User Manual - 1m Robotic Fish

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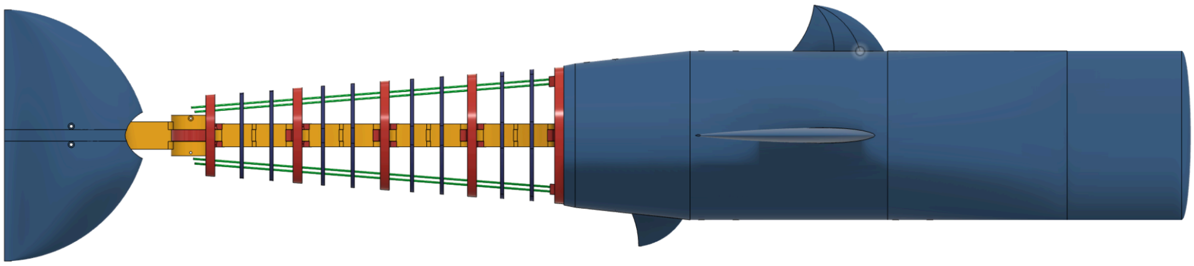
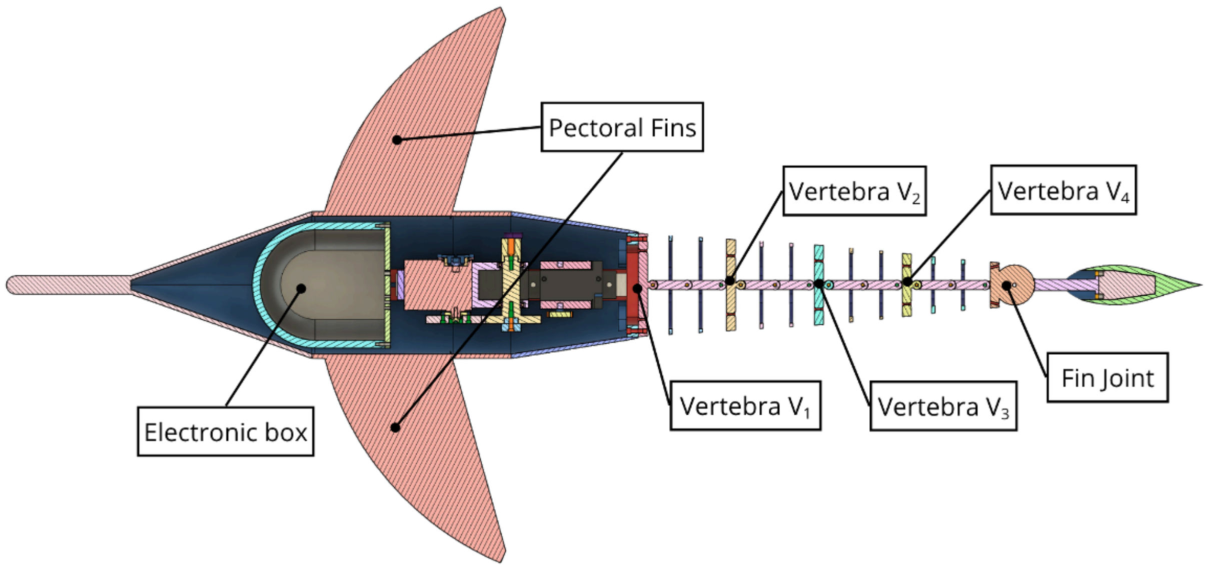
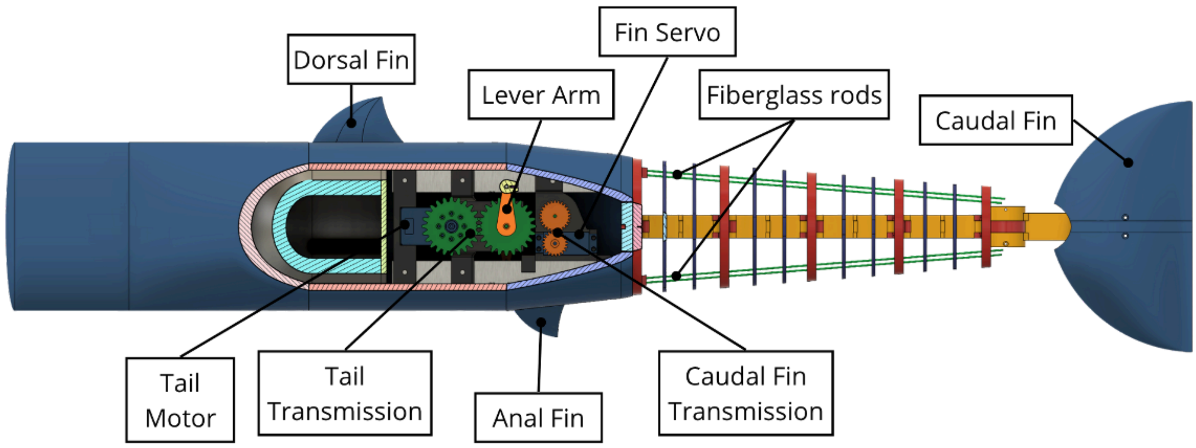


