Da Vinci Flying Machine Sheet Metal Sculpture
ENGR 2330 Mech Proto

Amy Phung

Project Team:

Jack Rokous   Katie Goldstein   Mads Young

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1 Executive Summary

We created a sculpture inspired by Leonardo da Vinci's fantastical vision of a flying machine. Imagining he was inspired by the fluid movement of bird wings, we chose to articulate the wings beyond the straight glider-type wings his sketches portrayed. These wings were articulated with two 6-bar linkages that were powered by a bevel gear transmission. A tail was also articulated to further enhance the sense of flight and liveliness within our sculpture. A resin-printed person attached to the bottom of the flying machine reinforces da Vinci's vision for human flight through his machine.

To create a bird motif, we also included a small bird off to the side to represent da Vinci's inspiration for the man-made sculpture. This bird was animated with a cam, which was driven via a chain drive from the motor. These mechanisms are housed within a wooden structure which pays homage to the Renaissance-era architecture. It's design is mostly derived from St. Peter's Basilica in Rome, featuring similar structural features including a dome, pillars, arches, and triangular pediments. One of our design goals was to minimize the amount of visible support within our sculpture that didn't keep in line with the Renaissance theme, which we achieved with this decorative box. The basilica covered most of the support for the flying machine, acting as a subtle way to contain the structural elements of our sculpture.

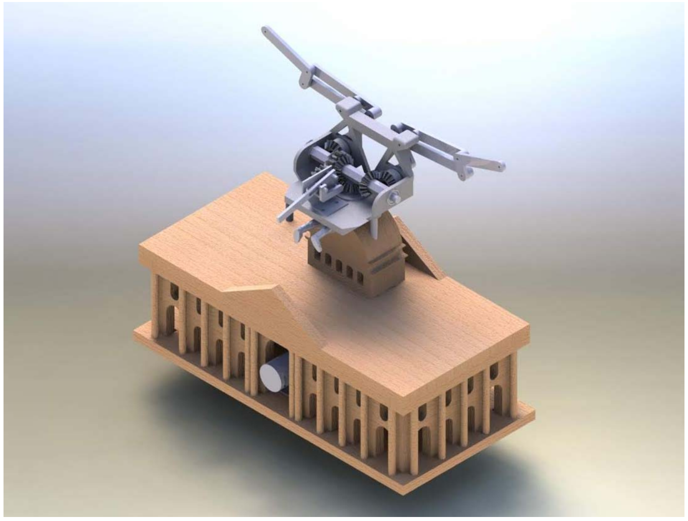


Figure 1: Assembly render from backside to show different mechanisms

2 Detailed Design

The major sub-assemblies of our sculpture include the 6-bar linkage flying machine, the slot-slider tail, the cam bird, and the wooden Renaissance-style Basilica housing.

2.1 Flying Machine Sub-assembly

Figure 2: Flying machine sub-assembly

The design of the flying machine sub-assembly was my main contribution to this project. The main structure here is the 6-bar wing linkage, so everything in this sub-assembly was designed in to animate the wings in the most visually elegant way.

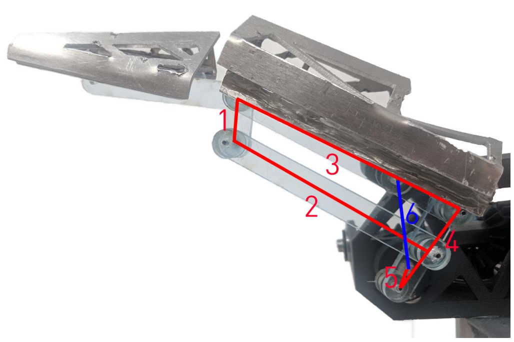


Figure 3: 6-bar linkage diagram

To minimize friction, the linkages were laser cut from acrylic and were assembled with extra acrylic spacers inserted between linkages. The linkage joints are spring pins, and heated acrylic caps were pressed onto the ends of the pins to secure them axially. To drive the linkage assembly, a spring pin secures the last linkage to a round 3D printed part, which is attached to a 1/4in aluminum shaft with a set screw.

This aluminum shaft is driven by a set of bevel gears that are connected to the 3/8in hex steel midshaft, which in turn is driven by another set of bevel gears connected to the main drive shaft. The bevel gears are constrained axially and radially onto the aluminum shafts with spring pins. On the midshaft, they are constrained axially with an E-clip and radially with a hex shaped bore.

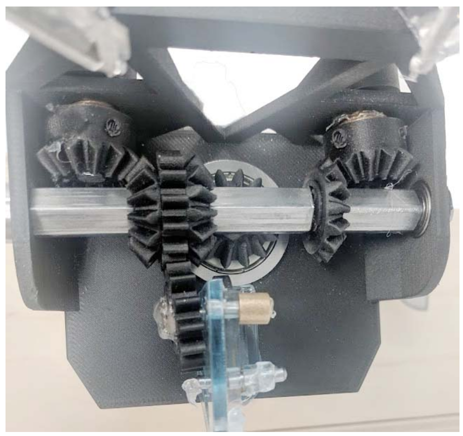


Figure 4: Bevel gear transmission with e-clips, press-fit bearings, and spring pins

There are a lot of bevel gears, but given the design of the wings this was the minimal number of gears required in order to convert counter-clockwise motion from the z axis to the clockwise and counter-clockwise motion on the y axis.

To hold the shafts at the precise locations that were required to make the flying machine work, we chose to use 3D printed part due to the difficulty of making a precise part with lots of non-planar features on other machines. Flanged ball-bearings and flanged bushings are pressed into the part to improve the performance of the metal shafts going through the part.

The main drive shaft is driven by a bevel gear attached to a round clamping hub fixed to the motor gearbox. This drive shaft is secured by two points –at the top of the assembly with a hex bearing, and at the bottom of the assembly with a flanged bushing. E-clips are used at both ends of the shaft to keep it in place.

