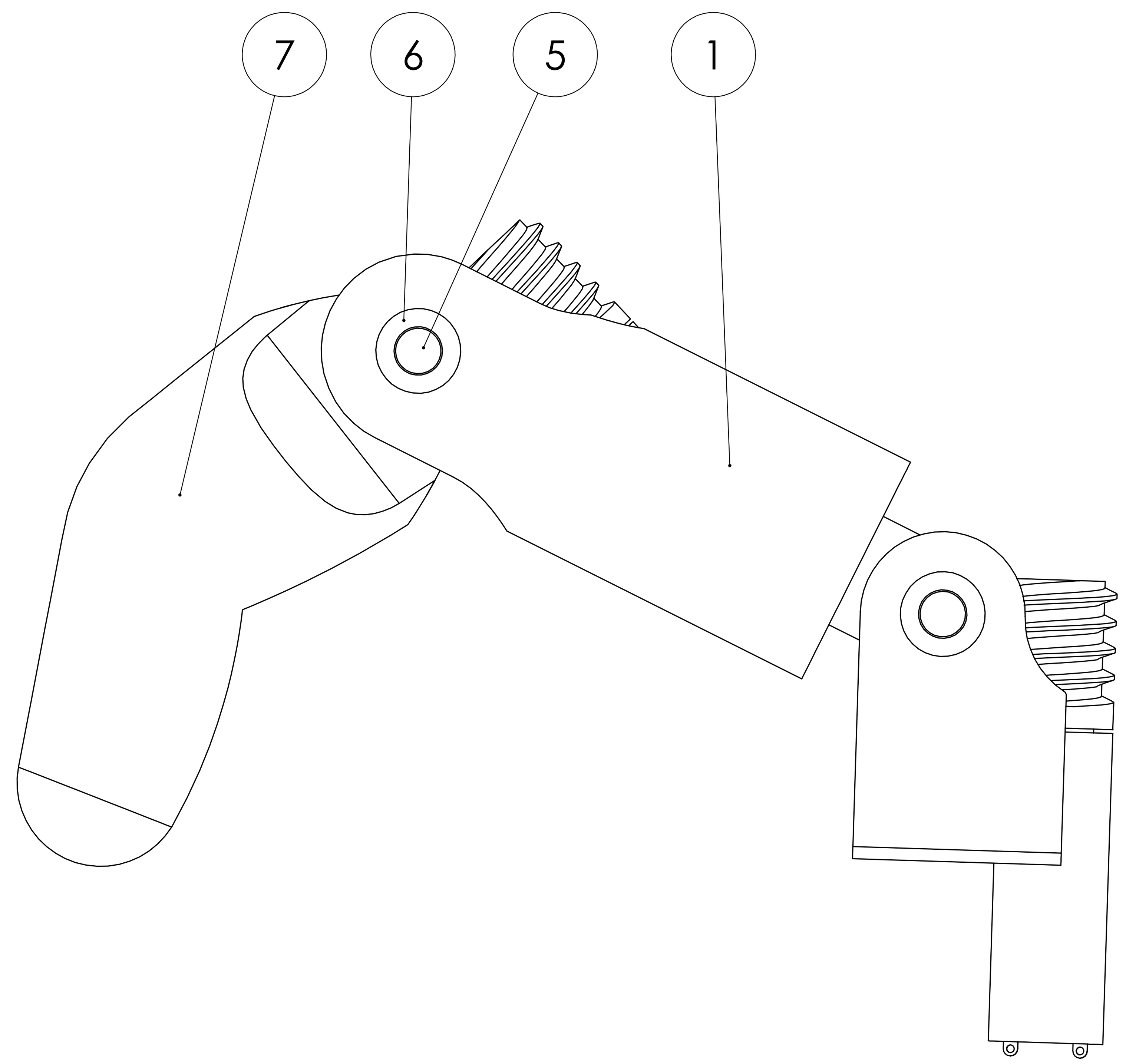
COMMENTS:
SUBASSEMBLY FOR FINGER JOINT BASE

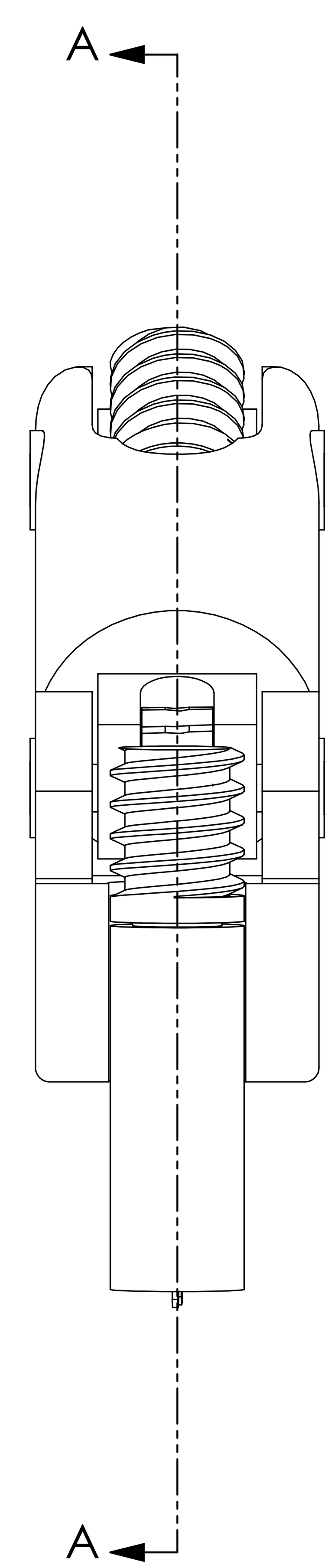
TITLE:
baseGears