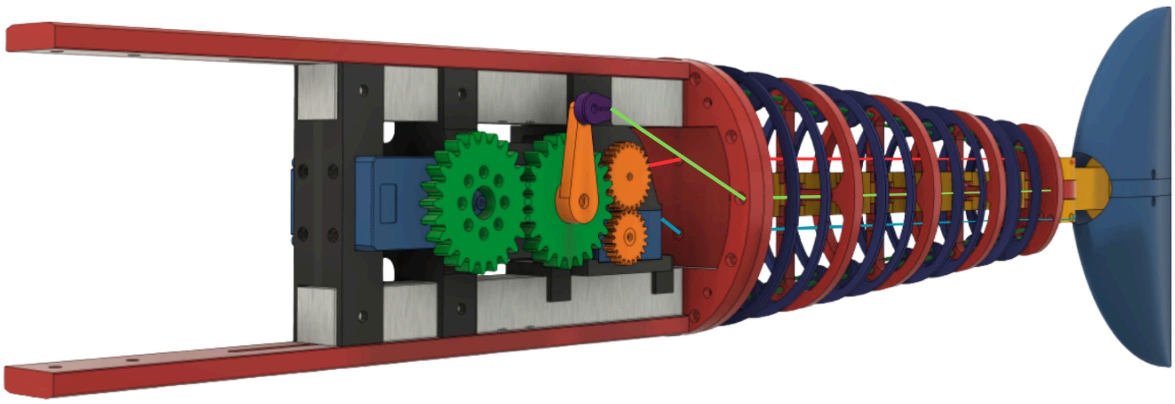
Robot Overview :

Definitions

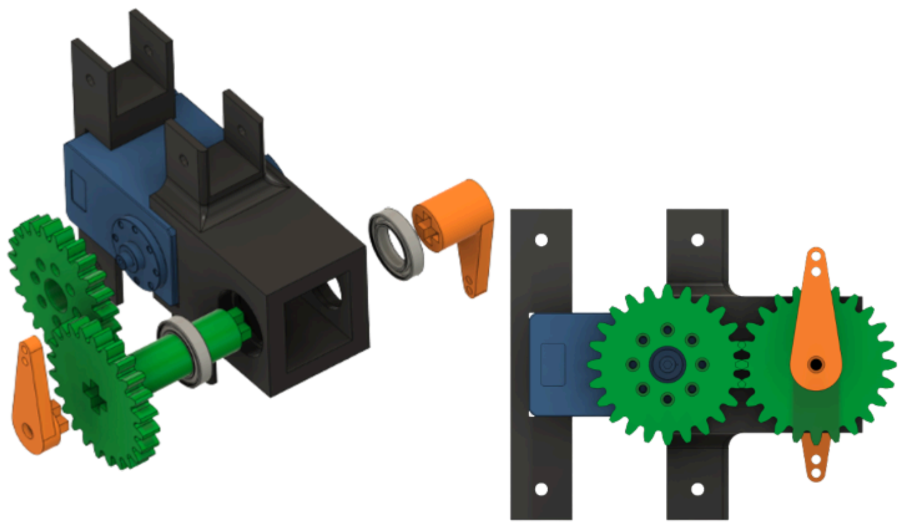




Transmission :

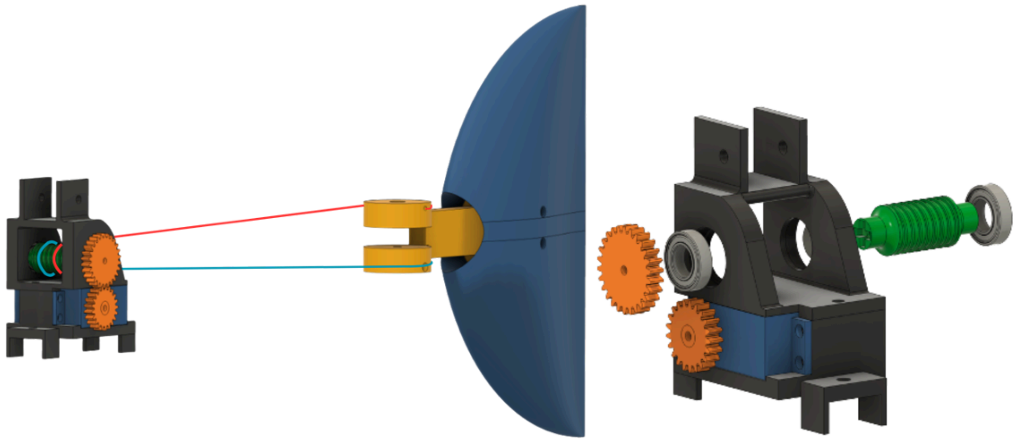


Tail Actuation



$$\begin{bmatrix} A_t \\ \phi_t \end{bmatrix} = C \begin{bmatrix} 1 \\ \theta_m \\ \theta_m^2 \\ \theta_m^3 \end{bmatrix}, \quad C = \begin{bmatrix} 0 & 4.846 & 0 & -3{,}26e^{-4} \\ 0 & 1.277 & 0 & -5.22e^{-5} \end{bmatrix}$$

Fin actuation :



The fin actuation works as a simple pulley mechanism with antagonistic tendons.

