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Orthopedic Screwdriver Design

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MEMS 411

Final Report

Orthopedic Screwdriver
Group 2

Ryan Blumenstein, Tiffany Ewing,
Beenish Qayum

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1 Introduction

1.1 Project problem statement

This team was tasked with designing an adjustable mechanical clutch screwdriver suitable for driving orthopedic screws into bone material. The clutch mechanism should be accurate within 5% of the torque setting and prevent over-tightening. The prototype design must be ergonomically sound, allow one-handed use and be suitable for modification into a medical device. The design documentation should specify material changes and design details that would be needed for the ultimate production model. The final design should be easily disassembled/assembled for cleaning between uses and the final materials would need to be autoclavable.

1.2 List of team members

Ryan Blumenstein
Tiffany Ewing
Beenish Qayum

2 Background Information Study

2.1 A short design brief description that defines and describes the design problem

Design a torque-limiting screwdriver with an adjustable clutch that can insert orthopedic screws into bone without over-tightening. Over-tightened screws can cause damage to bone material. The prototype design should also list steps for converting to a medical instrument.

2.2 Summary of relevant background information

Useful Patents:

[EP 1477278 A2](#)

[US 5484440 A](#)

[Torque Limiting Screwdriver US 6487943 B1](#)

[Torque Limiting Screwdriver US 2732746 A](#)

[Torque limiting screwdriver US 4063474 A](#)

[Torque limiting screw driver US 2984133 A](#)

Relevant Standards:

[ASTM Medical Instrument and Implant Standards](#)

[1983 ASTM Medical Device Standards available in Olin](#)

[ASTM F543 Standard Specification and Test Method for Metallic Medical Bone Screws](#)

[ISO Osteosynthesis and Spinal Devices](#)

Background Research Links:

[General Principles of Internal Fixation](#)

[Millenium Surgical Screwdriver Bits](#)

[Joining and assembly of medical materials and devices](#), Zhou and Breyen [looks very helpful for specifying materials -- RB]

[Stryker Screw system](#)

[Stryker Cannulated Screw System](#)

[Kirschner Wire Sizes](#)

[How Does a Torque Screwdriver Work?](#)

3 Concept Design and Specification

3.1 User needs, metrics, and quantified needs equations.

3.1.1 Record of the user needs interview

Table 1: User Needs Interview

Question	Client Response	Interpreted Need
Should this screwdriver be a manual or powered device?	Either a hand tool or a power tool could be an acceptable design solution. Of course, it needs to apply enough torque to drive a screw into bone. A separate device can be used to prepare the hole.	Does not need to be a power tool.
What range of torque should this device be able to apply?	I'm not sure, you'll have to research that.	Screwdriver must have sufficient torque capacity for general orthopedic surgery needs.
What types of surgical screws should this tool accommodate?	Figure out what kinds of screws are most commonly used, and pick one.	This tool can be specialized to insert a specific type of surgical screw; it does not need to be compatible with multiple varieties, but it would be good.
Does this tool need to be autoclaved?	The surgical environment needs to be maintained in sterile conditions. If parts of the tool aren't suitable for autoclaving, they should be isolated from the patient with some form of container or barrier.	Any components entering or nearing patient must be designed for sterilization by autoclave. Other components may not need to be autoclaved if they can be otherwise isolated from the surgical environment.
Are there any ergonomic considerations unique to a surgical environment that should be considered?	Maintaining a sterile surgical environment is critical. This device should be easy to use with one hand, so it should hold the screw until it is inserted. You may want to research ergonomics further.	One-handed operation is required. Consideration should also be given to surgical gloves and possible exposure to fluids. Driver should grip the screw until it is inserted.
Does this device need to be capable of	Yes, it should be able to work in reverse.	Tool operation should be bidirectional.

removing screws?		
Does this tool need a "lock" setting, such that the applied torque is not limited?	No, the point of this tool is to limit the applied torque. If greater torque is required, a standard surgical screwdriver can be used.	No "lock" setting is required.
Is a handle design that accepts standard surgical driver bits acceptable?	Yes, you can go either way.	Handle accepting standard bits ok.
Are there any size requirements for this device?	Only that it should be easy to use one-handed. It shouldn't be too long or really heavy.	No specific size requirements.
Is the manufacturing or sale price an important design factor?	Not really. The patient's health is the most important thing in medicine, so price isn't as important.	Price is not a significant concern.

3.1.2 List of Needs

Table 2: List of User Needs for Orthopedic Screwdriver

Need #	Interpreted User Need	Importance
1	Accepts standard screw bits	1
2	Holds screw to bit	4
3	One-handed operation	4
4	Surgically ergonomic	4
5	Adjustable torque	5
6	Able to work in reverse	3
7	Made of surgically appropriate material	5
8	Maintains a sterile environment	5
9	Prevents over-torque	5
10	Able to apply sufficient torque for bone	5

3.1.3 List of identified metrics

Table 3: List of Identified Metrics for Orthopedic Screwdriver

Metric #	Need #	Metric	Units	Best Value	Worst Value
1	1	accepts ¼" and cannulated hexagonal driver shaft	int.	1	0
2	2	Amount of time screw is held in "dry" conditions	sec	60	0
3	3	weight	kg	0	1
4	3	large handle diameter	mm	50	60
5	3	small handle diameter	mm	30	50
6	3	handle length	mm	125	100
7	4	handle maintains grip (% reduction in torque)	%	0	100
8	4,2	tool maintains grip on screw in "wet" surgical conditions	sec	30	0
9	5	torque accuracy (% difference)	%	0	5
10	6	Works in reverse	int.	1	0
11	7	can be autoclave	int.	1	0
12	8	meets surgical standards	int.	1	0
13	8	number of parts	int.	1	10
14	9	% over-torque	%	0	25
15	10	maximum torque	N•m	5	0

3.1.4 Needs Equations

Need	Need	Metric															Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value		
		accepts 1/4" hexagonal driver shaft	Amount of time screw is held in "dry" condition	weight	large handle diameter	small handle diameter	handle length	handle maintains grip (% reduction in torque)	tool maintains grip on screw in "wet" surgical conditions	torque accuracy (% difference)	works in reverse	can be autoclaved	meets surgical standards	number of parts	% over-torque	maximum torque					
1	Accepts standard screw bits	1																0	0.024	0	
2	Holds screw to bit		0.5						0.5									0	0.098	0	
3	One-handed operation			0.25	0.25	0.25	0.25											0	0.098	0	
4	Surgically ergonomic							0.7	0.3									0	0.098	0	
5	Adjustable torque									1								0	0.122	0	
6	Able to work in reverse										1							0	0.072	0	
7	Made of surgically appropriate material											1						0	0.122	0	
8	Maintains a sterile environment												0.8	0.2				0	0.122	0	
9	Prevents over-torque														1			0	0.122	0	
10	Able to apply sufficient torque for bone															1		0.96	0.122	0.1171	
	Units	int.	sec	kg	mm	mm	mm	%	sec	%	int.	int.	int.	int.	%	N•m					
	Best Value	1	60	0	50	30	125	0	30	0	1	1	1	1	1	0	5			8	
	Worst Value	0	0	1	60	45	100	100	0	5	0	0	0	0	10	25	0				
	Actual Value																				
	Normalized Metric Happiness																				
	Total Happiness																				0.117

Figure 1: Blank Happiness (Needs) Equation

3.2 Four (4) concept drawings

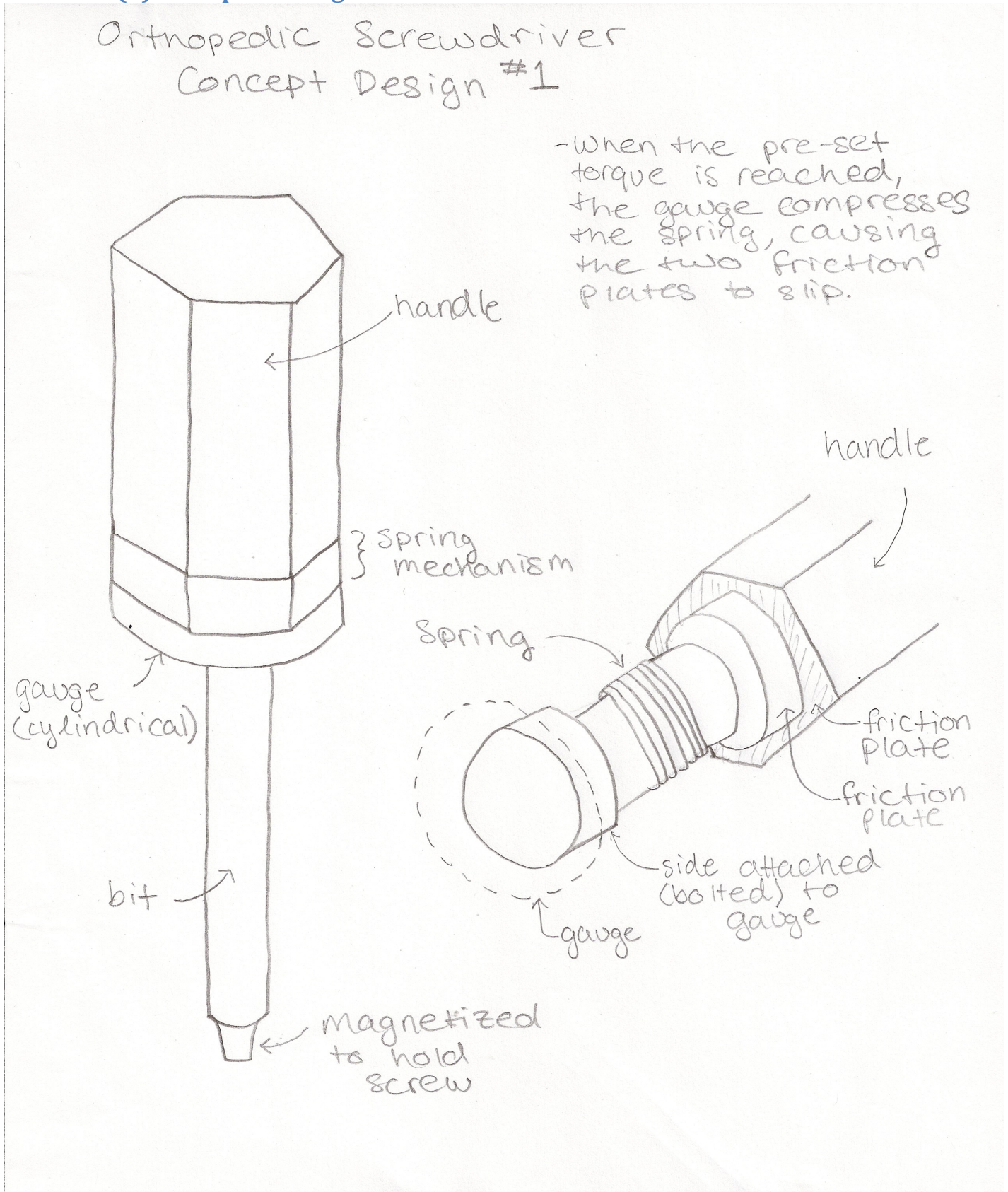
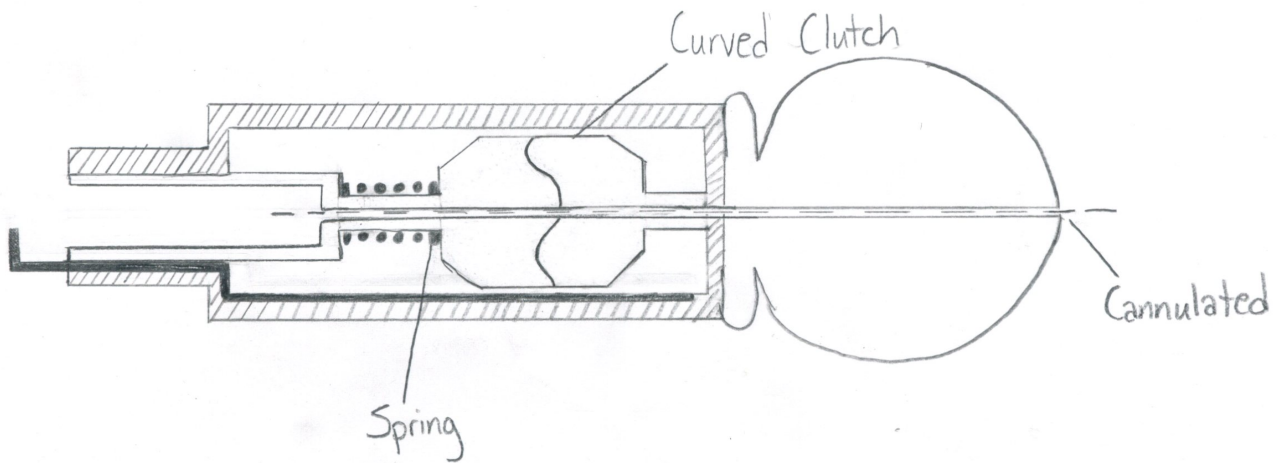
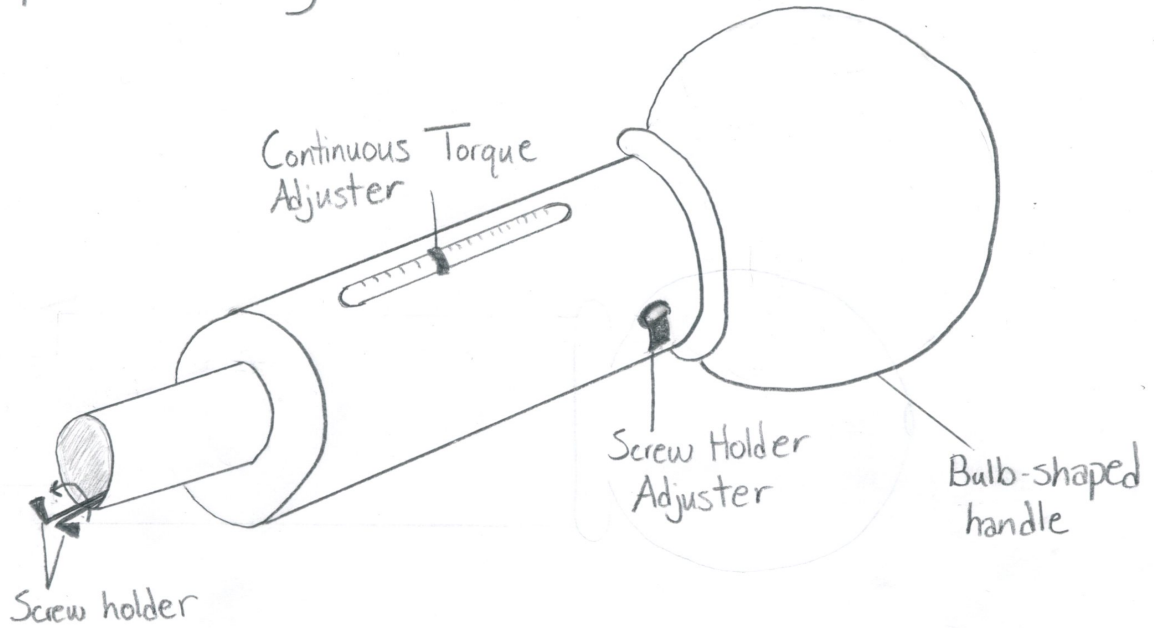


