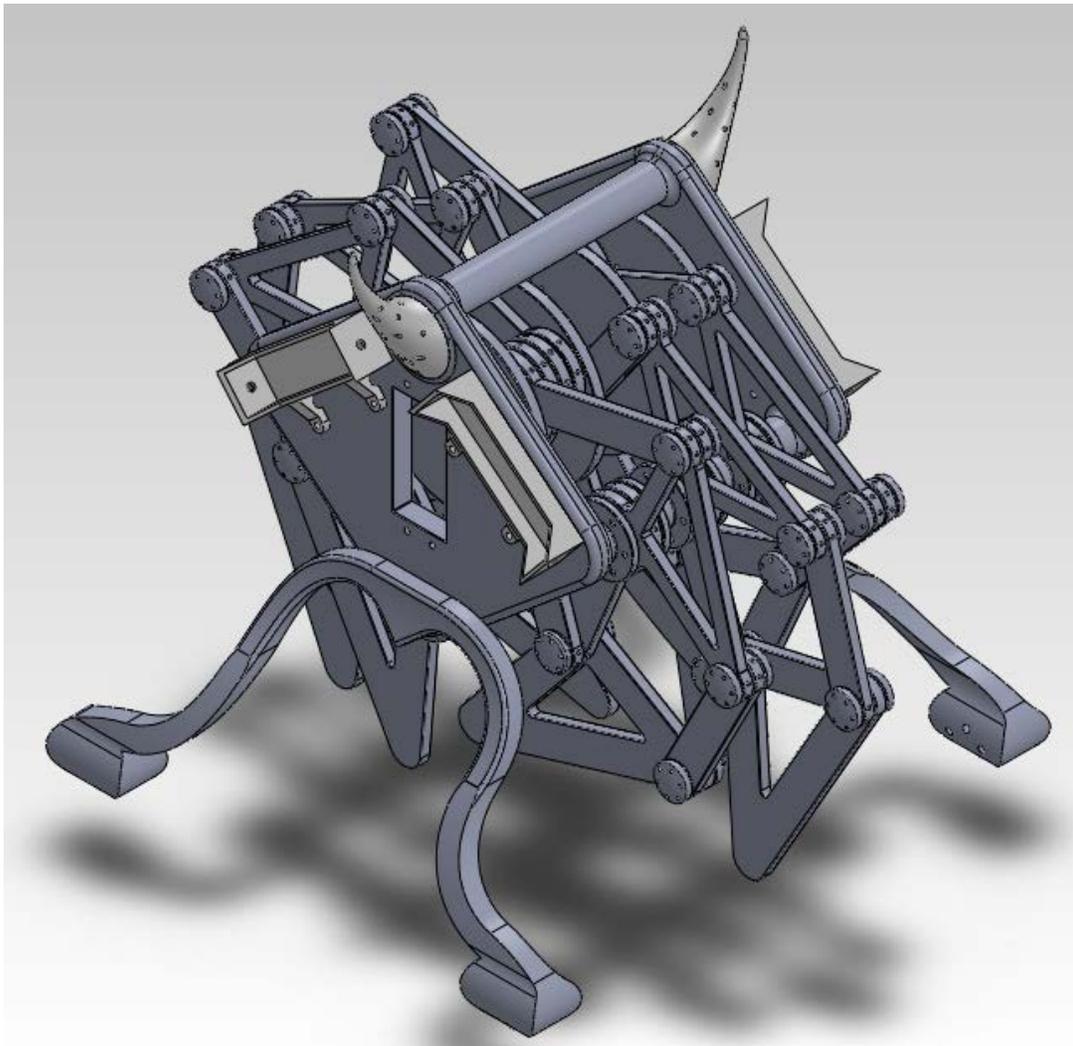


# 2011

Mechanical Prototyping ENGR 2330

Arjun Aletty, Charlie Behling, Ben Chapman, Murphy Kitchell, Jenny McConnell



[Rapid Prototype Crawler]

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# Executive Summary:

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## **Executive Summary:**

In this project our goal was to use the skills and techniques associated with 3D-Printing and Rapid Prototyping to create a crawler. As a team we decided to try to use the printer to its full potential: printing complex shapes that would be difficult to create in other machining techniques, and printing our entire crawler with as little assembly required as possible. This means that in addition to the complicated and interestingly shaped parts, our entire crawler was printed as a single piece. This allowed us to design joints, pins, linkages, and crankshafts into a single piece that would be fully functional when printed. This enabled us to merely mount servos to finish the assembly. In addition to these, we decided to use the Theo Jansen linkage to enable our crawler to walk in a natural-seeming manner. However, in an attempt to ensure that all the support material from the 3D-Printer, there was too much play in the linkages, and retaining rings were required. In addition, due to poorly distributed weight, we needed to add extra external legs to enable better balancing.

# Structures, Joints, and Fasteners:

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## Structure:

We decided to print our crawler with a few specific goals in mind: printing in as few pieces as possible, and effectively utilizing a Theo Jansen linkage. The Jansen linkage is named after its inventor, who used them extensively in walking kinetic sculptures called Strandbeests. The linkage is complicated, but creates a smoother, more natural gait than most other walking linkages. The Strandbeests use dozens of legs to move smoothly across the ground, but for practical purposes we chose a design with three legs sets. One set of our leg sets can be seen in figure 1.

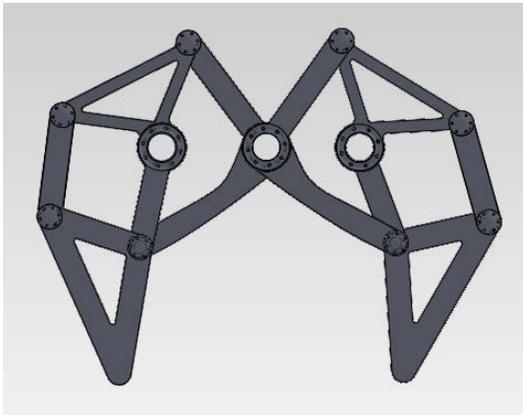
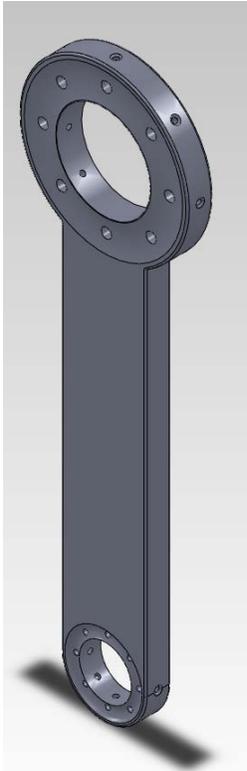


Figure 1: One set of legs with the Jansen linkage

3D printing utilizing the Fused Deposition Modeling (FDM) technique required us to take into account several factors. Since FDM layers the filaments, the object printed is weak in the z-axis since it can shear. Thus we had to choose the parts under the greatest stress and made sure those parts were printed in an orientation such that direction of the stress was parallel to the z-axis. In the case of the crawler, the crankshaft was under the greatest stress since it had to support three sets of legs and thus we opted to print the crawler with the crankshaft on the x-y plane.

The way FDM works is by utilizing support and build material, meaning that in the gaps between parts in the crawler, it was filled with support material. The support material allowed the printer to print the crawler without it collapsing on itself whilst printing. After printing, the crawler was placed in a lye bath in order to dissolve the support material. Because of this, it was necessary for us to put in drainage holes anywhere that there was support material, especially in tight, enclosed areas in order for the lye to reach the support material. Since we planned on printing the crawler in one piece, any support material left over would render it

unusable. Because of this, we needed plenty of drainage holes; however, it came at the cost of a weaker part. Since all the joints were tight and almost enclosed all the linkages had to include drainage holes. Figure 2 shows a linkage with a plethora of drainage holes.



**Figure 2: Linkage from Crawler showing the myriad drainage holes**

Because one of our design goals was to print our entire crawler in one piece, we had to design joints that took into account that the FDM printer had a resolution of .01 inches, meaning we needed to have at least a .01 inch gap between the individual linkages and the linkages and pins. However, since FDM printers produce a rather rough finish and since friction was a large concern for us (the Theo Jansen linkage is prone to high friction), we decided to leave a gap of .03 inches between all the linkages and the linkages and pins. After all the support material was removed, however, it was revealed that there was too much slop in all of the legs. Since the legs were too loose for the crawler to walk, we inserted metal retaining rings between the linkages to stiffen them. We were also careful with the number of rings we put in because we did not want to increase friction too much, or else it would not move.

With the addition of the retaining the crawler walked; however, since it only had three sets of legs, it was unbalanced. To remedy this issue, we designed and printed a set of external legs to serve as “training wheels” and provide balance.

## Power:

The power for the crawler was provided by four batteries, two for each servo. The batteries themselves were wired in series, connected by wires routed through the upper structural member, and the servos are connected to the batteries in parallel. We decided to use servos instead of the gearbox because the servos could easily be mounted on the outside of the frame, enabling us to more easily print the crawler as a single piece. As seen in figure 3, the batteries are mounted with one on each side of each servo. The servos are mounted in the center holes of the frame.

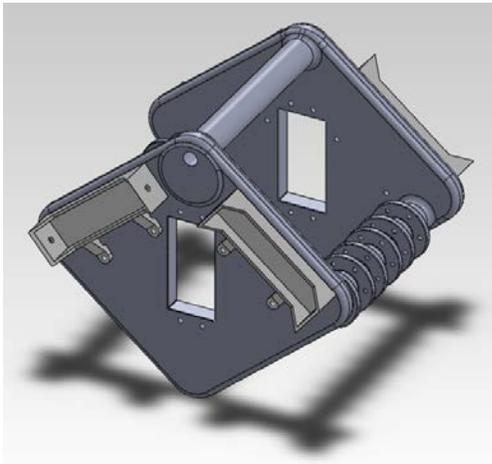


Figure 3: frame with holes for servos, battery packs

## Transmission:

The transmission of our crawler converted the circular motion of the servo to an actual step of the crawler. The path that each leg follows can be seen below in figure 4.