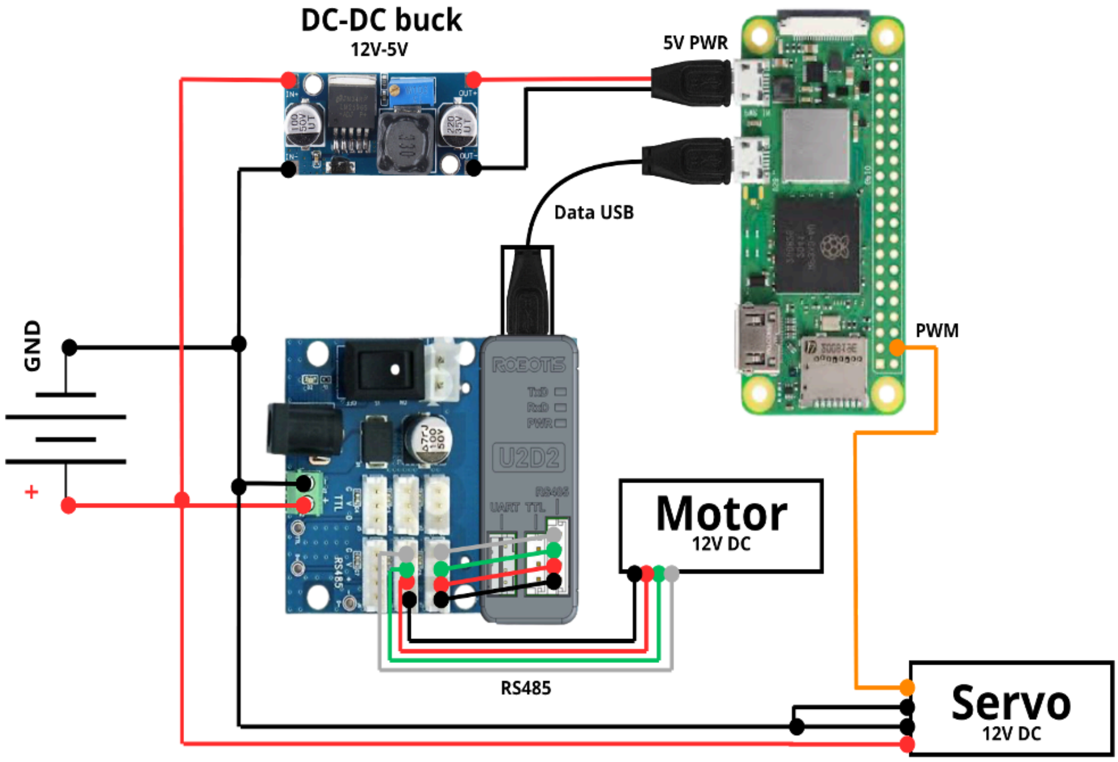
The transmission chain is as follow :
Servo Gear (theta_s) -> Body Pulley Gear -> Body Pulley -> Tendons -> Fin Pulley (phi_f)

$$\phi_{\text{fin}}(\theta_s) = \frac{\Delta l(\theta_s)}{r_{\text{out}}} = \frac{r_{\text{in}}}{r_{\text{out}}} G_g \, \theta_s,$$

$$\phi_{\text{fin}}(\theta_s) \approx 0.34 \cdot \theta_s$$

$$G_g = \frac{N_1}{N_2} = \frac{21}{26}, \qquad r_{\text{in}} = 7.25\,\text{mm}, \qquad r_{\text{out}} = 17.25\,\text{mm}.$$

Electronics and Firmware :



Electronics setup

The figure above shows the electronics setup.

At the end of my thesis, the electronics had to be off-board.

It would be better to move them on-board. (see **future work** for potential advice on direction)

Firmware

- On startup, the Raspberry Pi Zero 2W connects to the EPFL network using my personal credentials.
    - You may need to update these credentials later to keep the auto-connect working.
- You can reach the RPi over SSH from your own computer.
    - Note: the EPFL network rotates the IP address every few days. Sometimes you must plug an HDMI cable into the RPi and read the current IP in the top-right corner at boot.
    - To connect over SSH, run:

ssh fish_pizero@128.179.xxx.xxx

- On boot, the fish can start its code automatically if these checks pass:
    - Dynamixel motor detected

    - Servo motor detected
    - If one of them is not connected, fish.service does not start.
- You can start fish.service manually on the RPi (RPi terminal or over SSH connected terminal):

sudo systemctl start fish.service

Code base :

https://github.com/Gabos111/fish-control#

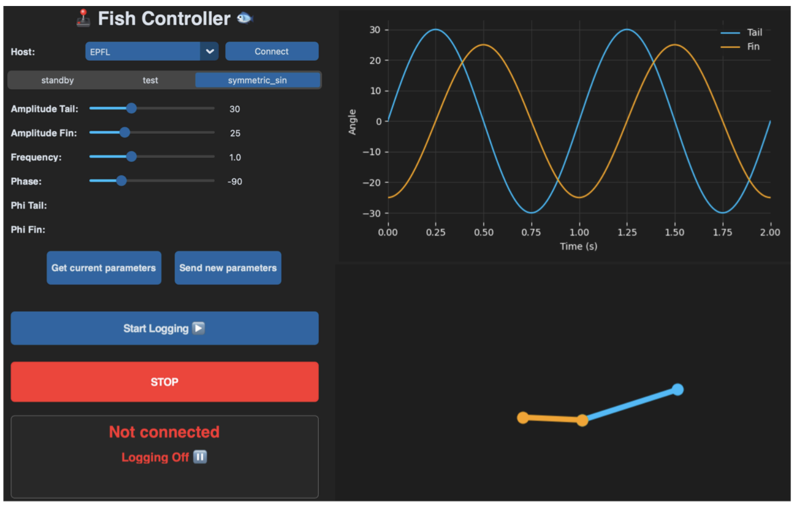
Note : When changing the C++ code you'll have to compile it before running the fish.service again. In a Rpi Terminal type (in ./build) :

cmake ..
make -j4
sudo make install

Wireless control :

