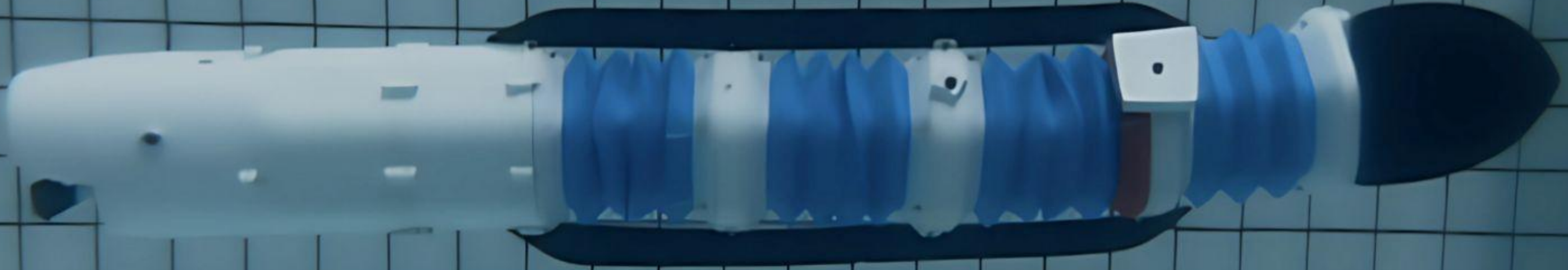
EELSWARD: Soft Robotic Eel



Electronic Eel Locomotion Soft Water Anguilliform Robotic Device

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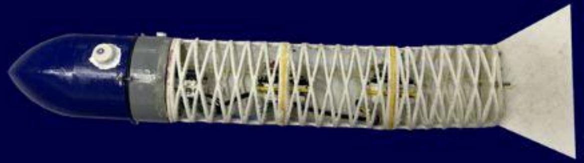
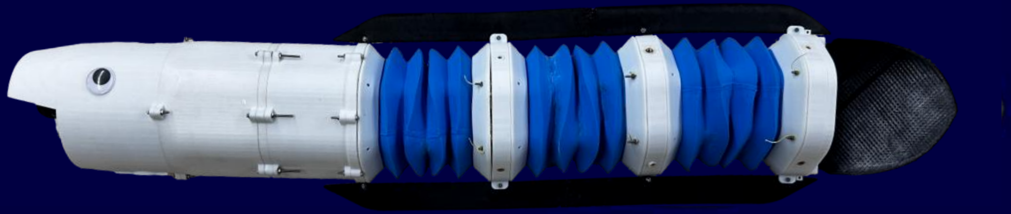
Overview

- Designed and built a robot inspired by anguilliform swimming to explore soft-bodied underwater locomotion, worked to improve upon a previous eel robot
- Focused on achieving flexible, scalable motion using 3D-printed accordion segments and servo-actuated cable routing'''
- Prioritized modularity, maneuverability, and repairability under tight constraints in time, budget, and team size
- Prototype demonstrates core movement principles and lays groundwork for future autonomous or sensor-integrated versions.