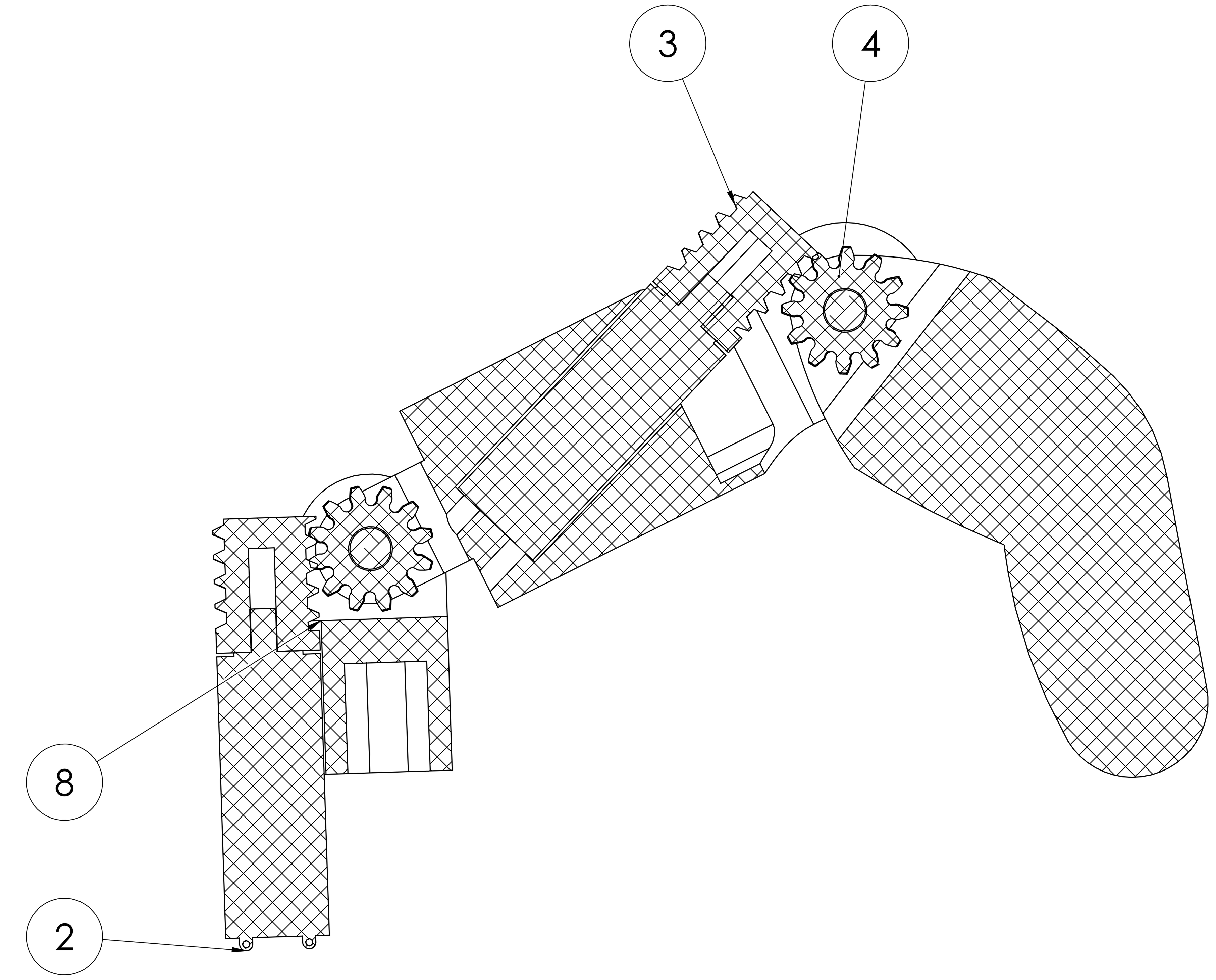
SIZE D | DWG. NO. SUBASSM_A | REV A

SCALE: 5:1 | WEIGHT: | SHEET 1 OF 1

ITEM NO.	PART NUMBER	manual explode/QTY.
1	finger_segment1	1
2	smallMotor	2
3	wormGear	2
4	wormGearCustom	2
5	mainAxle	2
6	sleeveBearing	4
7	finger_segment2	1
8	finger_base1	1







