The Energetics of Submeter Aquatic Robots

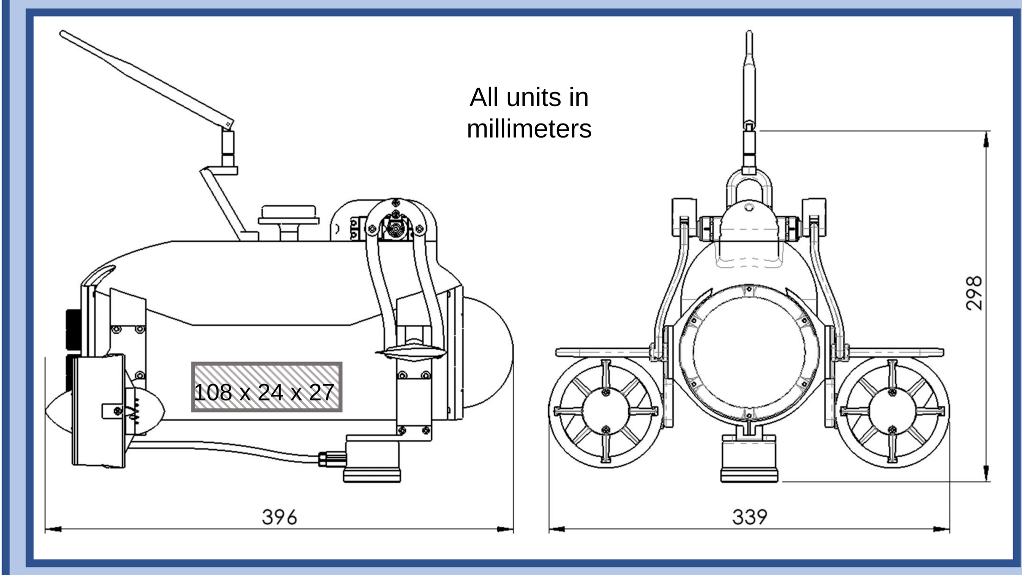
By Pascal Spino, Konstantin Matveev, and Néstor O. Pérez-Arancibia

1 Abstract

Energy and power limitations are particularly relevant in aquatic robots because locomotion at useful speeds requires significantly more energy to overcome drag than in air and on land due to water's density; water is eight hundred times denser than air at moderate atmospheric temperatures. Aquatic robots with sizes of several meters have payload capacities large enough to carry complex energy systems and have been successfully used in numerous research, commercial, and military applications. However, these vehicles are expensive, require complex maintenance, and have high operational costs. Submeter aquatic robots, in contrast, are low-cost and easily deployable.

This poster describes the primary energy and power challenges as well as potential solutions for submeter aquatic robots by examining the energetics of two aquatic vehicles developed at Washington State University (WSU). One robot utilizes traditional underwater propulsion methods, whereas the second–currently under development–draws inspiration from more efficient eel locomotion modes.