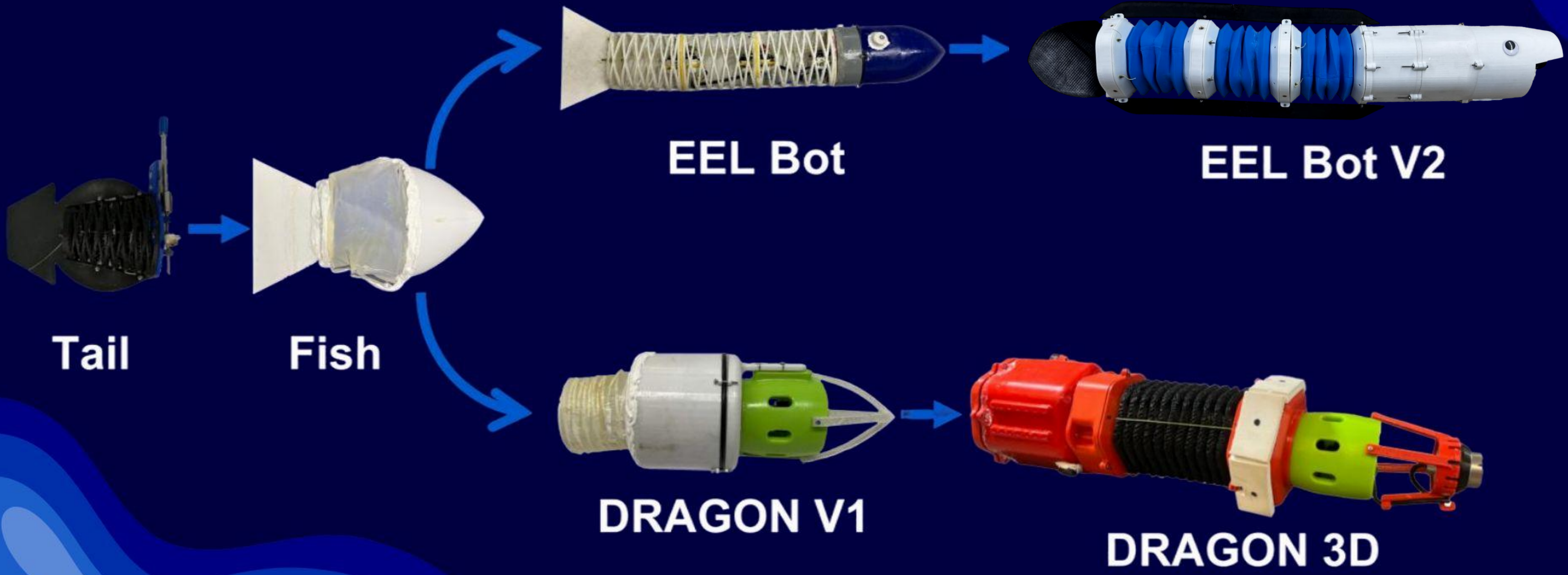


560 mm long



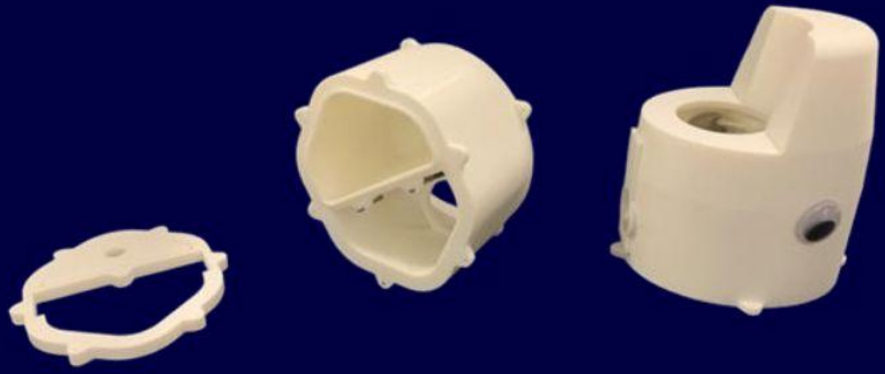
814 mm long

Prior Inspiration



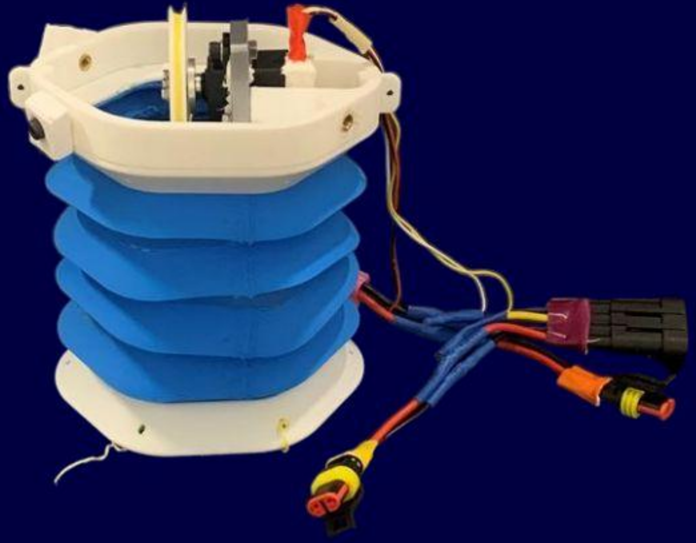
Development

Development: Overview



Head

Tail

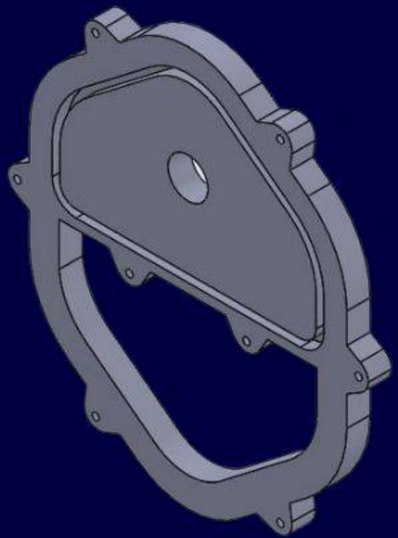


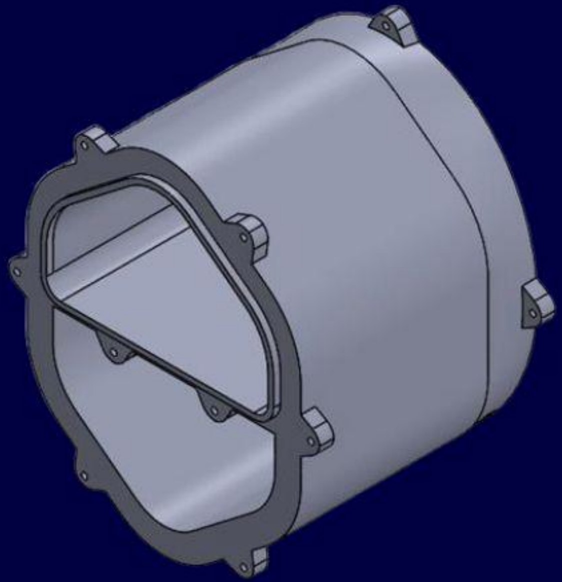
Body Modules

Development: Head - Mechanical

Battery/Sensor Compartment: This section currently houses the battery and was designed to eventually be able to house sonar and depth sensors, as well as a microphone for acoustic control

Control board compartment cover: This piece acts as the seal for the watertight compartment. It contains a rubber O-ring that uses pressure to keep water from getting in.

