Computer Aided Design and Prototyping

(ME444 – FALL 2024)

Chompy the Piranha Plant

Design Report

Group No. 3

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Revision History

S. No.	Date	Revision ID	Revision Details (Page No., Paragraph, Line No. etc.)	Author
1.	12/3/24	Revision A	Initial Release	McKenna Marlar
2.	12/6/24	Revision B	Appendix Creation	Ryan Spees

Executive Summary

The Piranha Plant Action Toy Project is an attempt by group A3 to bring to life the famous character from the Super Mario series as a motorized toy. It contains mechanical motions such as a chomping mouth and a rising and falling stem both of which are controlled by a cam-follower system. These motion systems accurately capture the motions of the character from his multiple appearances in games. Made with 3D printed components, reinforced with fiberglass, and painted to match the bright colors of the original character, this toy will not only win the hearts of Super Mario fans young and old but also stand out with its functional and interactive design. With its mechanical complexity and nostalgic appeal, the Piranha Plant toy can carve a niche in the video game toy market.

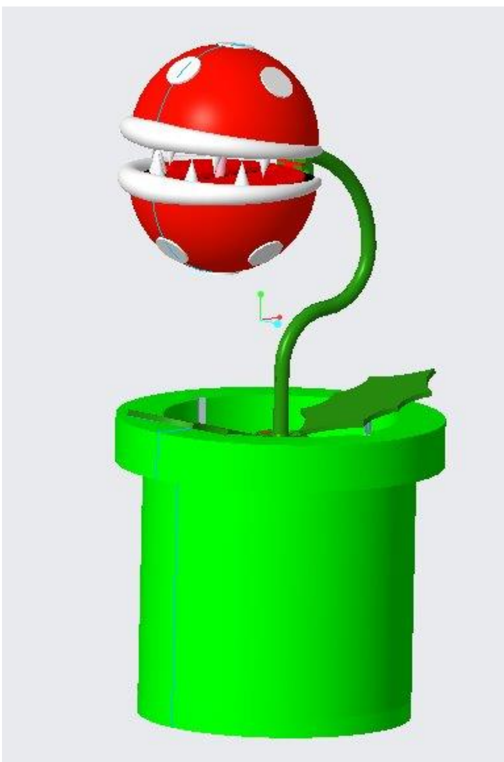

Figure i: Creo Model

Figure ii: Actual Model

(ME444_Group03/ActionToy_Proj/CAD/piranha_plant.asm)

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1. Introduction

1.1 Project Backgrounds

There is a real-world desire for replicas of well-known characters that the general audience would be able to enjoy. The *Super Mario* series has been a part of many childhood memories and is the bestselling video game series of all time. The Piranha Plant, as illustrated in Figure 1, is a feisty character appearing in *Mario Kart* and *Super Mario Bros.*, is an iconic enemy in the *Super Mario* universe. Its simplistic shape and motions allow it to be the perfect candidate for this project.

For the first action, it was chosen to characterize the chomping of the mouth by creating a mechanism that opens and closes the upper jaw of the Plant's head. In addition, the appearance and disappearance of the Plant from the pipe, as seen in the *Super Mario Bros.* series, is replicated by the rising and falling motion of the Plant's stem. This motion also allows the leaves to tuck into and fold out of the pipe.

Since *Super Mario* is such a beloved franchise, there are already numerous toys in the market relating to the famous games. However, many designs are of the main characters of the series and don't often incorporate mechanical aspects that allow the toy to move. The most similar toy today is the Lego Piranha Plant set #71426, which could allow the consumer to manually replicate the chomping motion but still doesn't involve electromechanical workings. That being said, a Piranha Plant toy would be a fresh addition to the toy market and would attract many consumers, both young and old.

Figure 1: Piranha Plant Character Design

1.2 Design Requirements & Constraints

Essential Requirements:

- Team must create a movable mechanical or mechatronic toy
- Design must have market potential
- Include a minimum of two non-trivial functions or actions
- Have an aesthetic design

Project Constraints:

- Complete toy must not exceed a 10x10x10 inch space
- The total cost of all purchased parts must not exceed $70
- Components from the guided project may be used

Engineering Specifications:

- Allow the head to rotate at least 10 degrees between its open and closed positions.
- Allow the Plant to rise and fall a minimum of 1 inch.
- Be able to have the stem support the weight of the head

2. Concept Generation and Selection

Originally, one function of the Piranha Plant that was considered was for a swiveling head. In the game, the stem of the Plant has a full range of motion allowing the head to point in various directions. Incorporating a rotating head would have caused shear stresses on the stem, which would be hollow due to wires having to be run through the stem, thereby exacerbating the stress concentration. This concept would also include more components within the head of the Plant, which is spatially limited. A top-heavy design is undesirable due to its instability and the possibility of excessive weight snapping the stem.

Furthermore, the concept pitch design had a scissor-lift mechanism for the rising and falling action of the Plant. This idea has multiple moving parts and would take up more space within the base, forcing the prototype out of the space constraint. With more components, the instances where interference could occur increases, as well as the probability for failure. Thus, the idea was scrapped.

Another idea that was conceived was to design a rack and pinion mechanism that would allow for up and down motion. One of the concerns about this design was that a 3D printed gear and rack would not be able to mesh well enough and that it would not functionally work. There were also concerns about space as for the motor to change direction an H-bridge would be required, which would take up too much real estate in the space constrained pipe.

The finalized design includes a cam-follower for both the chomping motion and rising and falling motion. These mechanisms take up minimal space within their respective housings and incur the least amount of excess weight. By minimizing the weight on the upper section of the toy, the risk of breaking the stem is decreased. Moreover, a cam-follower requires less components in the base. The ideal design was chosen to reduce the weight of the toy while still achieving fluid functions.

3. Detail Design

3.1 Sub-system 1

The first sub-system that was designed is chomping mouth motion. The first concept to mimic this motion was envisioned as a cam-follower system, illustrated in Figure 2, where a cam was located in the middle of the lower jaw that would rotate an eccentric disk. This cam would be controlled by a motor that is slotted into one side of the lower head. The lower head would be fixed and not be allowed to have motion relative to the stem. The follower of the system would be a separate part that is mounted perpendicular to the top jaw. The upper head would be able to have free motion with respect to the stem due to the head being sized as a clearance fit.

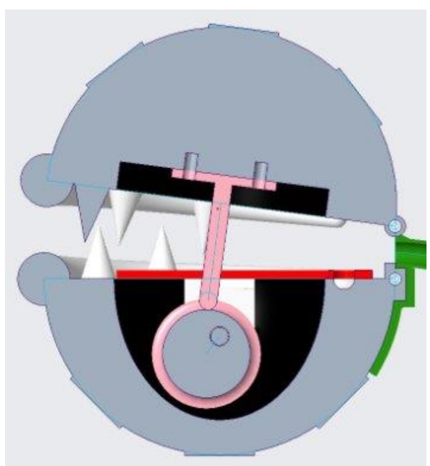


Figure 2: Cam-Follower Chomping System

One issue with the design of the cam-follower system is that it does not provide a large rotation for the mouth, only providing 12 degrees of rotation. Because of this, an alternative design was created that replaces the cam-follower with a 4-bar linkage system. The 4-bar linkage, illustrated in Figure 3, comprises of one link which is attached to the motor, another link which connects this first bar to an adapter. This adapter attaches to the same mounting point as the follower for the upper head. The third bar of the system is the upper head of the Piranha Plant itself. The design of the 4-bar linkage is therefore a crank rocker, as one bar is allowed full rotation, and thereby allows the pinned head to be allowed to oscillate between an open and closed position. This crank rocker was designed to cause more dynamic rotation, outputting 35 degrees of rotation for the head. Ultimately this design was not implemented into the final product as detailed later due to issues during testing.

