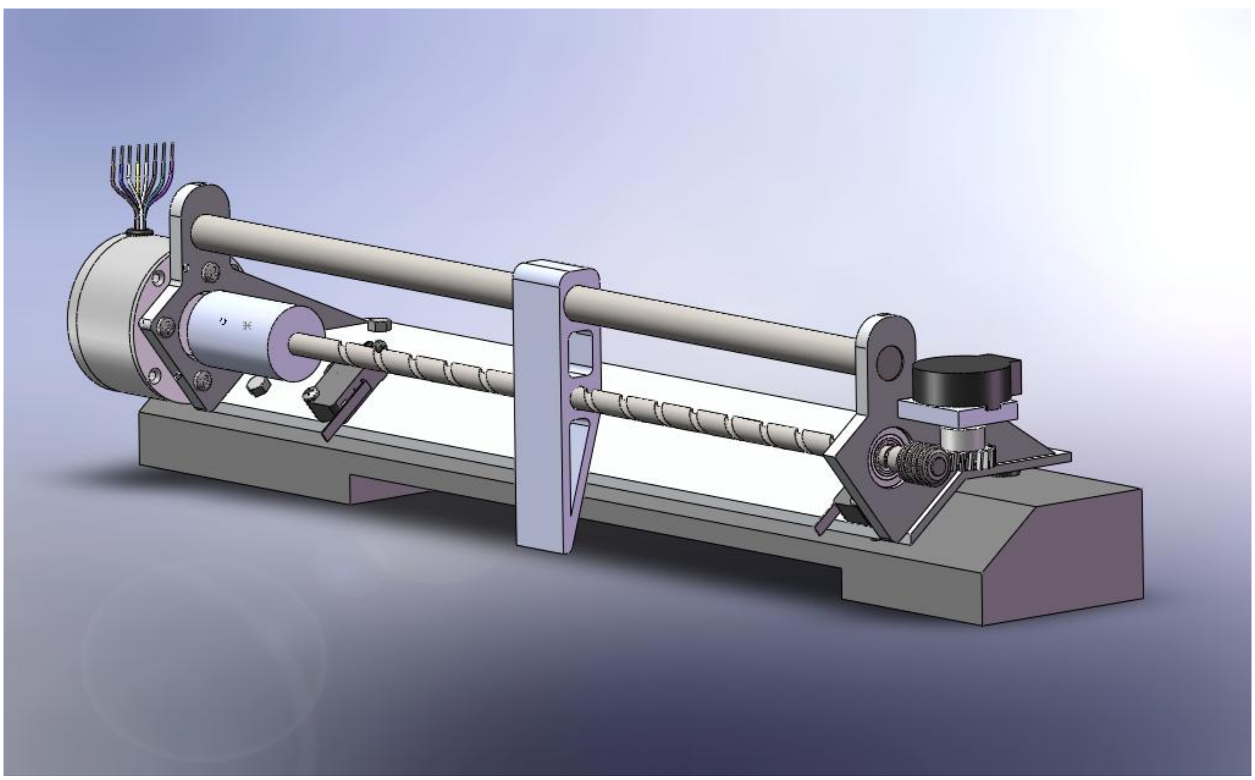
EML 2023 Air Hockey Goalie Design Project

Jay Coggin

CAD# 8793

4/20/09



Introduction

This project involved designing a mechanical system to be used in conjunction with a closed loop computer control system to act as a "goalie" on the end of an air hockey table. The system must use some sort of linear motion device controlled by a small DC electric motor to translate quickly across the 10" goal and defend against oncoming pucks. Three initial designs were sketched out from which one was chosen to develop into a fully designed system. A presentation and analysis of each design as well as reasons for picking the chosen design will be discussed herein.

It should be noted that several elements of the design are omitted in this project. An optical encoder and two initial position micro switches are mounted accordingly to be connected to a computer control system, but the puck location sensing device, closed loop control algorithm, and all other computer components of the system are assumed to be in place already.

Design Specifications

Several performance requirements and design limitations had to be met in designing this system. The first and most crucial performance requirement was how fast the goalie needed to be able to translate across the goal. According to Michael Worry, CEO of Nuvation Engineering, a company on the forefront of robotic air hockey technology, the maximum play speed of an air hockey puck is about 12 m/s (Freescale Technology Forum, 2008). Since the USAA (United States Air-Table-Hockey Association) rules state that a player can hit the puck from anywhere on his or her side of the centerline and the total table length is 8 feet, a worst case scenario of a 12 m/s shot from 4 feet away was used in computing the maximum necessary translation speed (USAA, 2003). Assuming that the computer would center the goalie after each puck block, the maximum translation distance would be 5" (10" wide goal). The computation of this maximum translation speed is computed below:

$$T_{min} = \frac{1\ s}{12\ m} \times \frac{1\ m}{39.37\ in} \times 48\ in = 101.6\ ms$$

$$V_{max} = \frac{5\ in}{.1016\ s} = 49.2\ in/s$$

Therefore, the goalie had to be able to translate at 49.2 in/s. In addition to this requirement, the goalie had to be able to rebound the puck smoothly without bending, giving way, or causing unnecessary stress to the system. This meant that the mechanism used to move the goalie needed to be very positive and precise.

In addition, design limitations had to be considered in order to meet the project requirements. For one, the goalie had to be no more than 1” wide. Without this requirement, project designs might consist of no more than a piece of sheet metal nailed across the goal, hardly an example of the design skills. Also, the completed system needed to mount to the hockey table with minimal changes to the table itself. This meant that the system needed to be free-standing with the exception of a few screws used to secure the assembly to the table. While this requirement wasn’t explicitly given, it’s only good design practice and common sense. Lastly, as with any project, budget needed to be considered. While having the cheapest design was not the ultimate goal, maintaining a reasonable cost is always an objective of design.

Design Concepts

Three initial designs were sketched out from which one design was chosen to further develop into working plans. The three designs differed mainly in their drive mechanisms. Two designs used a belt, and one a threaded shaft. Naturally, the ways in which each system mounted also changed to suit the drive mechanism used. In the sections that follow, all three designs will be presented and analyzed with respect to the design specifications.

Design 1

Design 1 consists of a pillow block at each end of the goal with two locating/guide shafts mounted between them on which a goalie slides (Fig. 1-2). The goalie piece extends above its two through holes where a timing belt is securely fastened to the goal piece. This timing belt runs around two idler pulleys mounted horizontally on each of two pillow blocks and then around a center rear mounted timing belt pulley driven by the motor. Fig. 2 depicts this motor assembly detail.

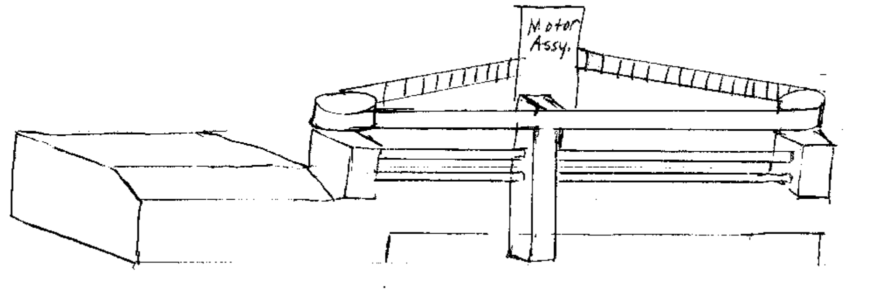


Figure 1a - Perspective View of Design 1

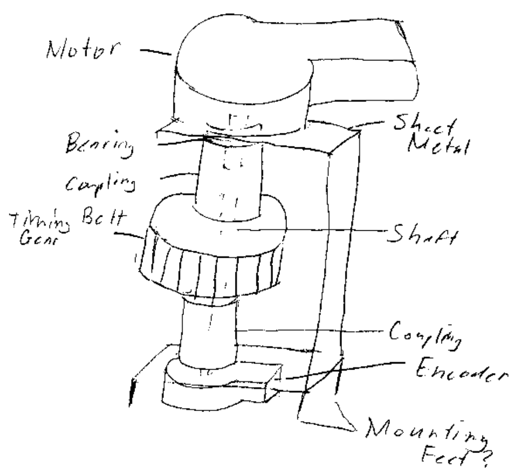


Figure 2 - Design 1 Motor Assembly Detail

The encoder is mounted vertically upwards at the bottom of the stack, mounted to some sort of base, then connected through a coupling to a shaft that runs through the drive pulley, another coupler, and then to the motor, mounted vertically downwards. The motor is also mounted to some sort of square frame structure which extends down where it meets with the encoder bracket. The combination of the motor mount and encoder mount fully locate the center shaft.