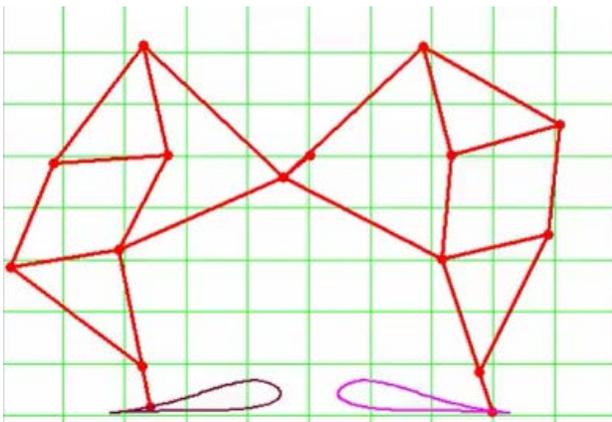


Figure 4: path traced by legs (in purple)

<http://www.youtube.com/watch?v=0CcB3Rb4Z0o&feature=related>

Two servos, one on each frame, create the circular motion, which is transmitted to the legs through the crankshaft (figure 5). Each set of legs is offset from each other by 120 degrees to maximize the number of contact points the crawler has with the ground at all times. We determined the lengths for all the leg pieces by using an online source (<http://www.mechanicalspider.com/elements/jpegs/jansenlinkage.jpg>), and then modified them slightly to achieve a more fluid, natural motion.

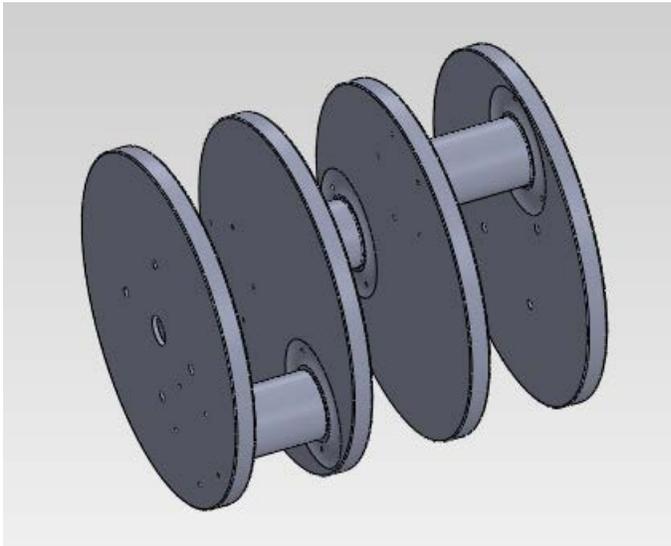
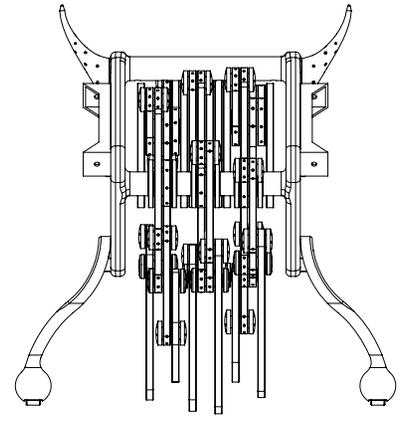
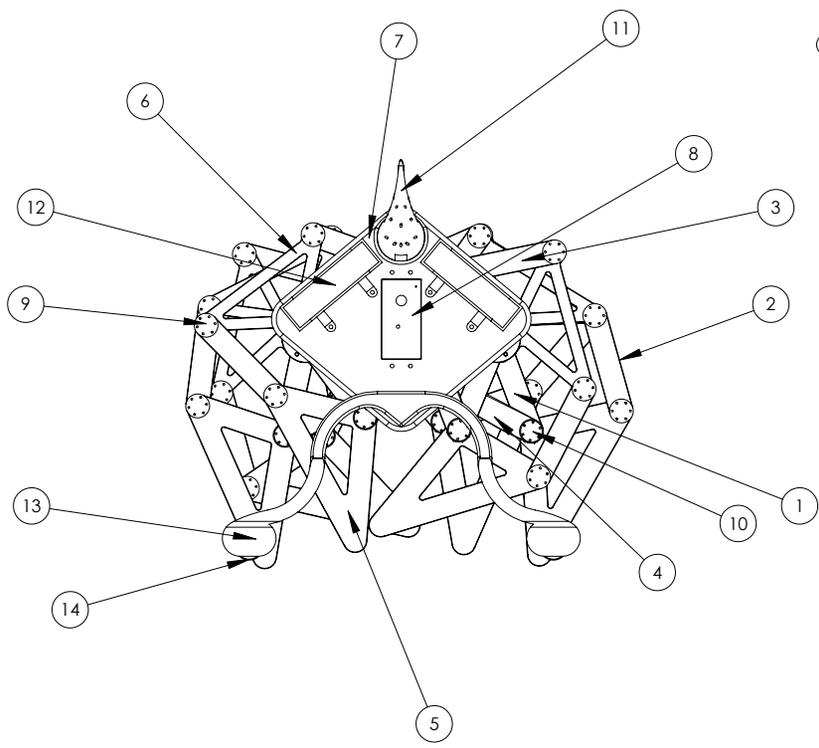
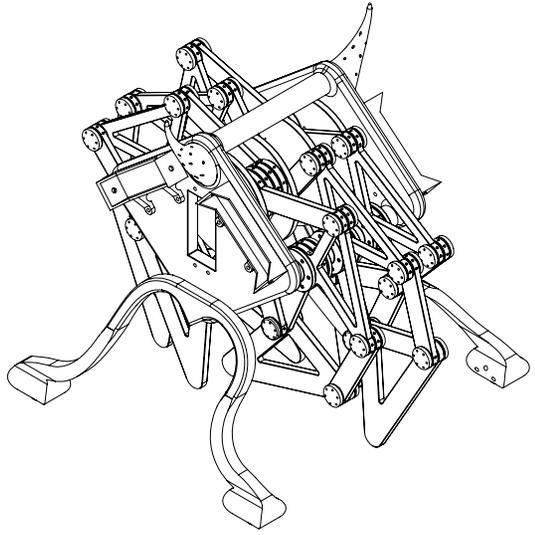
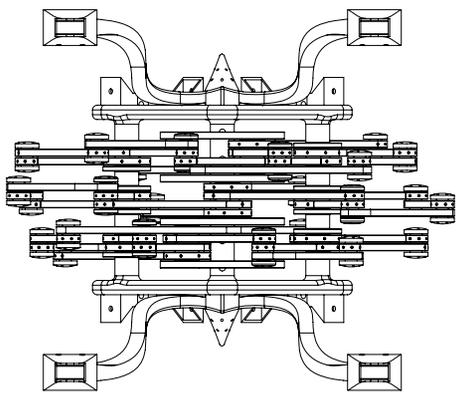


Figure 5: crankshaft

# Drawings

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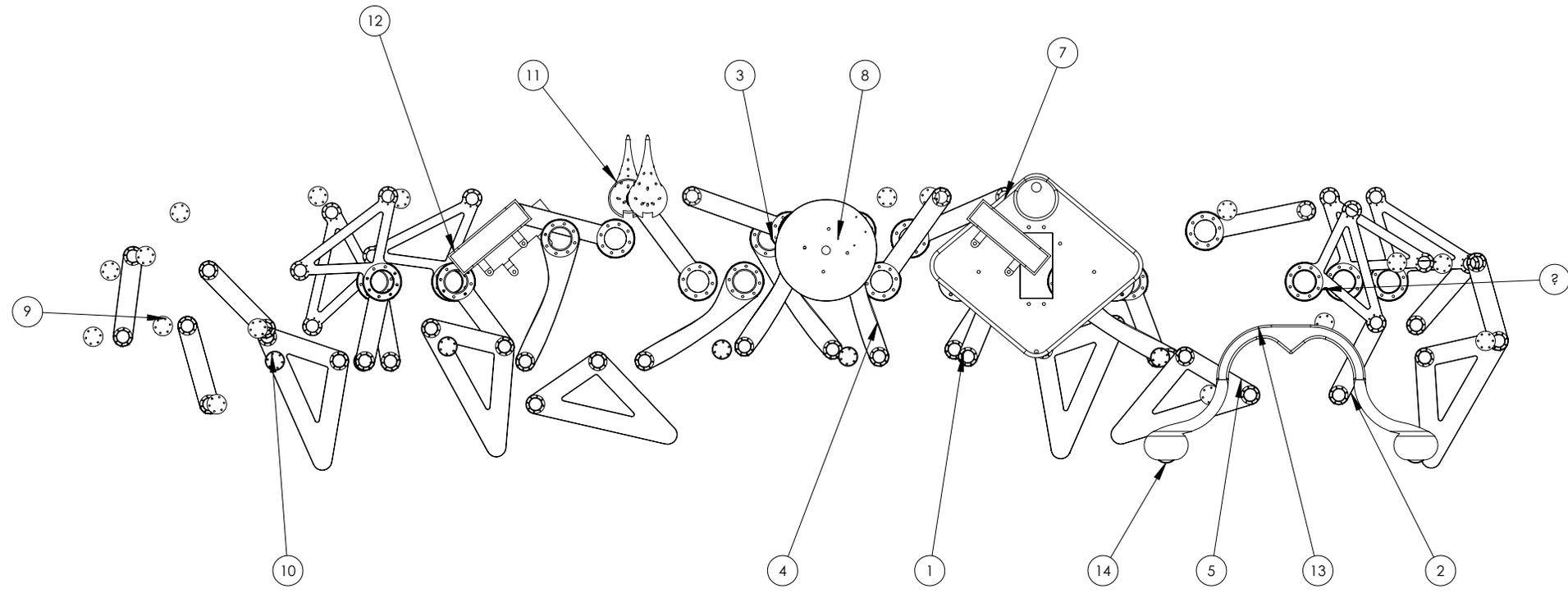
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6	top_triangle	6
7	frame	1
8	Crankshaft	1
9	quarter_PIN	18
10	3Peice_PIN	6
11	horn1	2
12	battery_holder	4
13	training wheels	2
14	training wheel wheel	4



Material: Rapid Prototype Material

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		SHEET 1 OF 1

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4	part_k+l+m	6
5	bottom_triangle	6
6	top_triangle	6
7	frame	1
8	Crankshaft	1
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12	battery_holder	4
13	training wheels	2
14	training wheel wheel	4