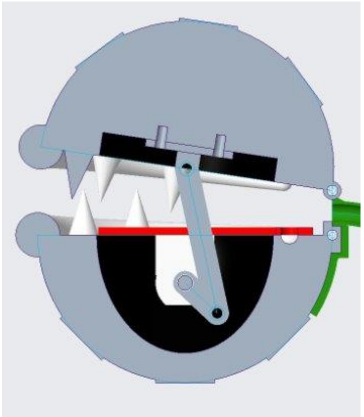


Figure 3: 4-Bar Linkage Chomping System

3.2 Sub-system 2

The next sub-system that was designed is the rising and falling action of the Piranha Plant in and out of the green pipe, which was accomplished using another cam-follower system. The cam, illustrated in Figure 4, would be located at the center of the pipe and mounted to a motor that is on a stand attached to the base of the pipe. The follower would be attached to the bottom of the potted bed which the stem of the Piranha Plant is mounted to. The cam system allowed for 22.5mm of vertical motion throughout the cam's cycle. Initially the motor that was chosen to drive the cam, illustrated in Figure 5, was a 130 sized DC hobby motor [1], though concerns about the motor not being able to provide enough torque to lift the entire Plant up, therefore a secondary design was considered. The secondary design, illustrated in Figure 6, replaces the hobby motor with a gearbox driver variant [2].

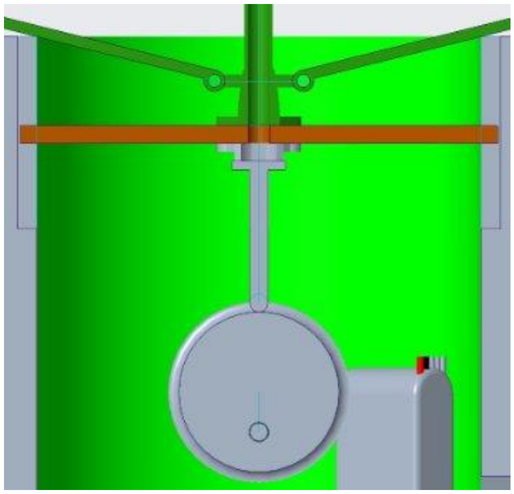


Figure 4: Cam-Follower Rise and Fall System

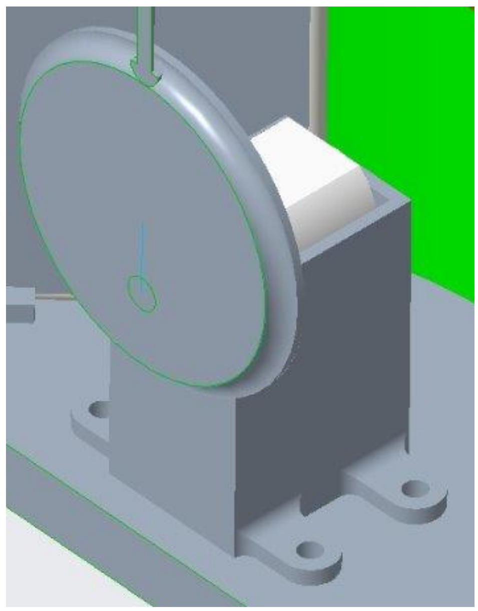


Figure 5: Hobby DC Motor Stand

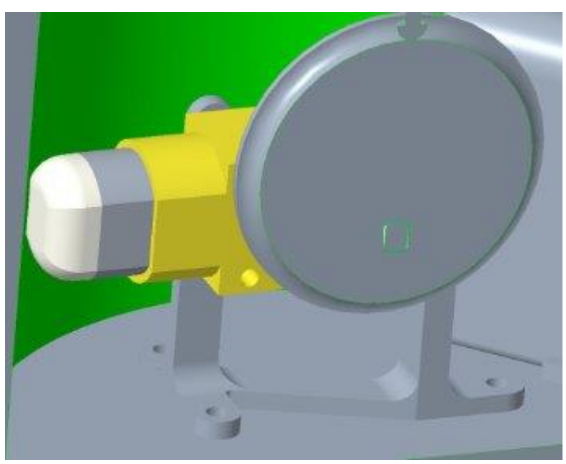


Figure 6: Geared Motor Stand

A secondary feature of the rising-falling action is the motion of the Plant's leaves. The leaves were designed to be clearance fits, allowing them to freely rotate. In their neutral position, illustrated in Figure 7, gravity pulls the leaves down until they rest on the edge of the green pipe. When upward motion occurs, the leaves are allowed to fold out more, illustrated in Figure 8, while when downward motion occurs, they are allowed to be folded up by the normal force exerted by the edge of the green pipe.

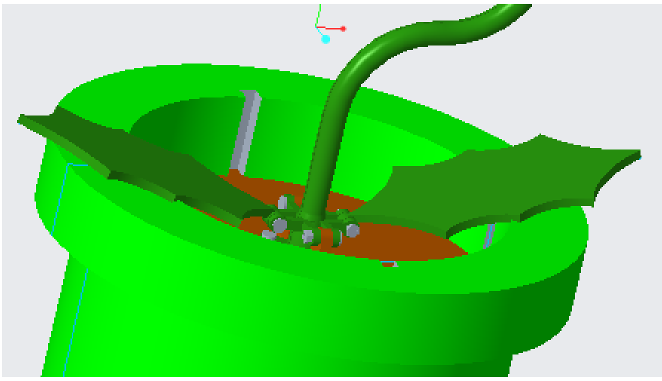


Figure 7: Leaves Folded Out

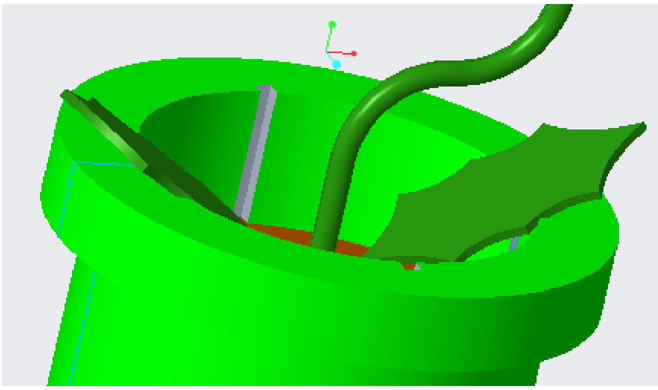


Figure 8: Leaves Pulled In

3.3 Sub-system 3 (Electronic Systems)

The electrical system is necessary for the Piranha Plant to be able to have motion independent of user input. The electronic system is powered by a 7.4V lipo battery, which gave an upper limit to the amount of voltage the motors chosen could run at. To get the most out of the motors, it was decided to run the two motors parallel to each other, such that they would both be able to receive the whole voltage. The two motors did not require any form of electronic control as all mechanisms designed required 360 degrees of rotation at a constant speed to function properly. The only other addition to the system was a push button that was connected before the motors to the battery to allow for the user to turn the toy on and off at their choosing. All electronic components were wired through a breadboard. The complete electronic circuit is visible in **Appendix E**.

3.4 System Integration

The mechanical sub-systems were integrated through the creation of a skeleton model that provided a framework behind how the general motions look and operate, illustrated in Figure 9. Simulations of this skeleton model were created by modeling the two motors running at the same time at a constant 72 degrees/second. One inconsistency that was necessary for the skeleton model to be fully modeled is that the leaves are modeled parallel to the Piranha Plant head, when the character's design has the leaves located perpendicular to the head. This finished prototype has the leaves located in their proper location.

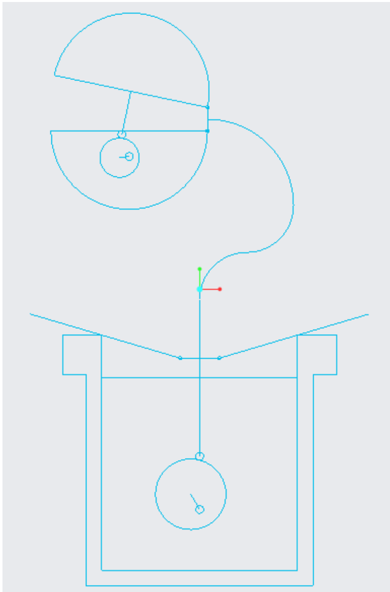


Figure 9: Skeleton Model

With the skeleton model created, all parts were designed and based around their skeleton representation. The electronic system was integrated into the mechanical systems by having the battery and breadboard placed on the bottom plate which the pipe is screwed into. The battery's charging port is fed out of the pipe through a hole to allow the user to be able to connect the battery to a charger. The battery was then wired into the breadboard. The button is placed into a hole located above the charging hole, with its wiring also fed into the breadboard. The lower motor that controls the rising and falling cam is then wired into the breadboard. The wiring for the motor is accomplished by having it be fed through a slot on the lower head, down the stem, and out of the potted bed the stem is mounted to. The stem of the Piranha Plant was modeled as two separate pieces to allow for ease when feeding the wiring. This wiring is then attached to wires placed into the breadboard for this motor, these wires are ensured to have enough slack to allow for them to move during the rising and falling motion without becoming detached. Complete wiring pictured in Figure 10.