Remote parameter control

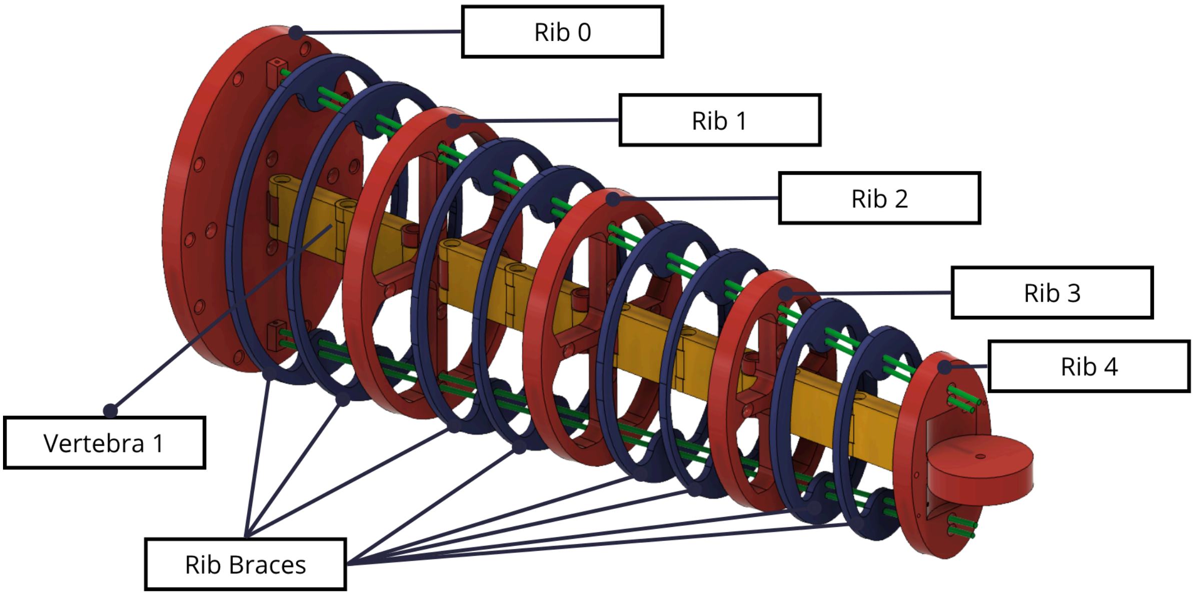
- You can control the parameters remotely with a Graphical User Interface (GUI) on an external computer.
- The GUI code is in the GitHub repository.
- The GUI edits values in cfg.yaml over an SSH connection. You can start the SSH connection directly from the GUI.
- Each time cfg.yaml changes, the robot code reads the file and updates the parameters.

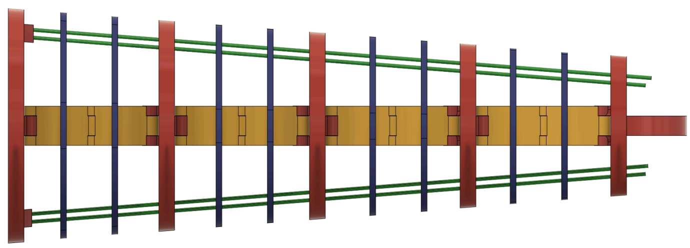


Assembly and Maintenance Instruction

The steps below are in assembly order. For simplicity, it is best to follow this order.

Tail Section :

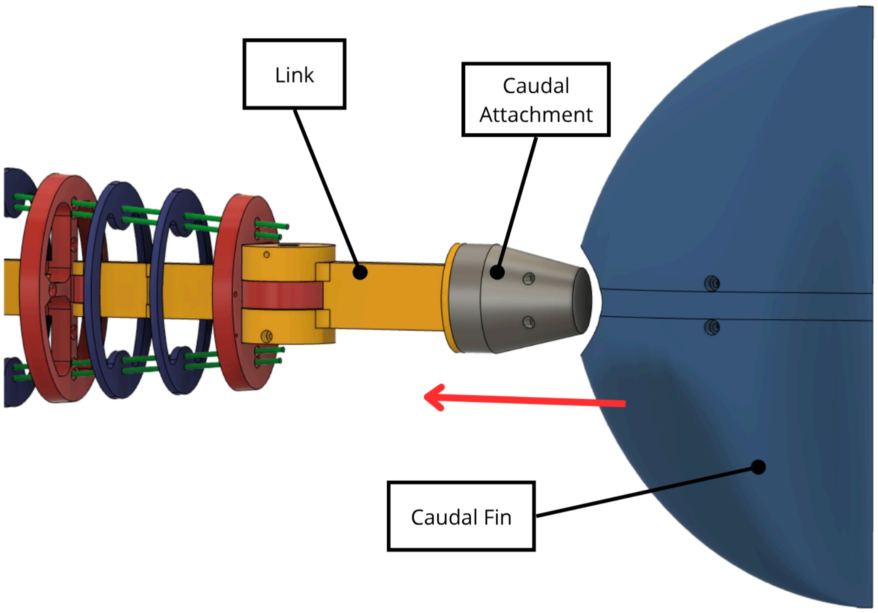




- Start with **Rib 0**.
- Attach **Vertebra 1** to **Rib 0**. Do not tighten the screws too much. These screws act as a pivot. Over-tightening will block the pivot or add a lot of friction.
- Insert the **fiberglass rods** (green) into the holes made for them.
- Insert the **rib braces** onto the fiberglass rods and slide them to their final position.
- Insert **Rib 1** onto the fiberglass rods and slide it into position at **Vertebra 1**.
- Attach **Vertebra 1** and **Rib 1** with one screw (this is the pivot).
- Attach **Vertebra 2** to **Rib 1.**
- Continue this assembly pattern up to **Rib 4**.

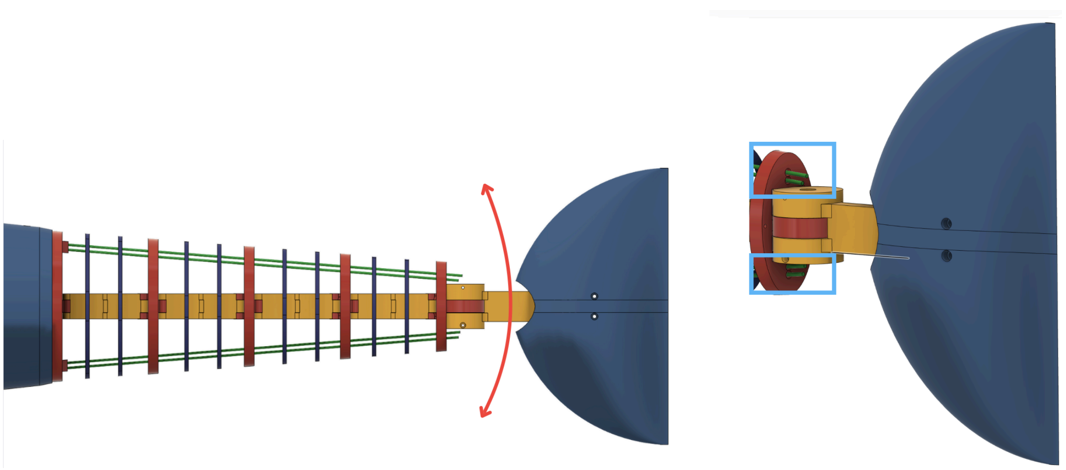
Caution: The fiberglass rods sit at a small angle to the horizontal. Because of this, the ribs and rib braces have a specific orientation. If you install them the wrong way, the fiberglass rods will be under stress.