Design 2

The idea guiding Design 2 was making a much simpler belt system than Design 1. This design uses only one square piece of sheet metal as the mount for all components (Fig. 3).

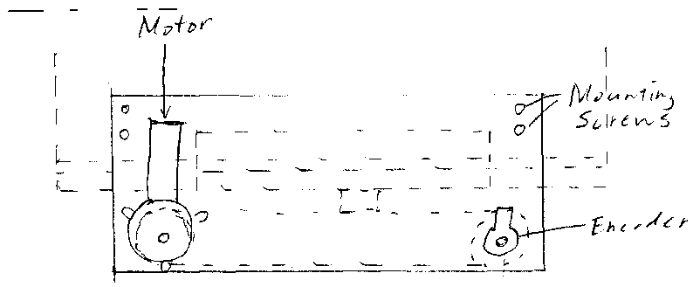


Figure 3 - Design 2 Top View

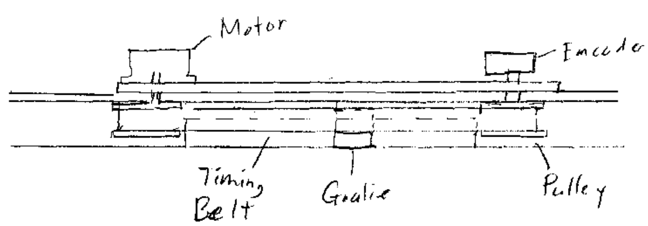


Figure 4 - Design 2 Front View

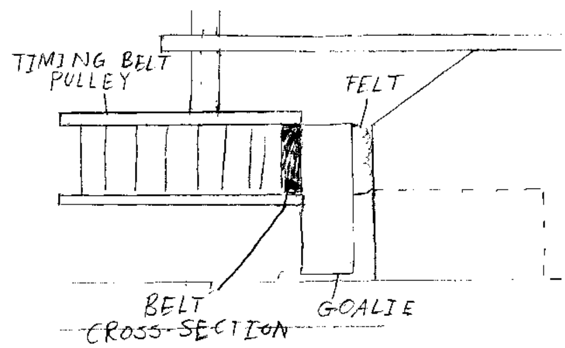


Figure 5 - Design 2 Goalie Detail (Profile View)

The base is screwed to the hockey table edge and hangs out over the goal. A pulley is mounted horizontally under the sheet on each side of the goal (Fig. 4). The motor is mounted concentrically over the left side pulley and is connected to it via a coupler, shaft, and flanged bearing through the sheet. A similar setup is on the right side, only the motor is replaced by the encoder and raised mounting tab. The pulleys are mounted such that between the backside of the belt and the goal edge of the table, a goalie piece would be mounted to the belt with a felt backing riding on the table edge (Fig. 5).

Design 3

In Design 3, the entire belt system was dropped in favor of a threaded shaft mechanism for motion. A single unthreaded "guide" shaft and a threaded shaft run parallel inside corresponding unthreaded and threaded through holes in the goalie piece to fully locate it (Fig. 6-7). The motor mounts directly to the threaded shaft via a coupler. A vertical support at each end supports the motor on one end, the encoder on the other, and the guide shaft on both. The encoder mounts through the vertical support where a coupler connects it with the threaded shaft.

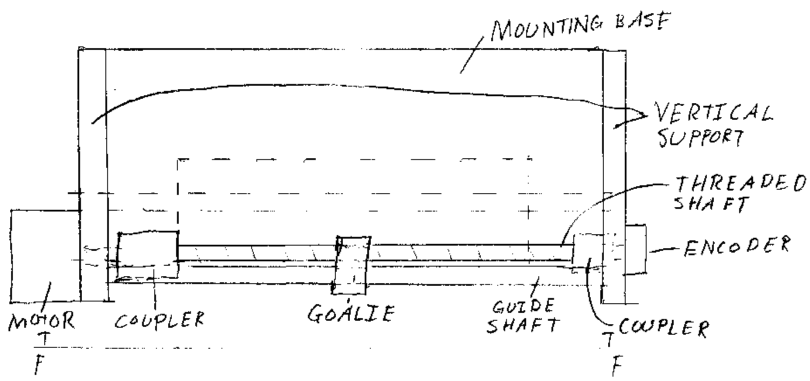


Figure 6 - Design 3 Top View

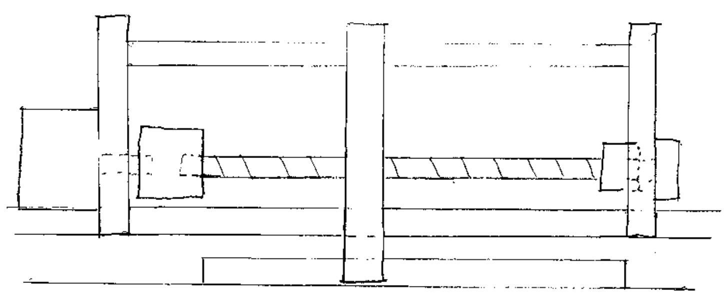


Figure 7 - Design 3 Front View

Selection of Design Concept

In picking the best design, several factors had to be considered. A few of the more important factors included:

- Number of moving parts
- Dependability
- Rotational inertia (ability to accelerate/brake/reverse quickly)
- Ease of production

- Ease of designing to work at high speeds (49.2 in/s)
- Cost

Design 1 quickly proved to be the weakest of the designs. The amount of physical structure required to support the motor assembly was simply unnecessary. Price would not be its strong point either because of the use of two guide shafts, pillow blocks, three pulleys and the structure previously mentioned. It was obvious after designing that a much simpler and cost efficient system could be designed.

Design 2 did indeed improve upon design 1 in several areas. For one, the system is much easier to fabricate and assemble. Cost was improved as a result of this and the removed cost of pillow blocks and guide shafts. The use of the felt-backed goalie supported entirely by the timing belt did appear to be the least positive of the three mounts though. While the drawings make the belt appear large and strong, it has to be considered that the total belt height might be no more than 0.5" tall. Whether or not this system would stand up to the fast-moving hockey puck was questionable. Quickly it was determined that by making a Z-bend in the sheet metal bracket, raising the mounting surface above the table edge, wider pulleys and belts could be used to alleviate this problem. With a more positive goalie surface, design 2 was a viable option. With pulleys easily available in the correct sizing for the motor, very few parts needed to be fabricated keeping costs down.

Design 3 seemed to trump the other two designs in nearly every category though. For one, the design has practically the fewest number of moving parts possible; two couplers and a shaft. This means the design would probably also be the most reliable. Also, because of the small rotational inertia (low mass closely centered about axis), the design naturally lends itself to quick acceleration and braking more than the systems involving large metal pulleys and belts. While the design does have more involved machined parts, all can still be made on standard lathes, mills, or CNC machines. The other factor concerning this design was the ability to design the system to work at high speeds. Using the given motor coupled straight to the threaded shaft would require an unreasonably large thread pitch to achieve necessary speed. Instead, the given motor was thrown out in favor of an un-geared, high RPM motor. With this problem solved, this design appeared to be the best out of the three and was therefore chosen to further develop.

