Assignment 3 – Final Report

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Introduction:

This report details the early design stages for our team's interactive mechanical pet. Our goal is to create a “pet” that has mechanical functions and triggers autonomously when presented with some sort of sensory input (e.g. loud noise, close object, etc…). We began by setting out a list of requirements for the pet, and then brainstormed as many different animals with mechanical functions as we could. We narrowed our ideas to the 5 best options, and then created a Pugh chart with different criteria for the project and selected the best option. We then discussed our materials and mechanical elements, and possible risks that might come up during our project, and created a Gantt chart to help us keep on schedule.

Project requirement:

Requirement	**Target metric**
Machine	Uses a mechanism of elements connected by joints that transmit motion to one of the elements that does work. Approved as a machine by the teaching team.
Interactive	The machine reacts without further human input to at least one sensor that does more than activate the machine.
Easy to disassemble	No permanent joints or fasteners, allowing components to be easily reused.
Consist of reused/reusable components as much as possible	Evident visually and in report that the machine has **multiple** reused/reusable components, and the use of new materials is well justified.
Easy to manufacture	Can be made using materials and tools we are provided.
Medium size	Smaller than 50x50x50 cm – Fits in the lockers at TCS and isn't too large to be difficult to carry.
Safe	No exposed wires, sharp pieces, hot elements.
Durable	Individual components and entire assembly don't fail through normal usage throughout the semester and showcase.
Animal-ish shaped	Project is recognizable as the correct animal.
Power	Batteries/wires/other electronics supply correct amount of power to drive motors.
Minimal distortion	Material is strong enough to withstand torque from motor.
Light weight	Less than 2 kg.
Aesthetics	Looks cool according to Alex (exterior design catches the eye and resembles a frill-necked lizard).

Our final design and the constructed machine meet most of the requirements we outlined at the beginning of the project. Our lizard has been approved as a machine by the teaching team and has an interactive component: the neck frill and the mouth open up when it senses vibrations (e.g., a shaking table). The lizard is also easy to manufacture using the materials and tools provided to us, as most of our components were either laser cut or 3D printed and were fastened together with brackets made in the metal workshop. The shape and weight of our machine also met our requirements as it fits in the storage lockers at TCS, weighs less than 2 kg, and is easy to carry. It also has no exposed wires, sharp edges, or hot elements, and hasn't posed any safety threat while we assembled and updated it. There is also no distortion to any of the elements as they move, which was confirmed through both equilibrium calculations and physical testing. The power is limited to a 9-volt battery, which has proved proficient to power our machine. Our lizard is also recognizable as a lizard (it has legs, a head, and a tail), especially when the frill neck opens up, and all our team members are happy with the design. Many other students have also been impressed when they see our machine and have complimented our design.

However, there are some requirements that we weren't able to fully meet. While most of our machine can be easily disassembled, there are a few components that are more difficult to take apart. These parts can still be disconnected but will likely be damaged and unusable. There are also some components of our lizard that aren't reusable, including thin and small MDF parts. Much of the exterior, however, is made of large pieces of MDF, which can be reused for smaller pieces in future projects. All the electronic components are reused from previous years and will be reusable in the future. In addition, our rack and pinion can be applied to some projects in the future for students so that those parts can also be reused for the next course.

The final design requirement is durability. We have assembled and tested our pet and so far, it hasn't had any functionality issues. We will continue to assess its performance throughout the next two weeks, especially at the pet parade, where our machine will be running for an extended period of time.

Concept development:

We had a concept generation session using the concept metaphor and analogy method on 9/8/22 at 1pm. We spent the meeting thinking of real-life animals and their unique motions and features and potential mechanisms that could serve as mechanical analogies to these motions. Our concept is based on the animal living in the desert such as lizards, scorpion and some animal leave near the coastal area such as bird and crab.

Our original ideas were:

- A frog's tongue sticking out
- A porcupine quills shooting out (Unsuitable due to risk)
- A chicken laying an egg (Unsuitable due to low interactivity)
- A frill neck lizard's frill extension
- A crab's claw grip
- A parrot/bird wing spreading out/folding up
- A dog taking a poo (Unsuitable due to low interactivity)
- A scorpion tail strike

When we took these concepts and eliminated ones we thought were unsuitable. We were left with 5 concepts that we were enough interested in to do more detailed analysis:

- A mechanical frog using a motor to move a tongue piece in the manner of a rack and pinion motion, with the 'tongue' being stored in the body of the frog when not extended. The frog could use ultrasound to detect when something is placed in front of it and then poke the object with its tongue.

- A mechanical frill neck lizard using an umbrella-like motion to extend a number of spokes and attached cloth to imitate the frills going up. It could do this in response to detecting a loud sound with a microphone, imitating going into a defensive position.

- A mechanical crab using the set of motor, servo motor, and linkage to hold the object in front of it and put that object to storage on top of it, imitating a hermit crab. The crab would be built with the IR sensor to help it detect the object near it.

- A mechanical bird with a system of strings and springs which would allow the wings to spread out and then fold up again. This could be triggered by a gyroscope detecting the bird shaking, indicating it would then fly away.

- A mechanical scorpion with mechanical pincers and tail, controlled by a motor and linkages that would open and close the pincers and move the tail. It would be in response to an IR or ultrasonic sensor to detect something moving near it.

For those concepts above, we then did a weighted Pugh Chart for further concept evaluation to determine which mechanical analogy was going to be implemented in our machine:

Pugh Chart

Criteria		**Concept**				
Category	**Weight**	**Frog**	**Frill neck Lizard**	**Crab**	**Parrot**	**Scorpion**
Interactivity	3	3	3	5	3	4
Reusability	1	4	4	4	4	4
Reliability	2	5	2.5	2	2	2.5
Complexity	2	1	4	4	4	5
Feasibility	3	5	3	2	2	1
Aesthetic	1	3	5	4	3.5	5
Wow-factor	2	1	5	3	3	5
Alex Choice	1	0	1	0	0	0
Kevin Choice	1	0.5	0	0.5	0	0
Nathan Choice	1	0	0	0	0	1
Score	73	45.5	**51**	47.5	40.5	50

After the concept evaluation, we decided to build the Frill neck lizard because of its interesting mechanism which is also more feasible than the robotic tail on the scorpion. Moreover, we also started to draw some concepts for mechanism design which we will try to implement.

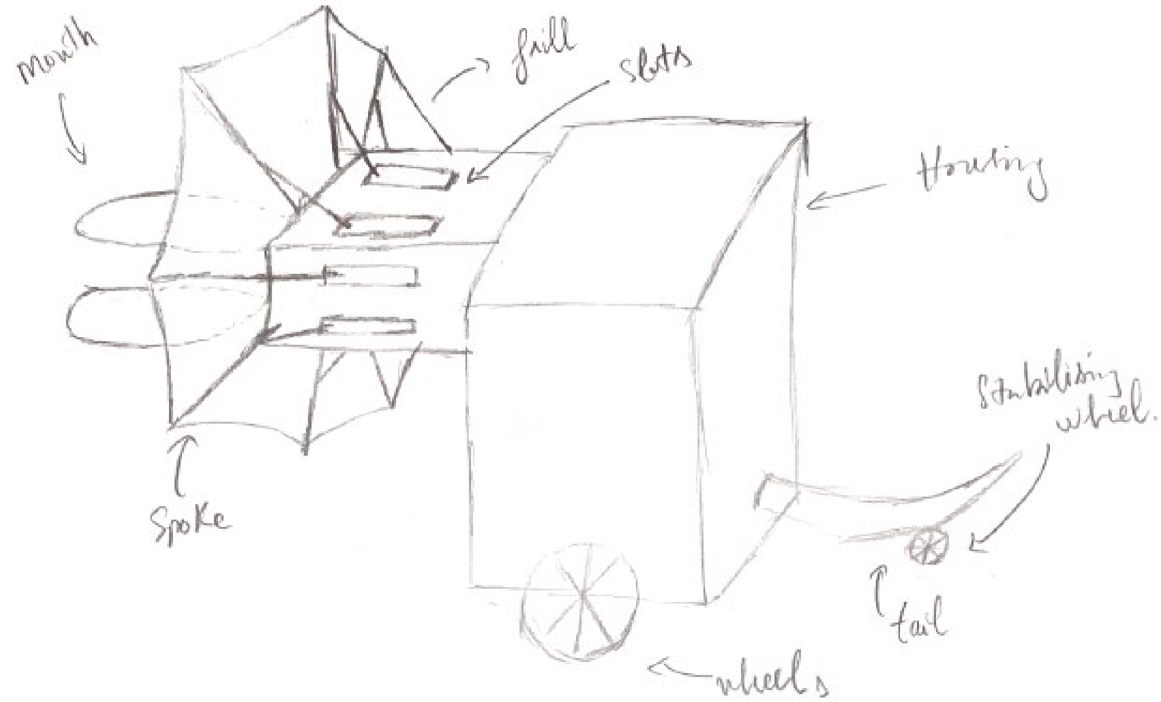


Figure 3: The design of frill neck lizard

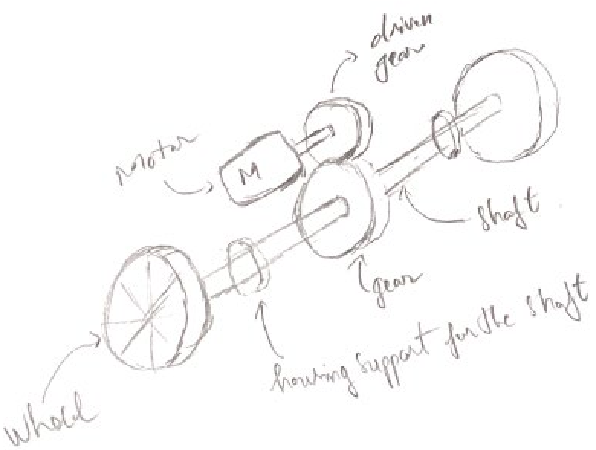


Figure 1: The mechanical design for the wheels

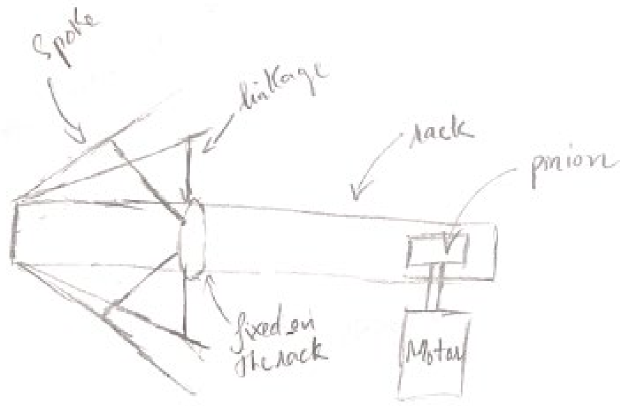


Figure 2: The mechanical design for the umbrella-like frill neck

Starting on the frill neck lizard, we considered that the motion of the frill was the most critical aspect of our lizard so we did the concept development for the frill in terms of how to perform the open and close the frill. During the discussion, our team provided 3 different designs which are using motor rotation to pull strings through linkages, rack and pinion, and the ball screw and lead screw. Therefore, our team considered the advantages and disadvantages of each of the designs above according to provided components, materials, and requirements.

Motor rotation to pull strings through linkages	
Advantages	**Disadvantages**
• Reduces the length of the neck helps reduces the size of the pet • Most of the provided motors for the project can drive enough torque to open the frill • The linkages are feasibly made from 3d-printing	• We have to 3d-print all of the linkages, which is time-consuming in the situation where we will do the repeated process from design and testing. • The linkages are hard to be made from laser cutting which can reduce the time. This is because drilling a small hole through each linkage having a 6mm thickness is impossible for us, as it breaks the material.

Rack and pinion	
Advantages	**Disadvantages**
• Most of the components in the design are easily made from laser cutting so that it is fast for the repeated process from design and testing when we have problems with the design such as size. • Most of the provided motors for the project can drive enough torque to open the frill	• Some components have to be made from 3d-printing because drilling a small hole through each linkage having 6mm thickness is impossible for us. • To provide enough torque and displacement of the rack to open the frill, the length of our frill might exceed the medium size.

Ball screw and lead screw	
Advantages	**Disadvantages**
• Reduces the length of the neck helps reduces the size of the pet • Most of the components in the design are easily made from laser cutting so that it is fast for the repeated process from design and testing when we have problems with the design such as size. • Most of the provided motors for the project can drive enough torque to open the frill	• It is complicated to be made from 3d-print and laser cutting. Moreover, this concept can be made from provided materials or components. In addition, this design violates the requirement of the course because we have to buy this from the market. • Costly

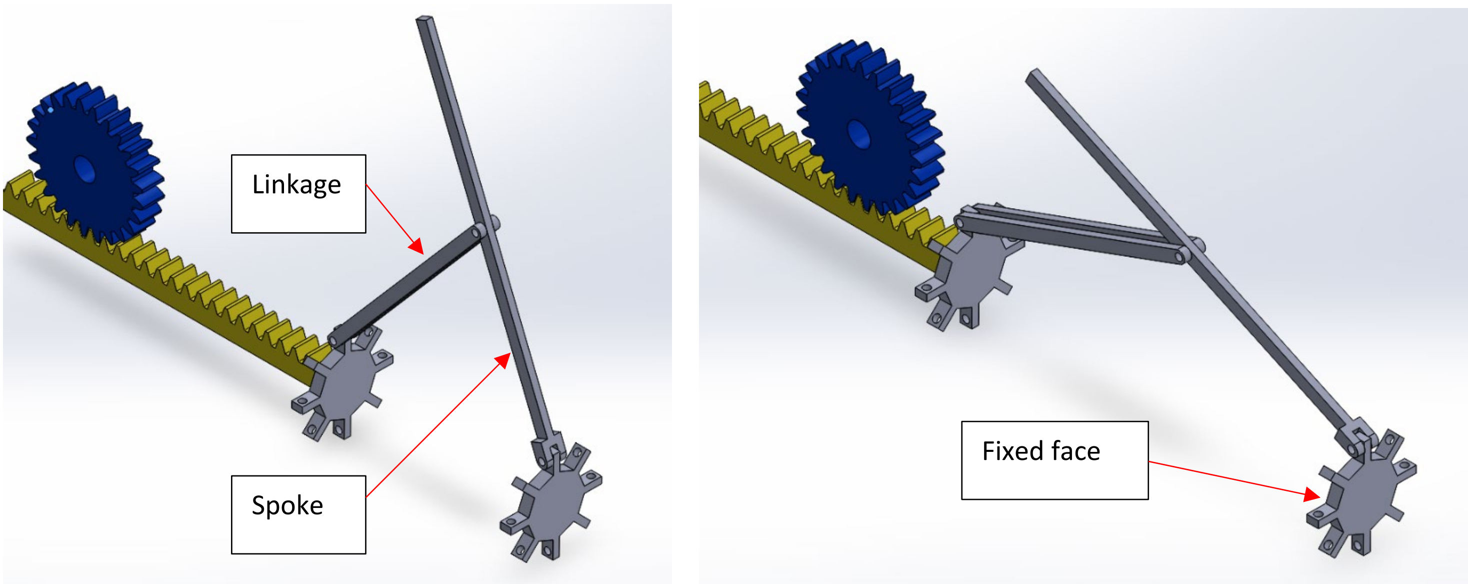
After considering all of the advantages and disadvantages above, our team decided to make the rack and pinion design due to the limitation of time and the feasibility of making it from laser cutting.

Design decision and prototype tests:

We applied the tree diagram for the critical function prototypes for the pet so that we start with the design and prototype tests for the frill motion since it is the critical aspect of our pet. After that, we will join the frill with the electronic section rather than building both of them at the same. Moreover, we planned to build the housing after we achieved the frill working as we expected.

1. Linkages and spokes for the frill and the face:

The mechanism of the frill imitates an umbrella's mechanism. We push the runner along the shaft to push out the spoke through a set of linkages. Therefore, we had a concept of using the rack and pinion to push the face which works like a runner in the umbrella to push out the spoke and linkages. Our initial design consisted of two 100mm linkages with one 150mm spoke attached together with a pin joint at the middle of the spoke. The linkages and the spoke would attach to the face which was designed based on an octagon with a bar extended at each vertex for hanging a set of spokes and linkages. As a result, our frill would have 8 spokes for the frill. Before having actual linkages from laser cutting, Kevin designed the simulation on SOLIDWORKS to assure that all of the linkages, spokes, and faces are placed in the correct position and would extend as dired, to fulfill the critical component of our project, the consistent extension of the frill.



After the CAD simulated the desired motion, we cut all of the linkages and the face (which linkages attach to) for prototyping, testing its size and whether it conveys the motion in practice. To prepare for the prototype test, all of the pin joints will be made from the nylon nut, screws, and washer to leave enough space to rotate. Therefore, from this prototype, we learned that:

- It gave the desired motion for our project.
- The current design is huge and it took a long distance to fully open the frill because the length of the linkages is 10cm. Therefore, it needed to be reduced its length to solve this problem. Moreover, we also shift the hole on the spokes to be near its end so that the spokes can open with the desired angle.
- The face cannot be made from laser cut due to the design and it is complicated to be made precise with the drill press. As a result, we decided to use 3d-printing to make it.
- The width of the linkages is small which will cause the pin joint to be broken.

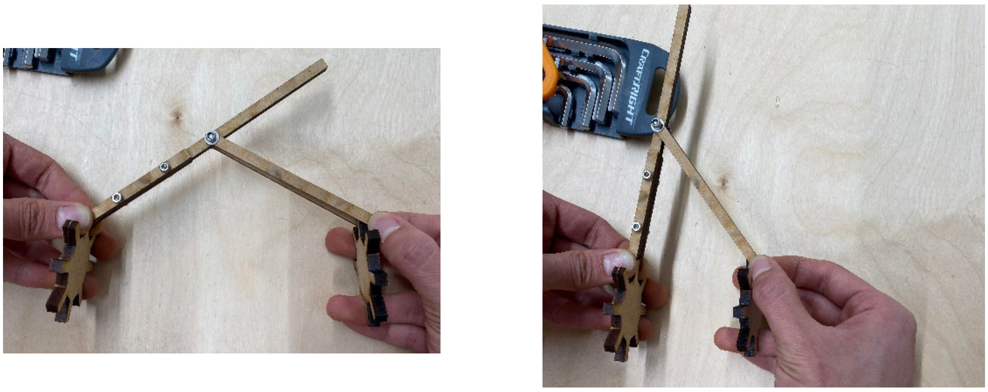


Figure 4: The linkages and spoke gave desired motion

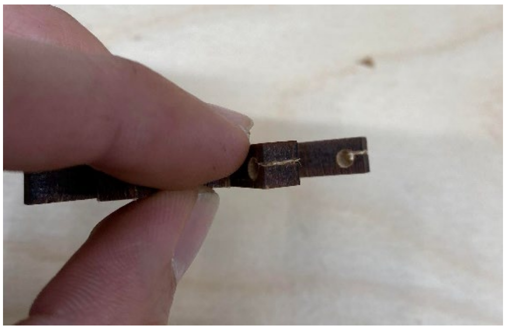
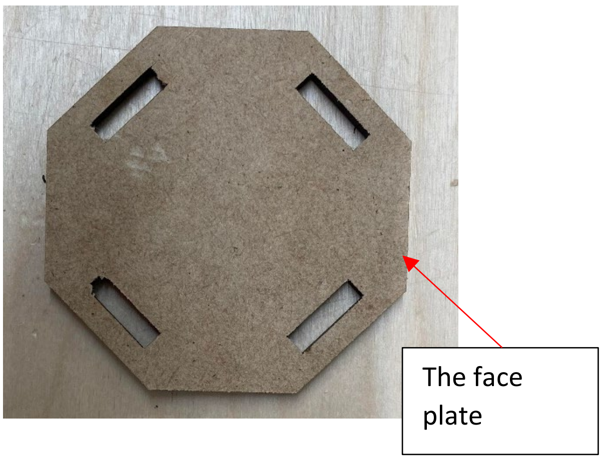


Figure 6: The problem with the face

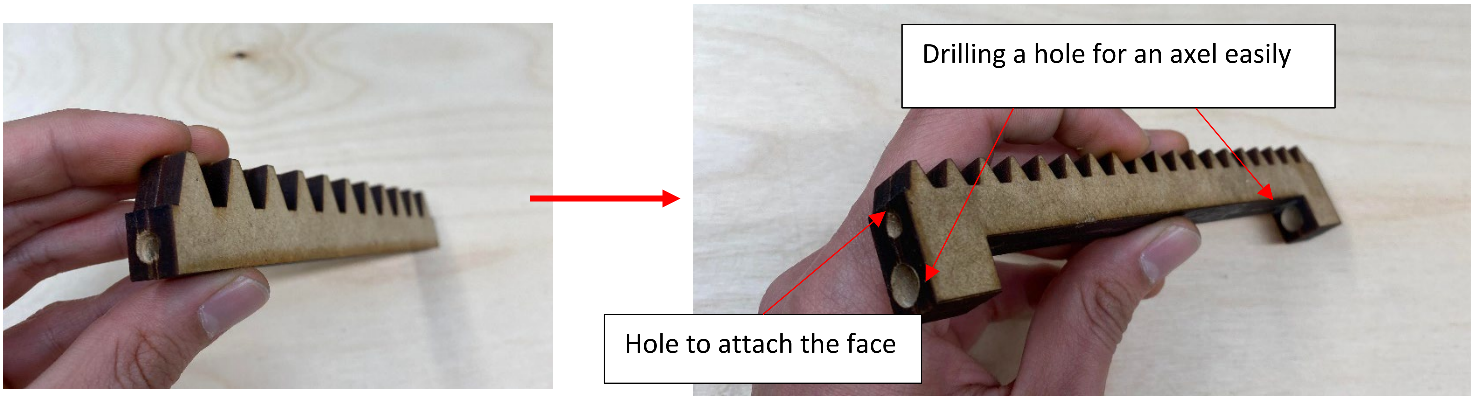
To resolve the problems we faced, we printed the face and changed the dimension of the linkages to 5cm long to reduce the travel distance of the rack in the future. Moreover, we also increased the width to 8mm to prevent the pin joint from being broken. After redesigning the linkages and 3d-printing the face, we were ready for the next step in our design which added the rack and the housing for our system (relating this design to the development of the housing section below). For this next prototype test, the issues of our new design were:

- It is redundant for having 8 spokes so we reduced the number of spokes to 4.
- We cannot attach the face to the face plate.



In order to reduce the number of spokes to 4, our face now was created based on a square and each vertex of the square would have a bar extended and we ended up with a face for hanging 4 sets of linkages and spoke.

Moreover, we wanted an axle to line everything up perfectly so that we want a hole through the rack. However, TCS does not have a drill that is long enough to drill through the rack. Therefore, we ended up with a new design which we adopted from the lecturer and the lecture on 2 points linear contact.



The new design for the rack has the main issue is that all of the holes are drilled by hand so the hole for an axle was not lined up perfectly. Moreover, the solution for attaching the face to the rack cannot be solved since it was not tight enough when we screwed it with the face. As a result, we decided to 3d-printing that rack which added the face to it. Before we did the 3d-printing, we considered calculating the module of the pinion and rack to assure it was able to open the frill because 3d-printing is time-consuming (refer to all of the calculations in the mechanical part).

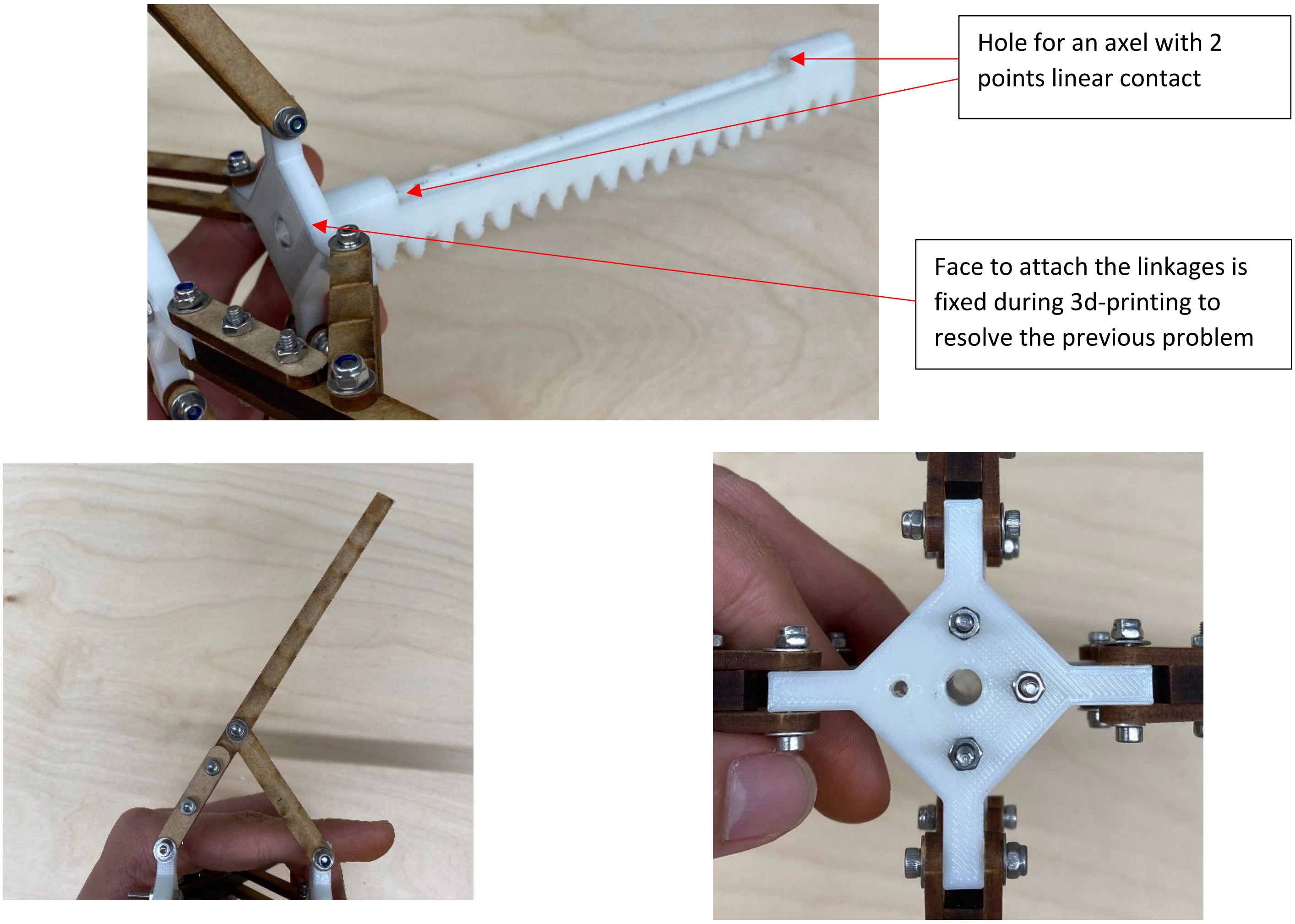
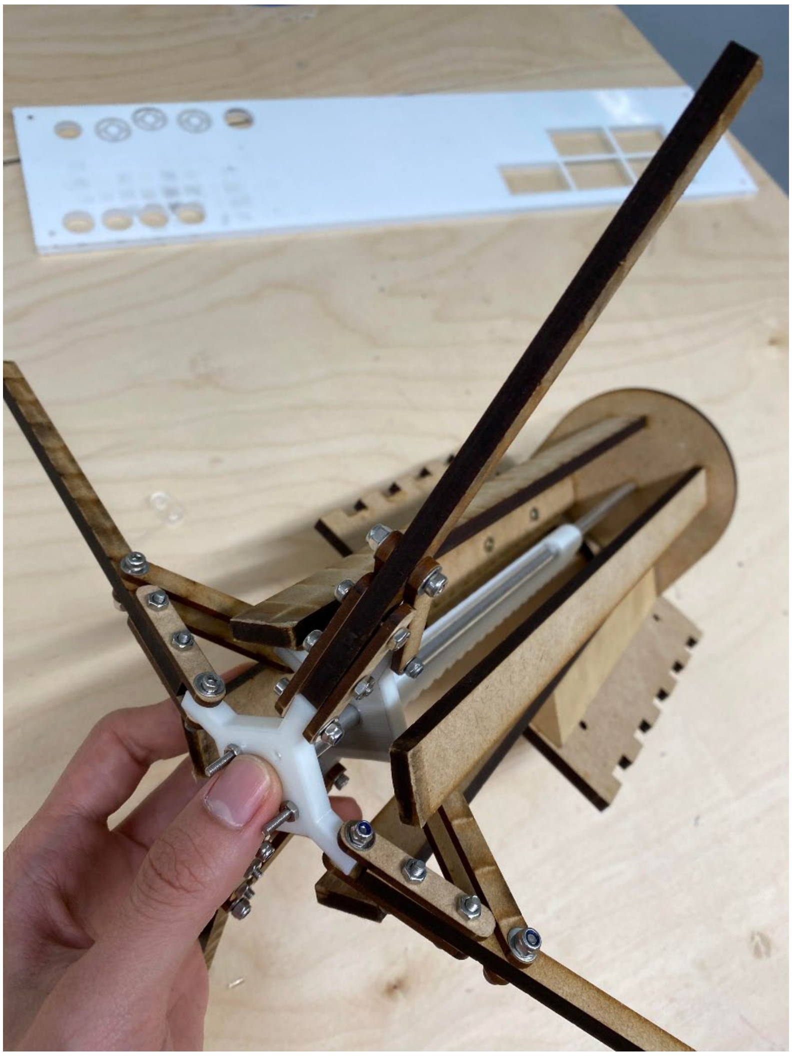
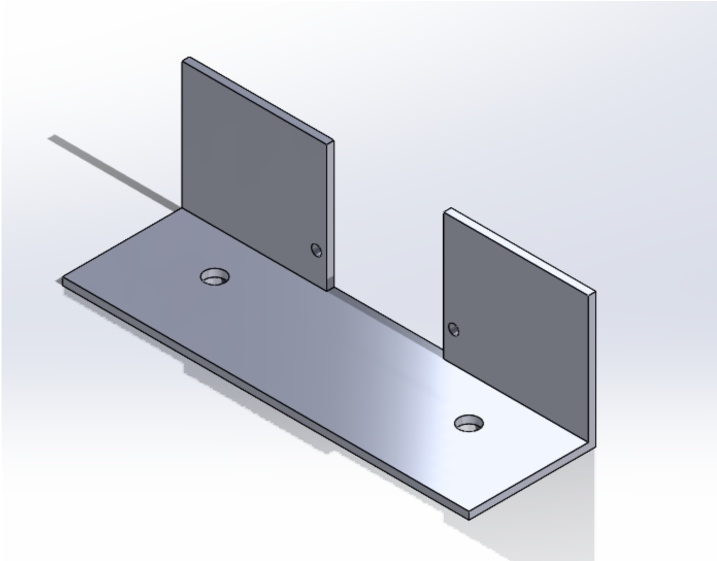


Figure 7: Final design on linkages, spokes, face and the rack

As a result, our system ended up providing the desired motion and every part lined up perfectly thanks to an axle.



In order to attach the gear to the servo, we drilled two 2mm holes on the gear and we then used the screw to screw the gear to the servo arm. In addition, because we did not know exactly the hole on the servo arm, our holes were made by adjusting the holes on the servo arm. After attaching the gear to the servo, the servo will then be fastened by the part below under the top of the housing (this part is demonstrated in the dimensioned drawing and housing part).