Fin Section :



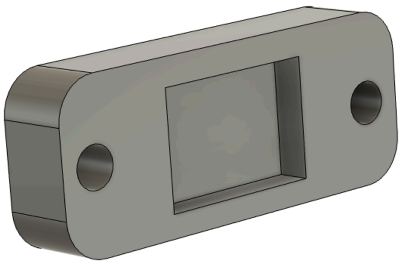
- Attach the **caudal attachment** to the **link** with a few screws. The caudal attachment has **threaded inserts**.
- Attach the **link** to **Rib 4** (do not tighten). Do **not** use a screw that is too long, or it may block the holes for the **actuation tendons**.
- **Before use only:** connect the **caudal fin** to the **caudal attachment** with screws. Be careful not to use screws that are too long; they may push into the screw on the opposite side.

Tail-Fin additional consideration :

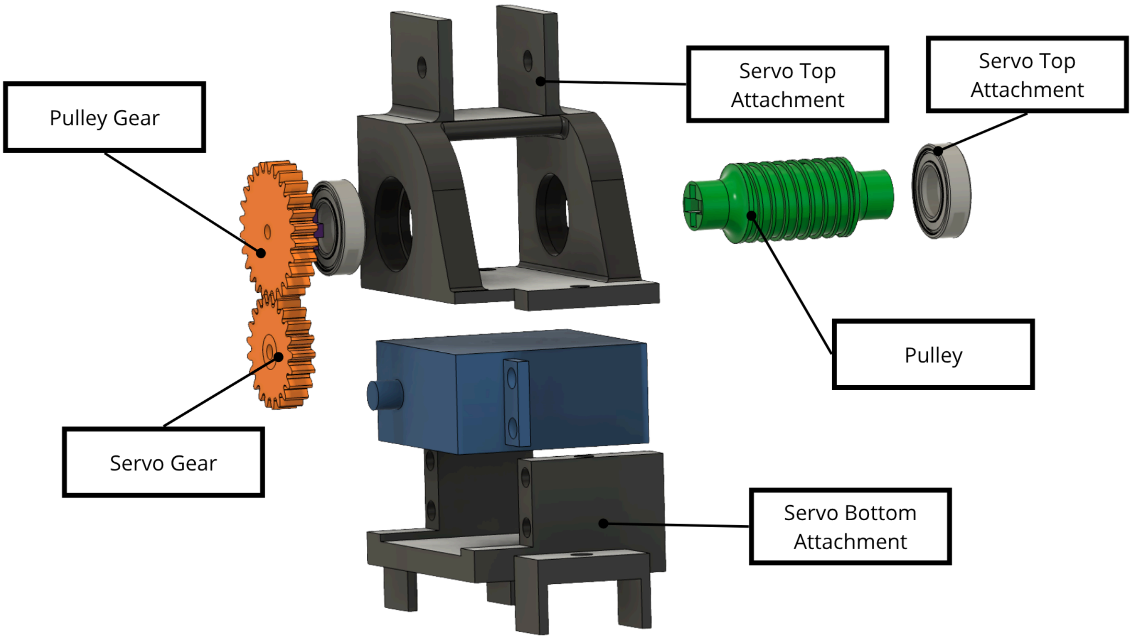


Under weight, the tail tends to move downwards, since the fiberglass rods are free to slide within the hole of the last rib it can move in the direction of the red arrow. To avoid that it would be wise to install 2 small parts that would constrain the sliding motion of the fiberglass rods considerably reducing the red arrow motion and greatly increasing the sturdiness of the

all assembly. A movement that has no parasite motion between parts will drastically improve the behavious of the fish under load.
Below is an example of the current part that limits that motion. It is on the rib4 (c.f. blue rectangles above)



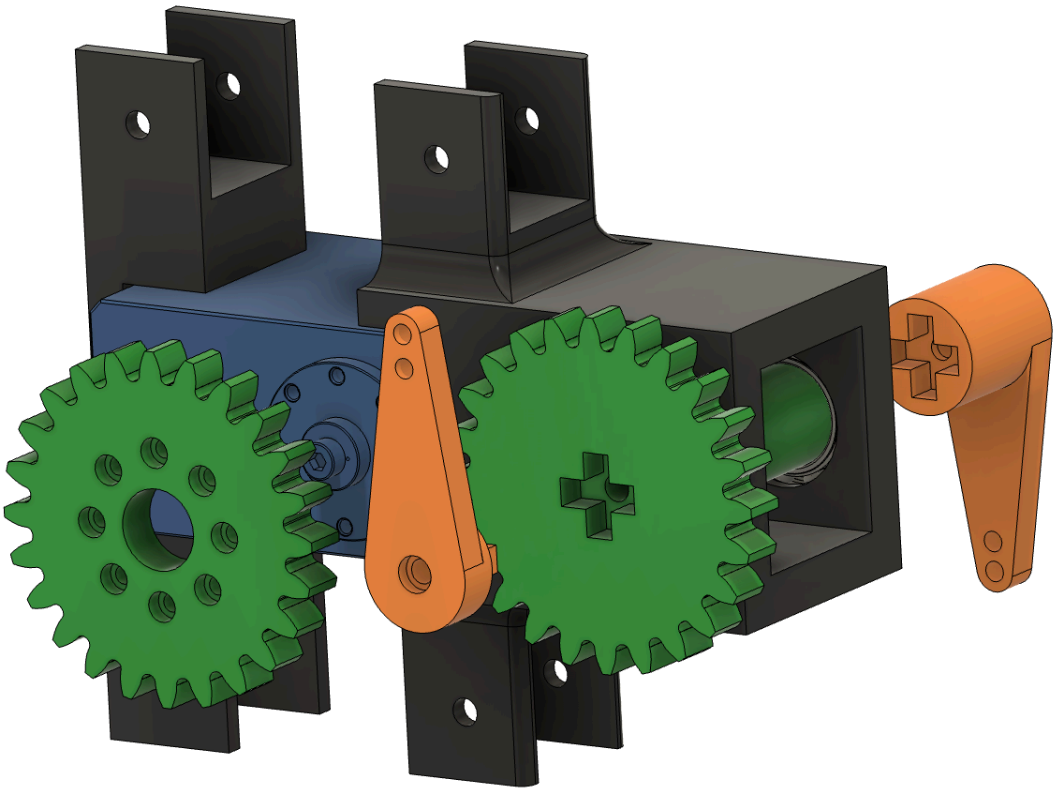
Fin Servo Sub-Assembly :