The full flying machine sub-assembly is supported by two 1/4in aluminum rods that are pressed into the basilica. A resin-printed figurine of Jack sits on the bottom of the sub-assembly as a decorative, story-telling element.

The plasma-cut, sheet metal wings that cover the acrylic linkages were designed by Katie. These were also added on as a decorative element, and were bent and assembled in a triangular shape to add more dimension to our sculpture while also simulating airfoils on flying machines.

2.2 Tail Slot-Slider Sub-assembly

Figure 5: Tail slot-slider sub-assembly

The tail sub-assembly was designed by Mads. To create an up/down motion resembling that of a bird's tail, a slot-slider mechanism was used. The linkages and mounting plate for this mechanism were laser cut from acrylic to minimize friction, which was especially important since a slot-slider is subject to more friction than other mechanisms. 1/8in dowel pins were used for the joints in this sub-assembly, and are secured radially and axially with a friction fit and glue.

This sub-assembly is powered by a spur gear that meshes with the drive transmission from the flying machine sub-assembly. The wings and tail are both designed to move with the same frequency, so a 1:1 gear ratio was used.

2.3 Bird Cam Sub-assembly

The bird cam sub-assembly was designed by Katie. A plasma-cut sheet metal bird sits atop a 1/4in aluminum rod follower that follows a 3D printed cam. We went through several iterations of what the contact point for the follower to the cam should look like, but ultimately found that just a smooth end of the aluminum rod worked best. This 3D printed cam is secured axially on a hex shaft with E-clips and radially with a hex bore, and is driven by a 24T sprocket

Figure 6: Bird cam sub-assembly

fixed on the same shaft. This sprocket is secured axially and radially with a hex clamping hub.

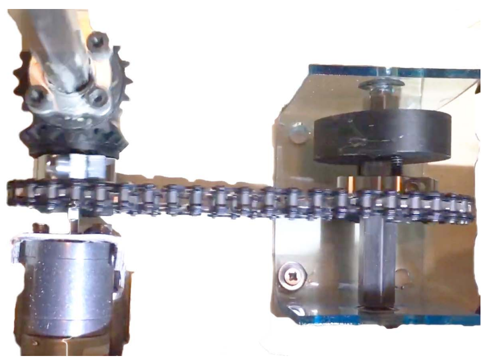


Figure 7: Internal drive train - motor provides power to the drive shaft via bevel gears and to the cam via a chain and sprockets

The cam profile we used makes it so that the bird moves up and down more often than the wings or tail in the large subassembly. Since the bird is designed to represent natural birds as a contrast to the man-made flying machine, we chose sprockets and a cam profile that would keep the bird's smooth motion but have it move at a different frequency than the flying machine. The gear ratio for the bird is 2:3, but to increase the frequency of the bird's movement we used a cam that has two high points.

Figure 8: Wooden basilica housing sub-assembly

2.4 Wooden Basilica Housing Sub-assembly

The wooden basilica housing was designed by Jack. The box design was first conceptualized in Adobe Illustrator and designed based on St. Peter's Basilica in Rome, and then loaded into SolidWorks to make it machinable by the ShopBot. The walls of the box mesh with the base through tab-and-slot T joints, and mesh with other walls in butt joints. These walls are held in place with sheet metal brackets that reinforce the corners.

The edges of the top of the box mesh with lap joints. The roof is held in place with wood screws into the sides of the box. The wooden dome that gives the building its distinctive shape supports the flying machine sub-assembly and meshes into the roof with tab-and-slot T joints. Wooden dowels were added around the box as decorative pillars to add dimension to the box and replicate the pillars of the St. Peter's Basilica. The title was painted on using a negative vinyl sticker as a stencil.

3 Reflection

Overall, I believe that our design process was successful considering that we were able to create the flying machine we had envisioned without compromising any major components that made it particularly interesting and unique. One of the elements of our design process that contributed to our success included using lots of detailed paper sketches to make quick iterations through different designs. While this was useful, an equally important part of our process was loading the more refined paper sketches into SolidWorks to make sure that the scale of everything we had envisioned was reasonable. Another element that contributed to our success was testing individual "risky" components first before finalizing the CAD. At first, we were fairly uncertain about how well the acrylic linkages with spring pin joints would work and whether spring pins could be heat-set into acrylic, so these were tested before any major CAD work.

While I believe our design process was successful overall, there were some elements to it that could be improved going forward. The biggest design process flaw was not measuring stock before drafting up designs in CAD, especially for the plywood which varied significantly in thickness. Another process flaw was thinking through the order in which we should design our components. Some of the components required other sub-assemblies to be done before starting on design to minimize the amount of work that needed to be redone, which resulted in some team members not having much to do at the beginning of the project but a lot more later on as the components it was dependent on were completed.

For the subassembly I worked on specifically, I had to work with almost all of the materials and keep in mind how they would interact with each other. When switching between materials, I'd sometimes forget the relative tolerances for each of them. For instance, being 1/32in off when working with wood is fairly precise, but the same tolerance would cause looseness in 3D printed parts and lots of rattling in metal parts. This caused certain parts to be looser or tighter than they should've been, which posed some difficulty when attempting to press-fit parts of different materials together.

4 Conclusion

At the end of this project, the sculpture was able to successfully do what we wanted it to, but it wasn't as reliable or "clean" as we would've hoped. Near the end, there were a lot of "quick fixes" that were needed to make it work right, which included things like hot glue, unplanned set screws and adhesives to hold supposedly "press fit" parts on right. Some other things that didn't turn out quite the way we had envisioned included how imprecise sheet metal and acrylic heat-bending could be. Overall, I'm glad things worked, but the solutions weren't always particularly elegant, robust, or in line with best practices.