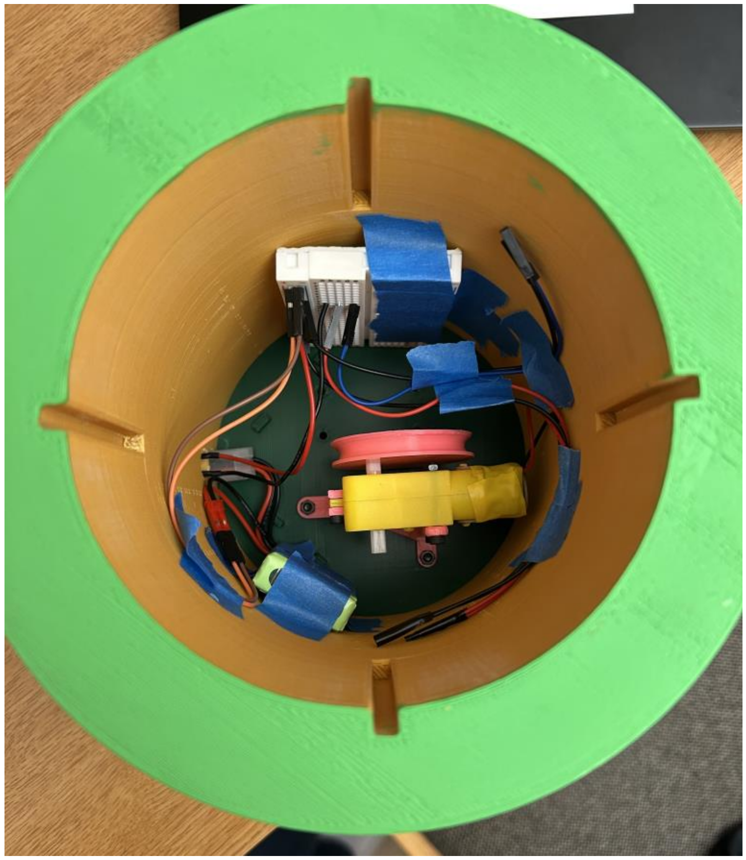


Figure 10: Complete Electrical Circuit

4 Prototyping and Testing

A cardboard prototype of the Piranha Plant was designed to provide a rough idea behind how the size and shape of the CAD model would look to a physical degree. Prototype pictured in Figure 11. Rudimentary representations of the sub-system mechanisms were also installed within the prototype to gain basic understanding behind how the mechanism could be implemented into the final design and their space limitations.

Figure 11: Low Fidelity Prototype

During the design process of the CAD, all parts were made with their fasteners being M3 nuts and bolts to allow for simplicity when assembling. The leaves were designed as duplicates of each other to allow for ease of assembling. The stem was designed in two pieces for ease of threading the wiring through the stem and fitting the Piranha Plant head to the stem. The stem had hasteners on its sides and at its base to keep the part secure to the potted bed and to prevent bending. The two raised mounting ports on the potted bed for the stem also serve to indicate which side is up. Channels were made in the pipe and lined up with extrusions along the potted bed that allowed for contact between the bed and the pipe, preventing the bed from rotating while inside the pipe. The two different motor stands made for the rising-falling cam had different number of screw holes to prevent confusion over which side each motor is to be mounted for testing. Small, raised ridges to hold the battery and breadboard in place also serve to indicate which side is up for the bottom plate. **Appendix B** contains the complete assembly drawings and exploded view drawings.

All CAD design parts were 3D printed using a combination of Pulse printers and Luzbot TAZ Pro and using PLA filament. The reasoning behind 3D printing is that a lot of the parts are round or curved in nature, therefore 3D printing would provide the quickest and cleanest method to fabricate these parts. A complete set of 3D printed parts is in **Appendix A**. The head parts were printed at 10% infill to reduce weight in the final product. Unfortunately, the support for the heads caused the tops to come out messy, and since the reprint time was 15 hours it was decided against giving the parts another run. The stems were printed with 70% infill to increase the strength in holding up the head. Unfortunately, these parts were still too bendable as initial assembly resulted in immediate bending that was deemed unacceptable. The solution for this was to coat the stems in fiberglass to strengthen the stems and prevent significant bending. Silicon putty was also used to fill regions missed by the fiberglass epoxy. The results of this processing were stems that could support the head and only had minor bending when the entire assembly was shaken. Complete Plant assembly with fiberglass pictured in Figure 12. The pipe featured troubles when printing as it would not properly adhere to the print bay and dislodged and shifted during printing, resulting in three total prints being started until a successful one was output. **Appendix C** contains a complete BOM of all parts, 3D printed or provided, used to assemble the finished product.

Figure 12: Complete Plant with Fiberglass

To maintain a clear resemblance with the original character model, some parts were painted with acrylic paint to replicate this appearance. When assembling the toy, there were issues with the clearance between the pipe and the potted bed, resulting in a lot of sanding to get the bed to slide freely in the pipe. The final bed can only freely move in one orientation, and rotating the bed can result in the bed being stuck. This final orientation has the push button align with the side profile of the Piranha Plant. Another issue that was encountered was that because the head was off balance due to the inclusion of a motor in one side, when the rising falling cam was activated, the Plant would tilt to one side and get jammed. It was during this testing that it was concluded that the non-gear DC motor was inadequate at lifting the Plant, resulting in the alternate gearbox motor to be implemented. Testing the alternate 4-bar linkage mechanism proved it futile due to the speed of the mechanism causing the nuts and bolts to disassemble rapidly, rendering the mechanism useless. When testing the chomping cam, it was found to have inadequate torque to lift the upper head. The motor was also spinning too fast, so instead of a cam making contact with the follower, it was a vibrating disk which knocked the follower out of place. Therefore, an alternate FF N20 07280 motor [3] to be used to provide enough torque for the cam-follower system to work. A complete breakdown motor specifications for all motors tested is in **Appendix D**. One issue with this motor was that it was much smaller than the previous motor used, meaning that it would not fit into the slot designed to hold the motor. The solution for this was to use tape to raise the platform the motor sits on and to secure the motor down. Luckily, this smaller motor allowed the Plant to be able to keep its balance better and prevent tilting and locking up. New motor installation pictured in Figure 13.

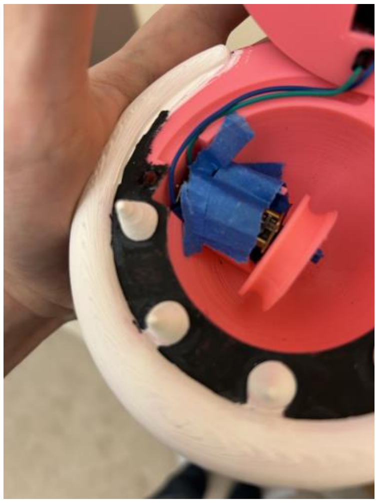


Figure 13: New Motor Installation

5. Results and Discussion

From the finished product, both major sub-systems function to an extent. The finish product is pictured in Figure 14. All electronics were successfully wired together such that when the on button is pushed both motors activate. For the chomping motion, since the new motor that was installed doesn't fit inside the designated slot, the motor is susceptible to shifting. This causes the cam to twist and rub up against the cover plate, thereby missing contact with the follower. When the cam was in place, the follower was found to get stuck on the cam, applying a lubricant to the cam appeared to provide minor assistance in allowing motion. The rise-fall cam did work, but was rotating too quickly, which caused the up and down motion to be too chaotic. This chaotic motion also caused the Plant to twist and lock up. The leaves were luckily fully functional, and their motion caused no issues to the project at large.