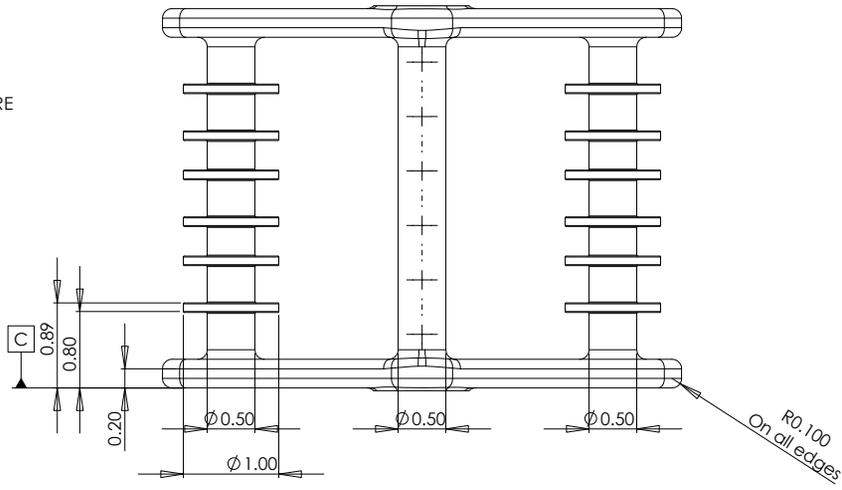


Printed as 1 piece Material: Rapid Prototype Material

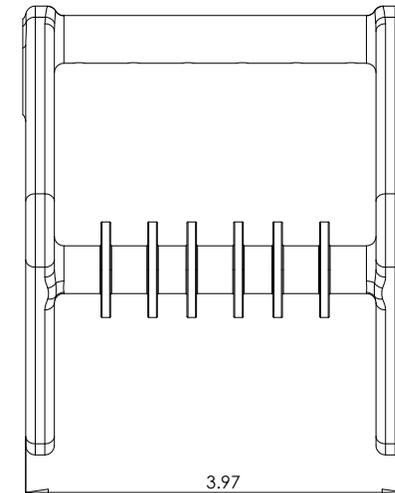
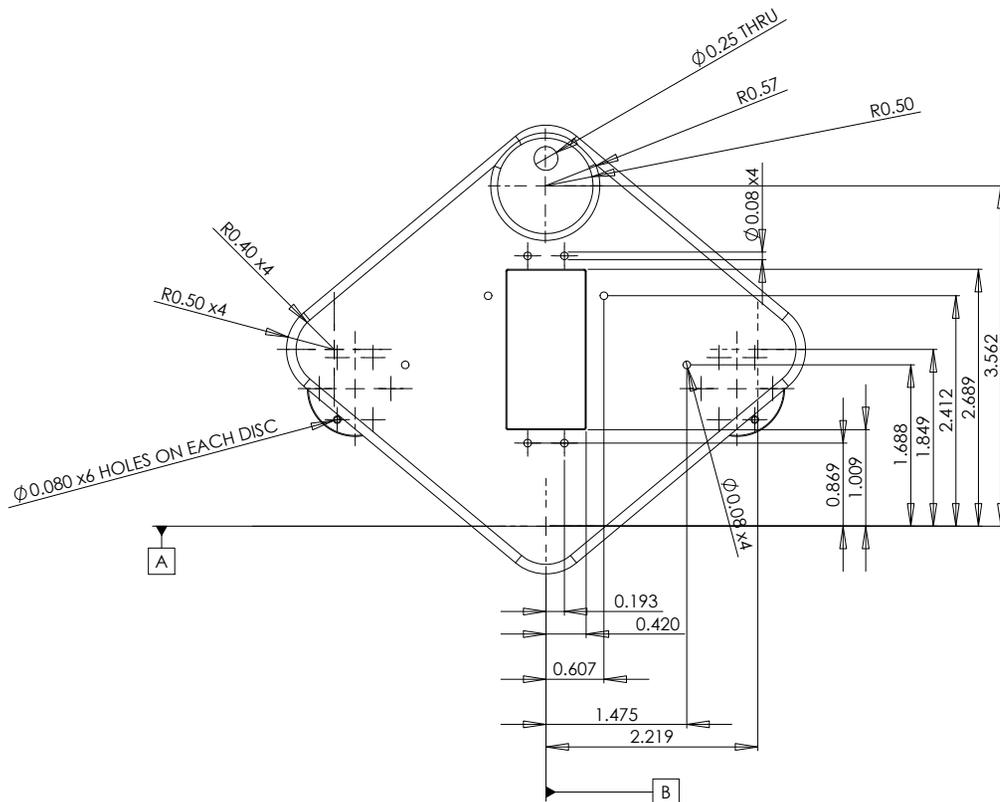
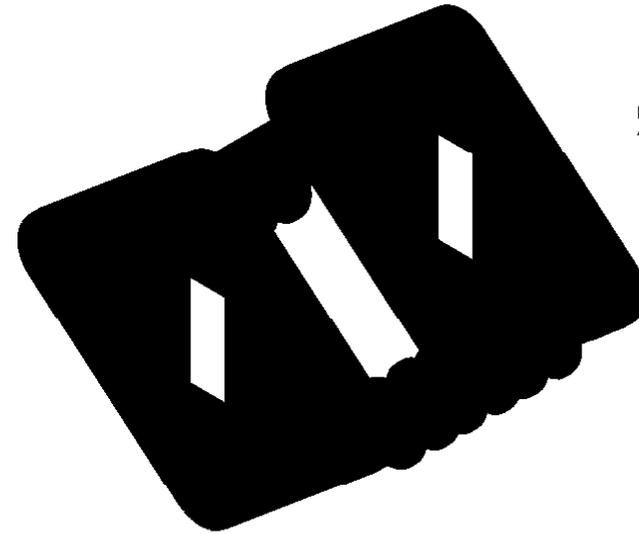
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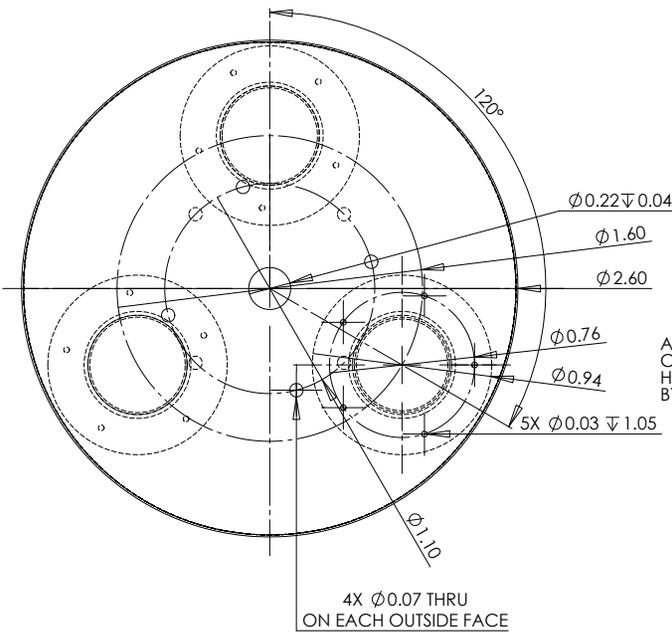
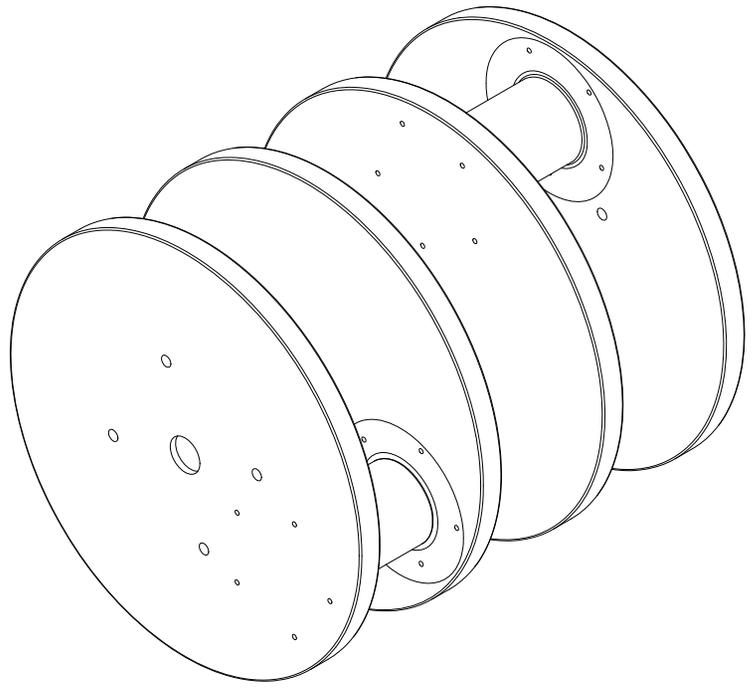
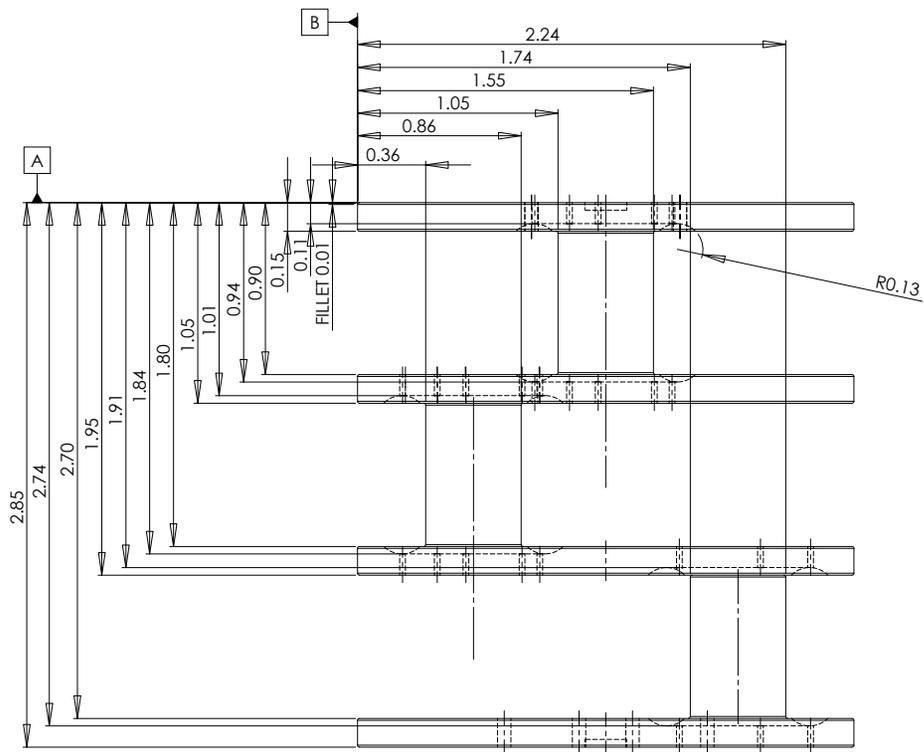
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NOTE: DIMENSIONS ARE SAME AS OPPOSITE SIDE OF FRAME