When I started to work on the 6-bar linkage wings, I had expected for it to eventually need to be re-scoped to a 4-bar linkage due to friction or the number of bevel gears needed to make it work. I figured I'd learn a lot from trying to make it work anyways and seeing what mechanism would cause the need for a pivot, but it worked out in the end! My main learning goal for this project was to get more practice rapid prototyping, and since I was able to CAD and get in the shop a lot I'd say this was a success.

5 Time/Labor Report

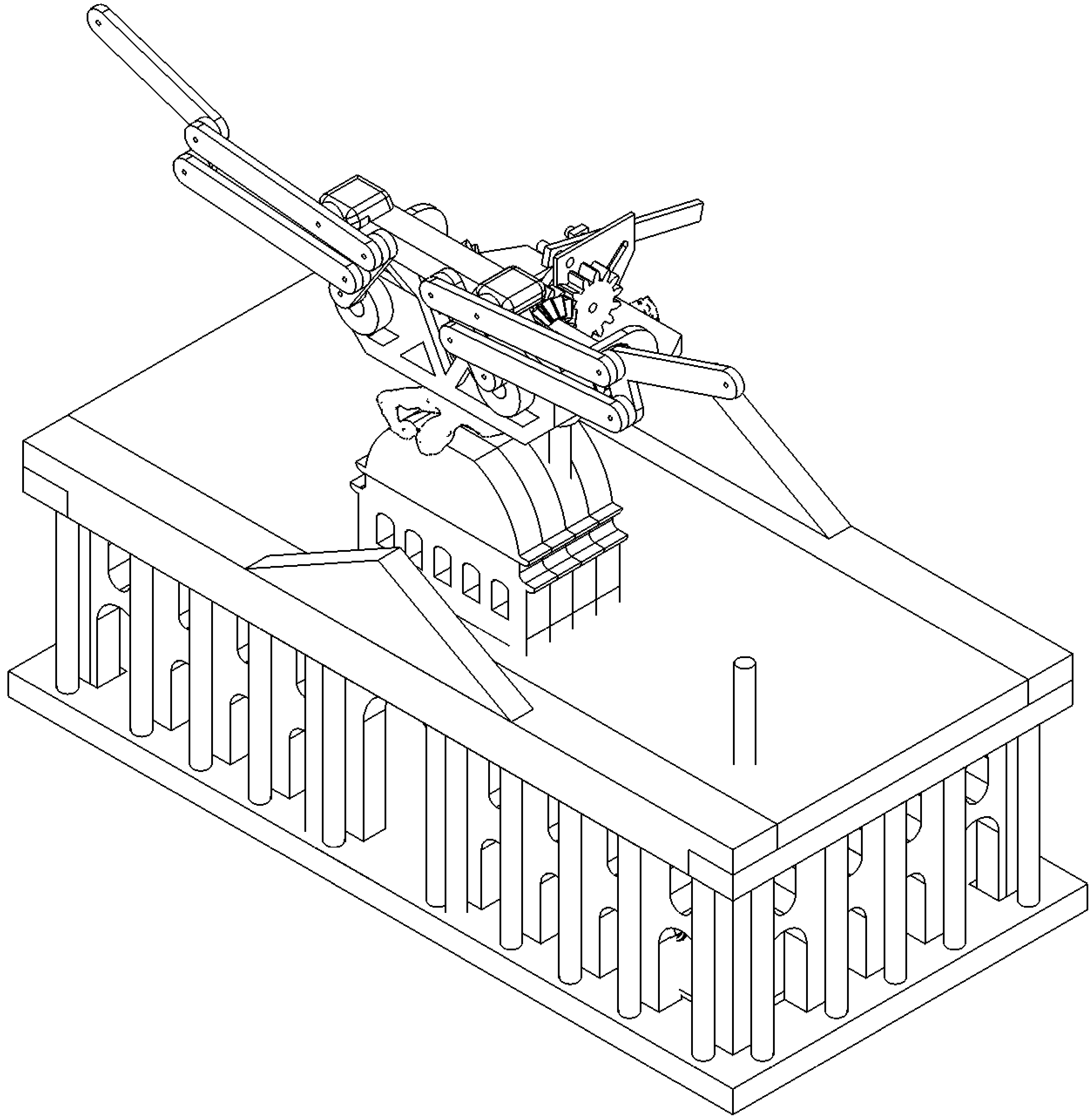
Task	Self	Total Estimate
Conceptual Development	4	16
SolidWorks	20	40
Fabrication	21	60
Assembly	8	24
Repair and Redesign	4	12

6 Appendix

Video with footage of sculpture movement and brief explanations of different mechanisms: `https://youtu.be/bdVC9FYhNiA`

See following pages for assembly drawings, detailed drawings, and bill of materials