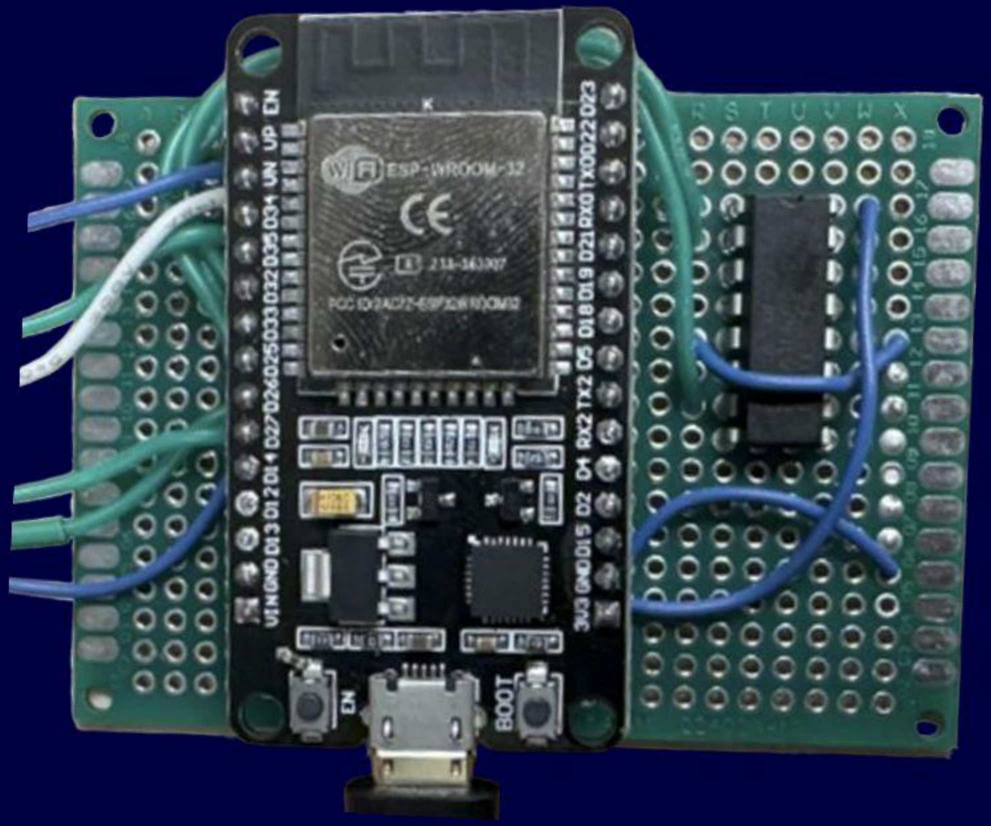




Control board compartment:
This section houses the control board and voltage regulator. It was designed to be watertight to keep our circuits from shorting.

Development: Head - Electrical

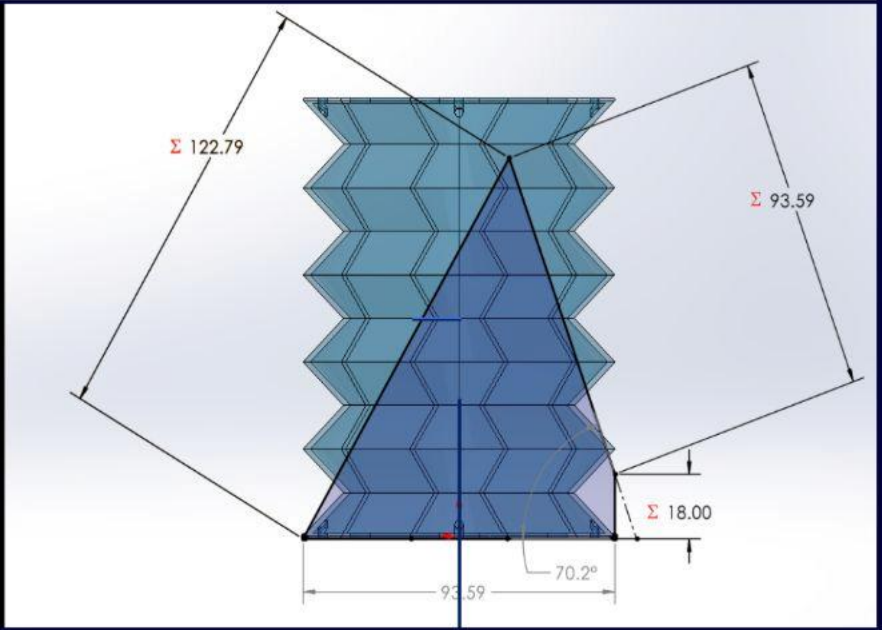
- Used a perf board for easy construction and modification
- ESP32 chosen for compact size and sufficient I/O pins
- Voltage regulator and L293D driver chip used for motor control
- Waterproof wire connectors for modularity and safety



