

ENGR2330

Möbius Gear Mechanism

ENGR2330 Final Project

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12/15/2011

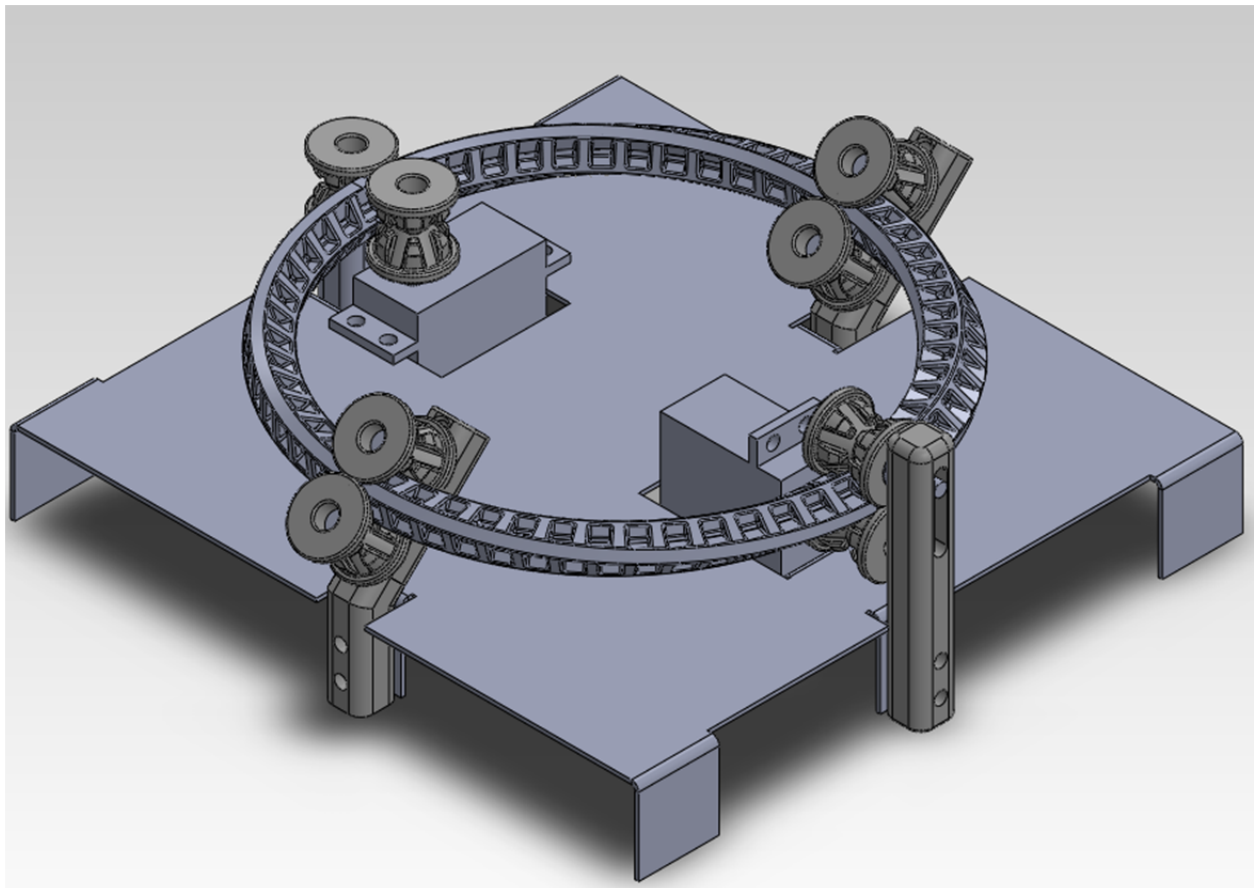


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Executive Summary

The purpose of this project was to create a mechanical system that integrated various techniques we had acquired throughout the course, Mechanical Prototyping, including manipulating sheet metal, 3D printing, casting polymers, and surface finishing. Specifically, Team Phillipp sought to achieve this through the design and construction of a functional moving Möbius mechanism. We drew inspiration from our instructor's original design but diverged from the actual design with our conclusion that having stationary gears that rotated the Möbius strip would be more effective.

Structures

Möbius Strip

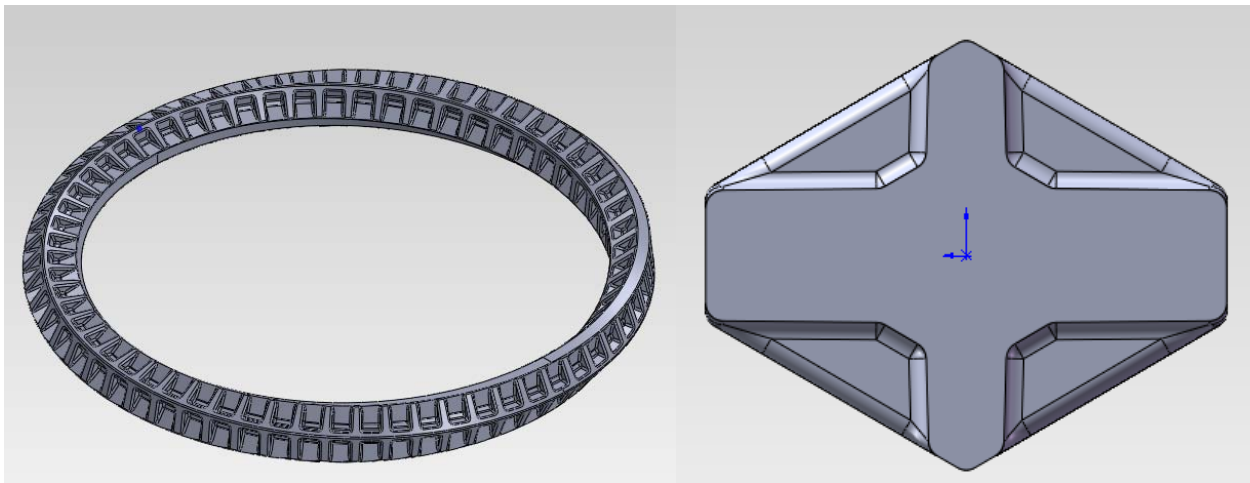


Figure 1: (R) The full Möbius strip on the right. (L) The profile view of the Möbius strip.

The Möbius strip was constructed by performing two sweeps 180 degrees apart and having each swept loft rotate 90 degrees. The strip is 6" in diameter, has a width of 0.6", and a height of 0.5". The gear track was created by offsetting a plane from the face of the strip and creating a lofted cut from the face of the strip to the new plane.

The profile of the strip is similar to a V belt. This design, along with the shape of the gear discussed later in this paper, prevents the strip from slipping out between the gears. This also provides more surface area between the gears and the strip.

Möbius Strip Molds

The Möbius strip had to be flexible and compliant enough to rotate to different angles through the gears. At the same time, the strip had to be sturdy enough such that it retained the pattern of the gear track and allowed the gears to push it along without drooping. We decided that the urethane rubber VytaFlex 40 polymer had the necessary characteristics we sought for our Möbius strip.

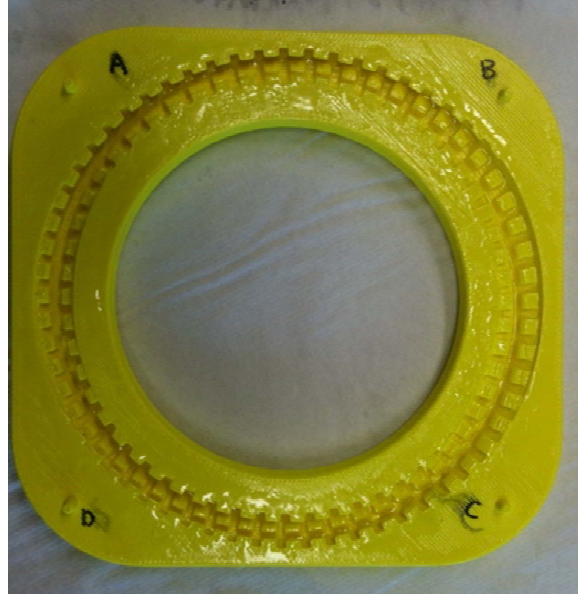


Figure 2: Epoxied Möbius Strip Mold. The pegs are labeled to ensure that the top and bottom halves align correctly

The Möbius strip molds were made by extruding a box around the Möbius strip in Solidworks. The Möbius strip was then subtracted from the extruded box. The mold was then cut in half. Pegs were added to the top half and holes were added to the bottom half to ensure that the molds were aligned correctly. The pegs were tapered to facilitate putting the two halves together.

The pegs were not labeled, so we had to determine after the RP print which pegs matched which holes. Fortunately the center hole was offset and it was fairly simple to figure out the correct orientation of the molds and label them. Epoxamite was applied to the mold to seal the RP filaments. The mold was also shellac-ed before pouring so that the polymer would not adhere to the mold.

First the VytaFlex 40 was prepared and poured into both halves of the mold, which were subsequently vacuumed in a Vic 12 vacuum, as shown in Figure 3. The vacuum removed the air pockets from the polymer in the mold due to the excessive amount of undercuts.



Figure 3: Vacuum for molds

After the polymers had partly cured, more VytaFlex 40 was prepared and applied to the semi-cured polymer. The mold was then clamped to the table and allowed to cure for 24 hours.

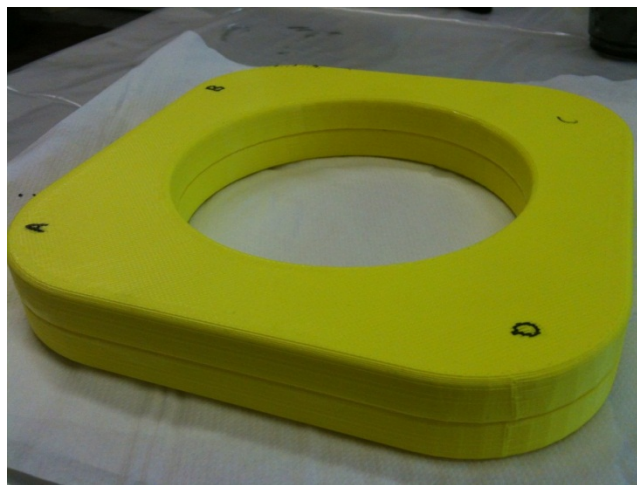


Figure 4: The Möbius mold

After the polymer was cured, attempts were made to pry open the mold. Since this did not work, the mold was sawn and chiseled away, resulting in the strip shown in Figure 7. In the future, the body of the mold would be smaller and shelled to facilitate removal of the mold.

Gear Stands

The gear stands were designed to be printed on the RP machine. The original designs are in Figure 5. However the stands were not printed correctly, so sheet metal variations were constructed due to time constraints. These stands retained the same characteristics as their RP counterparts would have had – holes of attachment and slots for adjustable gear positioning.

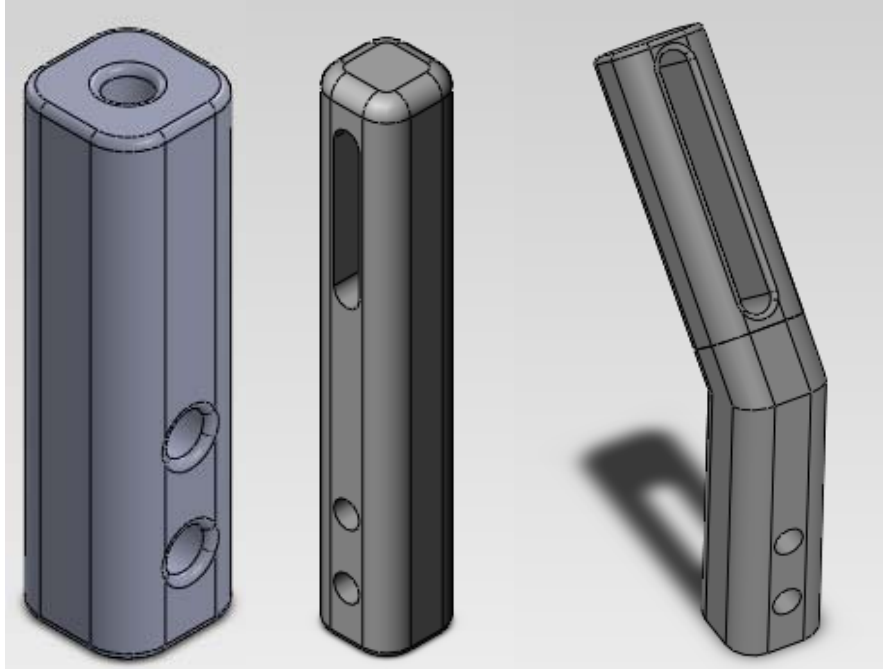


Figure 5: The 3 different stands for the gears. In order from left to right: horizontal gear stand, vertical gear stand, angled gear stand.

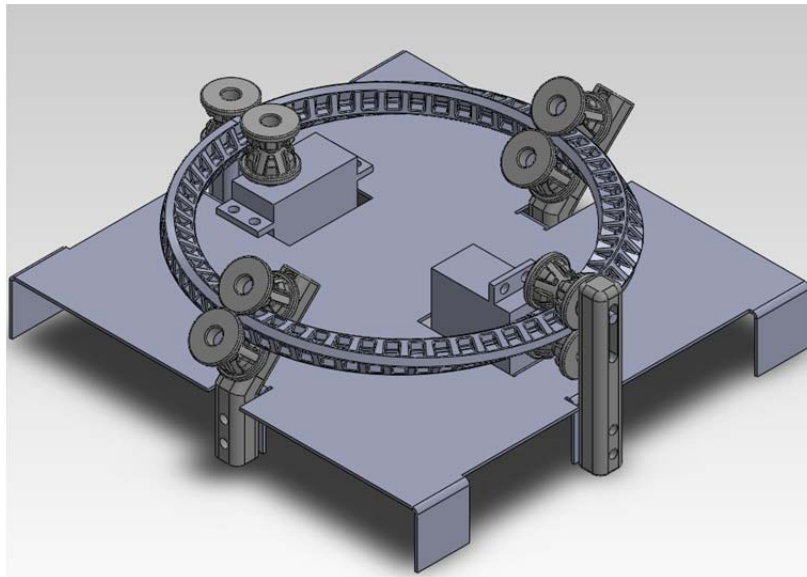


Figure 6: Implementation of the gear stands

There were a total of 8 gears in our design. The gears are paired together to hold the strip from above and below. Two of the gears are mounted directly to the servo horns while the other six gears are mounted on the gear stands shown above. The 4 sets of gears are spread evenly across the Möbius strip at the following angles: 0 degrees, 45 degrees, 90 degrees, and 135 degrees. At zero degrees, the gear is mounted on the horizontal gear stand and at 90 degrees the gear is mounted on the vertical gear stand. The same angled gear stand is used at 45 and 135 degrees.

The slots in the vertical and angled gear stands gave us flexibility on where the gears were mounted. There are no such slots on the horizontal gear stand – instead the slots are on the baseplate so that the gear stand can slide.