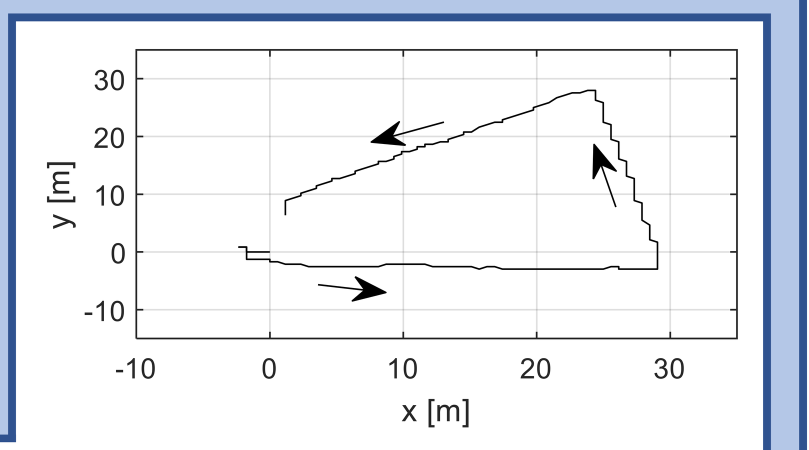
2 Semisubmersible Robot

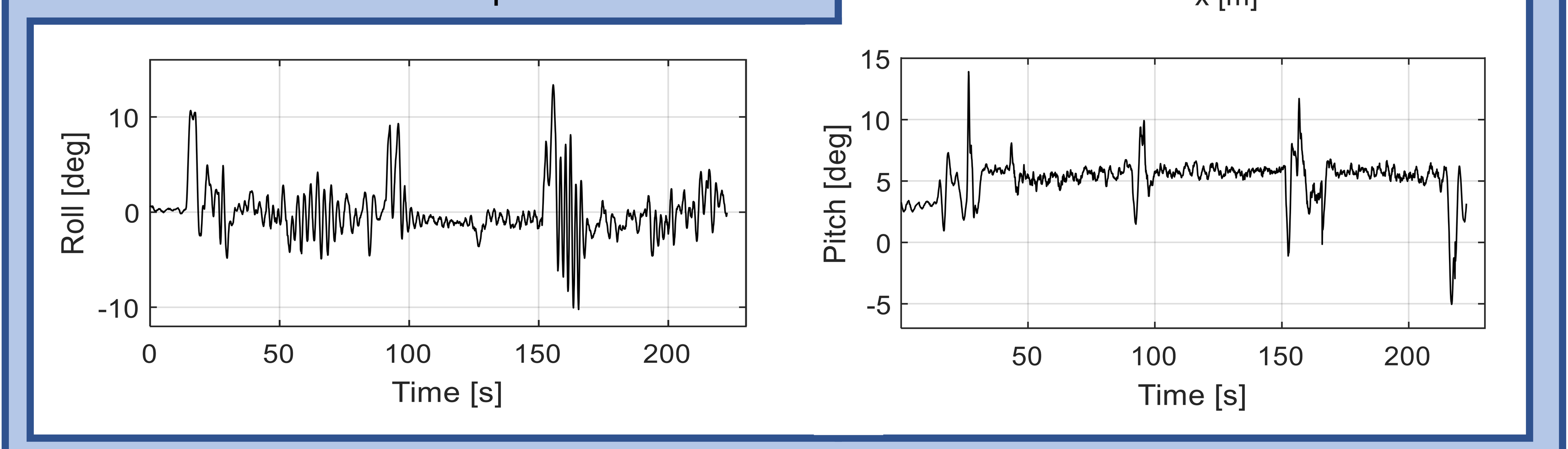


The semisubmersible is a hybrid underwater / surface vehicle developed at Washington State University [1]. Weighing just 4.2 kg, the robot is both teleoperable and autonomous-capable. The following sensing and actuation is integrated:

- Two Thrusters
- Two Actuated Hydrofoils
- Inertial Measurement
- Onboard Energy and Power Measurement
- GPS and Radio
- Echosounder Sonar

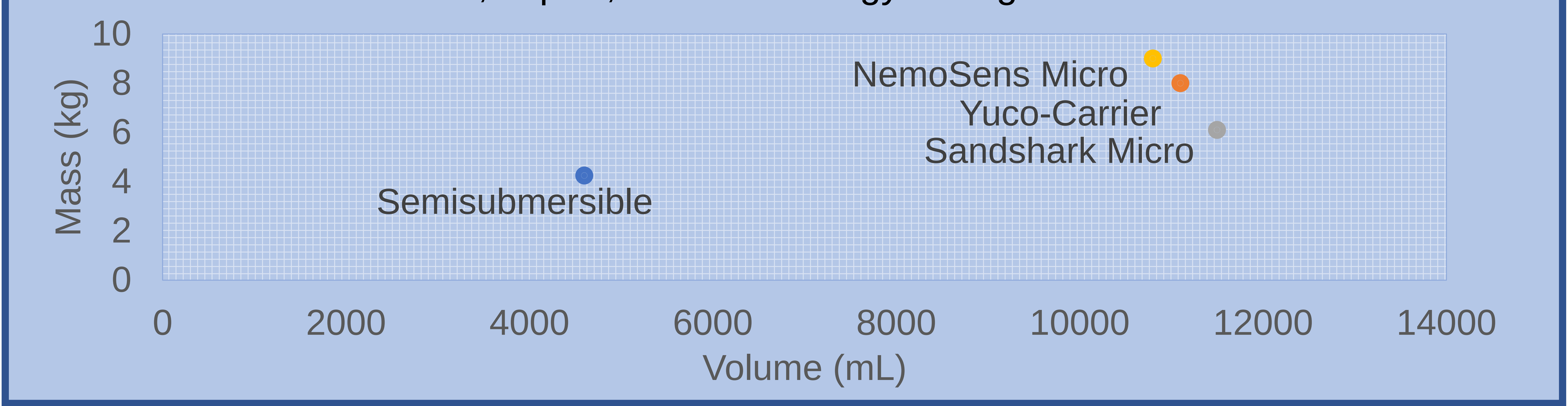
The semisubmersible's primary mode of operation is near the surface, where radio and GPS are operable. This regime presents additional control challenges for the small vehicle, especially in the presence of wind and waves. To overcome this, the hydrofoils can act on inertial measurement data to correct the robot's roll and pitch.