ITEM NO.	PART NUMBER	QTY.	MANUFACTURING TECHNIQUE	MATERIAL USED
1	shopbot bottom	1	shopbot	3/8 plywood
2	shopbot front	2	shopbot	3/8 plywood
3	side shopbot	2	shopbot	3/8 plywood
4	dowel pillar	34	scroll saw	3/16 dowel
5	top for pillars	2	shopbot	3/8 plywood
6	top side for pillars	2	shopbot	3/8 plywood
7	triangle update	2	shopbot	3/8 plywood
8	basilica	4	shopbot	3/8 plywood
9	Top	1	shopbot	3/8 plywood
10	Link4	2	lasercutter	1/8 Acrylic
11	Link2	2	lasercutter	1/8 Acrylic
12	Link1	2	lasercutter	1/8 Acrylic
13	Spacer	12	lasercutter	1/8 Acrylic
14	Inch - Straight miter gear 16DP14T 20PA 0.25FW --- 14O1H0.6MD0.375N	2	3D printer	Onyx
15	Inch - Straight miter gear 16DP14T 20PA 0.25FW --- 14O1H0.6MD0.375N	3	3D printer	Onyx
16	Inch - Straight miter gear 16DP14T 20PA 0.25FW --- 14O1H0.6MD0.375N	1	3D printer	Onyx
17	LinkMount	2	3D printer	Onyx
18	7815K11	2		
19	Ball Bearing	4		
20	MidShaft	1	Lathe	3/8 Hex Steel Shaft
21	e-external retaining ring_ai	1		
22	FlyingMachineGearbox	1	3D printer	Onyx
23	Hex Bearing	1		
24	Inch - Spur gear 16DP 14T 20PA 0.2FW --- S14N3.0H2.0L0.03125N	1	3D printer	Onyx
25	Link3	2	lasercutter	1/8 Acrylic
26	person	1	Resin Printer	Resin
27	SupportRod	2	Horizontal Bandsaw	1/4 Aluminum Rod
28	Motor	1		
29	GearBox	1	3D printer	Onyx
30	16T Sprocket	2		
31	Hex Clamping Hub	1		
32	Inch - Straight miter gear 16DP19T 20PA 0.4FW --- 19O1H0.75MD0.5N	2	3D printer	Onyx
33	camshaft	1	Lathe	3/8 Hex Steel Shaft
34	4mm Clamping Hub	1		
35	birdcam	1	3D printer	Onyx
36	camshaftsheetmetal	1	Lasercutter, Heat Bender	1/8 Acrylic
37	HBOLT 0.2500-20x1.5x0.75-N	1		
38	HHNUT 0.2500-20-D-N	1		
39	CR-FHMS 0.25-20x0.5x0.5-N	6		
40	HBOLT 0.2500-20x1.25x0.75-N	2		
41	HNUT 0.2500-20-D-N	2		
42	pin	32		
43	brassroller	2	Hacksaw	Brass tube
44	MotorPlate^Motor Mount_Clouds	1	Lasercutter, Heat Bender	1/8 Acrylic
45	DriveShaft	1	Lathe	3/8 Steel Shaft
46	Inch - Spur gear 16DP 14T 20PA 0.25FW --- S14N3.0H2.0L0.125N	1	3D Printer	Onyx
47	sheetreal	1	Lasercutter, Heat Bender	1/8 Acrylic
48	pinreal	4		
49	spin2	1	3D Printer	Onyx
50	link	1	Lasercutter	1/8 Acrylic
51	arm	1	Lasercutter	1/8 Acrylic



	NAME	DATE
DRAWN	Amy Phung	4/11/19

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ENGR 2330 Mech Proto

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Flying Machine Full Assembly

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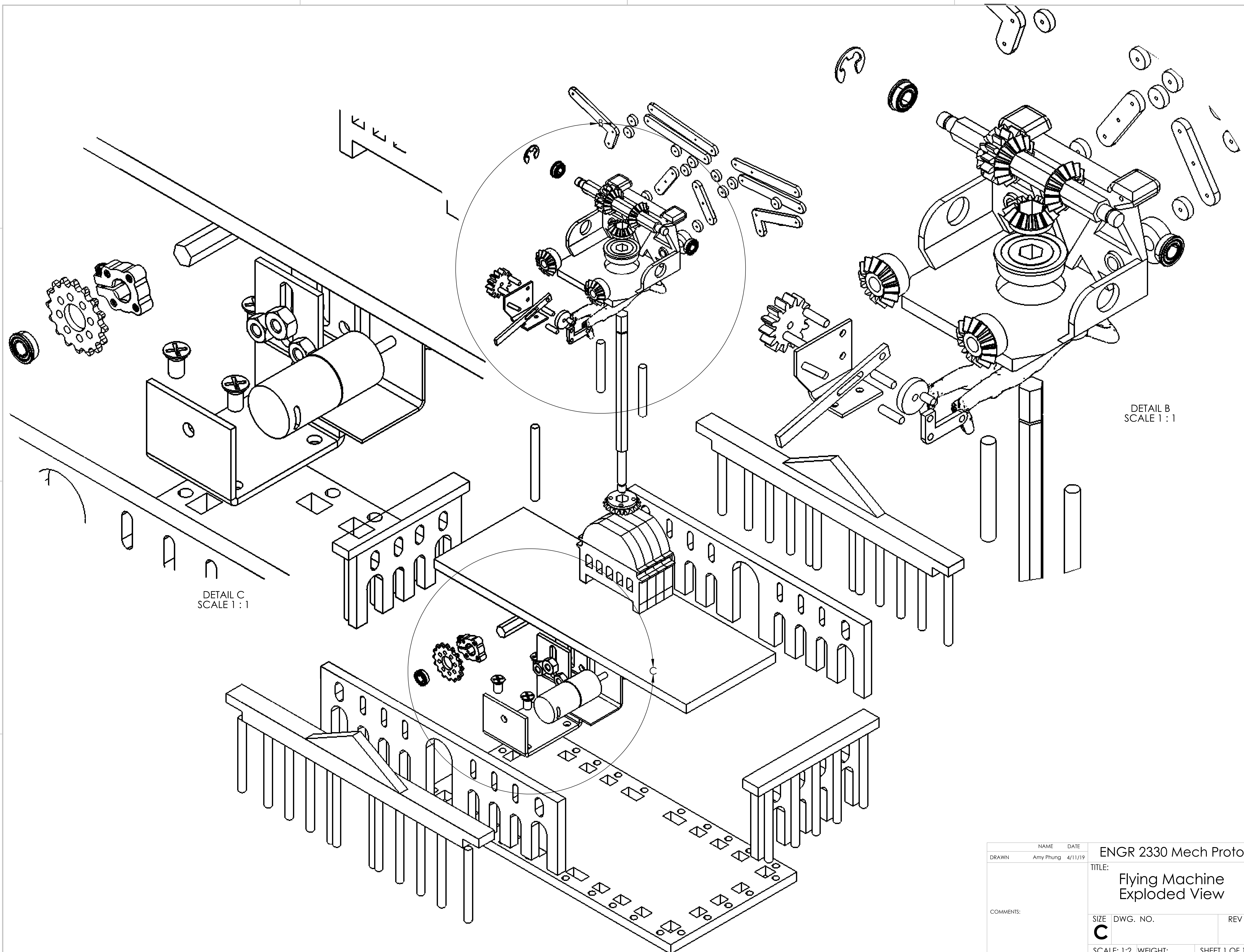