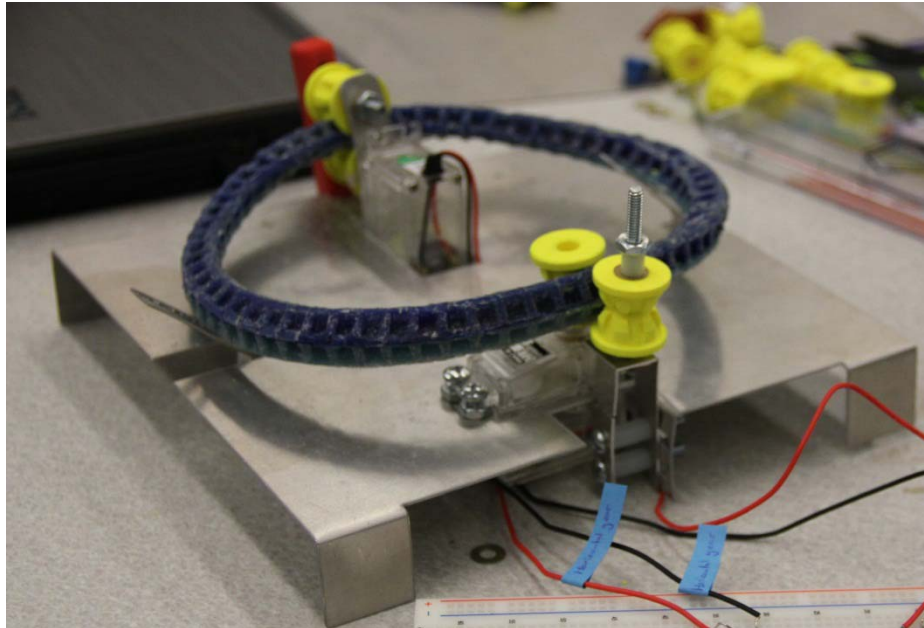


Figure 7: Möbius Strip Assembly

Base

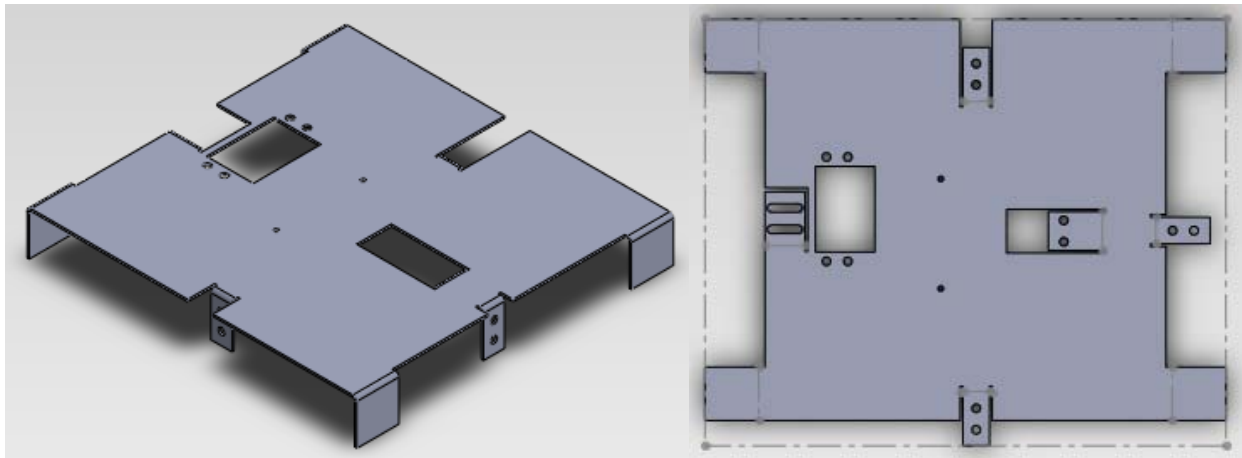


Figure 8: The folded sheet metal base is on the left and the unfolded pattern is on the right

The servo motors, gear stands, and batteries are mounted on the baseplate. The mounting points for the gear stands were designed such that the stands would lie flush with the ground. This, along with the 4 edge flanges, hold the base plate 1" off of the ground. The base plate is constructed of 0.030" aluminum sheet metal. The base plate was cut on the water-jet machine because it would have been difficult to cut the tabs and punch the holes by hand.

All of the mounting points are static with the exception of the slots for the vertical gear stand. This slot allows us to adjust the distance between the inner and outer gear.

Joins and Fasteners

The gears had a recessed cross onto which the servo horn was press-fit. The servos were then epoxied to the gears.

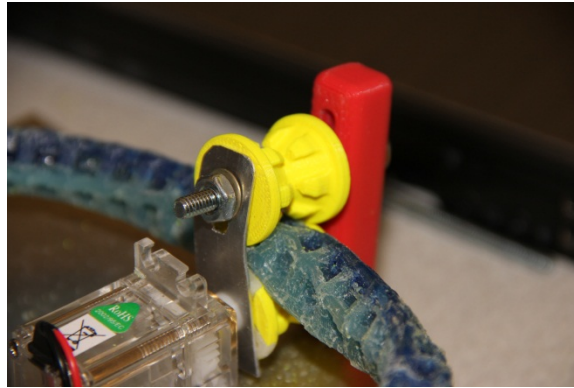


Figure 9: The servo horn is press-fit onto the gear

Many 8-32 screws of varying lengths – specifically, five 2", six ¼", three ½" – and two 1" 4-40 screws were used to attach the stands to the base as well as the gears to the stands. Nuts were used to secure the screws in place, and washers and nylon spacers were included to reduce friction between components.

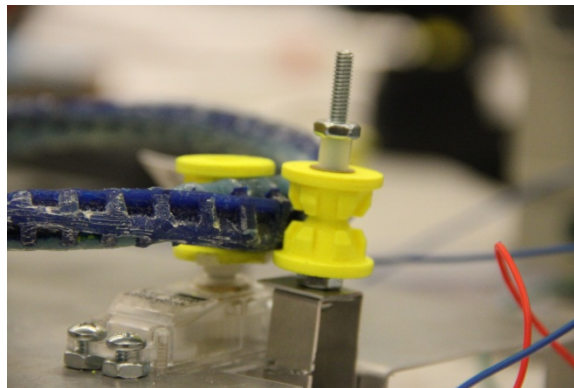


Figure 7: Close-up of a gear with a nylon spacer

Power

The gears that move the Möbius strip are powered by two Gear Motor 4 (GM4) servos. These continuous rotation servos have an operating range of 3-6 V, providing a speed of roughly 67-77 RPM. As mentioned earlier, two of the gears are directly mounted onto the two servos. Because the servos are driving the same Möbius strip, it is important that they run at the same speed. To achieve this

synchronization, they were attached in parallel to three AA batteries, which provided 4.5 V. Potentiometers were also attached to the motors so that fine-tune adjustments of the speeds of the servos could be made but the potentiometers only functioned as on-off switches.

A laboratory DC Power Supply was used instead, so that the voltage to each of the motors could be controlled independently. The driving voltage was 2.9 volts.

Transmission

Gears

The gears were designed to accommodate the shape of the Möbius strip. Since the Möbius strip is designed similarly to a v-belt to constrain the gears, the gears needed to be made with a groove along the toothed face. We designed them with a matching profile, but when we attempted to mate them in Solidworks they ended up having collision errors along every tooth. The only way to resolve this problem, while still retaining the ability to drive the Möbius gear, was to reshape the gears with a custom profile that is essentially the opposite of an involute.

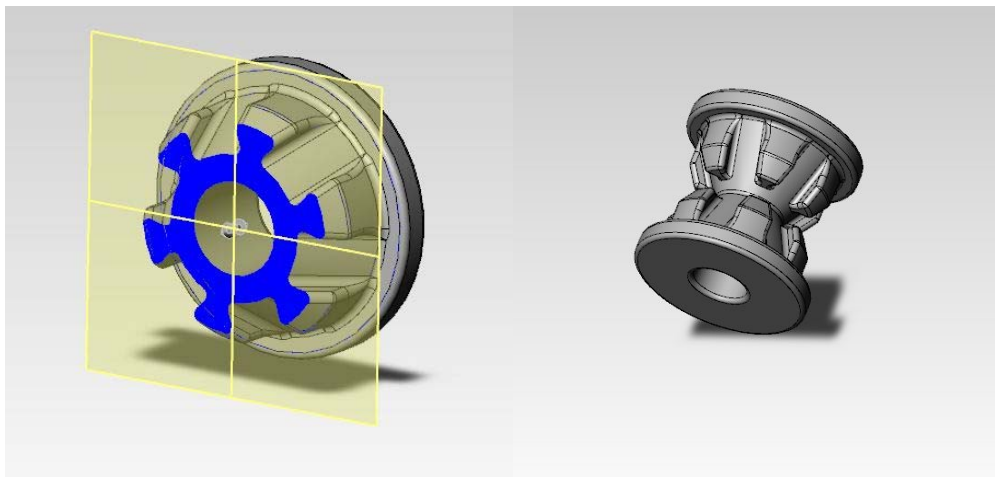


Figure 11: A cross-section of the driving gears, demonstrating the shape of the teeth that drives the Möbius gear

The gears were printed on the FDM rapid prototyping machine. We were able to run the Möbius strip with far fewer gears than we originally expected (we printed 16) because they fit so well. A nylon spacer was placed down the shaft of the gear to reduce friction.

There was no slippage on the Möbius strip when the distance between the paired gear stands were correctly maintained. The passive planetary gears were removed from the final design to reduce friction in the movement of the Möbius strip.

COTS

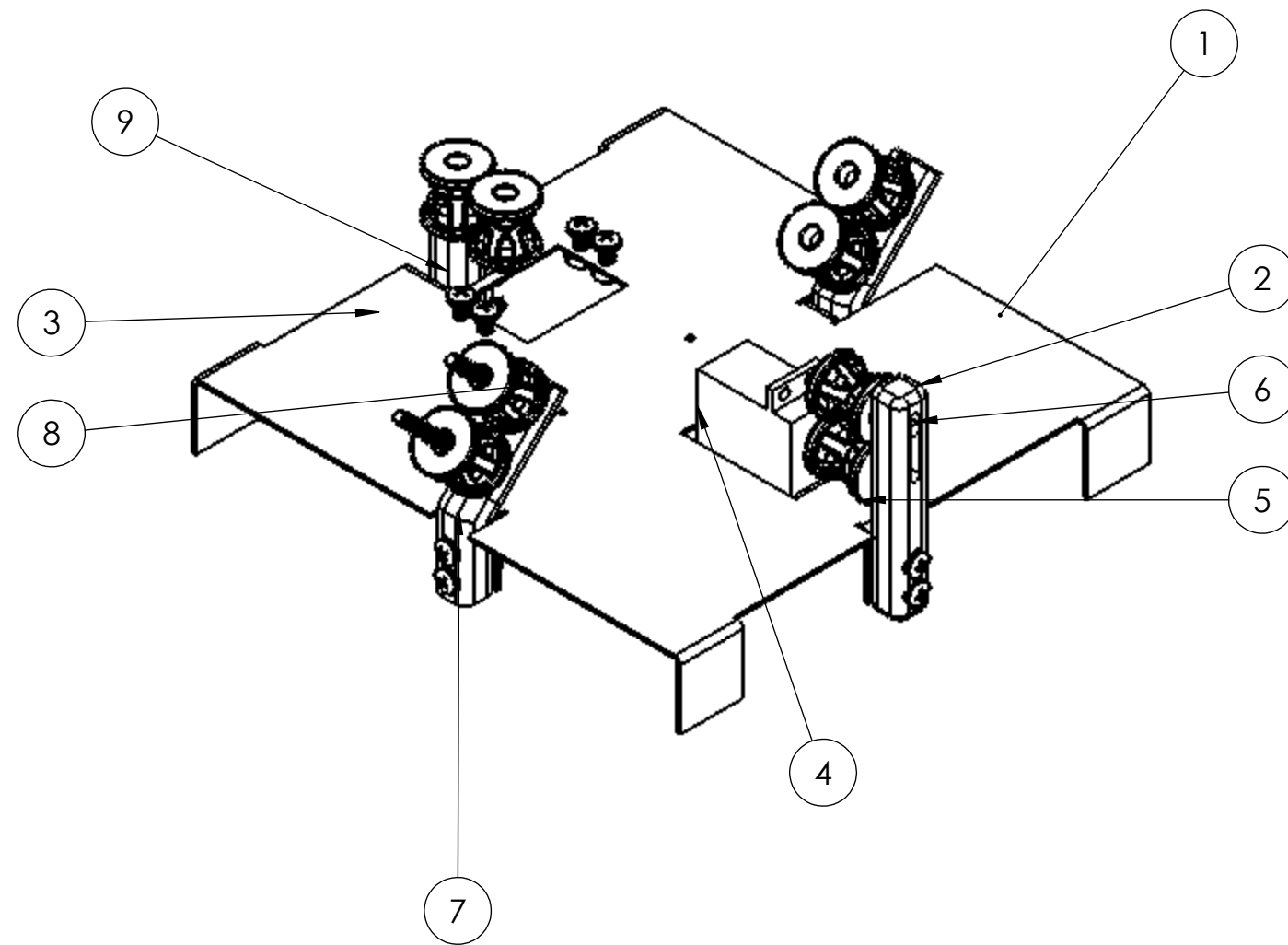
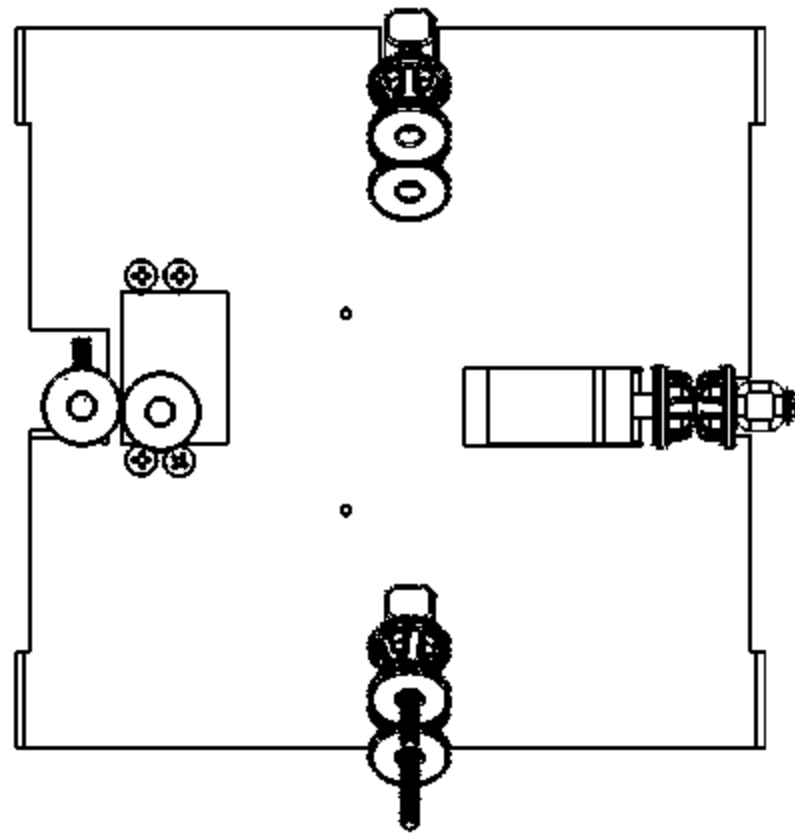
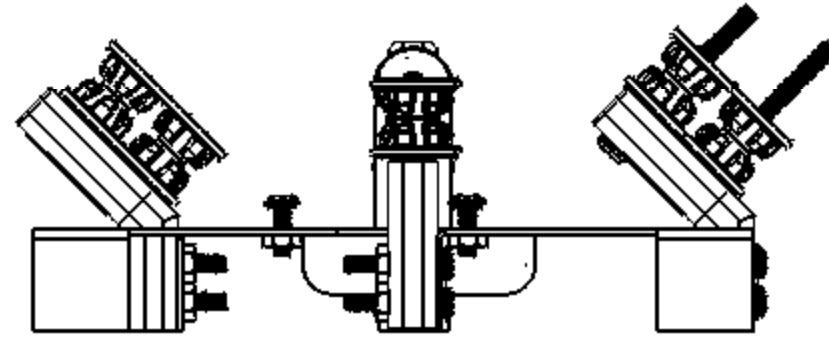
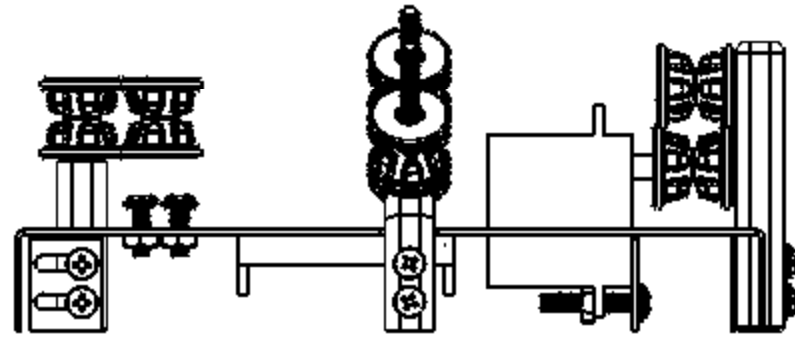
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2	8-32 1" machine screws
4	8-32 1/2" machine screws
2	8-32 1/4" machine screws
18	8-32 hex nuts
2	4-40 1" machine screws
2	4-40 hex nuts
2	1" nylon spacers
3	3/4" nylon spacers
4	1/2" nylon spacers