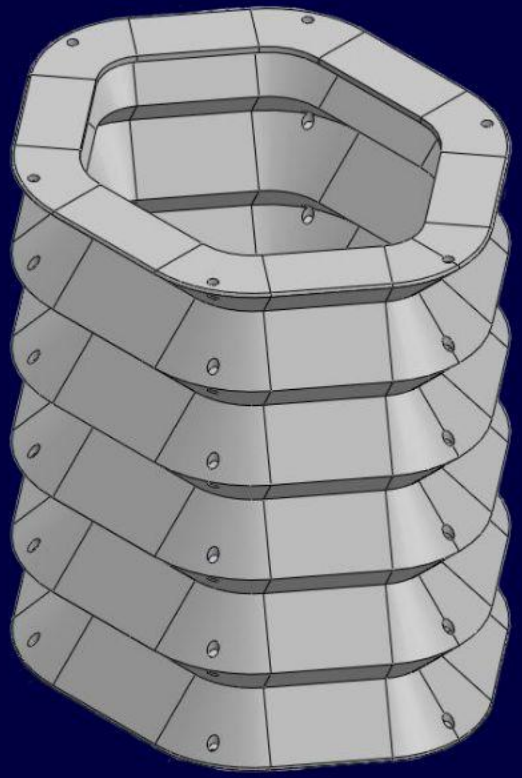
Development: Body Modules

Development: Accordions

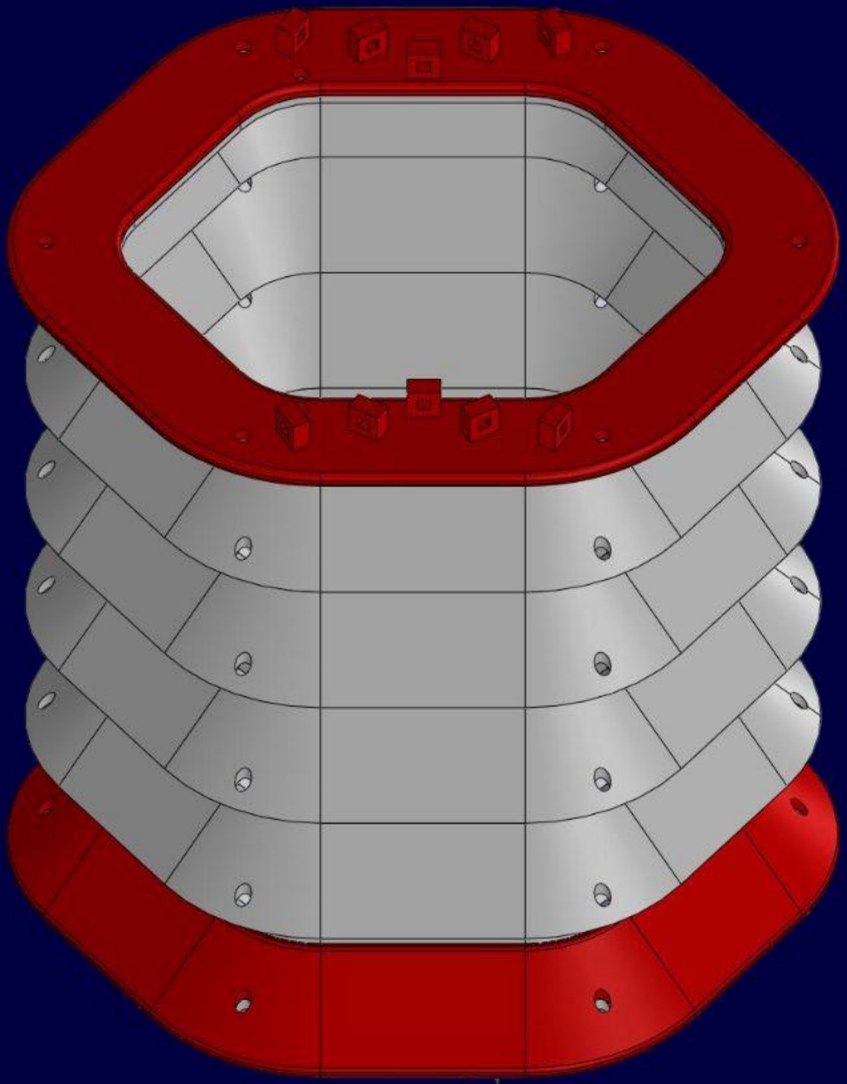
Iteration	0	1	2	3	4
Hypothetical Bend Angle (deg)	38.13	45.27	47.19	53.97	70.20
Height (mm)	100	100	100	100	125
Ridge width (mm)	10	20	15	15	15
Ridge angle (degrees)	30	30	30	45	45



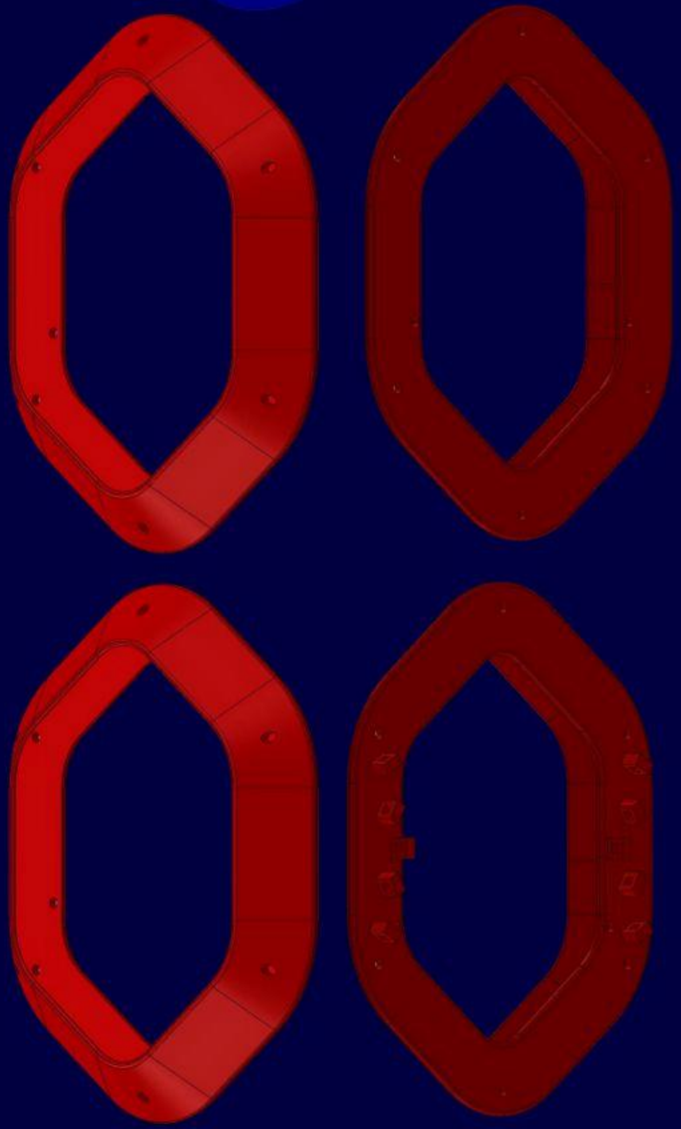
We utilized extensive parameterization/equations to model the impact of different characteristics on the bend radius