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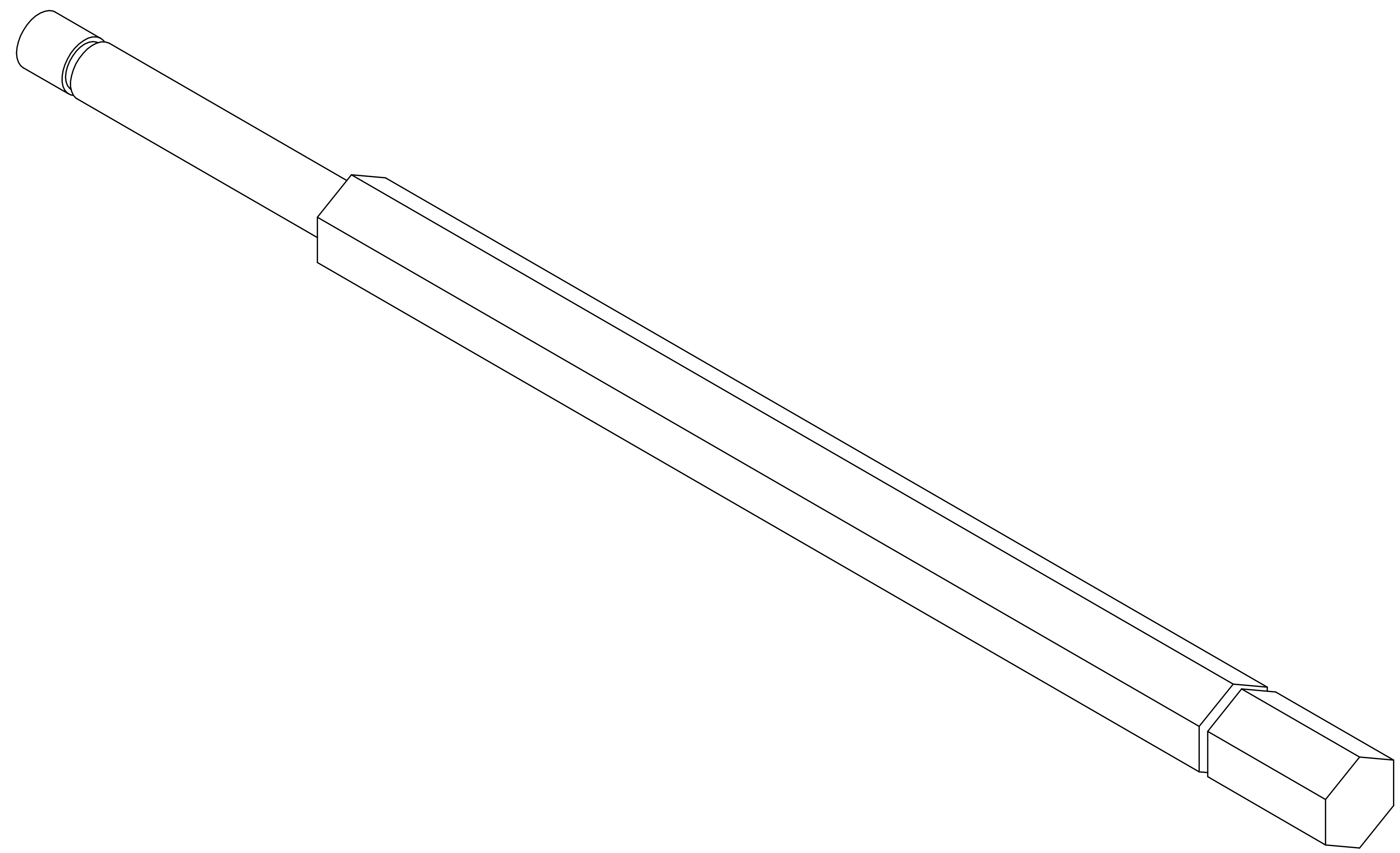

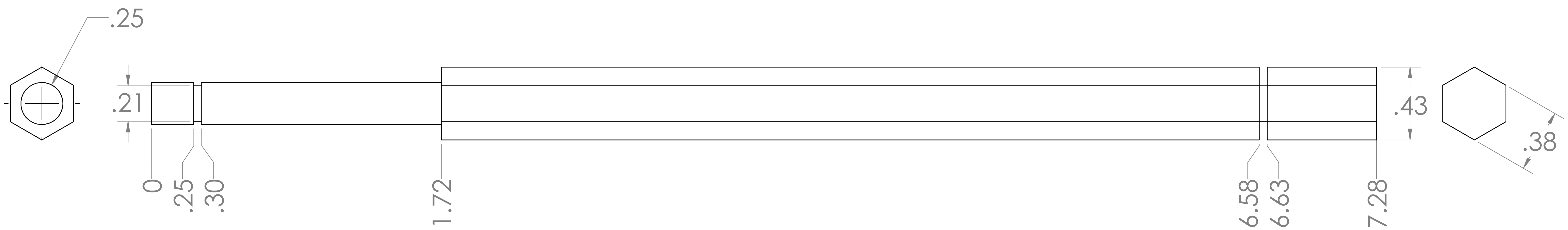

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QUANTITY: 1			
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ENGR 2330 Mech Proto