- Screw the servo to the bottom support.
- Screw the top support to the servo.
- Insert the pulley through one of the holes.
- Insert the bearings, then place the pulley directly on them.
- Screw the small gear to the servo.
- Screw the large gear to the pulley.
- Screw the cap on the other side of the pulley.

Note: The pulley shaft has **threaded inserts**.

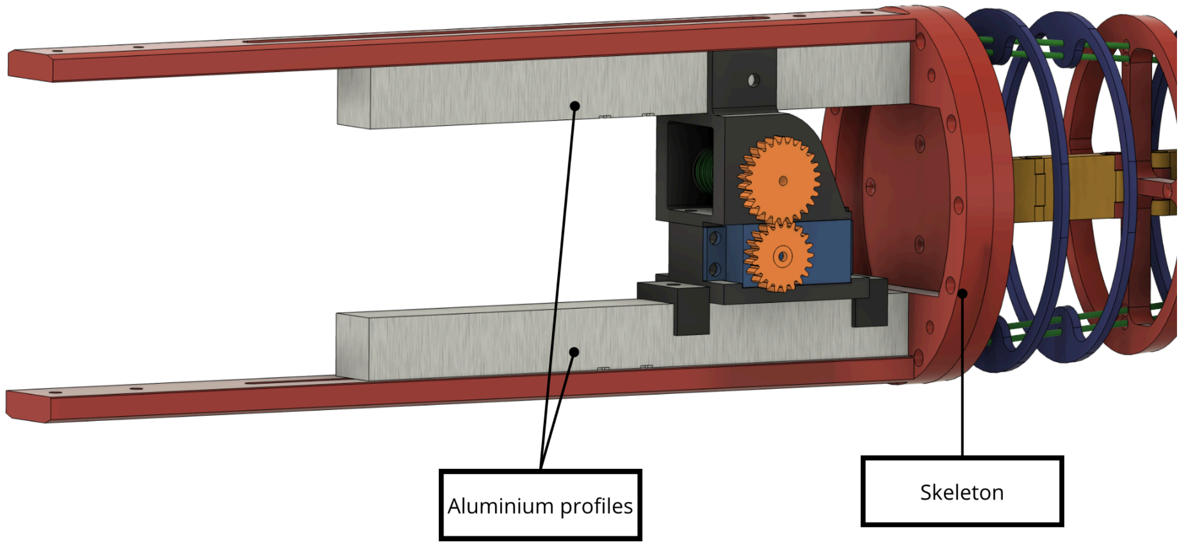
Tail Motor Support

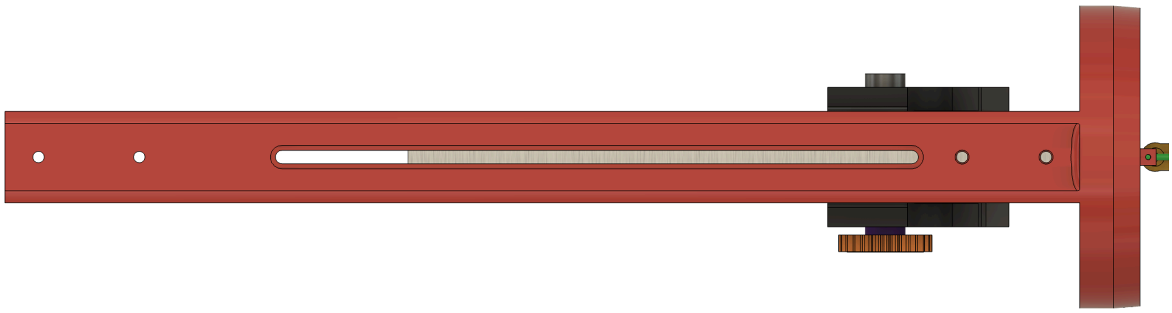


- Screw the **Dynamixel support** to the motor.
- Screw the **transmission support** to the motor.
- Screw the **motor gear** onto the Dynamixel output.
- Insert the **bearings** into the transmission support.
- Insert the **geared shaft** through the bearings.
- Screw both **levers** onto the shaft.

Note: The geared shaft has **threaded inserts**.