Design Specifications

In order to begin designing, first, dimensions of the existing table edge were taken and modeled in Solid Works to allow an accurate fit of the assembly. The base mount, shown in Drawing 2 uses 4 #10 lag screws (Pt. # 15) to secure itself to the table edge. 1/4" rubber grommets are placed between the base mount and table edge at every screw location in order to give clearance for the underside-mounted switch nuts discussed later. The rubber grommets are to be cut from the 1" long rubber tubing (Pt. # 14). The base mount is to be constructed from a single piece of 1/8" aluminum sheet (Pt. # 2) bent along its edge using a break. The vertical supports are both constructed from the ¼" aluminum plate (Pt. # 1) and are shown in Drawings 1b & 1c. Both vertical supports are to be TIG welded in their respective locations on the base mount at precisely right angles in order to ensure both shafts mount positively and mutually parallel. While ¼" aluminum may seem like overkill for such a small system, it was chosen because of the guide shaft's need to be pressed into the vertical supports with enough of a hole depth to fully locate and secure the shaft. Note that the encoder side mount (1b) has a through hole for the guide shaft while the motor side mount (1c) is bored 0.15" deep. This is so that once welded, the system can still be fully disassembled by pressing the guide shaft out the encoder side mount.

The guide shaft (Pt. # 4) is made from ½" cold rolled steel bar and presses into the vertical mounts as previously mentioned. Shrinking/ expanding of the two mating surfaces might be necessary for an easy installation.

Motor selection was a crucial element for this design. Since both max motor RPM and thread pitch affected translation speed, they had to be picked together. However, for a realistic thread pitch of 1" or less, the motor needed a max RPM upwards of 3000. Upon searching, a Moog BN23HP DC motor with a max rated RPM of 4500 was located for a good price (Pt. # 6). Moog is a trusted name in components so the motor was assumed to be of good build quality. The motor is mounted to the motor side vertical support using 4 #6-32 machine screws (Pt. # 16). With a max rated RPM of 4500, the necessary thread pitch was calculated as follows:

$$\frac{49.2\ in}{s} = \frac{4500\ revs}{min} \times \frac{1\ min}{60\ s} \times \frac{x\ in}{1\ rev}$$

Solving for x gives a necessary thread pitch of 0.66". A thread pitch of 0.75" was used to account for frictional losses and the additional time necessary for acceleration and braking. The threaded shaft is made of 5/16" cold rolled steel bar and would need to be cut on a lathe to achieve the correct groove as shown in Drawing 3.

The threaded shaft rides in a 5/16" ID flange bearing (Pt. # 9) pressed into the encoder side vertical support and is connected to the motor via a flexible spider coupling (Pt. # 7-8) on the other side. To the outside of the flanged bearing, the shaft size would be machined down to ¼" where the worm (Pt. # 11) is mounted. This worm gear setup used to drive the encoder was chosen for its large gear reduction ability. Since the encoder has a max RPM of 300 and the shaft could be doing up to 4500 RPM, a ratio of 15:1 was needed. The setup used gives a gear reduction of 20:1 just to be safe. This necessary reduction was obviously an oversight from the original sketch where the encoder was mounted directly the shaft. An encoder mount (Pt. # 1a) is to be TIG welded in its correct location according to Drawing A2. A slightly loose fit between the encoder and mount was desired for some adjustability of the gear mesh.

Two micro switches (Pt. # 13), one placed at each end of the goal, are used by the computer to get an initial position for the goalie and to temporarily cutoff current to the motor when the goalie reaches full extension. These switches were chosen in favor of the given switches because of their protruding levers that hang over the base mounts edge in the path of the goalie. These switches mount to the base mouont using 2 #4-40 machine screws (Pt. # 17) and matching nuts (Pt. # 18) per switch.

The goalie (Pt. # 5) is constructed from ¾" x 1" 6061 aluminum bar and has a plain through hole where the guide shafts runs through and a threaded hole to match that of the threaded shaft. The upper guide shaft hole was located slightly off center in order to match the horizontal center of gravity point. This means that the threaded shaft would have a minimal amount of work to do in stabilizing the goalie and would thus minimize friction. The two other through hole shapes were implemented for weight reduction purposes.

Cost Analysis

Total cost for the project proved to be very reasonable at slightly less than $165. Cost could have been further cut by making the base mount from ¼" aluminum also since only one 1' x 2' sheet would be needed to make all parts, but even so, the price is very manageable for this scale project. A Bill of Materials with pricing of each component is shown on the following page.

Note: Parts 1a-1c are labeled as such because each is made from Pt. # 1 ¼"aluminum sheet. Parts 7-8 are shown as one assembly in drawings since individual component modeling was unnecessary.

Bill of Materials

Part #	Part Name	Supplier	Catalog #	Quantity	Sub Total
1	¼” x 1’ x 1’ 3003-H14 Aluminum Plate	Metals Depot	P314	1	$16.03
2	1/8” x 1’ x 2’ 3003 Aluminum Plate	Metals Depot	S318	1	22.10
3	5/16” x 2’ cold finished steel round bar	Metals Depot	R2516	1	3.42
4	½” x 2’ cold finished steel round bar	Metals Depot	R212	1	2.76
5	¾” x 1” x 2’ 6061 aluminum bar	Metals Depot	F4341	1	9.50
6	Moog Silencer Series BN23HP DC Motor	Ebay Store (Electro Maven)	BN23HP-18DA-04CH	1	30.00
7	5/16” Spider Shaft Coupling Hub	McMaster Carr	6408K112	2	4.66
8	Buna-N Spider for Size B Coupling Hubs	McMaster Carr	6408K84	1	1.52
9	Flanged Ball bearing 5/16” ID	McMaster Carr	6384K353	1	5.19
10	20 Teeth Nylon Worm Gear	SDP-SI	A 1T 6-N242008	1	5.63
11	Right Hand Steel Worm Pitch 24 Lead 1	SDP-SI	A 1C55-N24	1	14.14
12	Honeywell 600 series optical encoder	Allied Electronics	753-0061	1	30.36
13	Miniature Snap-Acting Switch, Rigid Lever	McMaster Carr	7779K13	2	9.52
14	¼” ID x 1” Rubber Tubing	McMaster Carr	9697K211	1	3.25
15	#10 x 1” wood screws	Bolt Depot	11632	4	0.32
16	6-32 x ½” Phillips Machine Screw	Bolt Depot	1542	4	0.28
17	4-40 x 5/8” Phillips Machine Screw	Bolt Depot	7594	4	0.28
18	4-40 Hex Nut	Bolt Depot	2642	4	0.36
19	3/8”-32 Hex Nut	McMaster Carr	95621A300	1	5.23
			Total Cost:		**$164.55**