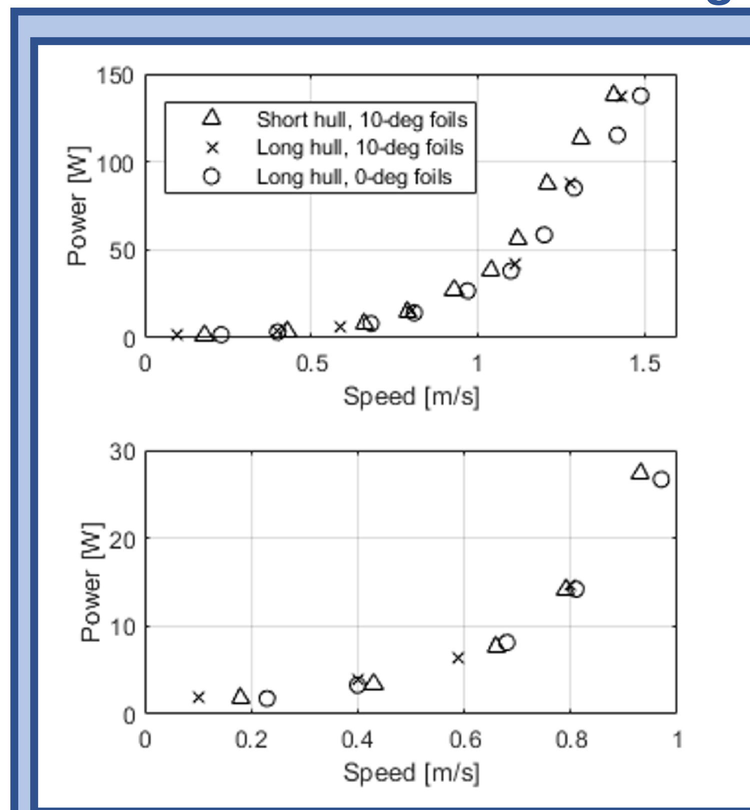


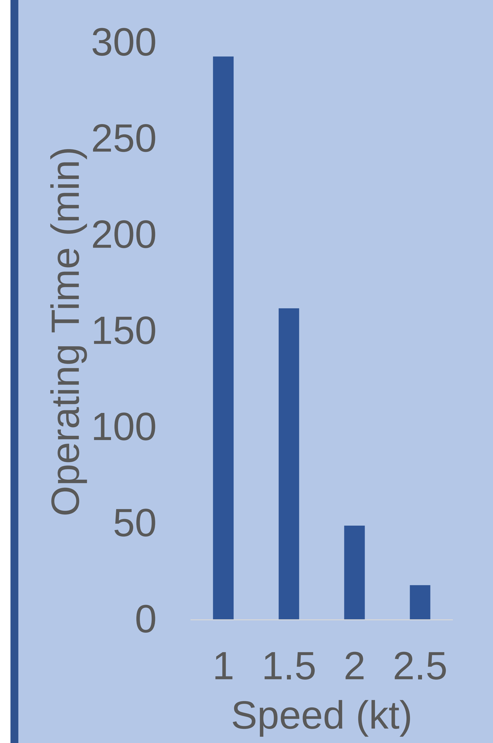
Roll and pitch data of the vehicle (bottom left and right) with hydrofoil assistance during traversal of a triangular path (top right). Large variation in roll and pitch correspond to abrupt speed changes and sharp turns.