4

3

2

1



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2	stand1_rev3		1
3	MobiusGear_rev4		1
4	servo		2
5	gear 4		8
6	gear_holder		6
7	stand_bottom_oute r_rev3		2
8	short_stand2_rev3		2
9	stand_horizontal		1
10	battery_holder		1
11	90272A205		2
12	90272A194		6
13	90272A199		9
14	90480A009		12

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 X.XXX ± .005 125/

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.005 R OR CHAMFER MAX

APPROVED	DATE
PREP BY Ariel Leigh	12-16-11
CHECKED HELEN WANG	12/16/2011
RESP ENG	
MFG ENG	
QUAL ENG	

Franklin W. Olin
College of Engineering

Mobius Gear Assembly
Mobius Gear - Team Phillip
December 16, 2011

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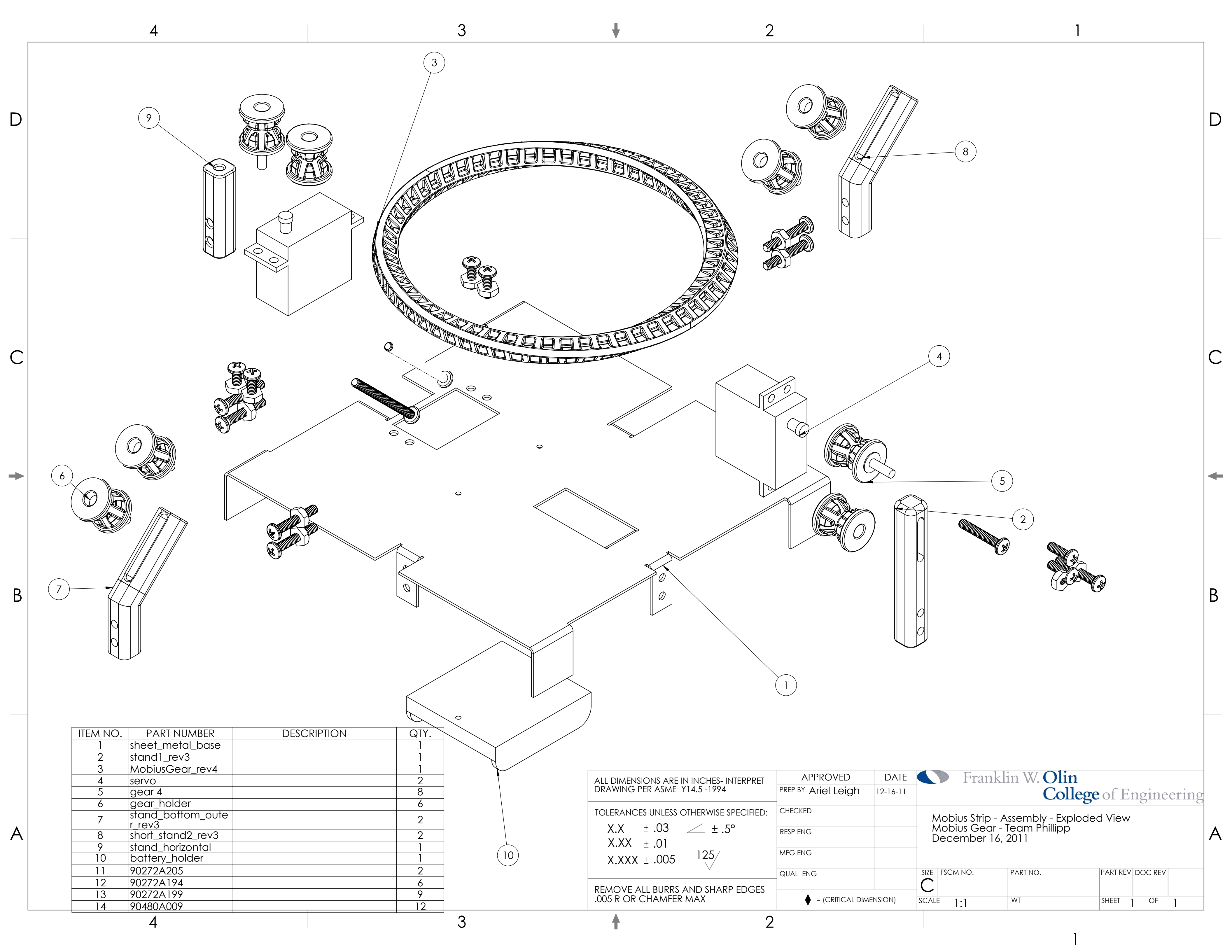
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ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
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4	servo		2
5	gear 4		8
6	gear_holder		6
7	stand_bottom_oute r_rev3		2
8	short_stand2_rev3		2
9	stand_horizontal		1
10	battery_holder		1
11	90272A205		2
12	90272A194		6
13	90272A199		9
14	90480A009		12

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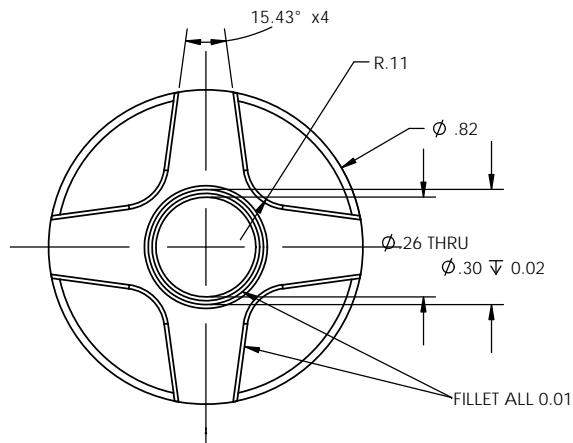
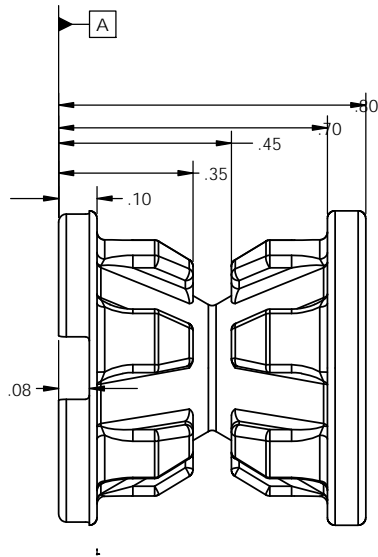
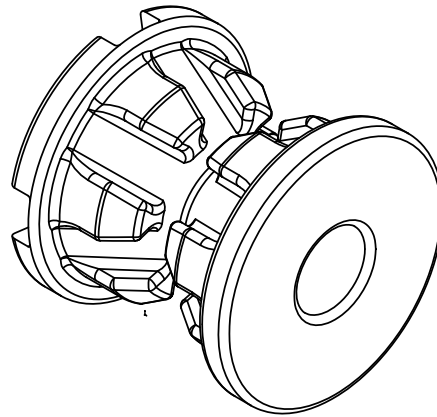
APPROVED	DATE
PREP BY Ariel Leigh	12-16-11
CHECKED	
RESP ENG	
MFG ENG	
QUAL ENG	

Franklin W. Olin
College of Engineering

Mobius Strip - Assembly - Exploded View
Mobius Gear - Team Phillipp
December 16, 2011

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SCALE	1:1	WT	SHEET 1	OF 1

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 Refer to part file for exact dimensions



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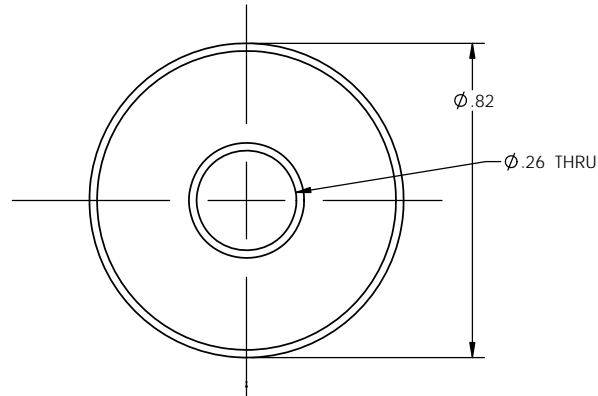
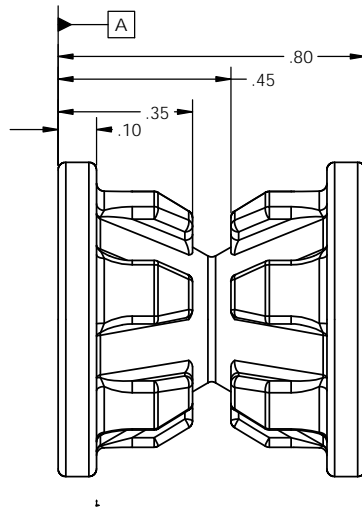
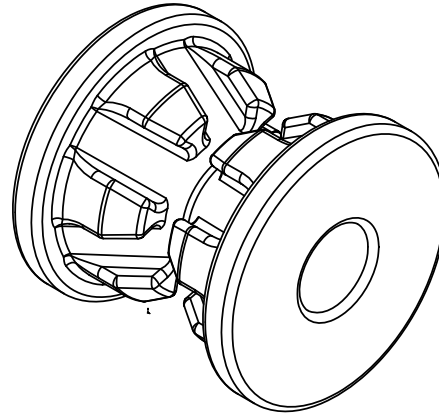
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 .005 R OR CHAMFER MAX

APPROVED	DATE
PREP BY MURPHY KITCHELL	12/15/2011
CHECKED HELEN WANG	12/16/2011
RESP ENG	
MFG ENG	
QUAL ENG	
MATERIAL: ABS	

Franklin W. Olin College of Engineering		GEAR 4 WITH SERVO CUTOUT Mobius Gear - Team Phillip 12/15/2011			
SIZE C	FSCM NO.	PART NO.	PART REV	DOC REV	
SCALE 4:1	WT	SHEET 1	OF 1		

Print on RP printer
 Fillet all edges 0.02"
 Refer to part file for exact dimensions



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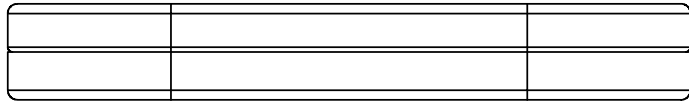


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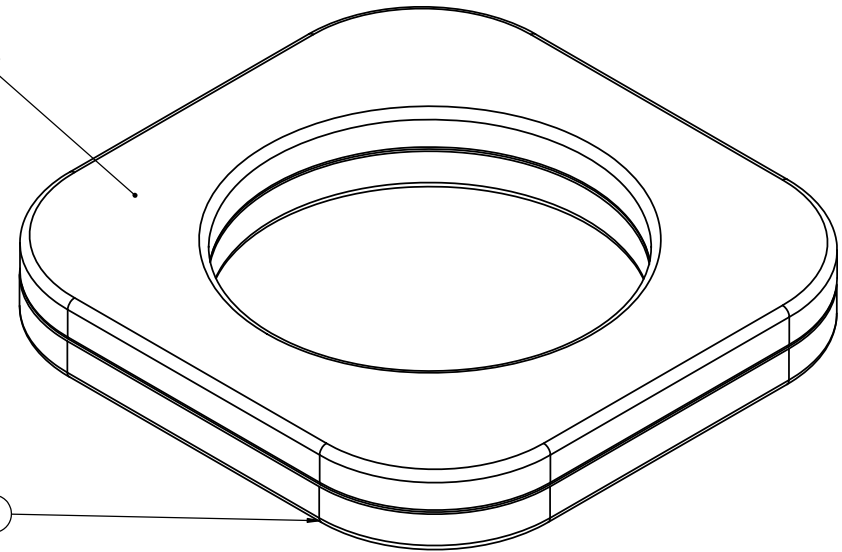
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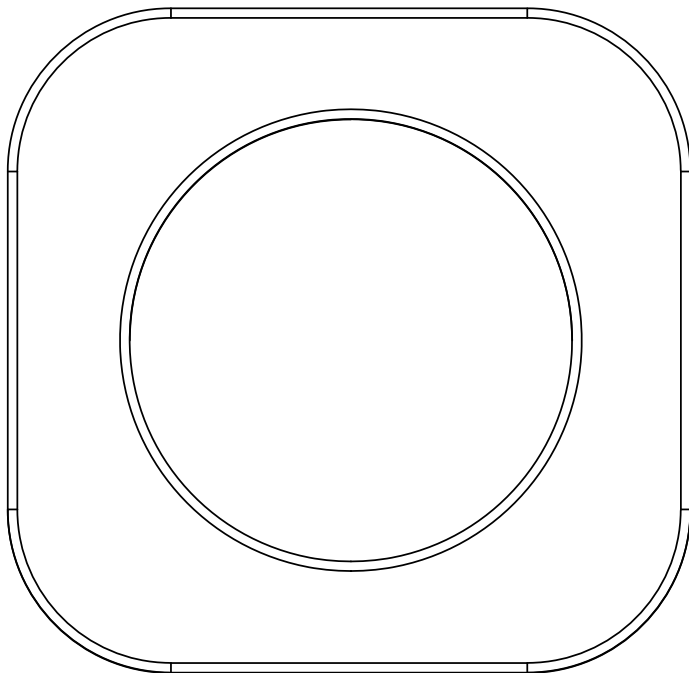
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Apply epoxamite to mold. Let cure for 10 hours.
 Pour Vytaflex-40 into each side of the mold. Place in vacuum chamber at 30mm Hg
 Let cure until partially hardened. Pour uncured polymer onto one half.
 clamp the mold closed. let cure for 24 hours.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
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2	MobiusGearMold_rev3-bottom		1