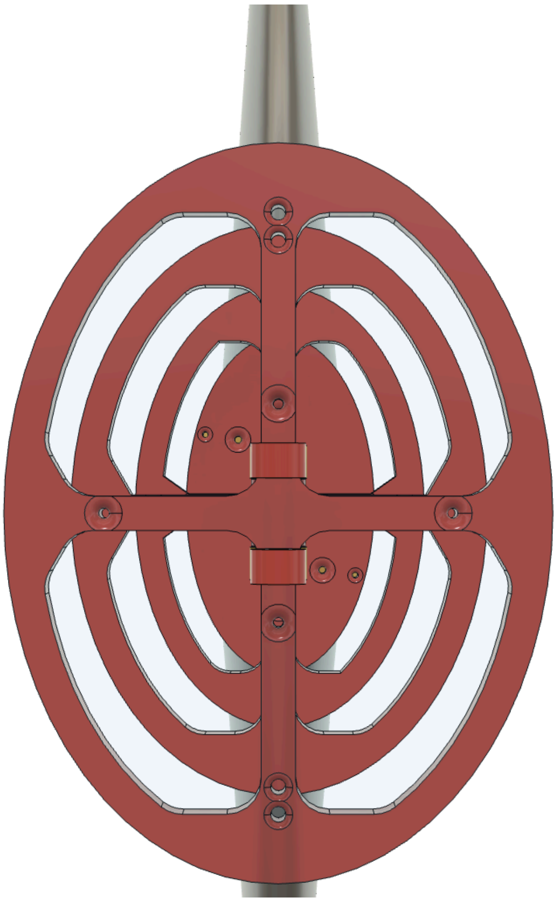
Skeleton :

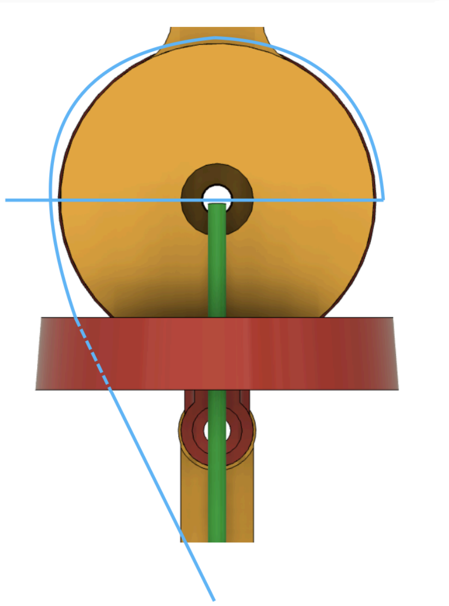




- Attach the **skeleton** to **Rib 0**. You do not need all the screws; **4 are enough**. Install **threaded inserts** on Rib 0 on the side **opposite** the skeleton for a stronger hold.
- Fasten the **aluminum profiles** to the skeleton using the **grooves**. **Two clamps/fasteners per profile** are enough.
- Mount the **servo assembly** onto the aluminum profiles using the **profile clamps**.
- Slide the servo assembly to the **front of the skeleton**, but **do not tighten** the clamps yet.

Fin Tendons :

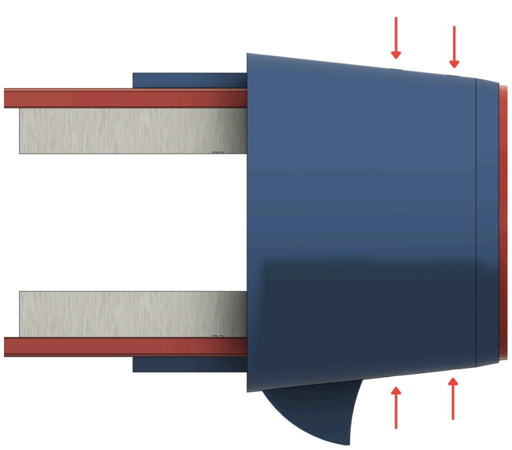


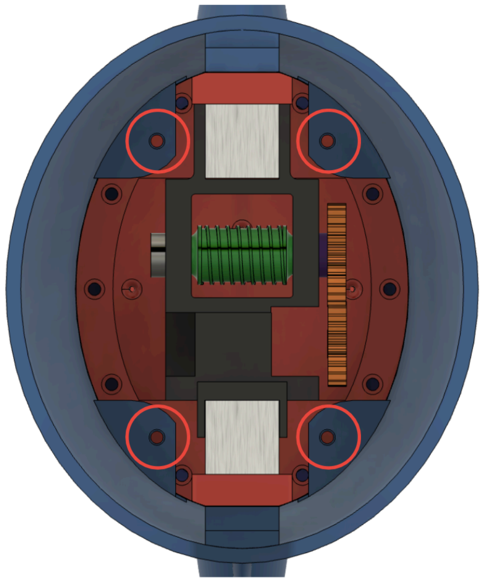


- Start at **Rib 4**. Insert the **tendon wire** into the **outermost hole**.
- Thread the wire through all the ribs down to **Rib 0**, using the **hole in the vertical bar** of each rib.
- At the **servo pulley**: route the main tendon **under** the pulley. For the **antagonist** tendon, route it **over** the pulley. Make **about 2 wraps**.
- Pass the wire through the **pulley through-hole**, then add a **screw at the exit** to secure it.
- Do the same on the **other side**.
- After **Rib 4**, route the tendon **as shown in the image** (blue path).
- Do the same on the **other side**.
- Align the **caudal fin** straight and **lightly tension** the tendon to remove slack. Fix the tendon end with a **countersunk screw**, fully seated, so it does not limit movement.
- Repeat for the **antagonist tendon**. Keep the fin straight.
- Pull the **servo assembly** toward the **front of the fish** to set the final tension. Tighten the **profile screws** when the tension is correct.

Note: After you insert and secure the tendons at the **servo pulley**, power the servo and set it to its **neutral position**. This makes it easier to attach the tendons at the **fin pulley** and helps avoid tension or alignment offsets.

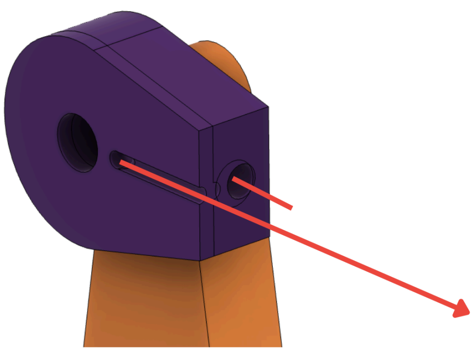
Rear-Half body :

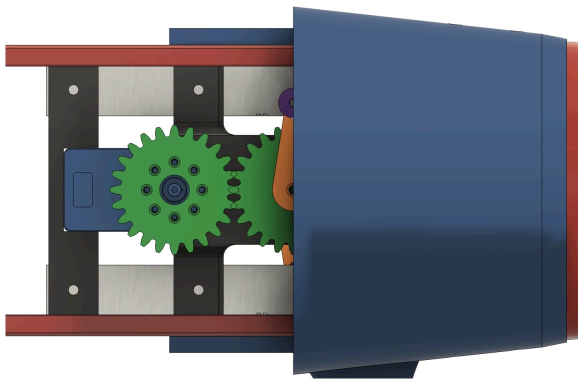




- Slide the **rear-half body** onto the **skeleton** until it touches the base.
- Fasten the screws at the **red marks** in the photos above. **Start with the four screws inside the body** so the outer screws line up with their holes.