Figure 14: Complete Design (Closed Mouth and Down)

If more time was devoted to the project, some changes would be to redesign the bottom jaw to accommodate the new motor and see if the slower speed of the motor now allows the 4-bar linkage design to work without disassembly. The lower cam system would also be redesigned. Instead of having a cam perpendicular to the bottom plate, have a parallel disk spinning clockwise to a motor mounted perpendicular to the plate as to parallel. Model a sinewave on the edge of the disk, so that when the disk spins, the sinewave drives the up and down motion of the follower. The number of followers should also increase from one to four to allow for better stability of the final product. Finally, all cam systems should have better lubrication to prevent sticking between the cam and followers. A focus should also be placed on having more dynamic motion for the model, such as having the head open its jaw 45 degrees and having the up-down travel length be 75 mm. In terms of the physical design, applying a cleaner coat of fiberglass and using a primer before the acrylic paint would be useful in cleaning up the final design.

Some learning objectives that were learned are ow to create a skeleton model and model a simulation of its motion. How to create a CAD assembly around a skeleton model and model parts off skeleton parts. How to design cam-follower and 4-bar linkage systems and model them in CAD. How to specify motors and test them for suitability. A personal objective was learning how to mix and apply fiberglass to parts.

6. Conclusion

In conclusion, a prototype was successfully made and assembled of a Piranha Plant from the Super Mario series, which features two electro-mechanical systems: a rising-and falling cam-follower system, and a chomping cam-follower system. The prototype was fabricated using 3D printed parts, fiberglass, acrylic paint, a 7.4 battery, a breadboard, a button, A N20 Micro Gear Motor, a TT DC Motor Gearbox, wires, and M3 nuts and bolts. Both mechanisms had trouble fulfilling their required actions. The chomping motor wasn't properly connected resulting in the cam twisting and not being in line for the follower. The rise-fall cam was travelling too fast and causing the Plant to tilt and shake. In the future, the motor controlling the chomping would be given a better mounting connection, and the rise-fall cam-follower system will be redesigned to a slower parallel mounted sinusoidal cam with more followers to allow for better motion and prevent tilting. The motions will also be more dynamic with increased mouth rotation and linear translation.

References

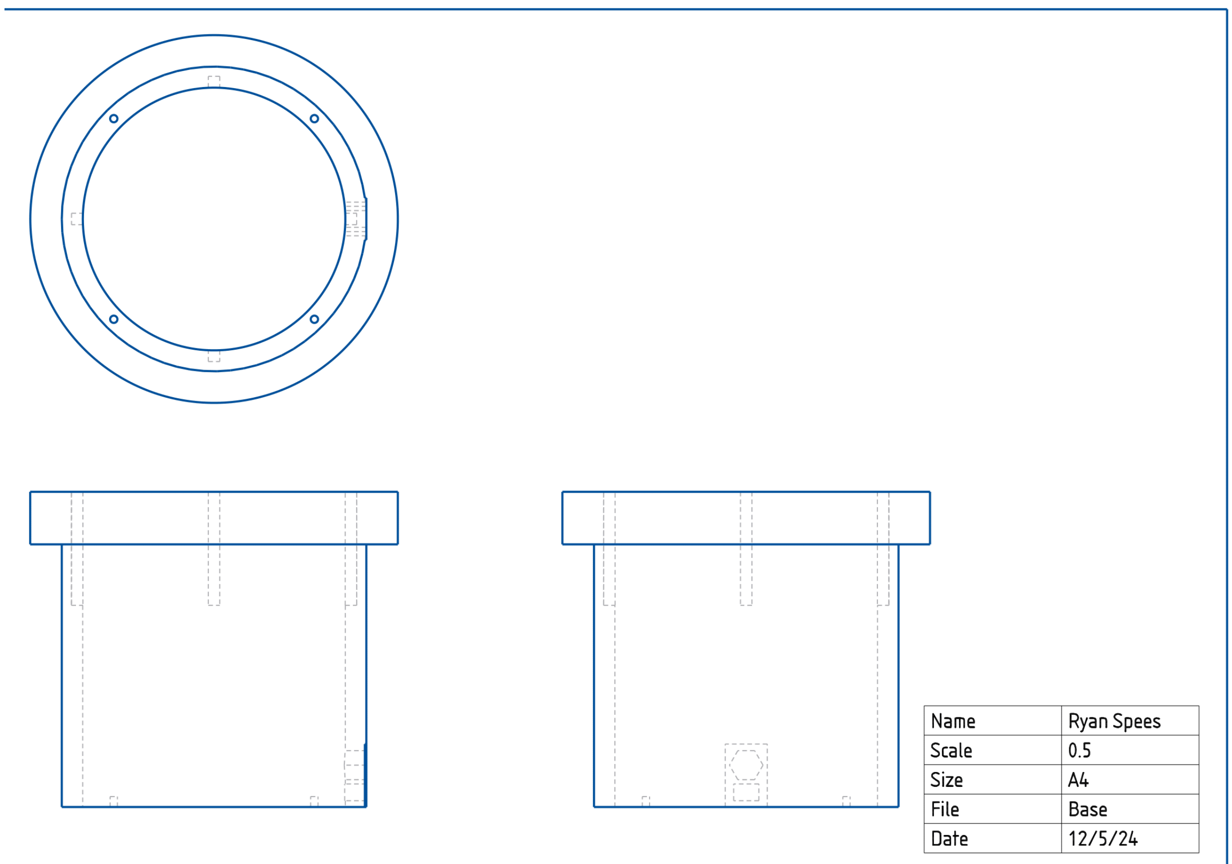
[1] Industries, A. (n.d.-b). *DC Toy / Hobby Motor - 130 size*. adafruit industries blog RSS. https://www.adafruit.com/product/711?gQT=1

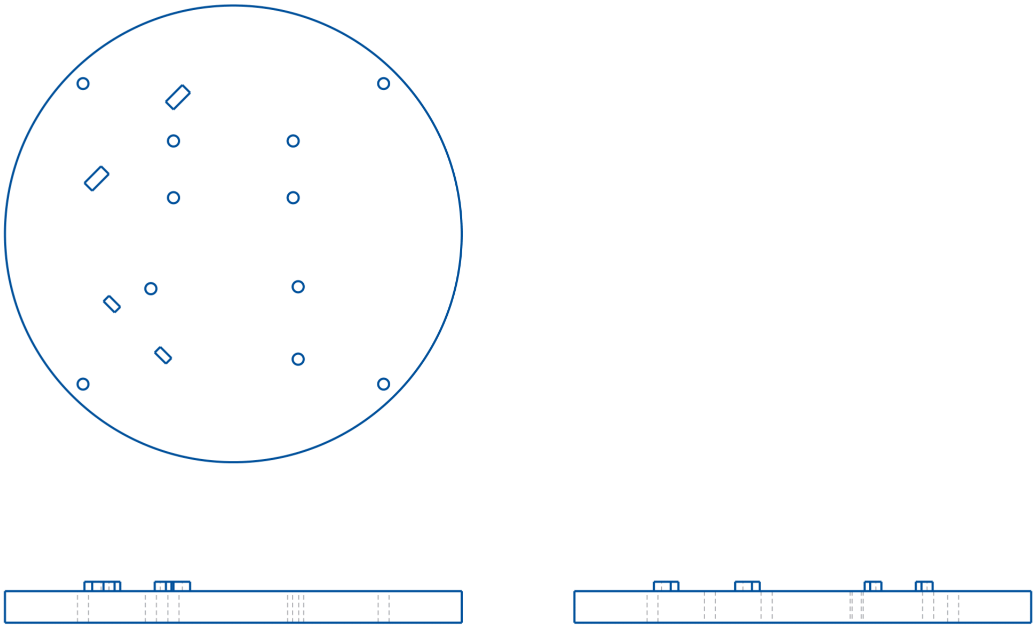
[2] Industries, A. (n.d.). *DC gearbox motor - "Tt motor" - 200RPM - 3 to 6VDC*. adafruit industries blog RSS. https://www.adafruit.com/product/3777#technical-details

[3] *N20 Micro Gear Motor: 12mm DC gear motor for Model Train - Ric Motor*. N20 micro gear motor | 12mm dc gear motor for model train - RIC MOTOR. (n.d.). https://www.ricmotor.com/details/12mm-dc-gear-motor