Development: Hex Caps



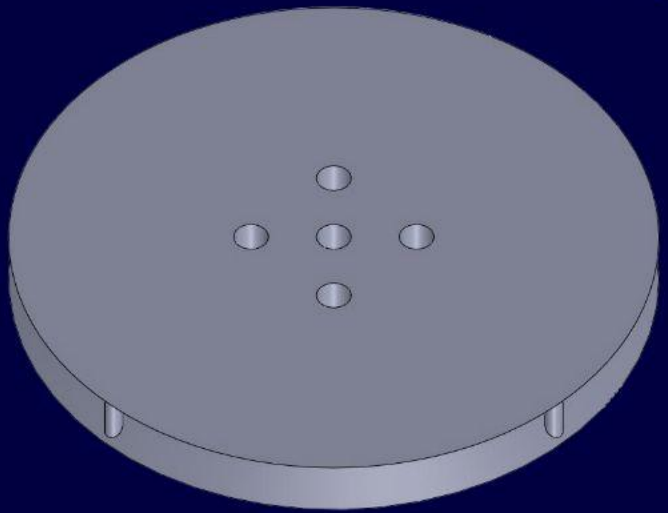
- Redesigned to reduce string tension by shifting string convergence to the passive side
- Added angled notches to replace sharp bends and improve motor efficiency
- Introduced snap-fit features and slots for potential electronics integration
- Focused on strength, printability, and minimizing unnecessary material use.



Development: Spacers and Spools

Spacers:
- Provide clearance for string guides
- Include attachment points for weights and floats
- Act as <u>motor mount</u>

Spools:
- Added angled grooves for better string centering
- Included string stoppers to prevent derailment
- Tuned size for 180° rotation without slippage
- Balanced friction and motor load.