Figure 2: Concept Drawing #1

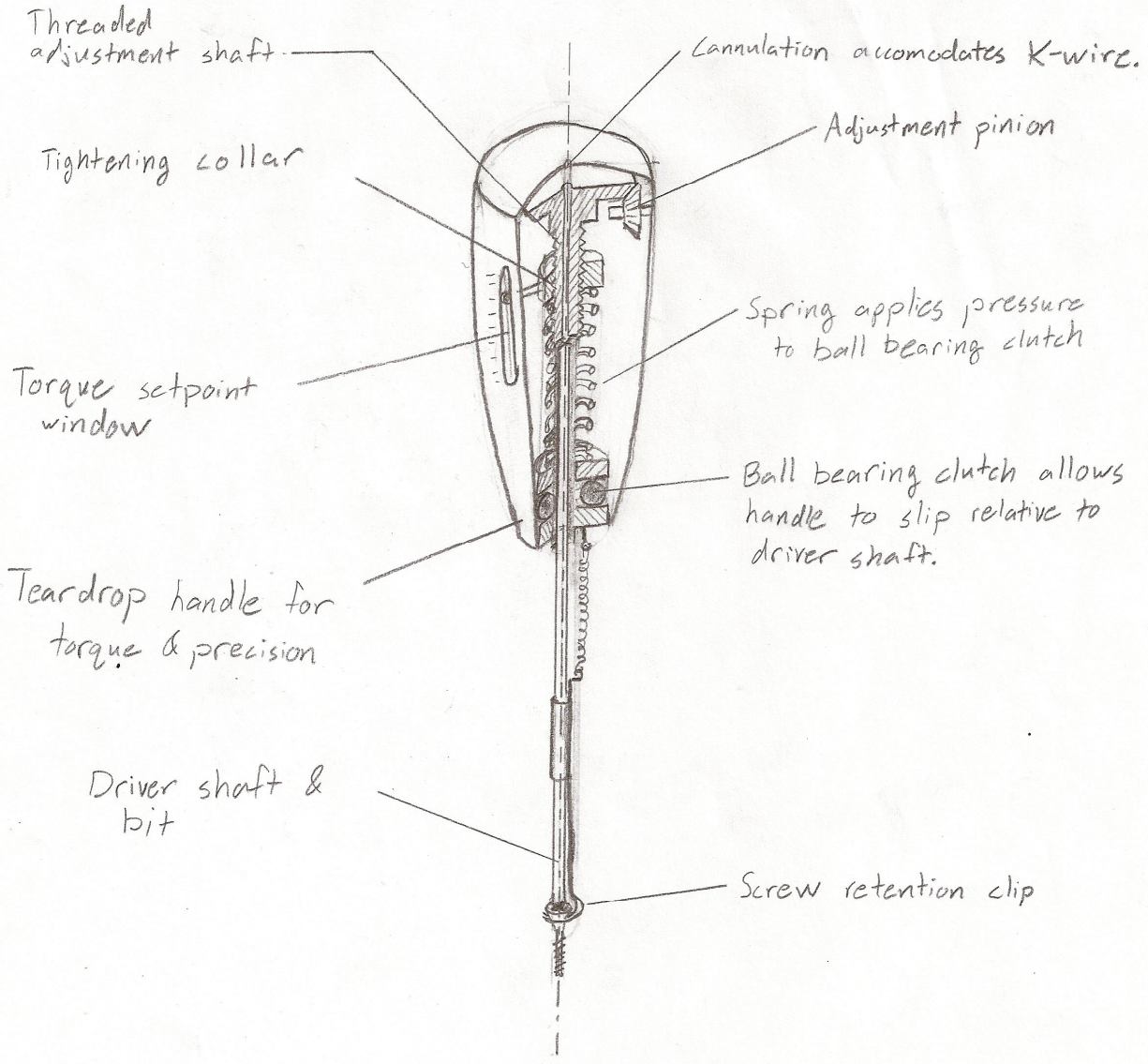
Concept Drawing #2



*Spring mechanism inspired by Bosch Power Tools

Figure 3: Concept Drawing #2

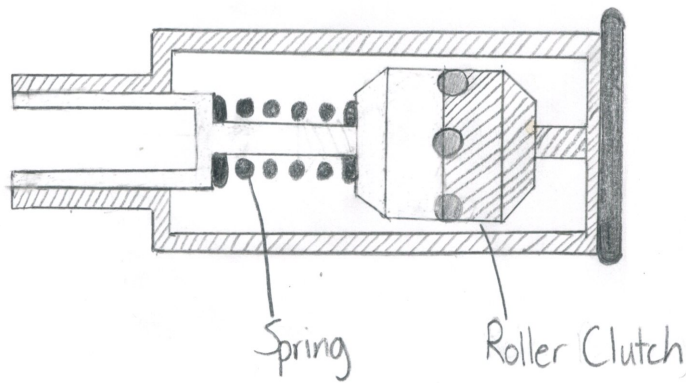
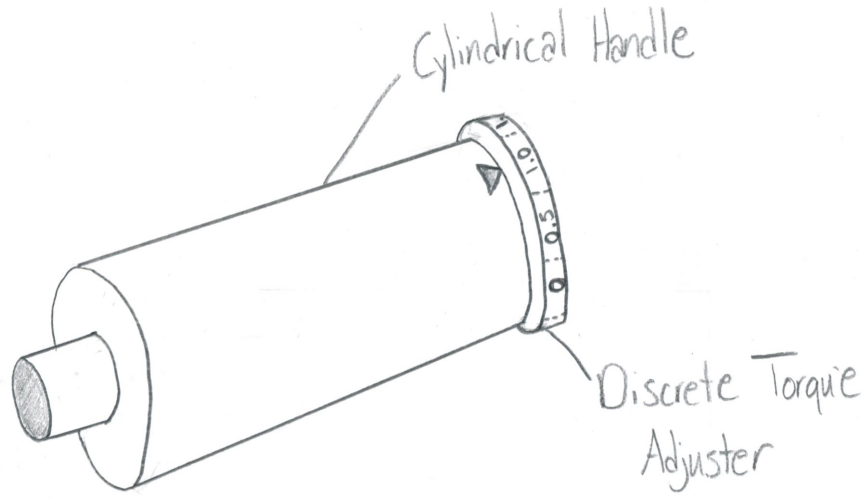
CONCEPT: ORTHO. DRIVER BALL CLUTCH, TEARDROP, CANNULATED



Concept Design #3

Figure 4: Concept Drawing #3

Concept Drawing #4



*Discrete knob inspired by Pro Torque Tools

Figure 5: Concept Drawing #4

for a greater variety in usable bits. One of the advantages to the clutch mechanism included in this design is that the teeth are created to work in reverse relatively easily. The screw retention clip of this design allows for a secure and accurate way to place the screw during one-handed operation.

Concept Design #3

In this design, the ball bearings used as a clutch mechanism, increase the complexity and maintenance of the device. When taken apart, to be autoclaved and sterilized, the clutch mechanism produces a greater number of parts than the previous two designs. The teardrop shape of this handle is ergonomically designed for torque and precision. One end of the handle allows for smaller amounts of torque to be applied, while the other allows for bulk application. As in the previous concept design, the screw retention clip allows for a secure and accurate way to place the screw even under surgical conditions where the device may become covered in bodily fluids. This design is also cannulated, like the previous one, allowing for both regular and cannulated bits to be attached to the handle.

Concept Design #4

The main drawback of this design is the cylindrically shaped handle, which may hinder the grip in surgical conditions, especially if it becomes covered in a liquid substance. The ball bearings, as with the previous design, increase the amount of maintenance needed to keep the device sterile. This particular design includes a rubber sleeve mechanism for holding the screw to the screwdriver. This mechanism may not maintain its frictional capacities during surgical proceedings if it comes in contact with a liquid substance. This design, unlike the previous three, has discrete gauge settings, which reduce the accuracy and variety of the torque limits that can be set.

3.3.3 Final summary

Winner: Design Concept #3

The cannulation feature of this design allows for the use of a wider variety of bits than the other non-cannulated designs. This is especially useful because many orthopedic surgeries require a variety of screws for plate insertion, rod insertion or general bone repair. The screw retention clip is simple to operate and manufacture. It also guarantees that the screw will be precisely held every time the device is used. The ball bearings in this design create the most reliable clutching mechanisms out of the four concepts examined. The ball bearings also allow for bidirectional operation, which satisfies the need to use the screwdriver in the reverse direction. The friction plate clutching mechanism does not allow use in the reverse direction and is more likely to decline in performance over time due to wear. Also, the friction plate mechanism is inherently less precise because Coulomb's Law used to approximate torque settings is only fully accurate when objects are stationary. The teardrop handle is ergonomically designed to address various needs. The handle length reduces the user's susceptibility to hand cramps. The portion of the handle with a smaller radius is ideal for fine torque application near the end of screw insertion. The larger radius region is best suited for initial bulk applications of torque. Consistent with the rest of the designs, this screwdriver uses a spring clutch mechanism to limit the torque and disengage the ball bearings when the preset torque is reached. The main drawback to this design is the number of parts, when disassembled could prove challenging to sterilize.

3.4 Proposed performance measures for the design

The performance goals for this project are:

- Torque – the tolerance of the applied torque is within 5% of the following set torques: 4.5, 3, and 1 N•m.
- Screw Retention – the retention mechanism must hold the screw for 60 seconds in “dry” conditions and 30 seconds in “wet” conditions.
- Surgical Conditions – meets appropriate surgical standards.

4 Embodiment and fabrication plan

4.1 Embodiment drawing

4.2

PARTS LIST				
ITEM	QTY	PART NUMBER	DESCRIPTION	MATERIAL
1	1	Handle Body		ABS Plastic
2	1	Handle Cap		ABS Plastic
3	1	Fixed Clutch Plate		Stainless Steel
4	1	Float Clutch Plate		Stainless Steel
5	1	Compression Plate		Stainless Steel
6	1	Drive Shaft		Stainless Steel
7	1	Hollow Shaft		Stainless Steel
8	1	Screw Clip		Stainless Steel
9	1	Extension Spring1	McMaster 9654K949	Steel
10	1	Compress Spring1	McMaster 9434K142	Steel
11	1	Axial Handle	Paragon Medical PMNR-106-0004-A	Generic
12	1	Cannulated Star AO Drive Bit	Medline MSN30002	Stainless Steel
13	3	Ball	McMaster 9642K35	Stainless Steel
14	1	ANSI B18.6.3 - No. 1 - 72 - 1/8	Cross Recessed Binding Head Machine Screw - Type IA	Steel, Mild
15	2	ANSI B18.6.3 - No. 5 - 40 - 1/8	Cross Recessed Pan Head Machine Screw - Type I	Steel, Mild

DRAWN Ryan Blumenstein CHECKED Tolerances .X = +/- .1 In. .XX = +/- .03 In. .XXX = +/- .010 In. Angles +/- 1/2 deg	WASHINGTON UNIVERSITY in St. Louis TITLE Orthopedic Screwdriver Assembly Orthopedic Screwdriver SIZE A DWG NO REV 1 SCALE Orthopedic Screwdriver.dwg
--	---

SIZE B SCALE 3:2	.XXX = +/- .010 In. Angles +/- 1/2 deg	DWG NO Orthopedic Screwdriver.dwg REV 1
---------------------	---	---

Clutch Ball Bearing:

Catalog Number: McMaster-Carr 9642K35

Quantity: 3

Price: \$7.72 per pack of 50

Main Clutch Spring:

Catalog Number: McMaster-Carr 9434K142

Quantity: 1

Price: \$5.71 per pack of 5

Screw Retaining Clip Spring:

Catalog Number: McMaster-Carr 9654K949

Quantity: 1

Price: \$7.22 per pack of 12

Screwdriver Socket:

Catalog Number: Paragon Medical PMNR106-0004-A

Quantity: 1

Price: Not displayed on website (<http://www.paragonmedical.com/catalog/425-medium-axial-handle-nr.html>)

Screwdriver Bit:

Catalog Number: Medline MSN30002

Quantity: 1

Price: Not displayed on website (<http://www.medline.com/sku/item/MDPMSN30002#>)

Medical-Grade Test Screw:

Catalog Number: Medline MSD03024

Quantity: 1

Price Not displayed on website (<http://www.medline.com/sku/item/MDPMSD03024#>)

Fixed Clutch Plate Screws:

Catalog Number: McMaster-Carr 91772A123

Quantity: 2

Price: \$6.22 per pack of 100

Spring Securing Screw:

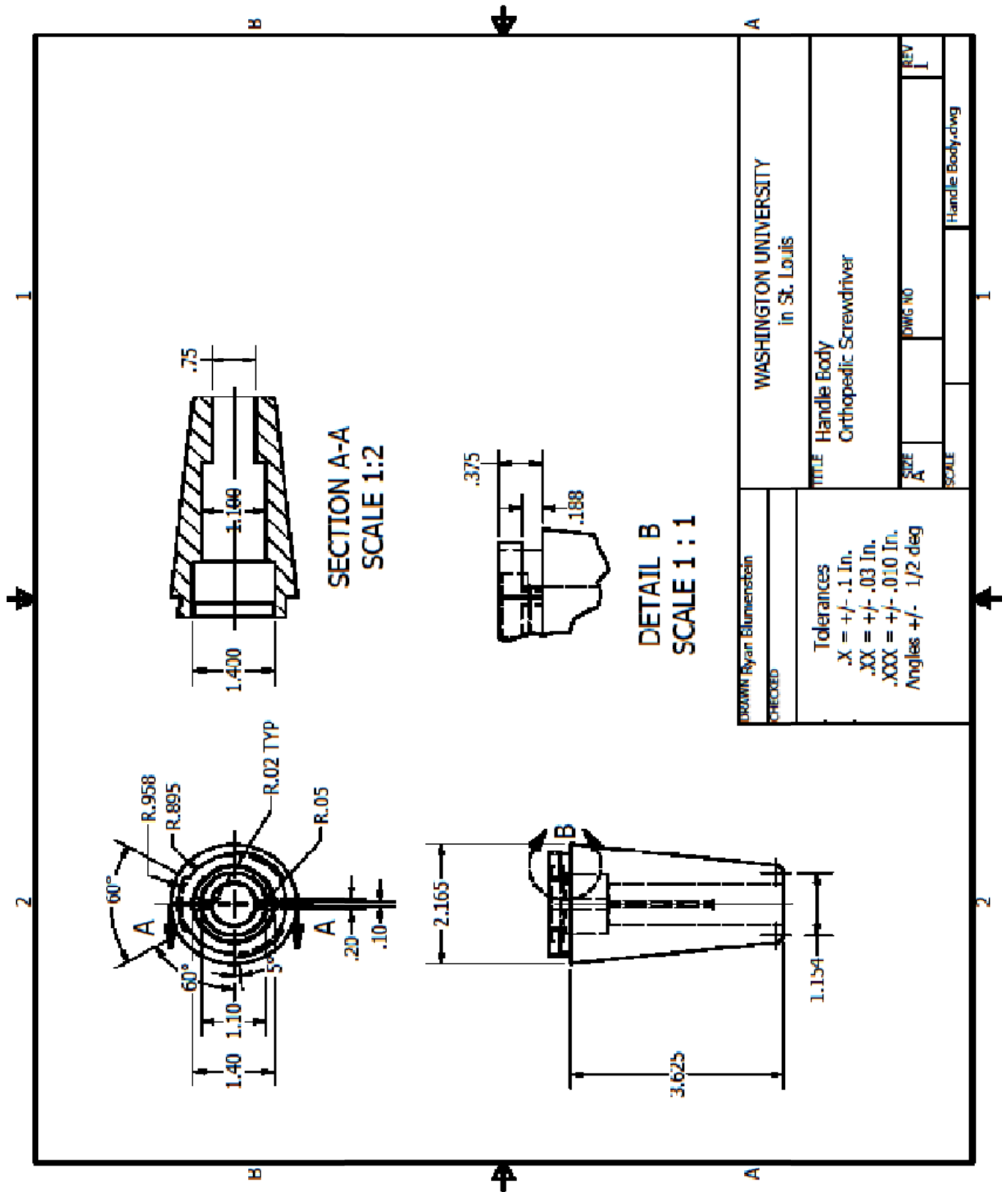
Catalog Number: McMaster-Carr 91772A063

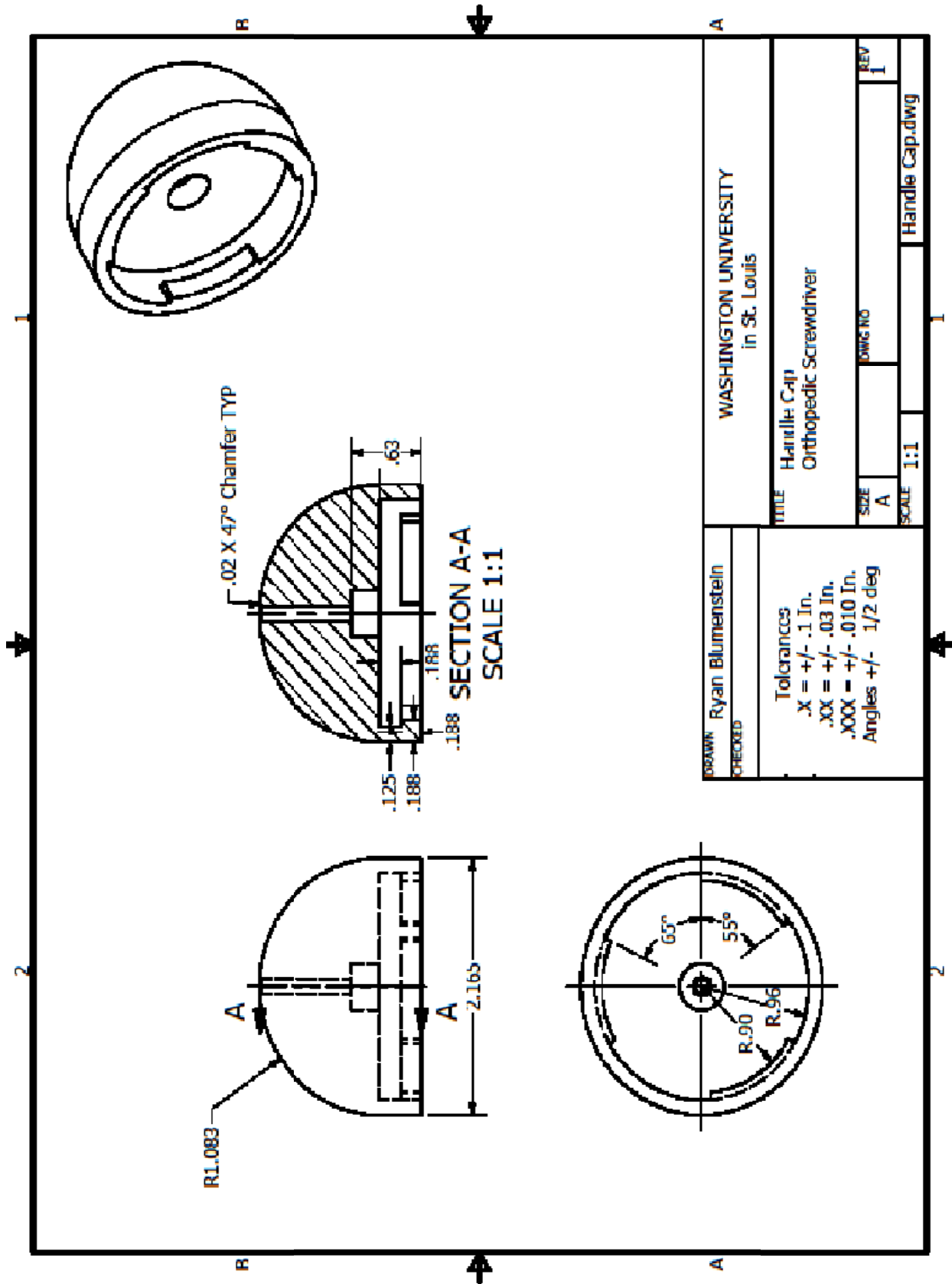
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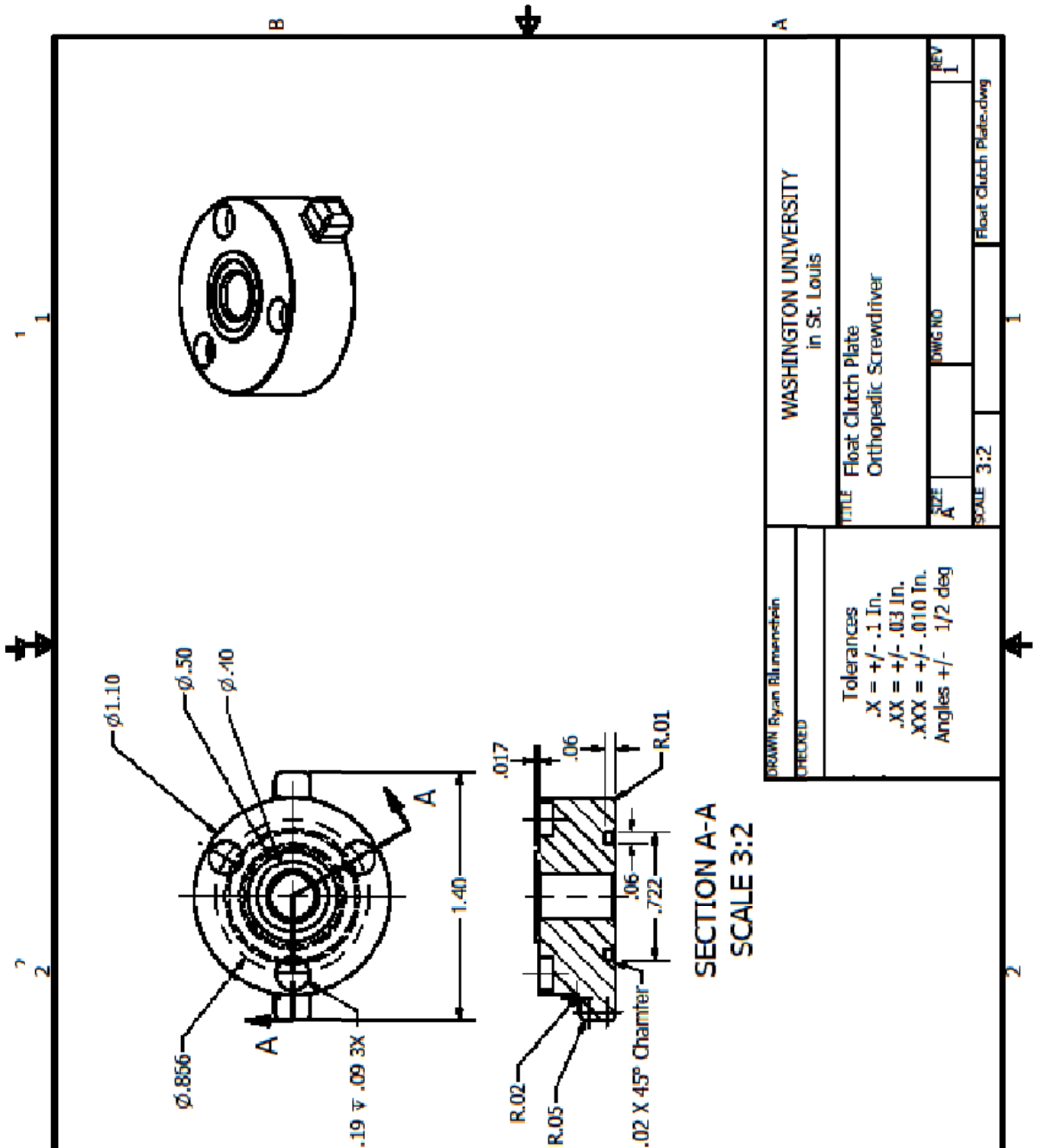
Price: \$10.15 per pack of 100

Total Price (of items with prices): \$37.02

4.3 Draft detail drawings for each manufactured part



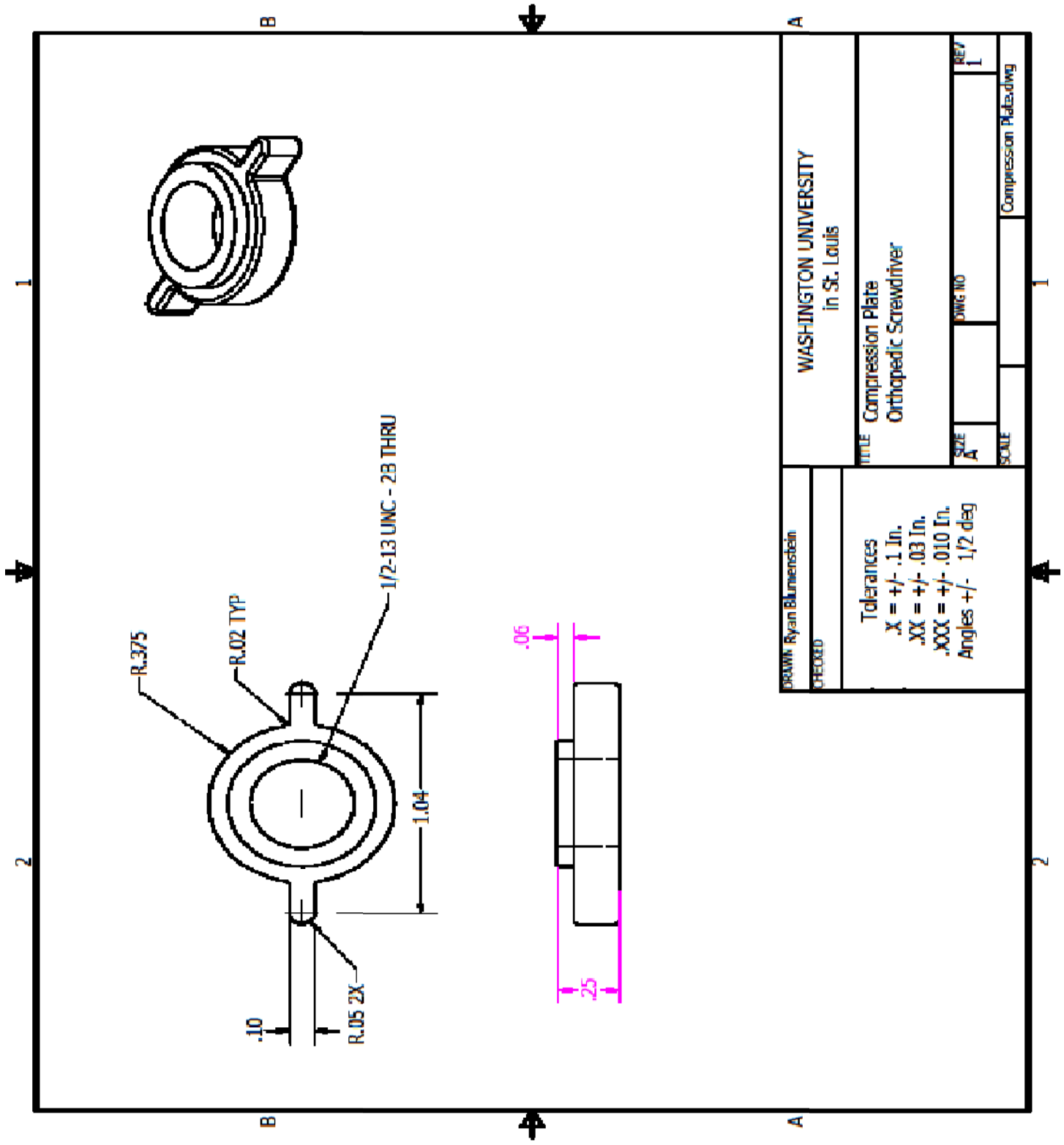


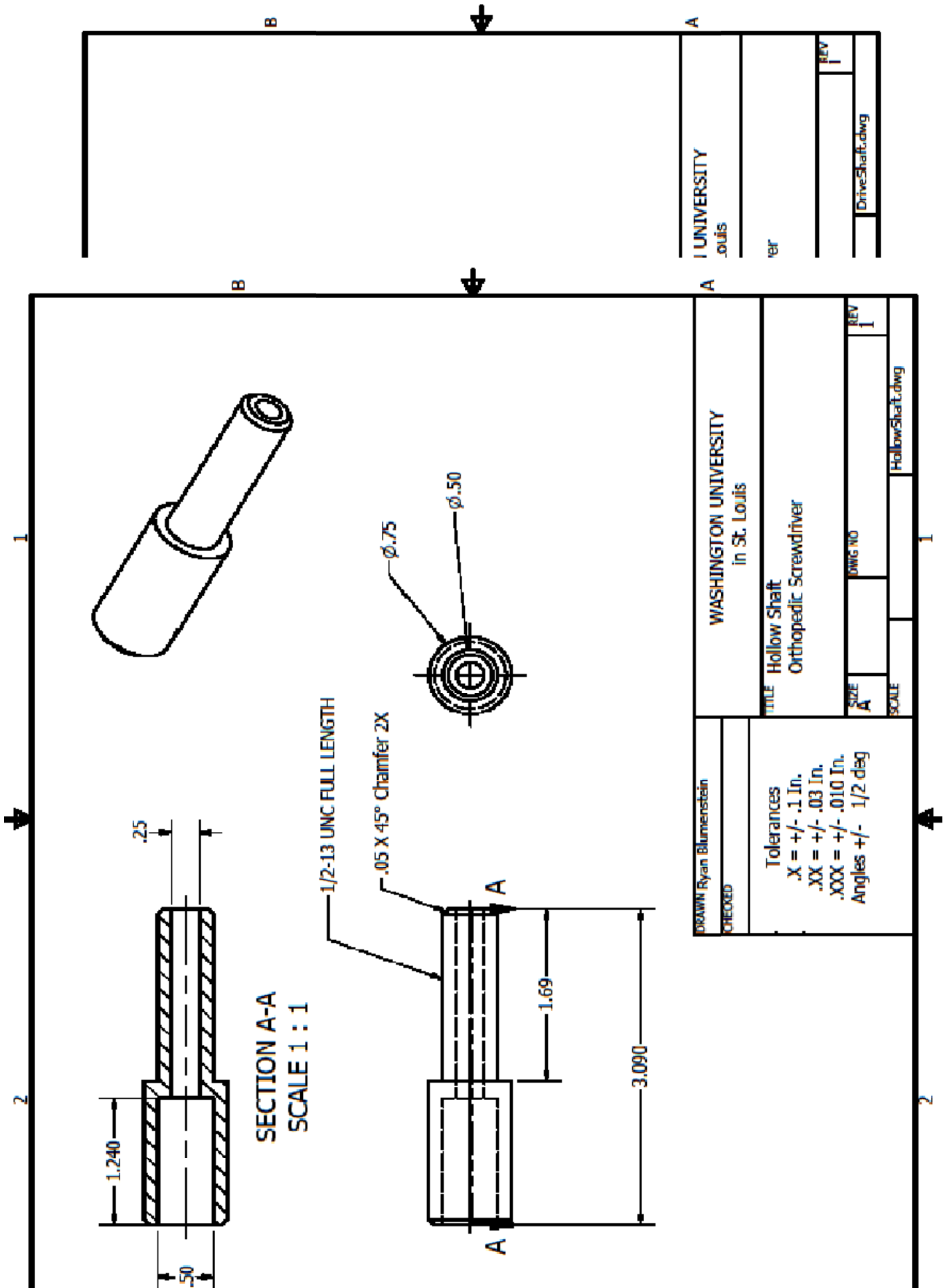


DRAWN Ryan Blumenstein		WASHINGTON UNIVERSITY in St. Louis	
CHECKED		TITLE Float Clutch Plate Orthopedic Screwdriver	
SIZE A	DWG NO	REV 1	Float Clutch Plate.dwg
SCALE 3:2		1	

Tolerances
 .X = +/- .1 In.
 .XX = +/- .03 In.
 .XXX = +/- .010 In.
 Angles +/- 1/2 deg

SECTION A-A
 SCALE 3:2



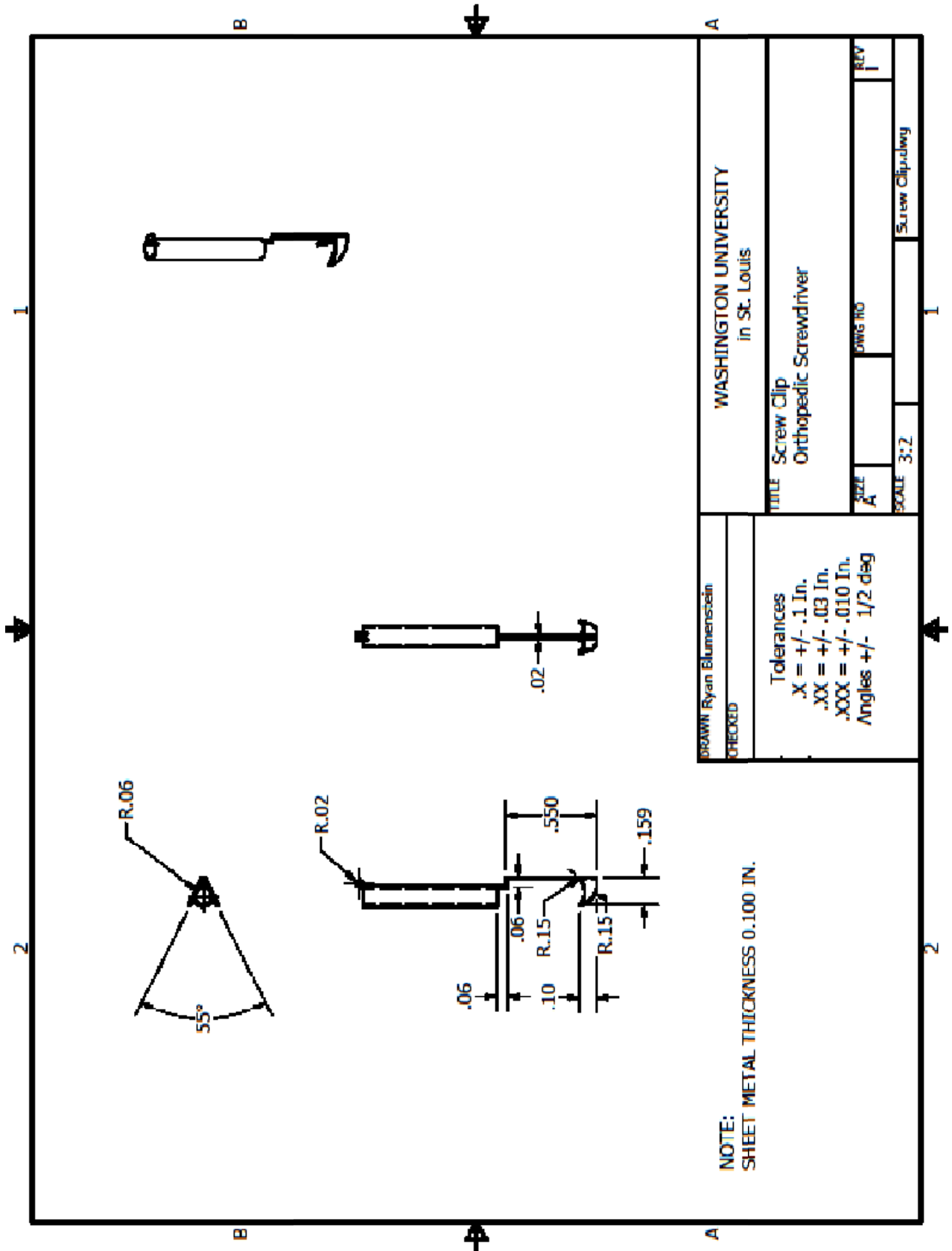


WASHINGTON UNIVERSITY in St. Louis	
TITLE Hollow Shaft Orthopedic Screwdriver	
SIZE A	DWG NO
SCALE	1
HollowShaft.dwg	

WASHINGTON UNIVERSITY in St. Louis	
TITLE Hollow Shaft Orthopedic Screwdriver	
SIZE A	DWG NO
SCALE	1
HollowShaft.dwg	

DRAWN Ryan Blumenstein	
CHECKED	
Tolerances .X = +/- .1 In. .XX = +/- .03 In. .XXX = +/- .010 In. Angles +/- 1/2 deg	

DRAWN Ryan Blumenstein	
CHECKED	
Tolerances .X = +/- .1 In. .XX = +/- .03 In. .XXX = +/- .010 In. Angles +/- 1/2 deg	



4.4 Description of the design rationale for the choice/size/shape of each part

- I. Design Rationale by Part
 - a. Mechanism Layout

The winning concept design has been modified such that the clutch mechanism is located at the top of the handle. This adjustment decreases the likelihood of the user inadvertently changing the gauge setting and allows torque to be applied more easily to the wider section of the handle. The new weight distribution also improves balance properties.