The semisubmersible is smaller and lighter than existing vehicles in the related class of micro-AUV. However, its operating time at comparable speed is **less than one tenth** of these vehicles. This is due, in part, to lesser energy storage.



2.1 Semisubmersible Energetics





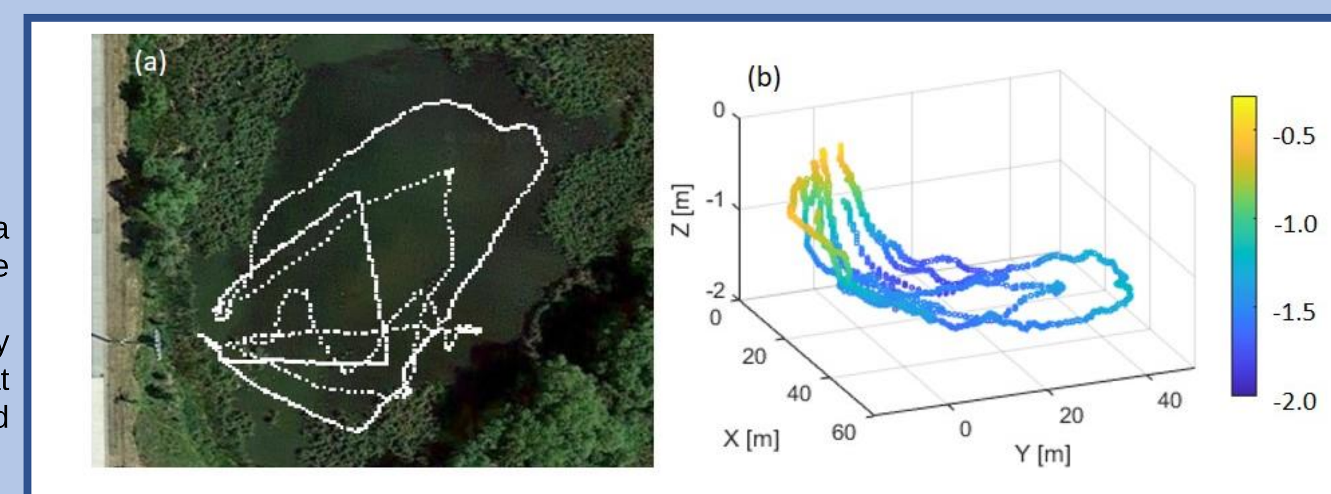
Semisubmersible power draw near the surface (left) and derived endurance graphs (right).

At useful speeds, energy is primarily expended through propulsion. Greater speeds require significantly more power due to fluid interaction. A typical micro-AUV vehicle travels at two knots. For the semisubmersible, this speed affords about **fifty minutes**, or three kilometers, of endurance. This relatively limited endurance could be suitable for longer missions when the ease of redeployment is considered.

Endurance (@ 2 knots, surface)	50 mins
Battery Recharge Time	2 hrs
Redeployment Time (including battery exchange)	5 mins

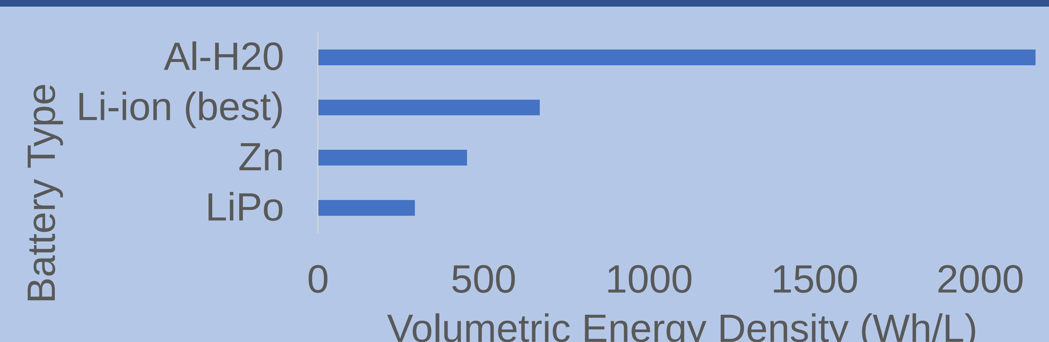
The semisubmersible may be equipped with application-specific payloads. In its present form, the vehicle performs depth mapping of small water bodies on a single battery charge. The energy requirements of the payload will have some effect on endurance.