TITLE:

Drive Shaft

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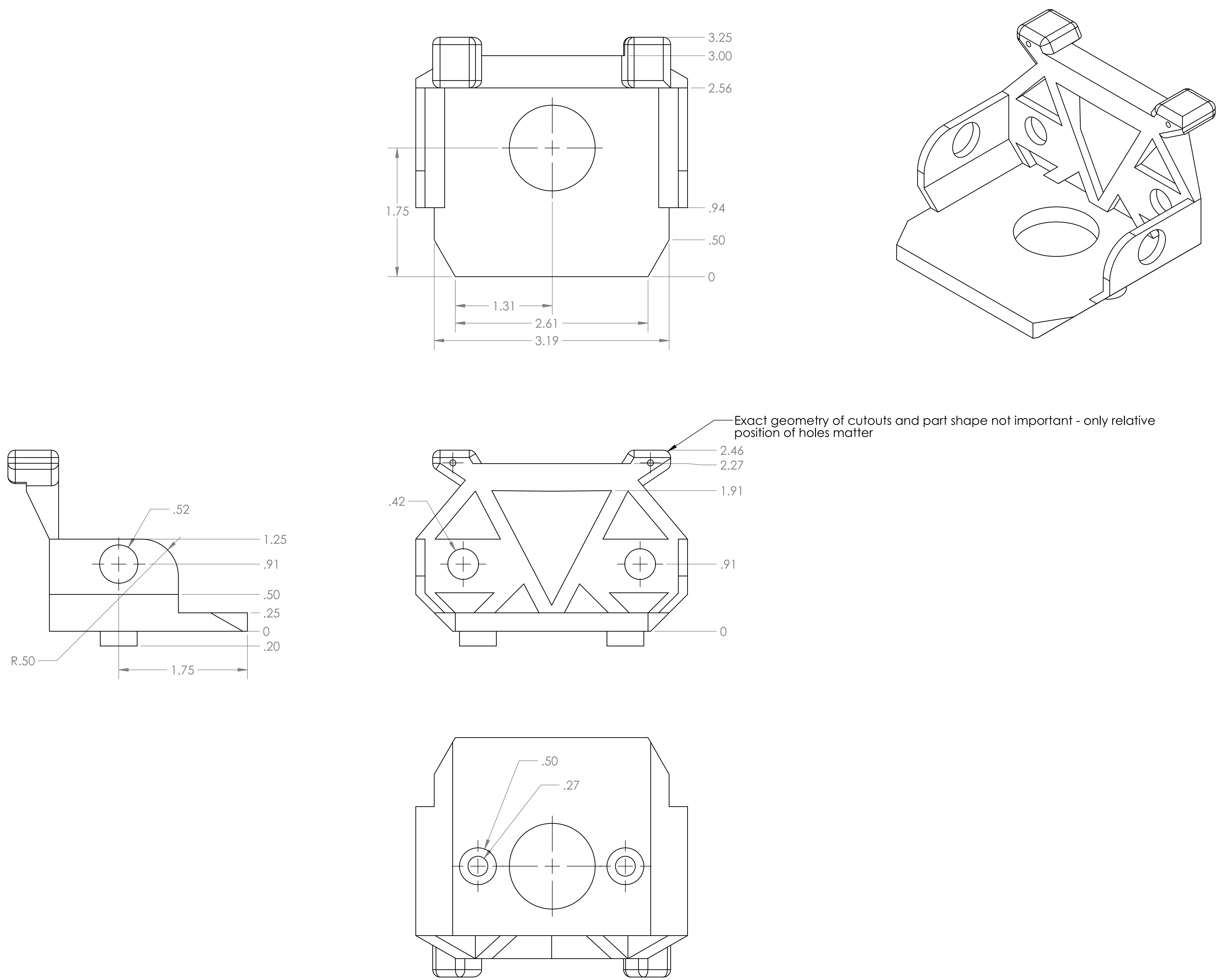