Tail Tendons :

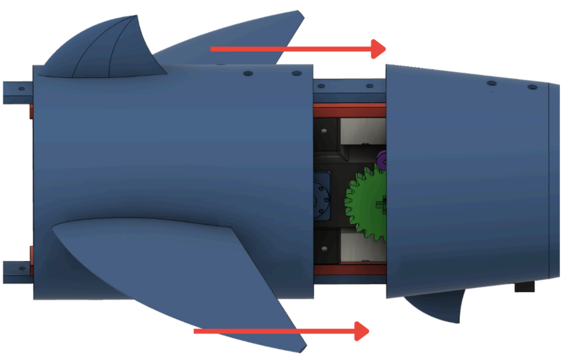


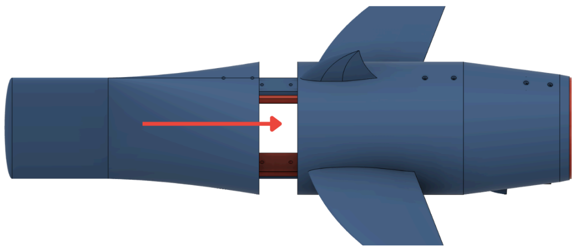


- Slide the **tail motor sub-assembly** into the **aluminum profiles** up to the **servo sub-assembly**. **Do not tighten** the screws yet.
- Starting from the **rear or the front**, route the **tendon wire** through all the rib holes (on the **horizontal bars**).
- Pass the **tendon** through the **attachment** as shown above. The arrow shows the side where the tendon exits toward the **tail**.
- Add a screw in the **other hole** to secure the tendon.
- Screw the **attachment** to the **lever**. Do **not** over-tighten; it must **rotate freely**. Do **not** use a screw that is too long, to avoid interference with other parts.
- **Power the motor** and set it to its **neutral position** (torque on).
- Keep the **tail straight** and fasten the tendon to **Rib 4** with a screw. As with the caudal fin, **lightly tension the tendon** while tightening.
- Do the same for the **antagonist tendon**.
- Slide the **tail motor sub-assembly** forward to set the final **tendon tension**, then tighten the **profile screws** to lock it in place. Tighten enough so the sub-assembly **cannot move** and reduce tension, which would change the **kinematics**.

<u>IMPORTANT NOTE :</u> Make sure the cables of the servo and the motor are well secured in a place that is not into contact with the gears or any moving parts.

Front-Half body & Head





- Slide the **front-half body** forward until it contacts the **rear-half body**.
- Insert the **four screws** (two on top, two on the bottom) to join and secure the two parts.
- Then do the same with the head (also 4 screws)

Potential improvements & future work :

Hardware :

Streamlined outer sleeve for the tail

***Objective*.** Eliminate the “rib” exposure that trips the boundary layer and destroys vortex coherence, reducing considerably the drag and improving the effect of the caudal fin

Implementation. Thin latex sleeve stretched wet and bonded at head/fin roots, or (2) cast silicone skin with anisotropic thickness (thicker on the leading edge for shape, thinner on the trailing edge for flexibility).

Stiffer, larger vertebrae

Objective. Increase torsional stiffness so the beam bends predominantly in the intended sagittal plane.

Current PLA vertebrae twist under load, robbing power

Implementation. Replace PLA with carbon-filled nylon printed shells or CNC-machined HDPE. add keyed flats to receive the four glass-fiber spars so they cannot roll.

Global fuselage slimming & ballast redistribution

***Objective*.** Lower wetted area and wave-making drag, and shift mass downward for passive roll stability.

***Rationale*.** The pink buoyancy block and boxy hull add ≈70 % excess frontal area.

***Implementation*.** Monocoque pressure hull (PETG/CF-PETG) with blended nose cone; removable internal lead ballast rails to bring CG below the thrust line.

Active pectoral fins

***Objective*.** Add heave, roll and fine yaw authority without large tail deflections.

***Rationale*.** Biological swimmers use pectorals for slow-speed manoeuvres, dynamic lift and station-keeping.

***Implementation**.* Pair of waterproof micro-servos (BlueRobotics S-300) driving compliant TPU fins; integrate into the same RS-485 bus and command via augmented cfg.YAML file.

WaterTight body - Ballast

Active Pectoral fins

Onboard electronics full watertight

Tail improvements :
Sleeve on the tail.
Vertebrae a lot more sturdy and bigger

Software & Control :

Closed-loop rigidity scheduling

***Objective**.* Map desired manoeuvre (cruise, accelerate, brake) to an optimal stiffness set-point.

***Rationale**.* Phase optimisation experiments showed best performance at a 30–50° tail-leading phase; a stiffness controller could replicate this automatically by matching peduncle bend rate to fin inertia.

Algorithm sketch

- Burst mode : high tail amplitude, set rigidity higher for burst accelreation
- Cruise mode : set rigidity lower
- Assymetric stiffness for manoeuvrability
- Keep positional control for gliding turns.

On-board state estimation

Sensor fusion. 6-DoF IMU + pressure + flow sensor to estimate body velocity (for instantaneous St) and attitude (for fin scheduling).

***Benefit**.* Removes overhead camera dependency; enables real-time Strouhal targeting and mid-water operation.