Depth mapping data produced by the semisubmersible along an arbitrary teleoperated path at the Valley Road Pond in Pullman, WA, USA.

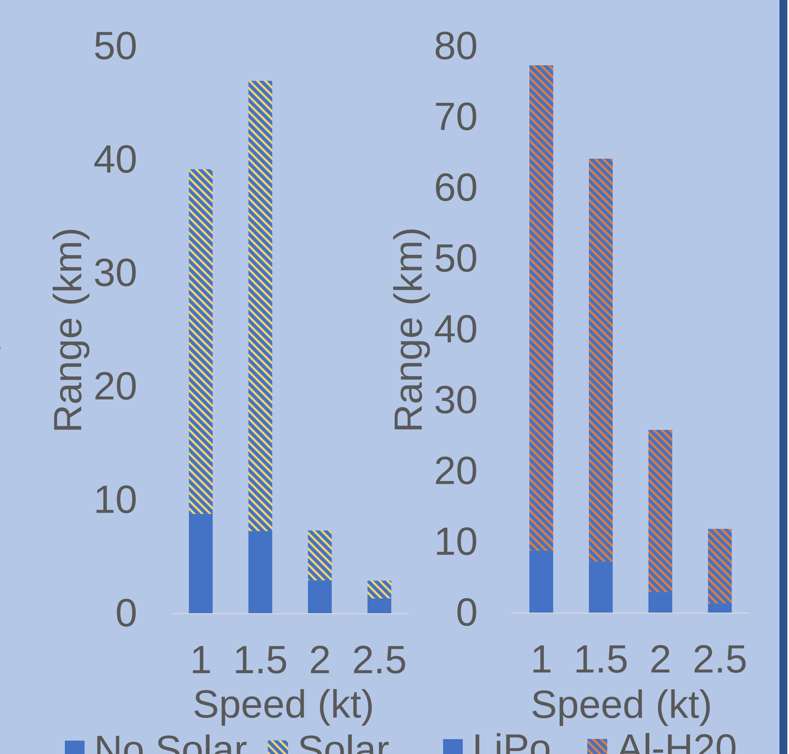


2.2 Analysis of Alternative Energy Strategies

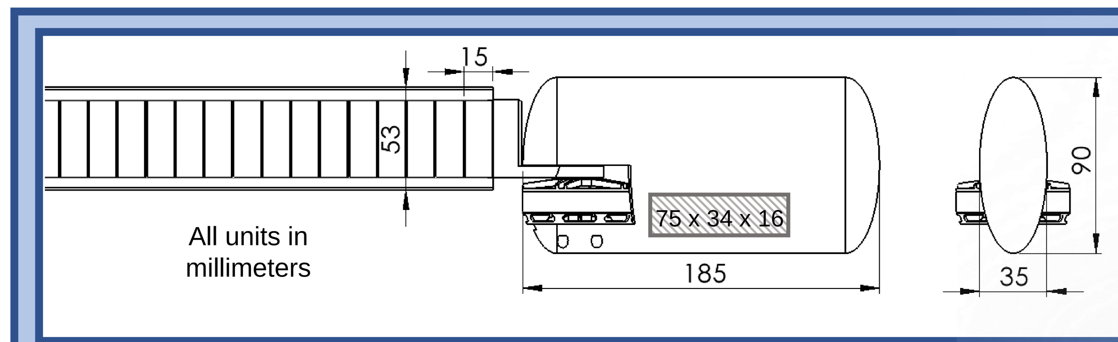
Comparison of different battery types by volumetric energy density [2]. Only the best four options are shown, with 'LiPo' corresponding to the chemistry of the current semisubmersible battery. In practice, energy mass density can also be an important consideration.