Works Cited

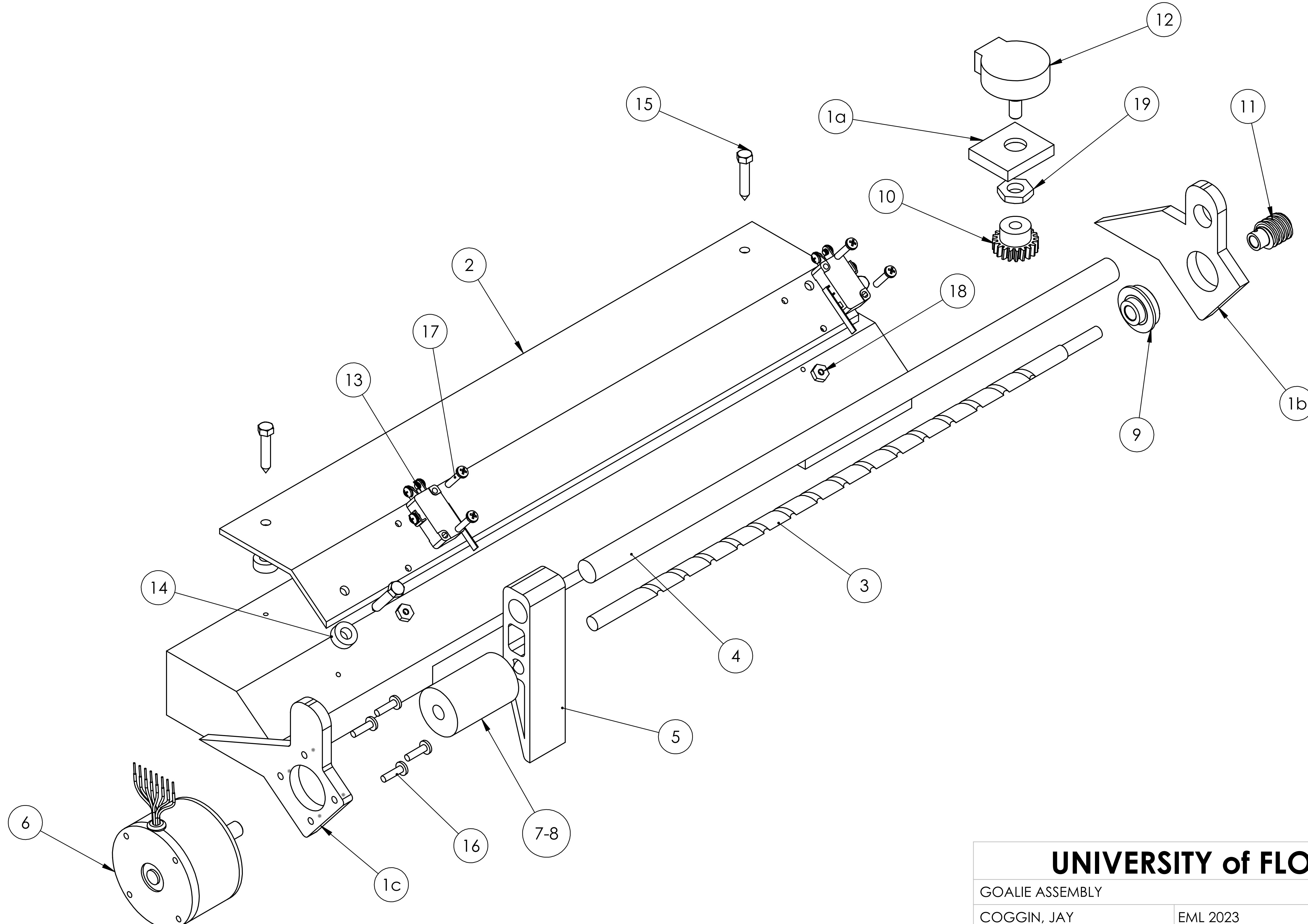
"Nuvation's Airhockey Demo Features Flexis AC and PowerQUICC Products." Youtube. June 18, 2008. Accessed April 10, 2009. http://www.youtube.com/watch?v=oNEjtVUxyX4

"USAA Official Rules and Procedures." United States Air-Table-Hockey Association. July 7, 2003. Accessed April 10, 2009. http://www.airhockey.com/node/8

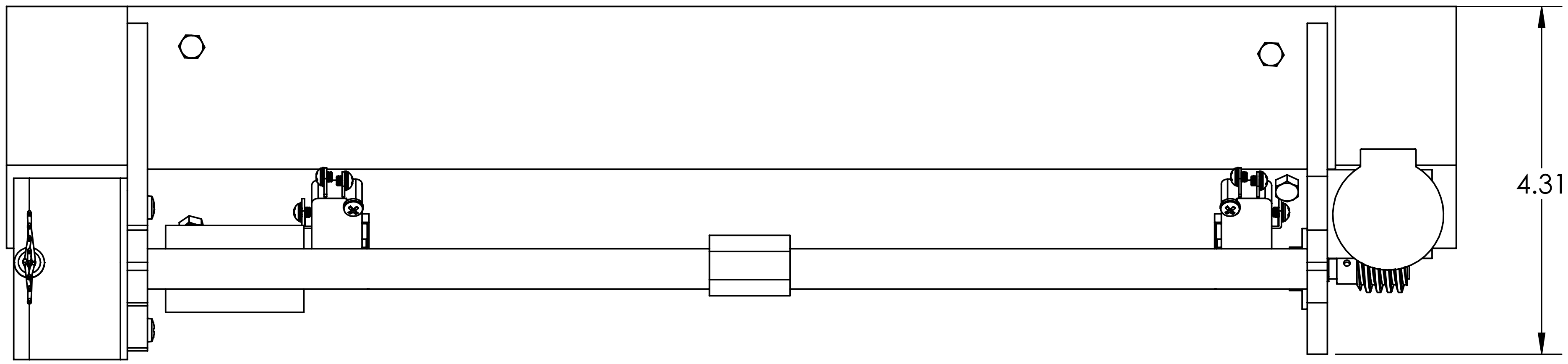
Appendix

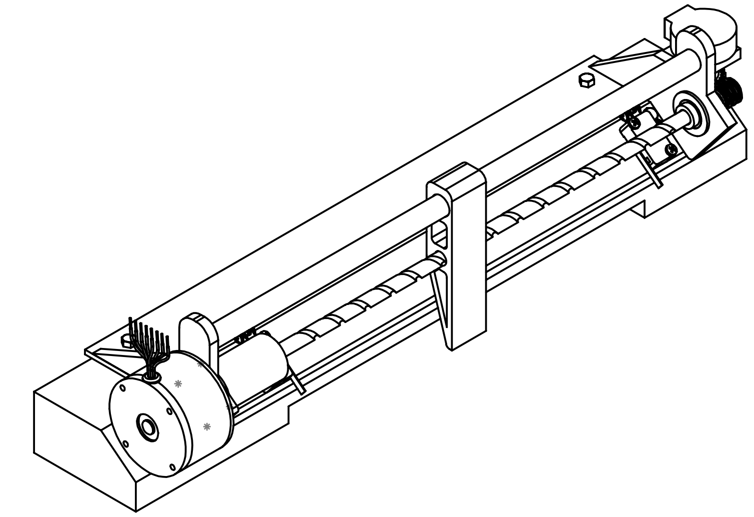
<u>Drawing #</u>

Part Drawings

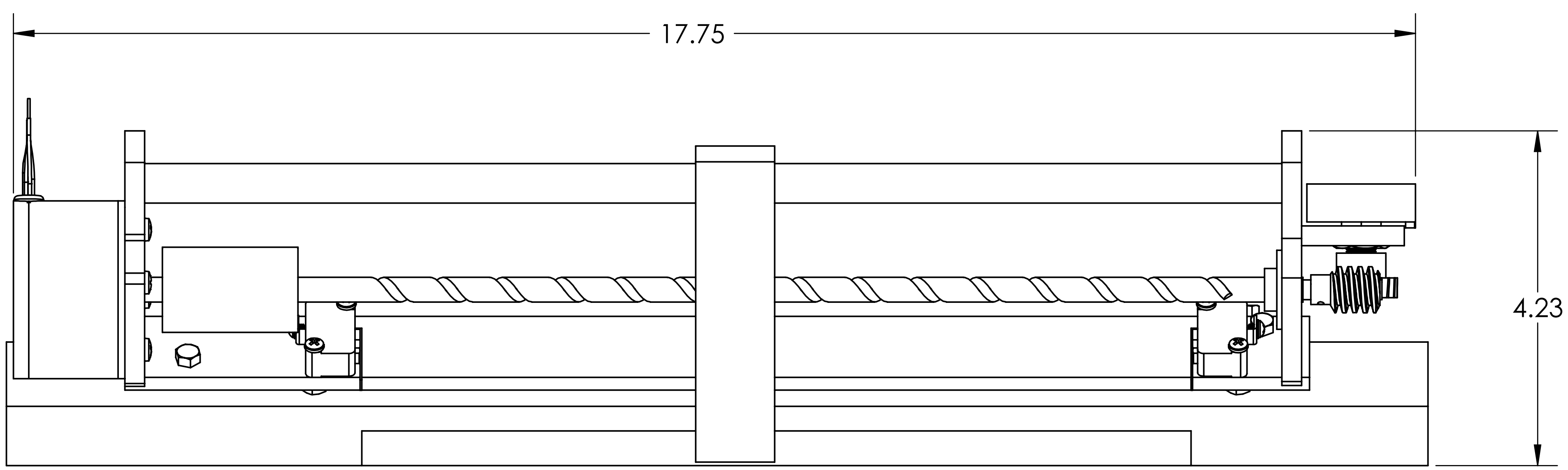


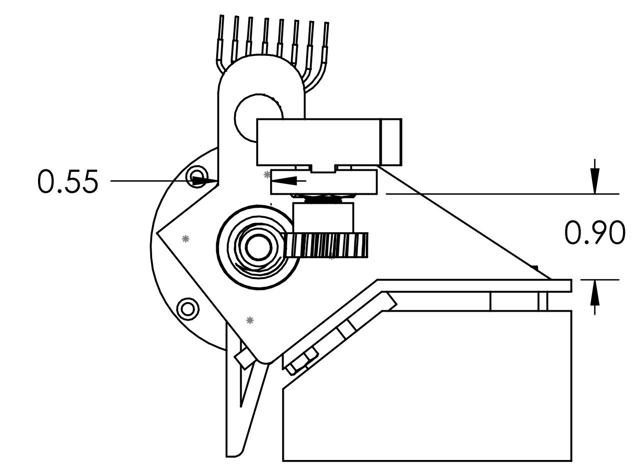
UNIVERSITY of FLORIDA			
GOALIE ASSEMBLY		SCALE: 1 : 2	A1
COGGIN, JAY	EML 2023	DATE: 4/20/09	
	SECT: 3226	ASSN:	
SIG:		CAD8793	