Appendices

Appendix A: Part Drawings





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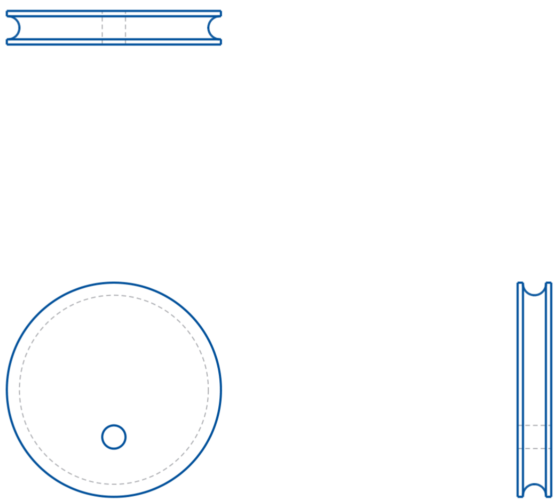

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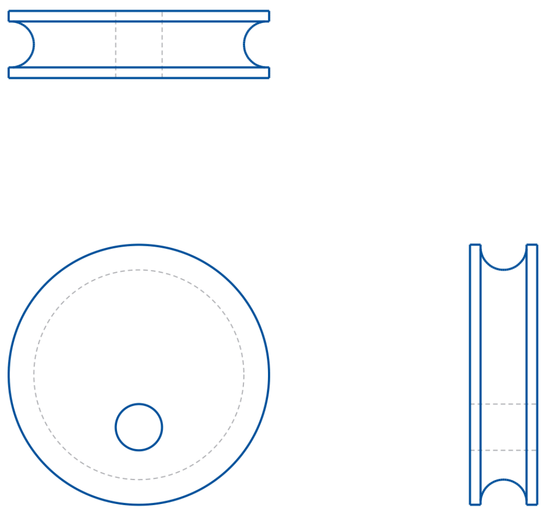

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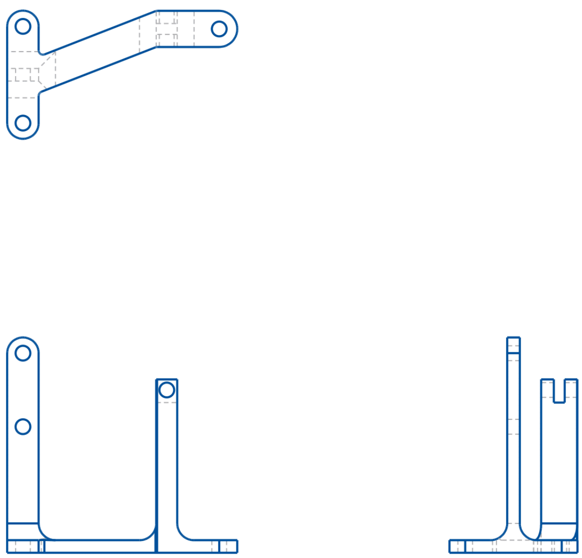

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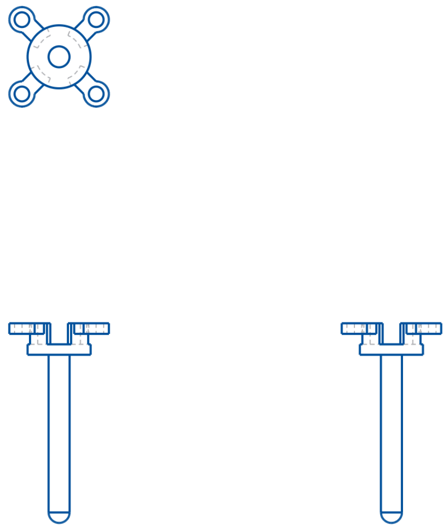

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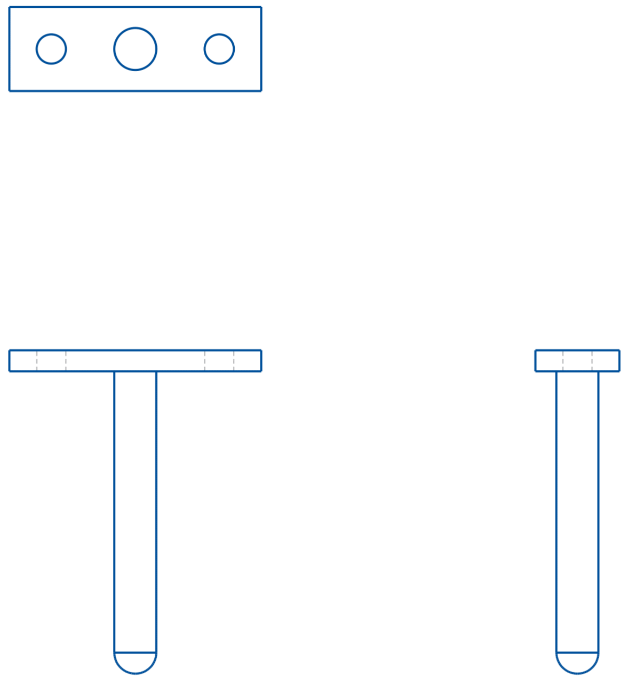

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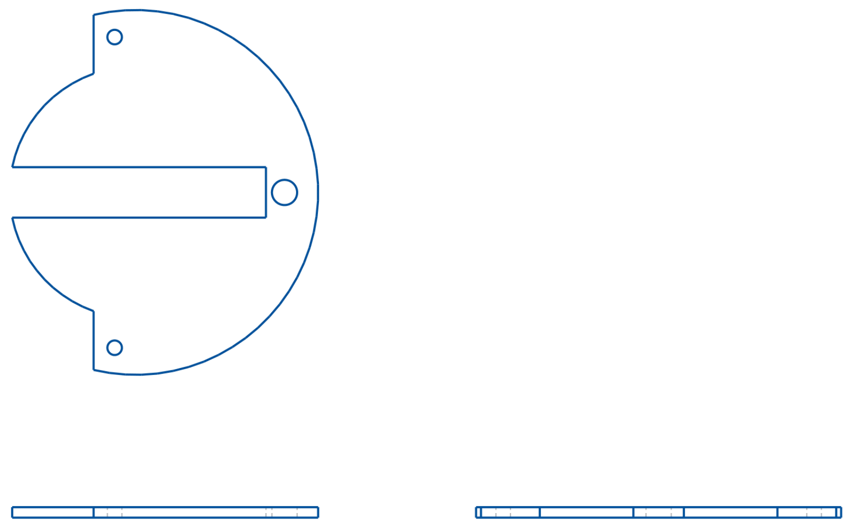

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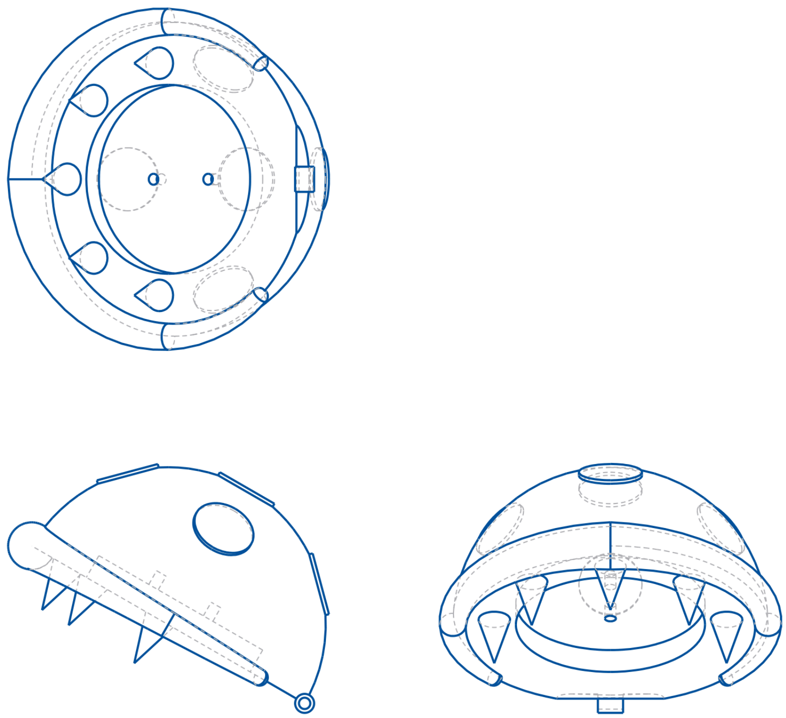