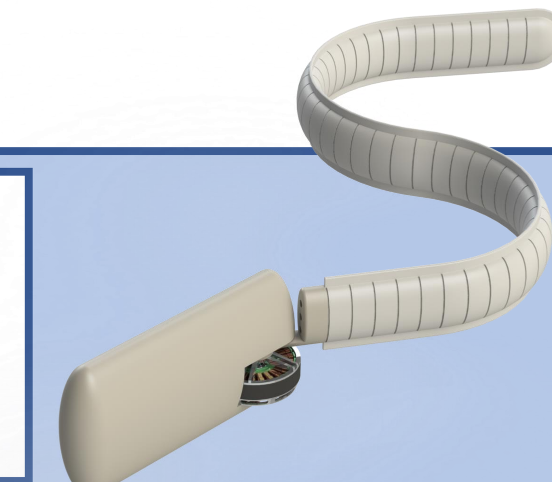


- Large underwater vehicle energy methods such as nuclear, combustion, and wave power are not feasible at this volume and weight.
- While continuously surfaced, an onboard solar array could supply as many as ten watts, or **four battery recharges** over a twelve-hour period.
- The greatest potential is in improved energy storage: recent developments in $Al-H_2O$ batteries could allow for up to **twelve times** current energy capacity by leveraging aluminum oxidization [3]. Commercialization of this technology is currently underway by unaffiliated groups.