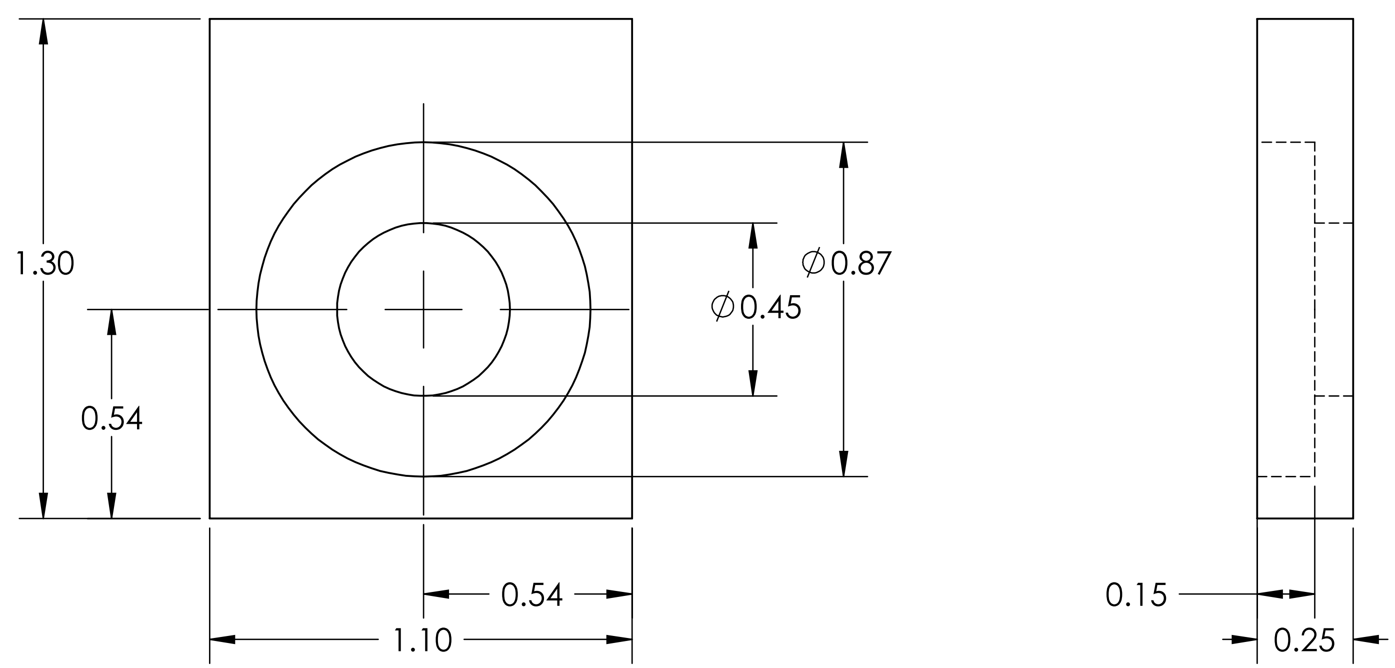
SCALE: 1 : 4

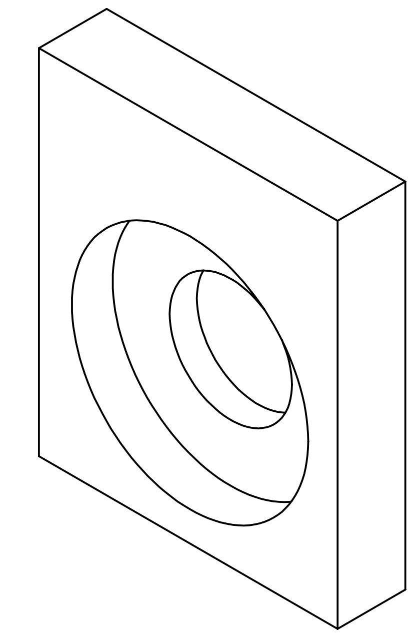




ALL 2-PLACE DIMENSIONS ARE ± 0.01"

UNIVERSITY of FLORIDA			
GOALIE ASSEMBLY		SCALE: 1 : 2	A2
COGGIN, JAY	EML 2023	DATE: 4/20/09	
	SECT: 3226	ASSN:	
SIG:		CAD8793	