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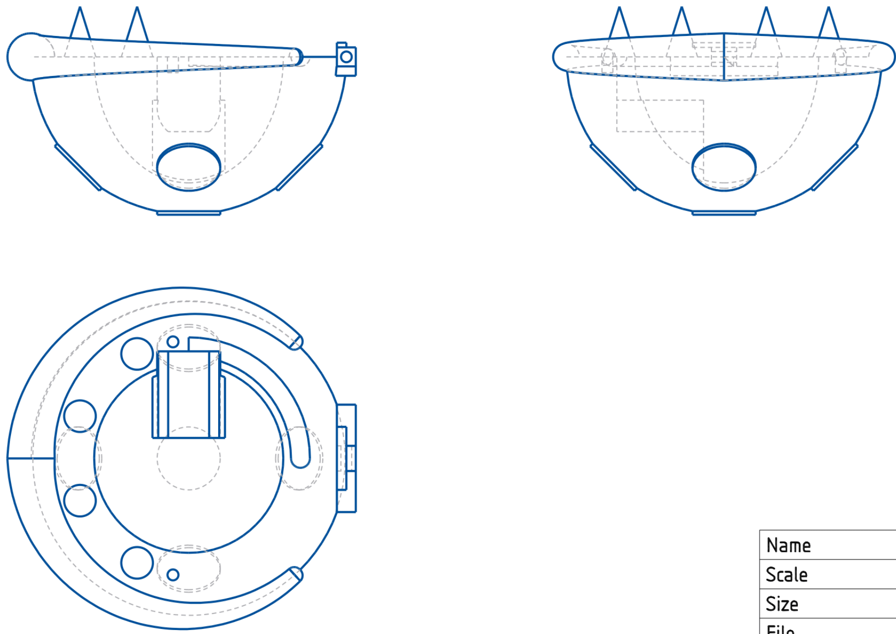

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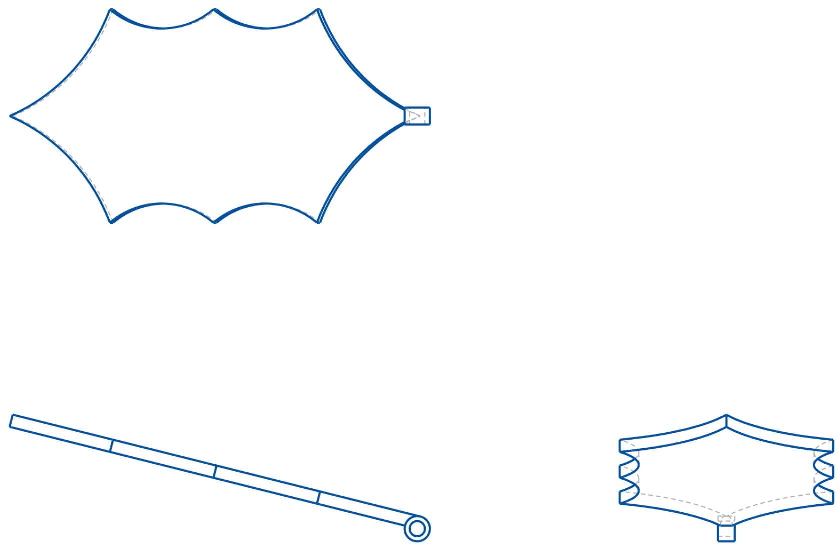

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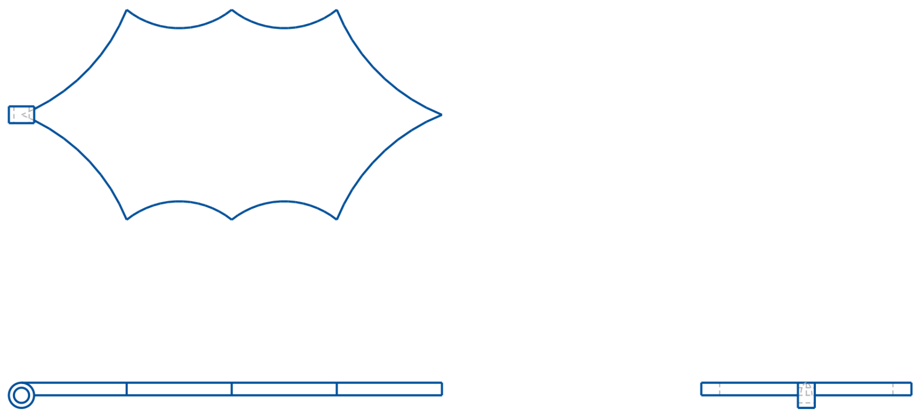

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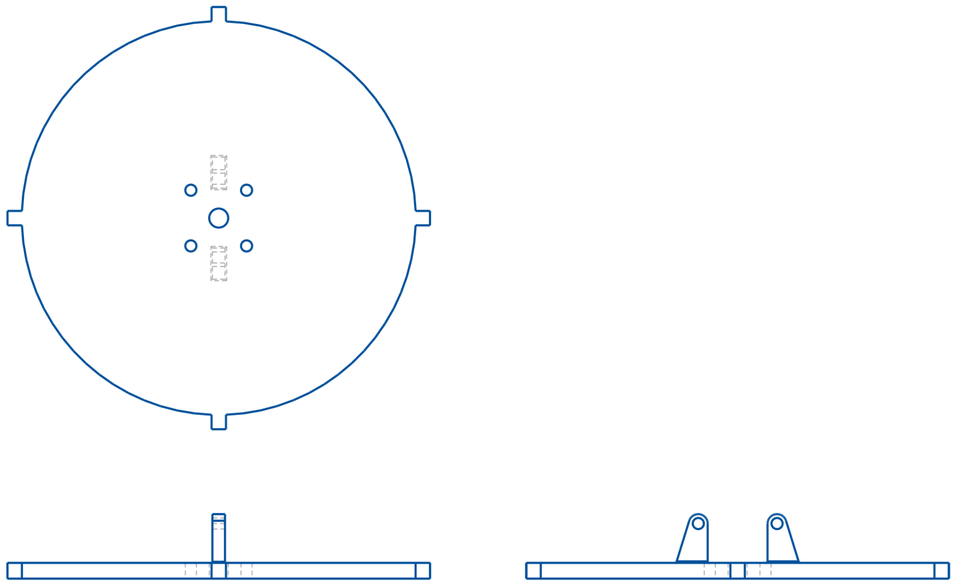

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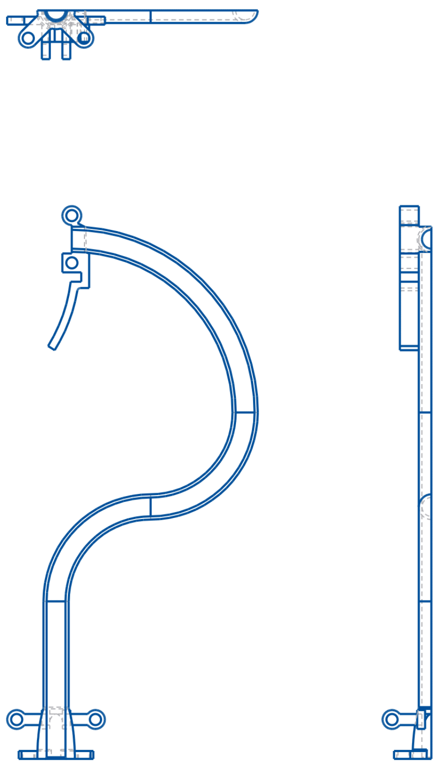

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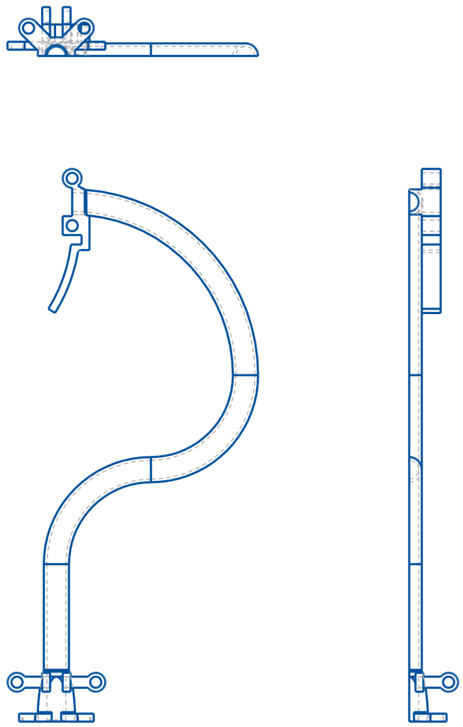