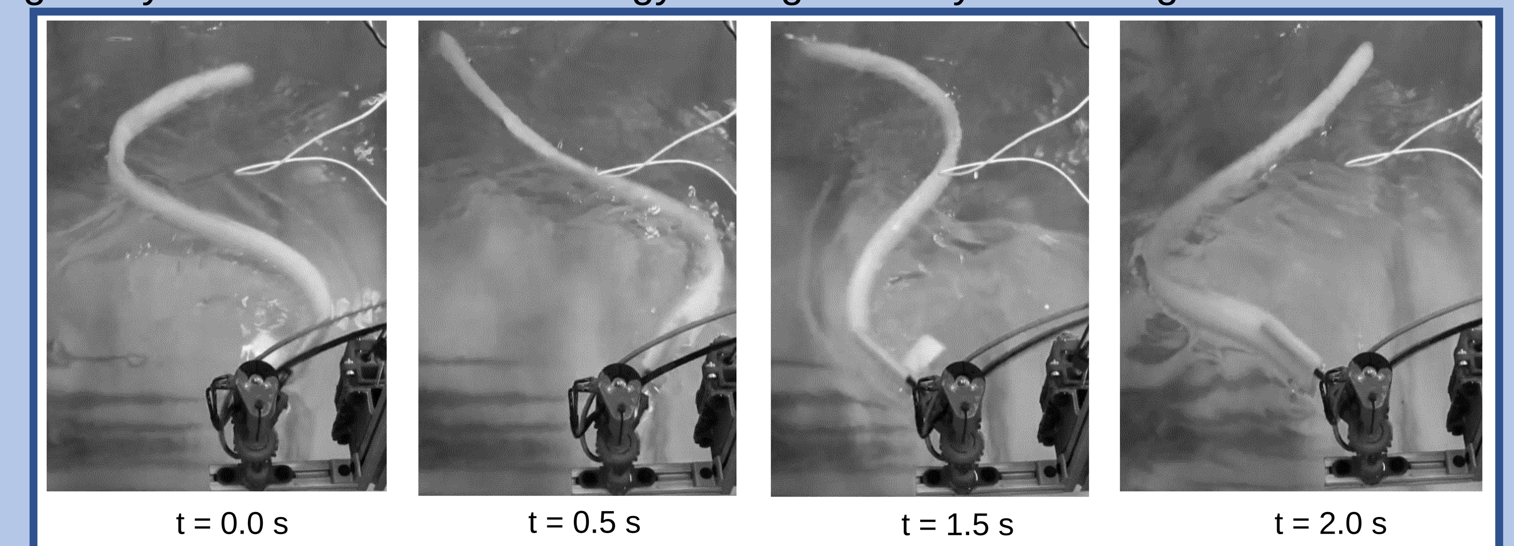


3 Biomimetic Eel Robot



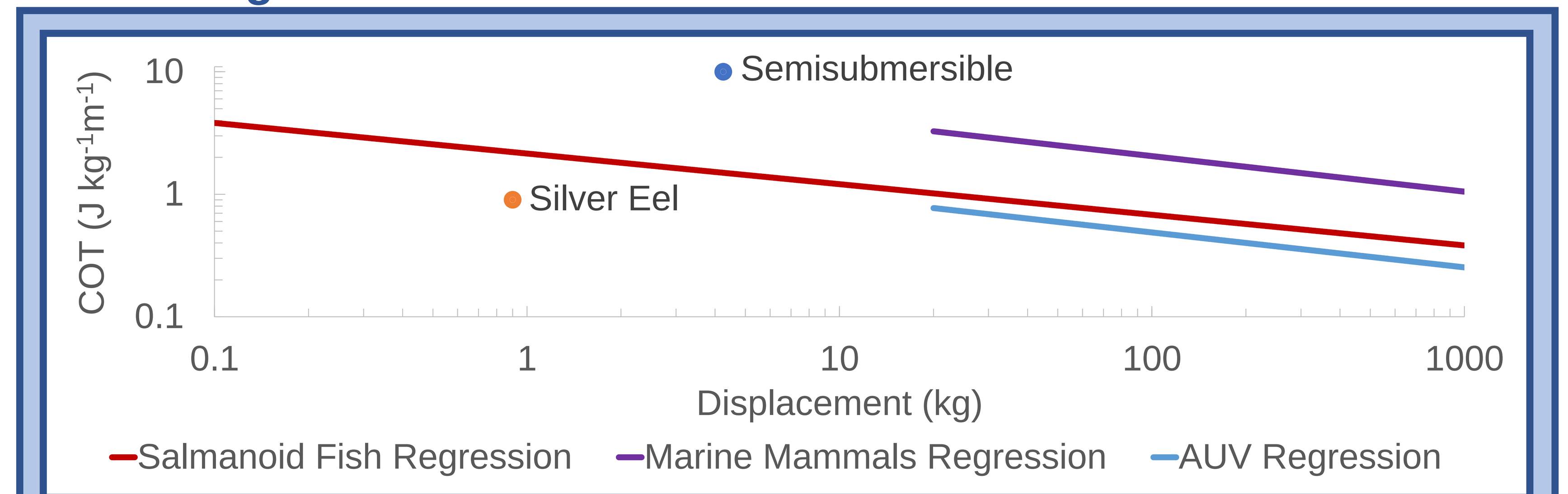


The biomimetic eel is an aquatic robot under development at WSU. The submeter vehicle leverages an underactuated soft structure to mimic anguilliform locomotion. This propulsion method is of interest in part due to its low cost of transport (COT) found in biological systems such as eels. Energy storage is likely to be a significant limitation.



Early testing of a candidate body design for the biomimetic eel. The silicone structure is underactuated compared to the biomechanics of an eel, yet can roughly approximate anguilliform motion through water-body interactions.

3.1 Energetics Discussion for the Eel Robot



Regression lines comparing the cost of transport between salmonoid fish, marine mammals, and typical AUV based on examples of each through a range of displacements [4]. The silver eel is included as it is a well-studied anguilliform locomoting animal [5][6]. Data is incomplete for marine mammals and AUV with displacements less than ~20 kg due to there being limited examples.

Anguilliform locomotion at optimal speed is highly efficient compared to alternative animal locomotion modes and manmade vehicles. The performance of AUV is helped by the fact that skeletal muscles found in biological systems exhibit efficiencies of ~0.3, compared to electric motors that can reach efficiencies of ~0.9 [4].

COT does not entirely determine endurance; biological systems still greatly outperform underwater vehicles of similar displacements in terms of operating time and range due to denser energy storage. The silver eel can travel 6000 km or 6 months in a fasting state [5] compared to 9 km or five hours for the semisubmersible. For this reason, catalytic combustion actuators utilizing biological fuels are a consideration for the biomimetic eel. This method of actuation is feasible for the eel but not for traditional thrusters.

References

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