SECTION A-A
SCALE 4 : 1

PROPRIETARY AND CONFIDENTIAL

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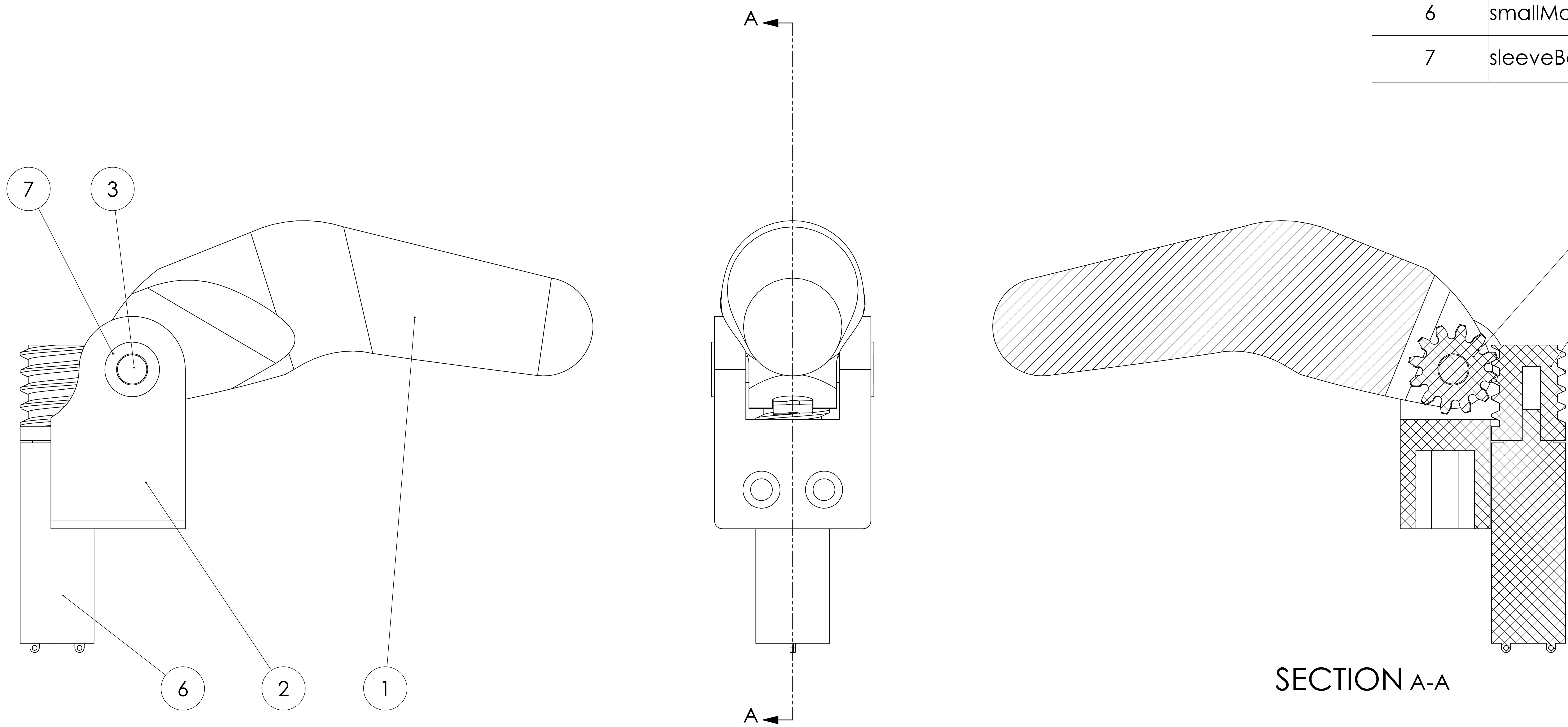
		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.03 THREE PLACE DECIMAL ±.01	DRAWN	C.SEGAR	12/10/18	TITLE: fingerAssm
			CHECKED			
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL	COMMENTS: SUBASSEMBLY FOR FINGER			SIZE D DWG. NO. SUBASSM_B REV A
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 2:1 WEIGHT: SHEET 1 OF 1

ITEM NO.	PART NUMBER	manual explode/QTY.
1	finger_seg2	1
2	finger_base1	1
3	mainAxle	1
4	wormGearCustom	1
5	wormGear	1
6	smallMotor	1
7	sleeveBearing	2



SECTION A-A

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.03
THREE PLACE DECIMAL ±.01

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	C.SEGAR	12/10/18
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