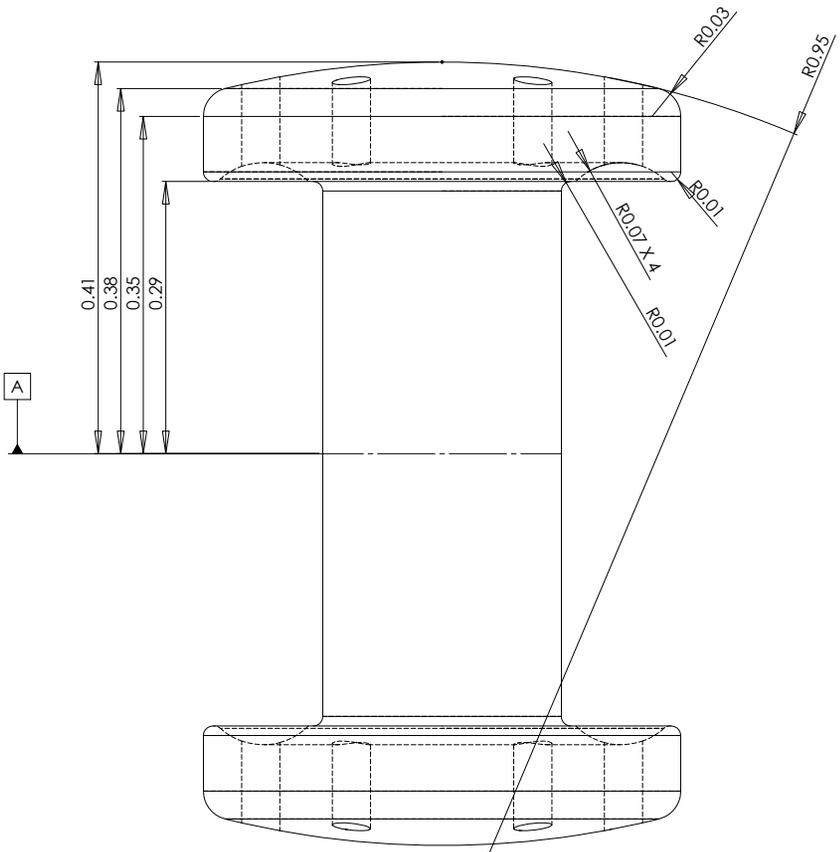
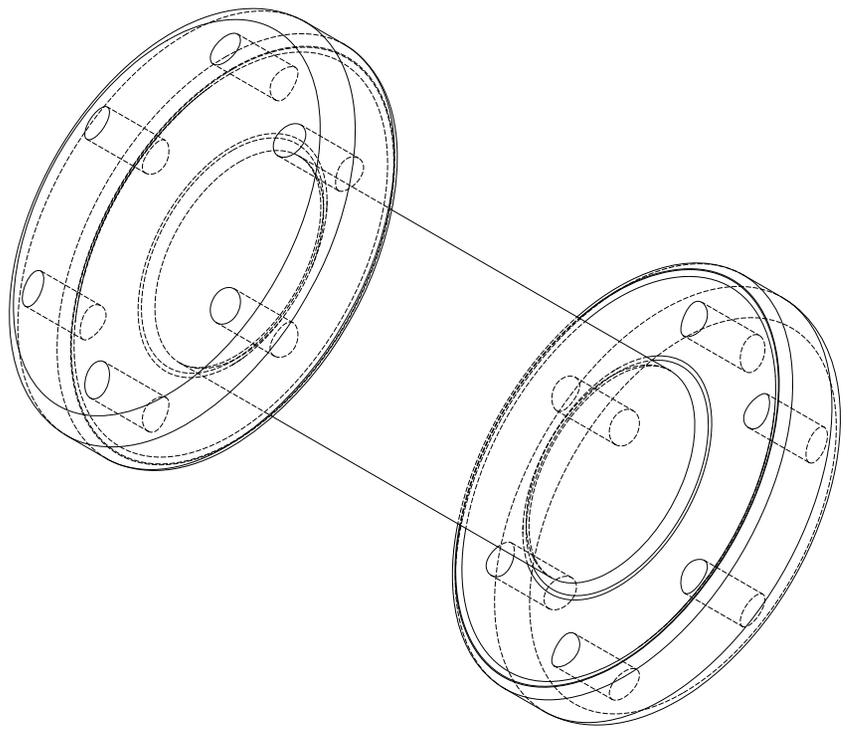
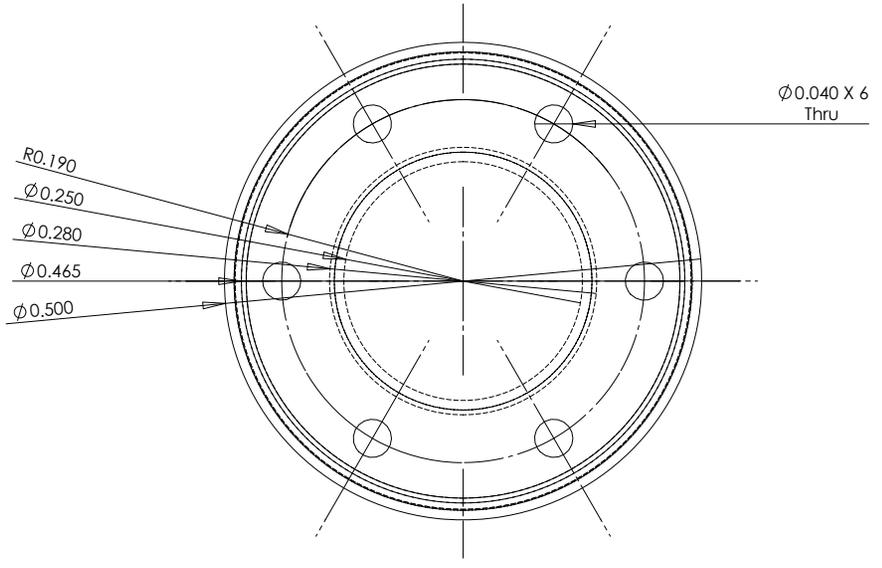
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A	Jenny McConnell	A	
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ALL MEASUREMENTS RELATING TO CRANKSHAFT PINS AND DRAINAGE HOLES ARE REPEATED 3 TIMES, OFFSET BY 120 DEGREES

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FILLET ALL EDGES R0.01

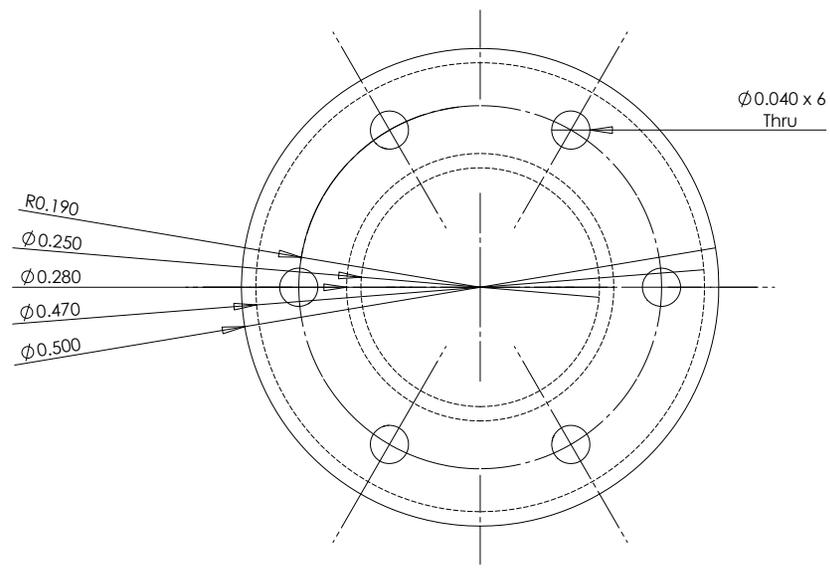
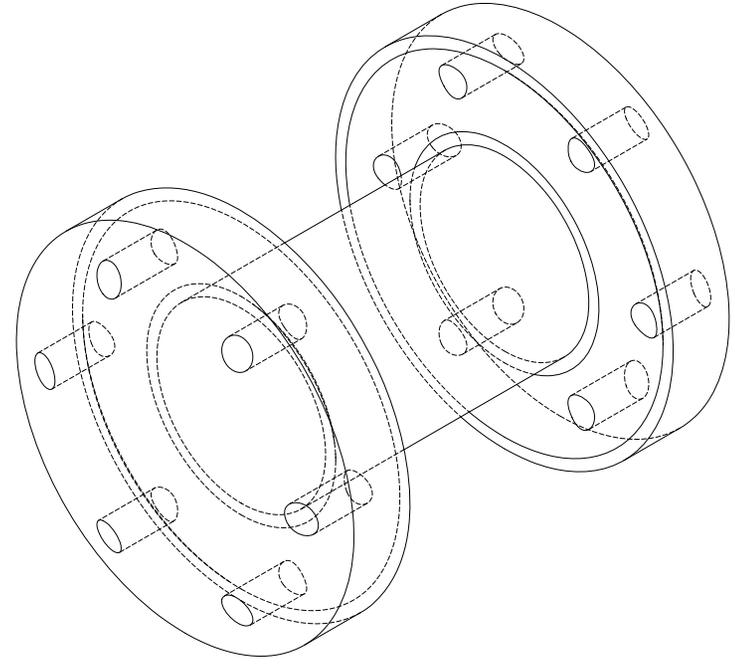
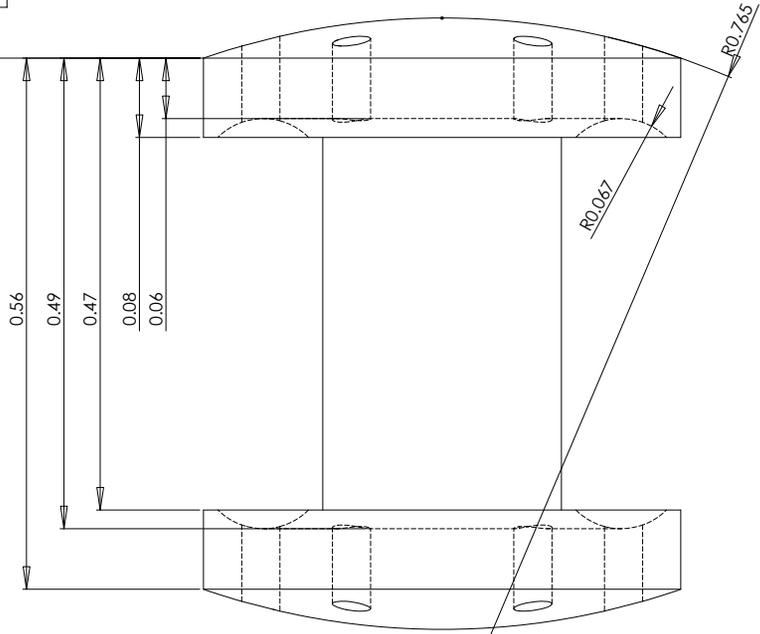


