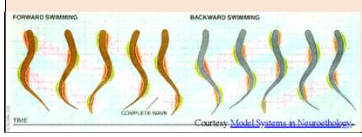
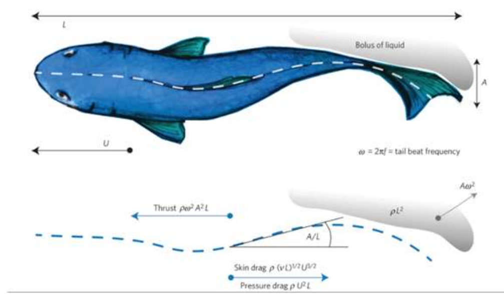
Mimicking Nature: High-Performance Tails for Underwater Soft Robots

Ramisa Anjum, Diego Llaverias, Dr Kourosh Shoele
Department of Mechanical Engineer, FAMU-FSU College of Engineering

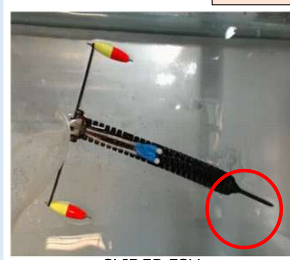
Abstract:

Bio-mimicry is the method that imitates nature to solve complex human problems. Soft robots can mimic biological motion as they can bend, stretch and deform continuously, much like fish, snakes and worms. In soft robots, the body and principle moving parts are made from flexible materials (like silicone, rubber, gels, or soft plastics) instead of rigid metal links. Current eel-like robotic swimmers use segmented robots with multiple moving parts. Simplifying these moving parts into a soft robot can potentially increase efficiency in swimming by improving speed and endurance.
The purpose of this research is to find the optimal tail shape for such a soft robot and obtain parameters that maximize the thrust of a swimmer robot. To develop a computationally efficient model, we use the programming language Julia to simulate how one fish with different tail shapes move and create required thrust force for swimming. After the best tail designs are obtained through simulation, those cases are validated through experiments using an MFC piezoelectric strip. The strip is actuated using controlled voltage signals at chosen frequencies causing it to bend and flap. The resulting thrust is measured using a force-torque sensor. Outcome of this research is to design a new tail that can enhance the swimming efficiency of bioinspired soft robotics for underwater swimming tasks.





A simplified shark model based on the swimming theory of slender fish [2] is used, focusing on the fish's **backbone**, representing the body as a thickness distribution around the centerline, while the motion is described as a lateral side-to-side traveling wave along the body.



SLIDER FSU

Methods

We mainly use two methods to optimize tail shape of a soft robot for increased thrust.
1) Simulated swimming motion, and 2) Experimental Validation.

Oscillatory motion of swimming uses the Strouhal number:

$$St = \frac{fA}{U}$$

Most animals fly and swim efficiently at: 0.2 <= St <= 0.4

Simulation:

- A simplified model is used where we focus on the backbone, (or top view) of the fish. This idealizes the shape of the fish.
- We use an open-source fluid simulator to analyze thrust generated by fish.
- Simulation results are used to identify tail configurations that produce maximum thrust.

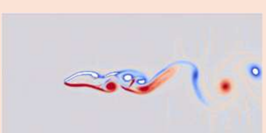
Thrust is a function of amplitude and frequency:

$$Thrust = \rho\omega^2 A^2 L$$

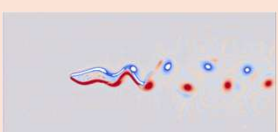
Actuation Parameters:
- Frequency
- Pressure
- Phase Offset

Experimental Validation:

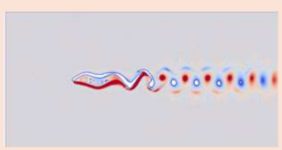
- MFC (Macro-Fiber Composite) piezoelectric strips is actuated using controlled voltage signals at chosen frequencies
- Tail motion actuated by controlling three key parameters:
  - Frequency: how fast the tail flaps.
  - Pressure / amplitude: how much the tail bends per flap.
  - Phase offset: timing between segments for coordinated motion.
- Force-torque sensor measured resulting thrust generated by each tail configuration.



St = 0.15



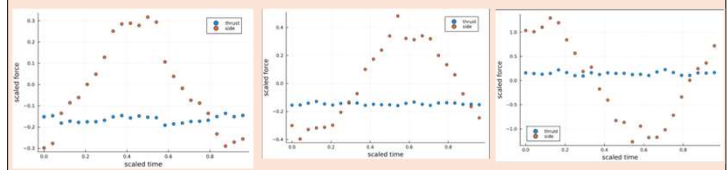
St = 0.3



St = 0.6

Preliminary Findings/Results:

- We vary tail flap frequency using the Strouhal number. At very high frequencies we see a net drag force instead of a net thrust force.



St = 0.15 St = 0.3 St = 0.6

Conclusions and Further Steps:

More data is needed to design optimally shaped robotic tail.
The next steps are to validate the simulated data by experimenting with an MFC strip which is a piezoelectric, soft, flexible material.

MFC Strip Used in Experiments

Resources:

1. Robert K. Katzschmann *et al.*, Exploration of underwater life with an acoustically controlled soft robotic fish. *Sci. Robot.* 3, eaar3449 (2018). DOI: 10.1126/scirobotics.aar3449
2. M. J. Lighthill, "Note on the swimming of slender fish," *Journal of Fluid Mechanics*, vol. 9, no. 2, pp. 305–317, 1960, doi: 10.1017/S0022112060001110.
3. Gazzola, M., Argentina, M. & Mahadevan, L. Scaling macroscopic aquatic locomotion. *Nature Phys* 10, 758–761 (2014). https://doi.org/10.1038/nphys3078
4. Anastasiadis, A., Paez, L., Melo, K. *et al.* Identification of the trade-off between speed and efficiency in undulatory swimming using a bio-inspired robot. *Sci Rep* 13, 15032 (2023). https://doi.org/10.1038/s41598-023-41074-9
5. Jia, Xinghua, et al. "Biological undulation inspired swimming robot." *2017 IEEE International Conference on Robotics and Automation (ICRA)*. IEEE, 2017.