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3



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MFG ENG							
QUAL ENG			SIZE	FSCM NO.	PART NO.	PART REV	DOC REV
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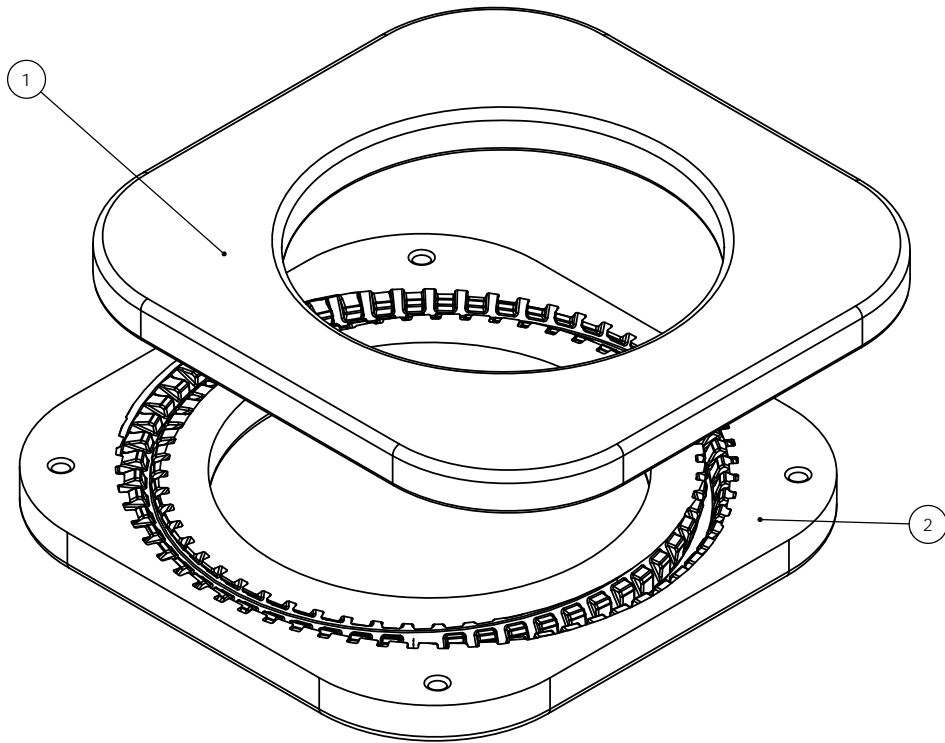


2

1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	MobiusGearMold_rev3-top		1
2	MobiusGearMold_rev3-bottom		1

ensure that the mold halves are aligned correctly. the flat part of the strip should align for both halves of the mold.



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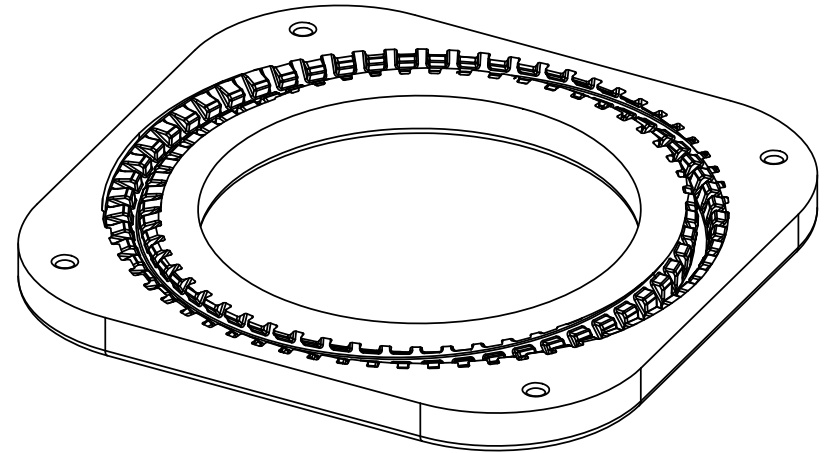
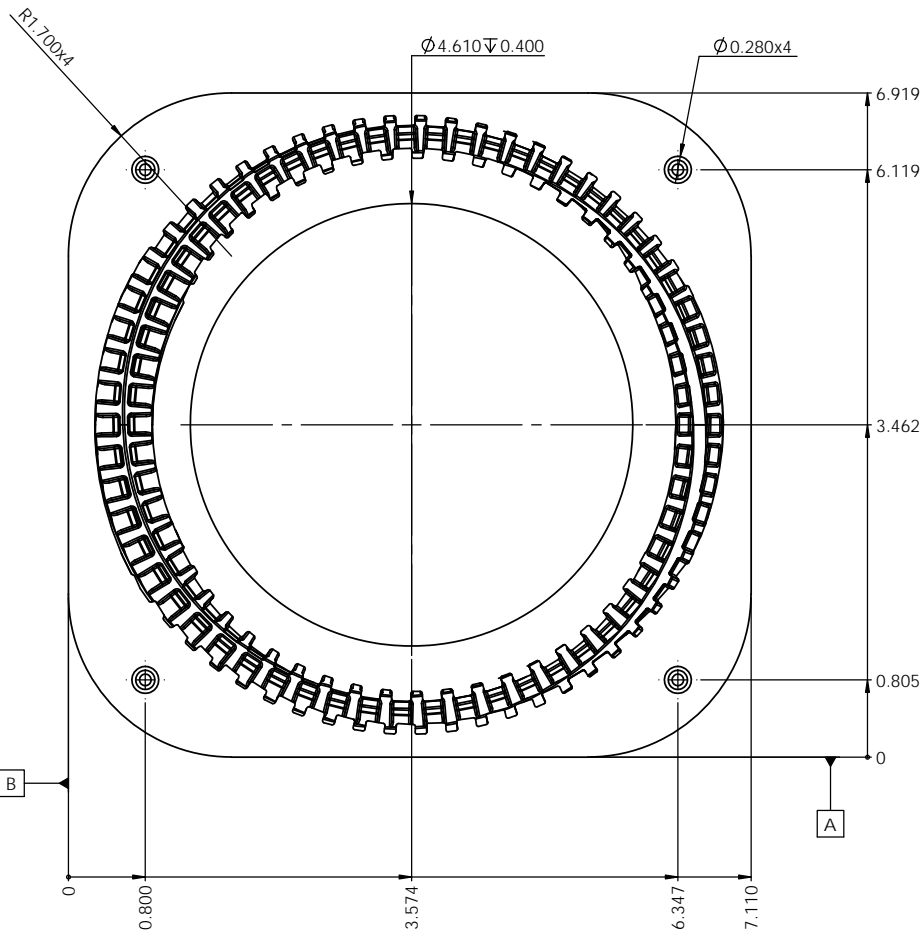
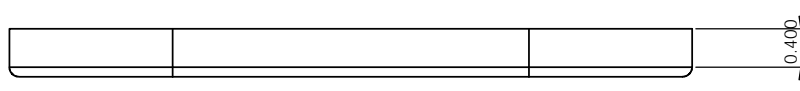
D

4

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2

1



Bottom half of mold for Möbius Gear.
See Solid Model for more details
Fillet all edges to 0.02"

Print on FDM RP Machine with a filament of 0.01"

Cover mold surface with Epoxite before pouring VytaFlex 40 into mold

ALL DIMENSIONS ARE IN INCHES- INTERPRET DRAWING PER ASME Y14.5 -1994 TOLERANCES UNLESS OTHERWISE SPECIFIED: X.X ± .03 ∠ ± .5° X.XX ± .01 X.XXX ± .005 125/√	APPROVED	DATE				
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QUAL ENG		♦ = (CRITICAL DIMENSION)				

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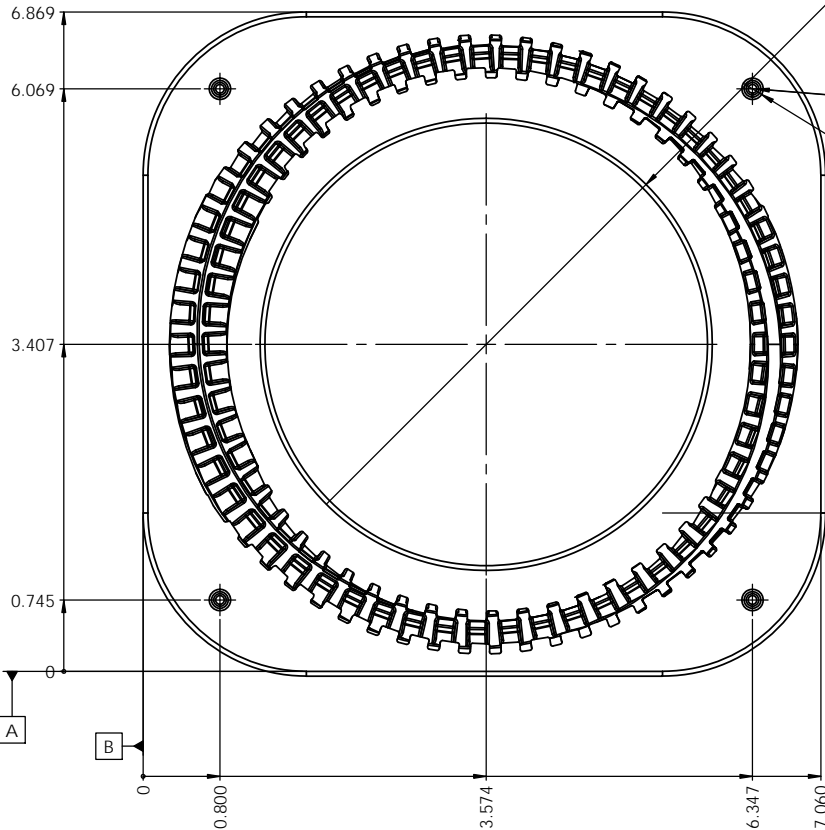
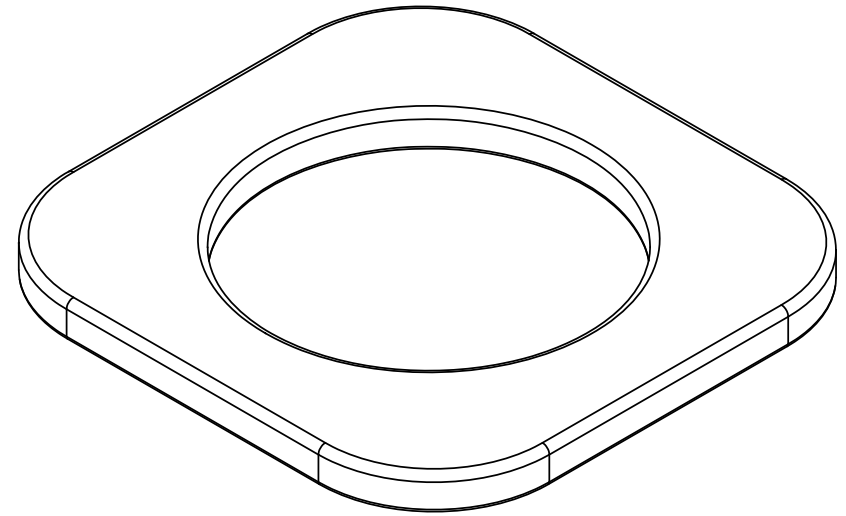
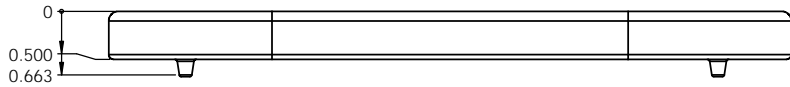
2

1



D

D



Ø4.710

Ø0.091x4

Ø0.223x4

R1.700x4

Print on FDM RP Machine with a filament diameter of 0.01"
 Top half of two-part Mobius Gear Mold. See Solid Model for details of the Mobius Gear.
 Fillet all edges 0.02"
 Cover mold surface with Epoxite before pouring VytaFlex 40 into mold