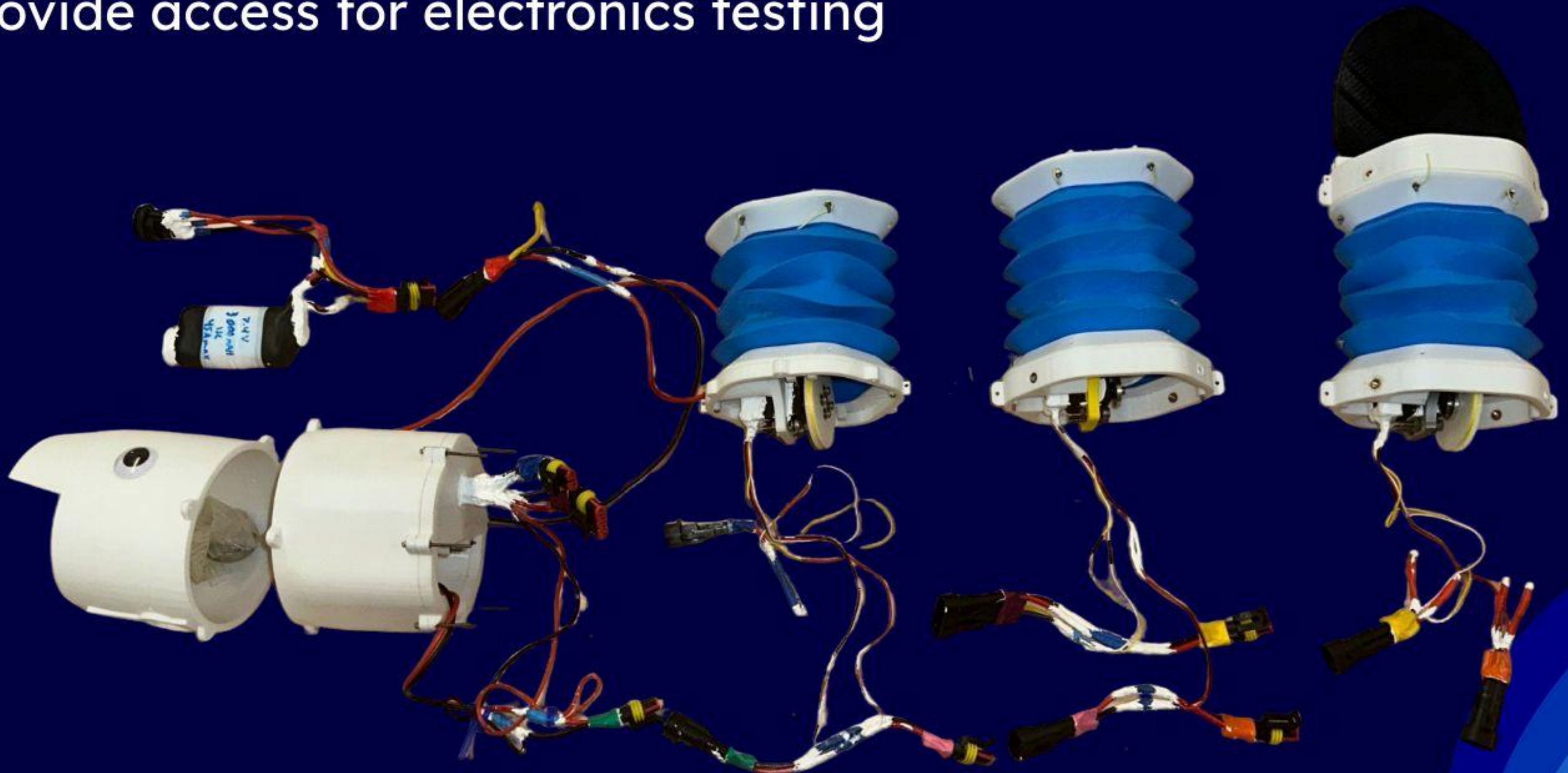


Development: Tail and Fins

- Tail is fully passive and printed using rigid NinjaFlex TPE for structural integrity
- Drain holes in the tail mount allow water to enter/exit easily
- Soft fins (attached via spacers) increase surface area, improving maneuverability and aiding smooth movement
- Design focuses on natural eel-like motion

Development: Wire Connectors

- Wiring between modules done with water-proof quick disconnect connectors
- Allow for easy disassembly and maintenance
- Provide access for electronics testing



Development: Software

$$\varphi = \frac{2\pi}{Number\ of\ Modules}$$

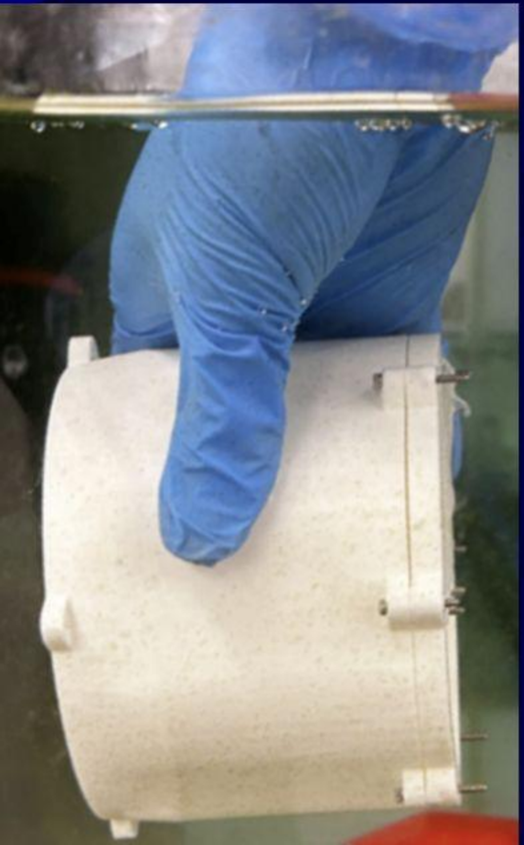
$$Angle = \underbrace{A}_{\text{Amplitude}}sin(\underbrace{\omega}_{\text{Angular Frequency}}\underbrace{t}_{\text{Time}} - \underbrace{\varphi}_{\text{Phase Shift}})$$

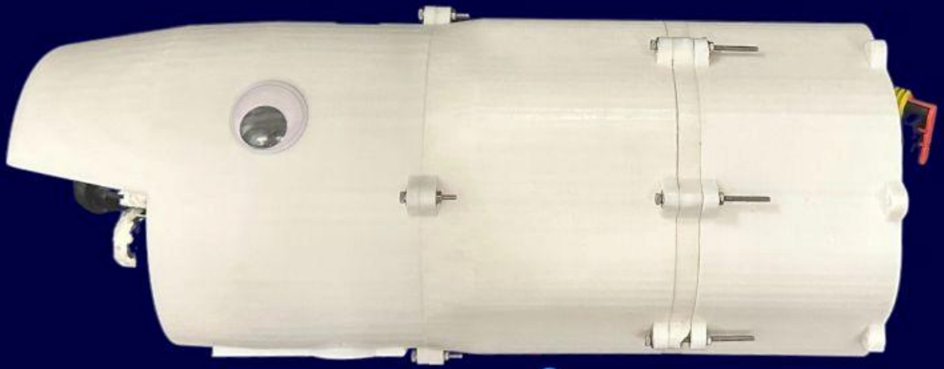
- $\omega = 2\pi f$, where f=frequency
- Biological eel frequency = 1.25Hz

Waterproofing

Waterproofing: PLA

In order to ensure that the watertight compartment of the head was completely sealed, an acrylic spray was applied to both the inside and outside of the part.