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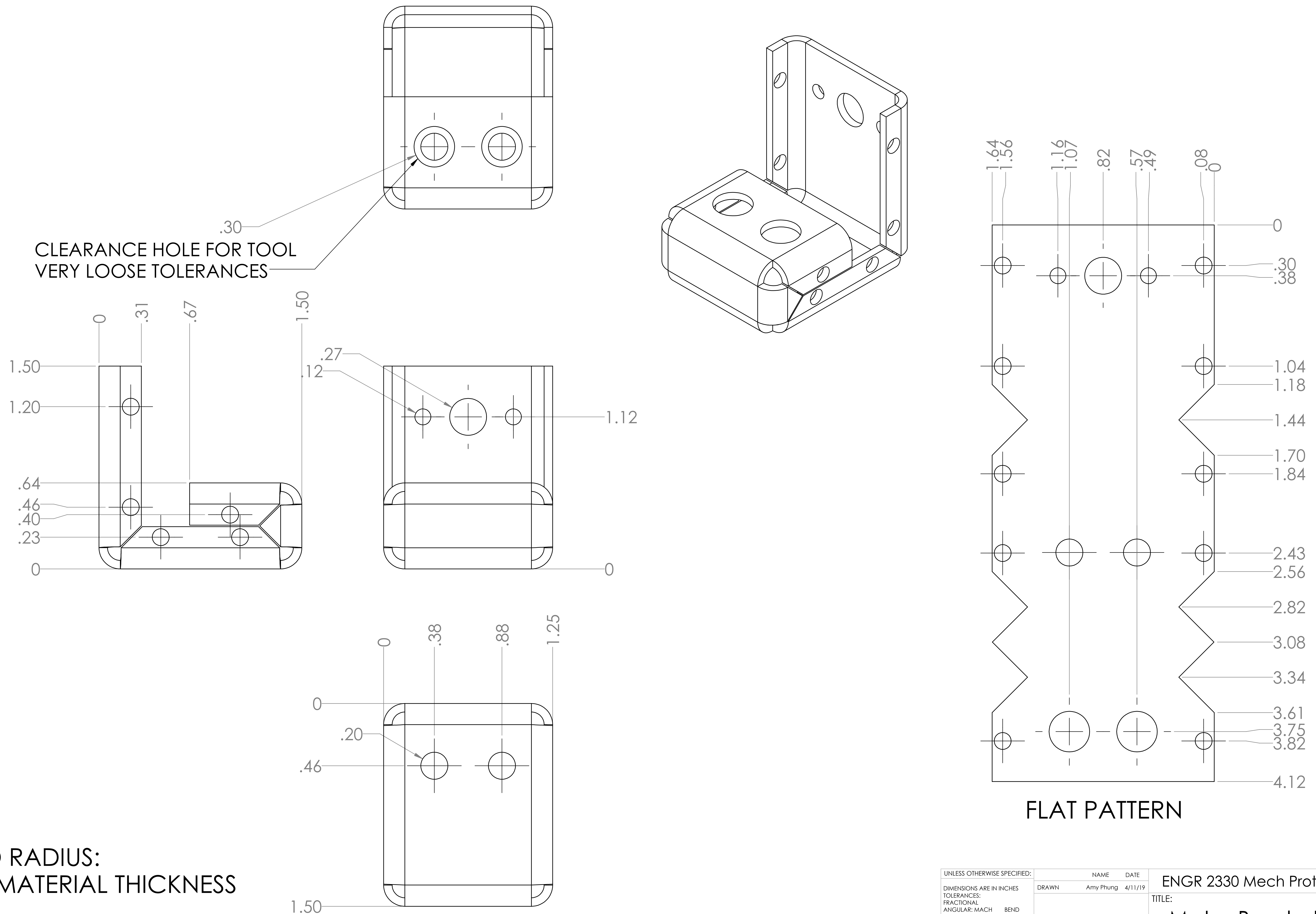

BEND RADIUS:
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MATERIAL: Aluminum 5086 Sheet 0.063" thick

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ANGULAR: MACH BEND
TWO PLACE DECIMAL
THREE PLACE DECIMAL

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL Aluminum

QUANTITY 1

DO NOT SCALE DRAWING

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DRAWN	Amy Phung	4/11/19

COMMENTS:

ENGR 2330 Mech Proto

TITLE: Motor Bracket

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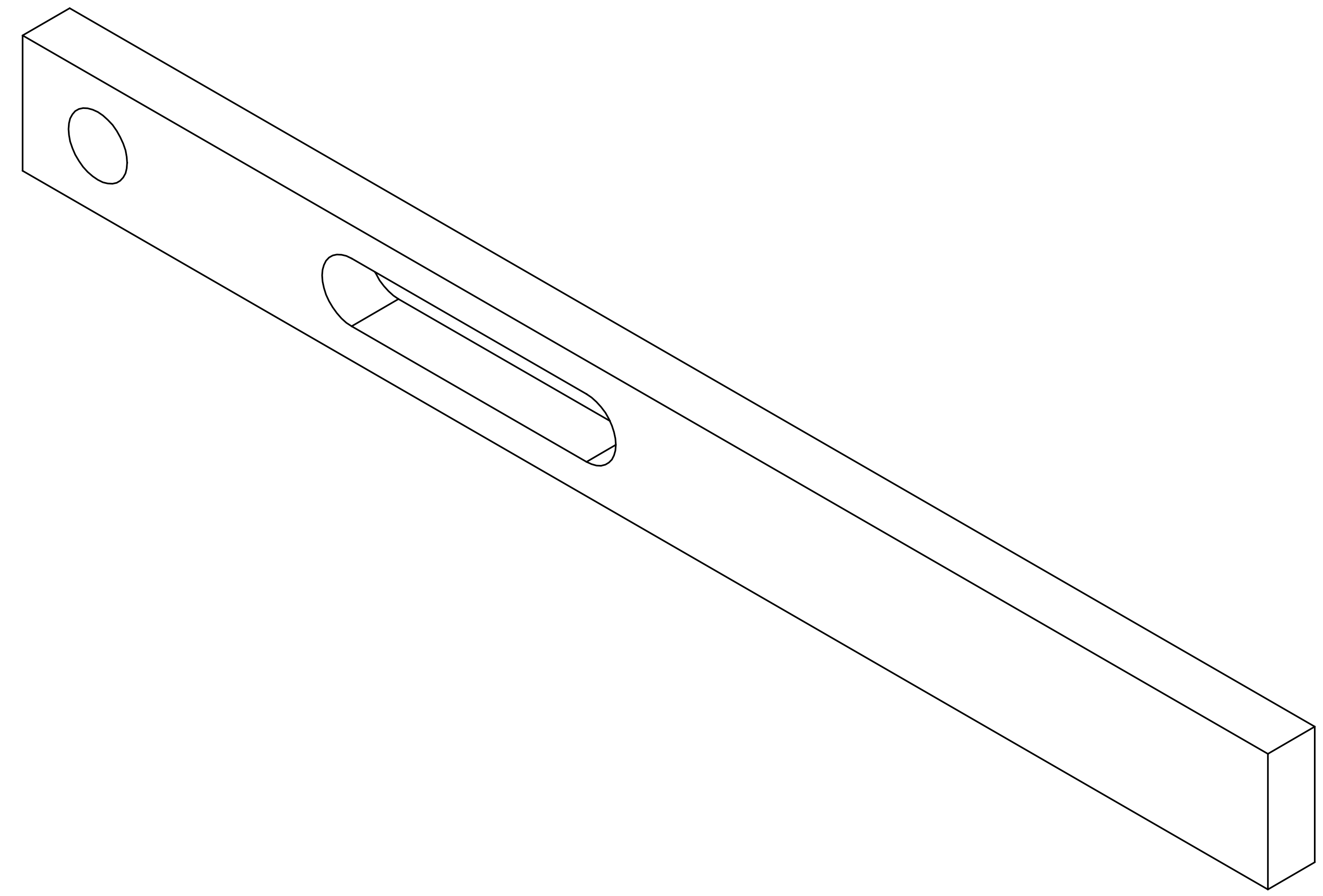