A

B

C

B

A

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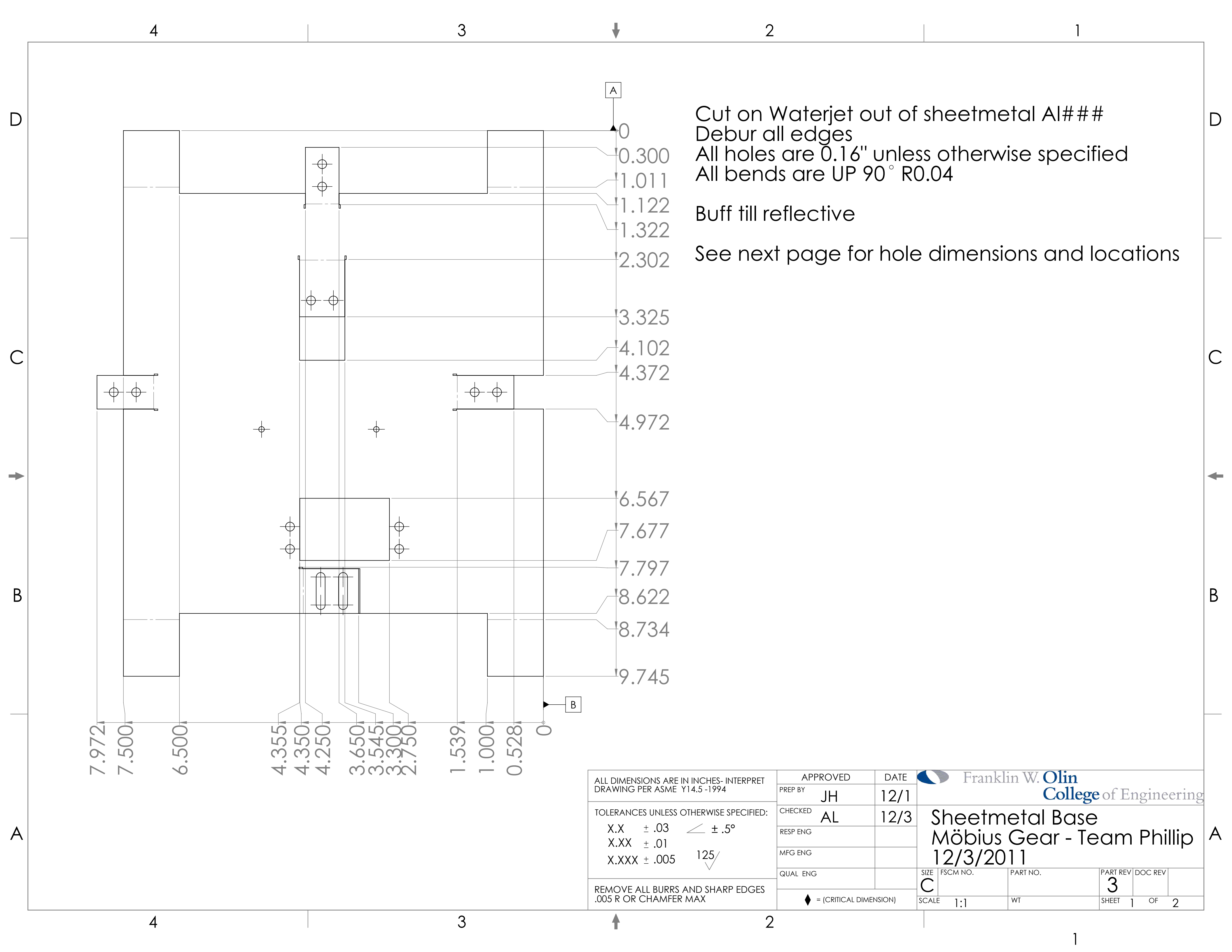
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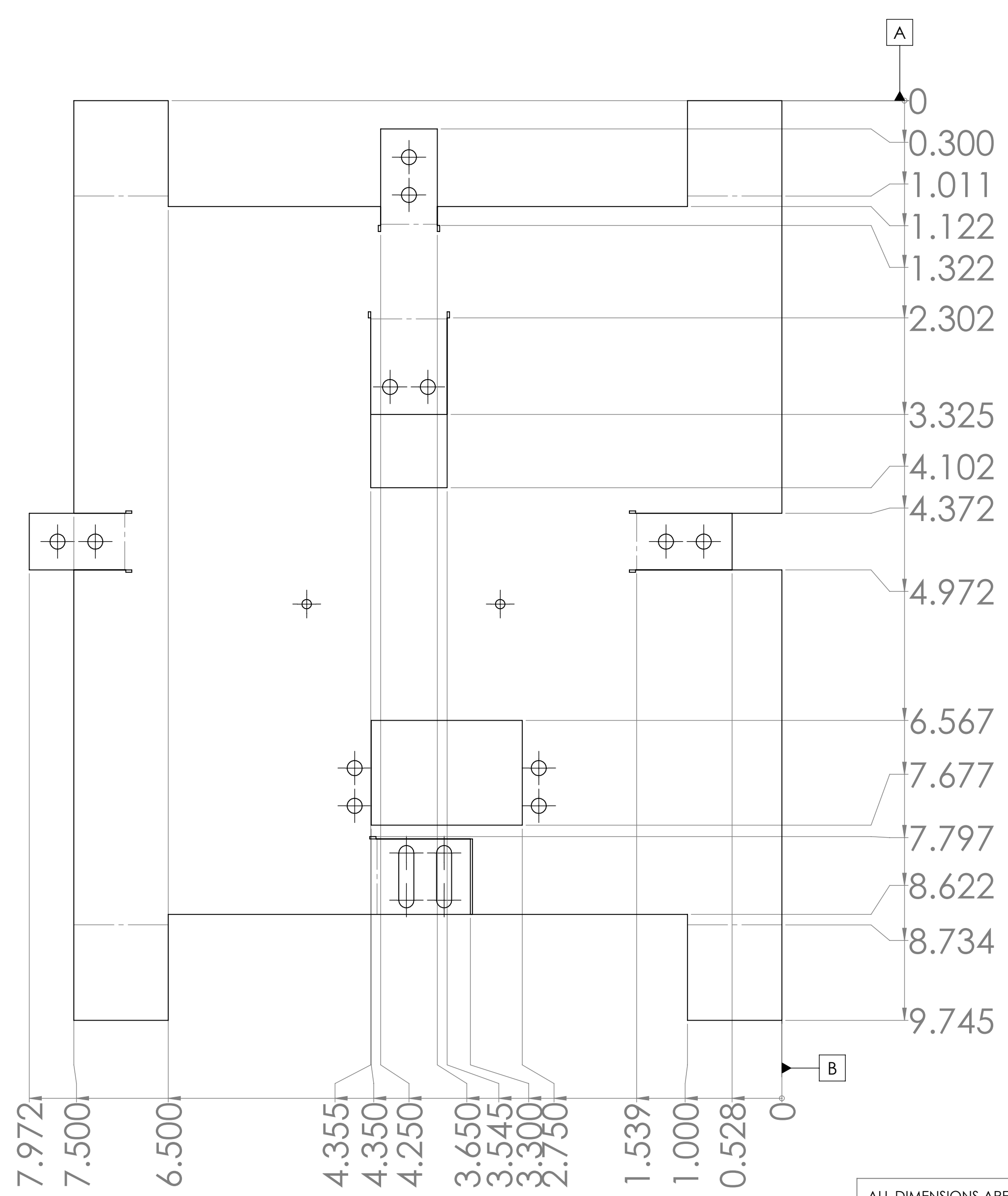
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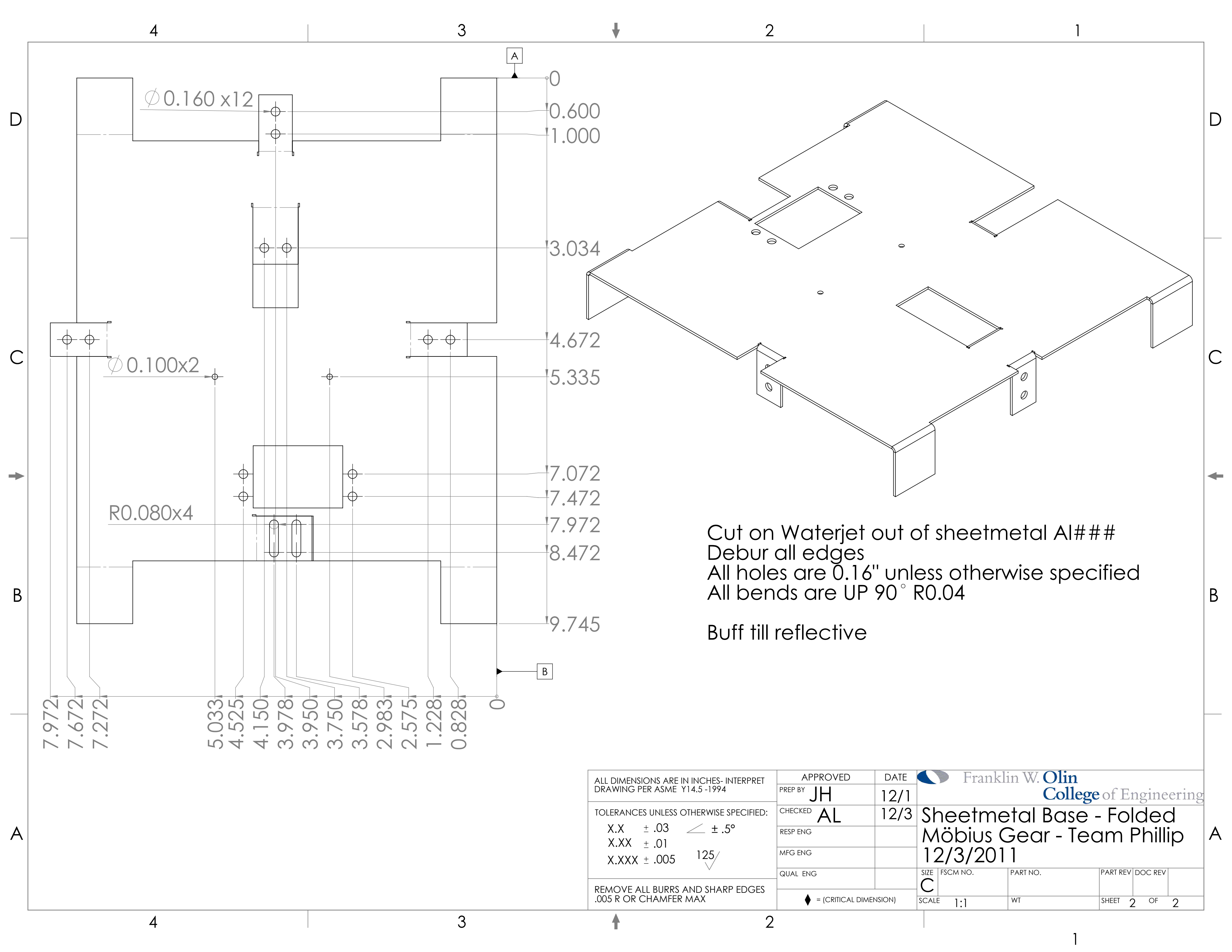
1



Cut on Waterjet out of sheetmetal Al###
 Debur all edges
 All holes are 0.16" unless otherwise specified
 All bends are UP 90° R0.04
 Buff till reflective
 See next page for hole dimensions and locations



ALL DIMENSIONS ARE IN INCHES- INTERPRET DRAWING PER ASME Y14.5 -1994 TOLERANCES UNLESS OTHERWISE SPECIFIED: X.X ± .03 $\angle \pm .5^\circ$ X.XX ± .01 X.XXX ± .005 125/	APPROVED	DATE					
	PREP BY	JH	12/1	Sheetmetal Base Möbius Gear - Team Phillip 12/3/2011			
	CHECKED	AL	12/3				
	RESP ENG						
MFG ENG							
QUAL ENG			SIZE	FSCM NO.	PART NO.	PART REV	DOC REV
REMOVE ALL BURRS AND SHARP EDGES .005 R OR CHAMFER MAX	◆ = (CRITICAL DIMENSION)		C			3	
			SCALE	1:1	WT	SHEET	1 OF 2



4

3

2

1

Ø 0.160 x 12

Ø 0.100 x 2

R0.080 x 4

A

0
0.600
1.000

3.034

4.672
5.335

7.072
7.472
7.972
8.472

9.745

B

7.972
7.672
7.272
5.033
4.525
4.150
3.978
3.950
3.750
3.578
2.983
2.575
1.228
0.828

Cut on Waterjet out of sheetmetal Al###
Debur all edges
All holes are 0.16" unless otherwise specified
All bends are UP 90° R0.04
Buff till reflective

ALL DIMENSIONS ARE IN INCHES- INTERPRET
DRAWING PER ASME Y14.5 -1994

TOLERANCES UNLESS OTHERWISE SPECIFIED:
X.X ± .03 < ± .5°
X.XX ± .01
X.XXX ± .005 125/

REMOVE ALL BURRS AND SHARP EDGES
.005 R OR CHAMFER MAX

APPROVED	DATE
PREP BY JH	12/1
CHECKED AL	12/3
RESP ENG	
MFG ENG	
QUAL ENG	
◆ = (CRITICAL DIMENSION)	

Franklin W. Olin College of Engineering				
Sheetmetal Base - Folded Möbius Gear - Team Phillip 12/3/2011				
SIZE C	FSCM NO.	PART NO.	PART REV	DOC REV
SCALE 1:1	WT	SHEET 2	OF 2	

4

3

2

1

A

A

4

3

2

1

D

D

C

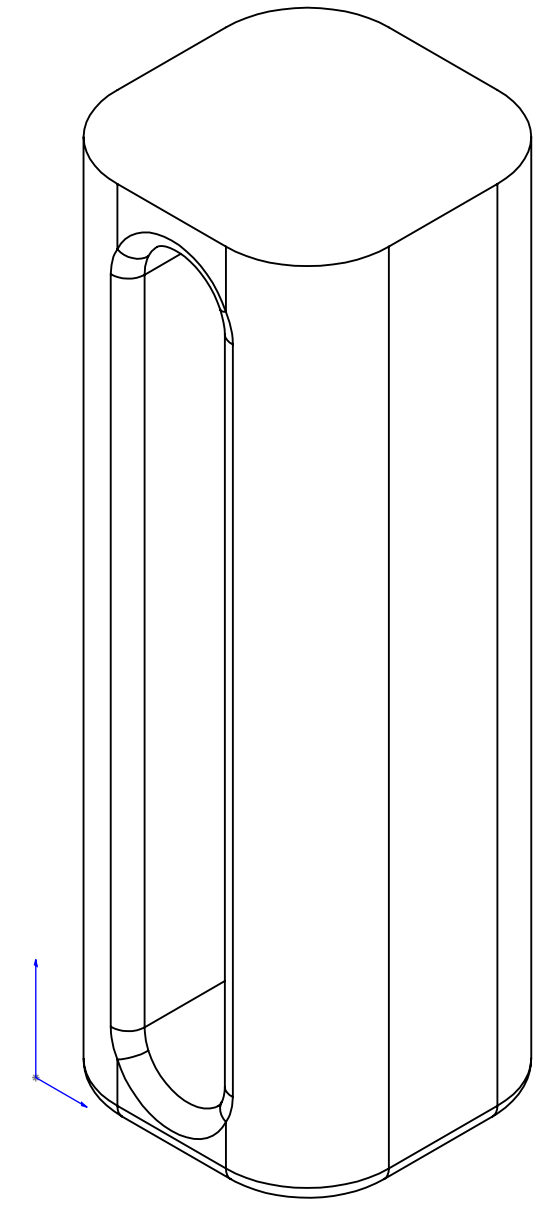
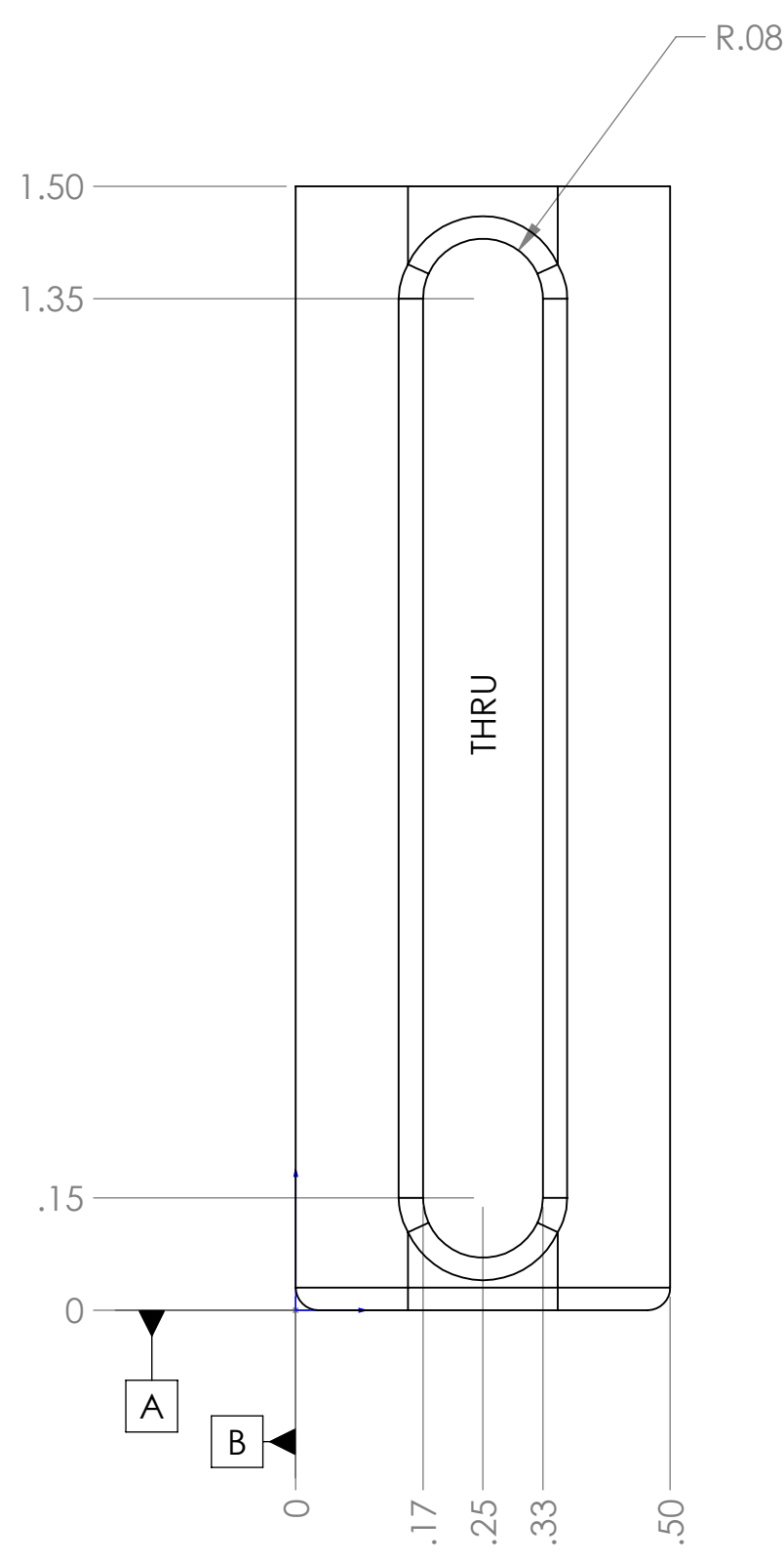
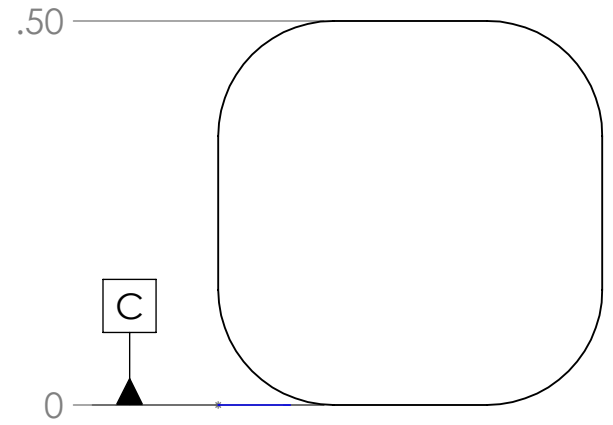
C