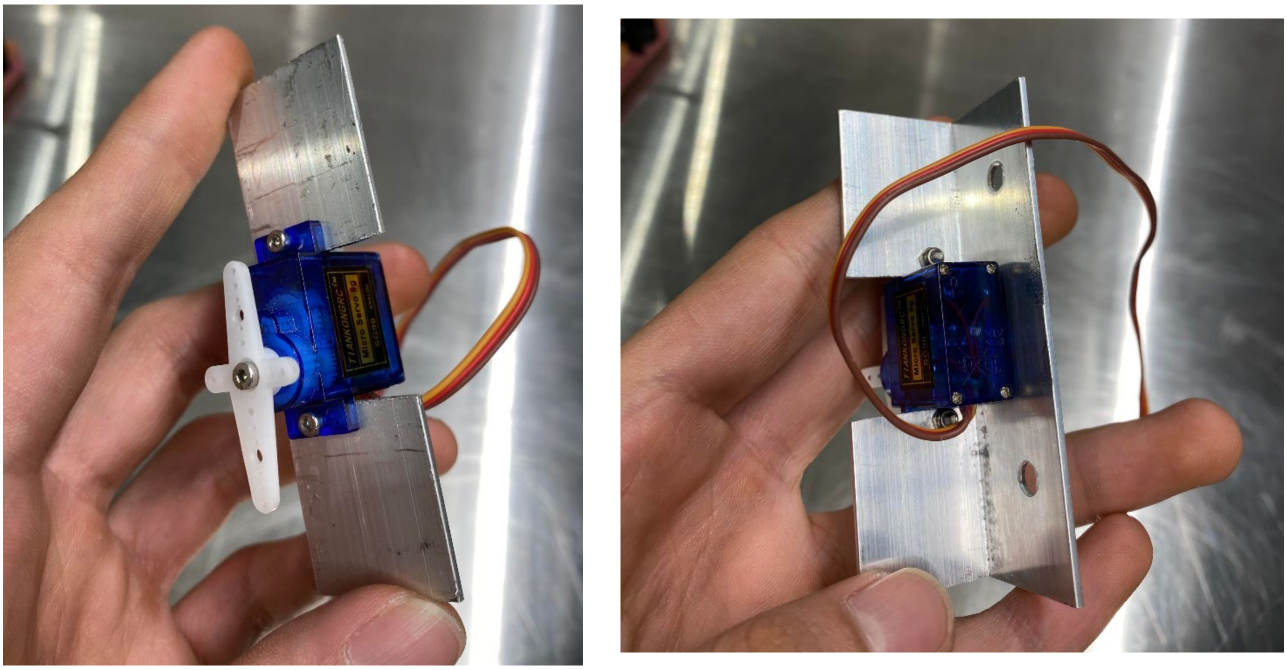
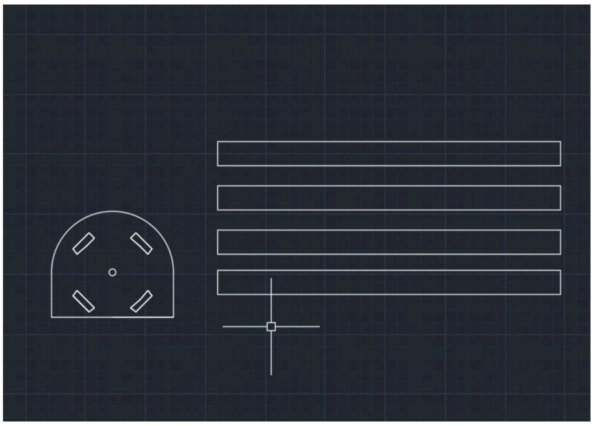


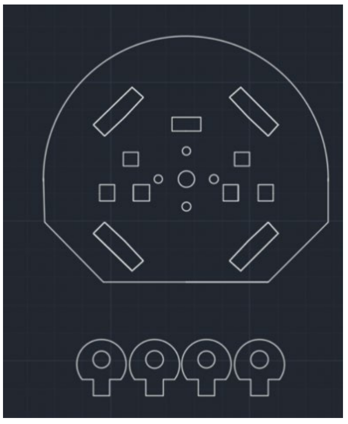
Figure: Servo Fastened

2. Housing:

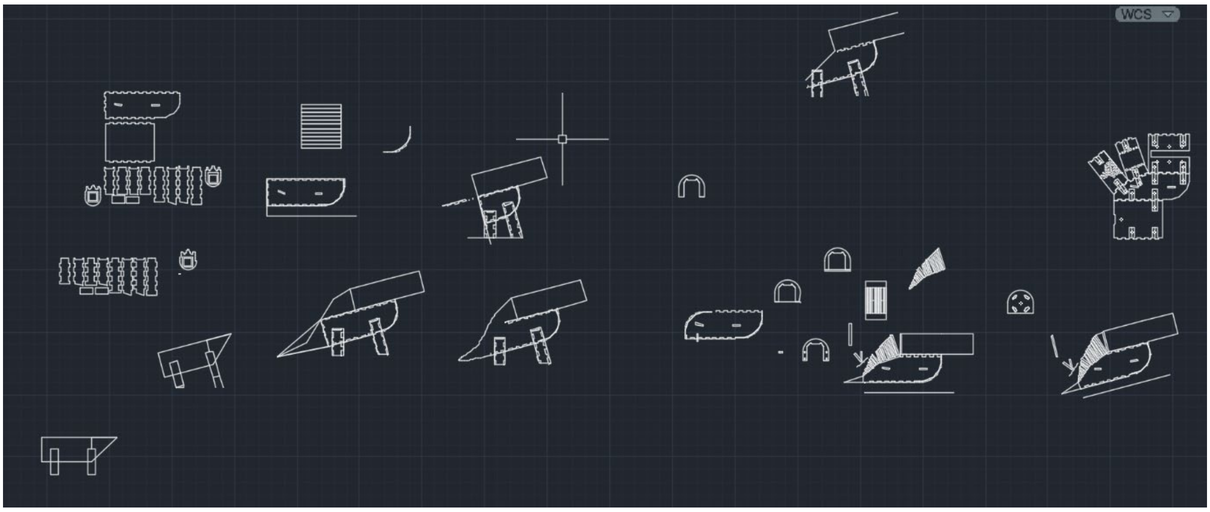
With the umbrella mechanism designed, we needed to then determine how it was going to be housed. A ¼” metal rod was intended to be the axis to which the rack would translate across. TCS had a lack of fittings to have the axel be attached with a threading and so we decided to use an interference fit, with the rod attached to two faceplates at either end with a 0.5mm smaller hole. To help keep the end plates together 4 support plates at 45-degree tilt and 90-degree rotations to one another were fitted to the plates for the spokes of the frill mechanism to extend between. The back faceplate was given a design to be flush against the top body plate with interference slots for the support plates and metal rod.



The front faceplate was off the end of the body and so did not need to be flush and was given an aesthetic design. The front faceplate additionally needed holes to attach the stationary face of the frill mechanism using M3 nuts and bolts, as well as a hole for the pulley to come through and attach to the bottom mouthpiece. The front faceplate additionally needed interference slots to attach the top mouthpiece and support brackets to act as hinges for the bottom mouthpiece.



The interference fit of the rod and the support plates supported each faceplate and could be assembled with the frill mechanism inside. The entire assembled mechanism would then be mounted to the top body plate by using wood screws to attach the bottom support plates to a wooden piece that could then be wood screwed to the top plate from underneath. These wooden brackets were cut by Alex in the TCS wood shop.

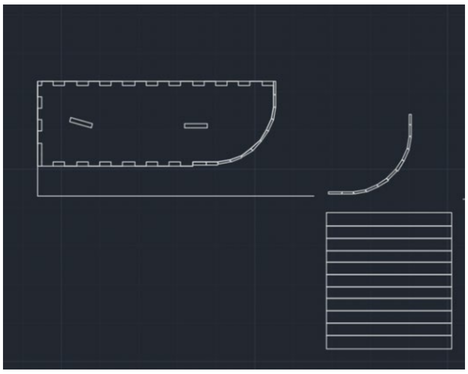


The housing for the rest of our pet went through many iterations. Early in concept development, we considered having an upright design, imitating the real animal running around. Eventually, however, we settled on a design much closer to that seen in the final product, deciding that it would be much easier to have a wider design instead, worrying about potential balance issues.

This would be done using 4 support legs attached to the body with a flat top for mounting the frill mechanism and a curved aesthetic belly. This housing would all be designed in AutoCAD and laser cut from MDF as the ease of design and implementation was appealing, and the housing would have very little strength requirements. A 5mm square fit was used on the plates to help with stability on the exterior plates. We decided a 300mm flat top looked best with the 150mm frill mechanism mounting attached to the front half, so there was enough room at the back.

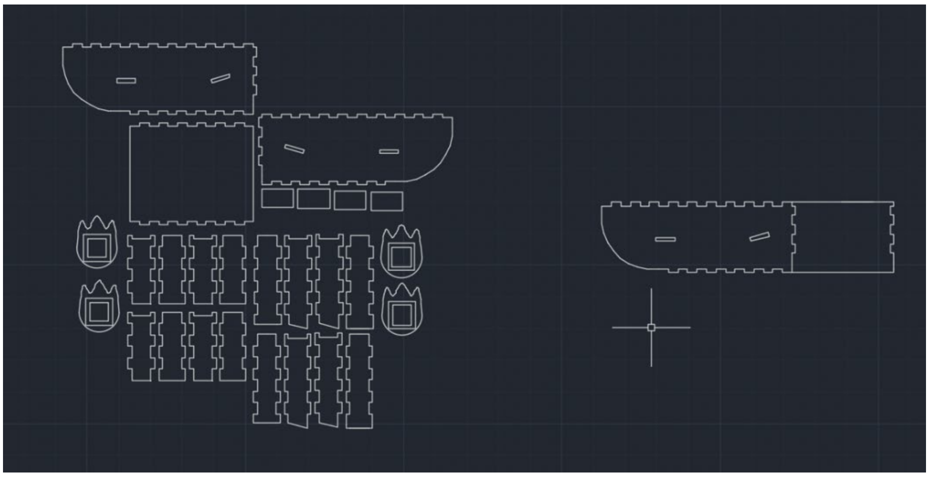
Making the housing so big meant we failed our size requirement from the initial plan but it allowed us to have a more aesthetic pet and ensured that we had enough room to house all of our components and support the large axis required for the frill mechanisms full extension and complete our critical function.

This was designed using a regular polyhedron to attach several flat boards of MDF to give a curved appearance and imitate the belly of a reptile.

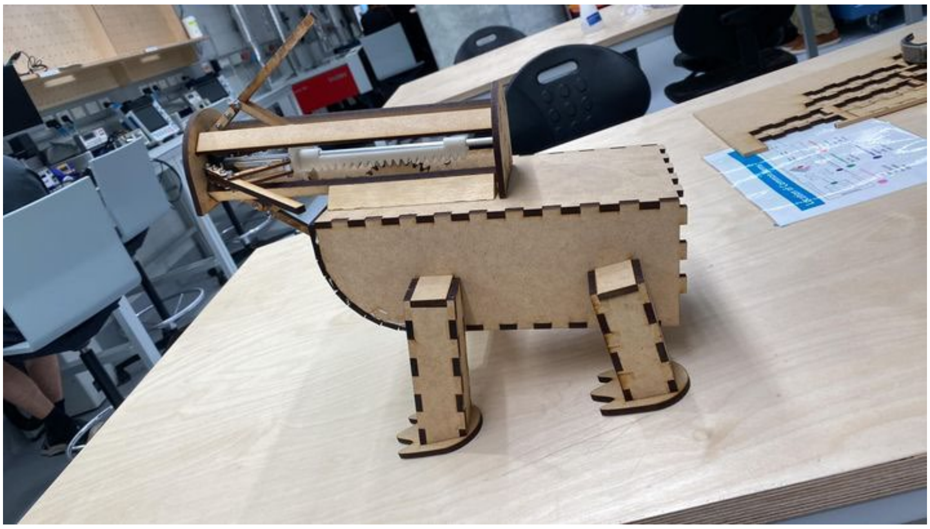


(Image sourced from Texas A&M University)

The support legs were designed to be constructed of 4 plates of 6mm MDF held together with wood glue and interference fit into an aesthetic foot plate. The front legs were intended to be angled out and slightly longer than the back legs.



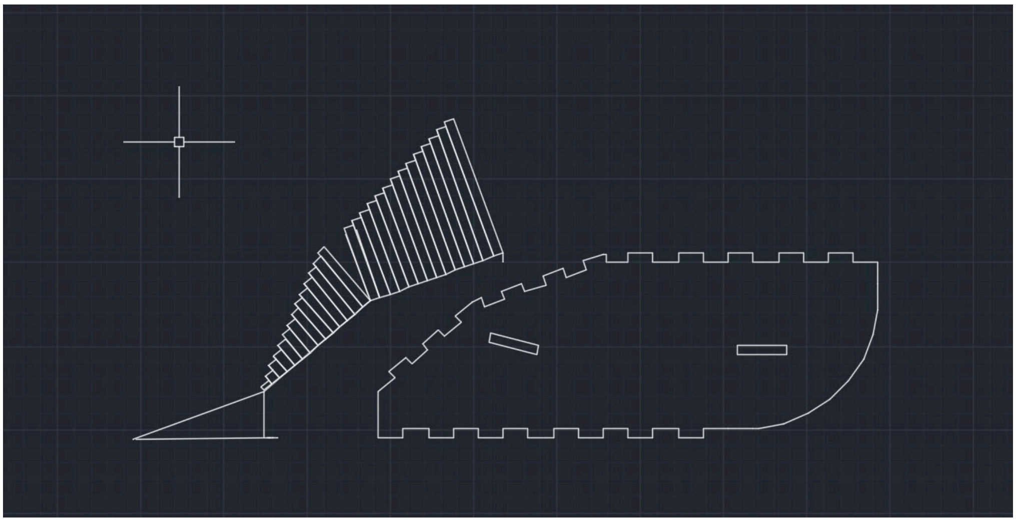
An aesthetic choice we made early in concept development was to have the housing placed at a 15-degree angle upwards, to have the lizard appear as though it were looking upwards. This was done by changing the angle of the attachment for the back support legs and the angle of the flat for the angled front leg. We built this first iteration of the housing unit for the first iteration of testing of the entire mechanism, with a mounted frill mechanism, servo, and implemented Arduino.



The initial testing of the critical feature was successful, with the umbrella-like frill mechanism worked well, with the Arduino able to rotate the servo and transmit the force to extend the frill.

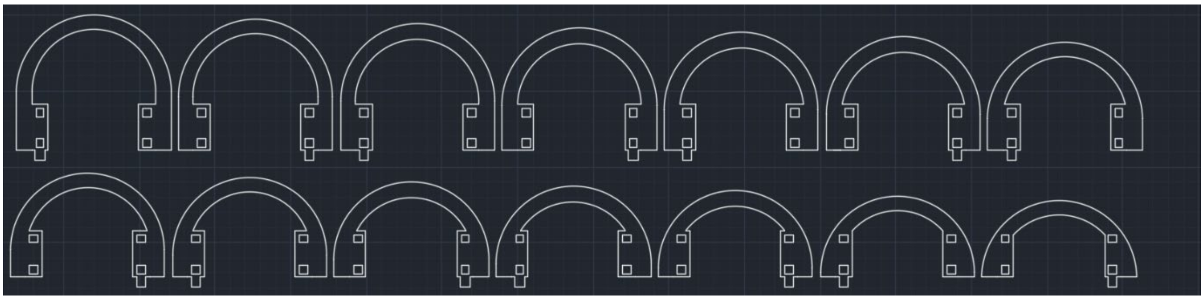
This first iteration of housing looked very bulky and was constructed using wood glue, which made disassembly difficult. We decided that for the next iteration, we would shrink the backside of the body down and mount each panel using aluminium brackets and M4 bolts.

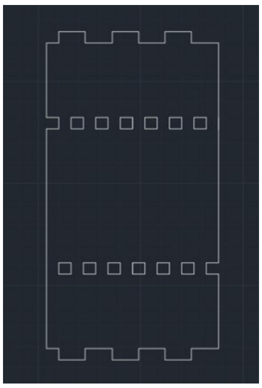
The backside of the body was to be made smaller; this could be done by a curve like a belly. Designs with circular cuts, regular polyhedral cuts, one, two, and three-panel cuts, were considered until a 2-panel cut was decided on, with a 20 degrees taper. Additionally, we began to consider the aesthetic tapering of the frill mechanism housing down into a tail. A 25mm gap was left between the end of the second back plate and the bottom plate to allow for easy access for the Arduino IO.

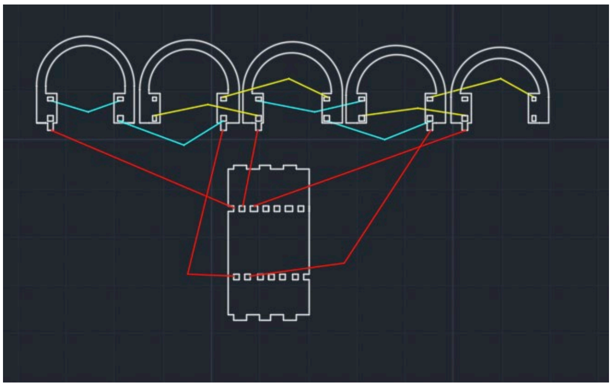


Our first concept for a tapered tail was used in the final concept. By laser cutting progressively smaller similarly shaped plates of MDF that could then be fit together and into the bottom plate, with the slight difference in heights between 6mm plates giving the illusion of a tapered, spiny tail.

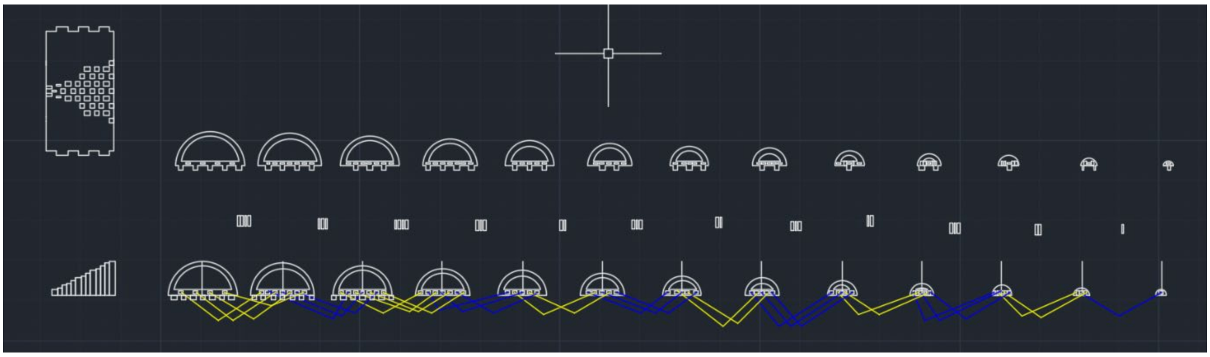
The first section of plates reduced the height of the plate by 3mm each plate, while keeping interference slots at a constant height from the base. This allowed for the plates to be fit together in an alternating pattern using a separately cut extrusion. Each plate then had an extrusion down the bottom to be fit into a corresponding slot on the plate.



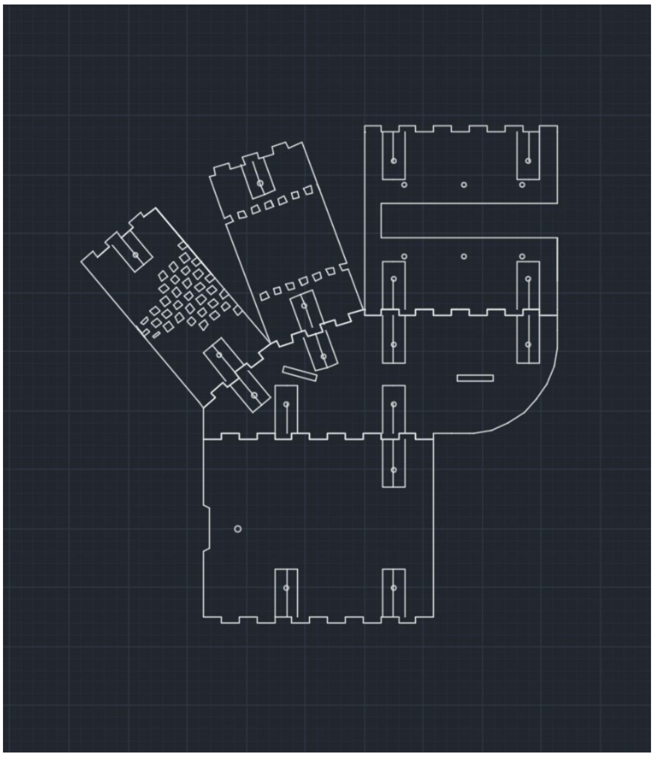




Each slot is 0.5mm smaller than the corresponding extrusion to ensure a tight fit.

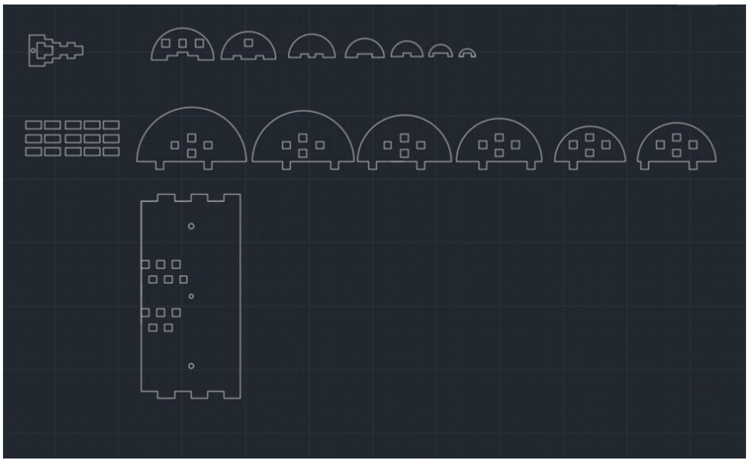


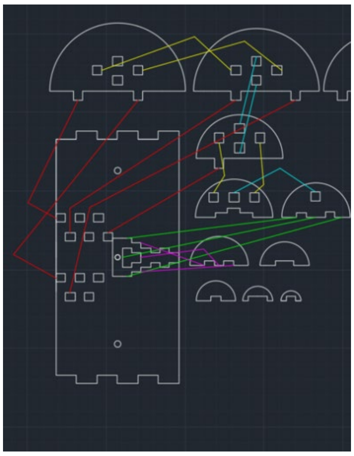
A similar concept was used in the initial concept for the second set of plates, where each plate was a semicircle of progressively decreasing radius. With interference slots a constant height from the base and alternating extrusions to be fit into the plate. Now that both base plates had been designed, the holes for the aluminium brackets to be mounted were placed 20mm from the edge of the plate in this manner.



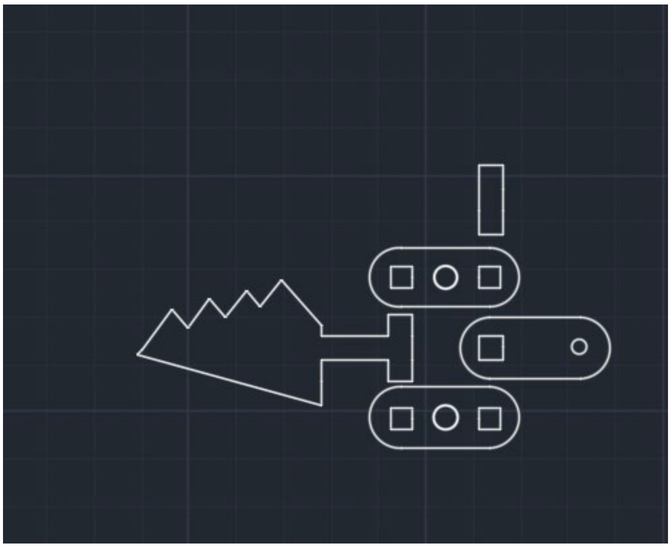
These parts were then laser-cut and assembled. The first set of plates worked very well, but the smaller radius of the second set of plates meant that the interference slots did not have enough space from the edge of the MDF and would split when tried to be fit together. This iteration of the tapered tail was a failure. Additionally, all the interference fits being slotted near the bottom of the piece meant that they were not held together vertically very well.

The next iteration used a similar concept as used in the first set of plates for the larger radius plates, but the smaller plates were to be fit together using a separate key piece attached to the plate with a bolt, with the reasoning that the smaller pieces would only need an interference fit at the bottom and not need to be fit with the other pieces. This resulted in a needed redesign of that the baseplate and each tail as well as the design of this new ‘key’ piece.





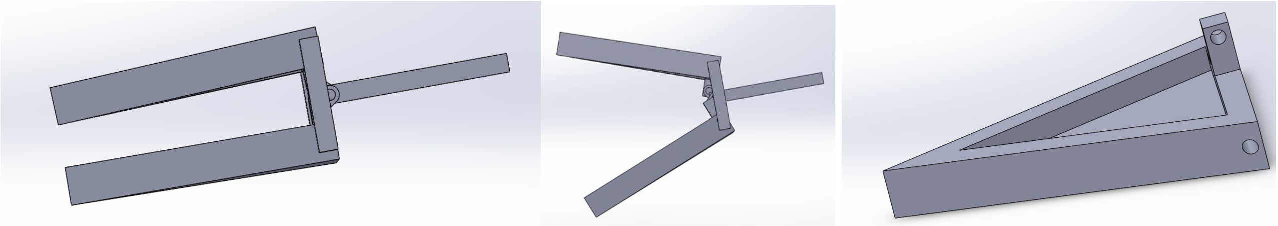
This design worked much better and was used in the final product. Each plate was assembled with their corresponding tail plates. Then it was time to design the tail mechanism, which very late into the design we decided it could double as a power on/off switch as an aesthetic enhancing choice. The tail would need to be able to rotate around an axis and trigger an electric switch.



This design was cut from 6mm MDF, to be fit together using an interference fit with .5mm smaller slots, and a central 6mm hole for the tail to fit an axis of rotation through. The end piece had a 3mm hole to place the electric switch inside and the aesthetic tail was reminiscent of a spiked lizard tail, on a 15-degree rotation to be parallel to the ground once the lizard was tilted. The bottom plate had a 5mm hole placed to screw an M5 bolt through to serve as an axis of rotation for this switch mechanism.

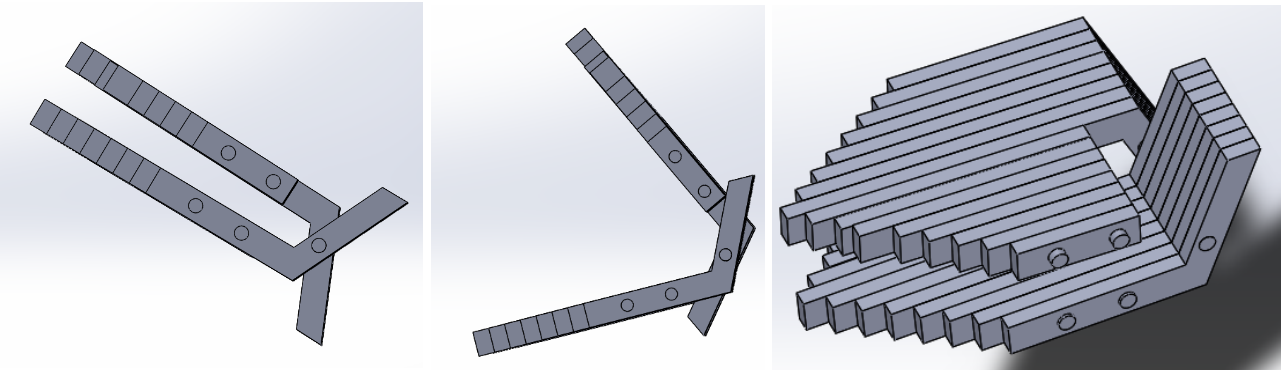
3. The Mouth:

Constructing the opening mouth proved to be one of the most difficult parts of our design process. We went through several different designs before we settled on the best option. Our original goal was to make both the top and bottom parts of the mouth open and close with the frill.



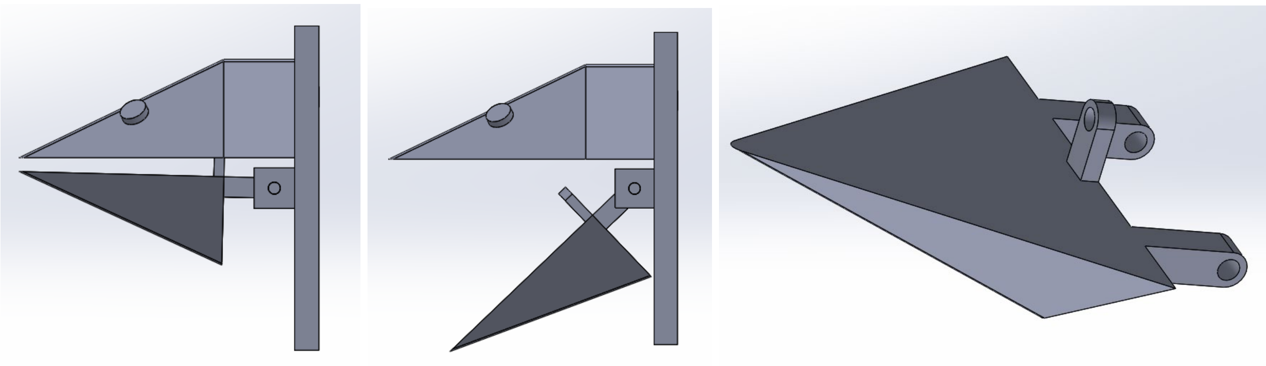
Design #1: The mouth closed (left), open (middle), and bottom jaw

This first design used a push-bar attached to the same rack that opened the frill. When the rack moved forward, opening the frill, the mouth would open. This ultimately was too complicated, so we started looking at ways to modify the design.



Design #2: The mouth closed (left), open (middle), and an additional view showing the design

This design was a lot simpler in terms of its mechanism and was also space efficient. However, since we wanted to make the mouth out of laser-cut MDF to save time, we also struggled designing the jaws to consist entirely of 2-dimensional components. In addition, the push-bar for this mechanism would have to be forked and it would be challenging to line it up in the right spot for both the mouth parts to open evenly. In the end, the whole concept of the push-bar seemed too complicated and would require severe modifications to the rack and face that we had already designed.



Design #3 (Final design): Mouth closed (left), open (middle), and bottom jaw (right)

In our third and final design, we did away with the push-bar entirely and decided to 3D print the mouth parts to simplify their design. We also decided that making both parts of the mouth open was too complicated. We fixed the top part to the face, only allowing the bottom part to rotate. We plan to run a string from the tab on the lower jaw through the face and fix it to the rack. As the rack moves forward, opening the frill, it allows the jaw to lower. As the rack moves backward, closing the frill, the string pulls the mouth back up. Changing our design expectations from the two moving parts to just one, in addition to switching from MDF to 3D printed, allowed us to come up with a much simpler design that was easier to implement and could be prototyped on its own without affected the other mechanical parts of our lizard.

4. Electronics:

Our project has the gyroscope MPU6050 which was reused from the project in the past. The first prototype test on the MPU6050 was to assure it is connected to Arduino and can detect motion. The prototype test below will print out in the Serial Monitor the acceleration and angular speed when the MPU6050 detects the motion (the code is adopted from the example of the library which is in the [Appendix Coding Section](#)).