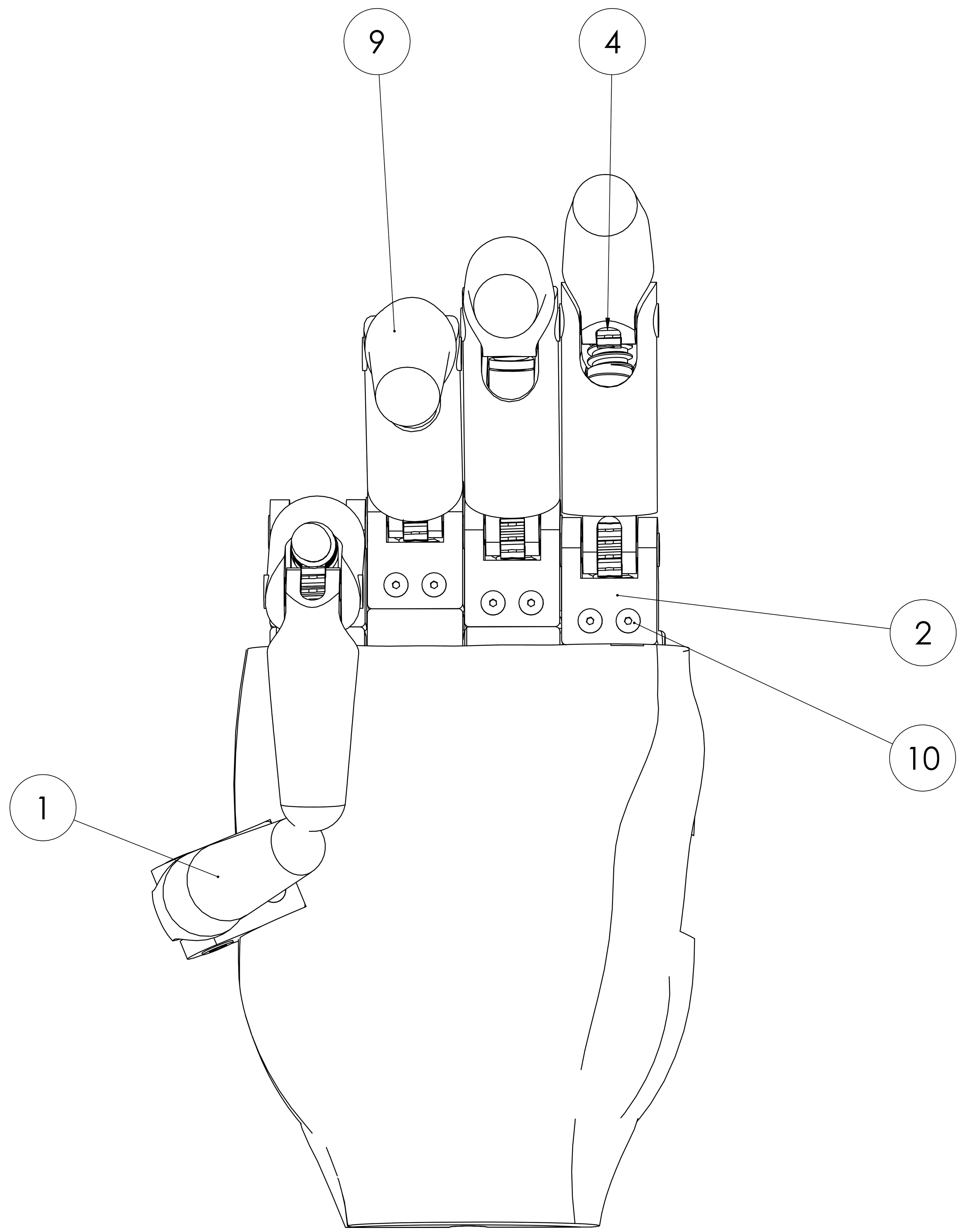
COMMENTS:
SUBASSEMBLY FOR THUMB

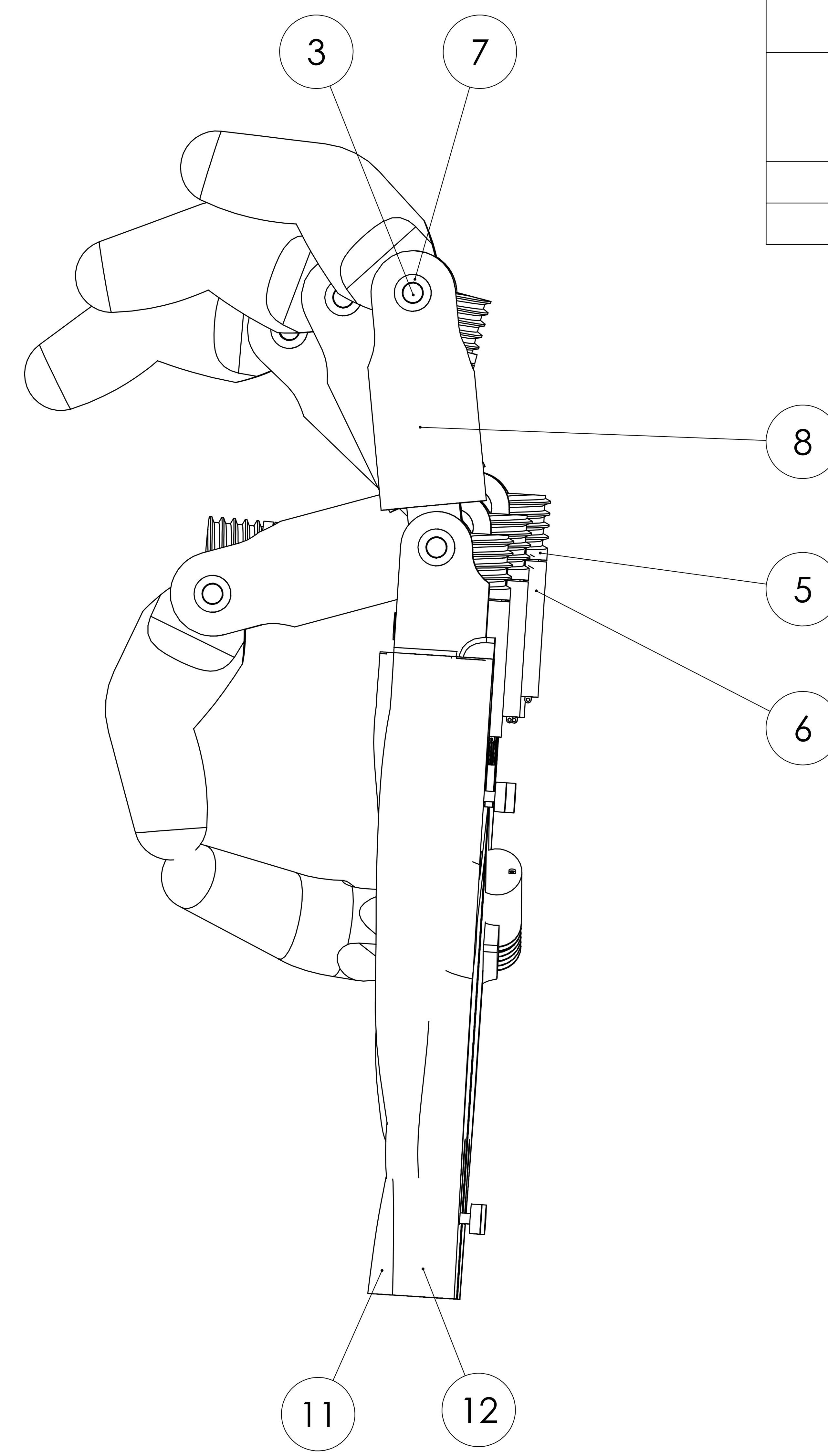
TITLE: thumbAssm

SIZE D DWG. NO. SUBASSM_C REV A

SCALE: 5:1 WEIGHT: SHEET 1 OF 1

ITEM NO.	PART NUMBER	manual explode/QTY.
1	finger_seg2	1
2	finger_base1	5
3	mainAxle	9
4	wormGearCustom	9
5	wormGear	9
6	smallMotor	9
7	sleeveBearing	18
8	finger_segment1	4
9	finger_segment2	4
10	SCHCSCREW 0.06-80x0.188x0.188-HX-N	10
11	palm_back	1
12	palm_front	1





NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.03
THREE PLACE DECIMAL ±.01

INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	C.SEGAR	12/10/18
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:
MAIN HAND ASSEMBLY

TITLE: fingersAssm

SIZE D | DWG. NO. MAINASSM | REV A

SCALE: 1:1 | WEIGHT: | SHEET 1 OF 1