- b. Ball Bearing

The clutching mechanism is a crucial part of the torque limiting screwdriver's design. The maximum torque input was estimated to be 5 N-m and the narrowest part of the handle is ideally 35mm in diameter (taken from Canadian hand tool standards). A ball diameter of 3/16 in (~11mm) was chosen to balance precision and ease of assembly.

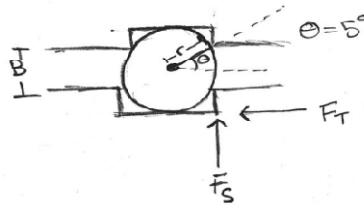


Figure 7: Free Body Diagram of Ball Bearing

The contact angle, θ , between the edge of a well and a ball bearing is 5 degrees. The following equation was used to approximate the distance between the fixed clutch plate and the floating clutch plate.

$$B = 2r \sin \theta = D \sin \theta = 0.44 \text{ mm}$$

- c. Spring

In order to find an appropriate spring, the spring constant, k , had to be determined based on the maximum torque applied and the geometry of the clutch.

Using the following equations, the spring force applied to the floating clutch plate was determined and used to estimate a spring constant.

$$F_S F_T = \tan \theta$$

$r = \text{dist. from ball bearing to center of shaft} = 11 \text{ mm}$

$$F_T = \tau 3r = 5 \text{ Nm} (3) 0.011 \text{ m} = 151.5 \text{ N}$$

$$F_S = 3 * F_T * \tan \theta = 39.76 \text{ N}$$

$$F_S = kx$$

$x = 20 \text{ mm}$.

F_s approximated as 40 N.

$K = 2000 \text{ N/m} = 11.42 \text{ lbf/in}$

Selected Spring: 9434K142 (McMaster)

- d. Tab size on Compression on Floating Plate

The two square tabs attached on opposite sides of the floating clutch plate were designed to guide the plate along the drive shaft without rotation. Two slots were created in the handle body interior to restrict the tabs. The following calculations show that the handle material (3-D printed ABS plastic) can withstand the stress applied by the tabs.

$$F_{\text{tab}} = 5 \text{ Nm} / 0.0152 \text{ m} = 329 \text{ N}$$

Two tabs

$$F_{\text{tab}2} = 165 \text{ N}$$

3D Printed ABS

$\sigma_y = 44 \text{ MPa}$ approximate as 22 MPa for 3D Printed Material

$$\sigma = 165 \text{ N} / (0.000762 \text{ m}) = 0.22 \text{ MPa}$$

$$\sigma_y < \sigma$$

- e. Set screws attaching Drive Shaft to Fixed Plate

The fixed plate must be attached to the drive shaft to transmit torque from the clutch mechanism to the bit. The most suitable attachment method was using a pair of set screws. The following calculations show that the drive shaft can handle the torque applied even with a reduced cross sectional area (area reduced by holes for set screws).

Stainless Steel: $\sigma_y = 290 \text{ MPa}$

Max Force

$$\text{Force} = \text{Max Torque} / \text{Distance} = 5 \text{ Nm} / 0.004 \text{ m} = 1250 \text{ N}$$

$$\sigma_B = 1250 \text{ N} / ((0.0032 \text{ m})(0.0016 \text{ m})) = 244 \text{ MPa} > \sigma_y$$

Two set screws:

$$\sigma_B2 = 122 \text{ MPa}$$

Original Shaft Thickness:

$$T_{\text{max}} = \pi / 16 \sigma_{\text{max}} (D^4 - d^4) = \pi / 16 (290 \text{ MPa}) (0.0098424^4 - 0.0049214^4) = 50.9 \text{ Nm}$$

Reduced Shaft Thickness:

$$T_{\text{max}} = \pi / 16 \sigma_{\text{max}} (D^4 - d^4) = \pi / 16 (290 \text{ MPa}) (0.0073824^4 - 0.0049214^4) = 18.4 \text{ Nm}$$

5 Engineering analysis

5.1 Engineering analysis proposal

ANALYSIS TASKS AGREEMENT

PROJECT: Orthopedic Screwdriver NAMES: Ryan Blumenstein *BB*

INSTRUCTOR: Thomas Bever

Beenish Qayum *BQ*

Tiffany Ewing *TME*

The following engineering analysis tasks will be performed:

Pre-Prototyping Analysis

- Torque/Force analysis of clutch mechanism design [All]
- Spring force analysis and design (clutch spring) [Qayum]
- Spring force analysis and design (retaining clip spring) [Ewing]
- Stress analysis of handle body design [Blumenstein]
- Design for Assembly/Disassembly analysis [Qayum/Ewing]
- Final weight estimated using AutoDesk Inventor model [Blumenstein]

Post-Prototyping Analysis

- Analysis of range and accuracy of torque, based on data from torque trials, under dry and "wet" surgical conditions [All]
- Screw insertion into bone trial [All]
- Screw-retention time-trials: statistical analysis [Ewing]
- Overall metric analysis and happiness equation evaluation [Qayum]

The work will be divided among the group members in the following way:

[See above]

Instructor signature: *Thomas Bever* ; Print instructor name: THOMAS BEVER

(Group members should initial near their name above.)

Figure 8: Analysis Agreement

5.2 Engineering analysis results

5.2.1 Motivation

The primary function of this orthopedic screwdriver is the prevention of damage to bone tissue through over-tightening of inserted orthopedic screws. The most critical element of the tool is therefore the ball detent clutch mechanism used to limit the applied torque. A mathematical model of the clutch behavior was developed based on the geometry of the clutch mechanism to predict the relationship between the applied spring force and the slipping torque. All other design goals (ergonomics, ease of assembly/disassembly, one-handed use) are insignificant if the tool cannot meet its primary function.

5.2.2 Summary statement

Geometric Clutch Analysis

The relationship between the spring force applied to the clutch and the torque at which the clutch will disengage is defined by the geometry of the ball bearings and their holes, specifically by the contact angle, θ , and the radial distance of the balls from the axis of the clutch. The possible dimensions were constrained by a previously established maximum handle diameter of 50-60 mm, which limited the radial distance and diameter of the balls. Through analysis of the forces at play in the mechanism, we selected an appropriate ball contact angle and spring force range to achieve the desired torque range of 0-5 Nm.

Experimental Calibration

Following construction of the prototype, the design team performed an experimental calibration of the tool's torque performance. Suspended masses were applied to the tool via a pivoting arm to supply a known torque. A torque scale was created to calibrate the tool from observations of the torque necessary to cause slip.

5.2.3 Methodology

Geometric Clutch Analysis

If friction effects are neglected, contact forces acting between the ball bearing and clutch plates are constrained to acting normal to the surface of the ball (see Figure , below). This contact force is the resultant of a normal compressive force due to the spring (F_S), and a shearing force due to the applied torque (F_T). For the condition above to be satisfied, $\frac{F_S}{F_T} = \tan\theta$, or $\frac{F_T}{F_S} = \cot\theta$; when $\frac{F_T}{F_S}$ exceeds $\cot\theta$, the ball detent will disengage, and slip occurs. Note that:

- The plate offset distance, B , is given by $B = 2r\sin\theta = D\sin\theta$
- The applied torque (T) and shear force (F_T), are related by R , the radial location of the bearings, as $F_T = \frac{T}{nR}$, where n denotes the number of bearings
- The maximum necessary spring force is therefore given by

$$F_S = F_T \tan\theta = \frac{T}{3R} \tan\theta$$

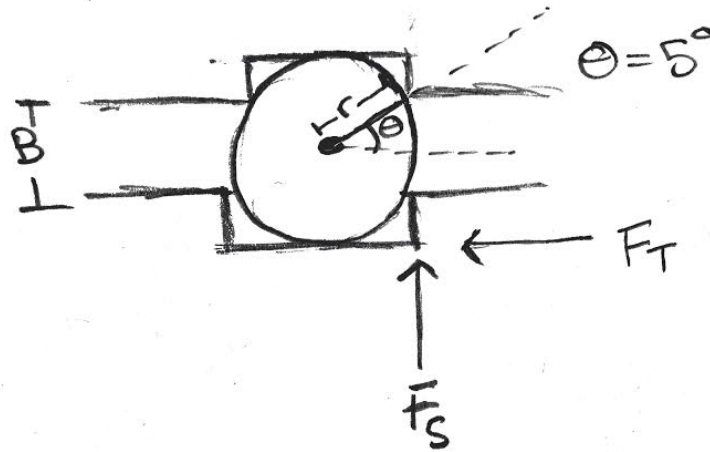


Figure 9: Force analysis of ball detent clutch.

Experimental Calibration

A simple test rig was constructed consisting of a pivoting arm with a mass hanger able to be set at a fixed, known lever arm length (Figure). The torque gauge was set to a fixed position, and mass applied until slip occurred; the mass was recorded, and measurements repeated multiple times at several settings along the length of the gauge. A torque scale



Figure 10: Torque calibration test apparatus.

was created from a linear fit of the data.

5.2.4 Results

Geometric Clutch Analysis

Based on tool geometry defined by ergonomic constraints, we selected a ball of diameter $3/16''$ (4.76 mm) and a radial position of 11 mm. We elected to use 3 balls to maximize stability and simplicity. A contact angle (θ) of 5° was found to give a satisfactory relation between torque and spring force, requiring a maximum of 40 N of compressive force to achieve the desired 5 Nm of applied torque. This required a plate offset of 0.44 mm.

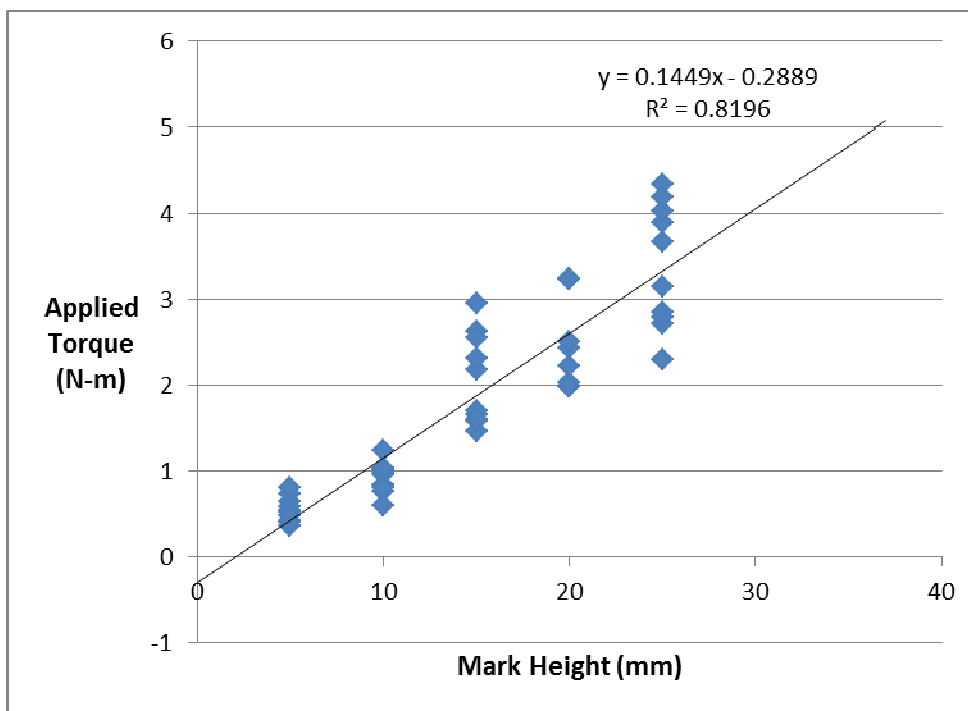
To balance accuracy and convenience in adjusting the tool to a desired torque setting, 20 mm was selected as an ideal gauge length; in this design, this dimension is also the maximum spring deflection. We therefore calculated our required spring constant as

$$k_S = \frac{F_S}{x} = \frac{40 \text{ N}}{.02 \text{ m}} = 2000 \frac{\text{N}}{\text{m}} = 11.42 \frac{\text{lbf}}{\text{in}}$$

Experimental Calibration

The data collected in calibration trials is plotted below in Figure. In prototyping, the gauge length was changed from 20 mm to 35 mm to allow for easier adjustment. As shown, the calibrated tool ranges from 0-5 Nm over the gauge length of 35 mm. This data revealed that the tool is less accurate than desired, with significant variation in slipping torque especially evident at higher torque settings.

Figure 11: Torque calibration data and linear fit.



5.2.5 Significance

The results of our post-prototype experimental calibration validated the results of our design calculations and our geometric model of the clutch behavior, but reveal inconsistency. A redesign of the clutch geometry to attempt to improve the reliability of the tool was deemed beyond the scope of feasibility for the current prototyping stage, but future development would need to consider experimenting with alternate clutch geometries to achieve the desired accuracy of $\pm 5\%$ specified by the client.

5.2.6 Summary of code and standards and their influence

Few codes and standards were found which applied directly to this design. Strict standards were found governing the material and design of surgical driver bits; however, this prototype used a standard tool socket and driver bit, and in

modification to a surgical device, would incorporate existing standard surgical socket and driver bits. This design, therefore, did not need to take those standards into consideration.

Great consideration was given to requirements of a surgical device, however. The tool was designed for simple and convenient disassembly/reassembly for cleaning and autoclaving between uses. The tool was also designed to operate without the need for any lubricants, which could contaminate a surgical environment, and stainless steel construction was selected for all metal components to ensure corrosion resistance during autoclaving.

6 Working prototype

6.1 A preliminary demonstration of the working prototype

Completed on 11/7/14

6.2 A final demonstration of the working prototype

Completed on 11/21/14

6.3 Prototype Photos



Figure 12: Orthopedic Screwdriver Prototype



Figure 13: Orthopedic Screwdriver Prototype in Use

6.4 A short video clip that shows the final prototype performing

Screwdriver Demo: <https://www.youtube.com/watch?v=0CDSzfPaT5U>

6.5 Additional digital photographs with explanations



Figure 14: Handle Body

Figure 14 show a view of the handle body's internal grooves for the clutch mechanism and drive shaft. 3D printing was essential to obtain the designed shape.



Figure 15: Views of Clutch Plates

Figure 15 shows two views of the handle body with the float clutch plate shown on the left and the fixed clutch plate shown on the right. The case-hardened balls inside of the clutch and the drive shaft are not shown in these photos.



Figure 16: Internal Mechanism

Figure 16 shows the internal mechanism of the screwdriver which includes the clutch mechanism, compression spring, drive shaft, socket, bit and screw retaining clip.



Figure 17: View of Major Components

Figure 17 shows the three major components of the prototype: the handle body, the handle cap and the internal shaft.

7 Design documentation

7.1 Final Drawings and Documentation

7.1.1 A set of engineering drawings that includes all CAD model files and all drawings derived from CAD models.

See Appendix B for CAD drawings. CAD model files are located in the Group File Exchange on Blackboard.

7.1.2 Sourcing instructions

Parts 1-10 will need to be custom fabricated following the dimensions shown in CAD drawings. Parts 11-16 (see parts list on page 43) can be ordered through McMaster-Carr or another company with an equivalent product. Part 17 can be purchased through Home Depot and cannibalized such that the socket can be re-attached to the hollow shaft of the orthopedic screwdriver.

7.2 Final Presentation

7.2.1 A live presentation in front of the entire class and the instructors

Completed on 12/4/14

7.2.2 A link to a video clip version of 1

Full Design Presentation: <https://www.youtube.com/watch?v=Lwty3KIYq8k>

7.3 Teardown

Figure 18 shows the Teardown Agreement Form completed on 12/3/14.

<p>TEARDOWN TASKS AGREEMENT</p> <p>PROJECT: Orthopedic Screwdriver Group 2</p> <p>NAMES: Ryan Blumenstein, Tiffany Ewing, Beenish Qayum</p> <p>INSTRUCTOR: Jakiela</p> <p>The following teardown/cleanup tasks will be performed:</p> <ul style="list-style-type: none">- Extra metal stock pieces will be returned to stock storage in shop- Extra ordered hardware will be stored in Jolley basement / Urbauer shop- Extra 3D printed pieces will be thrown out- Shop tools were put away as used- Testing material will be returned/salvaged- Prototype will be kept	<p>Instructor comments on completion of teardown/cleanup tasks:</p> <p>Instructor signature: <u>M. J. Jakiela</u>; Print instructor name: <u>JAKIELA</u></p> <p>Date: <u>12/3/2014</u></p> <p>(Group members should initial near their name above.)</p>
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Figure 18: Teardown Agreement Form

8 Discussion

8.1 Using the final prototype produced to obtain values for metrics, evaluate the quantified needs equations for the design. How well were the needs met? Discuss the result.

