# Silicone Fish Tail Actuator Capable of Variable Stiffening

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## Abstract

### Design Basis

- Often anatomy or function of an organism will inspire technological designs, particularly within the study of robotics.
- A fish's flexible anatomy and range of maneuverability make it a prime inspiration for soft robotics.

### Biological Background

- Studies have suggested a key to swim speed and efficiency in fish species has been through tunable musculature [1].
- The deceptively simple appearance of typical fish combined with the numerous species' traits provides several possible robot designs.

### The Potential

- How fish swimming in nature translates into an engineered construct benefits  from the close relationship between bio-inspired design and soft robotics. These robot designs can then be tested to gather valuable experimental data.
- This collaboration of technology and analysis then results in robots with advanced designs and special maneuvering capabilities.

**This research project aims to develop a tuna-inspired tail actuator capable of variable stiffness via a pneumatic system. Once attached to a 3D-printed fish body, it will be used to observe vorticity changes in fluid.**


## Expanding the understanding of fluid dynamics and fluid structures.

### Previous Research

- Previous studies in variable stiffening have examined and experimented with fish fin curvature [2].
- Taken advantage of pneumatic systems to create soft-body fish robots which from timed pumps of gas, the fish body oscillates, propelling it forward [3].

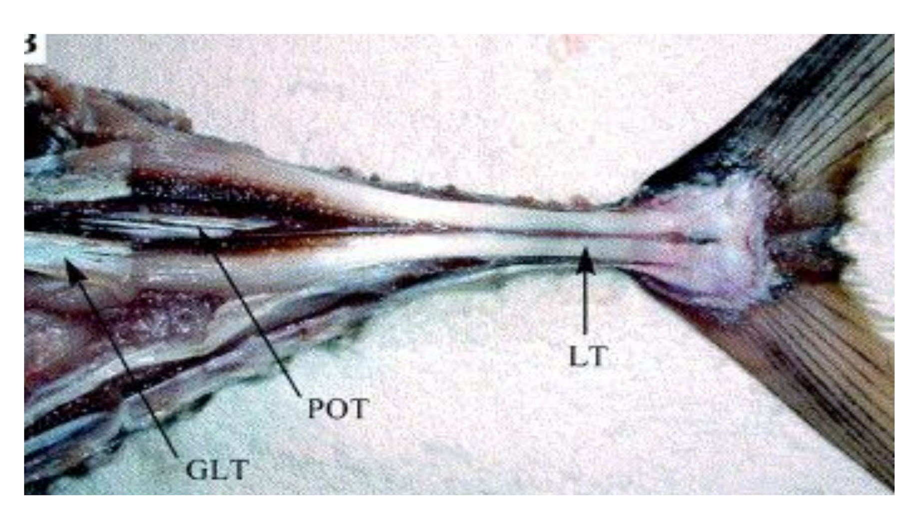
### Current Design Plan

- Explore material stiffener design (silicone, rubber, etc.).
- Stiffening will occur by creating a vacuum.
- Vacuuming instead of inflation to delay material failure and secure air seal.
- Actuation is caused by servo motor, not the pneumatic system.

## Design

### Initial Inspiration

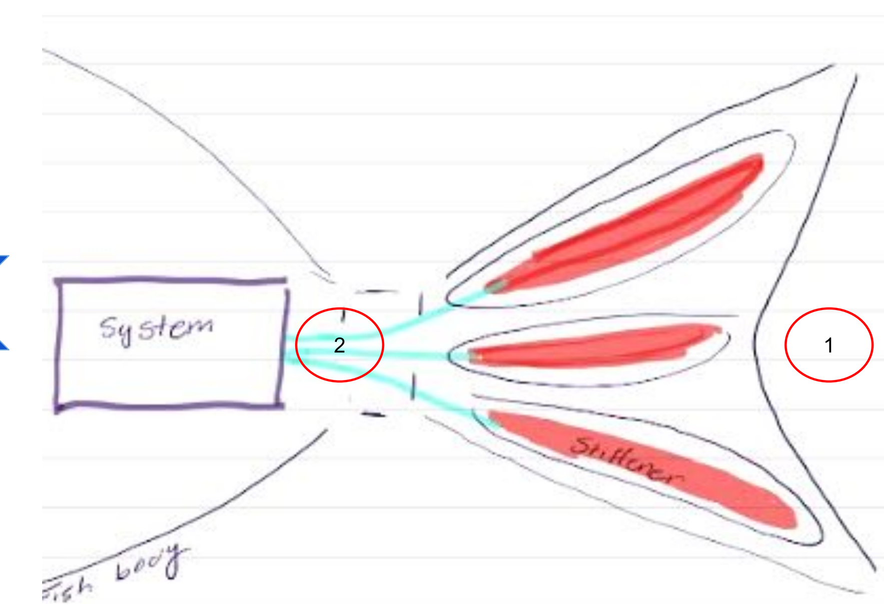
- The placement of the lateral tendon (LT) within tuna tails was a direct influence to component placement
- Tuna bodies and tail bases are much stiffer than the fin itself




Internal structure of a dissected tuna fish [4].