B

B

A

A



Print on RP printer
Fillet all edges 0.02"

ALL DIMENSIONS ARE IN INCHES- INTERPRET DRAWING PER ASME Y14.5 -1994 TOLERANCES UNLESS OTHERWISE SPECIFIED: X.X ± .03 $\angle \pm .5^\circ$ X.XX ± .01 X.XXX ± .005 125° REMOVE ALL BURRS AND SHARP EDGES .005 R OR CHAMFER MAX	APPROVED	DATE					
	PREP BY HELEN WANG	12/16/2011	short_stand2_rev3				
	CHECKED MURPHY KITCHELL	12/16/2011					
	RESP ENG						
MFG ENG			SIZE C	FSCM NO.	PART NO.	PART REV	DOC REV
QUAL ENG			SCALE 4:1	WT	SHEET 1	OF 1	
MATERIAL: ABS							

4

3

2

1

↑

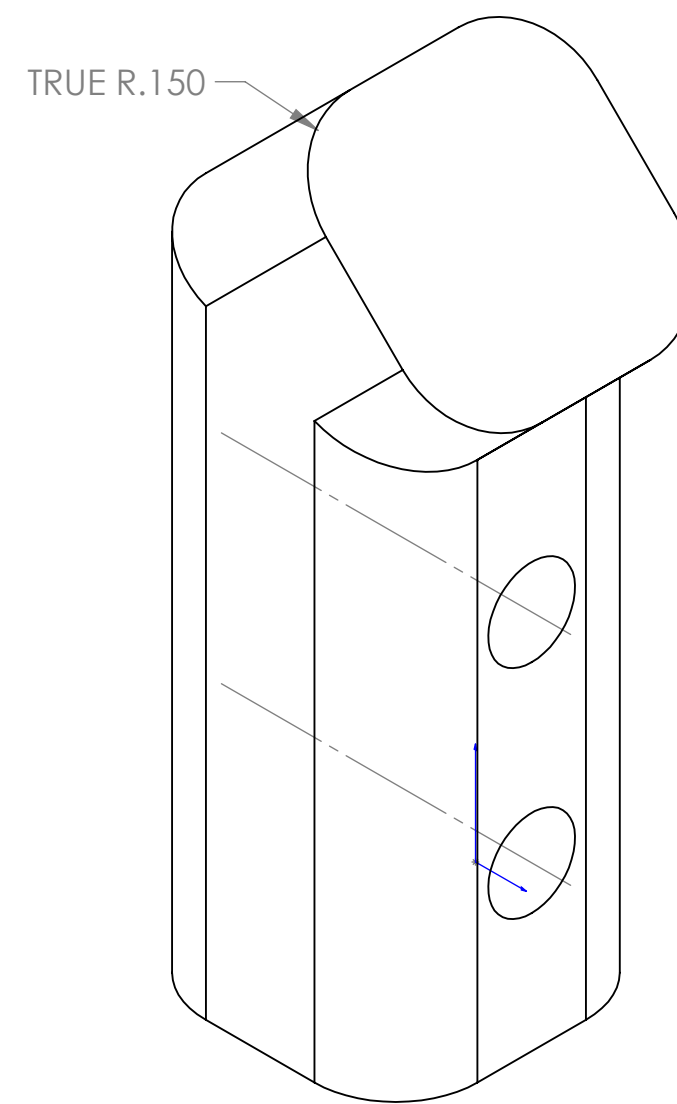
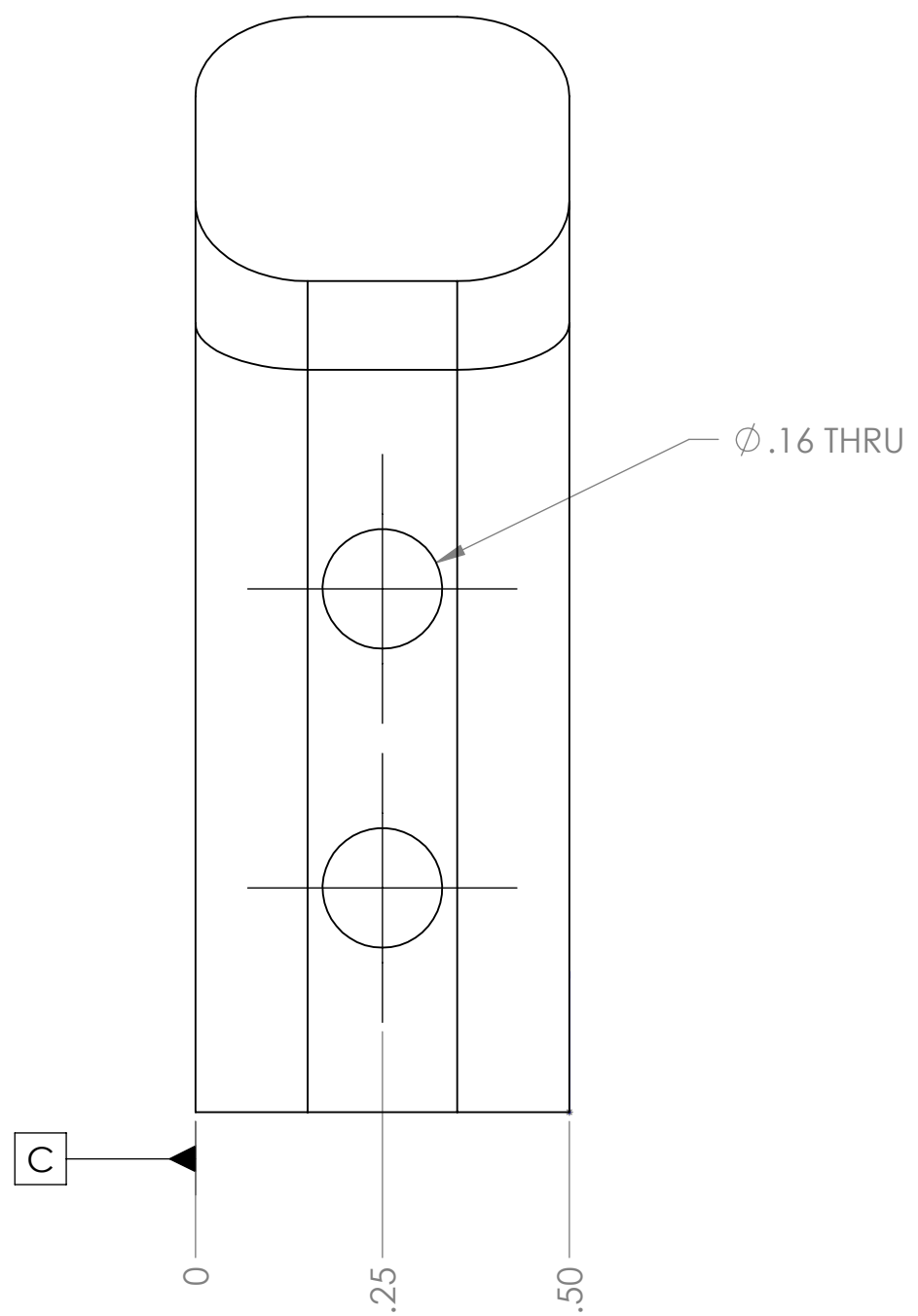
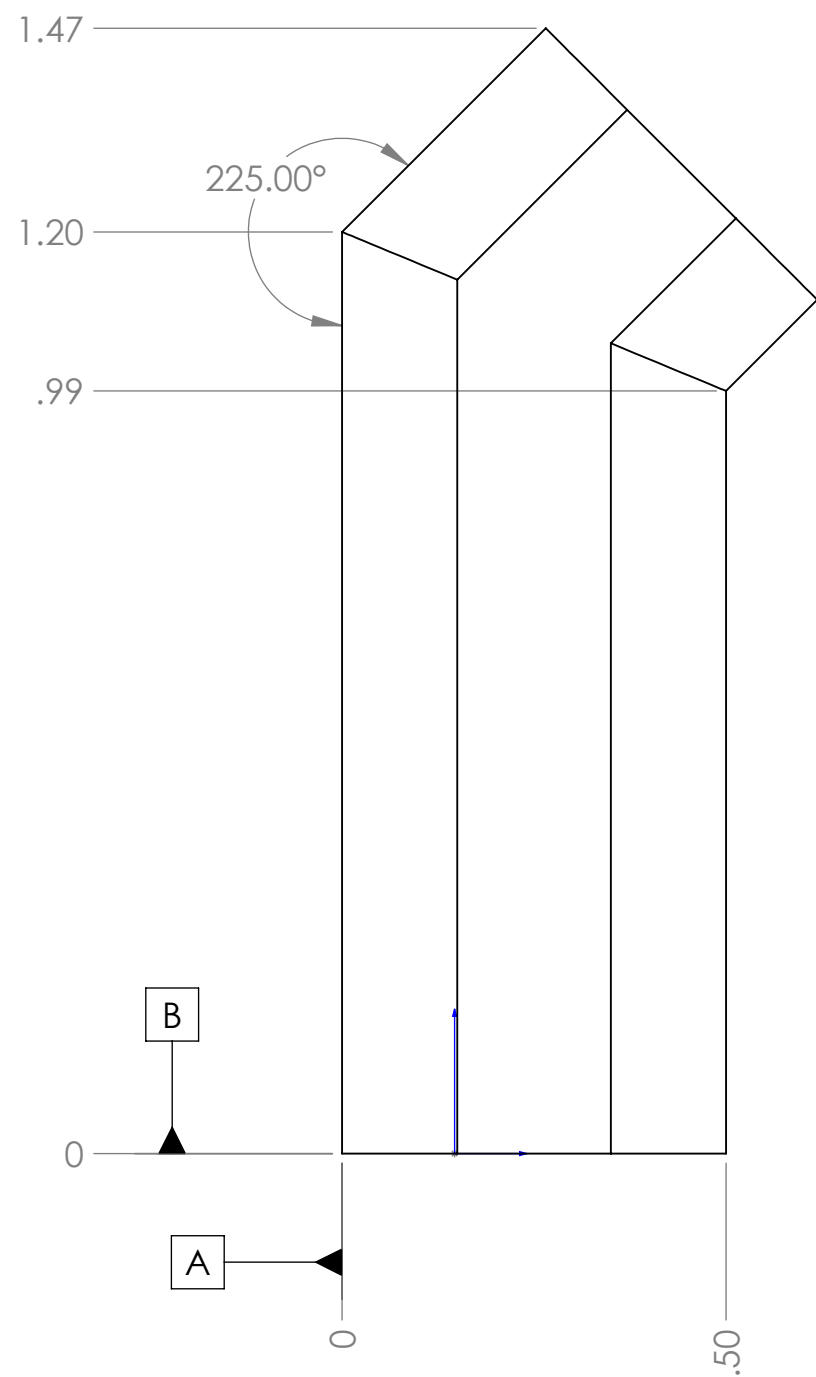
1

4

3

2

1



Print on RP printer

ALL DIMENSIONS ARE IN INCHES- INTERPRET DRAWING PER ASME Y14.5 -1994

TOLERANCES UNLESS OTHERWISE SPECIFIED:
 X.X ± .03 $\angle \pm .5^\circ$
 X.XX ± .01
 X.XXX ± .005 125/

REMOVE ALL BURRS AND SHARP EDGES
 .005 R OR CHAMFER MAX

APPROVED	DATE
PREP BY HELEN WANG	12/16/2011
CHECKED MURPHY KITCHELL	12/16/2011
RESP ENG	
MFG ENG	
QUAL ENG	
MATERIAL: ABS	

Franklin W. Olin College of Engineering				
stand_bottom_outer_rev3				
SIZE C	FSCM NO.	PART NO.	PART REV	DOC REV
SCALE 4:1	WT	SHEET 1	OF 1	