Metric	1	2	3	4	5	6	7	8	9	10	11	12	13
accepts 1/4" hexagonal driver shaft	1												
Amount of time screw is held in "dig" condition		0.5	0.25	0.25	0.25	0.25							
weight			0	50	30	125	0	30	0	1	1	1	1
large handle diameter				60	45	100	100	0	5	0	0	0	10
small handle diameter				55.1	35.85	131.5	0	30	12.52	1	1	1	7
handle length				0.85	0.82	0.74	1	1	0	1	1	1	0.3
handle maintains grip (% reduction in torque)													
tool maintains grip on screw in "wet" surgical													
torque accuracy (% difference)										1			
works in reverse										1			
can be autoclaved											1		
meets surgical standards												0.8	
number of parts													0.2

Figure 19: Final Design Needs Equation

The needs were met reasonably well (happiness value of 0.76 out of 1.00).

Looking forward, the team identified several key next steps. In prototyping, the design tolerances on the handle body were relaxed to account for inaccuracies in the 3D printing process. In the next revision, these tolerances would be tightened up to minimize play or extra shifting in the device. Another key step will be consulting with surgeons to improve the ergonomics of the handle. In modifying this prototype into a surgical device, the standard tool socket and driver used here will be replaced with surgical hardware. It will be crucial to experiment with the clutch geometry to improve the accuracy of the clutch, and case harden the clutch plates for wear-resistance. Currently, the clip spring is exposed— future designs will conceal it in a sleeve for both aesthetic and safety purposes (prevent S-link from catching soft tissue). Moving from prototyping to production, the ABS printed plastic would be replaced with an injection-molded thermoset such as epoxy or phenolic. Stainless steel reinforcement plates would also be incorporated at critical places in the handle for strength and durability.

8.2 Obtaining Parts

The team did not experience any significant part sourcing issues.

The majority of the parts for the screwdriver were machined by the team. These parts were made from stainless steel stock material found in the student machine shop. Pat Harkins was important to the success of the clutch mechanism. He provided guidance during the machining process and was particularly helpful when using the CNC Router.

The screwdriver handle and screw retaining clip were 3D-printed through the MEMS department. It did take multiple prints to obtain usable parts from this process. However, the source of this difficulty was incorrect calibration of the MEMS department's 3D printer. Dr. Ruth Okamoto was able to lend her expertise in this area and allowed the team to print parts using her lab's MakerBot. The parts printed in her lab were used in the final prototype.

The screwdriver socket and bit were cannibalized from a universal tool purchased through Home Depot. This part was ordered online and picked up in store. There were minor difficulties encountered when picking up the part because it was ordered and picked up by different people. In the future, it may be helpful for the MEMS department to leave a note in the comments section listing the name of the student picking up the order.

The remaining parts (springs, misc. screws, and case-hardened balls) were purchased through McMaster-Carr. This company's website allows for orders to be sent to a third-party (Linda Buckingham) for payment. This feature made the part ordering process easier for the team. Also, McMaster-Carr filled orders within 2-3 business days, which kept the fabrication process running smoothly.

8.3 Overall experience:

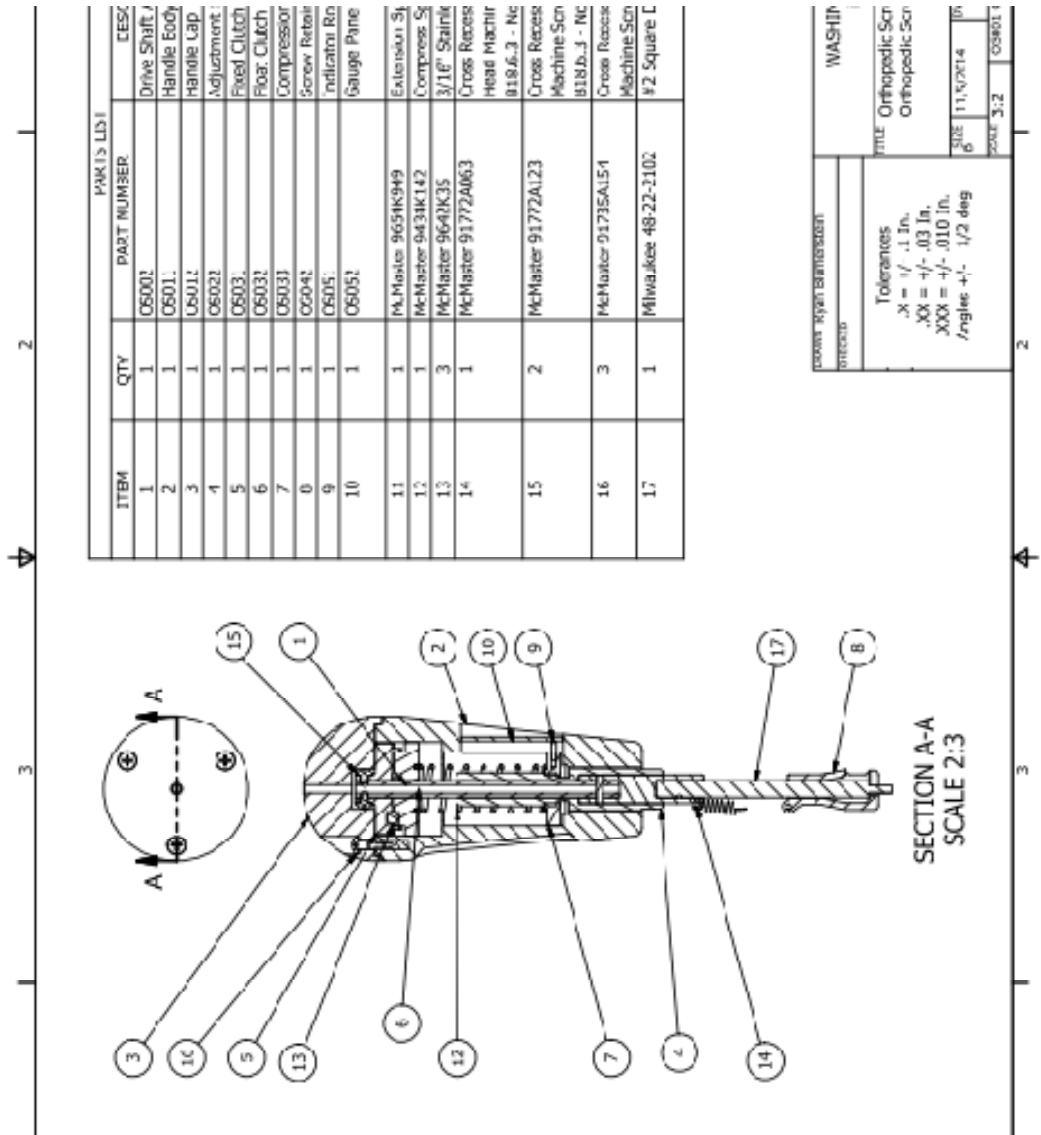
- **Was the project more or less difficult than you had expected?**
The difficulty of the project met our team's initial expectations. Ryan is currently a teaching assistant for Machine Shop Practicum and has a thorough understanding of part machining. Tiffany had worked with non-surgical torque-limiting screwdrivers at a previous job and Beenish had first-hand experience working sterile environments. These insights combined with background research gave the team sufficient grounds to estimate the difficulty of the project.
- **Does your final project result align with the project description?**
Our final product addresses all the parameters set by the design description. After researching ergonomics of hand tools and similar medical devices, we produced a design that could be easily modified into a medical device. The team tested and calibrated our tool ensuring that the clutch would slip at the predicted torque. Theoretically, a surgeon would adjust the tool to the desired setting and not worry about damaging bone material while inserting an orthopedic screw. Suitable medical grade materials were determined to allow for the final manufacturing of a surgical tool.
- **Did your team function well as a group?**
The team functioned very well as a group. Meetings were both productive and enjoyable. All of the team members were committed to the success of the project, which was essential to healthy team dynamics.
- **Were your team member's skills complementary?**
Yes. Every team member did not have identical work styles, but everyone was respectful and willing to compromise for the success of the project.
- **Did your team share the workload equally?**
The workload was distributed according to the strengths of individual team members and evened out over the course of the semester.
- **Was any needed skill missing from the group?**
No skill was missing from the group. Each team member contributed a unique perspective and set of skills. Also, any potential holes in knowledge were covered through background research.

- **Did you have to consult with your customer during the process, or did you work to the original design brief?**
Our customer, Professor Bever, was interviewed at the beginning of the design process to determine customer needs and design parameters. Both the interview and original design brief informed the selected concept design and little interaction was necessary past this point.
- **Did the design brief (as provided by the customer) seem to change during the process?**
The design brief as provided by Professor Bever remained the same during the entire process.
- **Has the project enhanced your design skills?**
The project has enhanced the design skills of each team member. It challenged us to put ourselves in the place of the user and account for many different scenarios. The fabrication process taught us how to use 3D-printing effectively. Also, the class assignments and presentation required us to organize our design process coherently.
- **Would you now feel more comfortable accepting a design project assignment at a job?**
All of us would feel more comfortable accepting a design project assignment at a job after this design process.
- **Are there projects that you would attempt now that you would not attempt before?**
This process developed the design skills of each member and increased our confidence in taking on design projects. This confidence would likely lead to more adventurous design projects in the future.

9 Appendix A - Parts List/ Bill of Materials

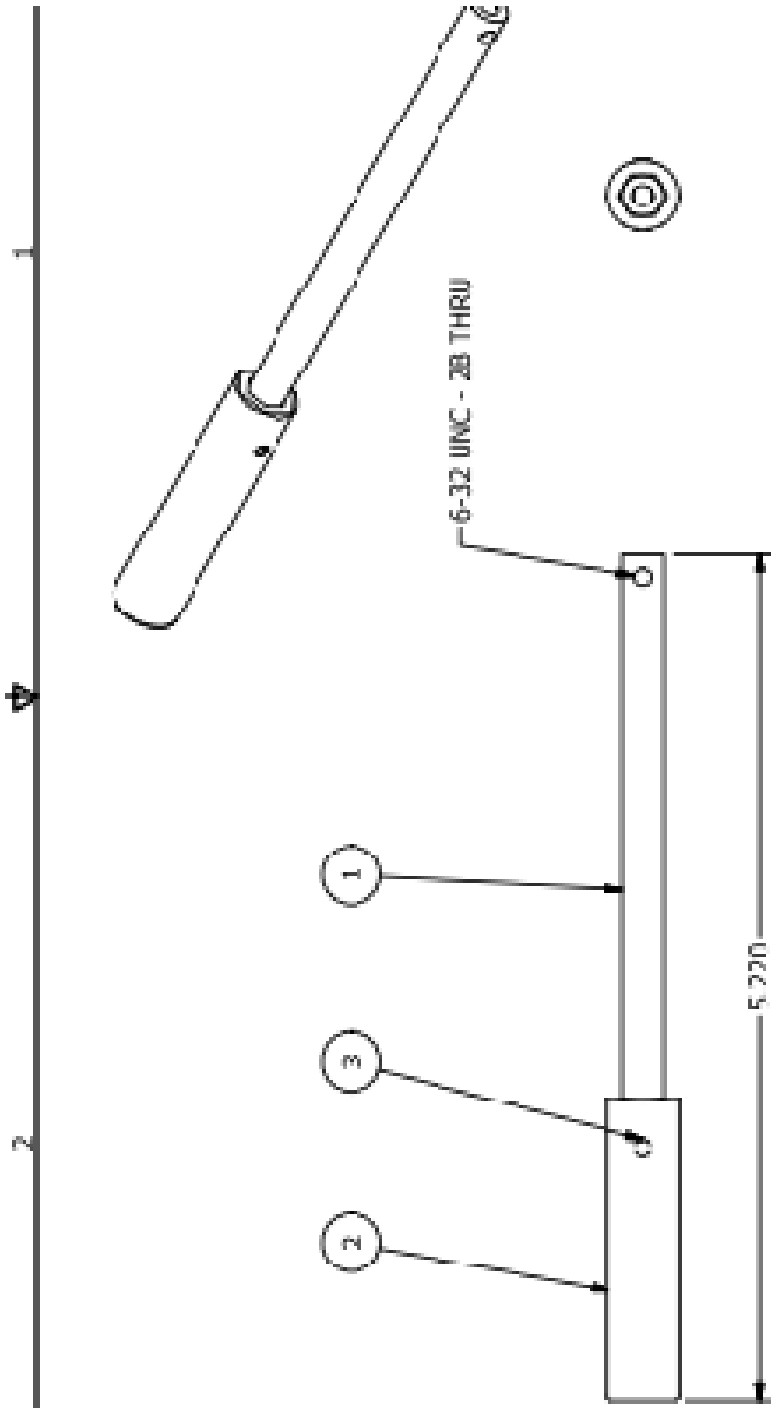
PARTS LIST				
ITEM	QTY	PART NUMBER	DESCRIPTION	MATERIAL
1	1	OS002	Drive Shaft Assembly	
2	1	OS011	Handle Body	ABS Plastic
3	1	OS012	Handle Cap	ABS Plastic
4	1	OS022	Adjustment Shaft	Stainless Steel
5	1	OS031	Fixed Clutch Plate	Stainless Steel
6	1	OS032	Float Clutch Plate	Stainless Steel
7	1	OS033	Compression Plate	Stainless Steel
8	1	OS042	Screw Retaining Clip	ABS Plastic
9	1	OS051	Indicator Rod	Stainless Steel
10	1	OS052	Gauge Pane	Polycarbonate, Clear
11	1	McMaster 9654K949	Extension Spring	Stainless Steel
12	1	McMaster 9434K142	Compress Spring	Stainless Steel
13	3	McMaster 9642K35	3/16" Stainless Steel Ball	Stainless Steel
14	1	McMaster 91772A063	Cross Recessed Binding Head Machine Screw ANSI B18.6.3 - No. 1 - 72 - 1/8	Stainless Steel
15	2	McMaster 91772A123	Cross Recessed Pan Head Machine Screw ANSI B18.6.3 - No. 5 - 40 - 1/8	Stainless Steel
16	3	McMaster 91735A154	Cross Recessed Pan Head Machine Screw - Type I	Stainless Steel
17	1	Milwaukee 48-22-2102	#2 Square Driver Bit	Chrome-plated steel

10 Appendix B - CAD Models



PARTS LIST				
ITEM	QTY	PART NUMBER	DESCRIPTION	MATERIAL
1	1	OS002	Drive Shaft Assembly	
2	1	OS011	Handle Body	ABS Plastic
3	1	OS012	Handle Cap	ABS Plastic
4	1	OS022	Adjustment Shaft	Stainless Steel
5	1	OS031	Fixed Clutch Plate	Stainless Steel
6	1	OS032	Float Clutch Plate	Stainless Steel
7	1	OS033	Compression Plate	Stainless Steel
8	1	OS042	Screw Retaining Clip	ABS Plastic
9	1	OS051	Indicator Rod	Stainless Steel
10	1	OS052	Gauge Pane	Polycarbonate, Clear
11	1	McMaster 9654K949	Extension Spring	Stainless Steel
12	1	McMaster 9434K142	Compress Spring	Stainless Steel
13	3	McMaster 9642K35	3/16" Stainless Steel Ball	Stainless Steel
14	1	McMaster 91772A063	Cross Recessed Binding Head Machine Screw ANSI B18.6.3 - No. 1 - 72 - 1/8	Stainless Steel
15	2	McMaster 91772A123	Cross Recessed Pan Head Machine Screw ANSI B18.6.3 - No. 5 - 40 - 1/8	Stainless Steel
16	3	McMaster 91735A154	Cross Recessed Pan Head Machine Screw - Type I	Stainless Steel
17	1	Milwaukee 48-22-2102	#2 Square Driver Bit	Chrome-plated steel