### 3D Mold Prototype

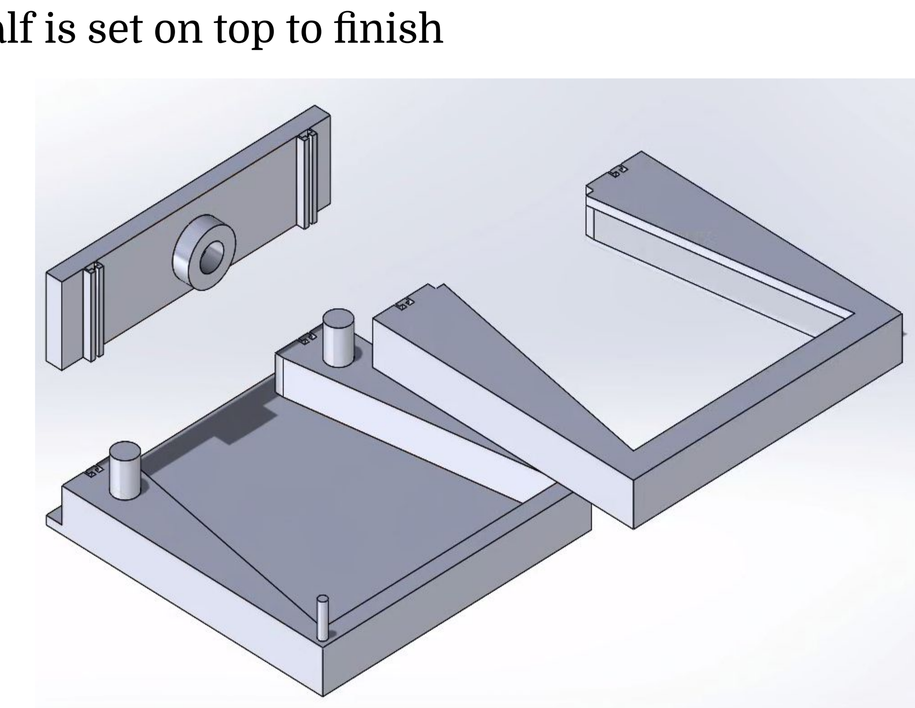
- The mold prototype was designed to the following specifications:
  - The fin at its widest point (1) must be 150 millimeters. Its narrowest point (2) and overall length was chosen to be 100 mm and 150 mm.
  - The prototype silicone tail will be 20 mm thick
- The mold was designed specifically to take into account leakage and the vacuum created by the silicon to the sides of the mold after curing.
  - Due to the internal stiffeners the mold process was designed to take place in two sections. A well created the bottom half of the fin, after which the stiffeners are added and the second half is set on top to finish the pour.




Initial drawing mimicking the internal structure of tuna tails.
The prototype will have:
- 3 equidistant  stiffeners.
- Silicon tubing will mimic the lateral tendons labeled above
- Connected to a pneumatic system in the fish body.

### Silicone Pouring

- Let's Resin Silicone Rubber poured into the first half of the printed molds.
- Wooden tabs were used to create cavities for the stiffeners.
- Extremely thin layer poured to create silicone sheets to build stiffener encasements.
- The pours were left to cure over 48 hours.



## Results

- The mold was extremely successful in containing any liquid silicone, as well as easy removal of the fin
- A flexible silicone tail prototype was successfully produced, however either due to the thickness of the mold or ratio of silicone mixture, the tail was unable to cure completely.
- Plenty of space is available for the stiffeners to be added.

Half of the silicone tail with cavities ready for stiffener insertion.

### Next Steps

- Stiffener encasements will be constructed out of the silicone sheet.
- Stiffeners will be constructed out of rubber and paper.
- A second layer of silicone will be poured on top to seal the stiffeners internally, completing the fin.
- The tail is heavier than necessary and may not be supported by the fish body. It has been determined the next iteration can be immediately half the current thickness of this prototype.


### References

[1] Q. Zhong *et al.* Tunable stiffness enables fast and efficient swimming in fish-like robots.*Sci. Robot.*6,eabe4088(2021).DOI:10.1126/scirobotics.abe4088
[2] Nguyen Khoi, Yu Ning, Bandi Mahesh M., Venkadesan Madhusudhan and Mandre Shreyas 2023 Corrigendum to: 'Curvature-induced stiffening of a fish fin' (2022) by Nguyen et al.J. R. Soc. Interface.2020220880
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[3] R. K. Katzschmann, A. d. Maille, D. L. Dorhout and D. Rus, "Cyclic hydraulic actuation for soft robotic devices," 2016 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Daejeon, Korea (South), 2016, pp. 3048-3055, doi: 10.1109/IROS.2016.7759472.
[4] Shadwick, Robert E., H. Scott Rapoport, and Joelle M. Fenger. "Structure and function of tuna tail tendons." Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology 133.4 (2002): 1109-1125.