4

3

2

1



D

C

B

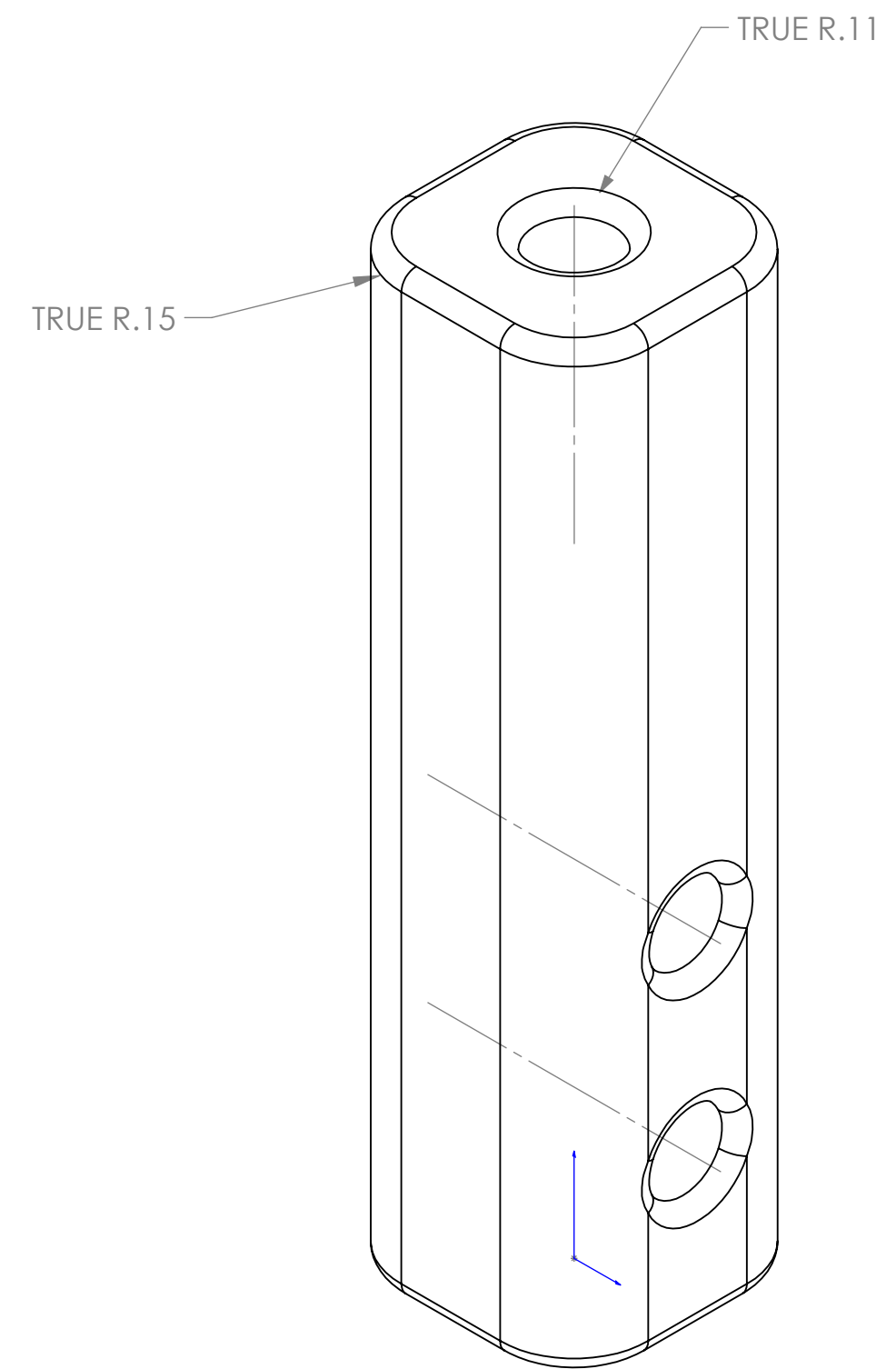
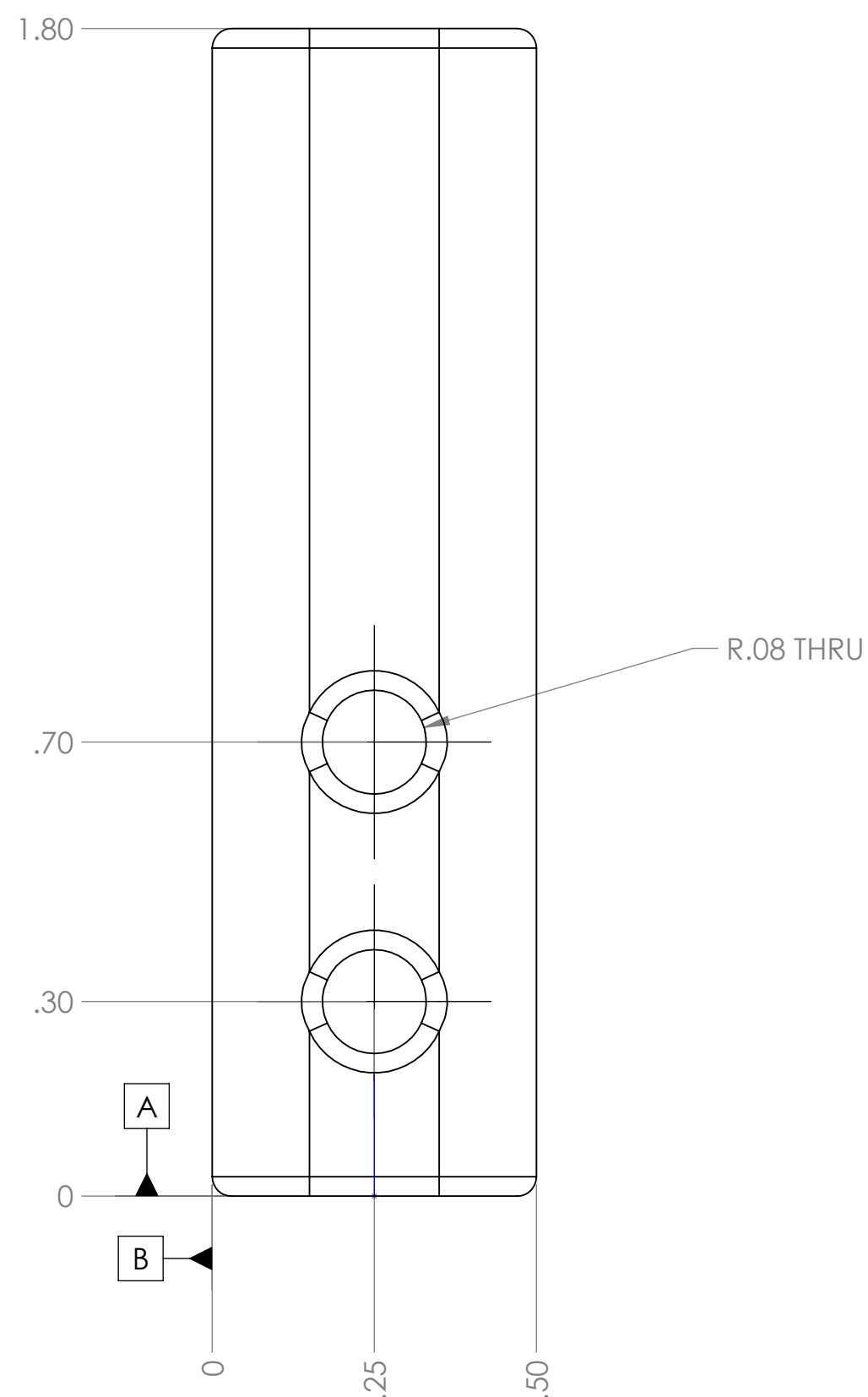
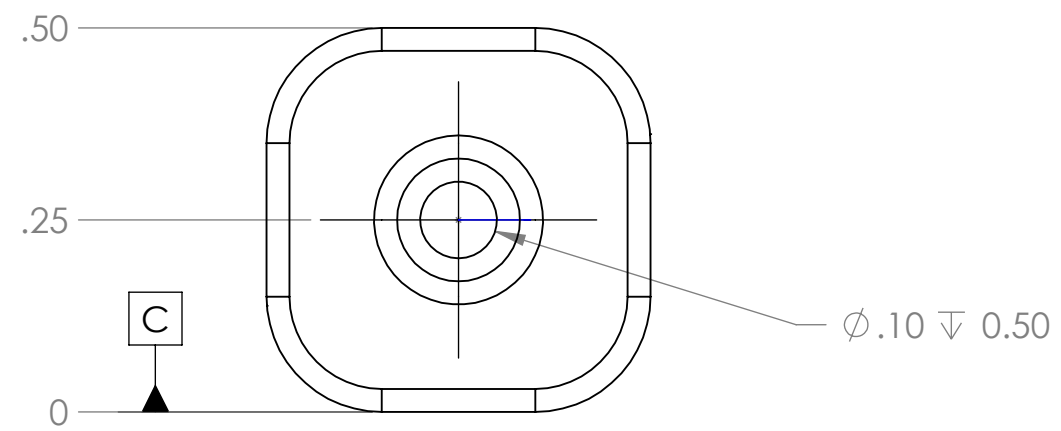
A

D

C

B

A



Print on RP printer
Fillet all edges 0.02"

ALL DIMENSIONS ARE IN INCHES- INTERPRET
DRAWING PER ASME Y14.5 -1994

TOLERANCES UNLESS OTHERWISE SPECIFIED:
 X.X ± .03 $\angle \pm .5^\circ$
 X.XX ± .01
 X.XXX ± .005 125°

REMOVE ALL BURRS AND SHARP EDGES
.005 R OR CHAMFER MAX

APPROVED	DATE
PREP BY HELEN WANG	12/16/2011
CHECKED MURPHY KITCHELL	12/16/2011
RESP ENG	
MFG ENG	
QUAL ENG	
MATERIAL: ABS	

		stand_horizontal	
SIZE C	FSCM NO.	PART NO.	PART REV
SCALE 4:1	WT	SHEET 1	OF 1

4

3

2

1

4

3

2

1

D

C

B

A

D

C

B

A

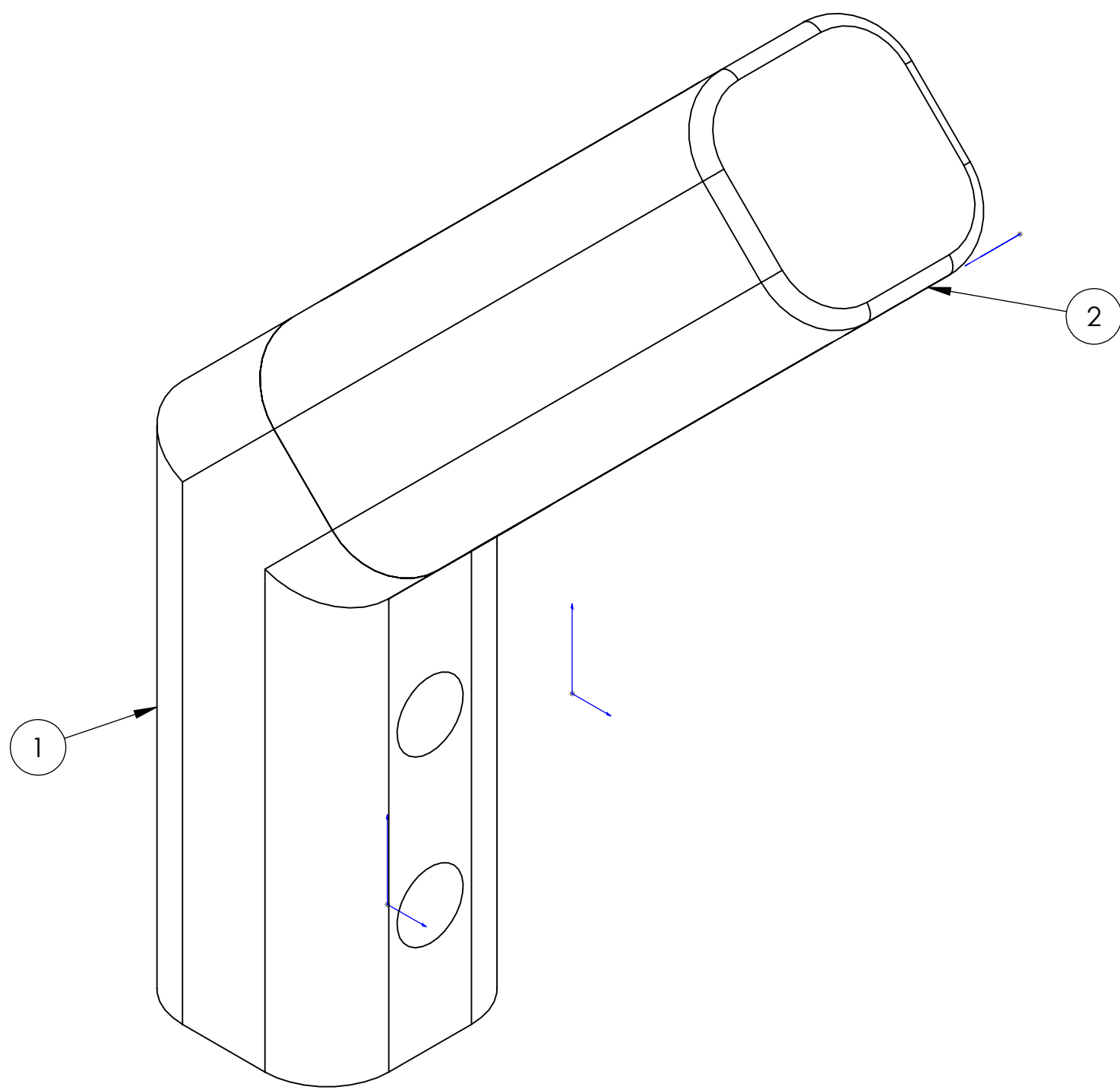
4

3

2

1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	stand_bottom_out r_rev3		1
2	short_stand2_rev3		1



ALL DIMENSIONS ARE IN INCHES- INTERPRET
DRAWING PER ASME Y14.5 -1994

TOLERANCES UNLESS OTHERWISE SPECIFIED:
 X.X ± .03 $\angle \pm .5^\circ$
 X.XX ± .01
 X.XXX ± .005 125°

REMOVE ALL BURRS AND SHARP EDGES
.005 R OR CHAMFER MAX

APPROVED	DATE
PREP BY HELEN WANG	12/16/2011
CHECKED MURPHY KITCHELL	12/16/2011
RESP ENG	
MFG ENG	
QUAL ENG	



stand_outward_rev3

SIZE	FSCM NO.	PART NO.	PART REV	DOC REV
C				
SCALE	2:1	WT	SHEET 1	OF 1

4

3

2

1



D

C

B

A

D

C

B

A

4

3

2

1



D

D

C

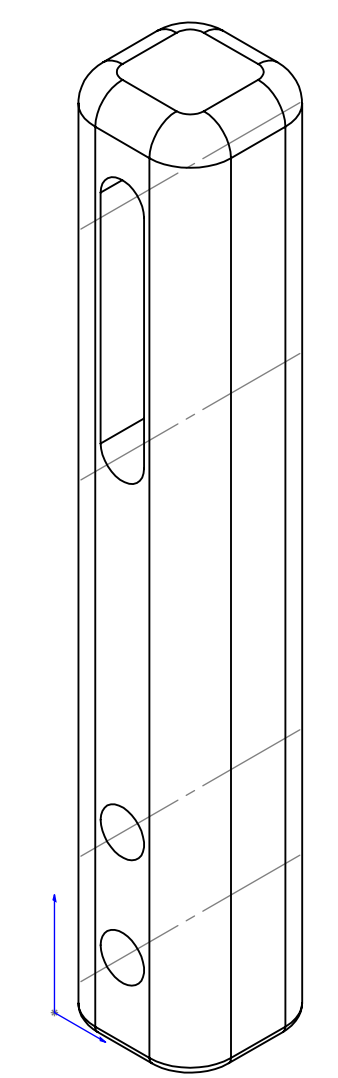
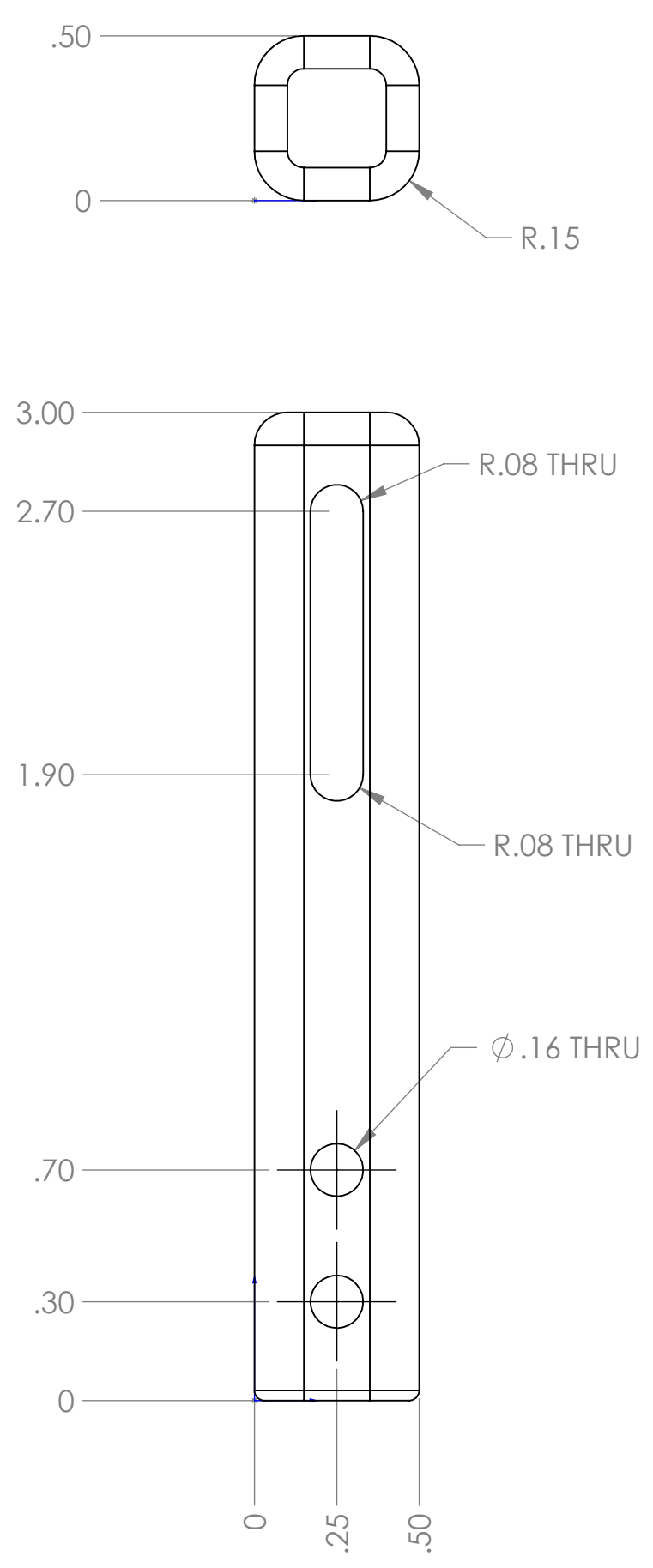
C