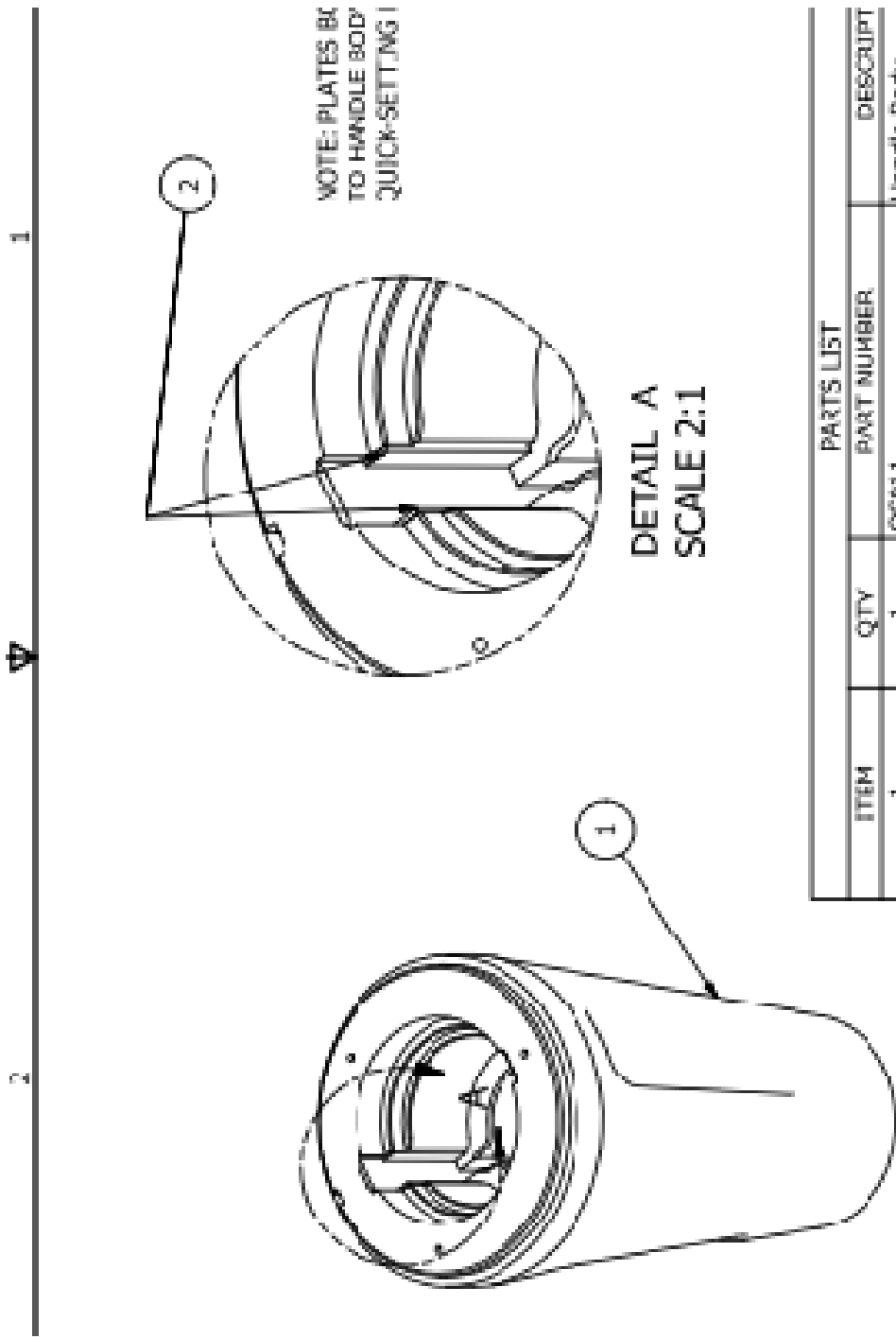
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PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	OS021	Drive Shaft
2	1	OS023	Driver Socket
3	1		Spring Pin 0.1 x 0

DESIGN R Blumenstein CHECKED		WASHINGTON UNIVERSITY St. Louis	
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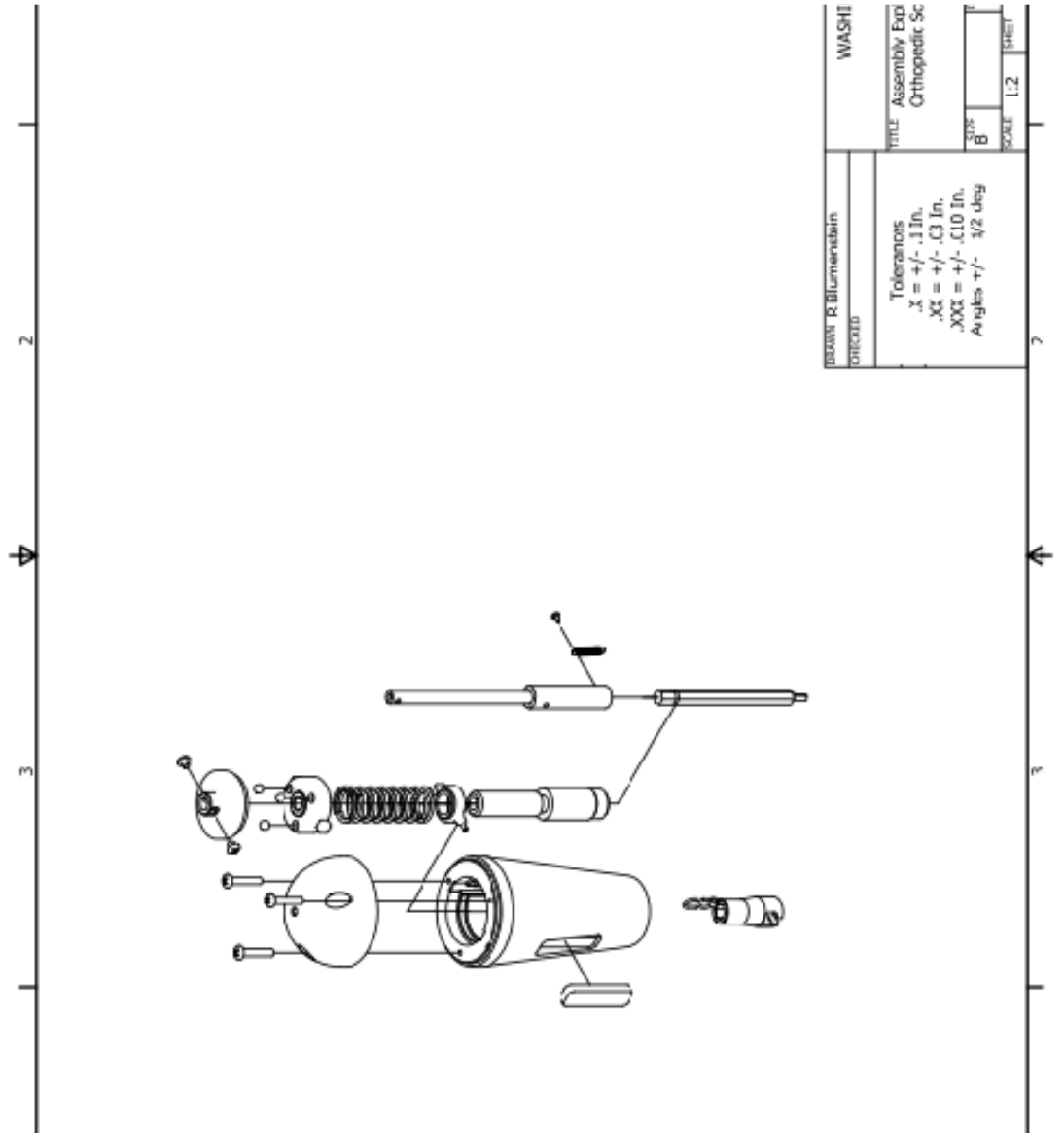
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 .XX = +/- .03 In.
 .XXX = +/- .010 In.
 Angles +/- 1/2 deg



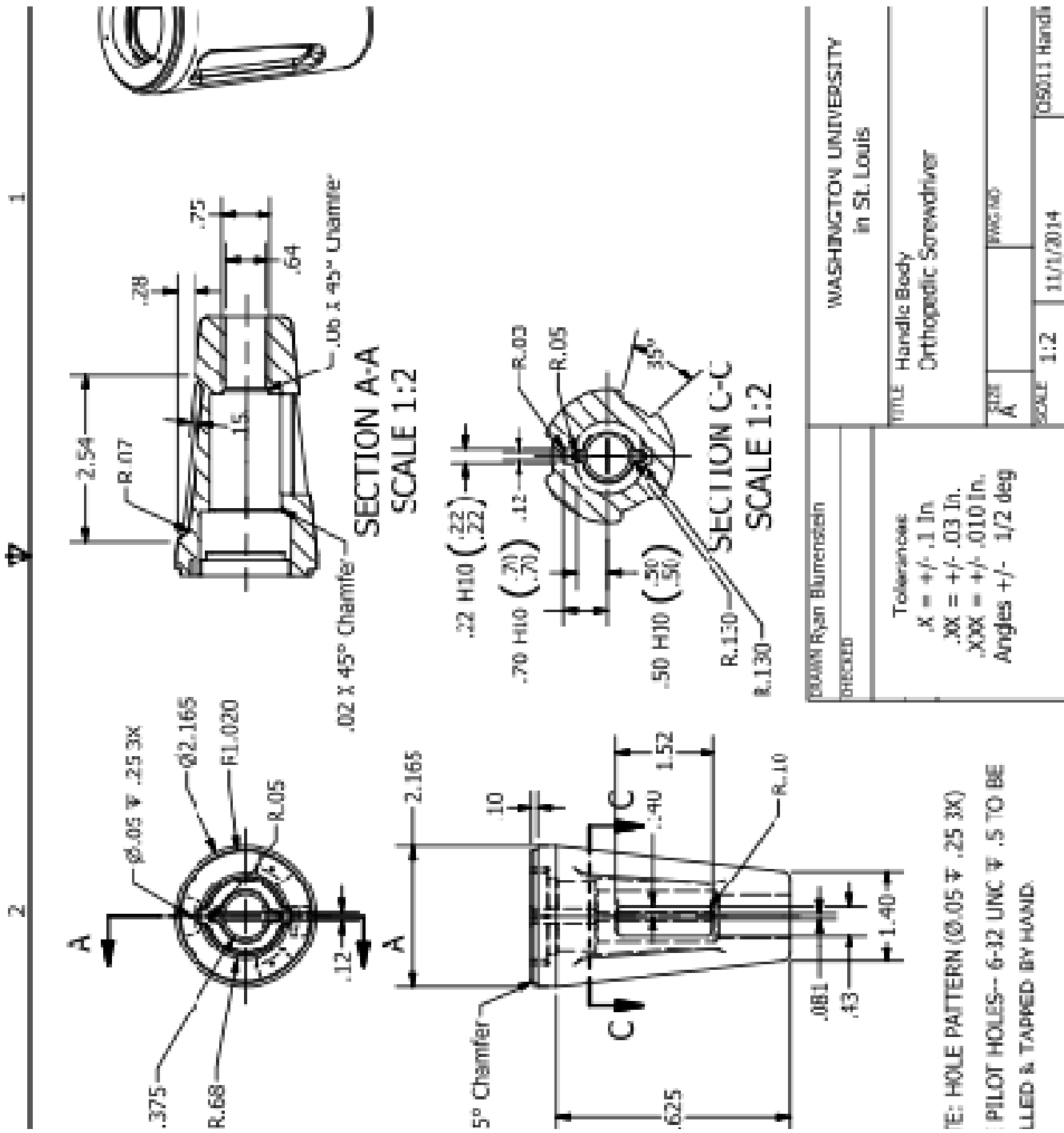
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2	4	OS013 Reinforcing Plate

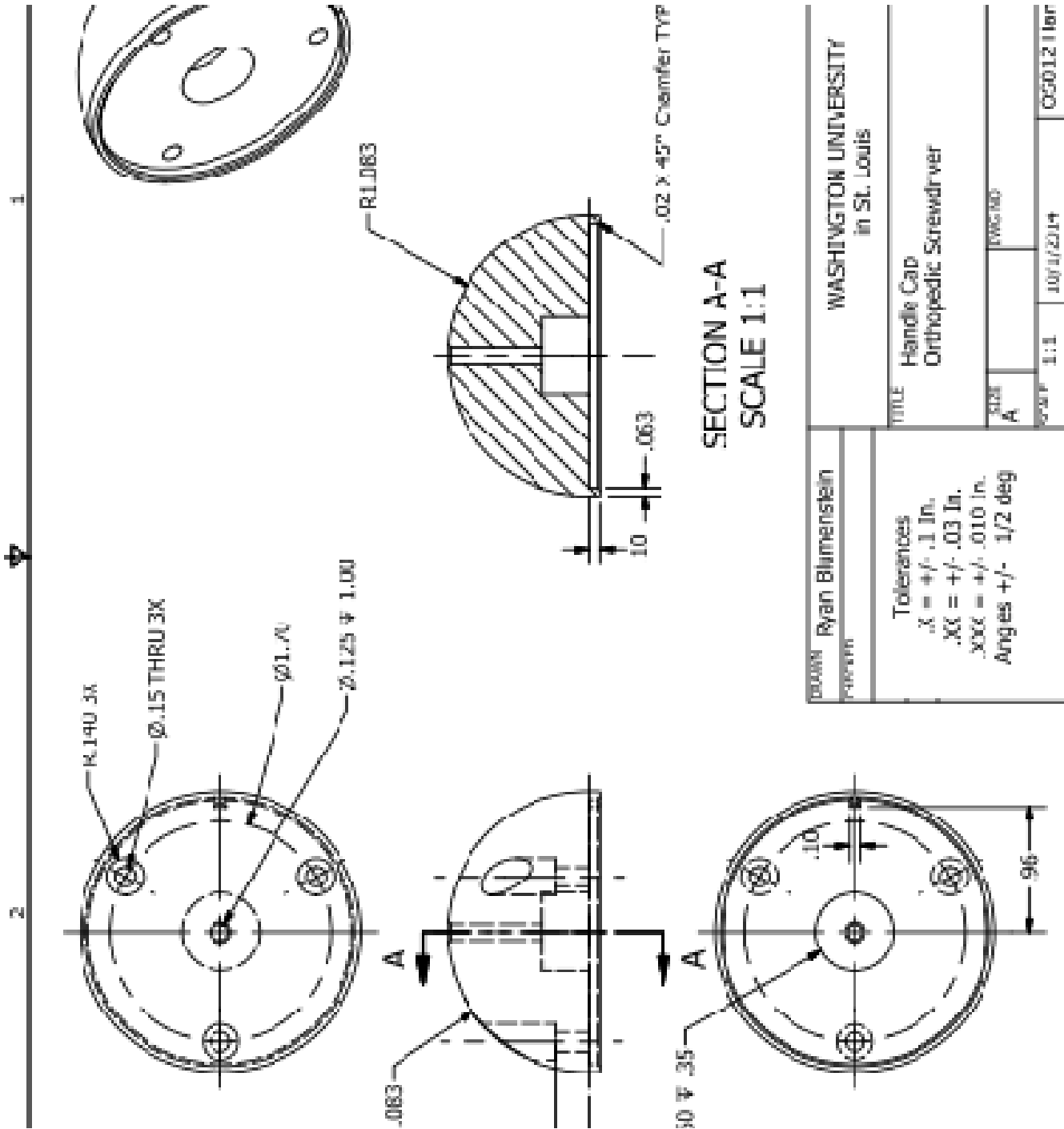
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DATE	11/25/2014	DESIGNED	
SCALE	A	DATE	
PART	1/1	OS003 Handle	

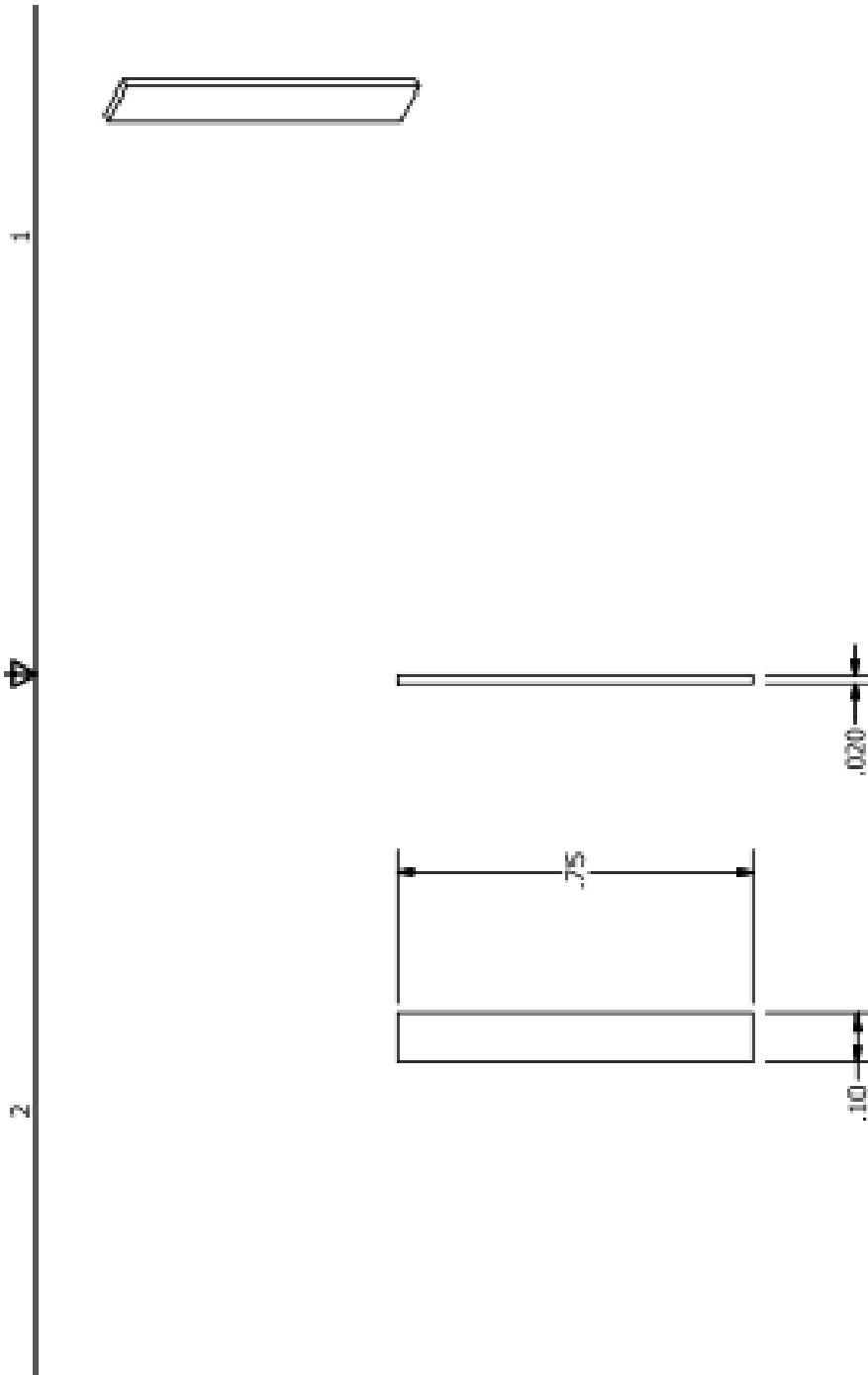
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 .XXX = +/- .010 In.
 Angles +/- 1/2 deg