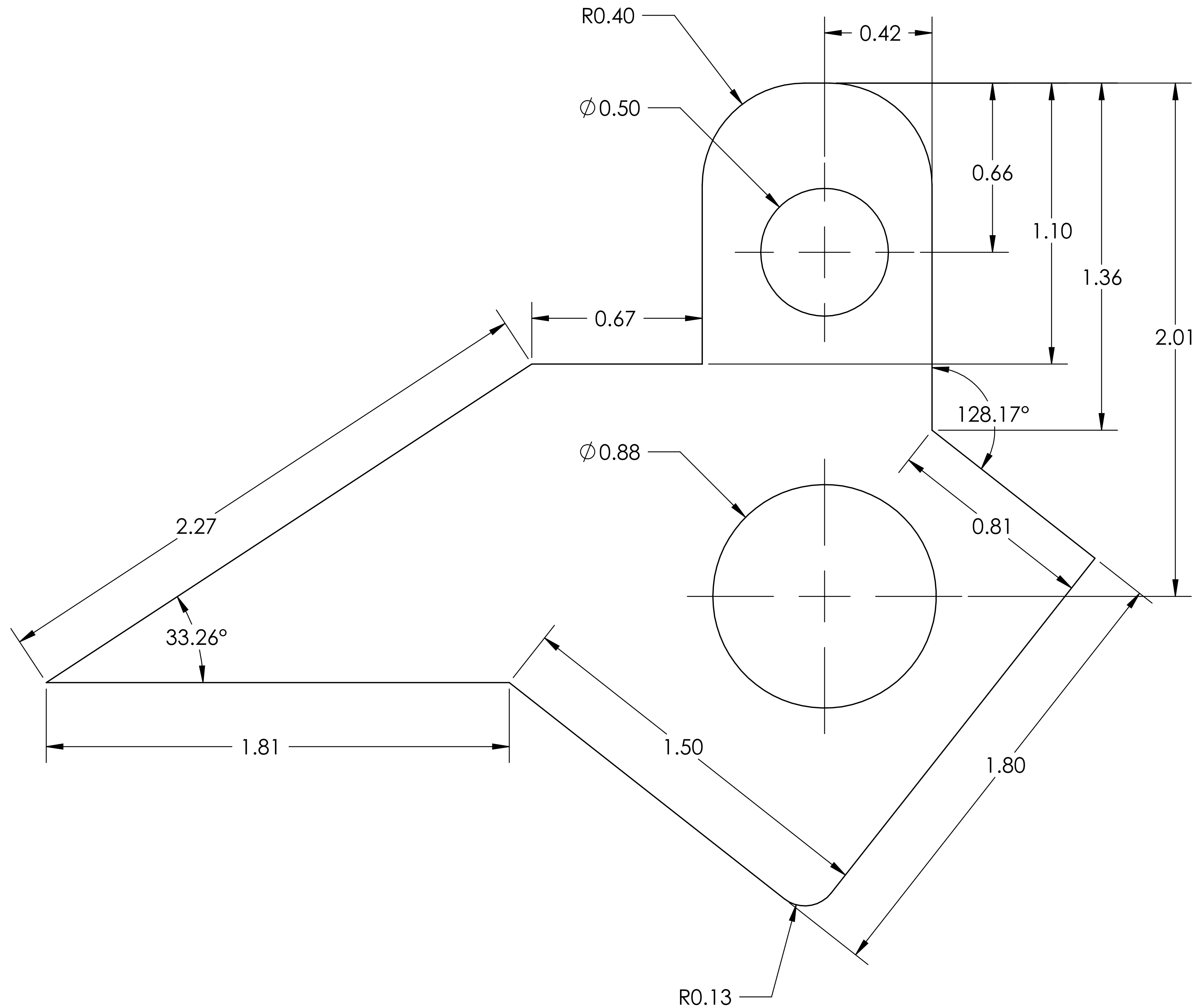


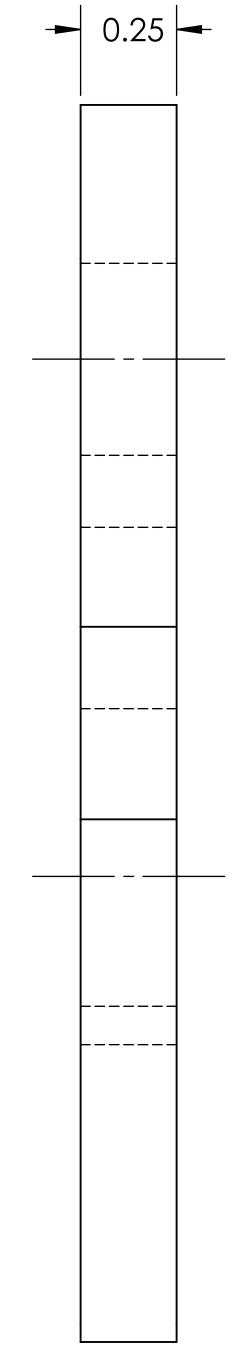


ALL 2-PLACE DIMENSIONS ARE ± 0.01"

NAT'L: 3003 ALUMINUM ALLOY

UNIVERSITY of FLORIDA			
ENCODER MOUNT BRACKET 1a		SCALE: 2 : 1	1a
COGGIN, JAY	EML 2023	DATE: 4/20/09	
	SECT: 3226	ASSN:	
SIG:		CAD8793	

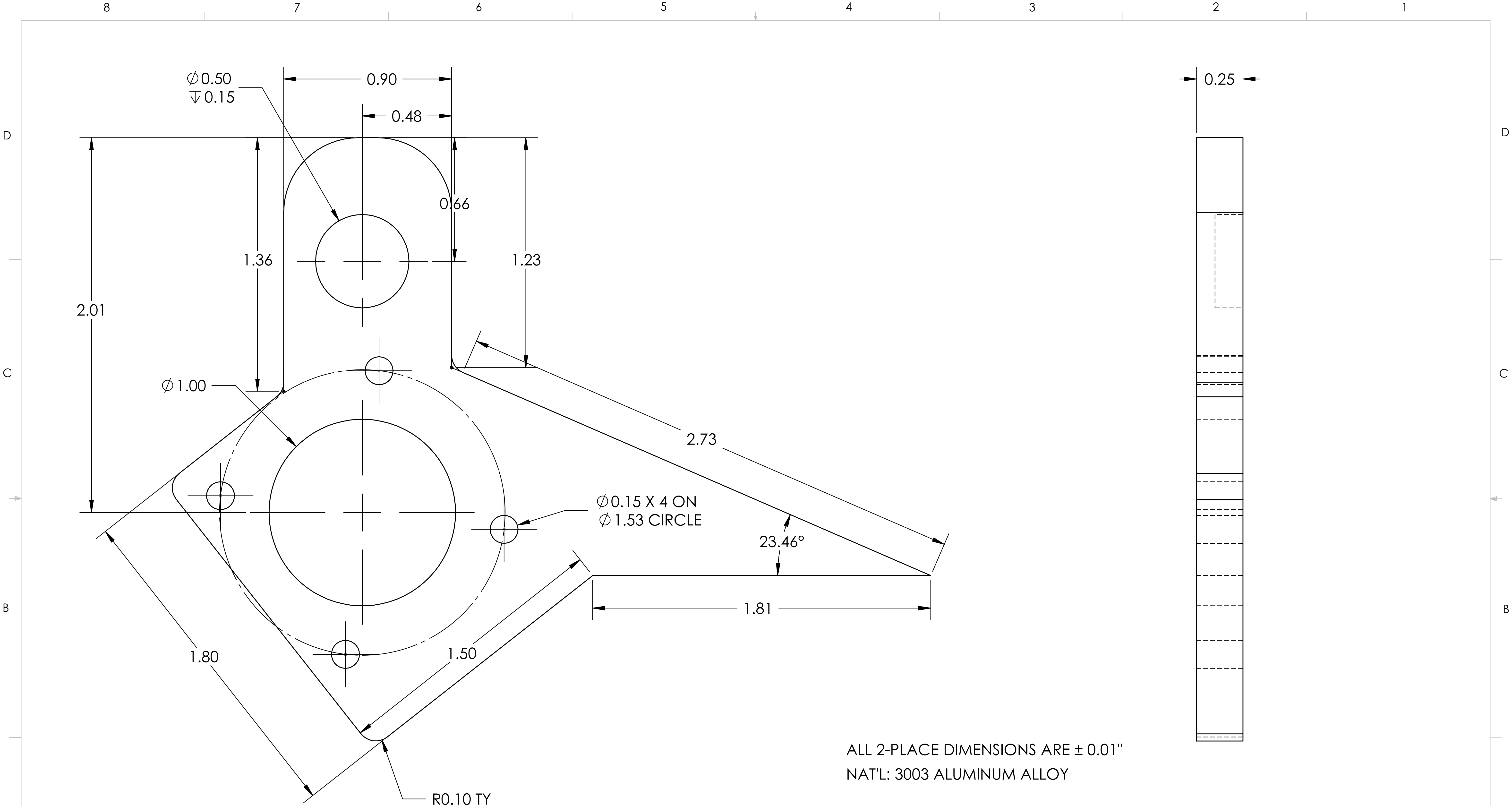




ALL 2-PLACE DIMENSIONS ARE ± 0.01"

NAT'L: 3003 ALUMINUM ALLOY

UNIVERSITY of FLORIDA			1b
VERTICAL SUPPORT - ENCODER SIDE 1b		SCALE: 2 : 1	
LAST, FIRST	EML 2023	DATE: 4/20/09	
	SECT: 3226	ASSN:	
SIG:		CAD8793	