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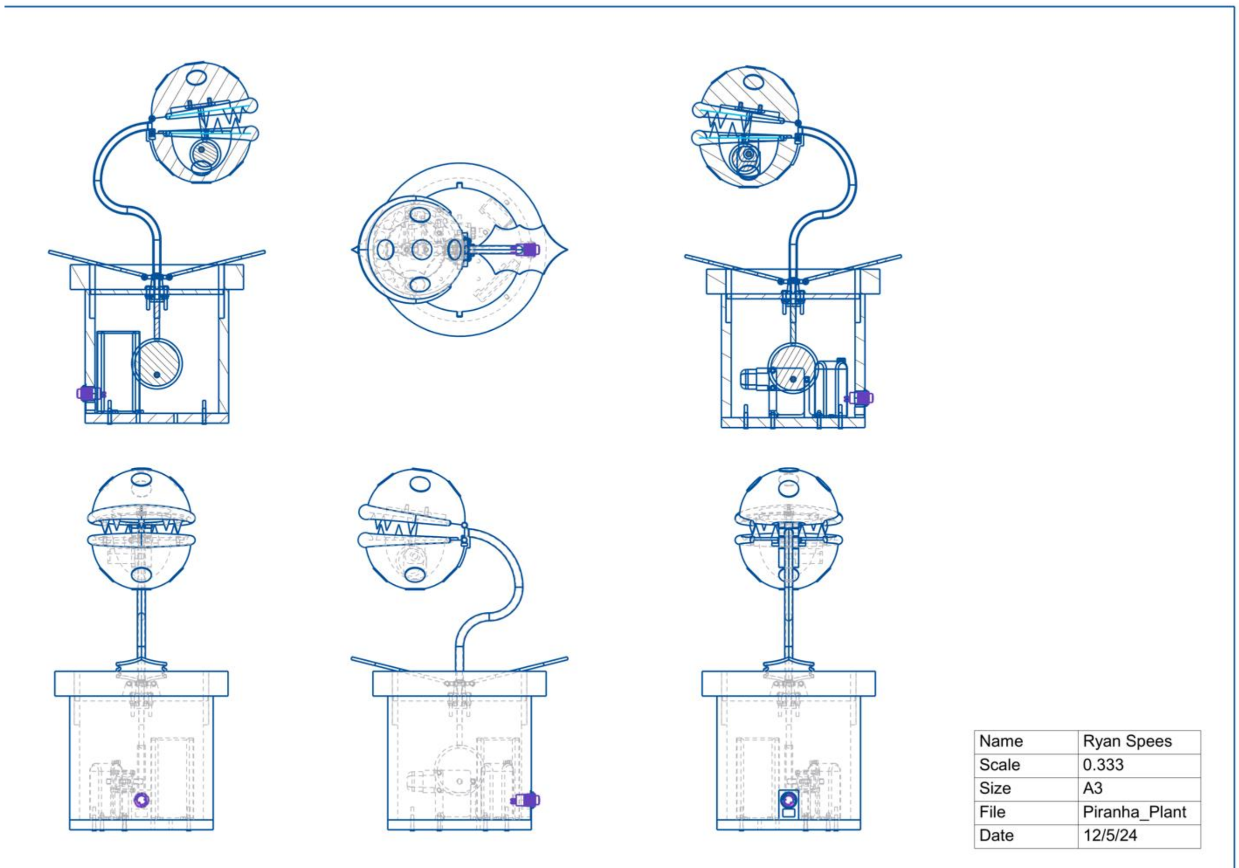
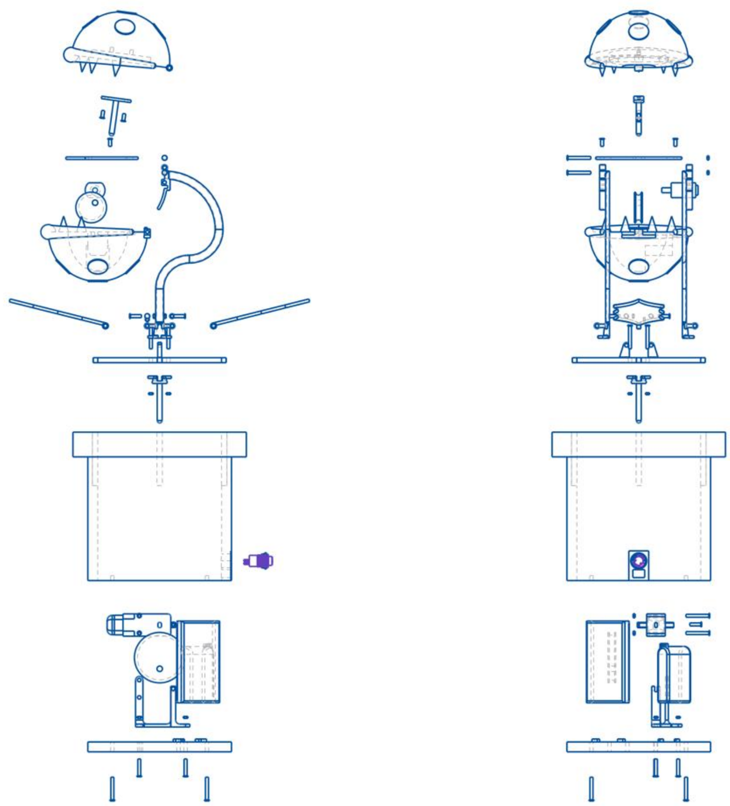
Appendix B: Assembly Drawings





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Appendix C: BOM

Bom Report : PIRANHA_PLANT

Assembly PIRANHA_PLANT contains:

Quantity	Type	Name	Actions
1	Part	BASE	
1	Part	STEM1	
1	Part	HEAD1	
1	Part	LEAF1	
1	Part	LEAF2	
1	Part	CAM_BASE	
1	Part	FOLLOWER_BASE	
1	Part	POTTED_BED	
1	Part	HEAD2	
1	Part	CAM_HEAD	
1	Part	MOTOR	
1	Part	FOLLOWER_HEAD	
1	Part	BOTTOM	
1	Part	LIPOBATTERY	
1	Part	BREADBOARD	
1	Part	STEM2	
1	Part	HEAD_COVER	
1	Part	DRIVE_MOTOR_STAND	
1	Part	DRIVE_MOTOR	
4	Part	M3_10MM	
4	Part	M3_6MM	
12	Part	M3_20MM	
1	Part	M3_8MM	
3	Part	M3_16MM	
16	Part	M3_NUT	
1	Part	BUTTON	

Appendix D: Motor Specifications

130 Size DC Hobby Motor

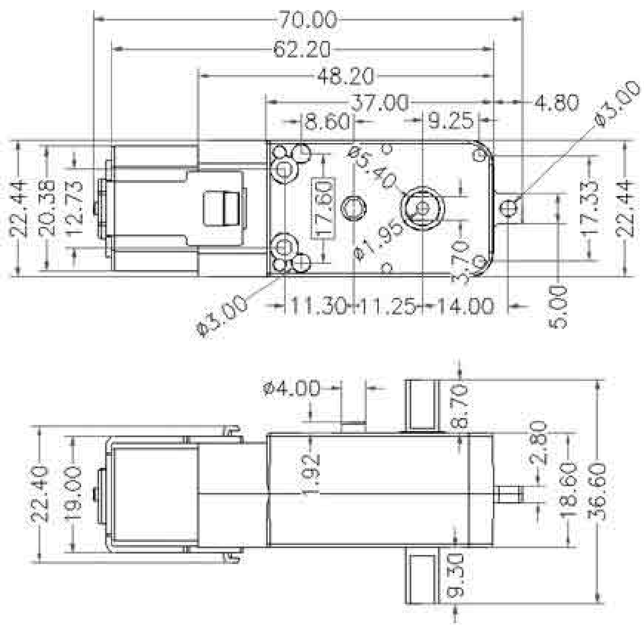
Technical Details

- Operating Temperature: -10°C ~ +60°C
- Rated Voltage: 6.0VDC
- Rated Load: 10 g*cm
- No-load Current: 70 mA max
- No-load Speed: 9100 ±1800 rpm
- Loaded Current: 250 mA max
- Loaded Speed: 4500 ±1500 rpm
- Starting Torque: 20 g*cm
- Starting Voltage: 2.0
- Stall Current: 500mA max
- Body Size: 27.5mm x 20mm x 15mm
- Shaft Size: 8mm x 2mm diameter
- Weight: 17.5 grams