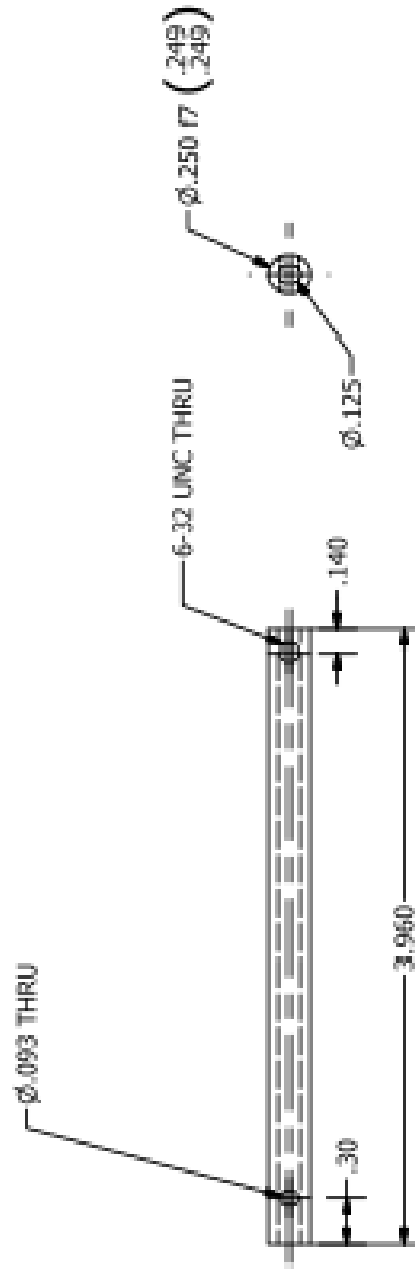
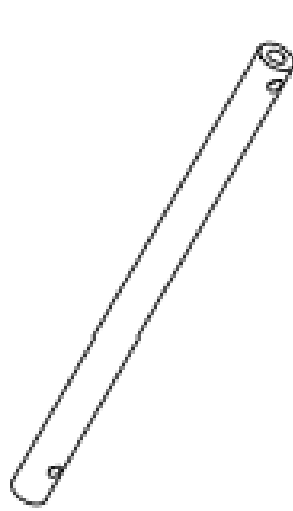
DESIGN: R. Blumenthal	WASHI
DRAWN:	
Tolerances .X = +/- .1 In. .XX = +/- .03 In. .XXX = +/- .010 In. Angles +/- 1/2 deg	
TITLE: Assembly Expl Orthopedic Sc	
DATE: 8/1/14	SHEET: 1
SCALE: 1:2	







DESIGN Ryan Blumenstein		WASHINGTON UNIVERSITY in St. Louis	
DRC: RDD		TITLE Reinforcing Plate Orthopedic Screwdriver	
Tolerances .X = +/- .1 In. .XX = +/- .03 In. .XXX = +/- .010 In. Angles +/- 1/2 deg		DATE 08/26/10	SCALE 4:1
A		11/25/2014	0.9013 Reinfo



DRUM R Blumenstein
CREATOR

WASHINGTON UNIVERSITY
in St. Louis

TITLE Drive Shaft
Orthopedic Screwdriver

SIZE A

SCALE 1:1

DATE 10/27/2014

Q1

030218 Drive

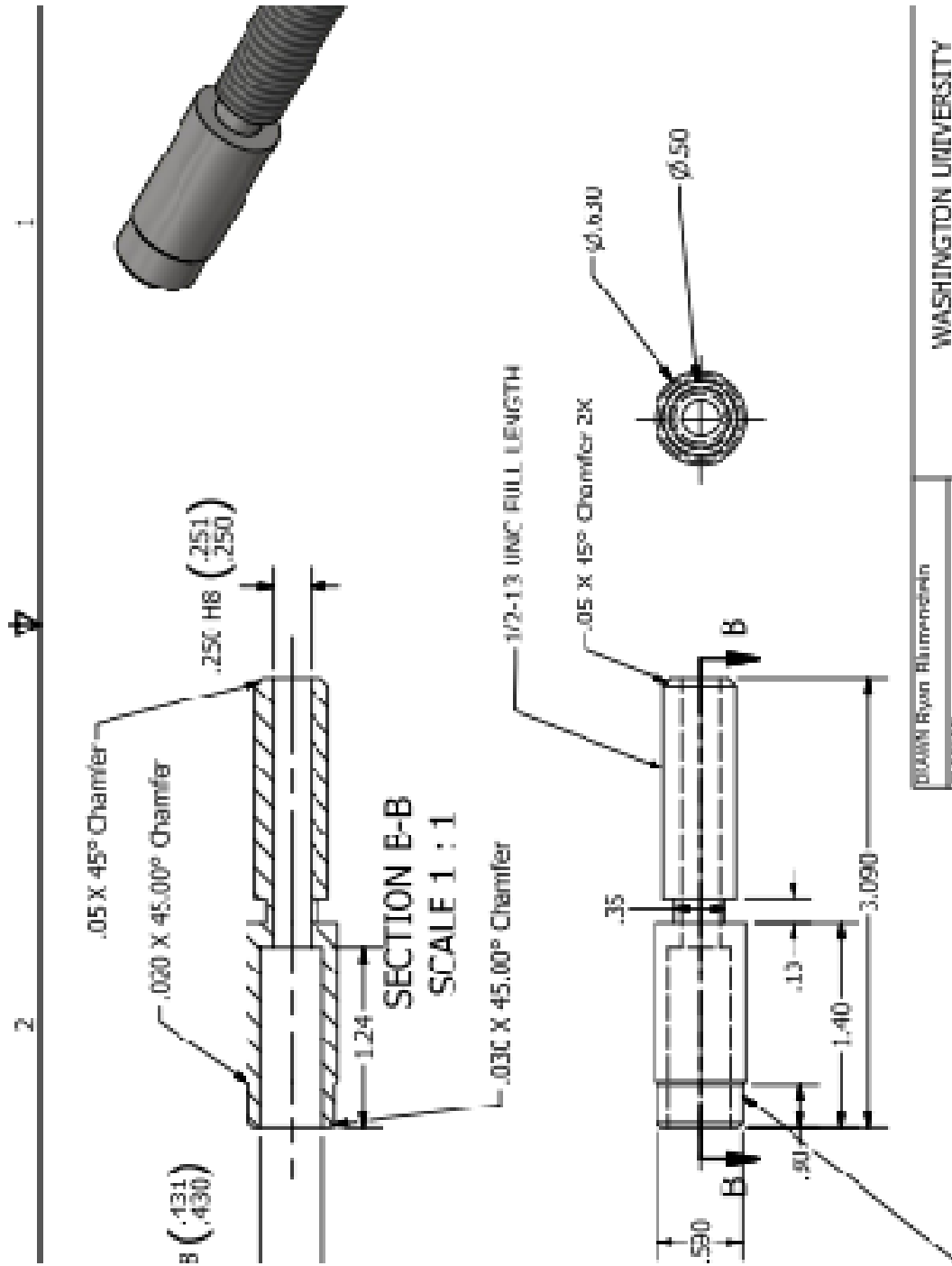
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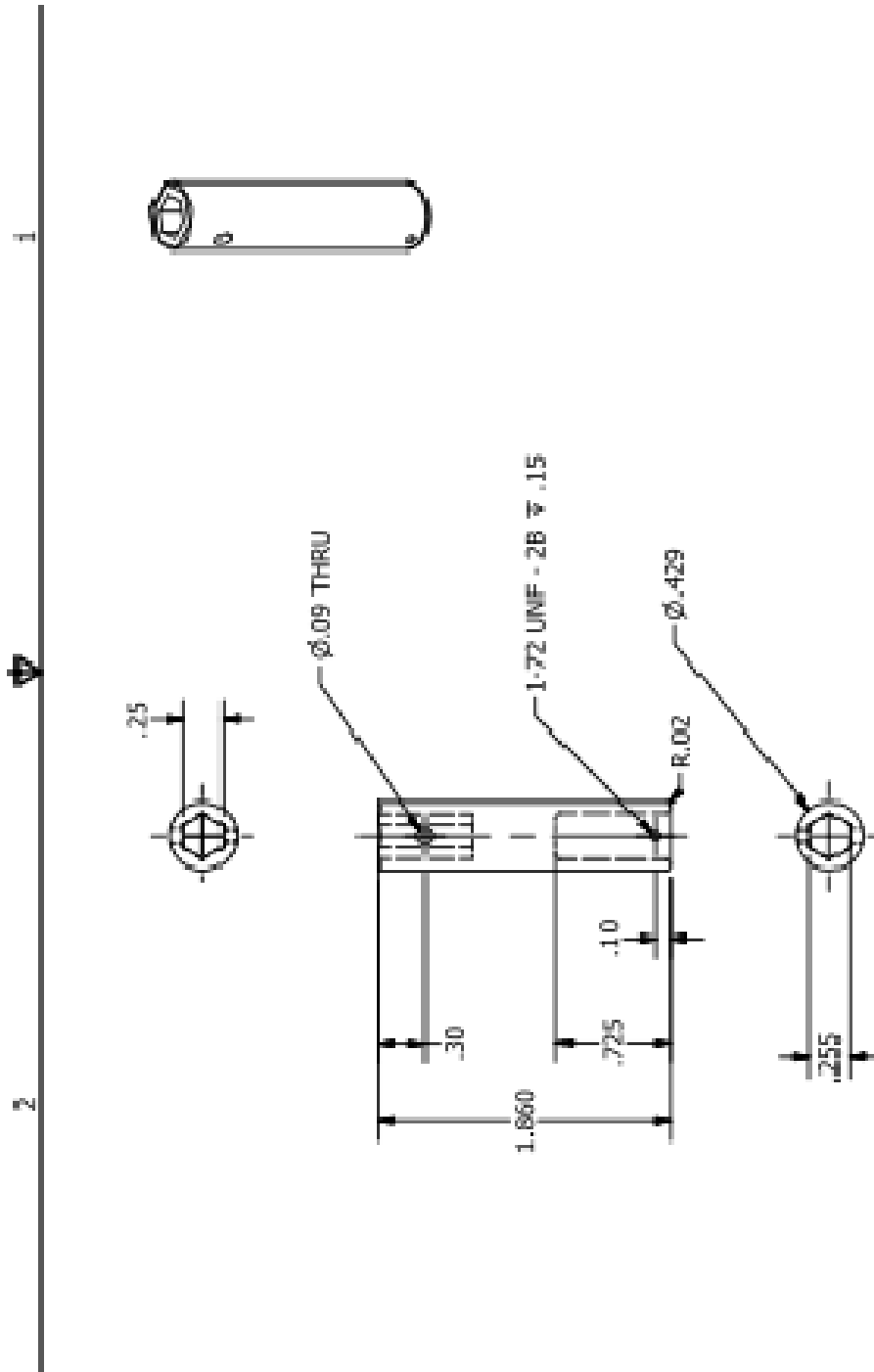
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T: LEAVE EXTRA LENGTH-- CUT TO
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H SOCKET.

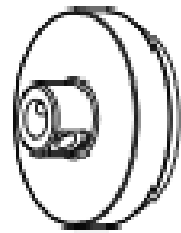
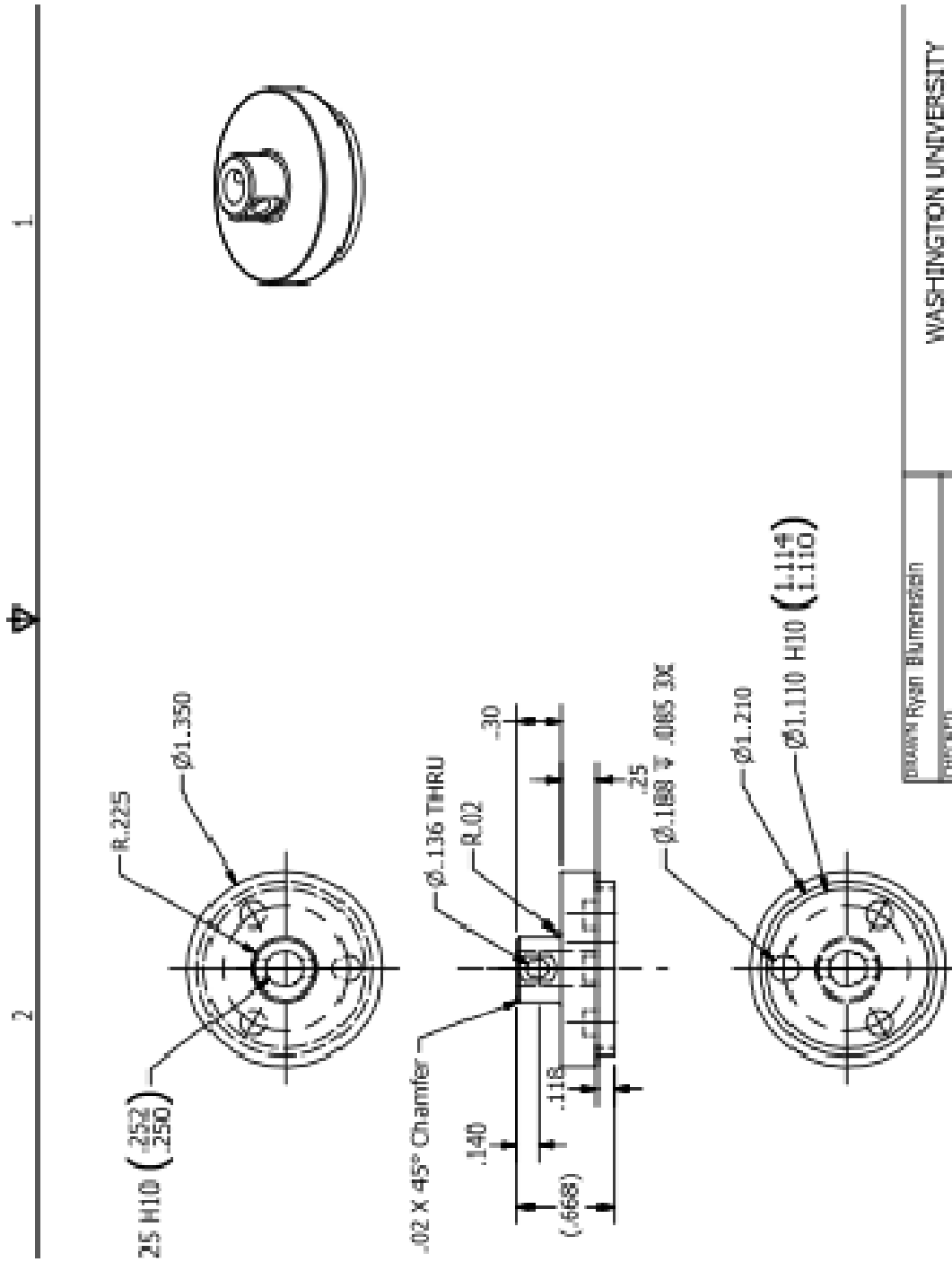
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.XX = +/- .03 In.
.XXX = +/- .010 In.
Angles +/- 1/2 deg



DARRIN Ryan Blumstein 050000		WASHINGTON UNIVERSITY in St. Louis	
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SCALE 1:1	DATE 11/5/2014	050000 Hollow	