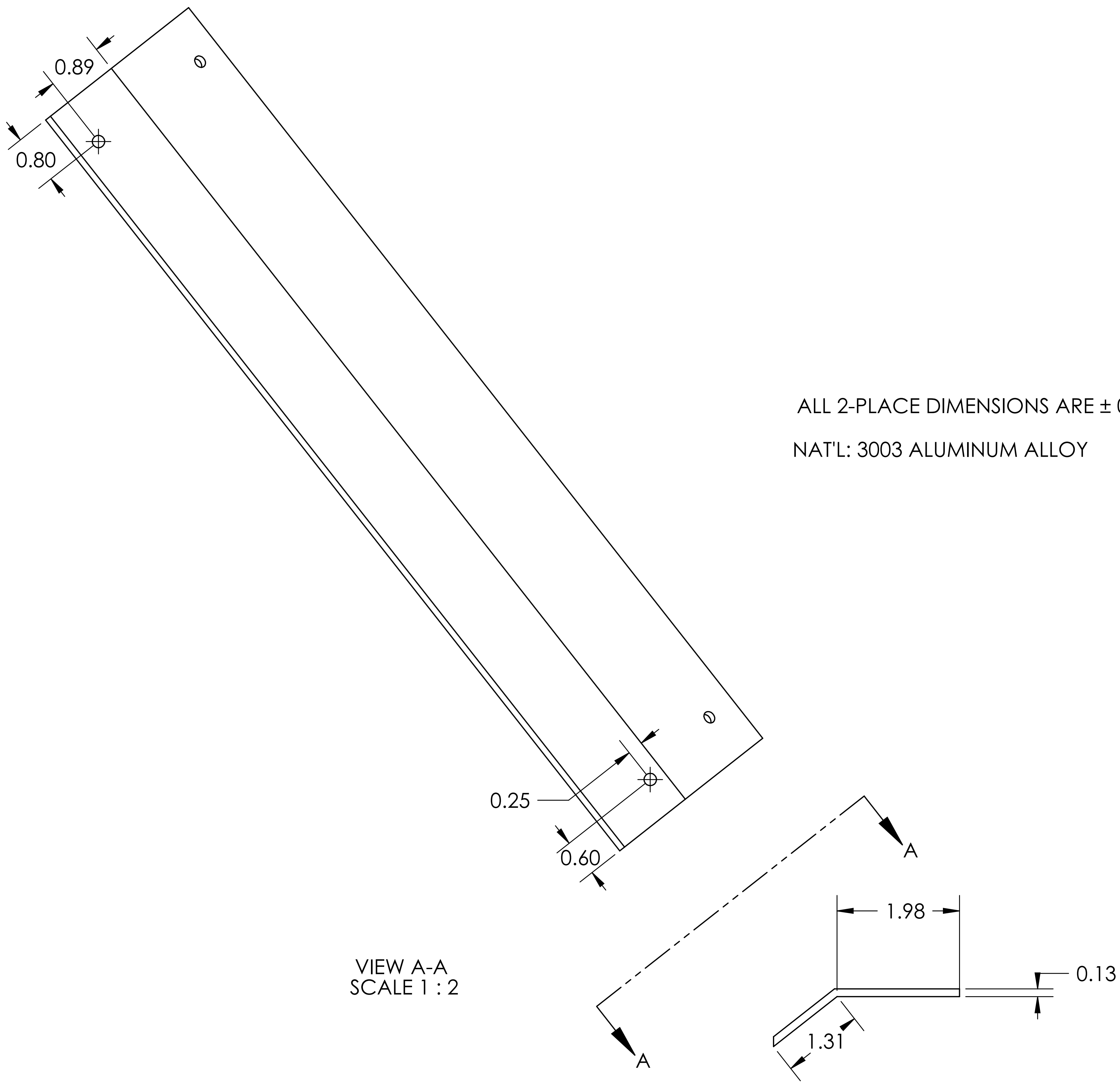


ALL 2-PLACE DIMENSIONS ARE ± 0.01"

NAT'L: 3003 ALUMINUM ALLOY

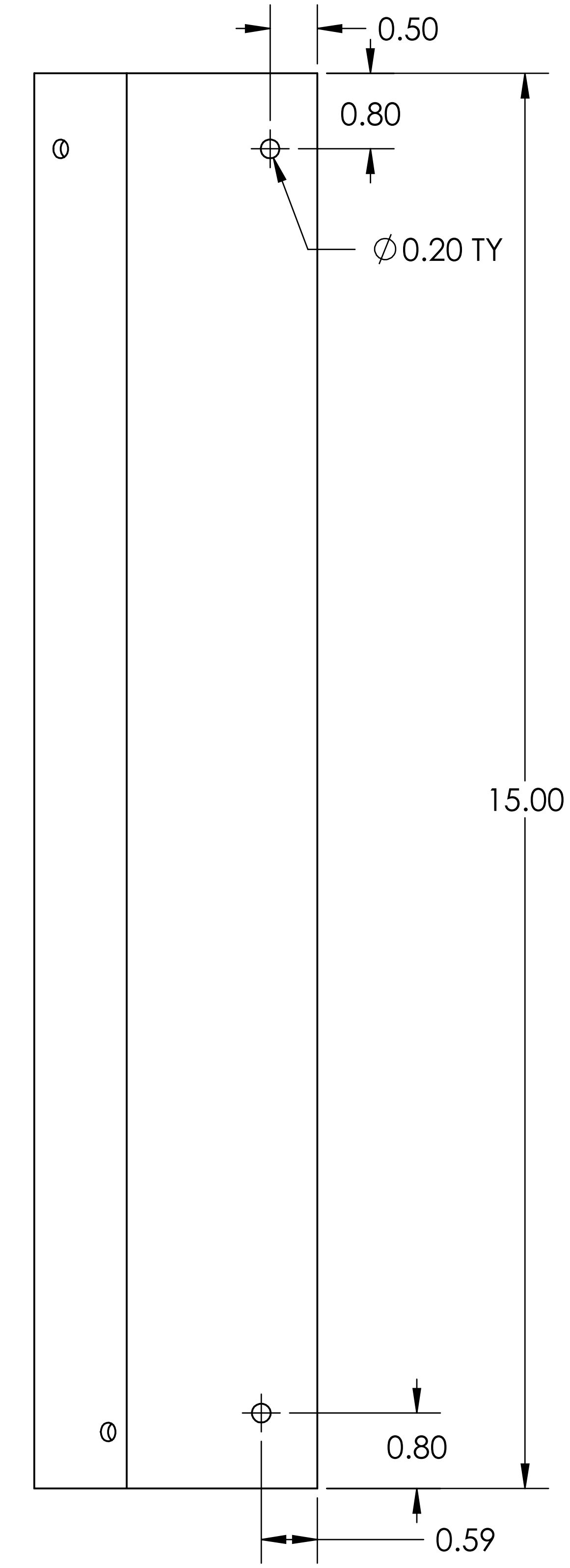
UNIVERSITY of FLORIDA		
VERTICAL SUPPORT - MOTOR SIDE 1c		SCALE: 2 : 1
COGGIN, JAY	EML 2023	DATE: 4/20/09
	SECT: 3226	ASSN:
SIG:		CAD8793

1C

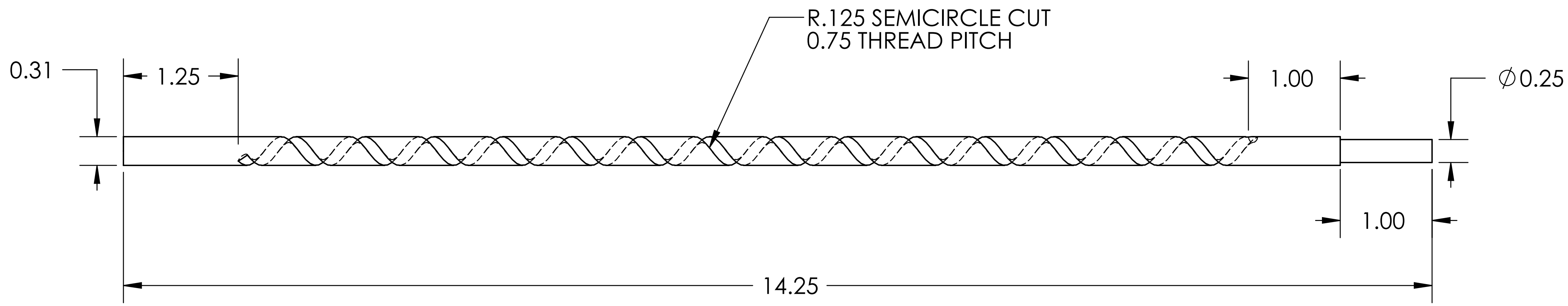


ALL 2-PLACE DIMENSIONS ARE ± 0.01"