B

B

A

A



Print on RP printer
 Fillet all edges 0.02"

ALL DIMENSIONS ARE IN INCHES- INTERPRET DRAWING PER ASME Y14.5 -1994 TOLERANCES UNLESS OTHERWISE SPECIFIED: X.X ± .03 $\angle \pm .5^\circ$ X.XX ± .01 X.XXX ± .005 125/√ REMOVE ALL BURRS AND SHARP EDGES .005 R OR CHAMFER MAX	APPROVED	DATE					
	PREP BY HELEN WANG	12/16/2011	stand1_rev3				
	CHECKED MURPHY KITCHELL	12/16/2011					
	RESP ENG						
MFG ENG			SIZE	FSCM NO.	PART NO.	PART REV	DOC REV
QUAL ENG			C				
MATERIAL: ABS	SCALE	2:1	WT	SHEET	1	OF	1

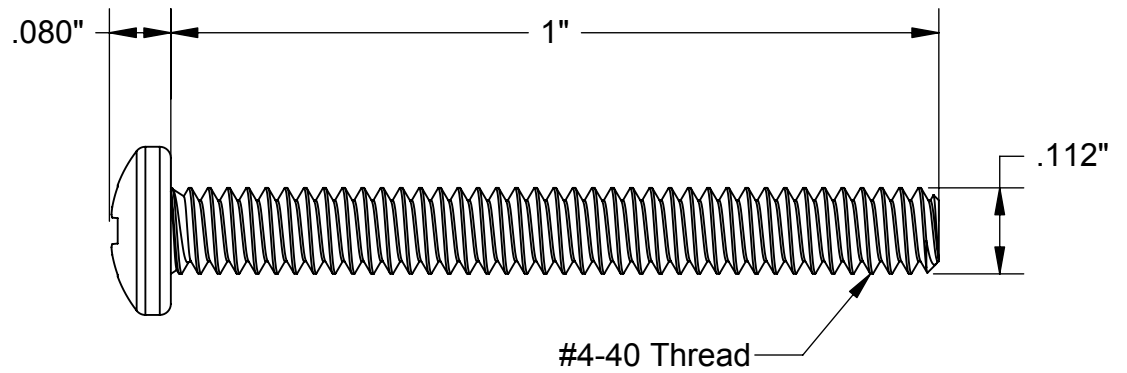
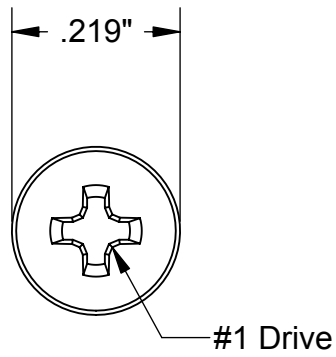
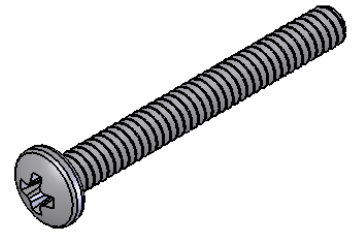
4


3

2

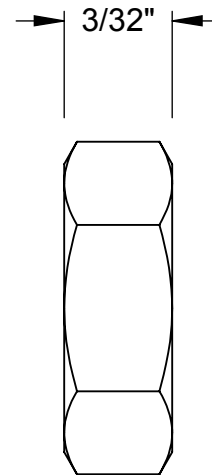
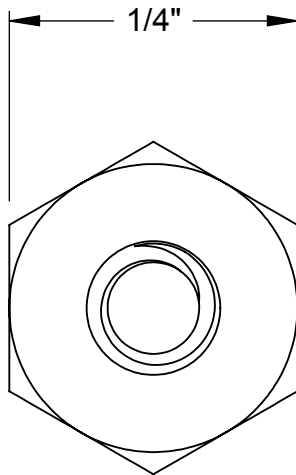
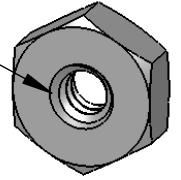
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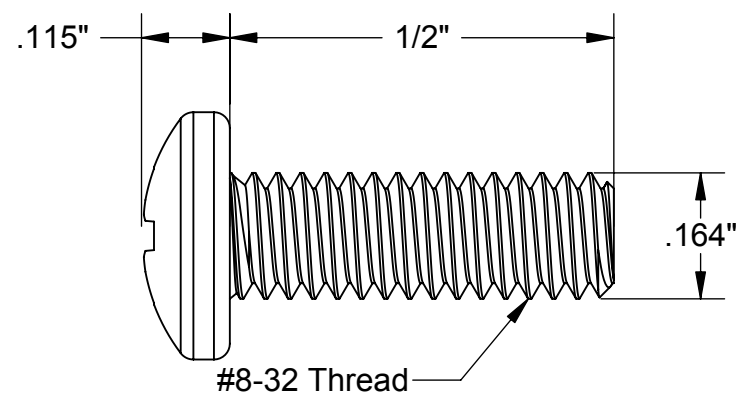
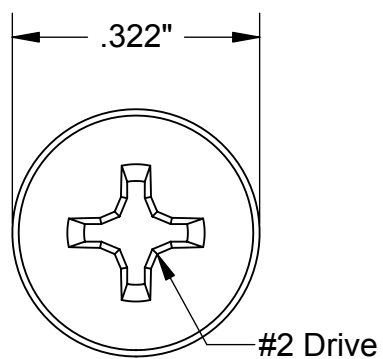
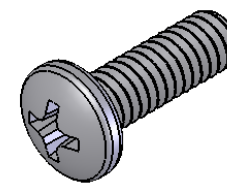


McMASTER-CARR 	PART NUMBER	90272A115
http://www.mcmaster.com © 2007 McMaster-Carr Supply Company	Zinc-Plated Steel Pan Head Phillips Machine Screw	
Unless otherwise specified, dimensions are in inches. Information in this drawing is provided for reference only.		

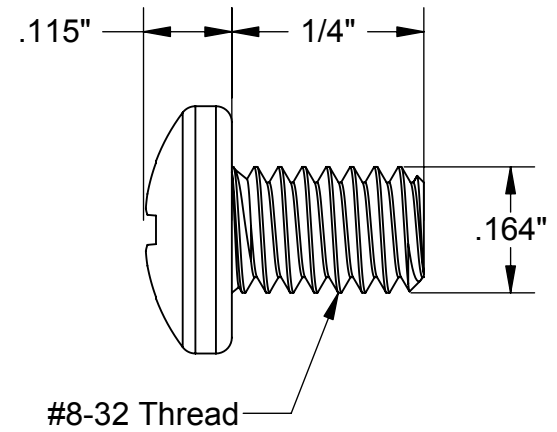
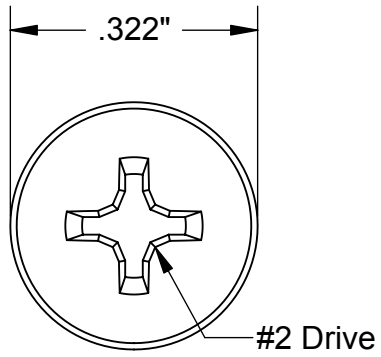
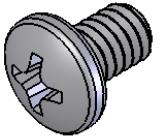
#4-40 Thread




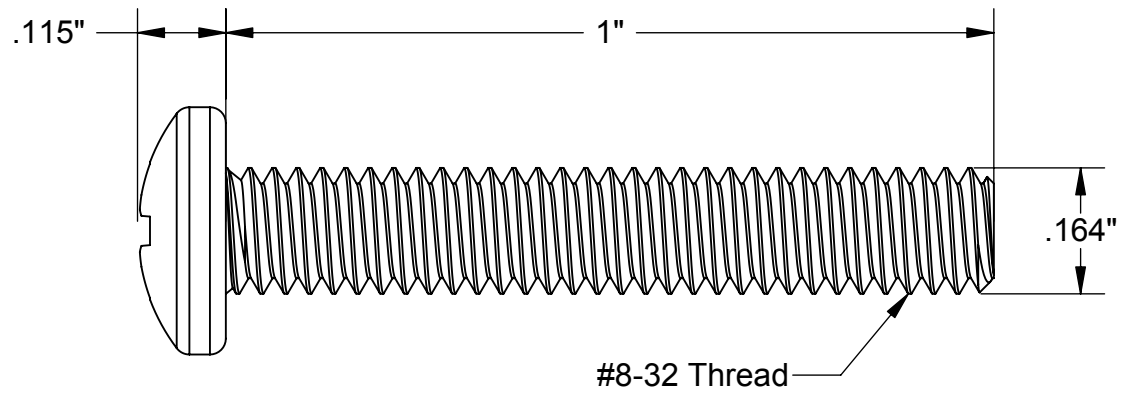
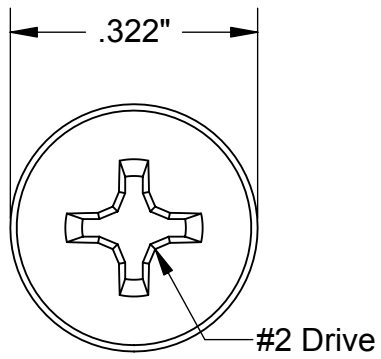
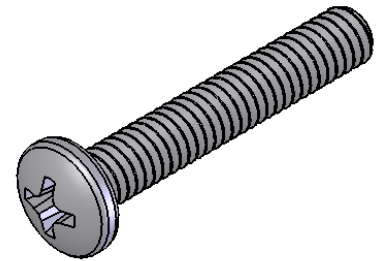
McMASTER-CARR <small>CAD</small>	PART NUMBER	90545A005
http://www.mcmaster.com		Titanium
© 2009 McMaster-Carr Supply Company		Hex Nut
Information in this drawing is provided for reference only.		



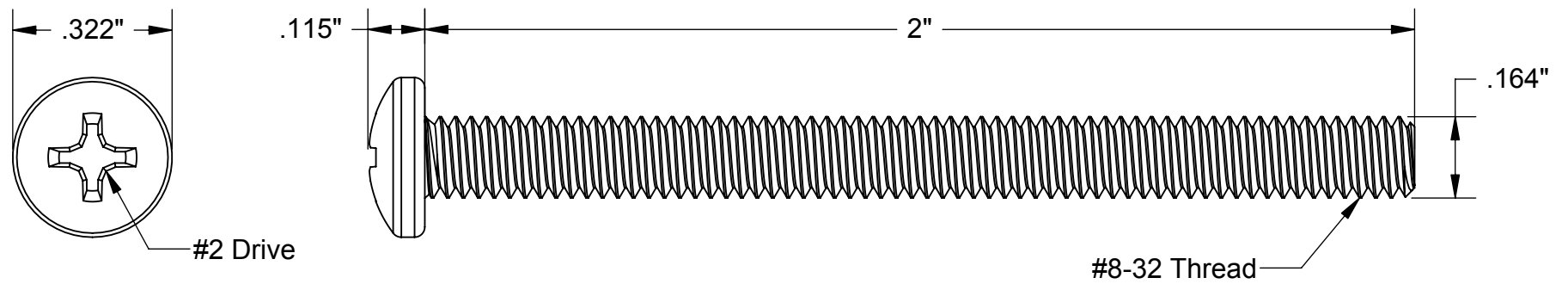
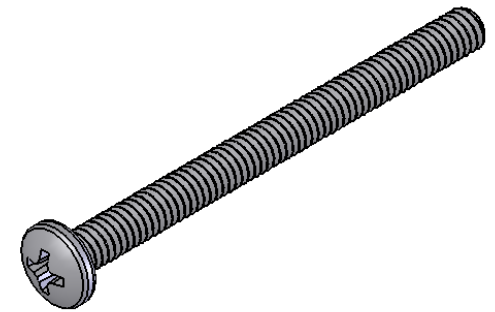
McMASTER-CARR <small>CAD</small>	PART NUMBER	90272A194
http://www.mcmaster.com © 2007 McMaster-Carr Supply Company	Zinc-Plated Steel Pan Head Phillips Machine Screw	
Unless otherwise specified, dimensions are in inches. Information in this drawing is provided for reference only.		



McMASTER-CARR 	PART NUMBER	90272A190
http://www.mcmaster.com © 2007 McMaster-Carr Supply Company	Zinc-Plated Steel Pan Head Phillips Machine Screw	
Unless otherwise specified, dimensions are in inches. Information in this drawing is provided for reference only.		

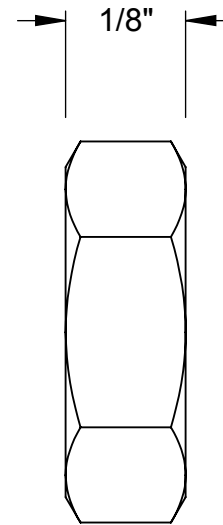
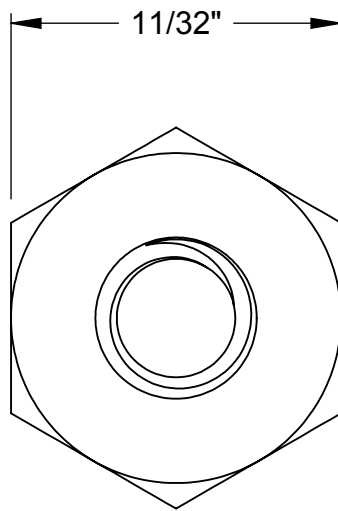
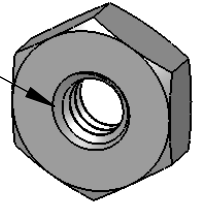


McMASTER-CARR <small>CAD</small>	PART NUMBER	90272A199
http://www.mcmaster.com	Zinc-Plated Steel	
© 2007 McMaster-Carr Supply Company	Pan Head Phillips Machine Screw	
Unless otherwise specified, dimensions are in inches. Information in this drawing is provided for reference only.		



McMASTER-CARR <small>CAD</small>	PART NUMBER	90272A205
http://www.mcmaster.com	Zinc-Plated Steel	
© 2007 McMaster-Carr Supply Company	Pan Head Phillips Machine Screw	
Unless otherwise specified, dimensions are in inches. Information in this drawing is provided for reference only.		

#8-32 Thread



McMASTER-CARR CAD

<http://www.mcmaster.com>
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Information in this drawing is provided for reference only.

PART
NUMBER

90545A009

Titanium
Hex Nut