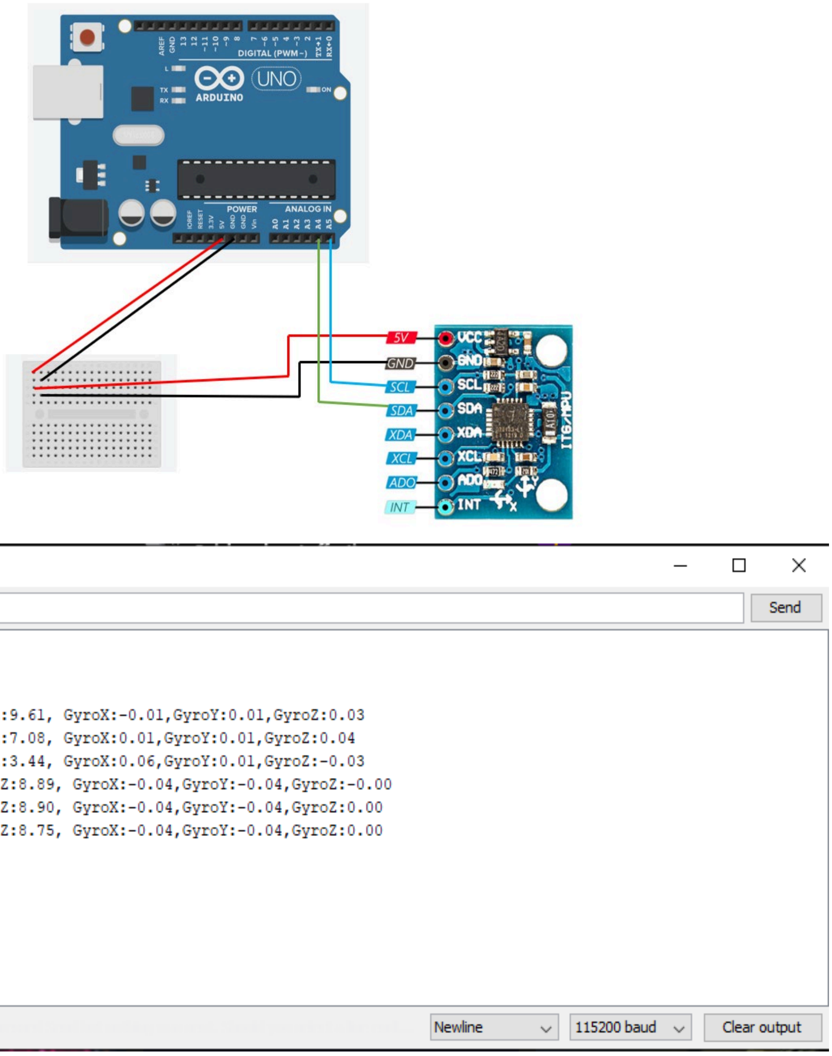


Figure 9: Circuit diagram and output on the prototype test for the MPU6050

When the MPU6050 successfully detects the motion, the next prototype test is that the code gives the exact interactivity for our pet. The interactivity is that the servo will rotate to the angle to open the frill when the motion is detected and rotate to the angle to close the frill after 5s without motion. The output on the Serial Monitor gives the desired interactivity for our pet. Moreover, our project used the Ramp library which will produce a ramp signal from the current position to the target position. By writing this signal to the servo, the servo will rotate smother than using normal writing an angle which will suddenly apply a force to our system. After this prototype test for the electronics, the electronics part is ready for the testing of our pet (this code and flow chart for this prototype test are the same as the final design for the pet).

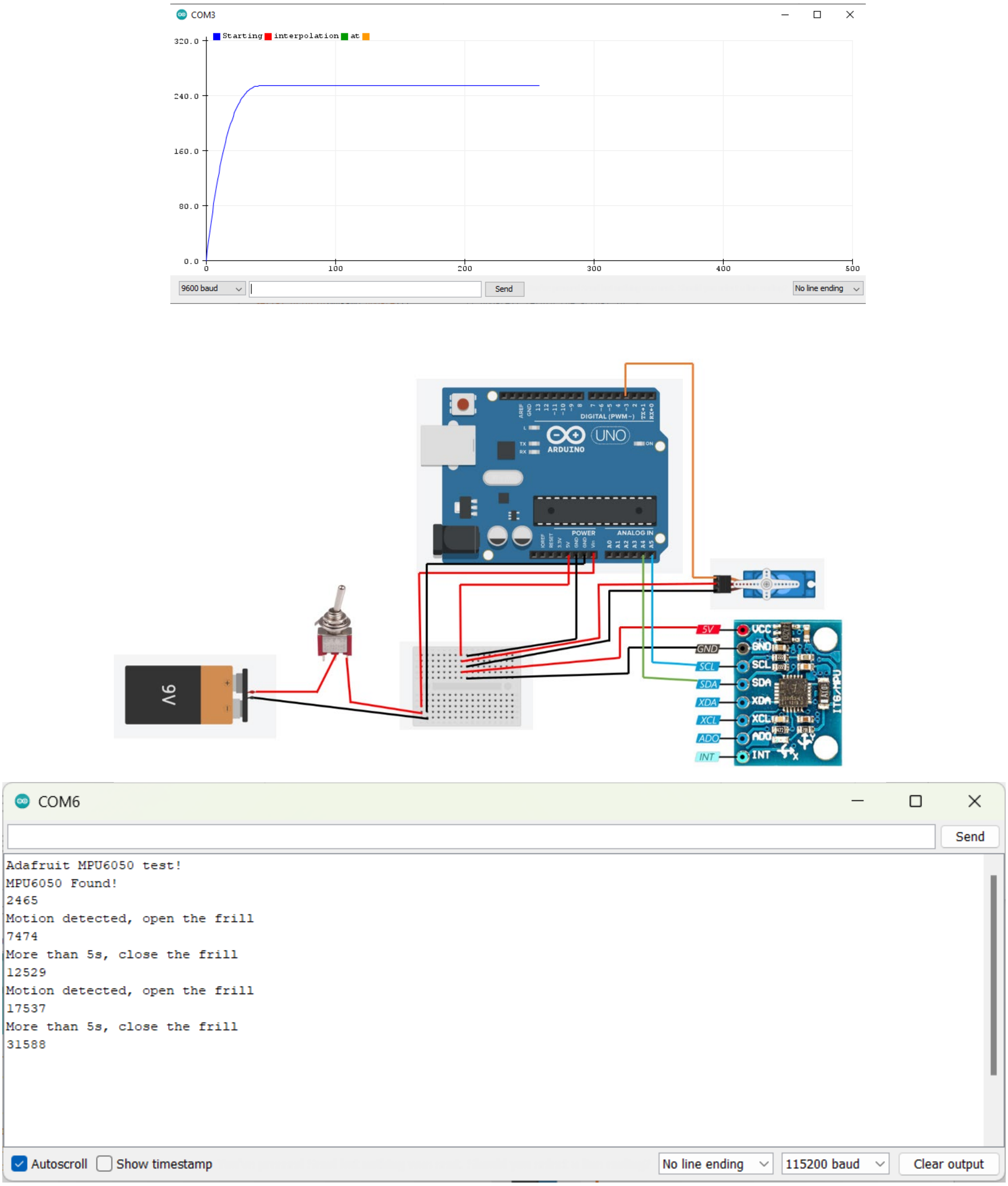


Figure 10: Circuit diagram and output on the prototype test for the interaction.

After we had both of electronics and the mechanical part of the pet were tested, we connected all of the parts together to form our pet for final testing with the pet. During the final testing, we observed that waiting for 5 seconds to fold the frill was too long and we changed it to 3 seconds for the final design. Moreover, it was significant to have a LED to indicate whether it is on or off. Therefore, the final circuit will be demonstrated below.

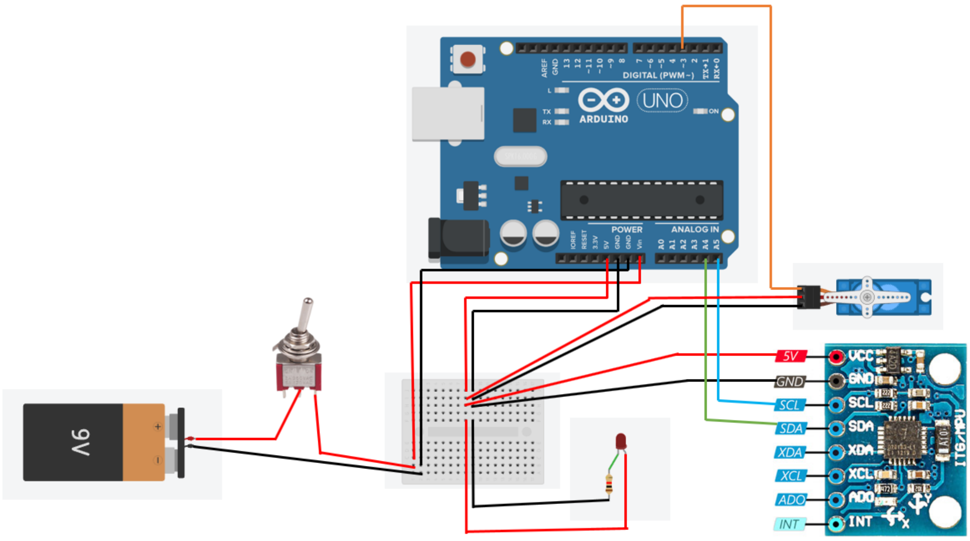


Figure 11: Finial circuit for the pet

Mechanical:

The main mechanical part of our Pet is the rack and pinion system to push out the lizard's frill. The problem was aimed to solve is that the rack and pinion system can provide enough force to push out the frill and can withstand the tension on the string. In order to analyze the forces acting on the motor, we modelled our system as if it were perpendicular to the ground, to maximize the load. First, we analyzed the upper linkages at full extension, as shown in figure a).

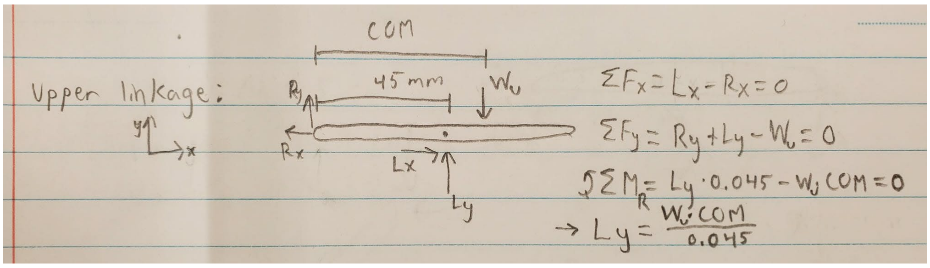


Figure a) FBD of Upper linkages and relevant equilibrium equations.

Next, we looked at the forces acting on the lower linkage that connects the upper linkages to the lower face, as shown in figure b).

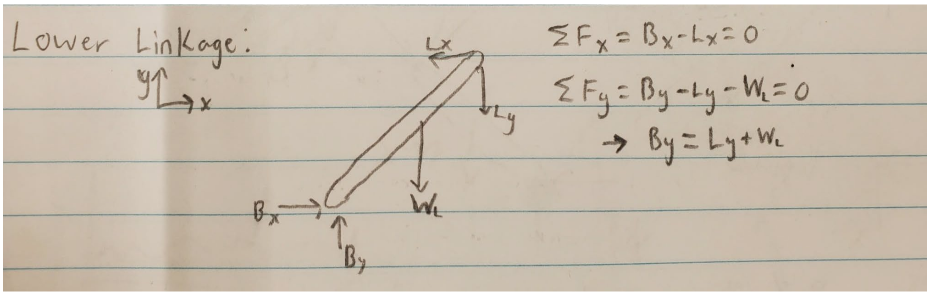


Figure b) FBD of Lower linkages and relevant equilibrium equations.

We also accounted for the tension in the string holding the mouth in position (shown below), which is connected to the same rack as the opening frill.

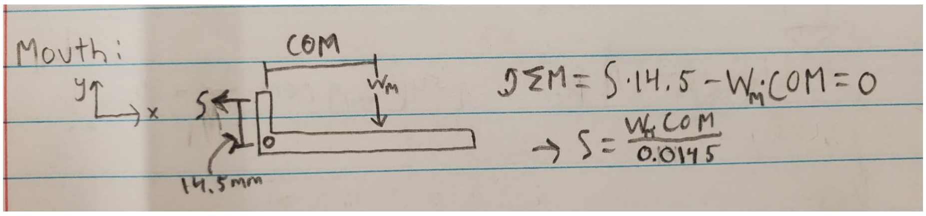


Figure c) FBD of Mouth and relevant equilibrium equations.

Finally, we analyzed the bottom face (figure d), which supports all the other elements in the system. By is multiplied by 4 in the equations because there are 4 sets of linkages that all connect to the face.

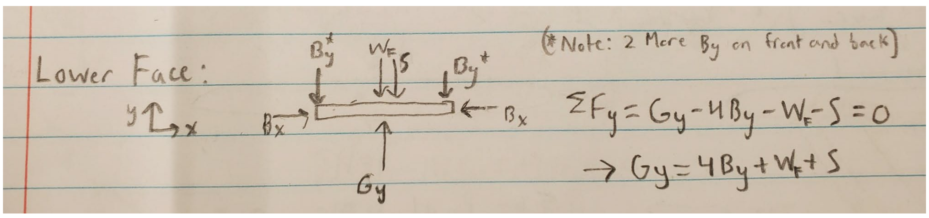


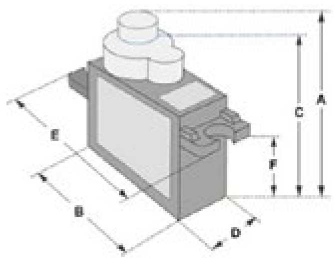
Figure d) FBD of the Lower face and relevant equilibrium equations.

Written as a single equation that takes the entire system into account, the total force required to be supplied by the motor is:

$$F_{total} = M_{Face}g + 4\left(\frac{M_{upper}g * COM_{upper}}{0.045} + M_{lower}g\right) + \frac{M_{mouth}g * COM_{mouth}}{0.0145}$$

When plugging in measured values for the mass and COM of each part, the total force = 1.018 N. This is our theoretical calculation so we multiply this force by 5 times and let this value as the willing force which the servo must provide. This value will be the input value as the willing force in the code mentioned in the Appendix Mechanical Section.

After having the willing force which the rack and the pinion should satisfy, we need to make decisions for the parameters of the pinion which are the number of teeth, the tooth system, and the radius of the pinion. Before choosing those parameters, we need some constant values as constraints for the rack and pinion system such as the torque of the servo and the minimum number of teeth on the pinion for avoiding interference. The torque of the servo can be accomplished from the datasheet of the 90G servo and the minimum number of the teeth on the pinion can be obtained by letting the teeth ratio become infinity in the interference equation since the number of teeth on the rack is modelled as infinity.



Dimensions & Specifications
A (mm) : 32
B (mm) : 23
C (mm) : 28.5
D (mm) : 12
E (mm) : 32
F (mm) : 19.5
Speed (sec) : 0.1
Torque (kg-cm) : 2.5
Weight (g) : 14.7
Voltage : 4.8 - 6

$$N_{P_{min}} = \frac{2k}{(1+2\xi)\sin^2\phi}\left[\xi + \sqrt{\xi^2 + (1+2\xi)\sin^2\phi}\right]$$

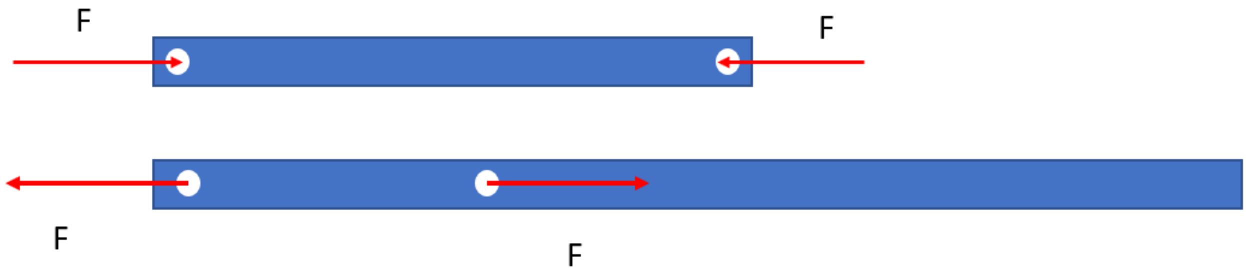
$$\lim_{\xi\to\infty} \frac{2k}{(1+2\xi)\sin^2\phi}\left(\xi + \sqrt{\xi^2 + (1+2\xi)\sin^2\phi}\right) \approx 17$$

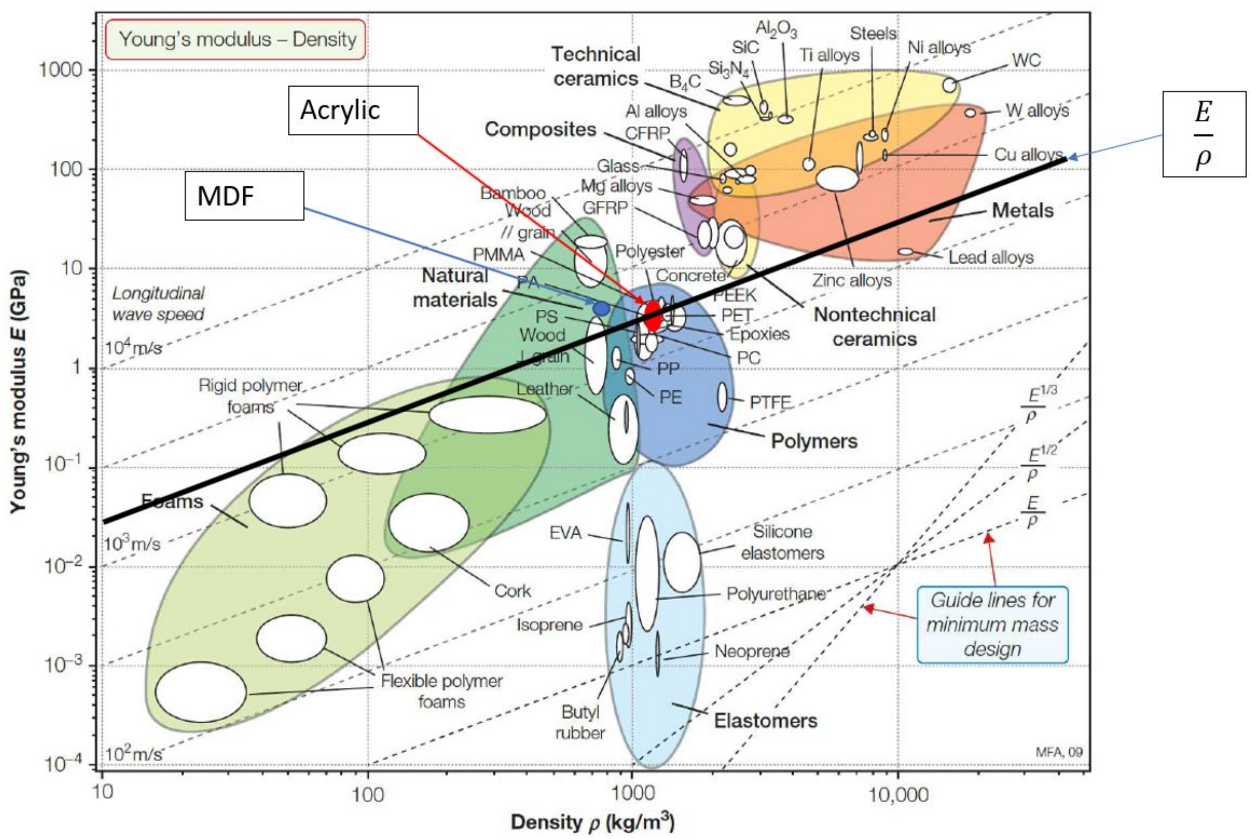
All of the input values are identified for the calculation of the gear, our decision on the gear is 32 teeth and 8cm for pitch diameter which is satisfied all of the constraints. Moreover, the minimum face width for the gear to withstand the force is 0.9323 mm. Therefore, our choice for the face width of the gear and the rack is 12mm which will help us easier when lining up the rack and the gear in the future.

Material Selection:

1. Material selection for linkages and spokes

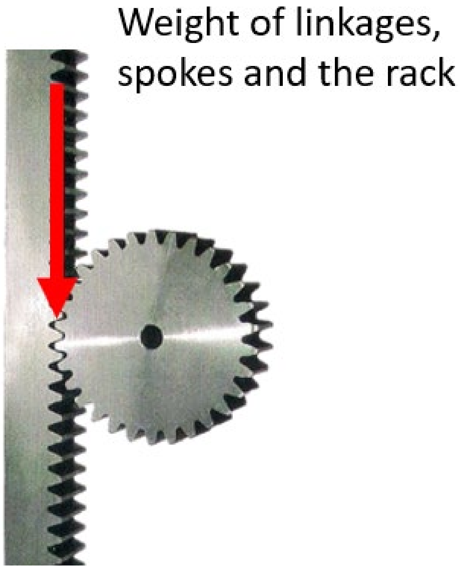
For our design, the linkages and the spoke will be modelled with the compression and tension force which is the same as the model demonstrated in the lecture for the loaded bar with the static load. For the constraints of the linkages and spokes, we want them to have minimum weights and their material has to have better performance among available materials in TCS which is MDF and Acrylic. Therefore, the material performance index which we have to look up in Ashby's chart is $\max(\frac{E}{\rho})$. By comparing the available materials with the $\frac{E}{\rho}$ line, we decided to laser cut our linkages and spokes from MDF which is higher performance than Acrylic.

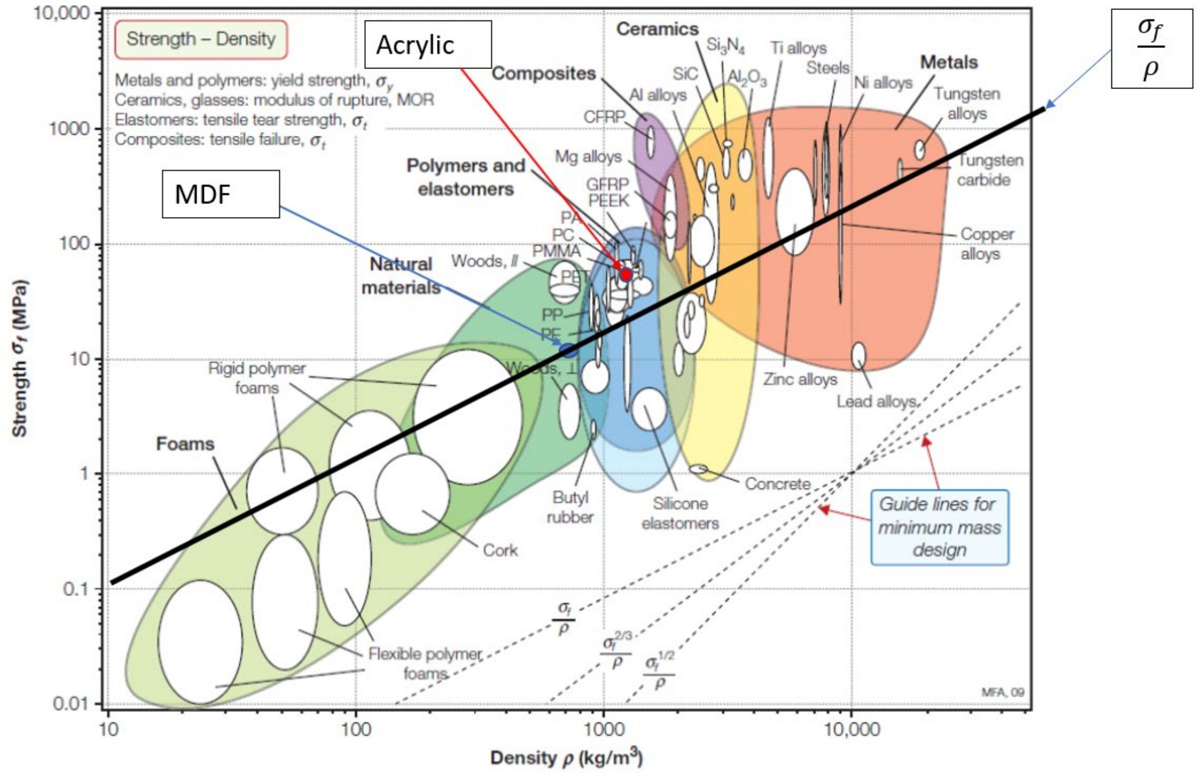




2. Material selection for gear and rack

In our design, the rack and pinion system are used for converting the rotational motion to linear motion to push out the lizard's frill. Therefore, the material selection for the gear and the rack is crucial. For our pinion, we also want it to be minimum weight and the tooth can withstand the weight of the linkages, spokes, and the rack system. From the model demonstrated in the lecture, our team has to look up the Strength – Density Ashby's chart with the performance index is max($\frac{S_e}{\rho}$). By comparing the available materials with the $\frac{\sigma_f}{\rho}$ line in the Ashby's chart, we decided to make our pinion from an Acrylic sheet which performs better than MDF.



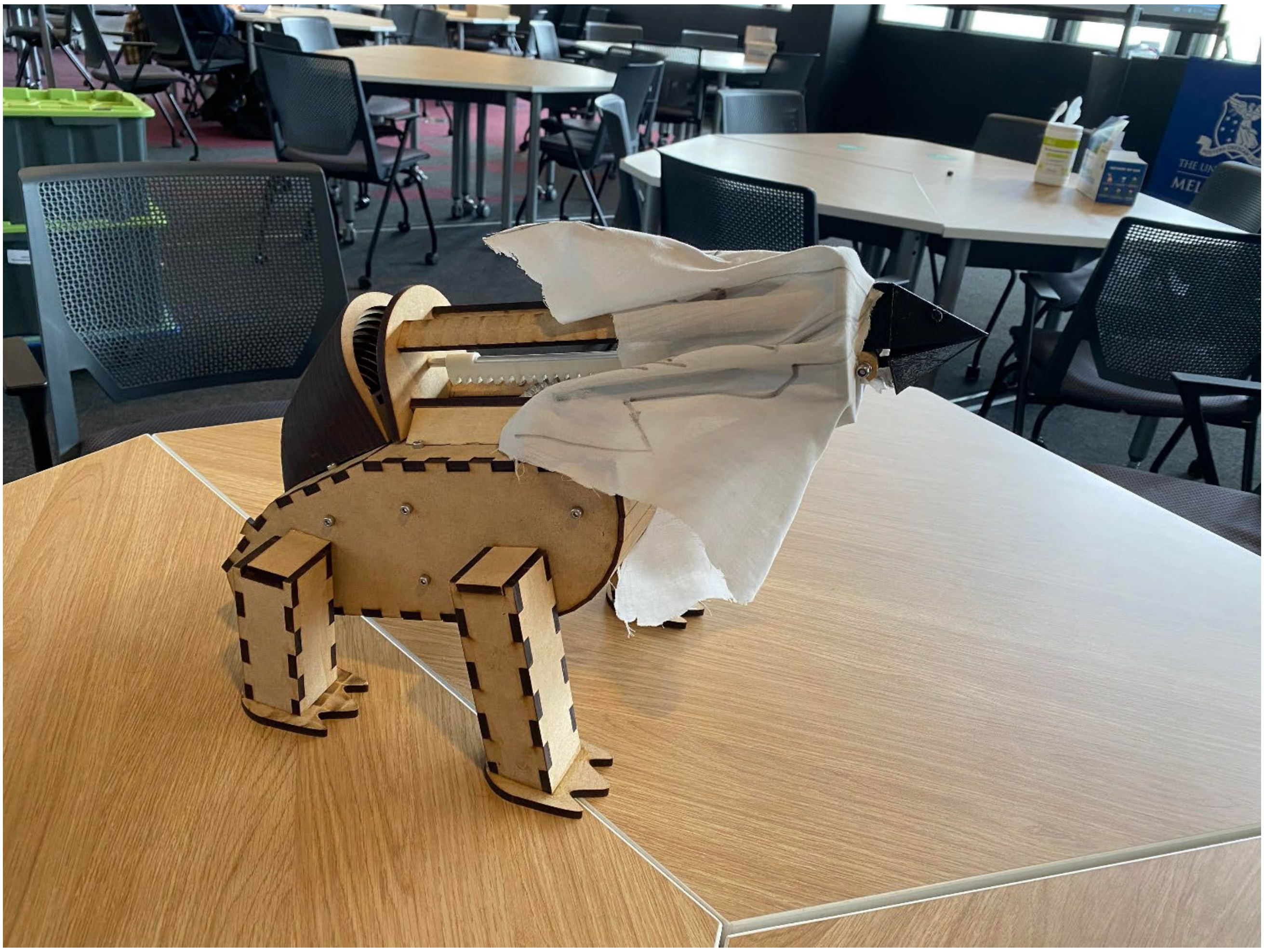


Since we decided to use 3d-printing for the rack during prototype testing, we want the rack made from a material that has a low coefficient of friction between it and the axle made from aluminium. As a result, our rack is made from PLA plastic which will have a low coefficient of friction during interaction with metal.

Final Design:

Our mechanical pet is a Frill-Necked Lizard. Just like the real animal, its most eye-catching feature is the umbrella neck frill that opens up, helping the lizard intimidate its predators. In order to imitate the actual lizard, we used a gyroscope so our pet can sense when there's danger nearby (i.e. the table is shaking). When it senses the vibrations, the neck frill pops open. The mouth is connected to the same mechanism as the frill and opens at the same time as the frill.