NAT'L: 3003 ALUMINUM ALLOY



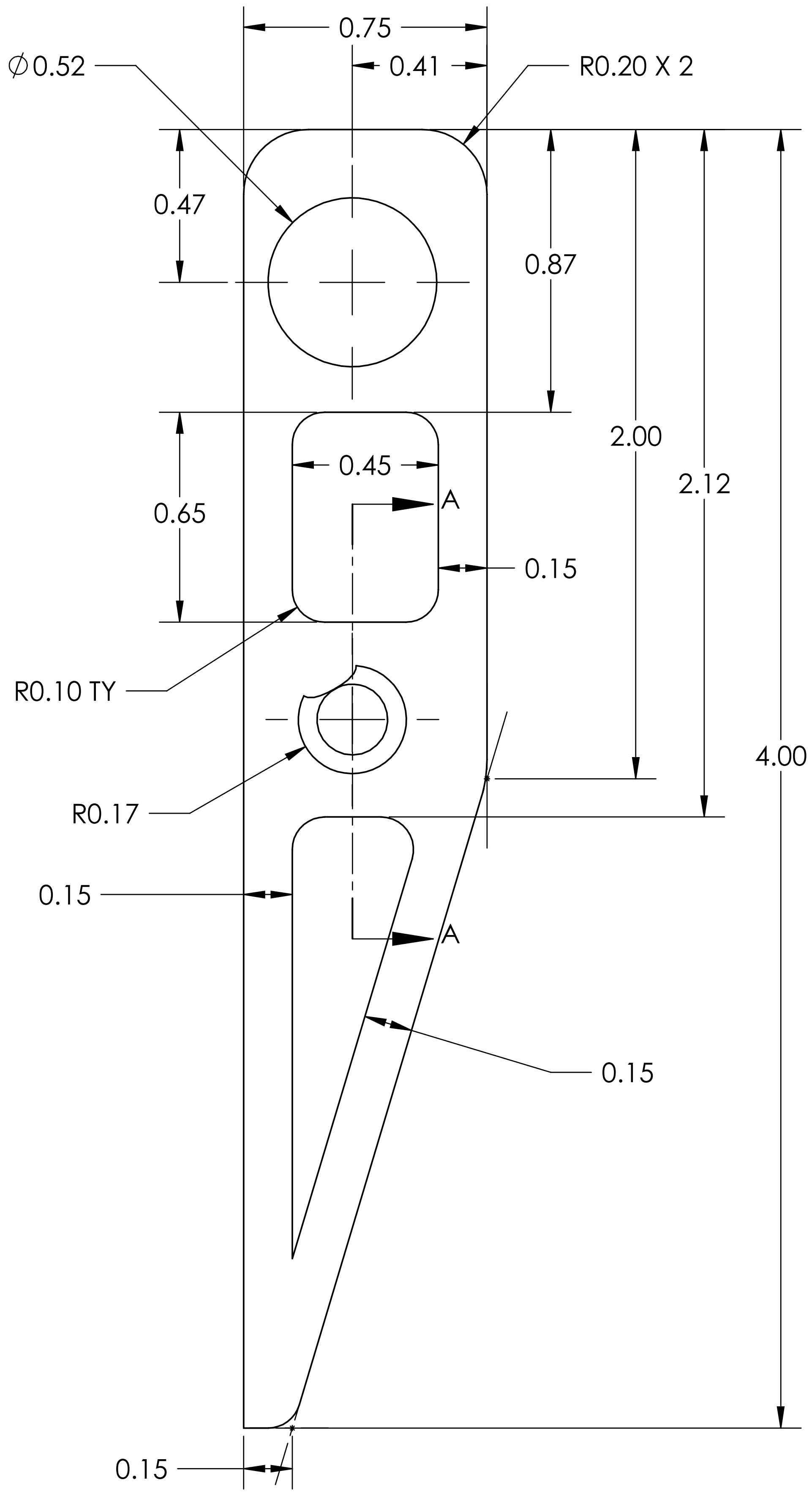
UNIVERSITY of FLORIDA			2
BASE MOUNT 2		SCALE: 1 : 2	
COGGIN, JAY	EML 2023	DATE: 4/20/09	
	SECT: 3226	ASSN:	
SIG:		CAD 8793	



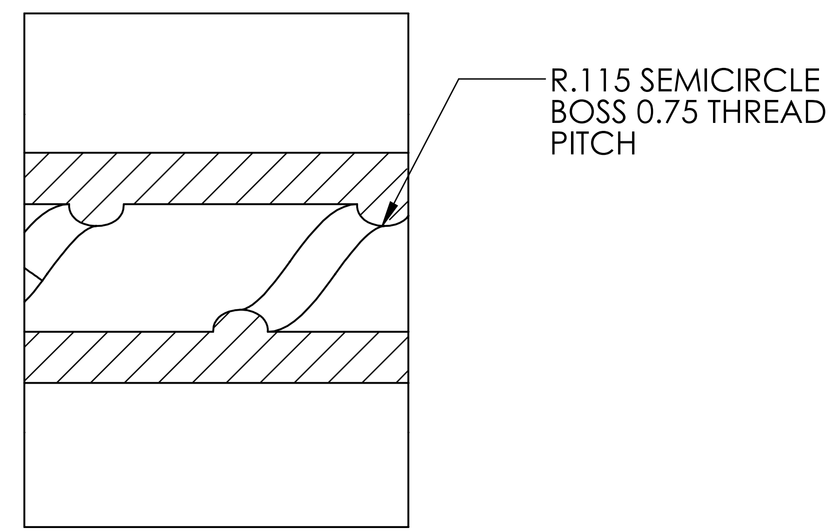
ALL 2-PLACE DIMENSIONS ARE ± 0.01"

NAT'L: 1080 C.R. STEEL

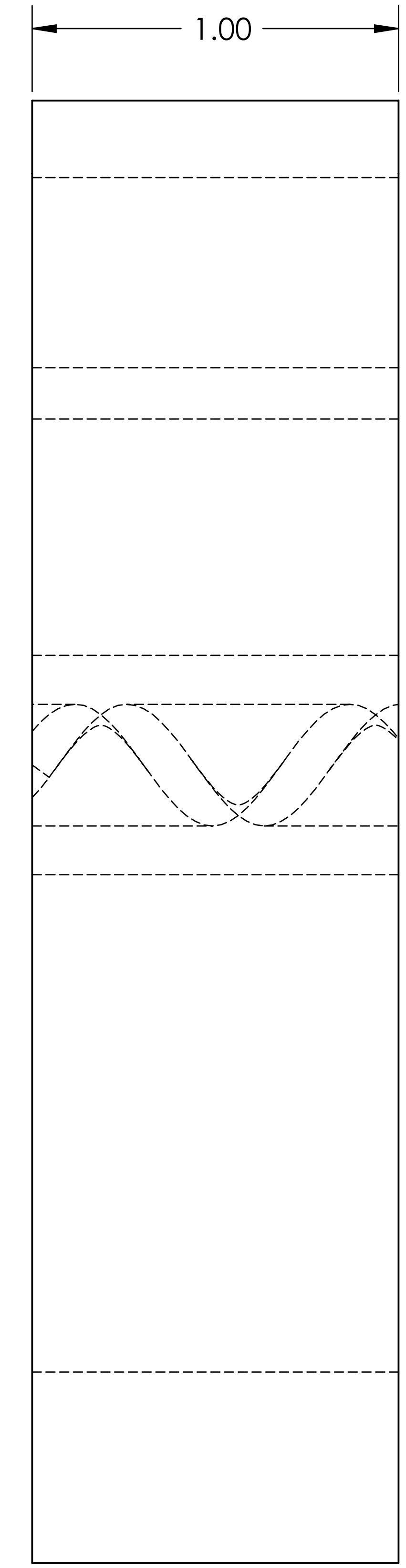
UNIVERSITY of FLORIDA			
GUIDE SHAFT 3		SCALE: 2 : 3	3
COGGIN, JAY	EML 2023	DATE: 4/20/09	
	SECT: 3226	ASSN:	
SIG:		CAD 8793	



Thread Detail



SECTION A-A
SCALE 2 : 1



ALL 2-PLACE DIMENSIONS ARE ± 0.01"

NAT'L: 6061 ALUMINUM ALLOY

UNIVERSITY of FLORIDA			
GOALIE 5		SCALE: 2 : 1	5
COGGIN, JAY	EML 2023	DATE: 4/20/09	
	SECT: 3226	ASSN:	
SIG:		CAD8793	