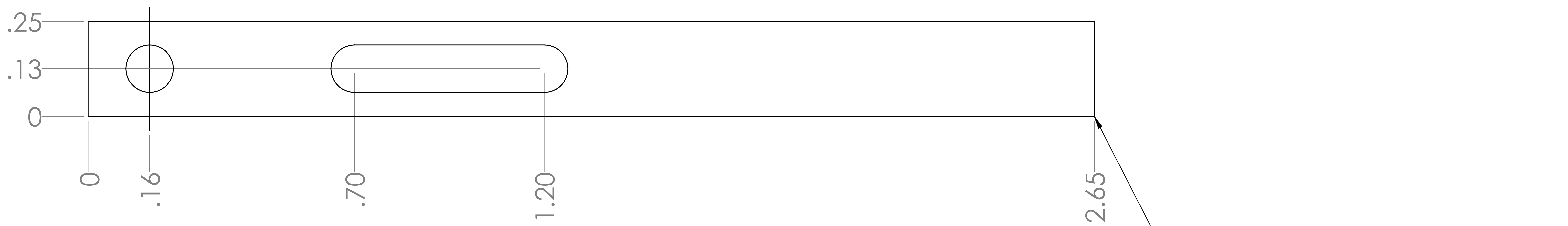

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THREE PLACE DECIMAL
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QUANTITY
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COMMENTS:

ENGR 2330 Mech Proto

TITLE:

Tail Arm

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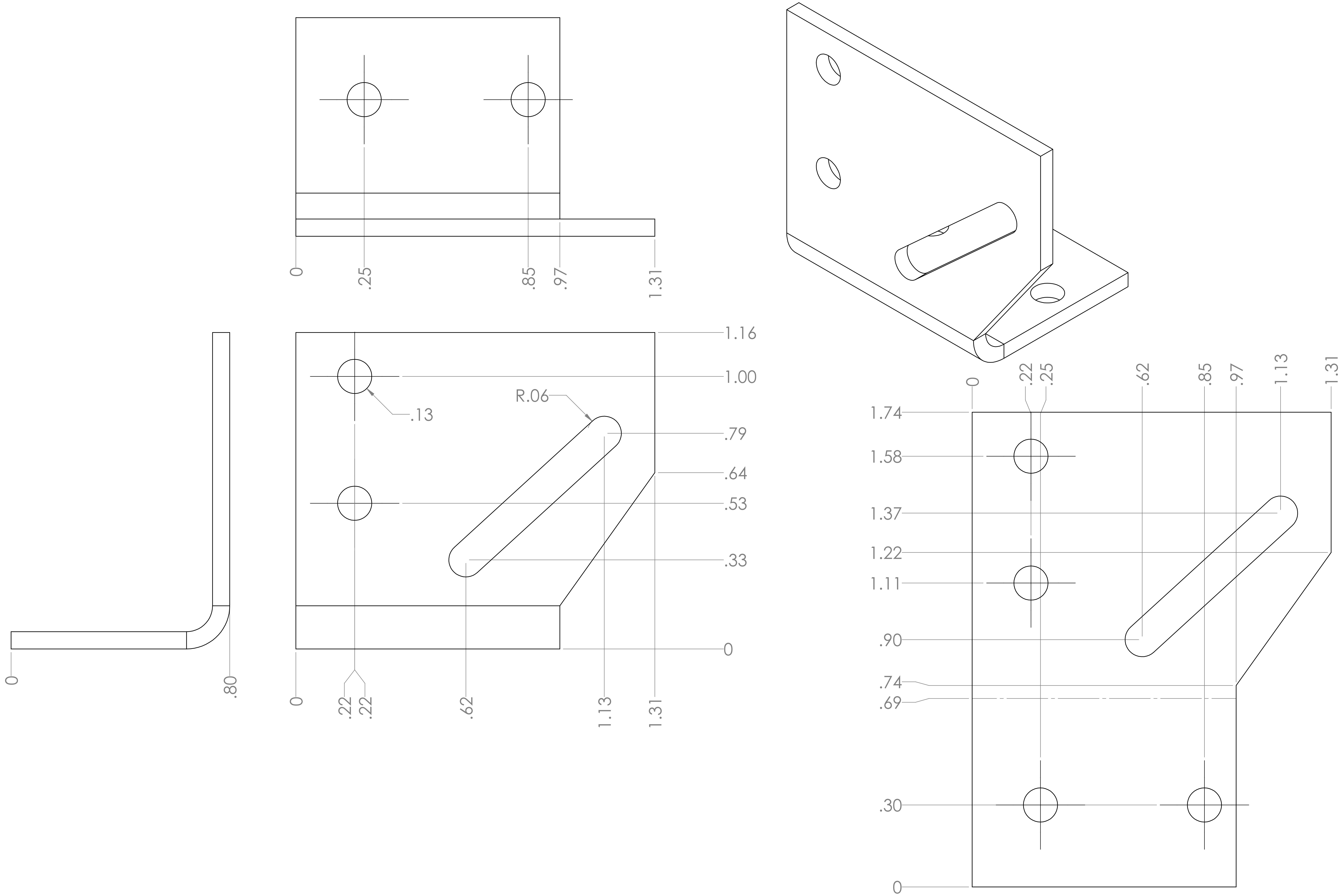

FLAT PATTERN

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