DC Gearbox Motor – TT Motor – 200 RPM – 3-6VDC

Technical Details

- Rated Voltage: 3~6V
- Continuous No-Load Current: 150mA +/- 10%
- Min. Operating Speed (3V): 90+/- 10% RPM
- Min. Operating Speed (6V): 200+/- 10% RPM
- Stall Torque (3V): 0.4kg.cm
- Stall Torque (6V): 0.8kg.cm
- Gear Ratio: 1:48
- Body Dimensions: 70 x 22 x 18mm
- Wires Length: 200mm & 28 AWG
- Weight: 30.6g



Product Weight: 30.6g / 1.1oz

FF N20 07280

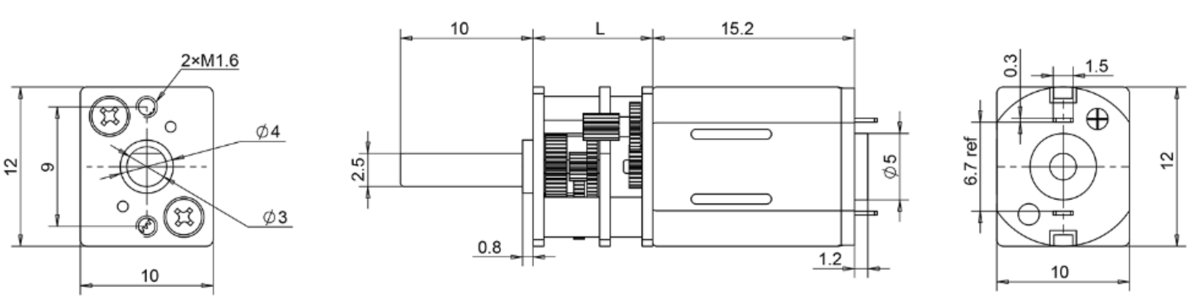
GEARED MOTOR TECHNICAL DATA

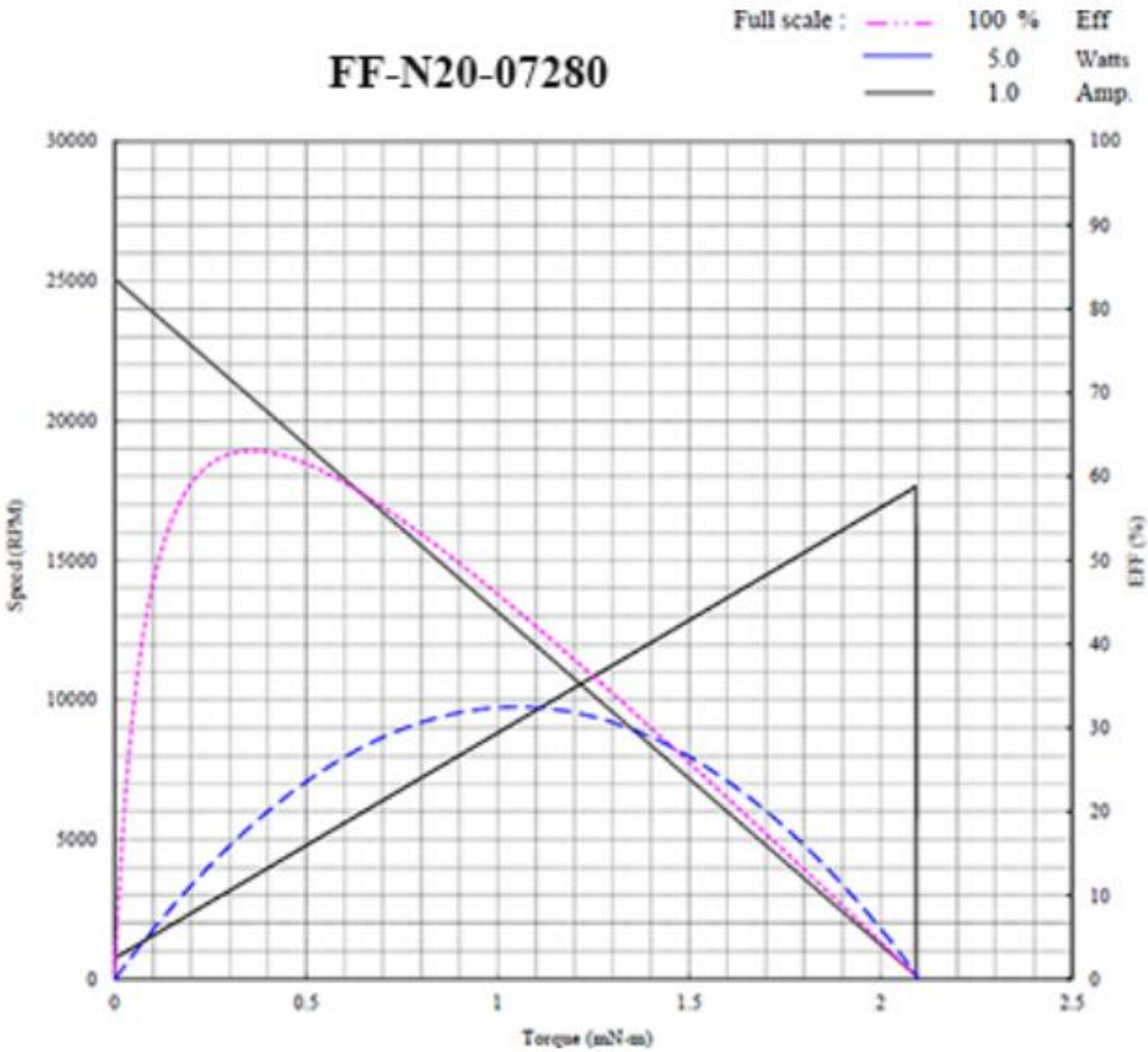
Rated voltage	Reduction Ratio	1/10	1/20	1/30	1/50	1/63	1/75	1/100	1/150	1/210	1/250	1/298	1/380	1/600	1/1000
3V	Rated Torque(kg.cm)	0.011	0.022	0.03	0.05	0.065	0.075	0.1	0.134	0.188	0.22	0.265	0.29	0.38	0.64
	Rated Speed(rpm)	619	309	206	118	98	82.5	62	41.2	29.5	25	20.8	16.2	10.2	6.1
5V	Rated Torque(kg.cm)	0.018	0.026	0.039	0.065	0.082	0.1	0.13	0.165	0.19	0.275	0.33	0.42	0.48	0.8
	Rated Speed(rpm)	1200	600	400	240	190	160	120	80	57	48	40	31	20	12
12V	Rated Torque(kg.cm)	0.016	0.033	0.045	0.078	0.1	0.112	0.156	0.2	0.277	0.33	0.395	0.5	0.58	0.96
	Rated Speed(rpm)	2100	1050	700	403	332	280	210	140	100	84	70	55	35	21
L(mm)		9	9	9	9	9	9	9	9	9	9	9	9	12	12

MOTOR SPECIFICATIONS

Model	Voltage	No-load		Rated				Stall	
		Speed	Current	Speed	Current	Torque	Output	Current	Torque
	VDC	rpm	A	rpm	A	g.cm	W	A	g.cm
FF-N20-08220	3	8060	0.025	6180	0.085	2	0.12	0.275	8.4
FF-N20-09195	5	15000	0.03	12000	0.14	2.5	0.31	0.64	13.3
FF-N20-07280	12	25000	0.02	21000	0.1	3	0.1	0.6	20

OUTLINE DRAWING




FF-N20-07280
Full scale :
100 %
Eff
5.0
Watts
1.0
Amp.
Speed (RPM)
30000
25000
20000
15000
10000
5000
0
EFF (%)
100
90
80
70
60
50
40
30
20
10
0
0
0.5
1
1.5
2
2.5
Torque (mN-m)

Appendix E: Circuit Diagram