Waterproofing: Electrical Connections

- Heat shrink tubing used to insulate and protect all solder joints on the electrical cables
- Marine sealant applied at cable entries into connectors and connector exit hole in the eel’s head, ensuring no leaks into the electronics compartment
- Waterproof connectors extend from the sealed head housing, allowing safe module-to-module wiring
- Focus was on protecting internal electronics without compromising modularity or ease of maintenance

Waterproofing: Motors

- The Waterproof servo industry is prohibitively small and expensive -> needed to waterproof motors ourselves

- Sealing with marine sealant and O-ring proved insufficient

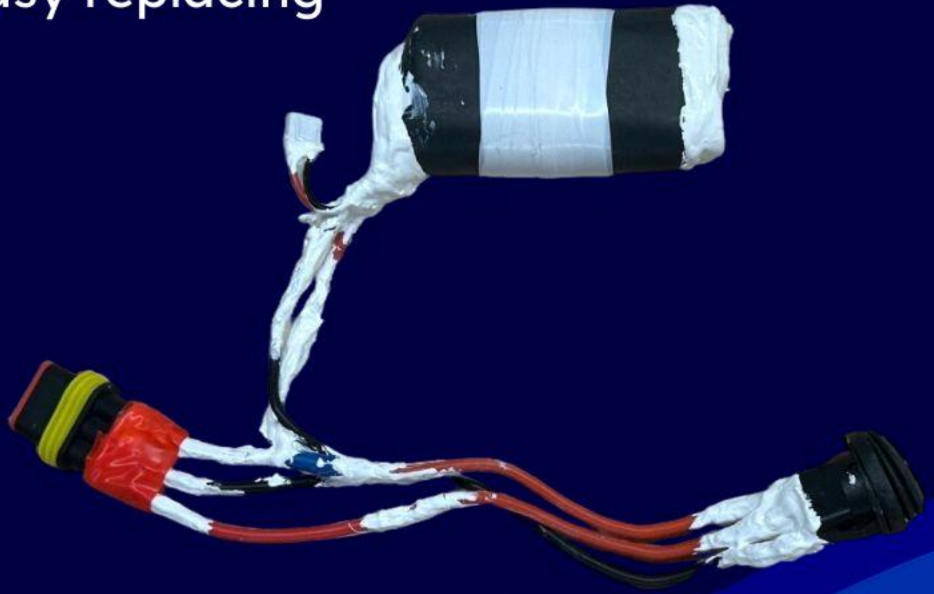
- Used dielectric hydrophobic greases internally:
- Thicker gel to servo horn opening and internal opening between gearbox and circuit board
- Thinner less effective lubricant to protect high-speed gears from water and thicker greases
- Coated circuit board in silicone grease

Waterproofing: Batteries

- Earlier iterations utilized an additional 5v battery for logic power
- Separate from 7.4v motor power with common ground
- Replaced with 3.2V voltage regulator

- Batteries waterproofed with heat shrink tubing and Marine sealant

- Separated by quick disconnect to allow easy replacing



Results and Recommendations

Testing Process

- To find the best possible amplitude for our modules to be bending at, we had to set up a decisive pool test

- The robot would swim over a camera with amplitudes ranging from 90 to 115 degrees

- By using Physlet tracker to calculate the speed of the eel with each pass, we could determine the best possible amplitude to pick for our modules.

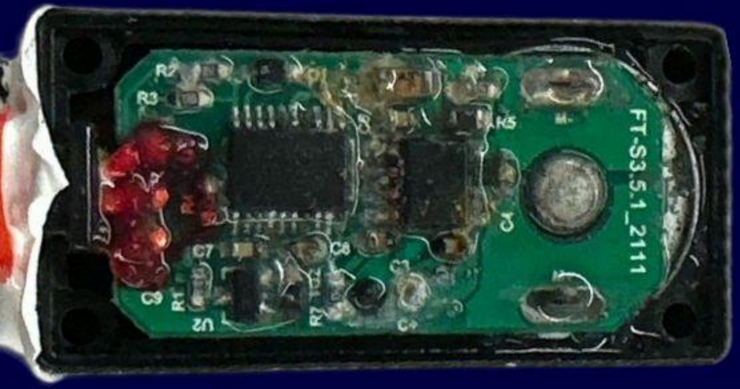
Challenges

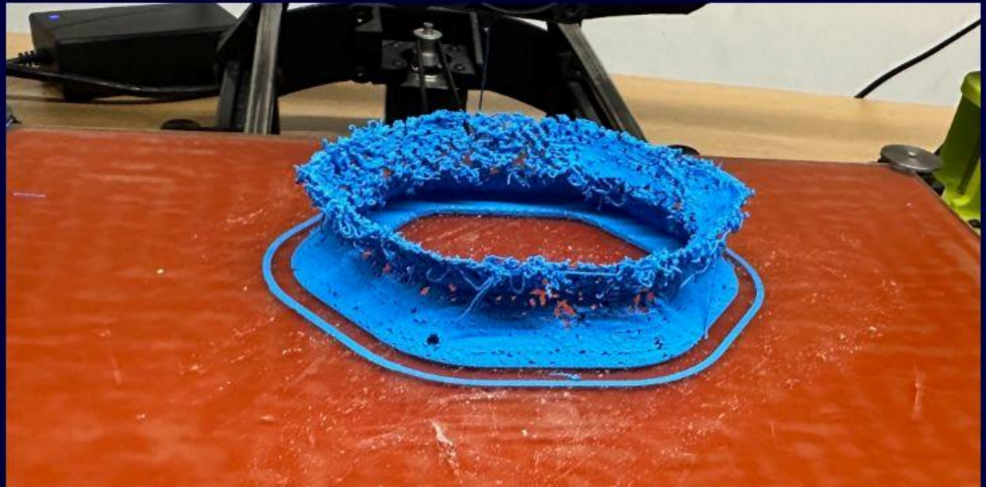
Chinchilla filament prints took extremely long and failed >80% of the time