Isometric view, exploded view, and dimensioned drawing of the lizard:



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6	face_place	1
7	short_spoke_assem	1
8	spoke	3
9	linkage	8
10	rack_case	4
11	back_housing_1	1
12	back_housing_2	1
13	bottom_housing	1
14	side_housing	2
15	top_housing	1
16	tail15	1
17	belly_slat	11
18	arduino_stand	1
19	arduino1.stp	1
20	tail1	1
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22	tail11	1
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41	tail_support	1
42	tail23	1
43	tail25	1
44	tail26	1
45	tail27	1
46	tail24	1
47	hinge_bracket	4
48	Top of head	1
49	bottom of head	1
50	fastening_servo	1
51	servo_motor_9g_sg90	1
52	BREADBOARD-1.stp	1
53	Battery-Holder-UM-9V-1 P with battery.STEP	1
54	Gyroscope sensor	1
55	long_leg	2
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57	leg_stand	4
58	tapered_tail	1
59	SPDT-Print-Switch.step	1
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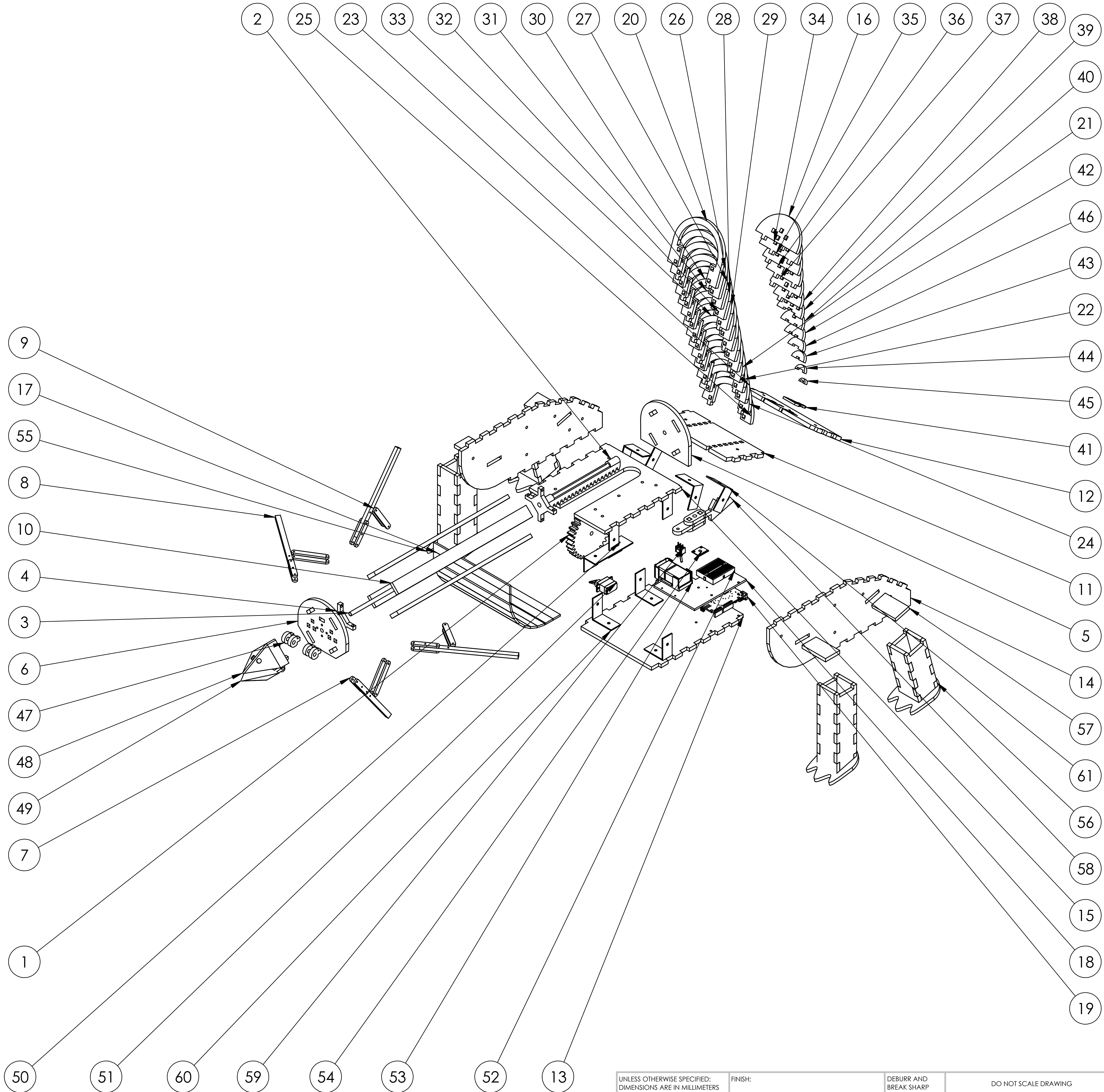
61	20-20 bracket	4



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TOLERANCES:
LINEAR:
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DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

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CHK'D			
APPV'D			
MFG			
Q.A			

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SHEET 1 OF 1

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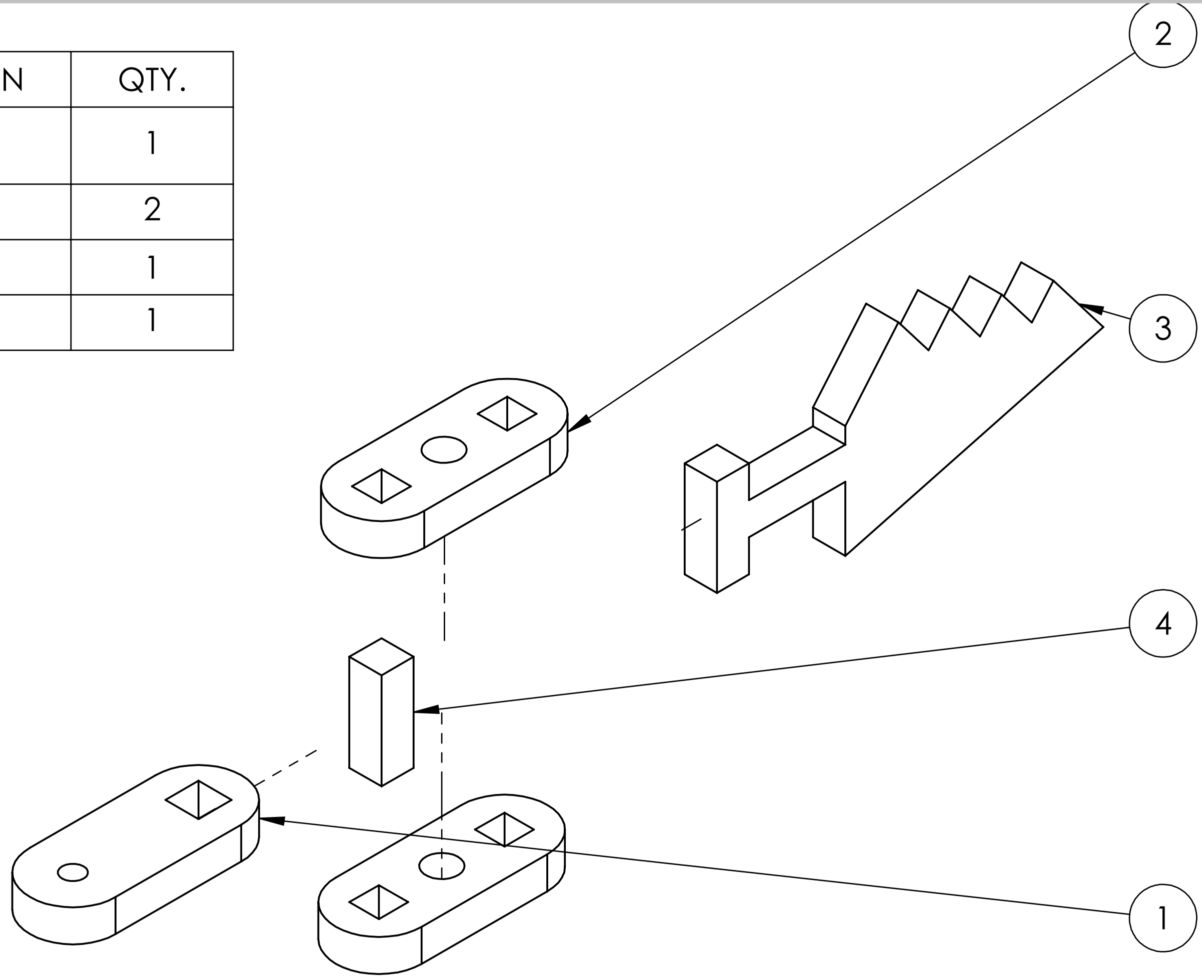

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DEBURR AND BREAK SHARP EDGES

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MATERIAL:

DWG NO.

tapered_tail_exploded

A4

WEIGHT:

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SHEET 1 OF 1

2 1

B B

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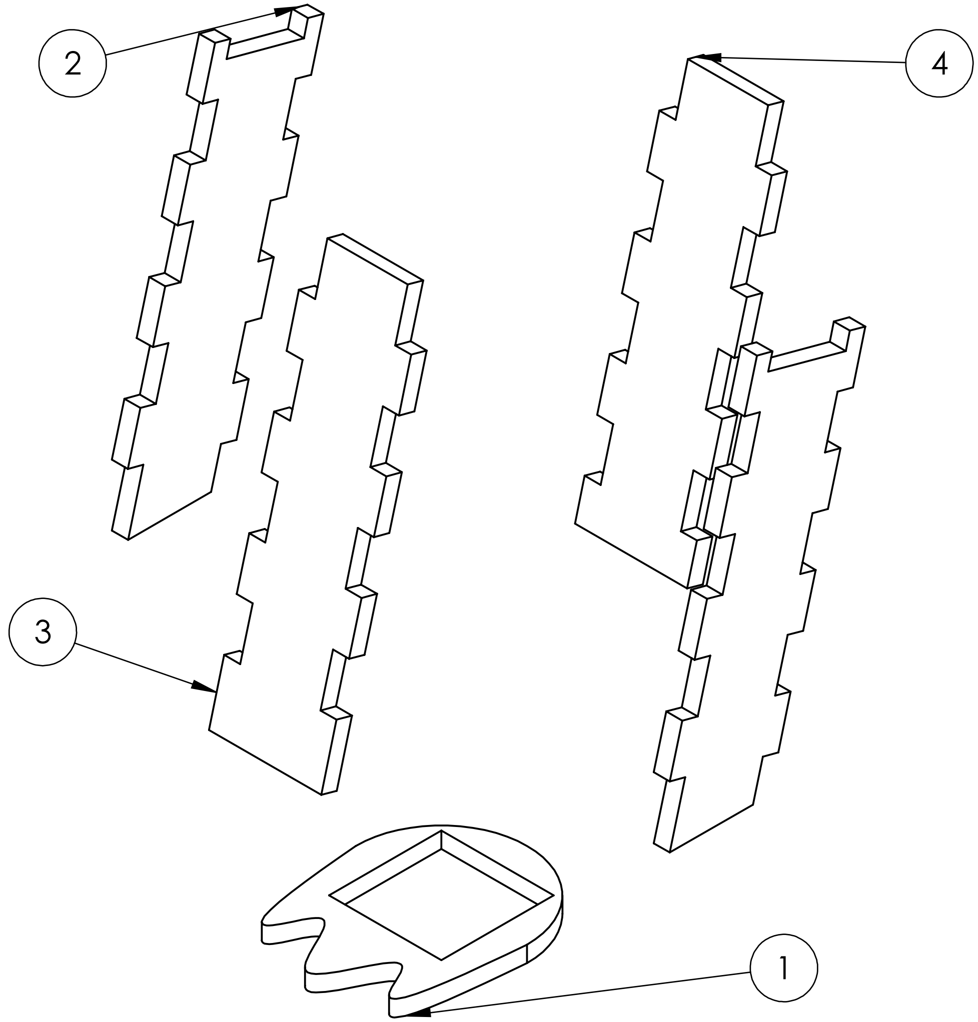

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THREE PLACE DECIMAL ±

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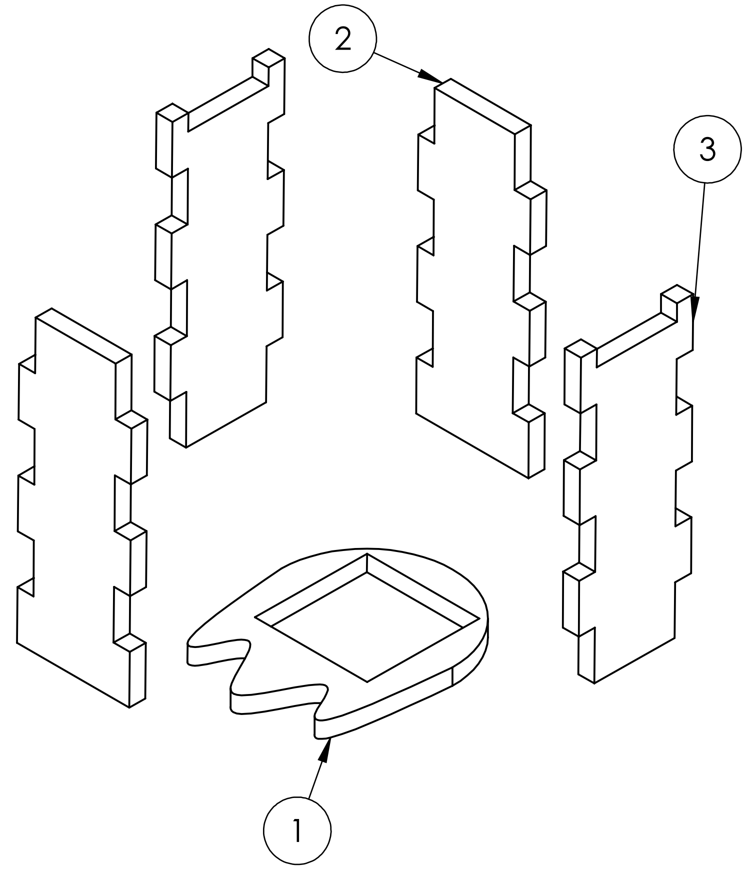

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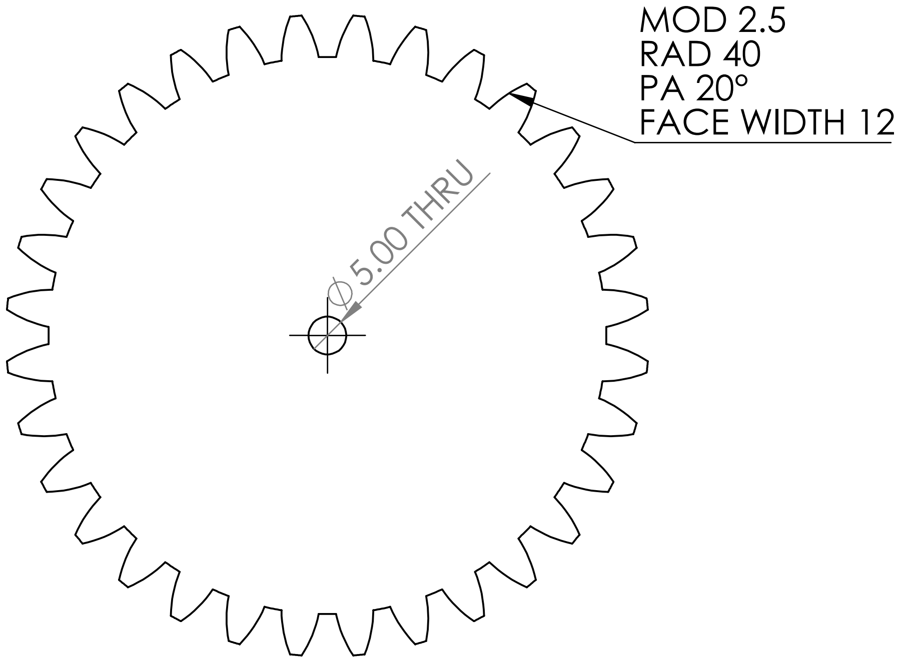

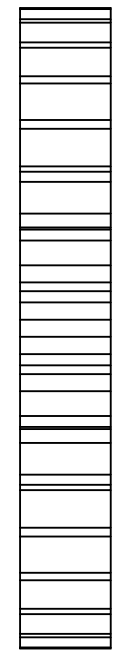

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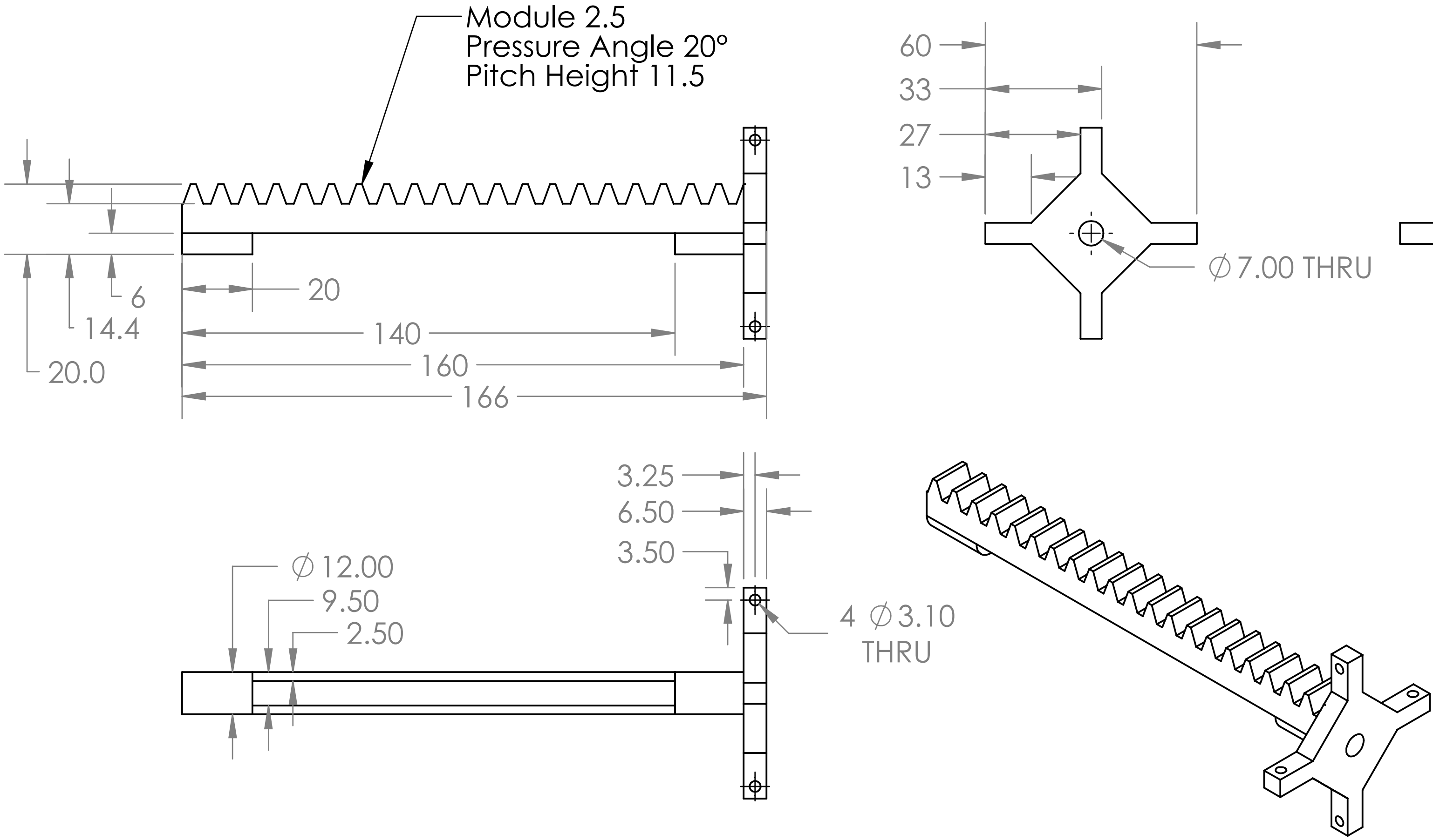

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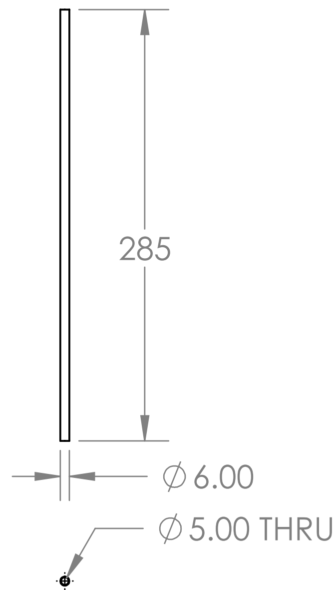

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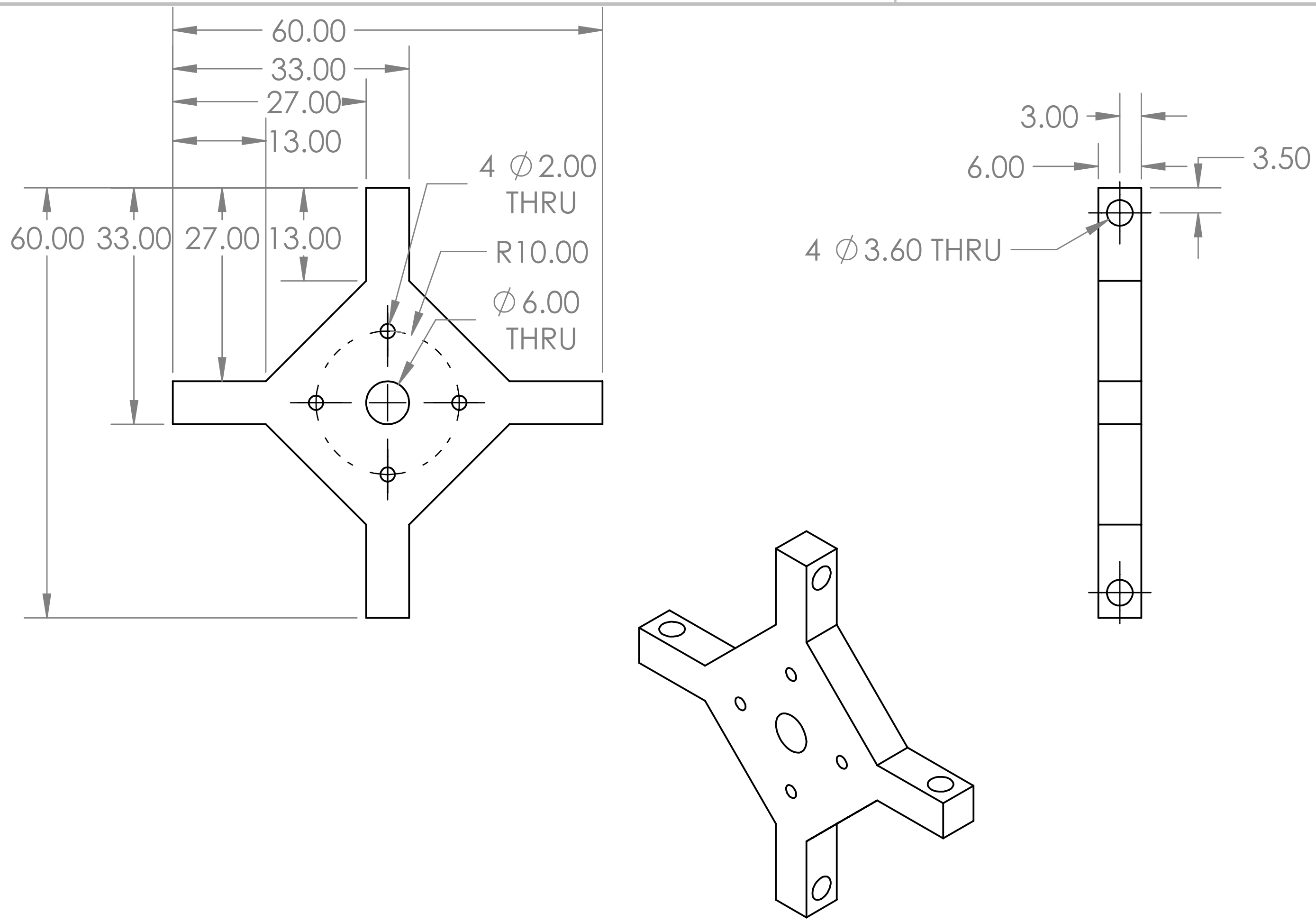

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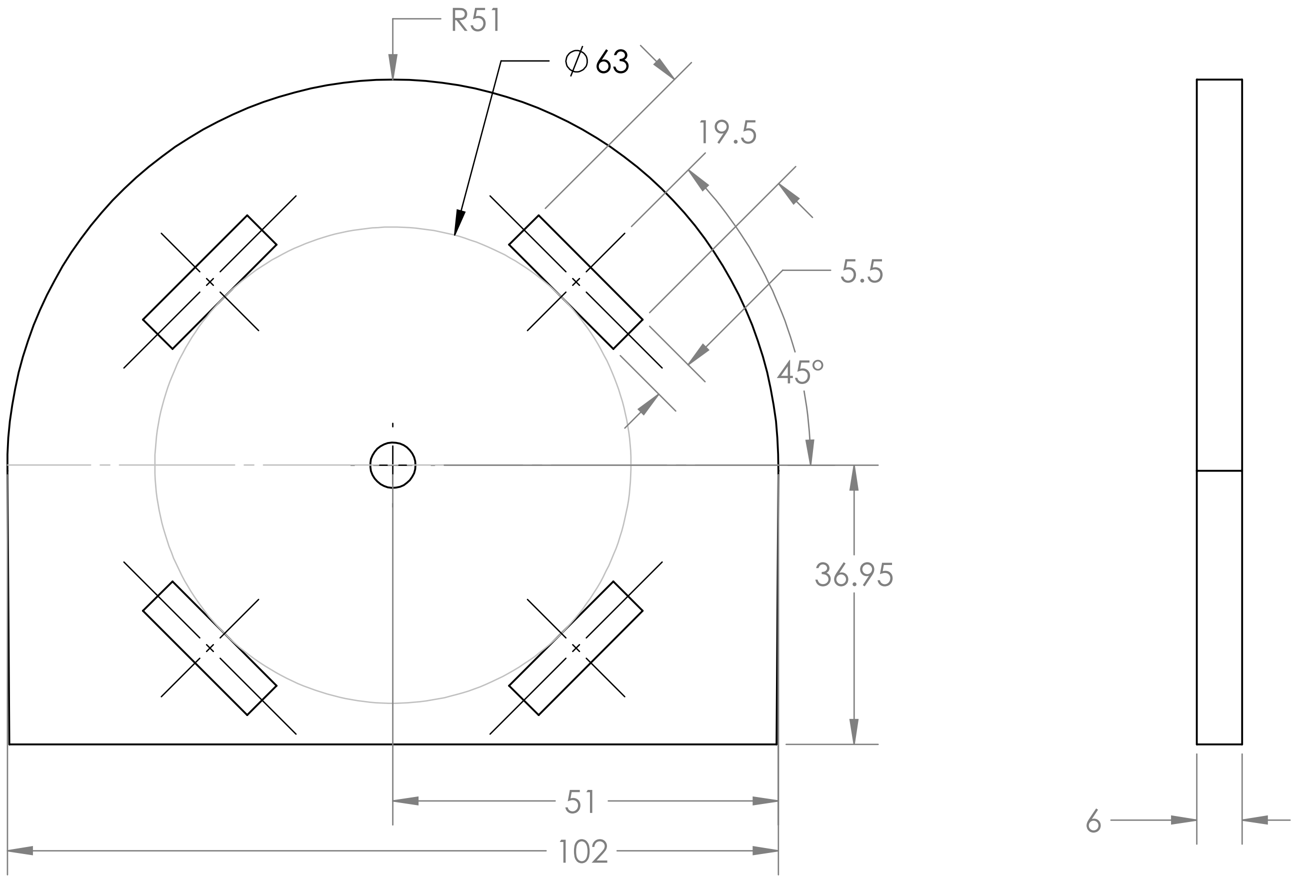

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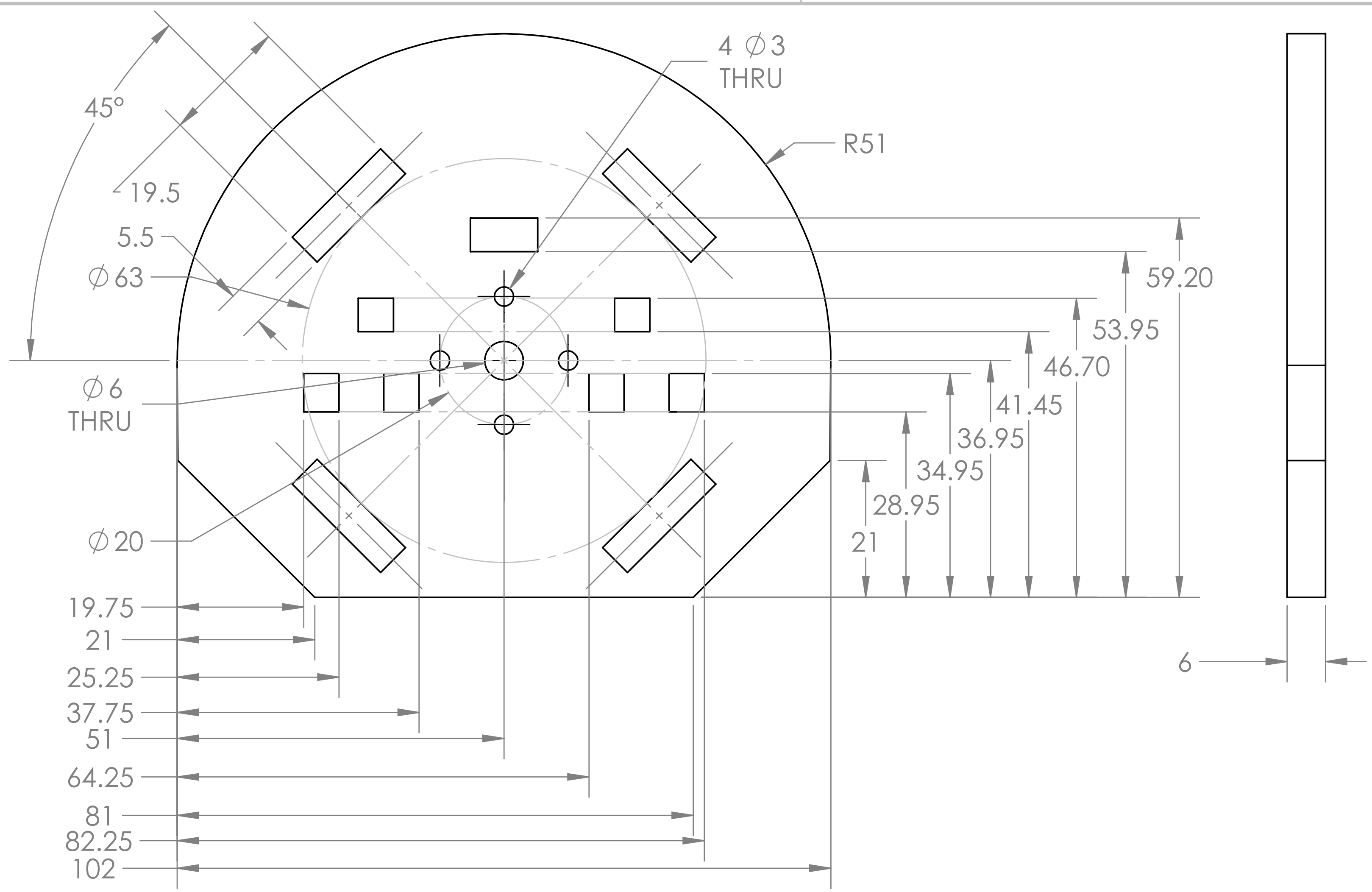

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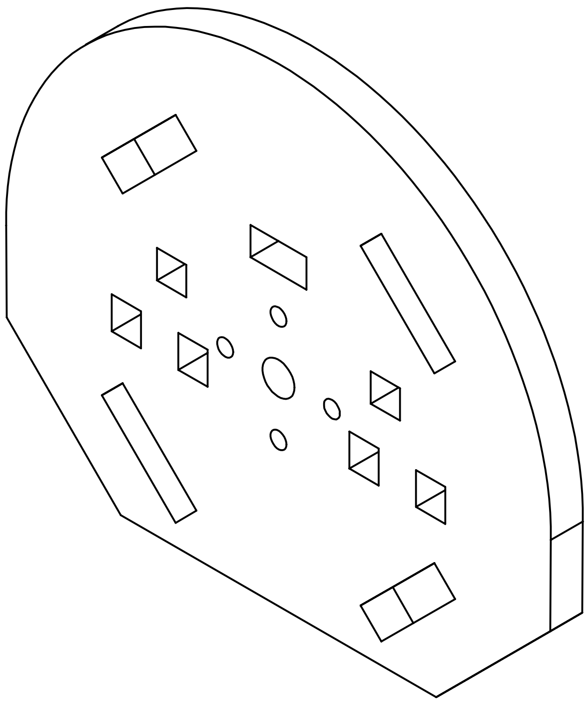
SCALE: 1:1 WEIGHT: SHEET 1 OF 2

B

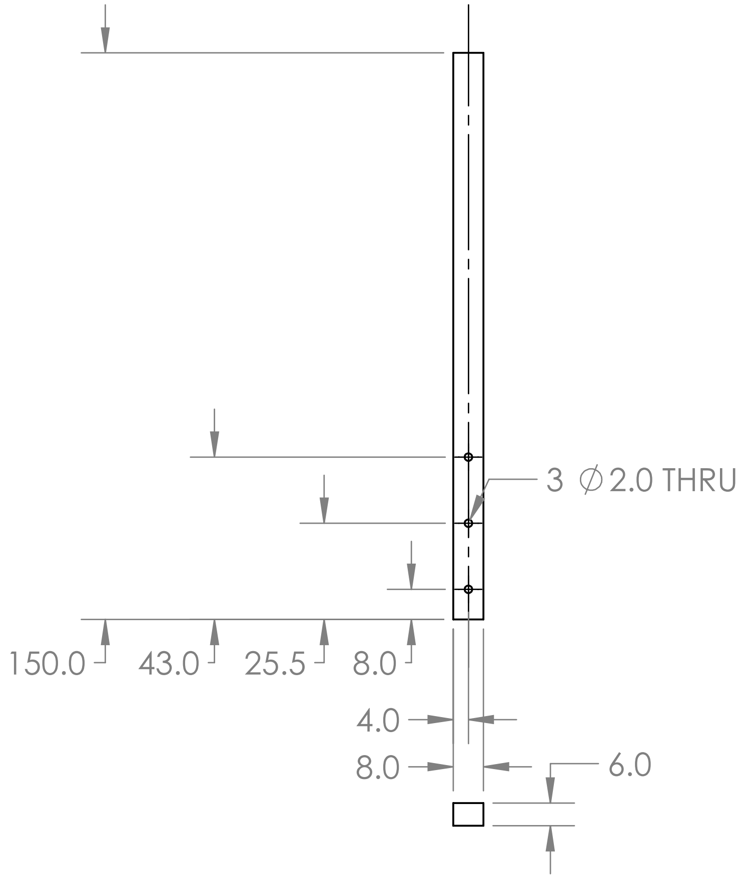


B

A

		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN			TITLE:
			CHECKED			
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL	COMMENTS:			SIZE A DWG. NO. face_place REV
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:1 WEIGHT: SHEET 2 OF 2