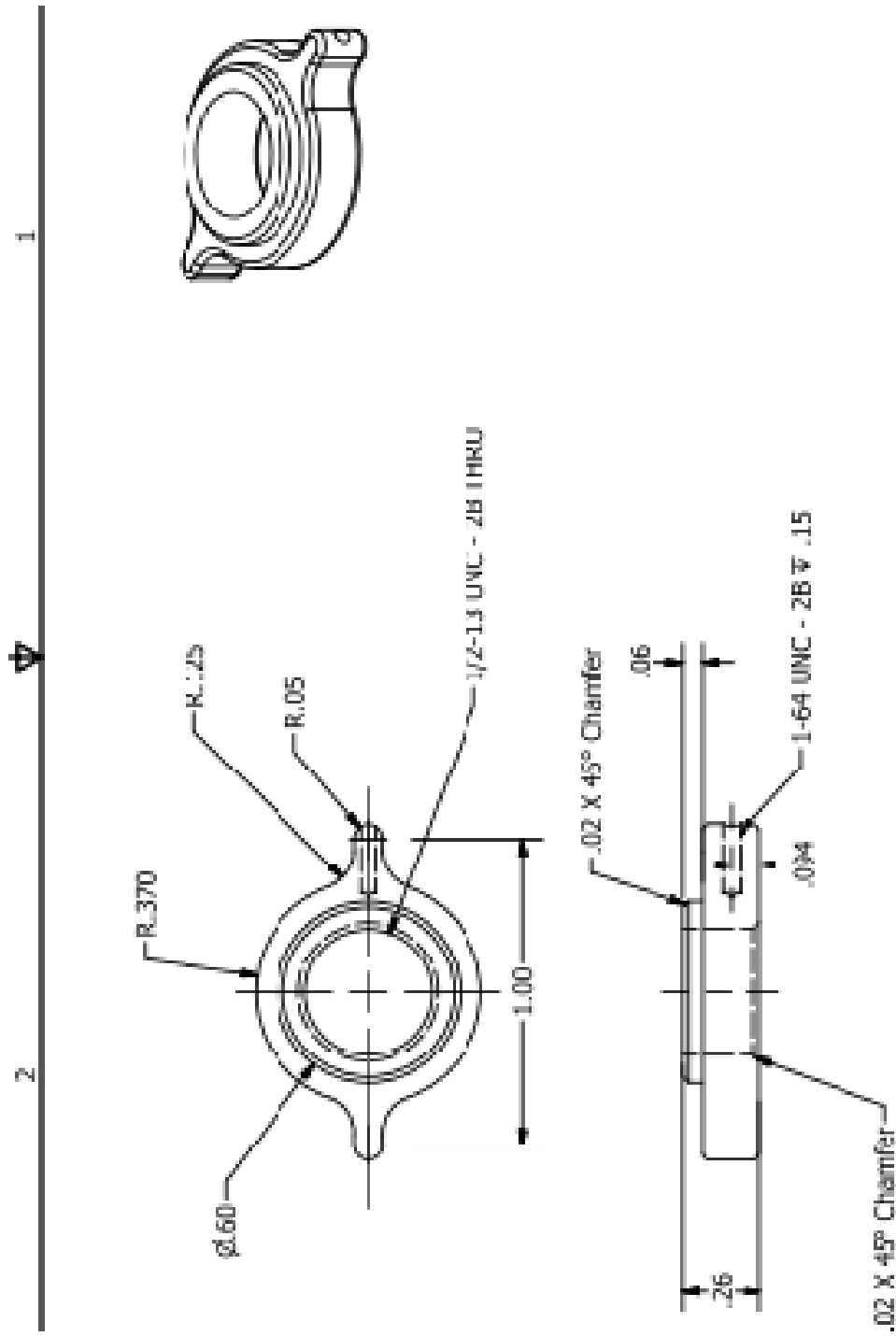


DESIGNER Ryan Blumenstein		WASHINGTON UNIVERSITY in St. Louis	
DRAFTSMAN		TITLE Driver Socket Orthopedic Screwdriver	
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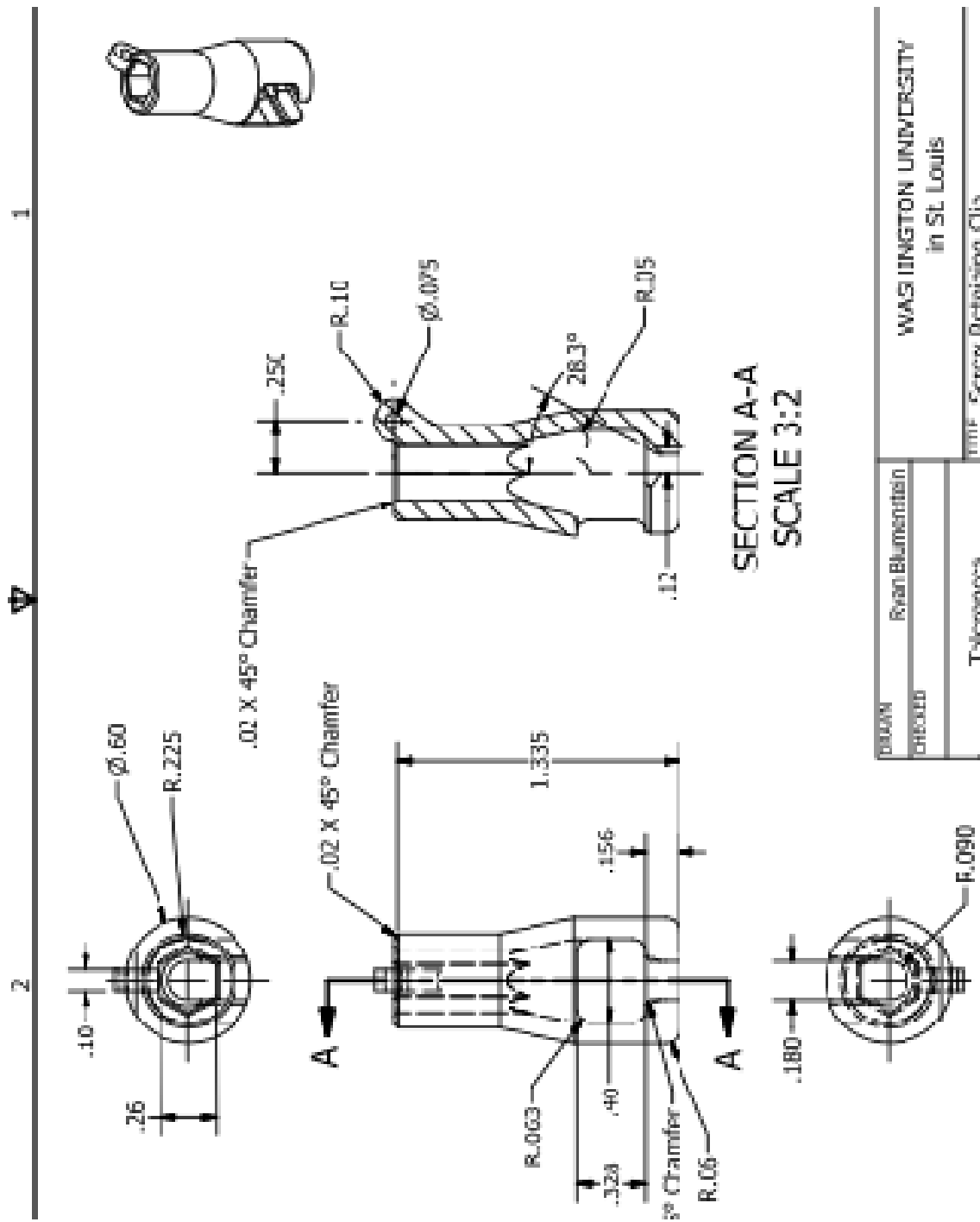


2 Ψ 1

DESIGNER Ryan Blumenstein		WASHINGTON UNIVERSITY in St. Louis	
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DRAWN A		CHECKED JMS/NO	
PART NO.		QTY 05031 Fixed 1	



Drew Ryan Blumentstein CHES010		WASHINGTON UNIVERSITY in St. Louis	
Tolerances .X = +/- .1 In. .XX = +/- .03 In. .XXX = +/- .010 In. Angles +/- 1/2 deg		TITLE Compression Plate Orthopedic Screwdriver	
DATE A	1/1	DWG NO.	C
SCALE 2:1	10/1/2014	138033 Compression P	

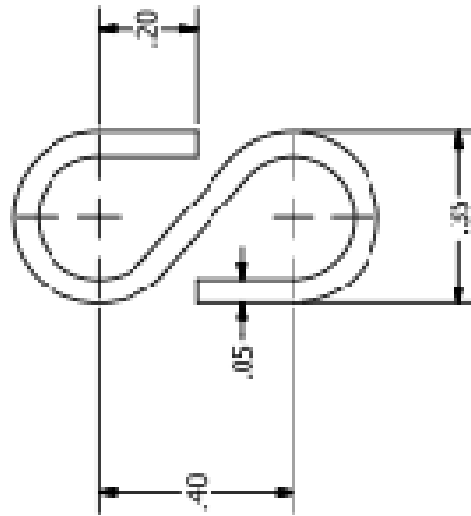
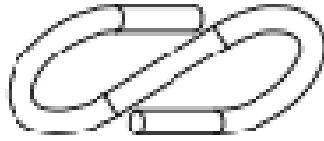


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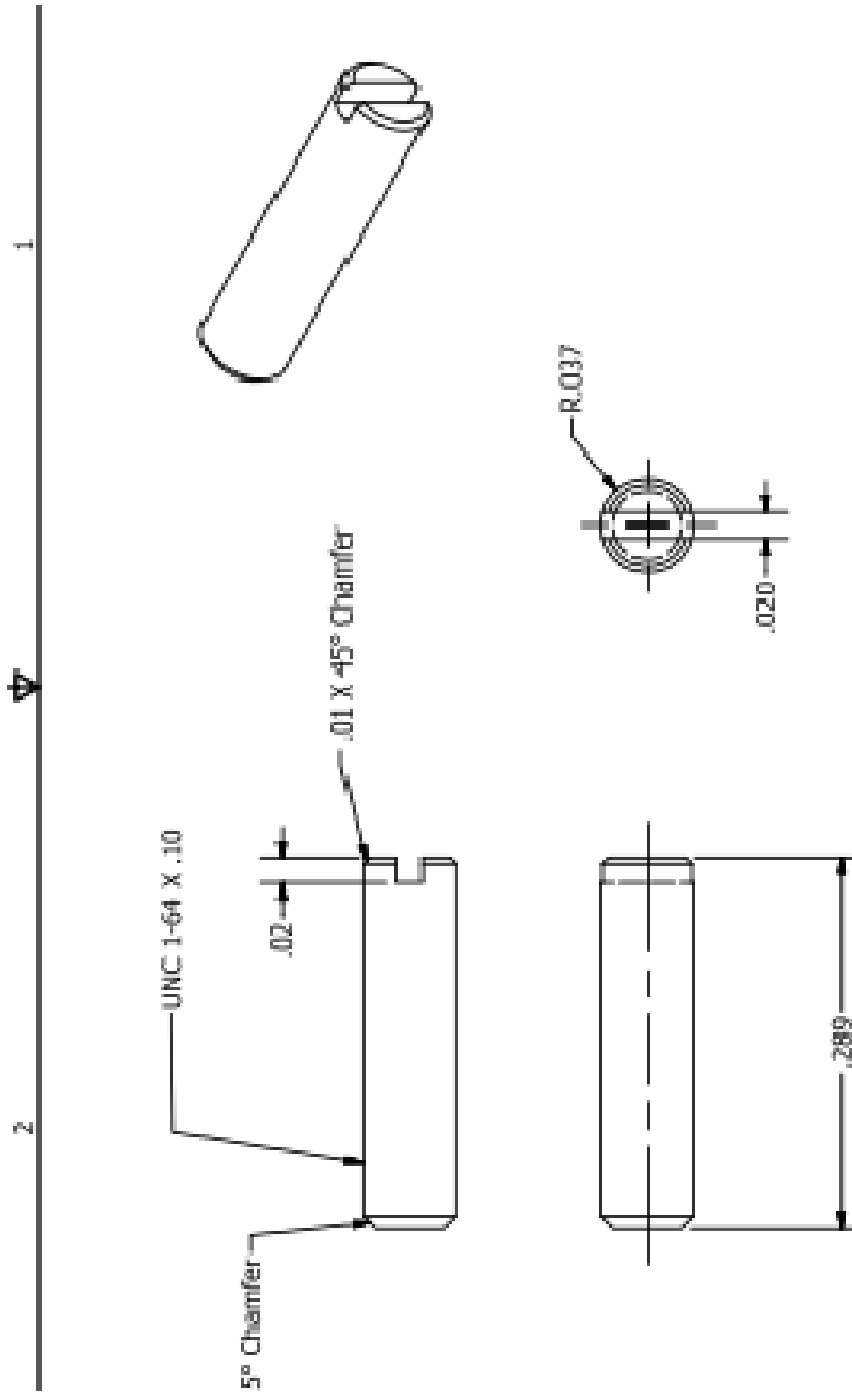
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PROJECT		Ortho Screw Retaining Clis Orthopedic Screwdriver	
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SIZE	A	DWG NO	
SCALE	3:2	DATE	11/5/2014
		USING SCHEM	

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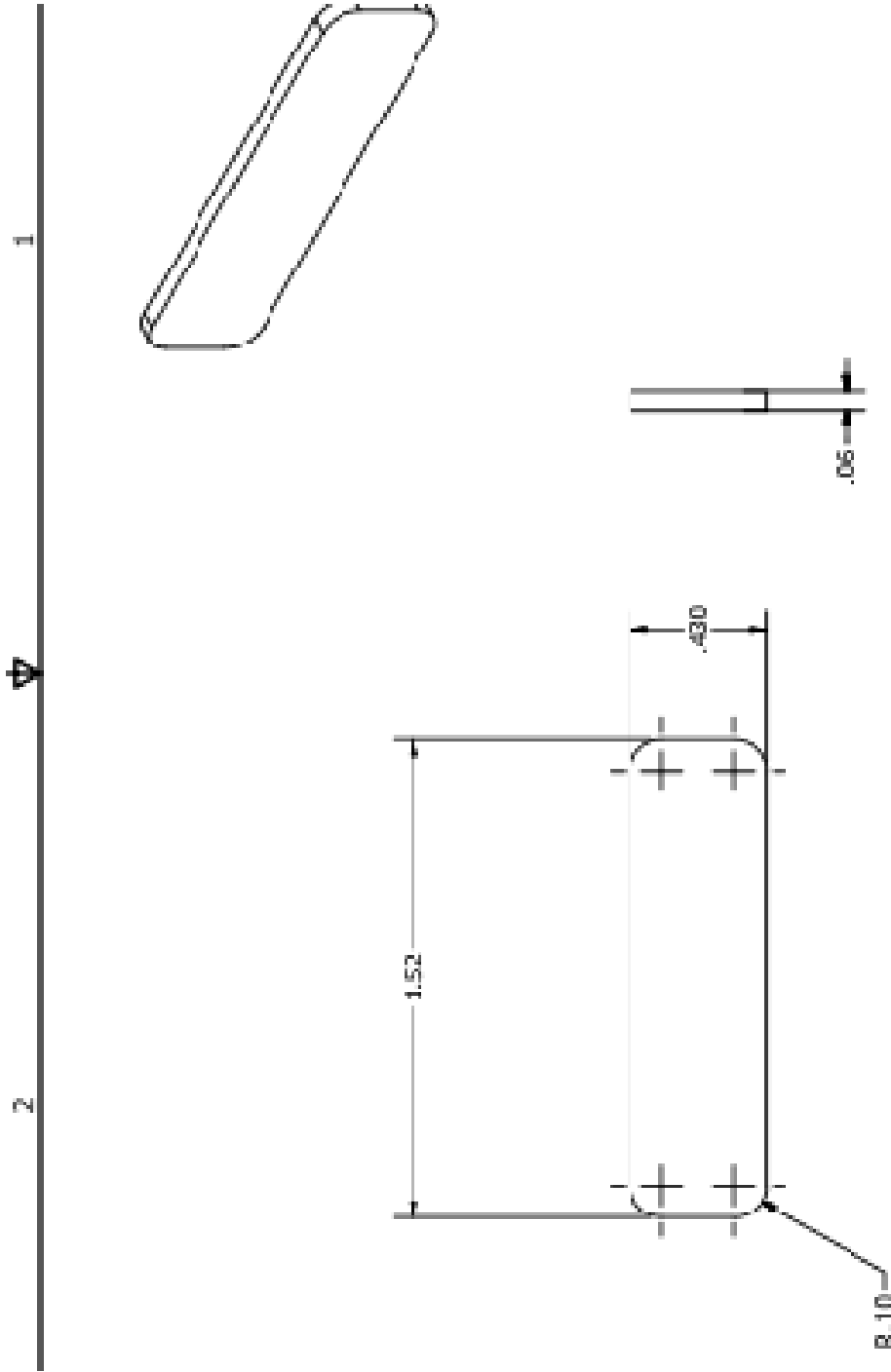
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DESIGN: Ryan Blumenstein ORFC600	WASHINGTON UNIVERSITY in St. Louis TITLE: S-Link Orthopedic Screwdriver DATE: 11/25/2014 SCALE: 4:1 SHEET: 090-3 S-Link	Tolerances .X = +/- .1 In. .XX = +/- .03 In. .XXX = +/- .010 In. Angles / 1/2 deg
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DESIGN: Ryan Blumenstein	WASHINGTON UNIVERSITY in ST. LOUIS		
CHECKED:	TITLE: Indicator Rod Orthopedic Screwdriver		
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		SCALE: 8:1	INDICATED:



DESIGN: Ryan Burmeister		WASHINGTON UNIVERSITY in St. Louis	
CHECKED:		TITLE: Gauge Plate Orthopedic Screwdriver	
DATE:	SCALE:	DATE:	SCALE:
A	2:1	10/15/2014	D3052 Gauge

Tolerances
 .X = +/- .1 In.
 .XX = +/- .01 In.
 .XXX = +/- .010 In.
 Angles +/- 1/2 deg

NOTE:
 MATERIAL: CLEAR POLYCARBONATE