- Extremely time consuming
- Prevented easy adjustments and improvements to design

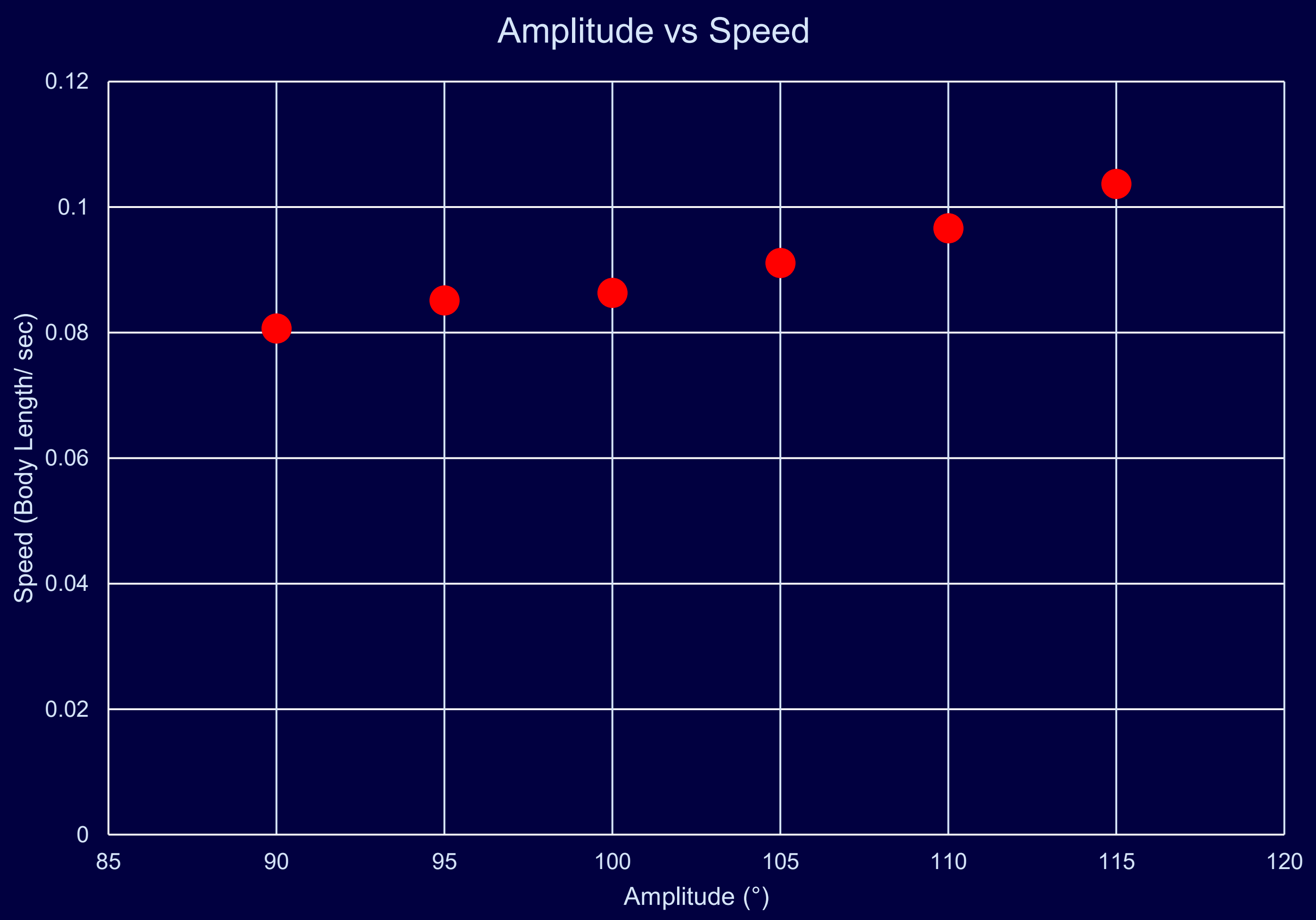
Original Motor waterproofing failed and the our lab requisition form was lost

- Lost valuable testing time
- Second water proofing attempt only partially successful





Results



Amplitude vs Speed
0.12
0.1
0.08
0.06
0.04
0.02
0
Speed (Body Length/ sec)
85
90
95
100
105
110
115
120
Amplitude (°)

Recommendations

Mechanical Design

- **S**witch to more durable, flexible materials (e.g., silicone or coated prints)
- Redesign segments for better spool alignment and stronger mounting points
- Add strain relief and clearance holes to prevent tearing and simplify reassembly

Electronics

- Miniaturize and waterproof wiring with better connector solutions
- Avoid vampire power draw using diode protection or power gating
- Route external micro-USB access

Controls

- Add autonomous capabilities like sonar-based obstacle avoidance
- Improve feedback integration for smoother motion control
- Experiment with different motors for higher torque or quieter operation

Testing

- With more time, we'd test in deeper water, more current, and longer durations
- We'd also validate autonomy, waterproofing, and new motor configs

Thank you!