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SHEET 1 OF 1			

BOTTOM AND TOP PART OF PIN ARE IDENTICAL



A



Qty: 18

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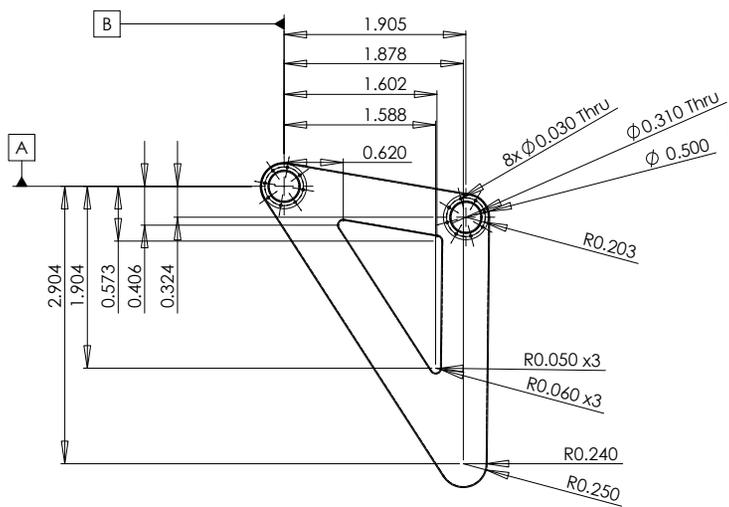
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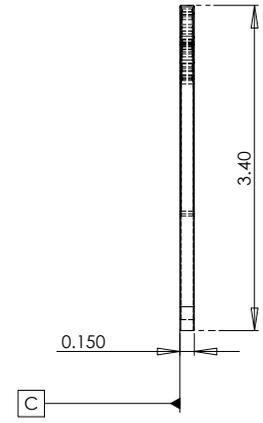
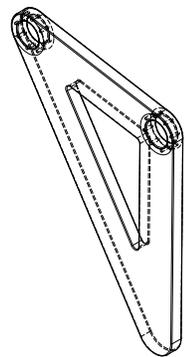
BOTTOM AND TOP OF PIN ARE IDENTICAL



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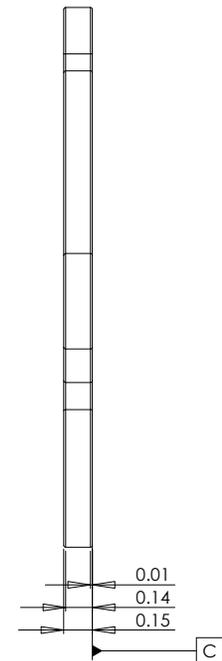
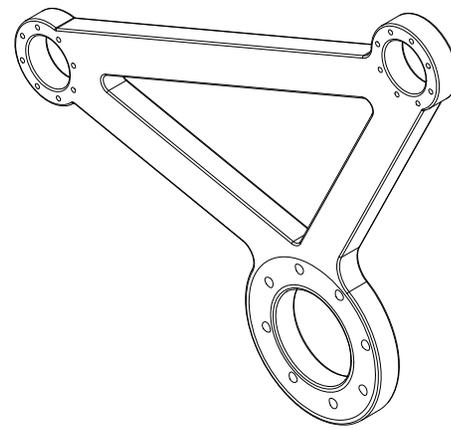
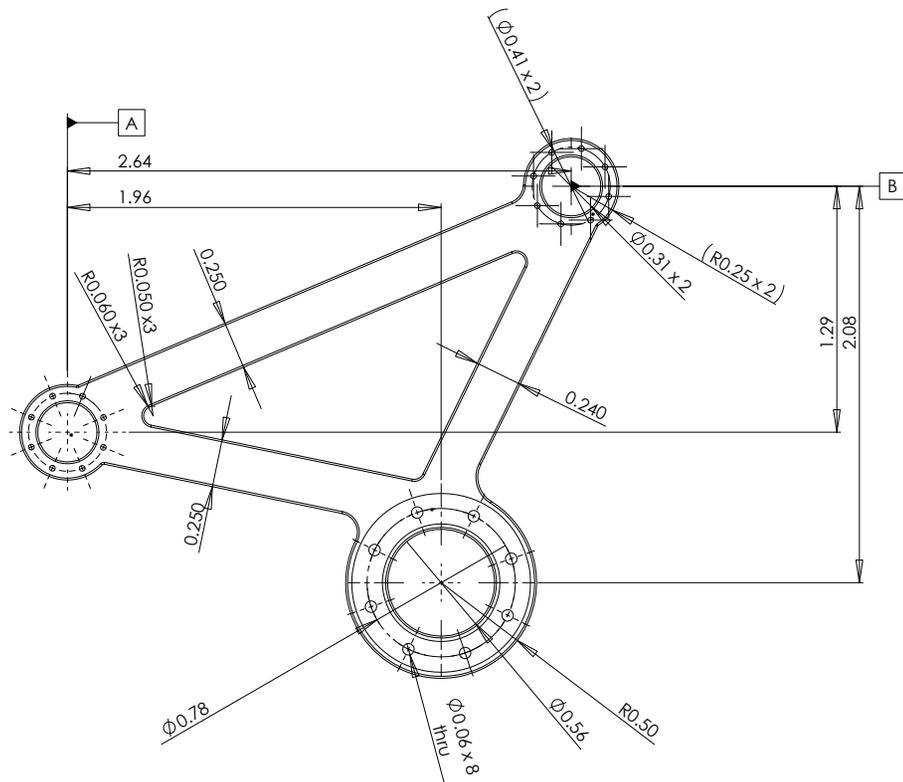
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FILLET ALL EDGES R0.01 INCHES



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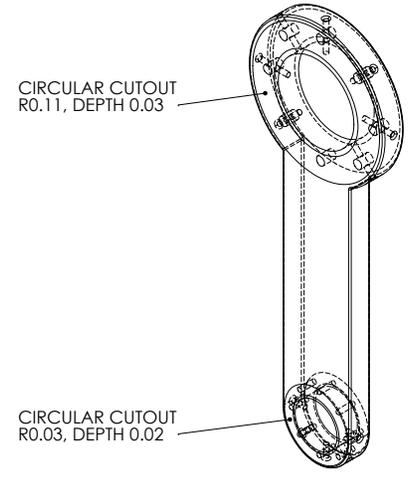
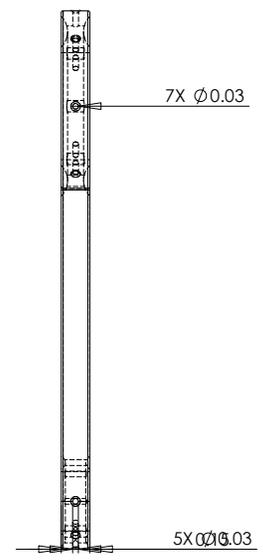
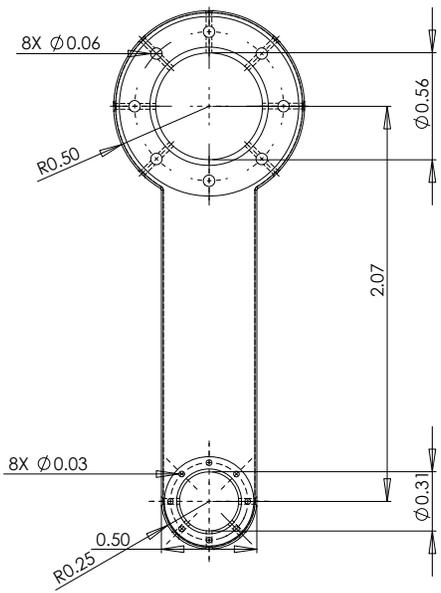
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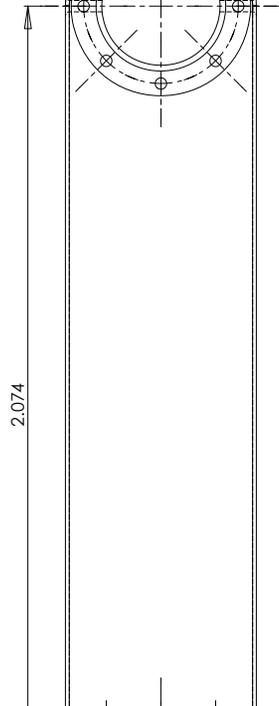
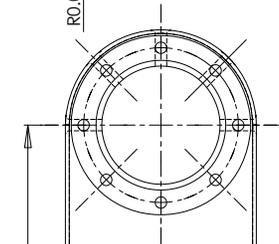
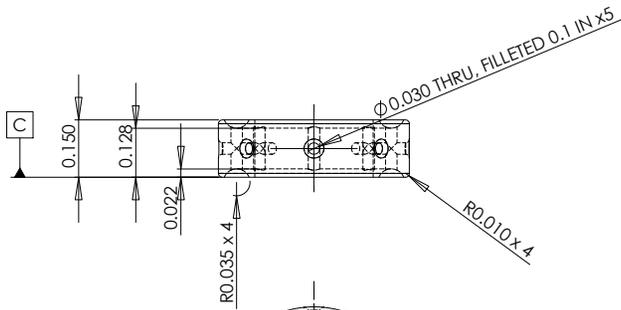
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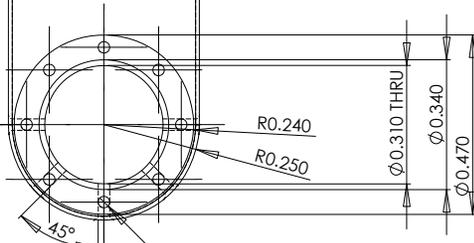