A



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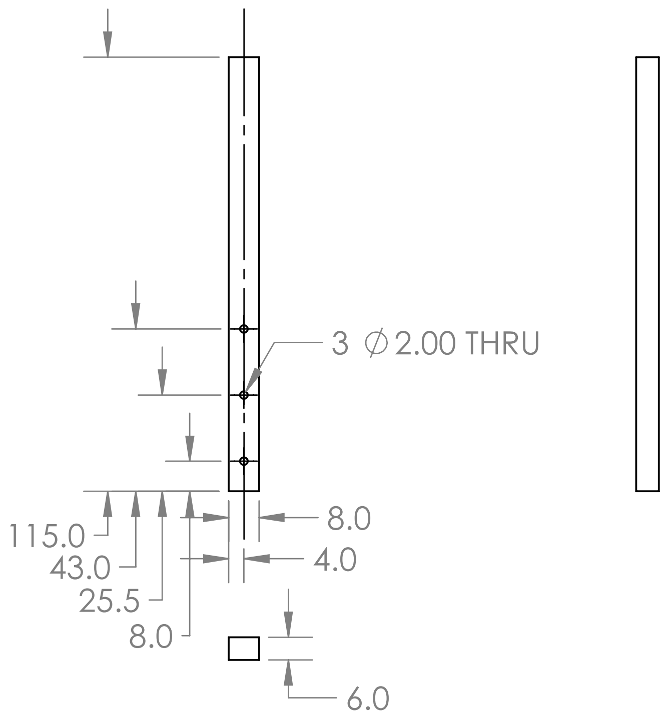
			CHECKED			
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL	COMMENTS:			SIZE A DWG. NO. long_spoke REV
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:2 WEIGHT: SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

SIZE	DWG. NO.	REV
A	short_spoke	

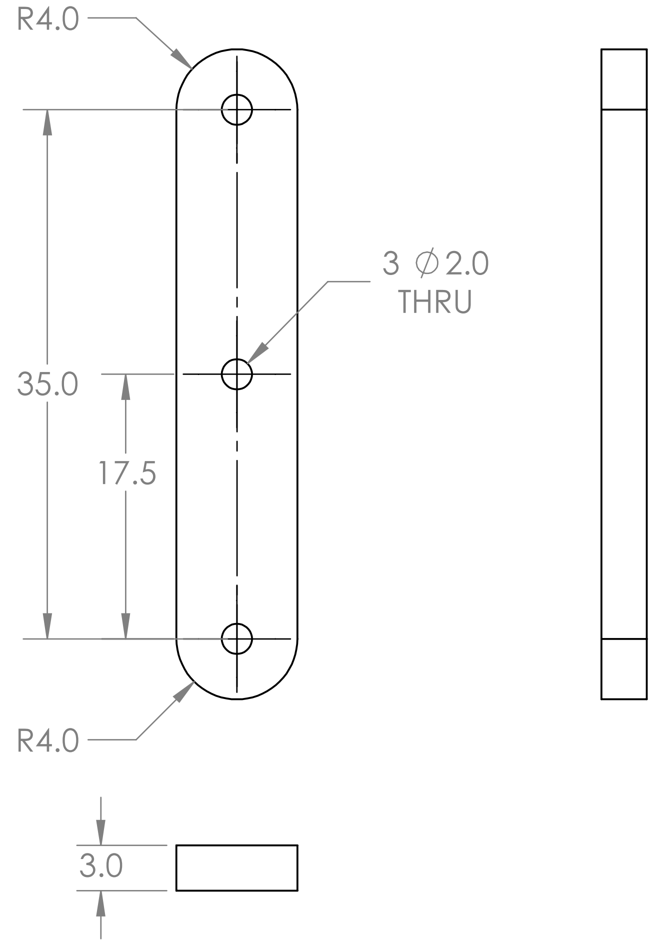
SCALE: 1:2 WEIGHT: SHEET 1 OF 1

NEXT ASSY	USED ON
APPLICATION	

DO NOT SCALE DRAWING

2 1

B B



A A

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NEXT ASSY	USED ON
APPLICATION	

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DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

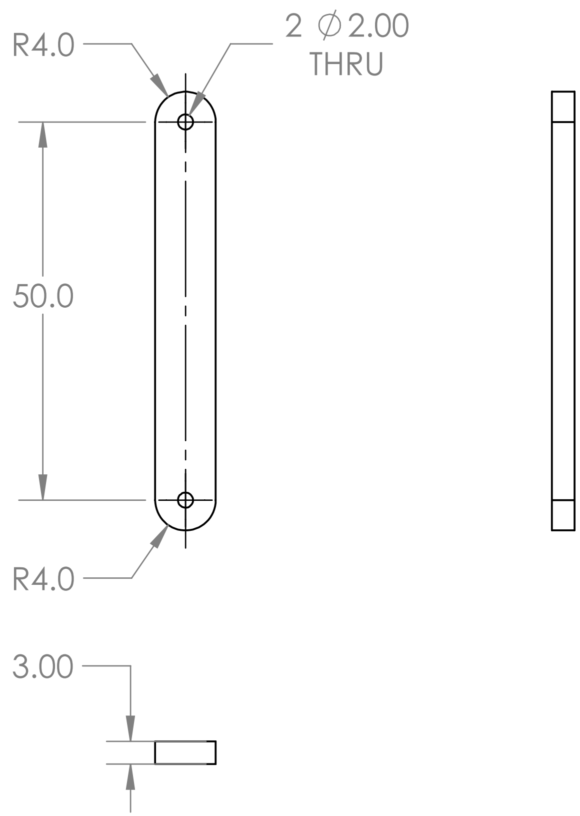
COMMENTS:

TITLE:

SIZE	DWG. NO.	REV
A	spoke_part	

SCALE: 2:1 WEIGHT: SHEET 1 OF 1

2 1



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NEXT ASSY	USED ON
APPLICATION	

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TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

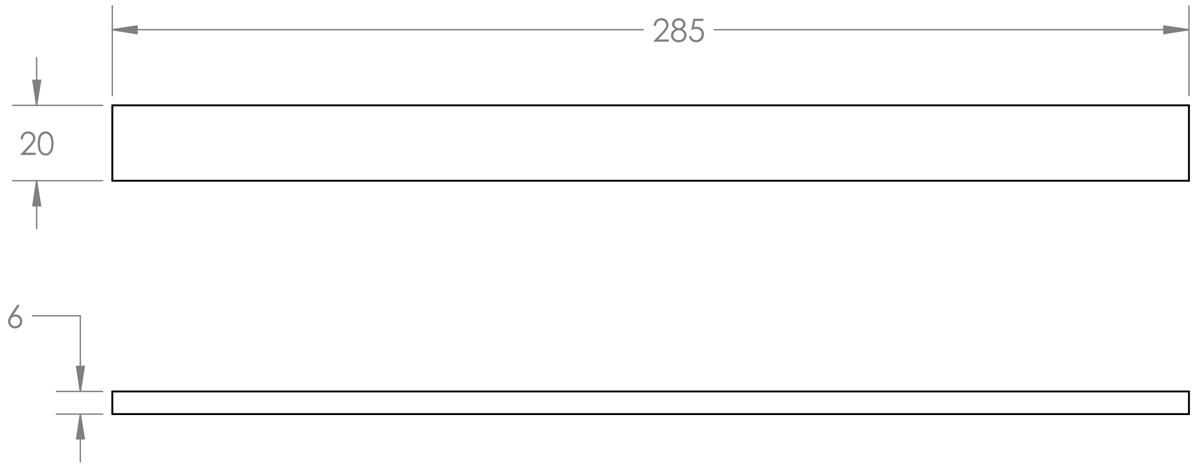
TITLE:

SIZE	DWG. NO.	REV
A	linkage	

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

2 1

B B



A A

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

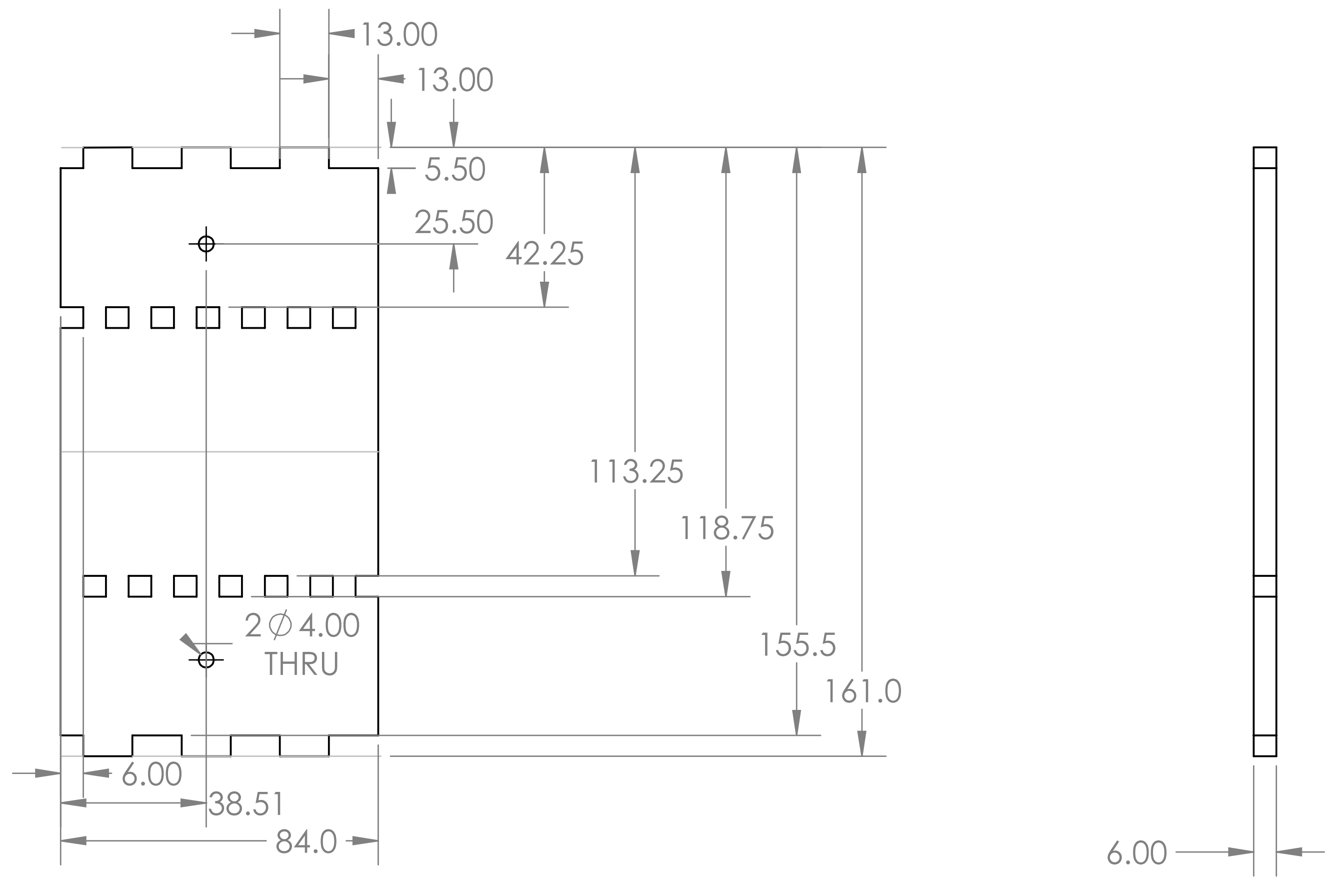
TITLE:

SIZE	DWG. NO.	REV
A	rack_case	

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

NEXT ASSY	USED ON
APPLICATION	

2 1



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UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

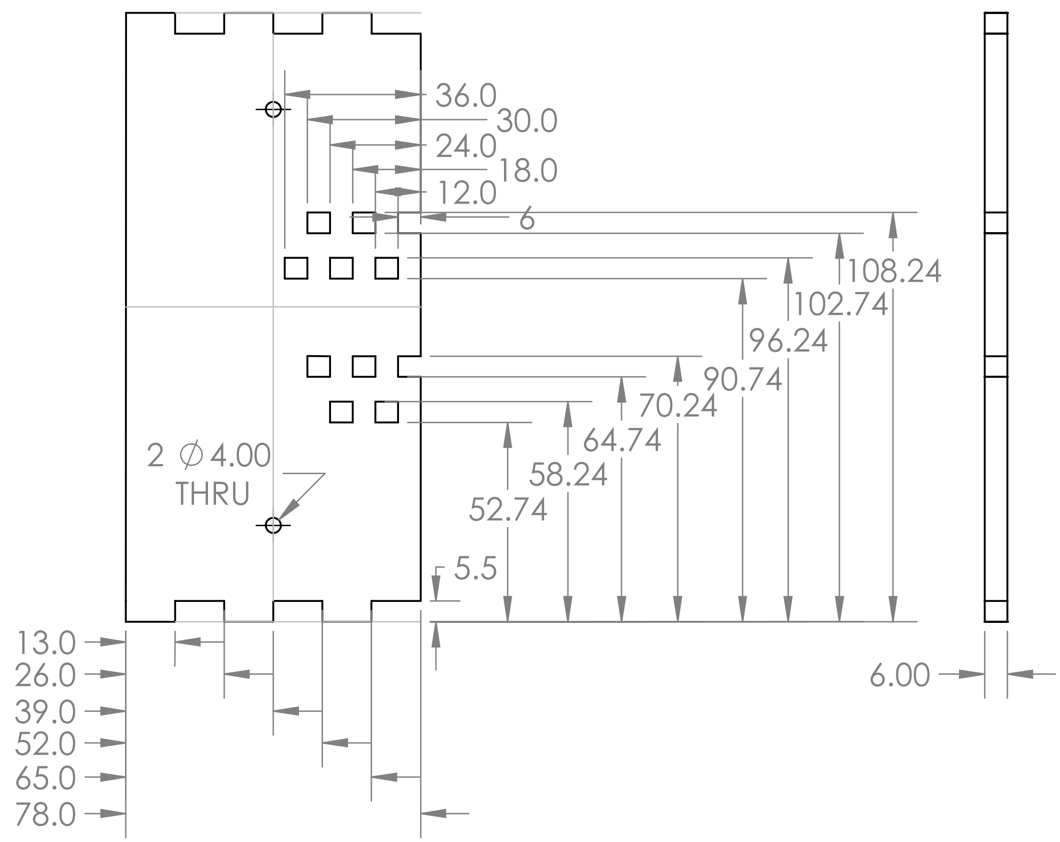
SIZE	DWG. NO.	REV
A	back_housing_1	

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

NEXT ASSY	USED ON
APPLICATION	

2 1

B B



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		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
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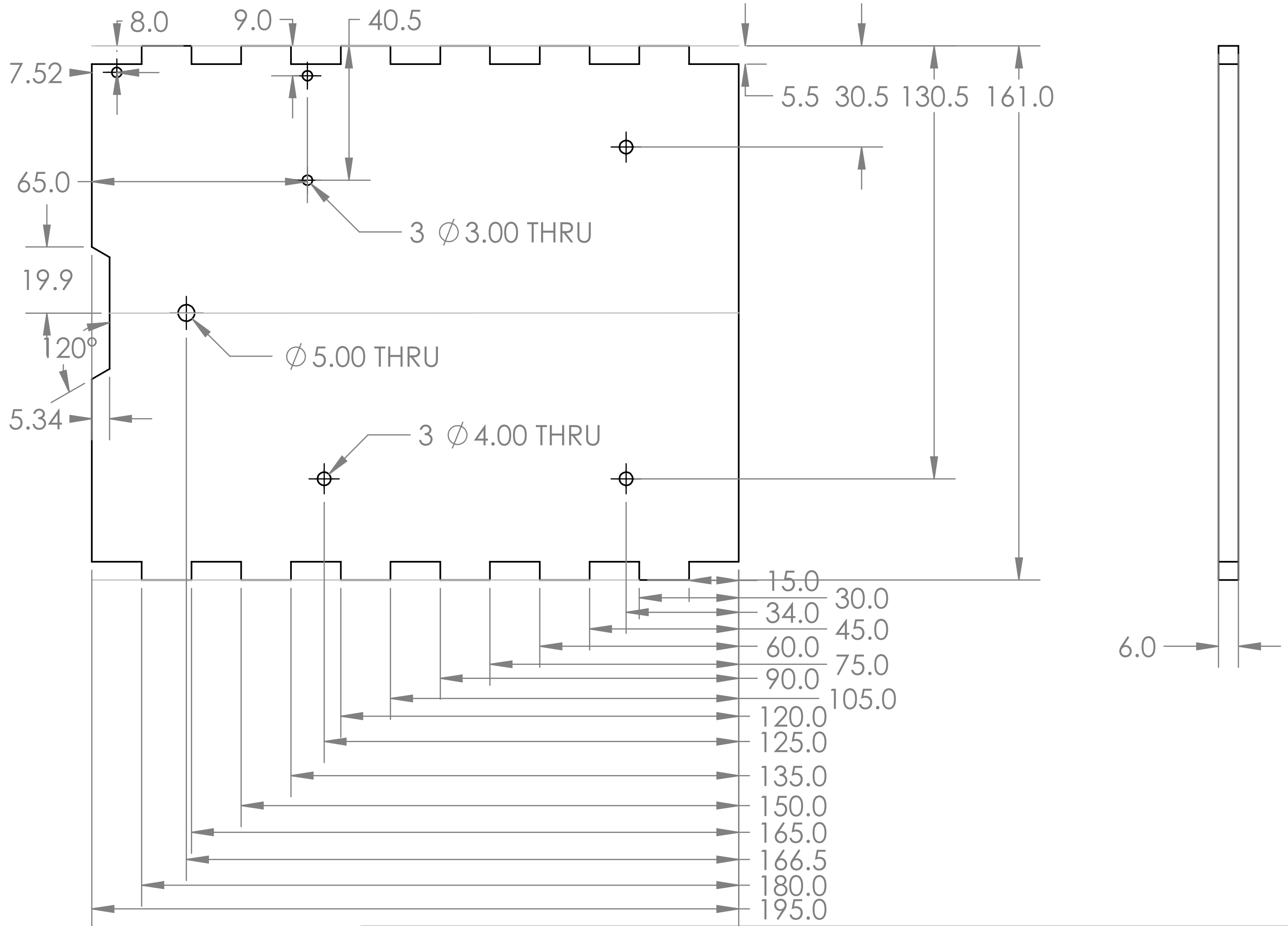
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

TITLE:

SIZE	DWG. NO.	REV
A	back_housing_2	

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

2 1



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NEXT ASSY	USED ON
APPLICATION	

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TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

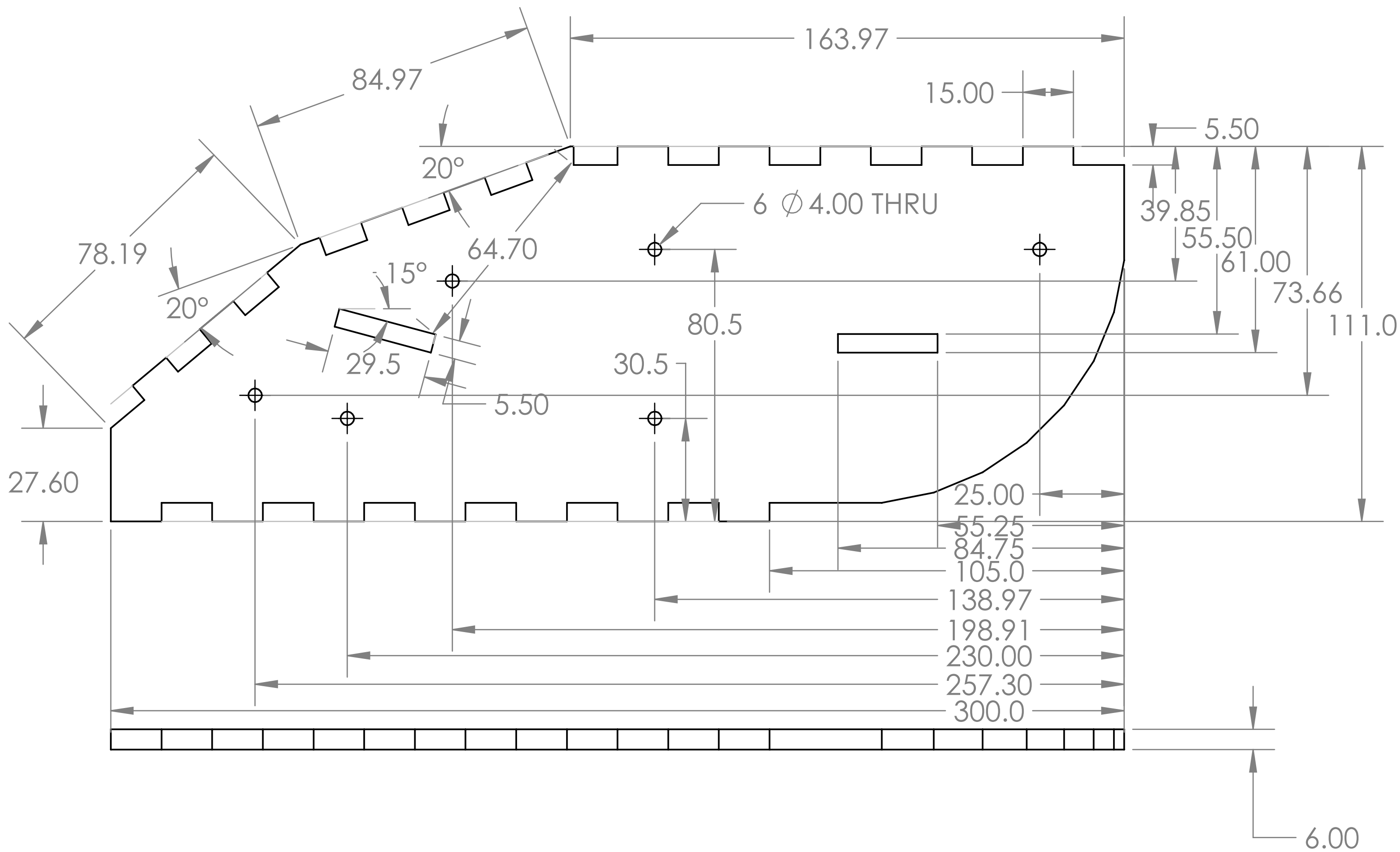
TITLE:

SIZE A DWG. NO. bottom_housing REV

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

2 1

B B



A A

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

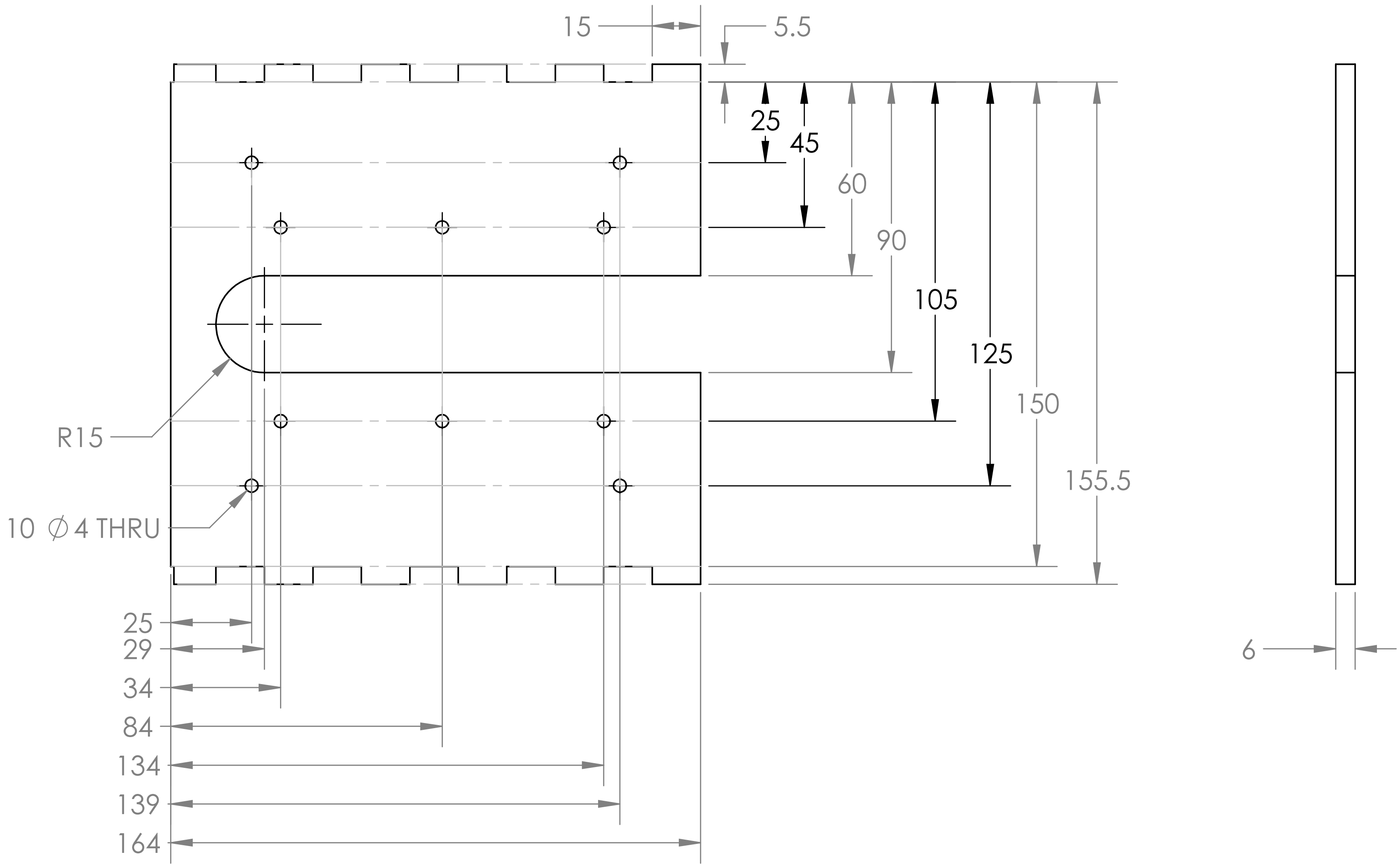
COMMENTS:

TITLE:

SIZE A DWG. NO. side_housing REV

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

2 1



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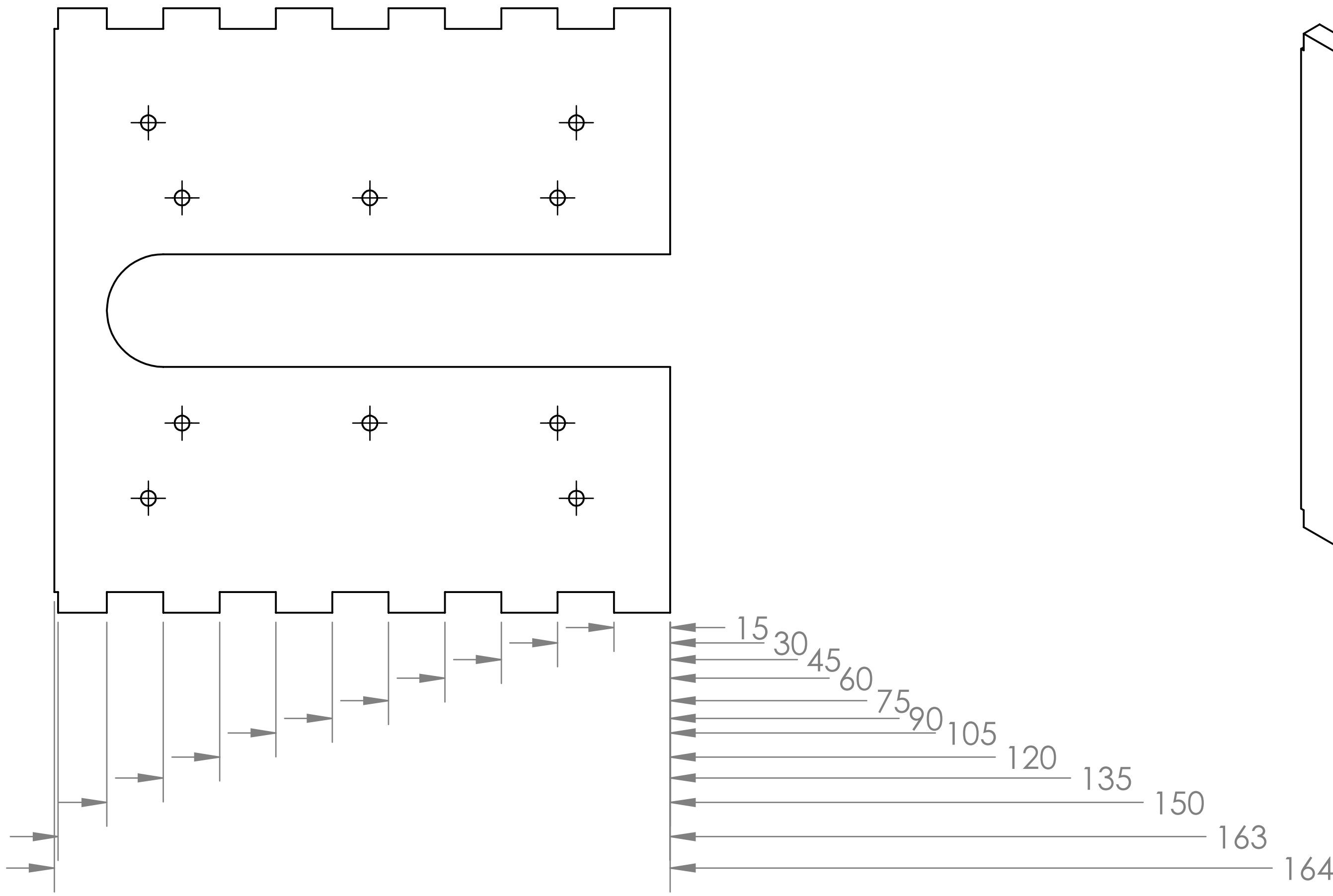
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

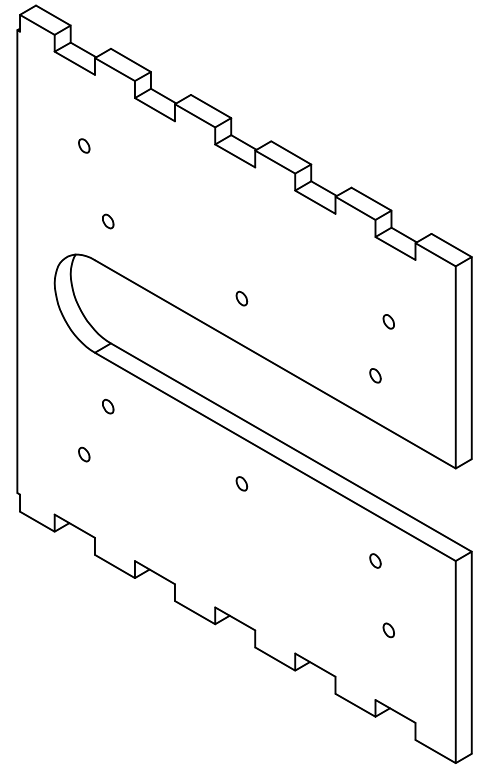
TITLE:

SIZE DWG. NO. REV

Atop_housing

SCALE: 1:2 WEIGHT: SHEET 1 OF 2





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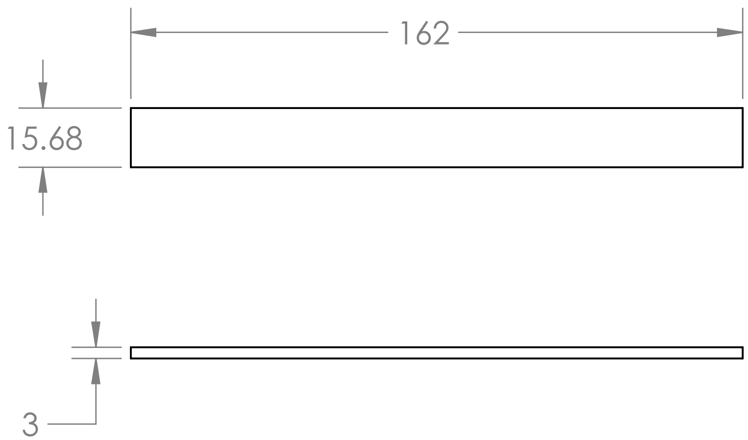
			CHECKED			TITLE:
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL	COMMENTS:			SIZE DWG. NO. Atop_housing REV
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:2 WEIGHT: SHEET 2 OF 2

2 | 1

B | B



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		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
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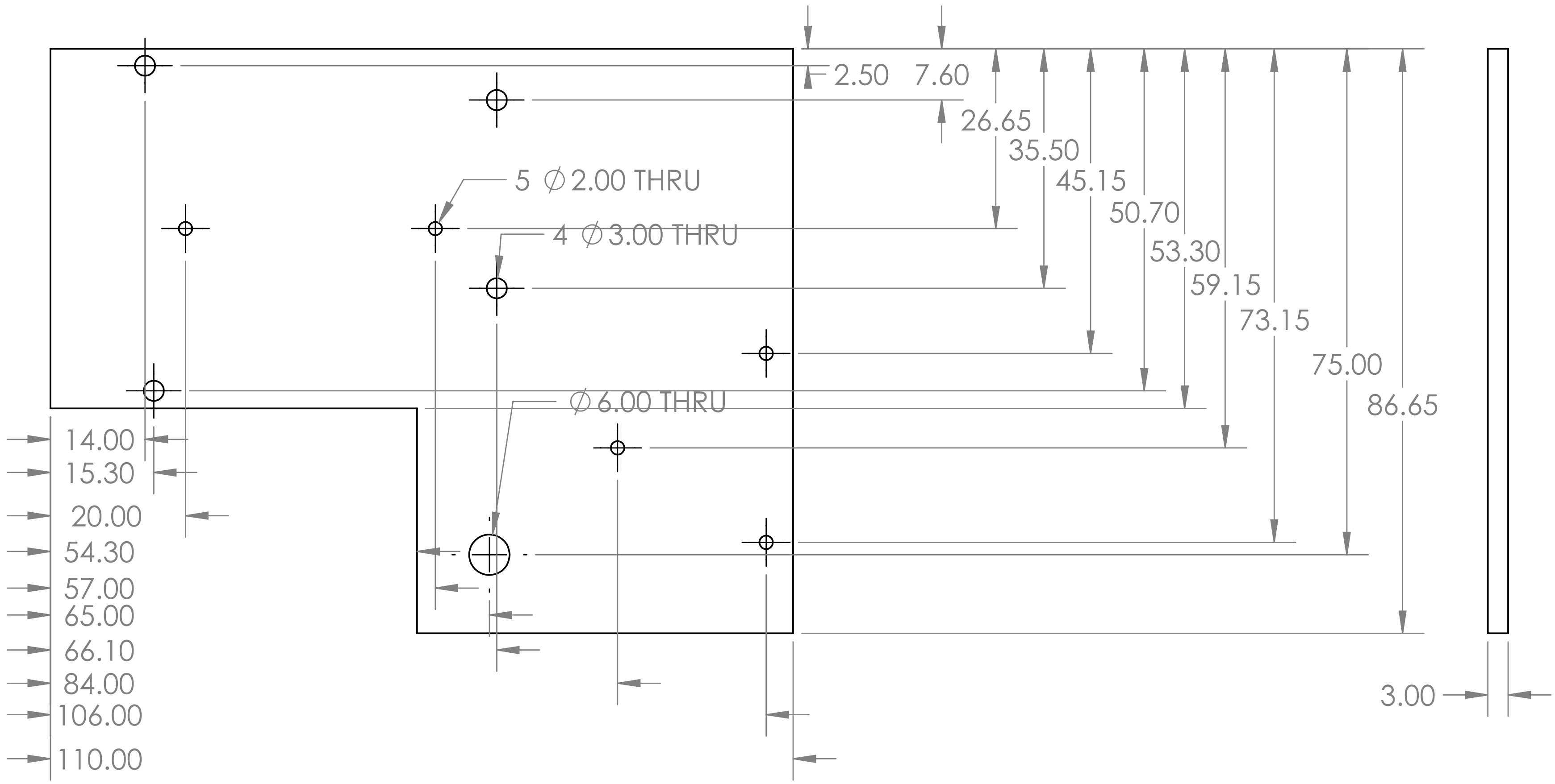
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

TITLE:

SIZE	DWG. NO.	REV
A	belly_slat	

SCALE: 1:2 | WEIGHT: | SHEET 1 OF 1

2 | 1



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN		
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

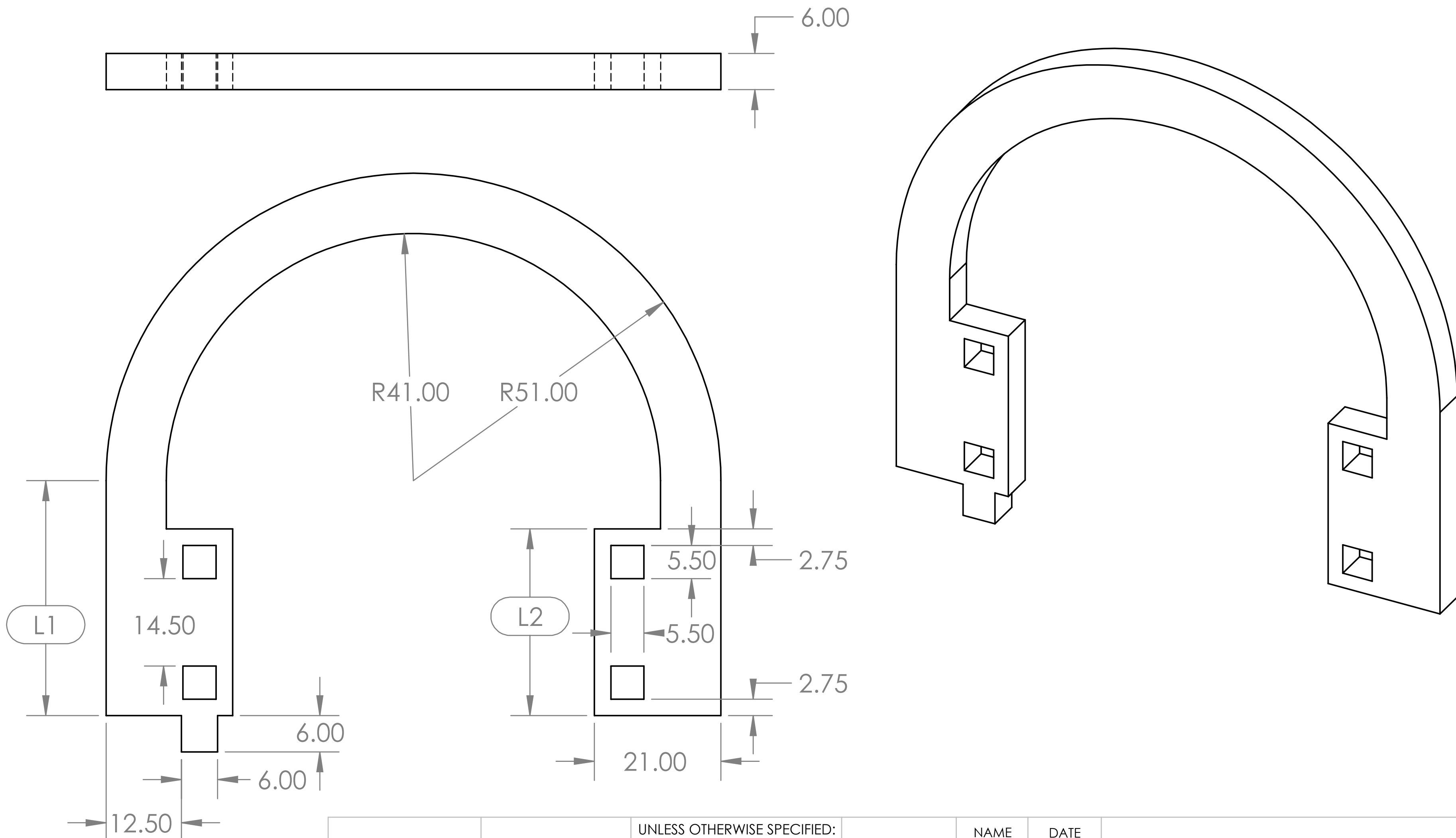
TITLE:

SIZE A DWG. NO. arduino_stand REV

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

Part:	L1 (mm)	L2 (mm)
Tail 1	39	31
Tail 2	36	31
Tail 3	33	31
Tail 4	30	31
Tail 5	27	31
Tail 6	24	31
Tail 7	21	31
Tail 8	18	31
Tail 9	15	31
Tail 10	12	31
Tail 11	9	31
Tail 12	6	31
Tail 13	3	30.95
Tail 14	0	27.95

Part:	Radius	W1	W2
Tail 15	43	14.95	27.05
Tail 16	39.93	23.88	11.98
Tail 17	36.86	8.86	20.86
Tail 18	33.79	17.79	5.79
Tail 19	30.71	2.71	14.71



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
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			CHECKED			
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL	COMMENTS:			SIZE A · DWG. NO. tail1 · REV
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:1 · WEIGHT: · SHEET 1 OF 1

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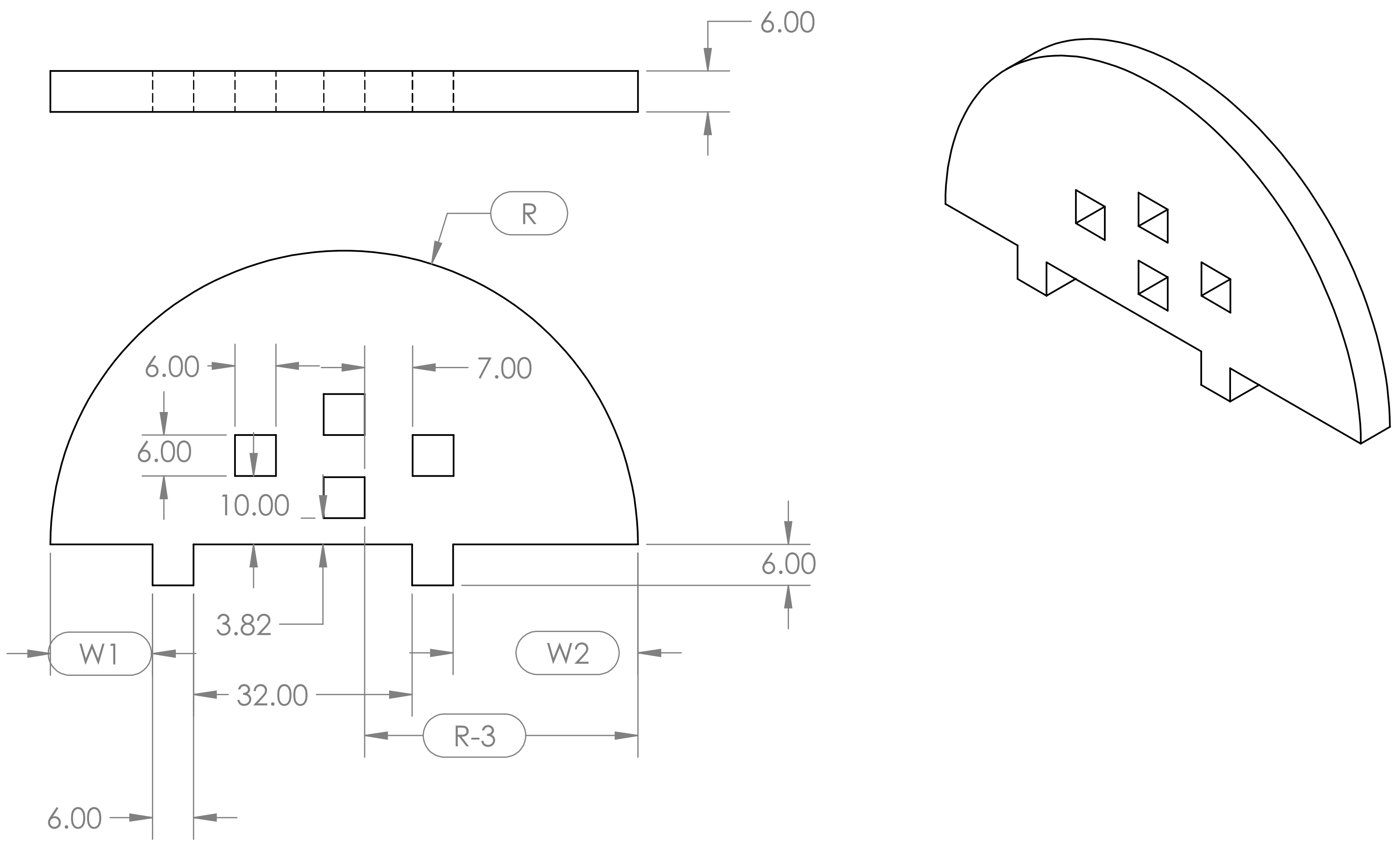

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NEXT ASSY	USED ON
APPLICATION	

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TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

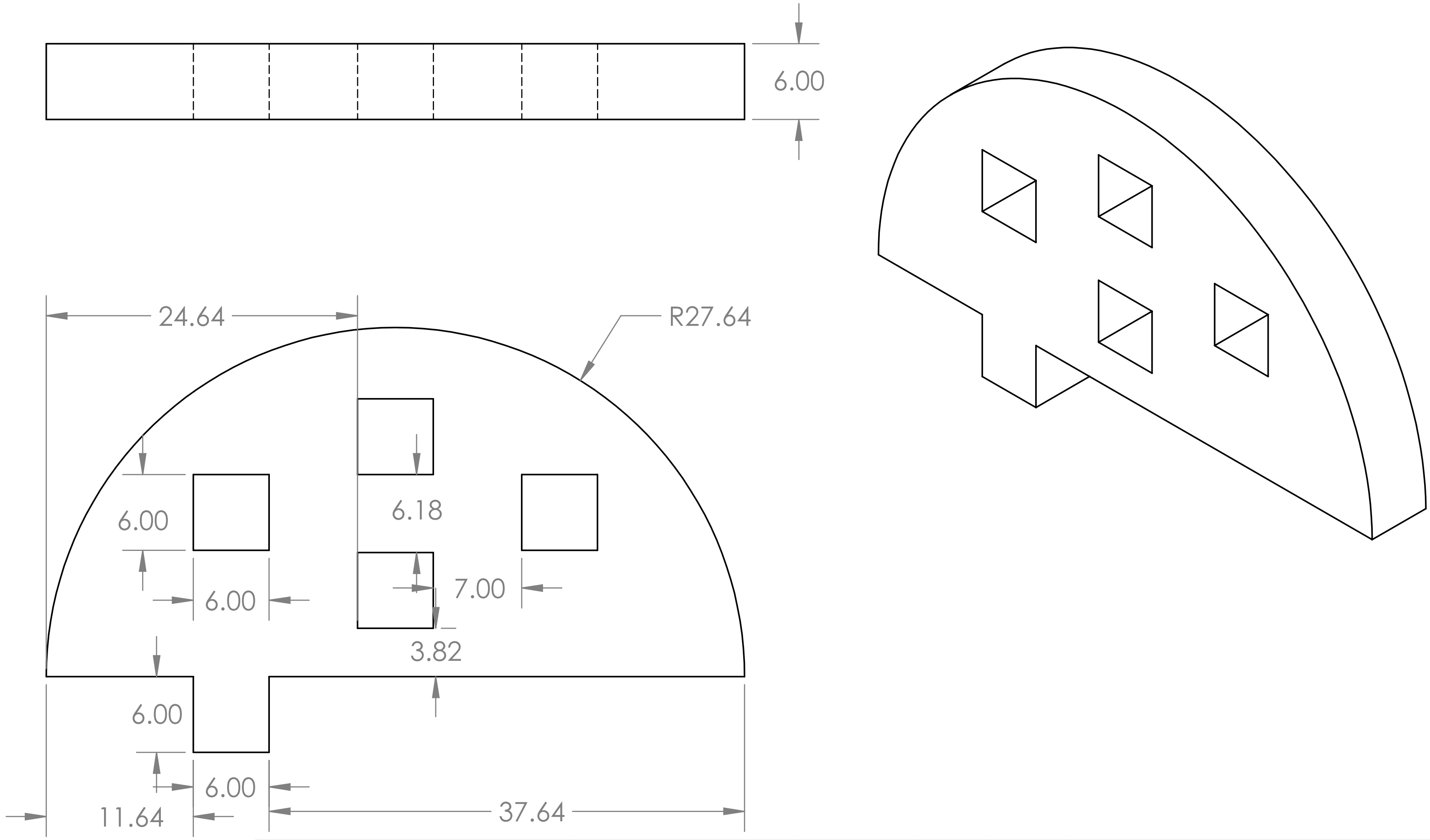
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

SIZE A | DWG. NO. tail15 | REV

SCALE: 1:1 | WEIGHT: | SHEET 1 OF 1



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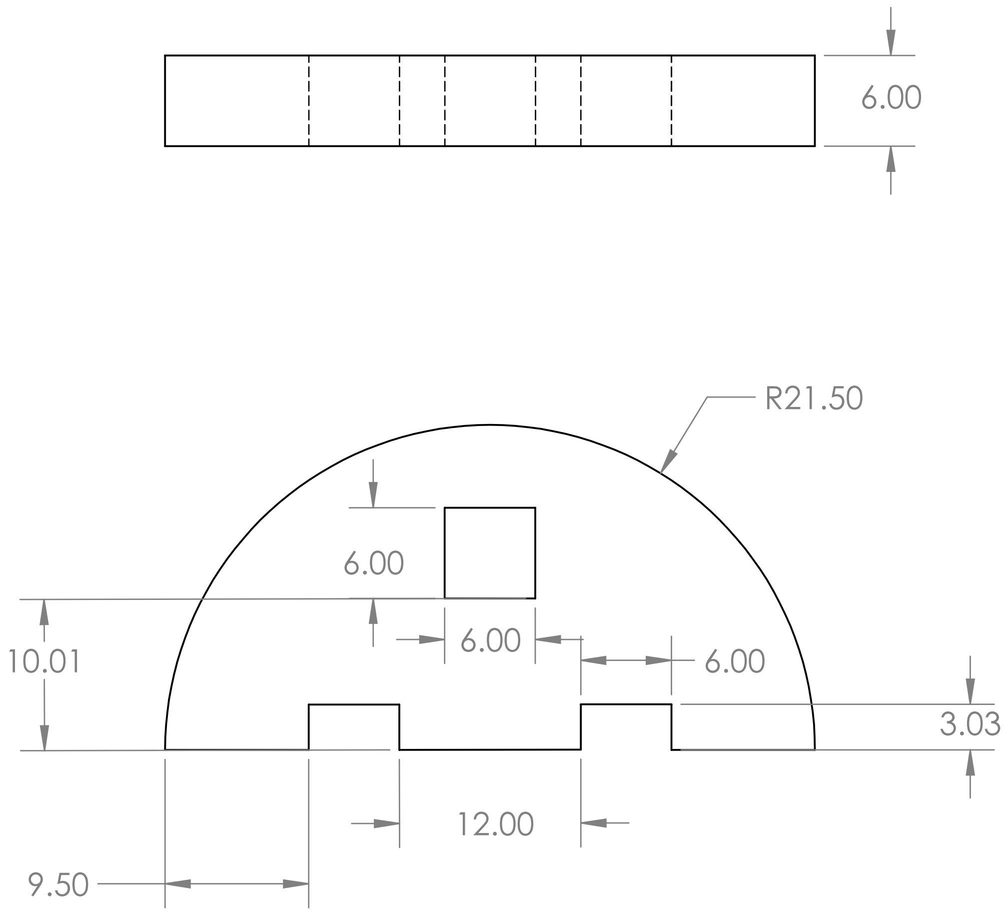
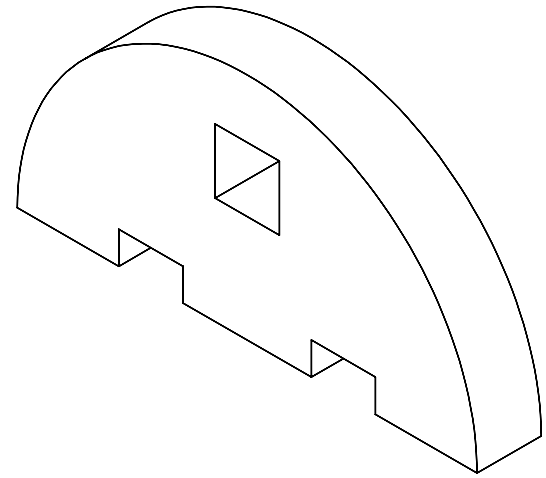
			CHECKED			
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL	COMMENTS:			SIZE A	DWG. NO. tail20	REV
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 2:1	WEIGHT:	SHEET 1 OF 1

2 1

B B





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NEXT ASSY	USED ON
APPLICATION	

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TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

SIZE	DWG. NO.	REV
A	tail22	

SCALE: 2:1 WEIGHT: SHEET 1 OF 1

2 1

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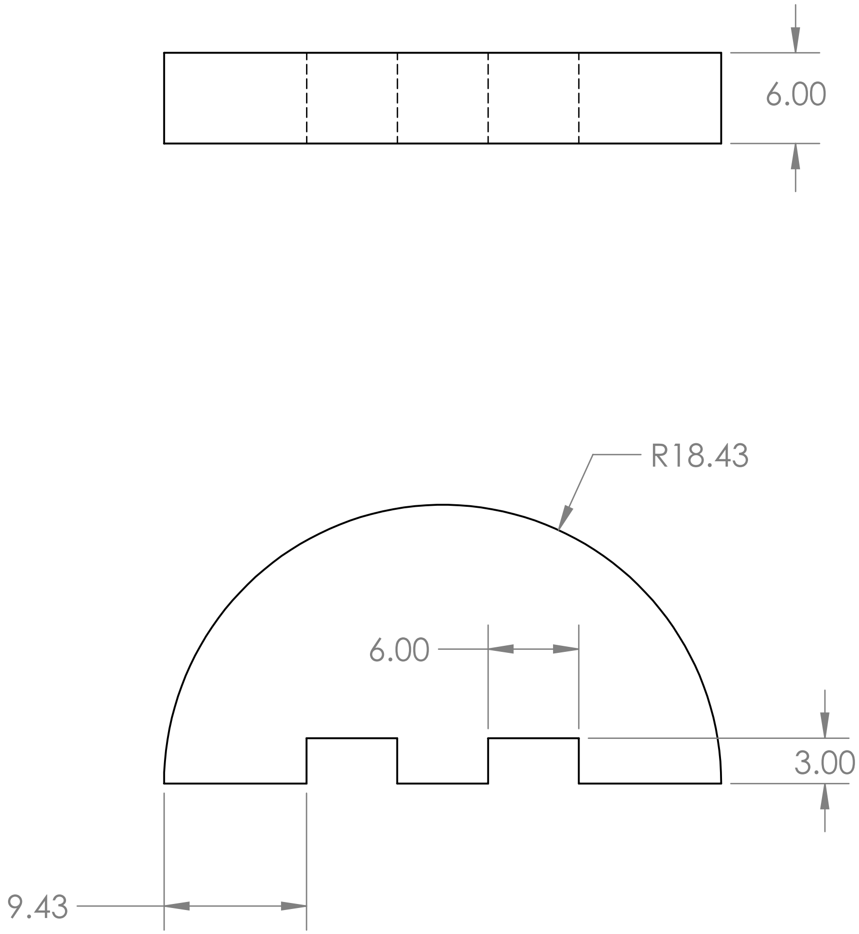

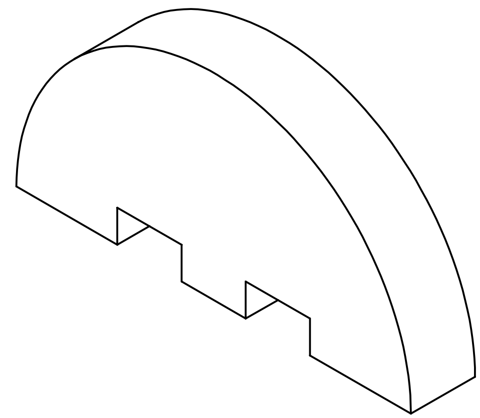

NEXT ASSY	USED ON
APPLICATION	

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TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

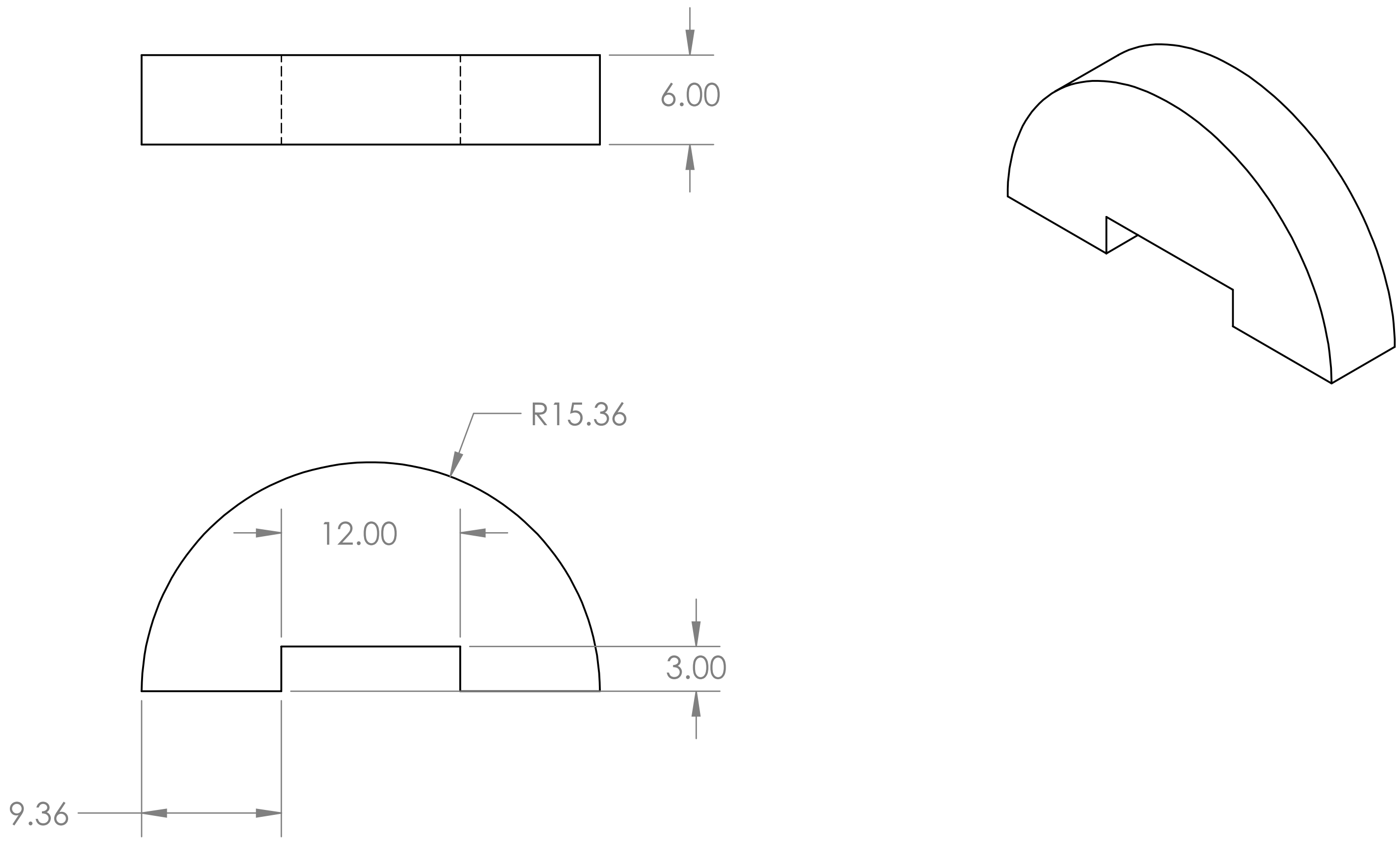
TITLE:

SIZE	DWG. NO.	REV
A	tail23	

SCALE: 2:1 WEIGHT: SHEET 1 OF 1

2 1

B B



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		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
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			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

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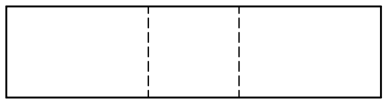
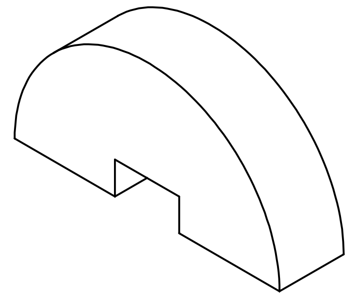
TITLE:

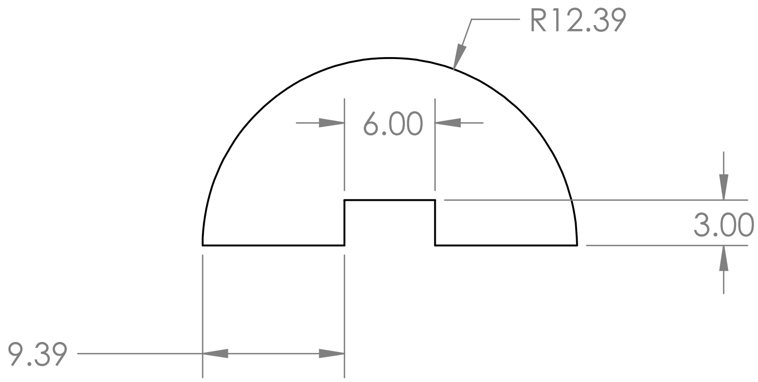
SIZE	DWG. NO.	REV
A	tail24	

SCALE: 2:1 WEIGHT: SHEET 1 OF 1

2 1







UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

SIZE	DWG. NO.	REV
A	tail25	

SCALE: 2:1 WEIGHT: SHEET 1 OF 1

NEXT ASSY	USED ON
APPLICATION	

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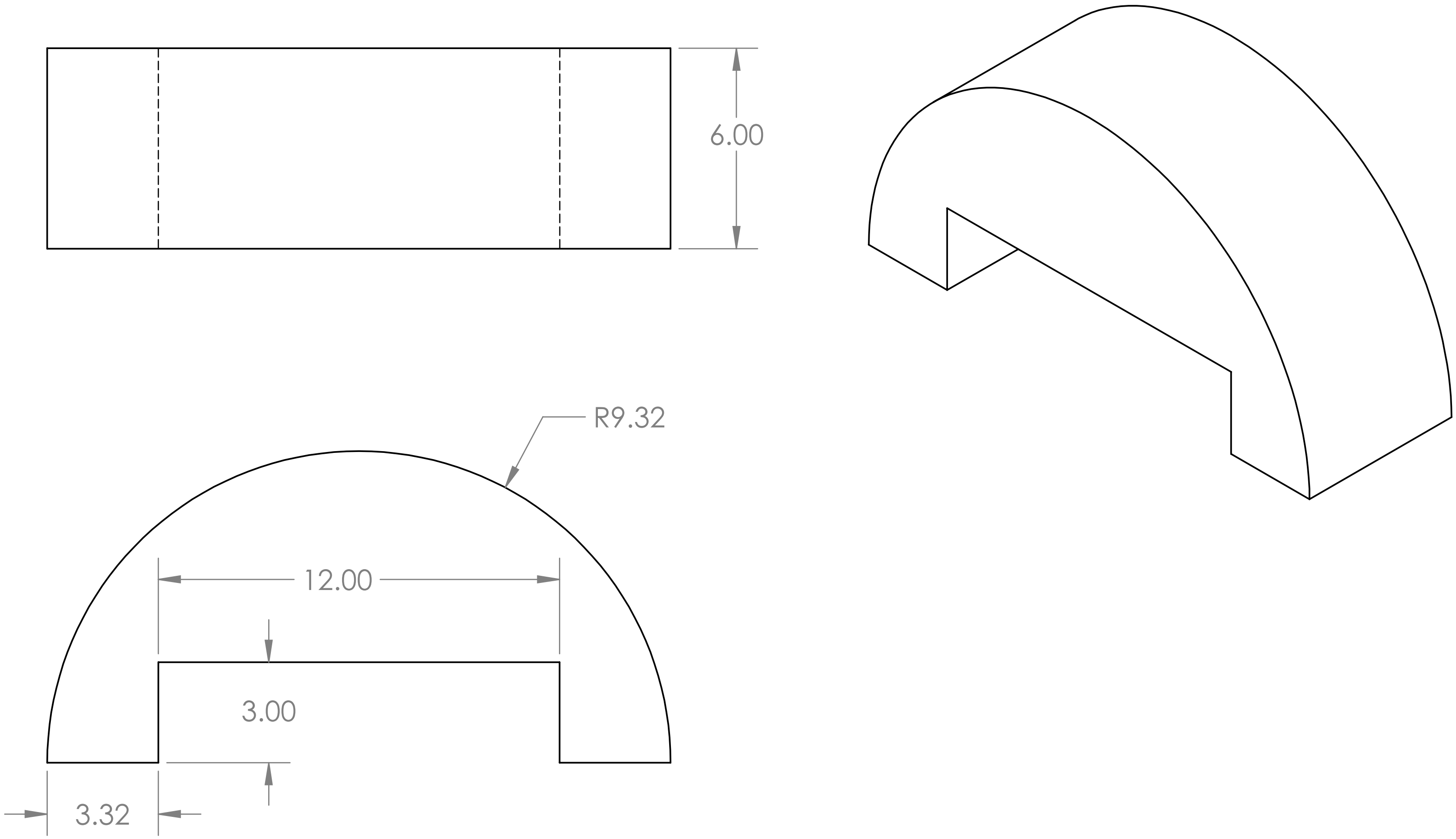

		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
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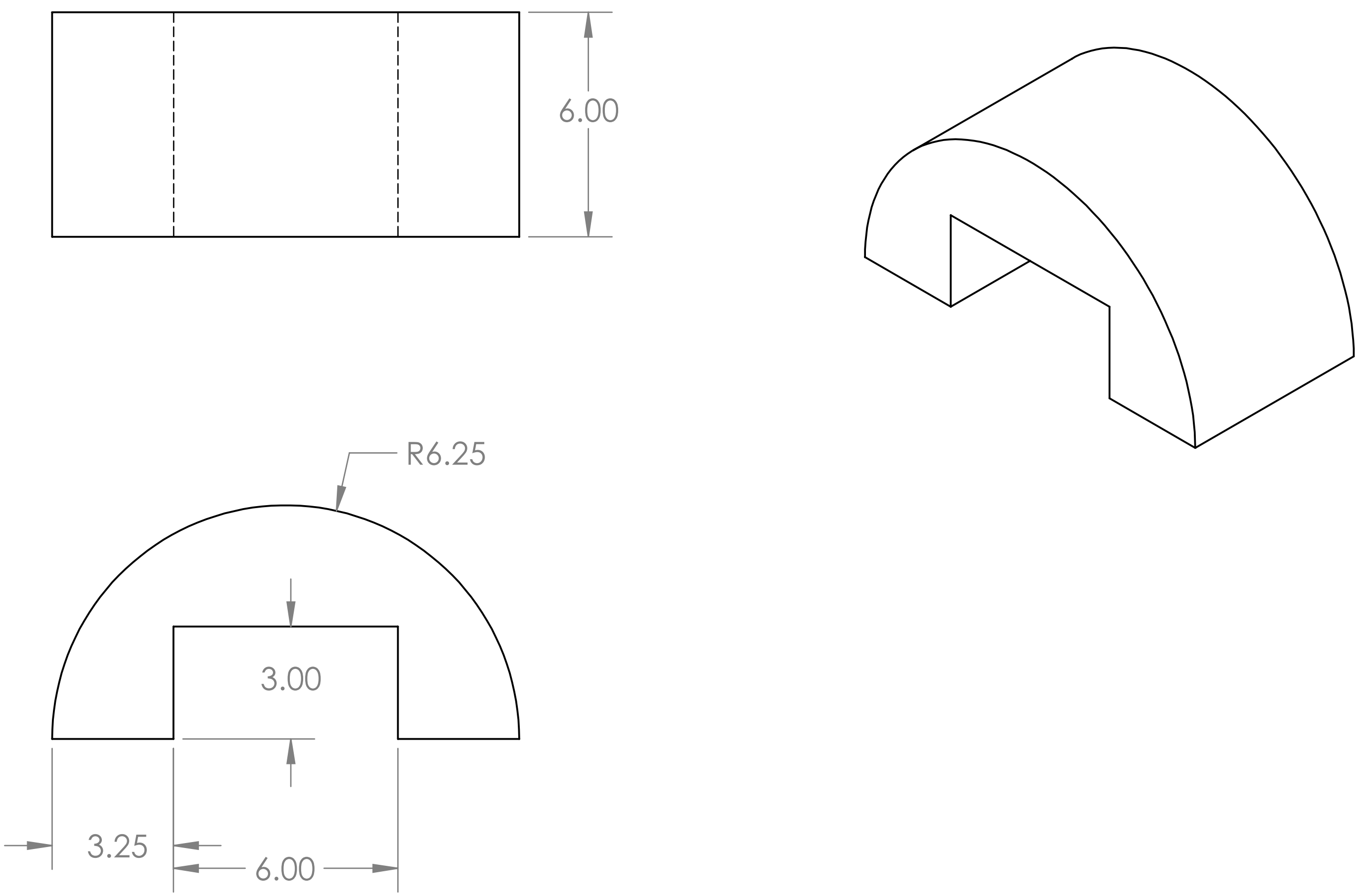
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

TITLE:

SIZE	DWG. NO.	REV
A	tail26	
SCALE: 5:1	WEIGHT:	SHEET 1 OF 1



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
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			CHECKED			
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL	COMMENTS:			SIZE A / DWG. NO. tail27 / REV
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 5:1 / WEIGHT: / SHEET 1 OF 1

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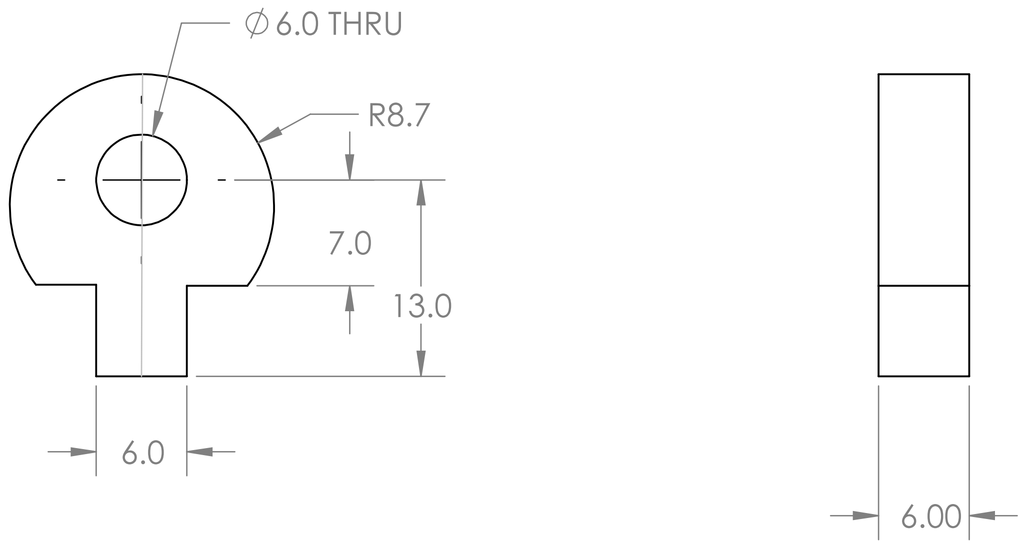

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			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

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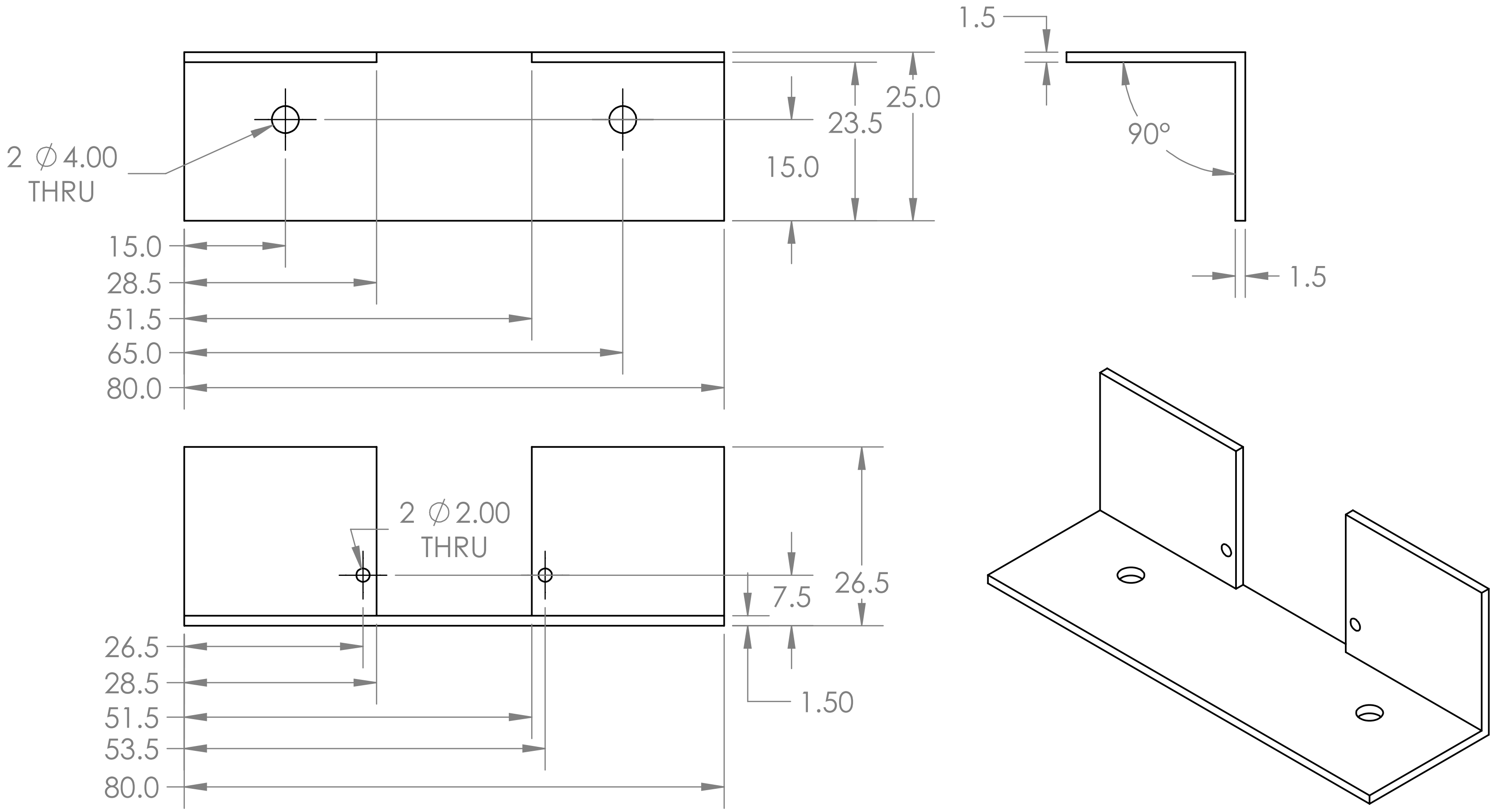
TITLE:

SIZE A DWG. NO. hinge_bracket REV

SCALE: 2:1 WEIGHT: SHEET 1 OF 1



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			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

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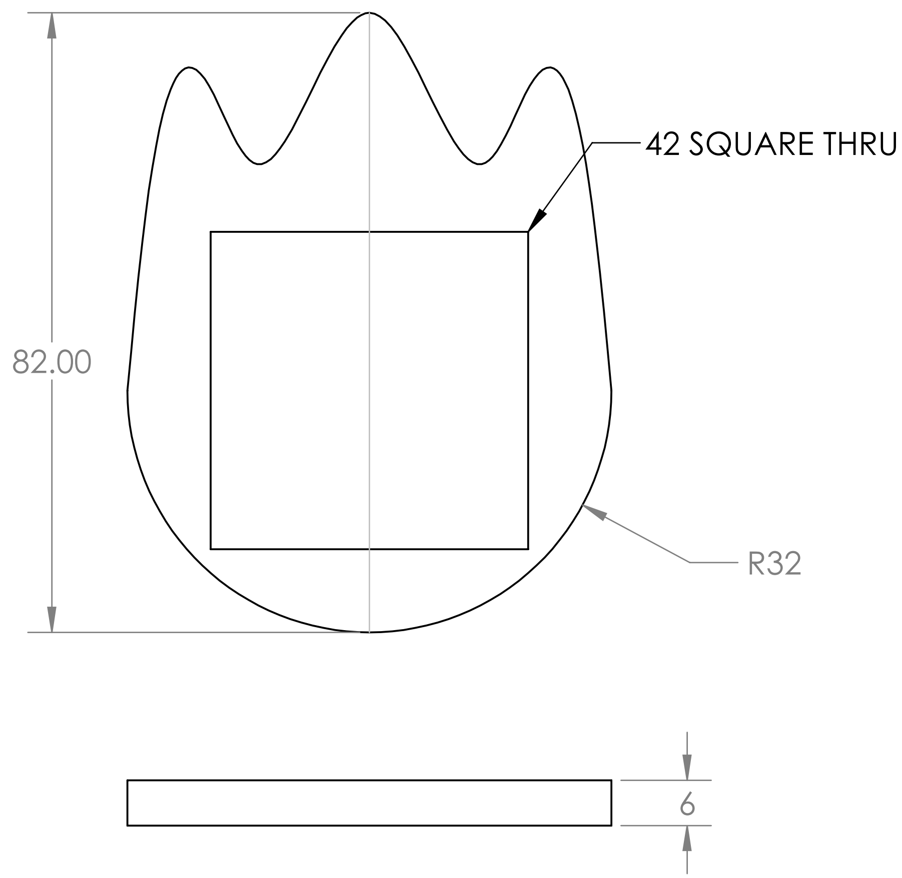
TITLE:

SIZE	DWG. NO.	REV
A	fastening_servo	
SCALE: 1:1	WEIGHT:	SHEET 1 OF 1



	NAME	DATE
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ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

UNLESS OTHERWISE SPECIFIED:

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TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

NEXT ASSY	USED ON
APPLICATION	

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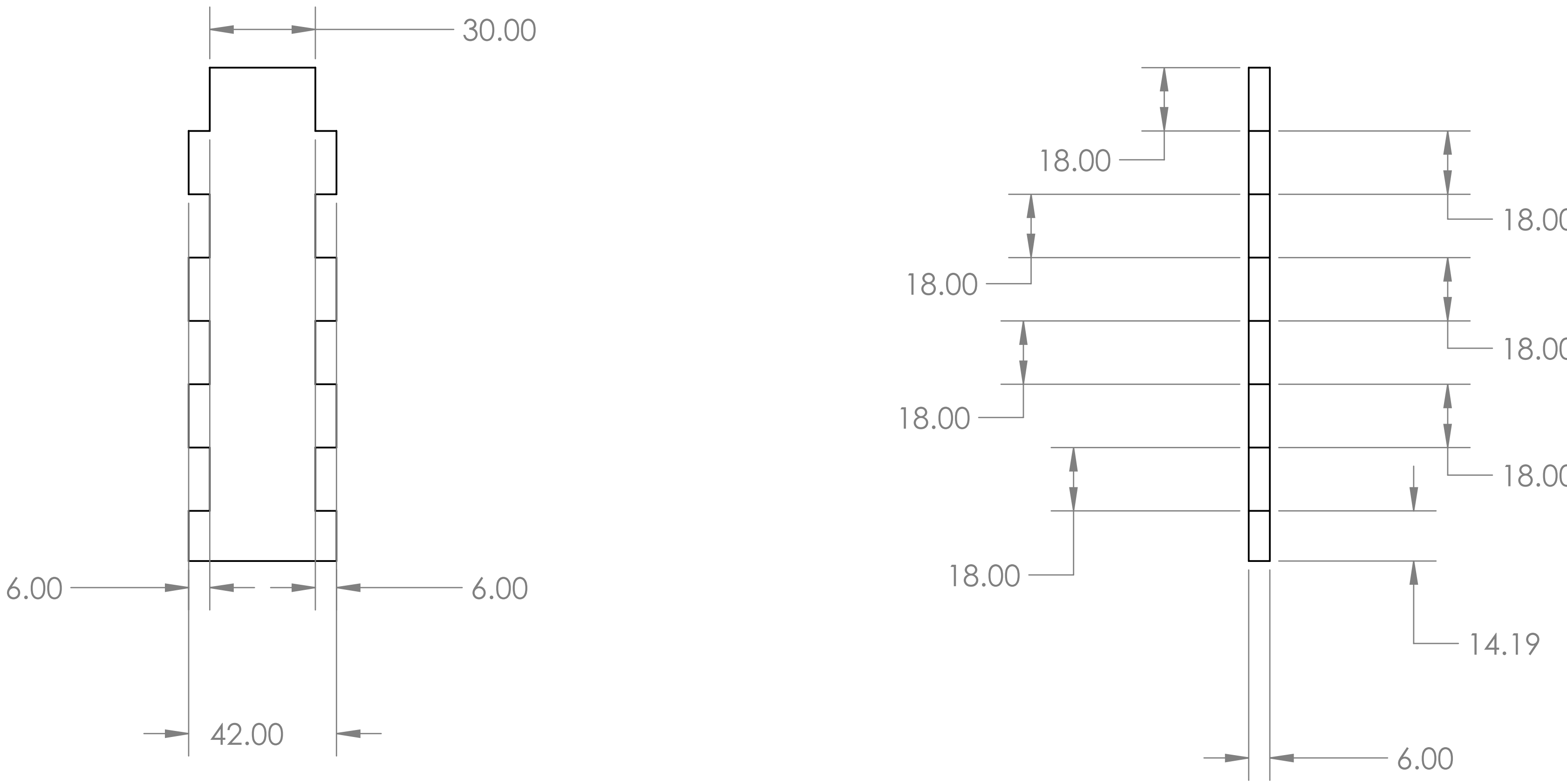
TITLE:

SIZE	DWG. NO.	REV
A	foot	

SCALE: 1:1 WEIGHT: SHEET 1 OF 1



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			CHECKED			
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL	COMMENTS:			SIZE A · DWG. NO. long_leg_back · REV
NEXT ASSY	USED ON	FINISH				
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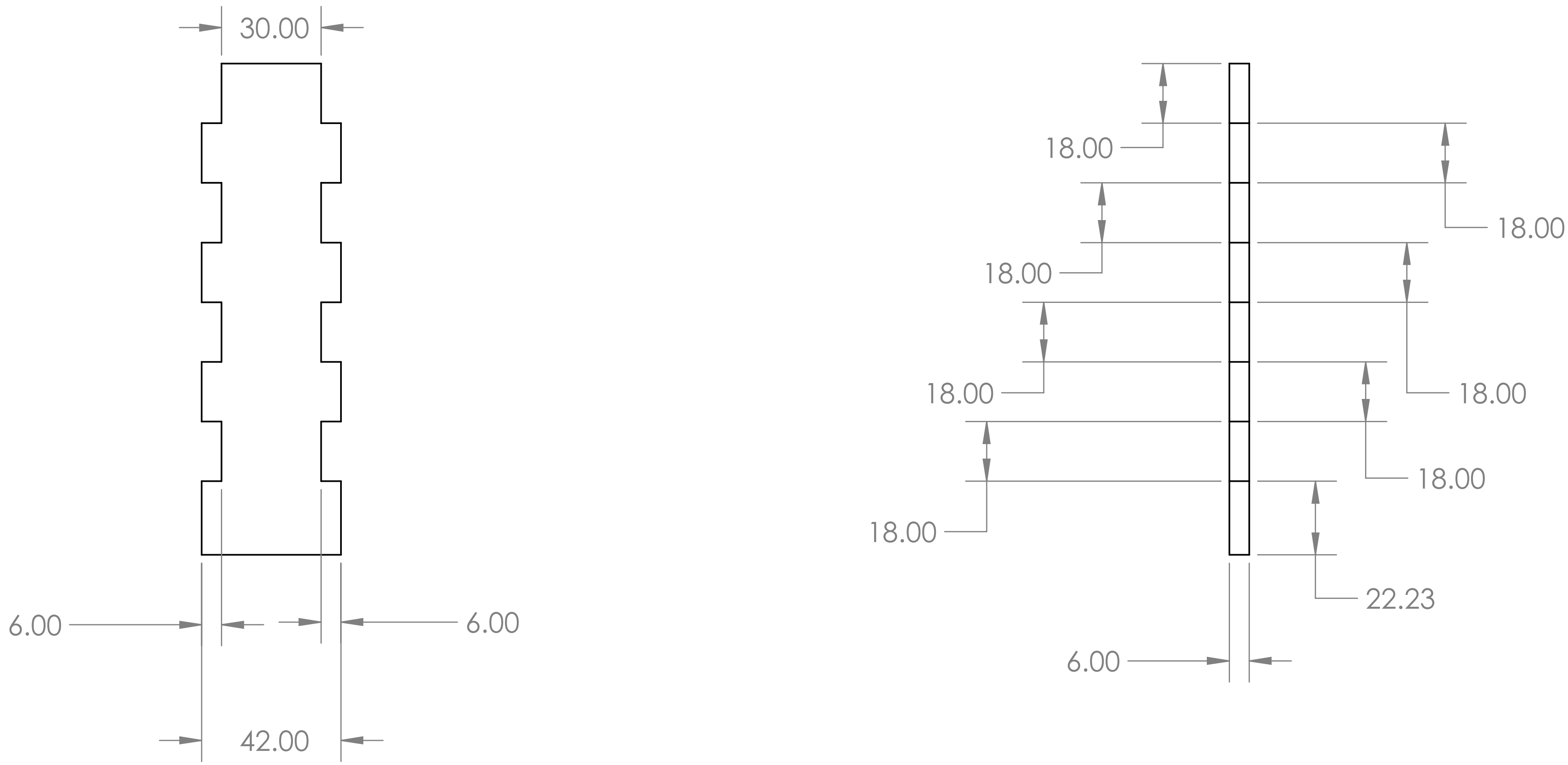

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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

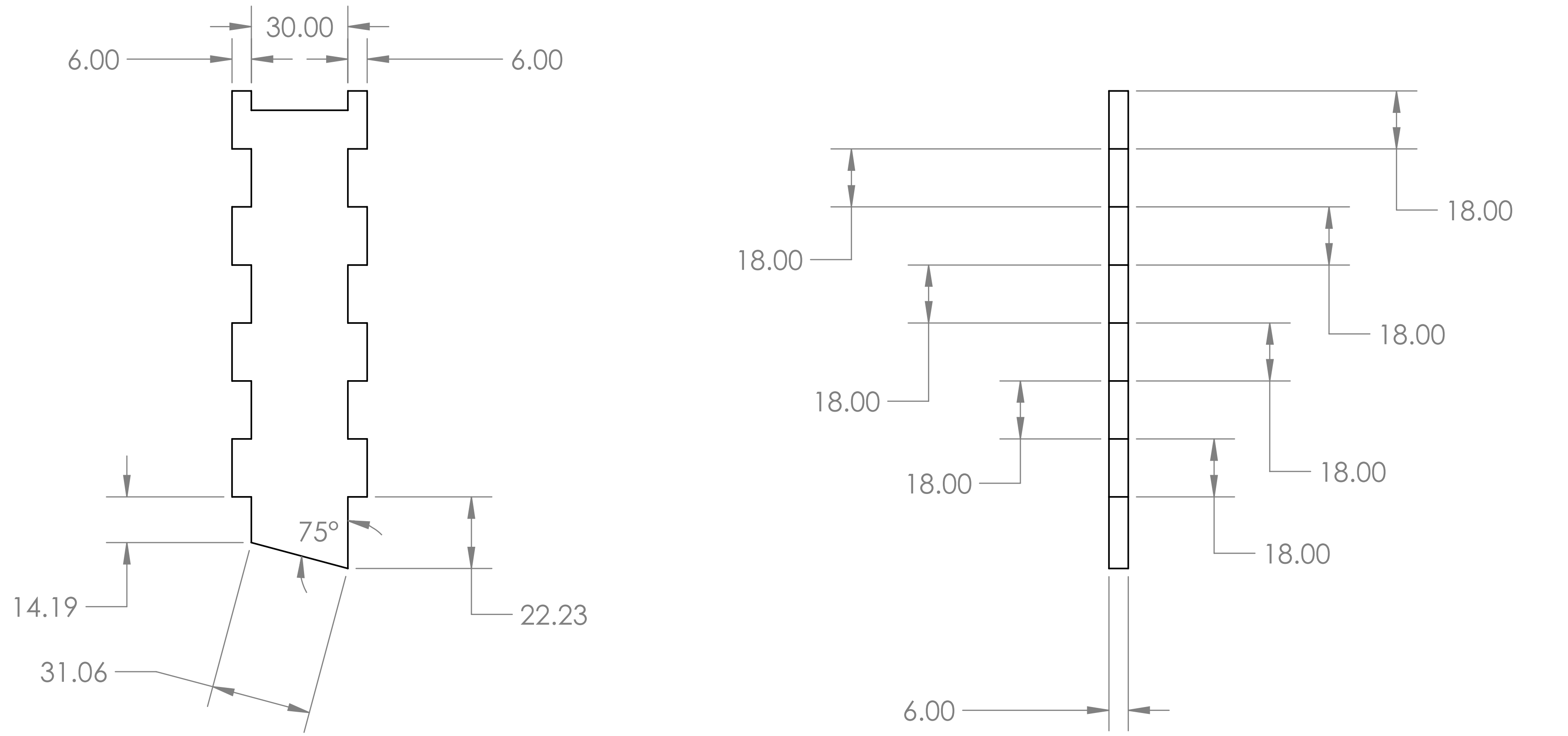
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

SIZE A DWG. NO. Long_leg_front REV

SCALE: 1:2 WEIGHT: SHEET 1 OF 1



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FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

NEXT ASSY	USED ON
APPLICATION	

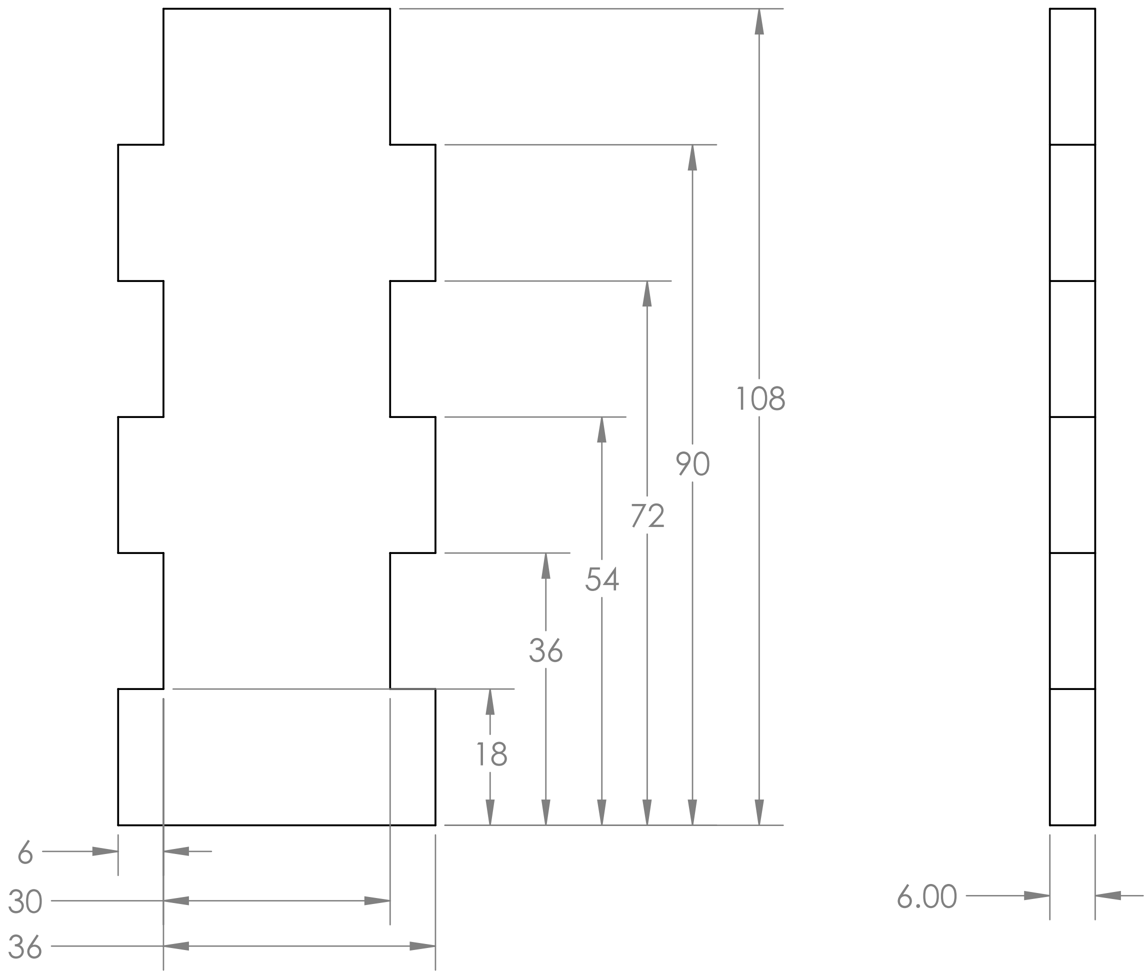
TITLE:

SIZE A DWG. NO. ong_leg_right REV

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

2 1

B B



A A

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

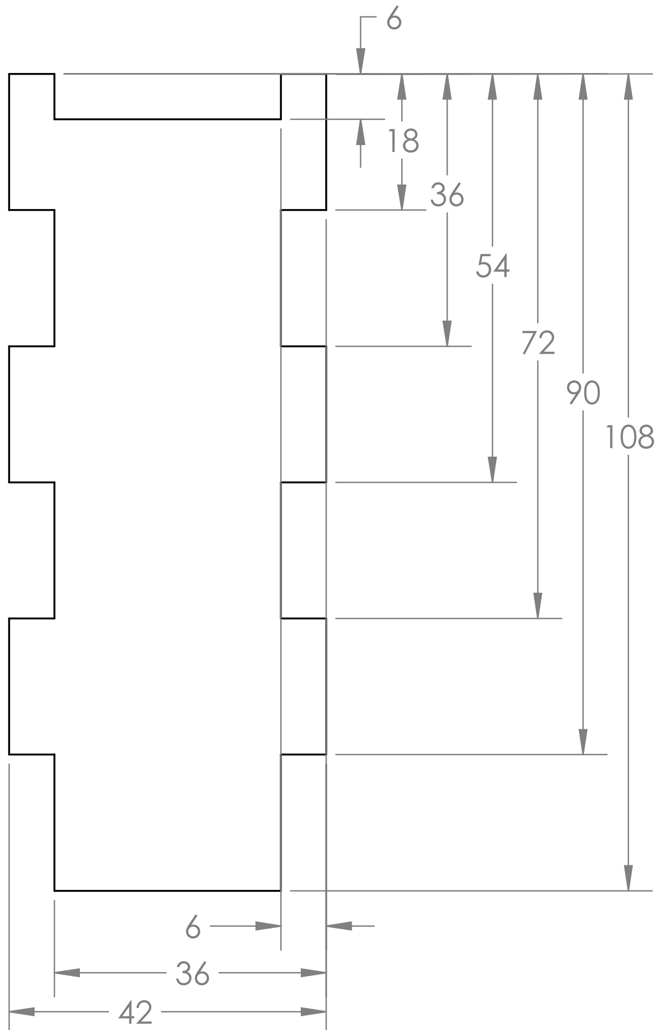
SIZE A DWG. NO. short_leg_front REV (1)

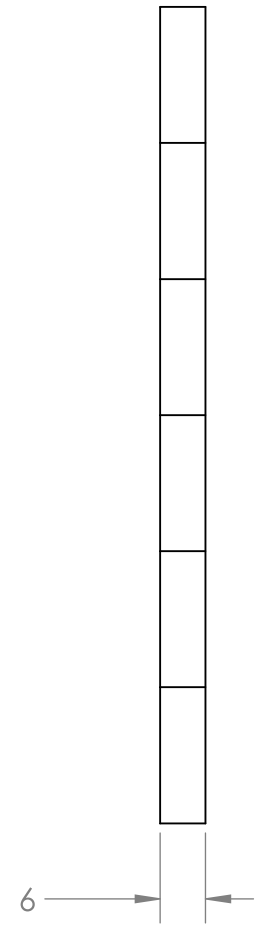
SCALE: 1:1 WEIGHT: SHEET 1 OF 1

NEXT ASSY USED ON

APPLICATION

2 1





NEXT ASSY	USED ON
APPLICATION	

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TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

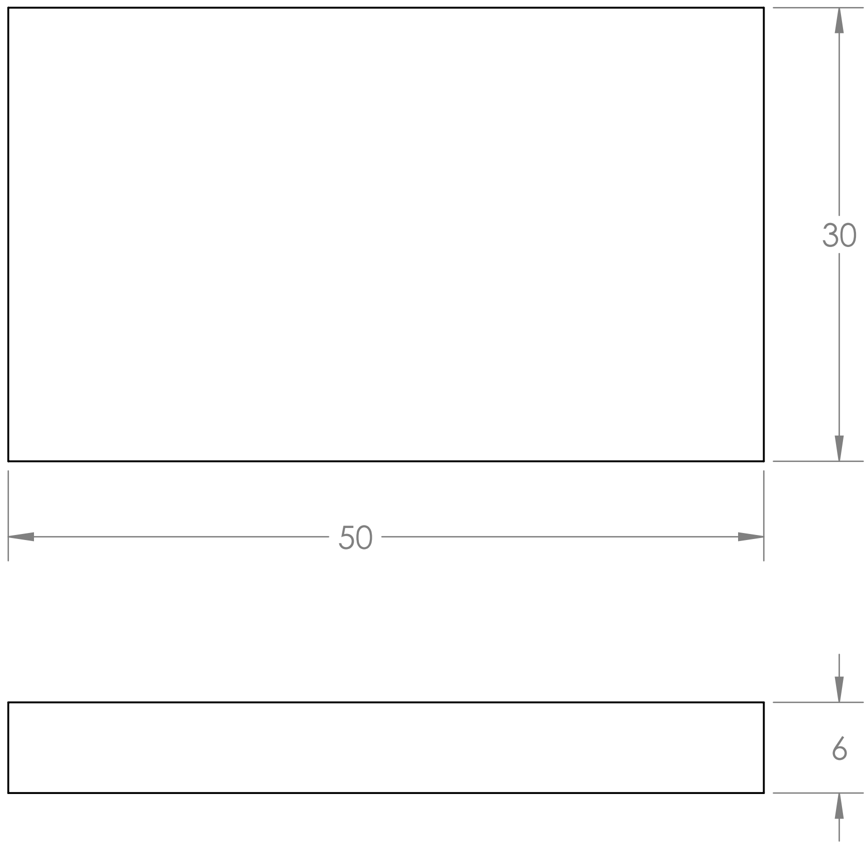
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

SIZE	DWG. NO.	REV
A	Short_leg_right	

SCALE: 1:1 WEIGHT: SHEET 1 OF 1



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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

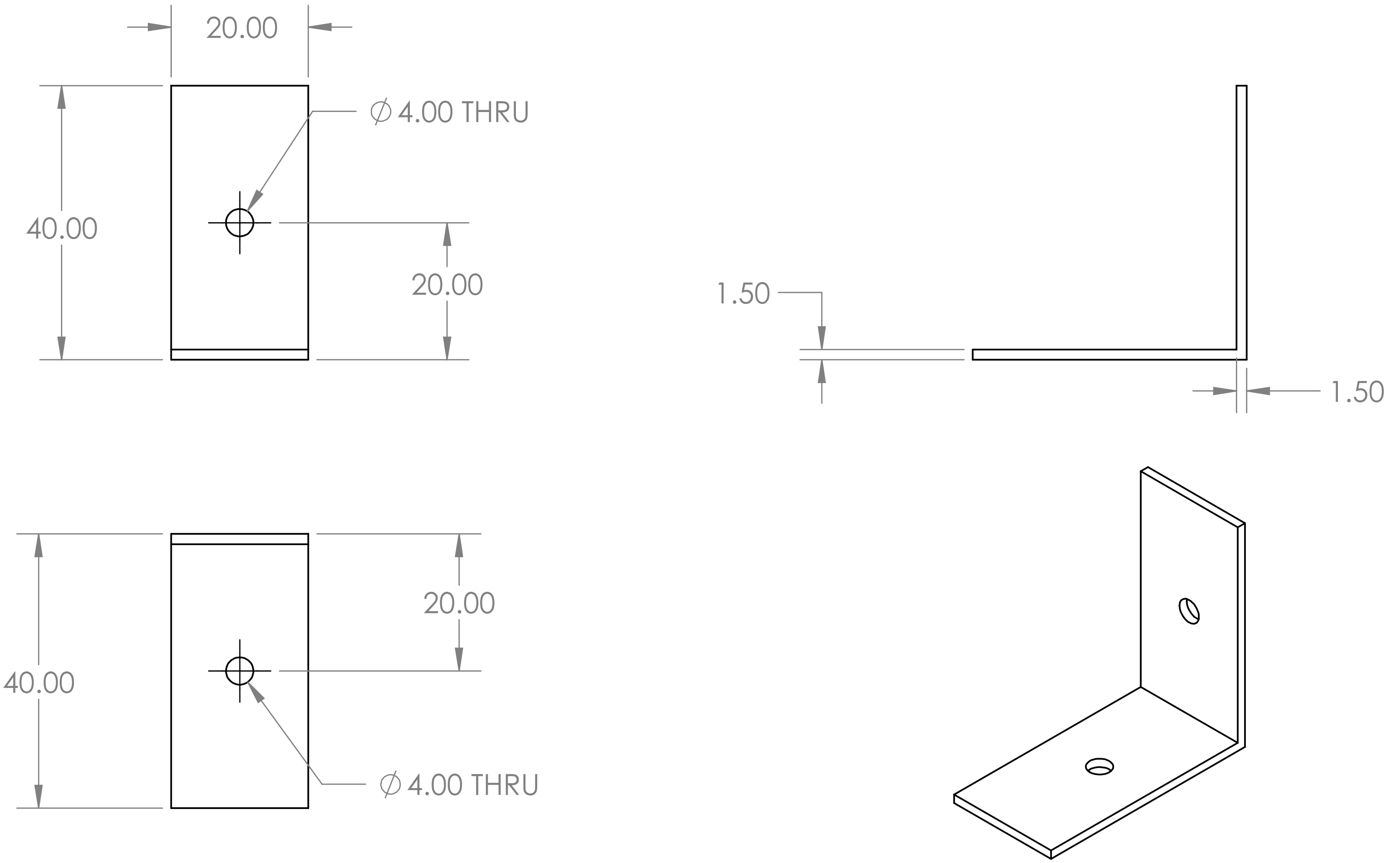
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

SIZE	DWG. NO.	REV
A	leg_stand	

SCALE: 2:1 WEIGHT: SHEET 1 OF 1



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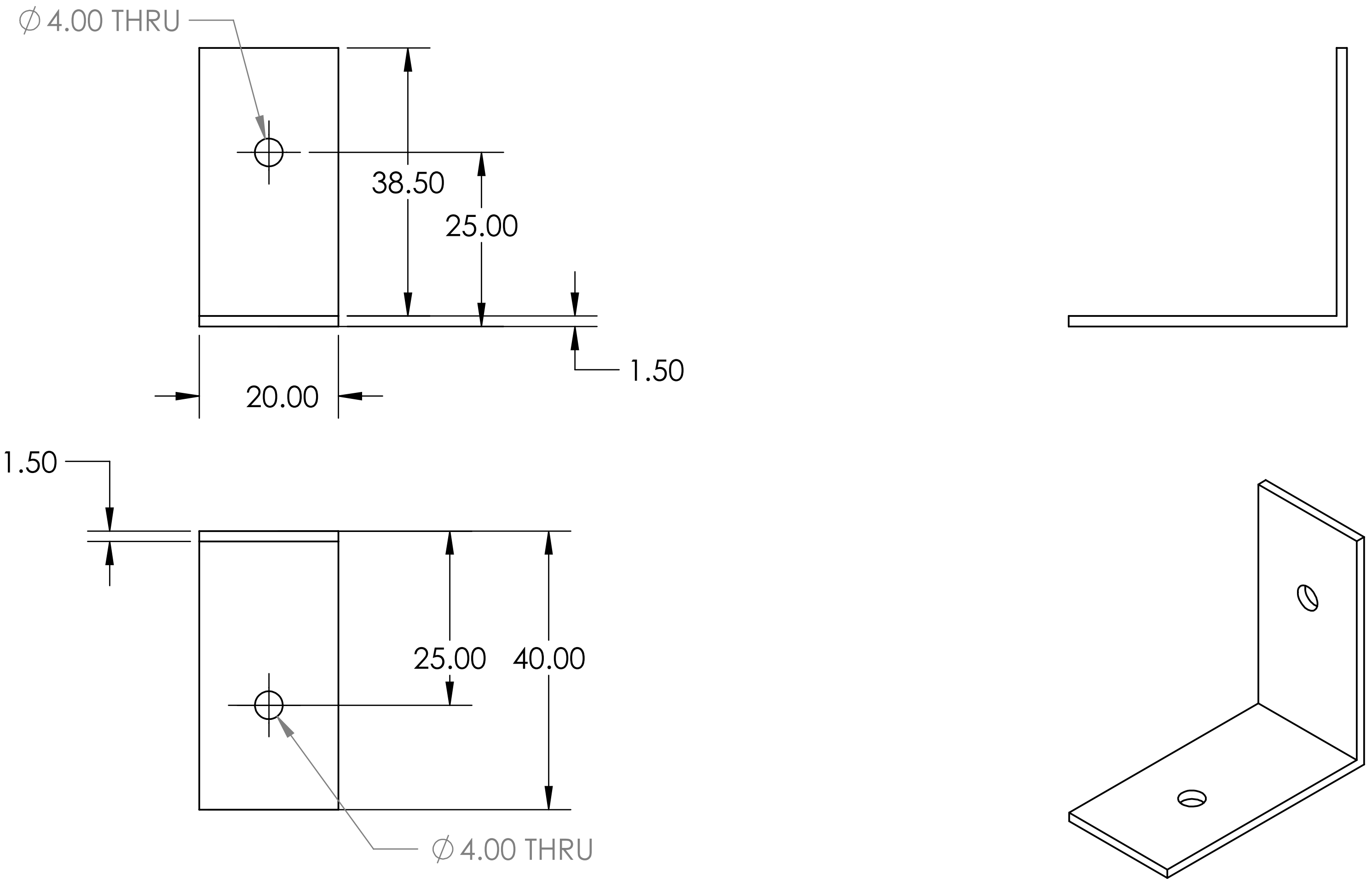
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

TITLE:

SIZE A | DWG. NO. 20-20 bracket | REV

SCALE: 1:1 | WEIGHT: | SHEET 1 OF 1



NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

SIZE A | DWG. NO. 25-25 bracket | REV

SCALE: 1:1 | WEIGHT: | SHEET 1 OF 1

Electronic:

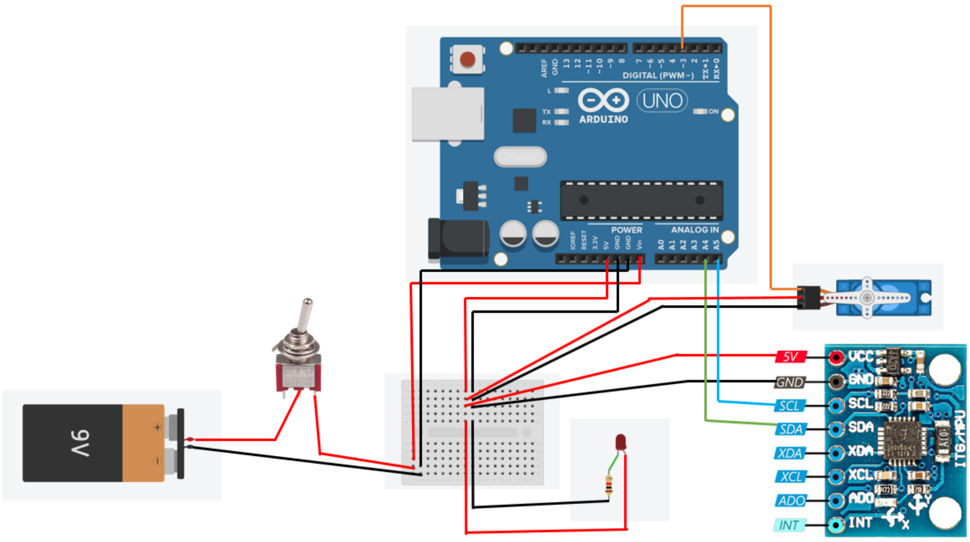
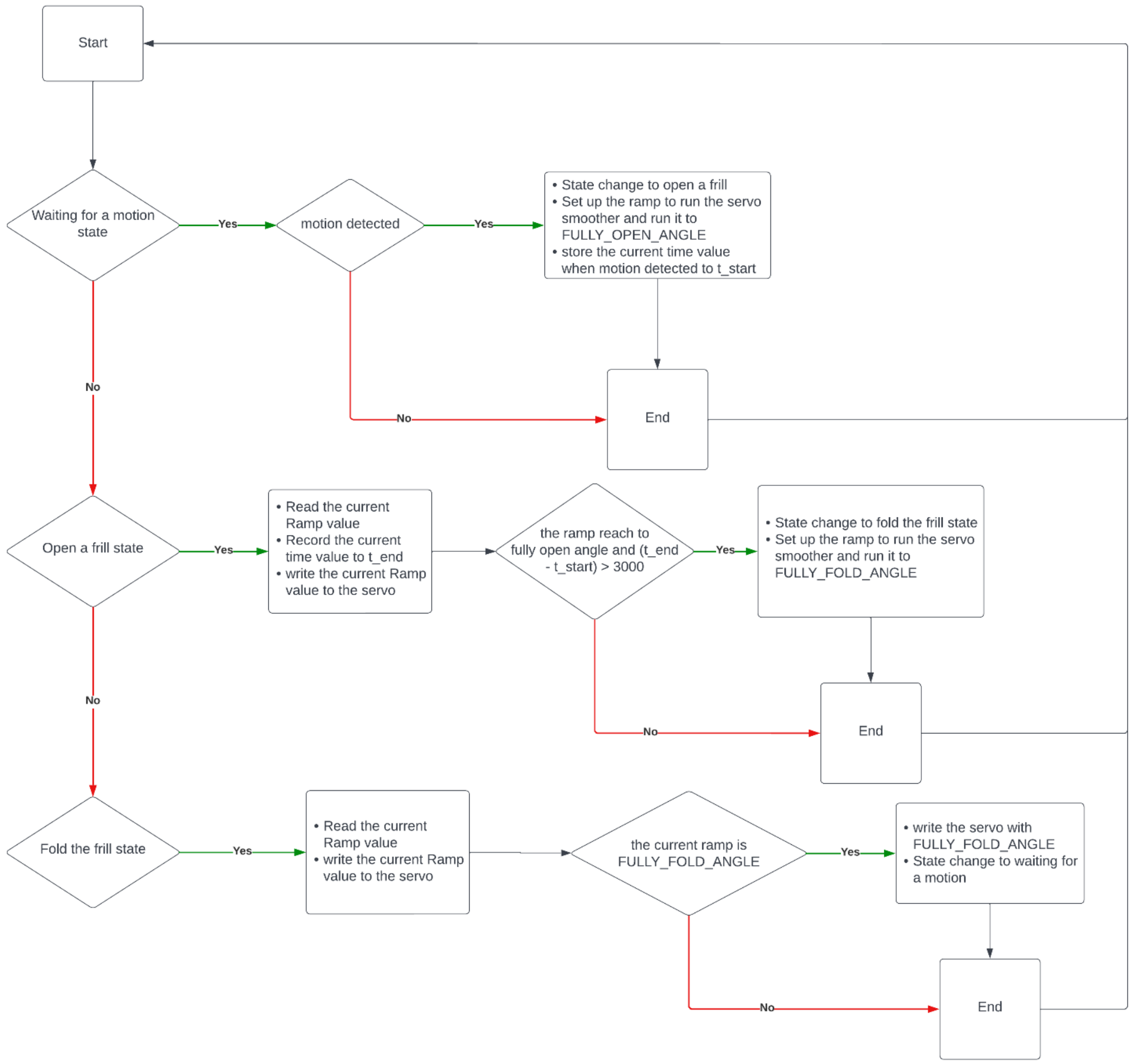


Figure: Final Circuit for Lizard

Our pet's functionality is that the lizard will open the frill whenever it detects a motion, and close its frill after 3 seconds of non-motion detected. Moreover, we are using the Ramp library to run the motor so that we also split the state into 3 states which are waiting for motion state, opening the frill state, and closing the state. As a result, our code will have the condition on these states and do the task according to that state. The information about the logic will be demonstrated below through the flow chart where the diamond box is the condition checking and the square box is the task.

The actual Arduino code is available in [Appendix Coding Section](#)


Start
Waiting for a motion state
Yes
motion detected
Yes
• State change to open a frill
• Set up the ramp to run the servo smoother and run it to FULLY_OPEN_ANGLE
• store the current time value when motion detected to t_start
No
No
End
Open a frill state
Yes
• Read the current Ramp value
• Record the current time value to t_end
• write the current Ramp value to the servo
the ramp reach to fully open angle and (t_end - t_start) > 3000
Yes
• State change to fold the frill state
• Set up the ramp to run the servo smoother and run it to FULLY_FOLD_ANGLE
No
No
End
Fold the frill state
Yes
• Read the current Ramp value
• write the current Ramp value to the servo
the current ramp is FULLY_FOLD_ANGLE
Yes
• write the servo with FULLY_FOLD_ANGLE
• State change to waiting for a motion
No
End

Risk Management:

Because this project is having a fixed deadline which is at the end of this semester, we need to account for the risk that will affect our ability to finish on time. After we identify the most two common risks, we also have to have the plan to deal with these risks so that we can minimize their effects on our project and academic results.

- **Risk one: Teammate absence due to illness**

  The likely event of a teammate's absence at some point throughout the project could negatively impact communication and the timeliness of the team. We can mitigate the likelihood of this risk by ensuring that multiple group members are trained to use each necessary part of the Telstra Creator Space so that one absence doesn't delay the project. In addition, we can also use virtual meetings using Zoom instead of insisting on in-person team meetings in case of absence. We can strive to stay ahead or in time with the planned schedule so that team members being incapacitated doesn't cause further project delays.

- **Risk two: The desired mechanism failing to meet requirements**

  In the case that a planned component does not work as intended, or breaks, these setbacks can negatively impact the team. This can be mitigated by completing thorough calculations and predictions for each mechanism to ensure they will work as intended and can sustain required stresses. In addition to this, we can create multiple draft prototypes so if one variation doesn't meet requirements, we can easily try another variation of the mechanism. These precautions will help us stay on schedule as well as lowering the risk of components failing.

Both risks identified in the previous report ended up coming to fruition.

Alex was sick and thus absent from the desired in-person meetings and workshop session in week 9. As prepared for, this was mitigated using online meetings, where the team participated in video calls on Messenger several times through this week and continuing afterwards. Additionally, due to Jewish Holidays; Rosh Hashanah, Yom Kippur, Sukkot, Shemini Atzeret, and Simchat there were several instances where Nathan was unable to attend TCS with the other group members due to religious reasons. These absences were mitigated by redelegating certain components to other group members and by altering the schedule to plan around these dates where possible. In both instances of teammate absence, our team was able to stay on schedule or ahead of schedule as to not let these setbacks significantly affect our project completion.

The project underwent countless revisions and alterations throughout the process, including instances where components did not meet requirements. Initial prototypes of the face piece that the frill linkages attached to were made of MDF, with the intention to drill holes through the side of the material to attach the linkages. This turned out to break the MDF when attempting to drill into the side of the material, thus we had to change our product to be 3D printed out of PETG and later again PLA, when it had been refactored to only have 4 linkages to attach. The first PETG 3D printed rack was broken by Alex as he attempted to remove the 3D printed supports between the rack teeth. This was a major setback, as the team was aiming to complete the first testing of the rack powered mechanism that day. The prototype testing was delayed 3 days until Alex could 3D print a new rack. This second rack was printed with eSUN PLA+ to help prevent another breakage and adhered to the required stresses as calculated.

Schedule:

The schedule for our group is in the table below with the tasks will be distributed according to the colours. Moreover, our team will help each other regardless that the task is distributed to only one person for dealing with the risk number one.

Our initial schedule was extremely optimistic in the length of time of certain sections. Sections such as the actual assembly were predicted to occur entirely within week 8. In reality, this section took place from week 8 to week 11 including the semester break. Additionally, due to student absences some responsibilities were shifted around between members, Alex and Nathan were given the responsibility for the coding section, but Kevin ended up completing the vast majority of coding as Alex was sick and couldn't access the Arduino in person. Our team strived to stay on or ahead of schedule for the project and ended up completing it without experiencing any major time issues. This is mostly due to any delays suffered were made up for by putting in addition hours of work on the project, totalling around 90 hours between all team members in TCS and an additional 15 hours by team members doing design work such as coding and producing drawings outside of TCS.

Anh Kiet	Alex	Nathan	Whole team

Project Schedule										
Task	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Mid Sem	Week 10	Week 11	Week 12
Conceptual design and report										
Update concept development in the report										
Mechanism Design										
CAD drawing										
Calculation of mechanical parts										
Material Selection										
Laser Cutting										
Electronics selection										
Coding section										
Assembling mechanical parts										
Circuit Design										
Testing the prototype of the frill neck										
Assembling electronics										
Update project requirements in the report										

Testing the prototype of the pet										
Final project report										
Final testing										
The pet parade										

Reference

3D drawing model:

3D drawing model for Arduino: https://grabcad.com/library/arduino-127

3D drawing model for servo motor: https://grabcad.com/library/servo-motor-c90-1

3D drawing model for toggle switch: https://grabcad.com/library/spdt-print-toggle-switch-pcb-mount-1

3D drawing model for mini breadboard: https://grabcad.com/library/breadboard-mini-format-1

3D drawing model for gyroscope: https://grabcad.com/library/mpu-6050-sensor-1

3D drawing model for battery and battery holder: https://grabcad.com/library/9v-battery-holder-um-9v-1-p-1

Library for Arduino coding:

Ramp library: https://github.com/siteswapjuggler/RAMP

MPU6050 library: https://github.com/adafruit/Adafruit_MPU6050

Appendix:

Mechanical

Code for checking the gear

```
% Input value
%The torque of the servo
Torque = 2.5*9.8*0.01; % In Nm

%The willing force to push out the frill
willing_F = 1.018*5; % In N

%The pitch diameter of the gear
D_p = 0.08; % In m

%The number of teeth on the pinion
number_teeth = 32;

%The minimum number of teeth to check for the interference
min_teeth = 17;

%The force that the servo can provide with the diameter D_p
F = 2*Torque/D_p;

if F > willing_F
    if number_teeth > min_teeth
        disp('This gear allows the servo to provide enough force');


        % diametral pitch
        P = number_teeth/(D_p*1000);

        % module
        module = 1/P
        number_teeth

        % addendum and dedendum for the full depth gear
        addendum = module;
        dedendum = 1.25*module;

        % Lewis form factor
        Y = 0.365;

        % yield strength of the material
        xigma_y = 18;

        % fatique factor with suddenly applied load
        Kf = 2.5;

        % the minimum face width to widstand the force
        face_width = (F*P/(xigma_y*Y))*Kf %In mm

        % The maximum distance that the rack can travel
        max_dis_travel = pi*D_p/2;
    end
else
    disp('do not meet the desired force');
end
```

Coding

Code for connecting MPU6050 for motion detection

```
#include <Adafruit_MPU6050.h>

#include <Adafruit_Sensor.h>

#include <Wire.h>


Adafruit_MPU6050 mpu;


void setup() {

 Serial.begin(115200);

 while (!Serial){

  delay(10);

 }

 Serial.println("Adafruit MPU6050 test!");

 // Try to initialize!

 if (!mpu.begin()) {

  Serial.println("Failed to find MPU6050 chip");

  while (1) {

   delay(10);

  }

 }

 Serial.println("MPU6050 Found!");


 //setup motion detection

 mpu.setHighPassFilter(MPU6050_HIGHPASS_0_63_HZ);

 mpu.setMotionDetectionThreshold(1);

 mpu.setMotionDetectionDuration(20);

 mpu.setInterruptPinLatch(true);  // Keep it latched.  Will turn off when reinitialized.

 mpu.setInterruptPinPolarity(true);

 mpu.setMotionInterrupt(true);


 Serial.println("");

 delay(100);

}
```

```
void loop() {
  // put your main code here, to run repeatedly:
  if(mpu.getMotionInterruptStatus()) {
    /* Get new sensor events with the readings */
    sensors_event_t a, g, temp;
    mpu.getEvent(&a, &g, &temp);

    /* Print out the values */
    Serial.print("AccelX:");
    Serial.print(a.acceleration.x);
    Serial.print(",");
    Serial.print("AccelY:");
    Serial.print(a.acceleration.y);
    Serial.print(",");
    Serial.print("AccelZ:");
    Serial.print(a.acceleration.z);
    Serial.print(", ");
    Serial.print("GyroX:");
    Serial.print(g.gyro.x);
    Serial.print(",");
    Serial.print("GyroY:");
    Serial.print(g.gyro.y);
    Serial.print(",");
    Serial.print("GyroZ:");
    Serial.print(g.gyro.z);
    Serial.println("");
  }
  delay(10);
}
```

Final code for the pet with servo and MPU6050

```
// include library
#include <Servo.h>
#include <Ramp.h>
#include <Adafruit_MPU6050.h>
#include <Adafruit_Sensor.h>
#include <Wire.h>

#define FULLY_OPEN_ANGLE 70
#define FULLY_FOLD_ANGLE 170
#define TIME_RESPONSE 3000

#define WAITING_FOR_MOTION_STATE 0
#define OPENNING_THE_FRILL_STATE 1
#define FOLDING_THE_FRILL_STATE 2

ramp myRamp;
Adafruit_MPU6050 mpu;
Servo servo;

// this varible will indicate which state the lizard is in
int state = WAITING_FOR_MOTION_STATE;

// this variable will stand for the time it took for the ramp
// to reach the target motion. Currently it is set to 0.5s to reach the target
int time_run = 500;

//these two variables will record when the frill opens and closes
long int t_start;
long int t_end;

void setup() {
  Serial.begin(115200);
```

```
  //all the code below is obtained from the library
  // Connecting the mpu6050
  while (!Serial)
    delay(10);

  Serial.println("Adafruit MPU6050 test!");

  // Try to initialize!
  if (!mpu.begin()) {
    Serial.println("Failed to find MPU6050 chip");
    while (1) {
      delay(10);
    }
  }
  Serial.println("MPU6050 Found!");

  //setup motion detection

  mpu.setHighPassFilter(MPU6050_HIGHPASS_0_63_HZ);
  mpu.setMotionDetectionThreshold(5);
  mpu.setMotionDetectionDuration(10);
  mpu.setInterruptPinLatch(true);
  mpu.setInterruptPinPolarity(true);
  mpu.setMotionInterrupt(true);

  Serial.println("");
  delay(100);

  //Initialize the position of the frill
  servo.attach(3);
  servo.write(FULLY_FOLD_ANGLE);
}
```

```
void loop() {
 // the first state is the waiting for the motion
 if (state == WAITING_FOR_MOTION_STATE){
   if(mpu.getMotionInterruptStatus()) {
     //detects motion change the state of the frill
     state = OPENNING_THE_FRILL_STATE;

     // start interpolation to the fully open angle
     myRamp.go(FULLY_OPEN_ANGLE, time_run, CUBIC_OUT);
     double actual = myRamp.update();
     servo.write(actual);

     //store the time that it detected the motion
     t_start = millis();

     Serial.println(t_start);
     Serial.println("Motion detected, open the frill");
     Serial.println(t_start);
   }
 } else if (state == OPENNING_THE_FRILL_STATE){
   //the state now is oppening the frill

   //get the current value of from the ramp
   //and write it to the servo
   double actual = myRamp.update();
   servo.write(actual);

   //get the current time value
   t_end = millis();

   //if it opens the frill longer than time response
   // it will change the state to fold the frill
   if (actual == FULLY_OPEN_ANGLE && t_end - t_start >= TIME_RESPONSE){
```

```
      // change the state to fold the frill state
      state = FOLDING_THE_FRILL_STATE;

      //start interpolation to the fully fold angle
      myRamp.go(FULLY_FOLD_ANGLE, time_run, CUBIC_OUT);
      double actual = myRamp.update();
      servo.write(actual);
      Serial.println(t_end);
      Serial.println("More than 3s, close the frill");
    }

  } else if (state == FOLDING_THE_FRILL_STATE){
    //the state now is folding the frill

    //get the current value of the interpolation from the ramp
    //and write it to the servo
    double actual = myRamp.update();
    servo.write(actual);

    if (actual == FULLY_FOLD_ANGLE){
      // if it reach the fully fold angle
      // change the state to waiting for motion state
      state = WAITING_FOR_MOTION_STATE;
    }
  }
  delay(10);
}
```