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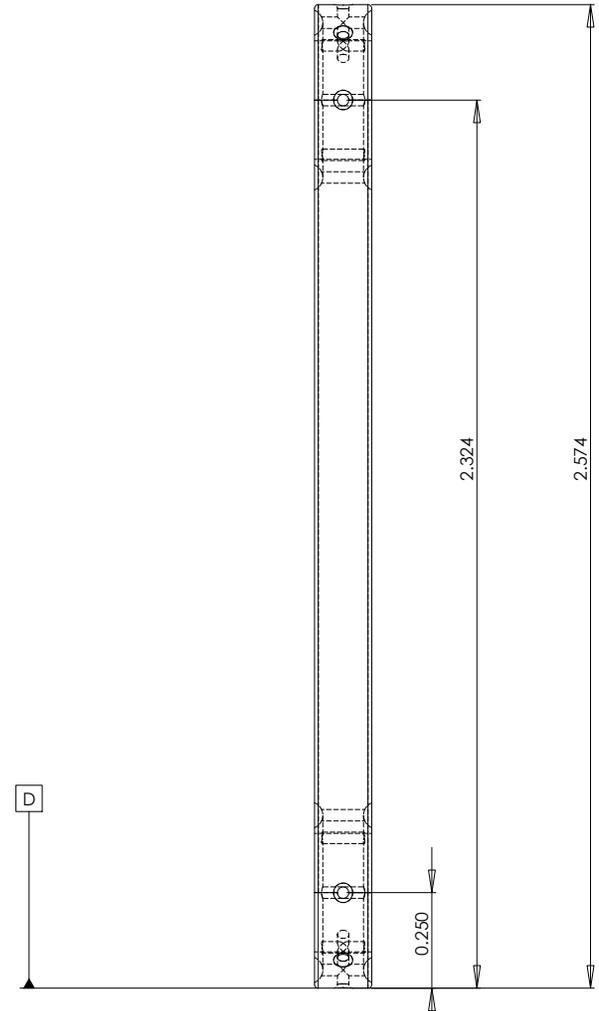
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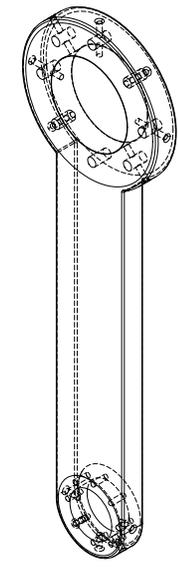
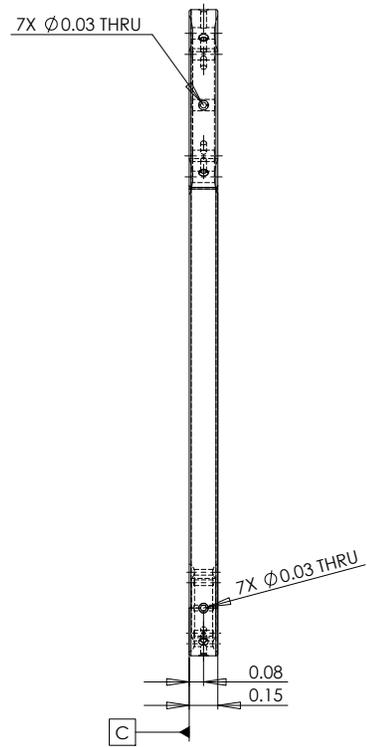
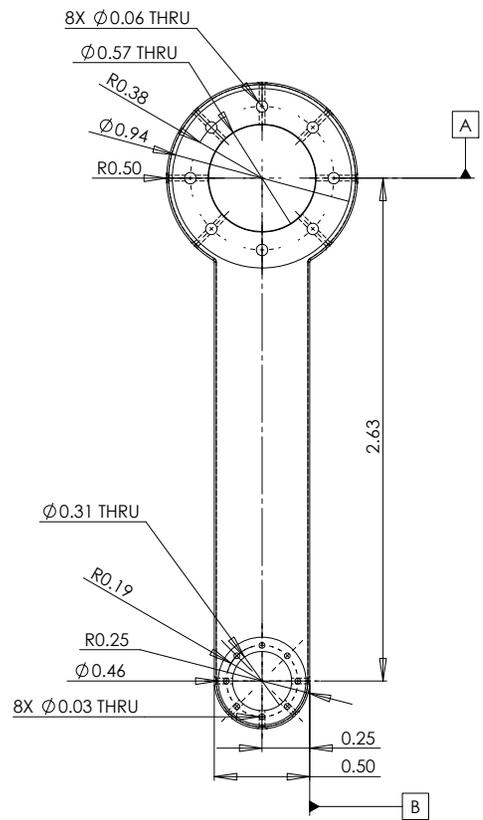


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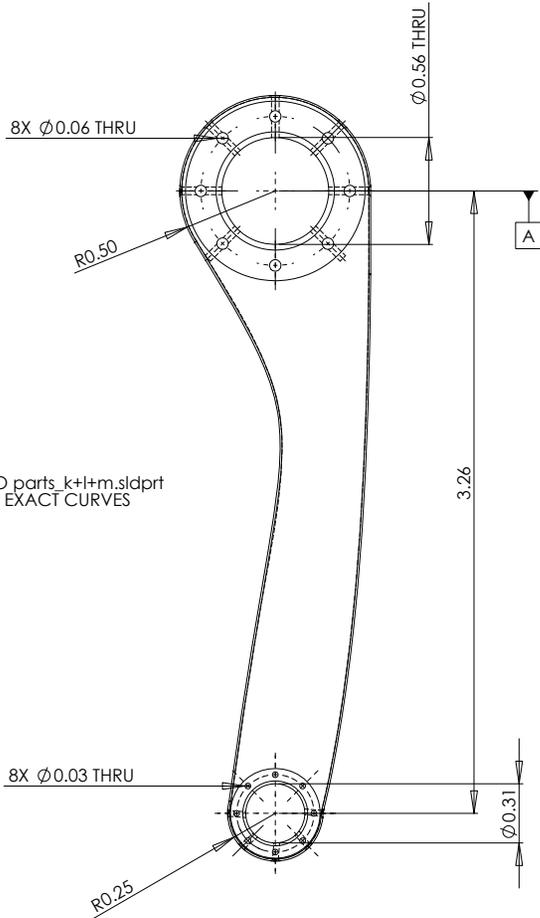
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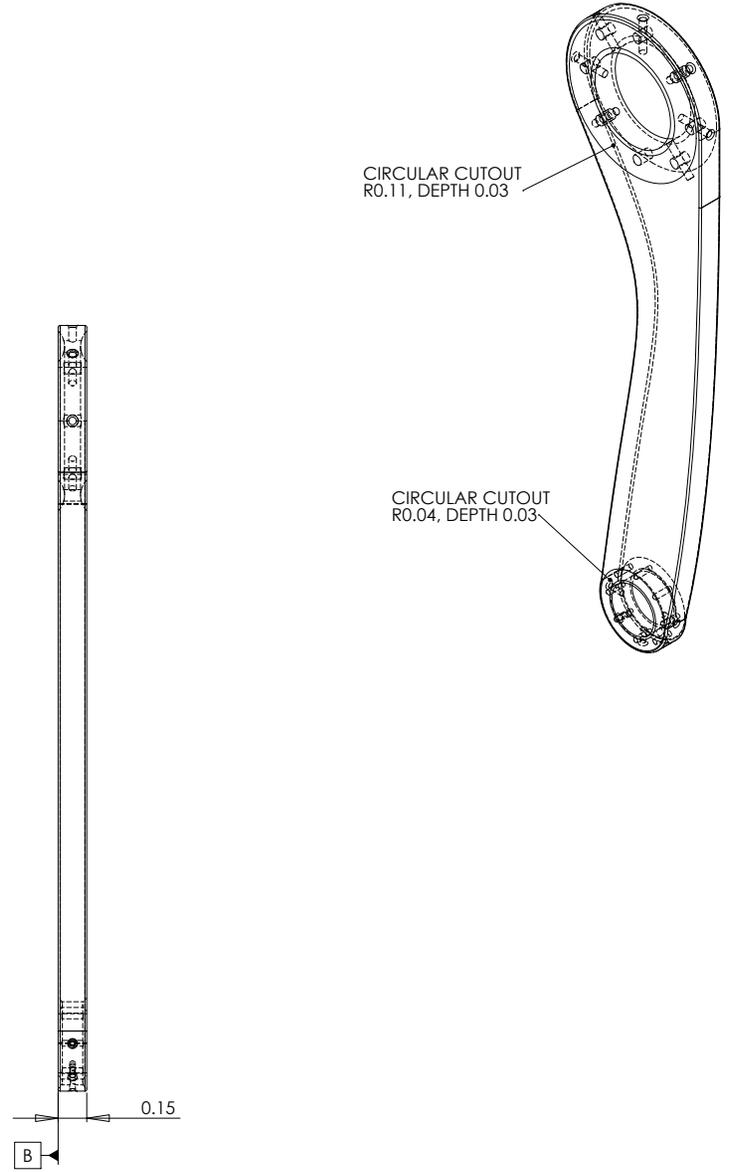


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FOR EXACT CURVES

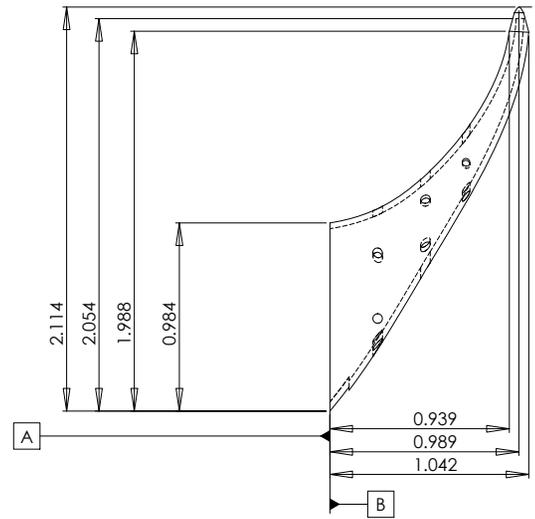
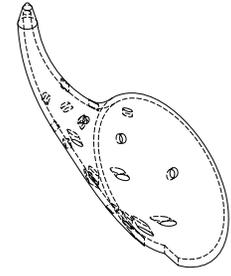
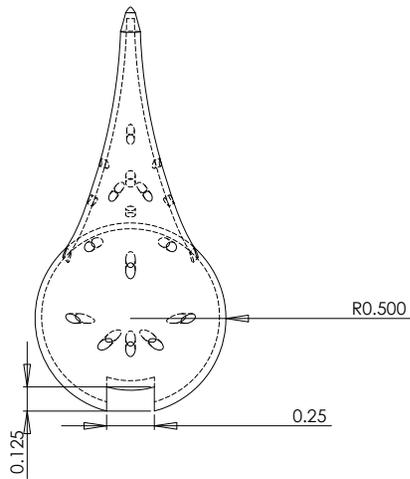


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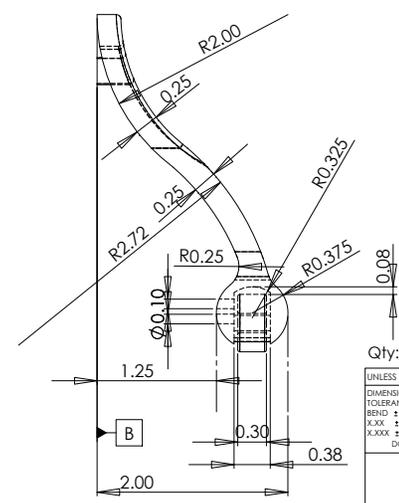
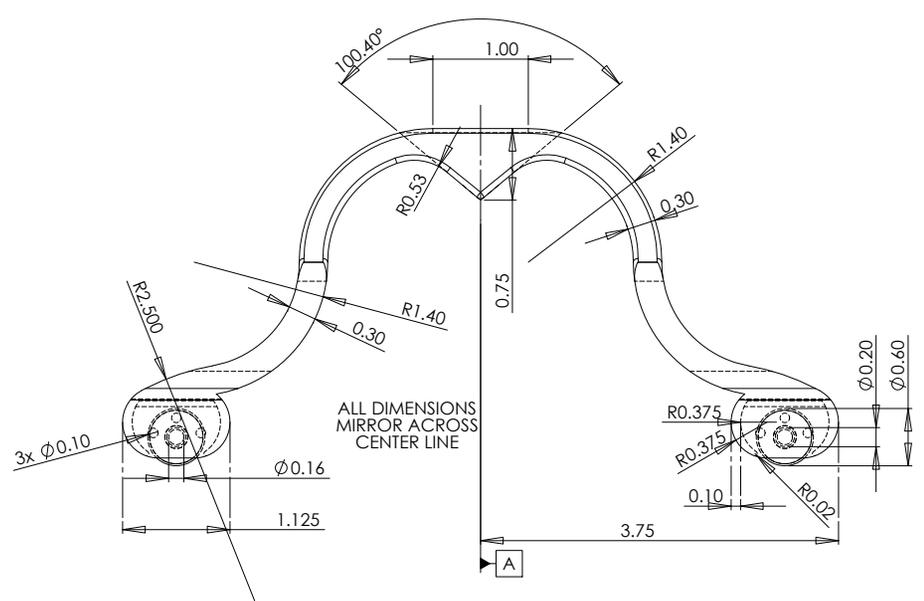
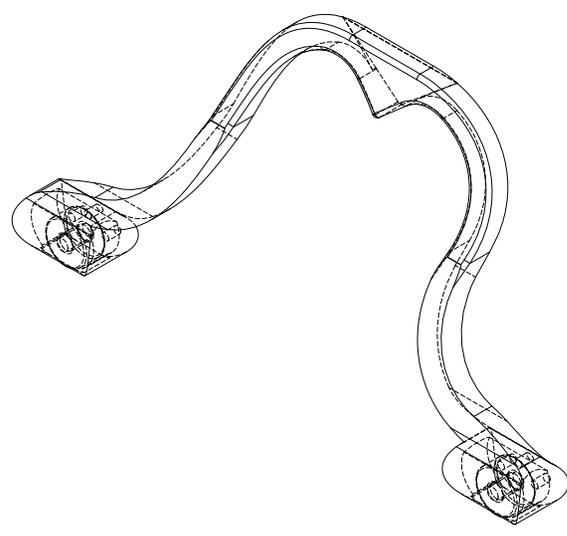
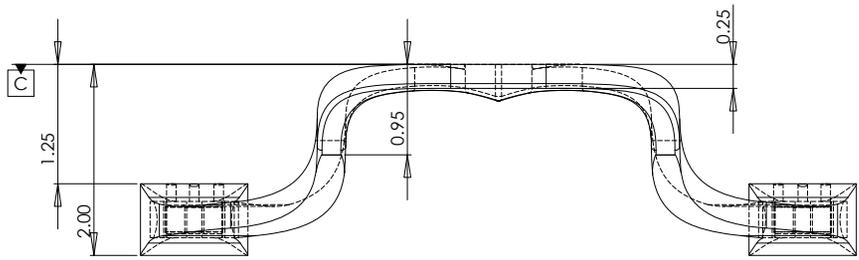
FILLET ALL EDGES R0.01



FOR FURTHER  
DIMENSIONS REFER TO  
SURFACES IN CAD FILE

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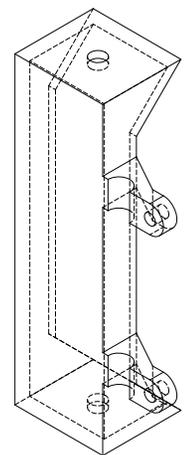
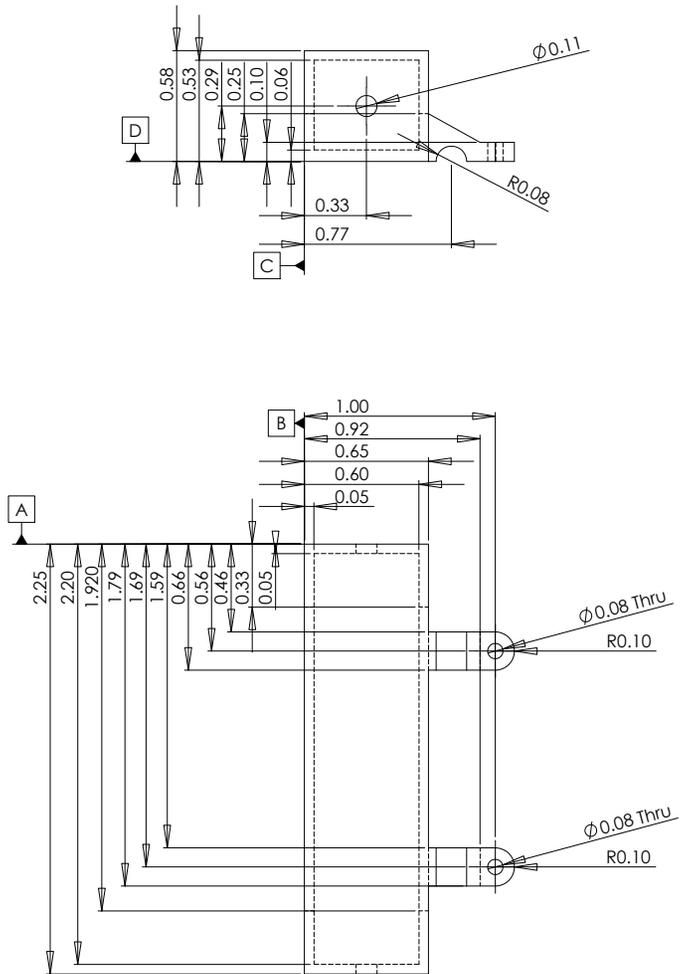




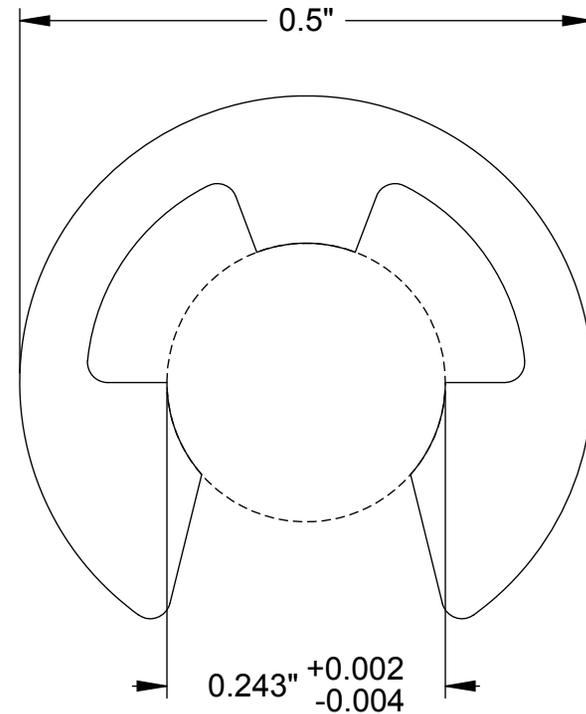
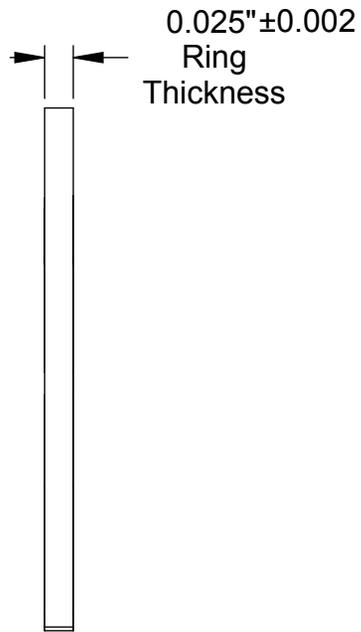
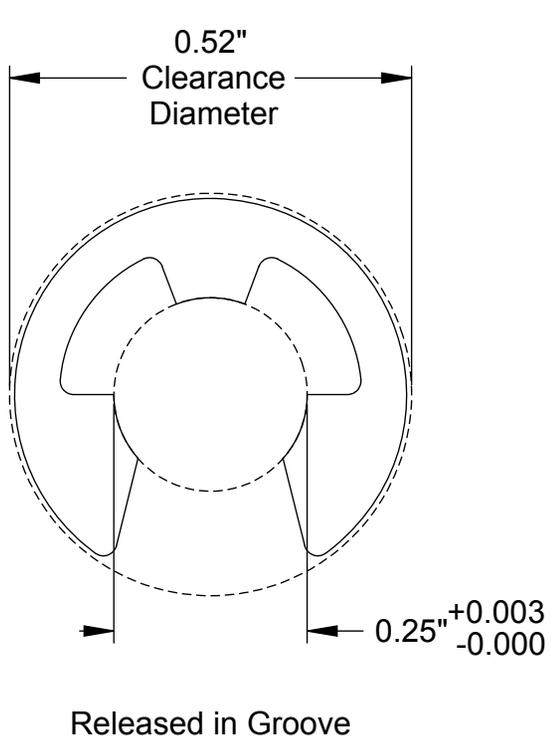
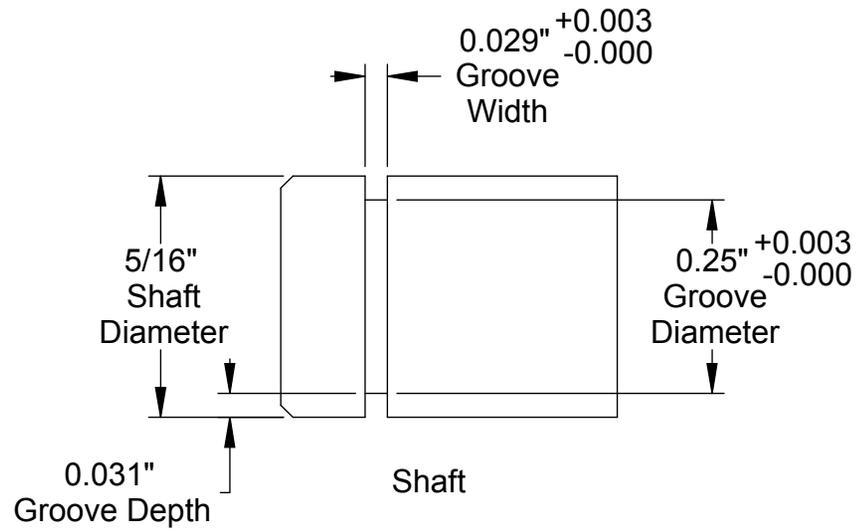
Qty: 2 Material: Rapid prototype material

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: BEND ±1° XXXX ±0.010 XXXXX ±0.005 DO NOT SCALE DRAWING	Team Name <b>BLANK</b>
TITLE: <b>Training wheel assembly</b>	
SIZE <b>A</b>	Sheet Prepared By: <b>Murphy Kitchell</b>
SCALE: 1:1	Checked by J. McConnell
	REV <b>A</b>
	SHEET 1 OF 1

ALL FILLETS R0.05 UNLESS SPECIFICALLY DIMENSIONED

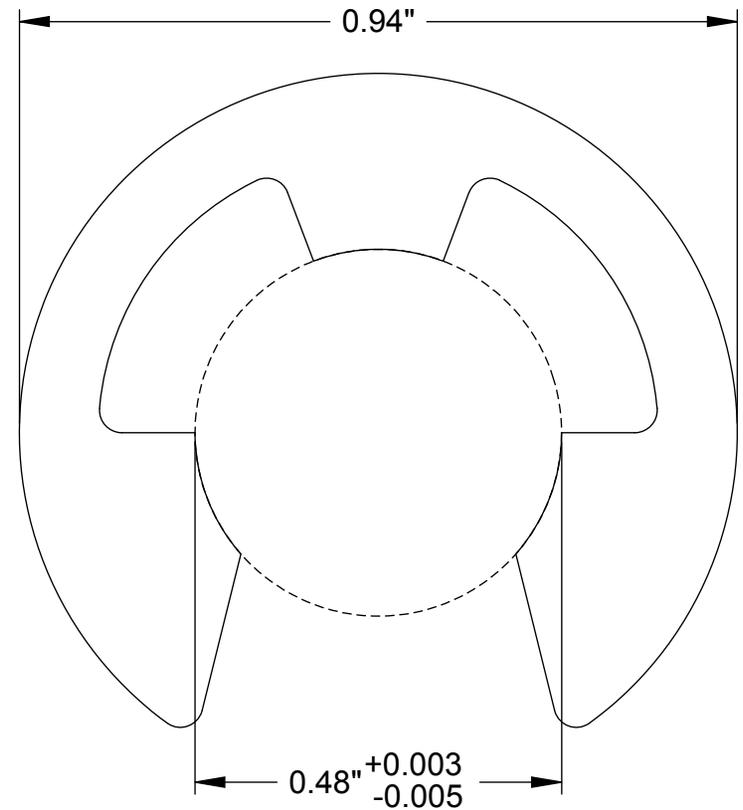
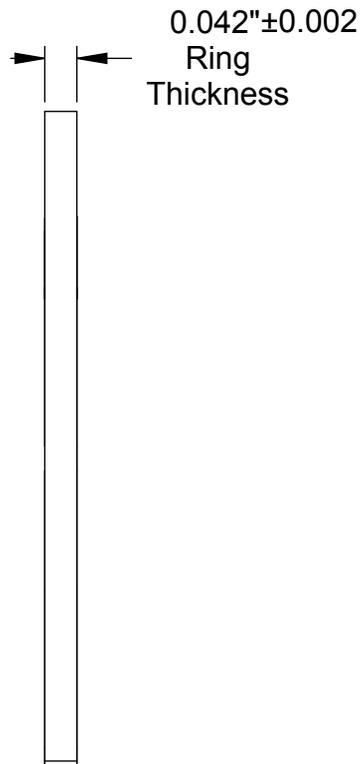
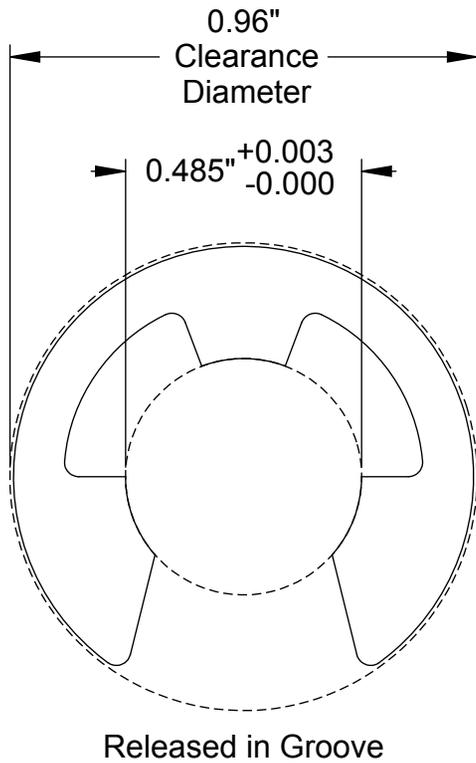
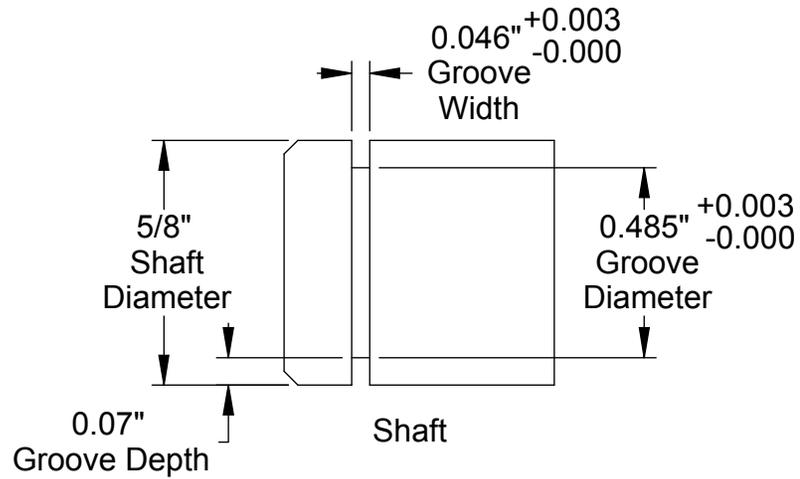


Quantity: 4		Material: Rapid Prototyping Material	
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: BEND ±1° X.XXX ±0.010 X.XXXX ±0.005 DO NOT SCALE DRAWING		Team Name: Team BLANK	
		TITLE: Battery Holder	
		SIZE: A	Sheet Prepared By: Arjun Aletty
SCALE: 1:1		Checked by: Murphy Kitchell	SHEET 1 OF 1



Note: Clearance diameter is the diameter of a housing that can pass freely over the ring.

<b>McMASTER-CARR</b> <small>CAD</small> <a href="http://www.mcmaster.com">http://www.mcmaster.com</a> © 2011 McMaster-Carr Supply Company <small>Information in this drawing is provided for reference only.</small>	PART NUMBER <b>98407A132</b>
	Zinc and Yellow Chromate-Plated Steel Side-Mount External Retaining Ring



Note: Clearance diameter is the diameter of a housing that can pass freely over the ring.

**McMASTER-CARR** CAD

PART NUMBER

**98407A140**

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Zinc and Yellow Chromate-Plated Steel  
Side-Mount External Retaining Ring

Information in this drawing is provided for reference only.