Bioinspired Sensing and Actuation for Improved Maneuverability

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Motivation:

Looking to nature, we commonly see animals such as the dolphin which are capable of balancing in extraordinarily destabilizing environments, and others such as the octopus which is capable of escaping faster than a rocket moves in space (relatively speaking). How are animals capable of these feats which human engineers have only dreamed of emulating? We propose that by developing unconventional and bioinspired sensors and actuators, underwater vehicles could be equipped with comparable abilities. Pressure sensors could provide the flow-relative feedback required for responding to and using the local flow to maneuver with greater dexterity, and fast modification of body shape can be developed as a novel actuator for accelerated escape maneuvers.


Left: Dolphin surfing on large wave (Willyam Bradberry). Right: Escaping octopus (http://blog.sprucedclothing.com/)

Bioinspired Sensing from Dolphins

Fig. 1: Dolphins surfing in front of a larger cetacean, and in ocean surf waves.

Dolphins have long been renowned for their ability to position themselves relative to another animal, surf on waves or to a hard surface such as the bow of a moving ship. These are all examples of complex underwater control tasks which are enabled by the dolphin's mechanoreceptive abilities. The skin of the dolphin, which is covered with longitudinal dermal ridges and a patterned arrangement of collagen and elastic fibres and preterminal nerves in tunnels at the base of the ridges suggest that the skin is a specialized pressure-transducing mechanism, which is instrumental in enabling the dolphin to become aware of its body image in relation to the water around it.

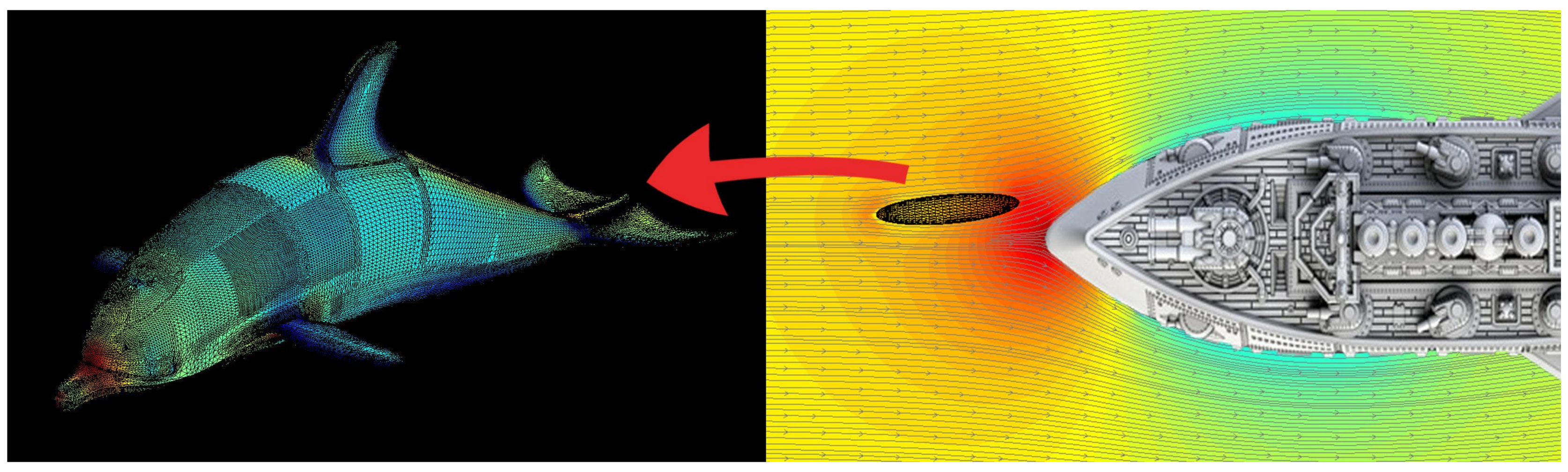

Fig. 2: A BEM model of a dolphin, and pressure field at the bow of a ship.

We are working to develop an underwater vehicle that emulates the ability of the real dolphin to stabilize in waves or other pressure fields through sensors. A surface array of pressure sensors provides the vehicle with the ability to sense its local flow, imparting critical information on its own velocity, body position and orientation relative to the flow. This flow-relative information in conjunction with the pressure which is measured by the array itself constitutes the feedback which is necessary to self-stabilize in dynamic and destabilizing environments, including the presence of waves or other bodies. Flow-relative control also yields the possibility of using local flows for efficient travel or fast maneuvers. Toward this goal, we have been developing fast algorithms which are capable of decoding information from local pressure fields to inform these control systems for improved stability or maneuverability, and building an experiment to investigate the ability of a pressure sensor array to provide the feedback necessary for robust control.

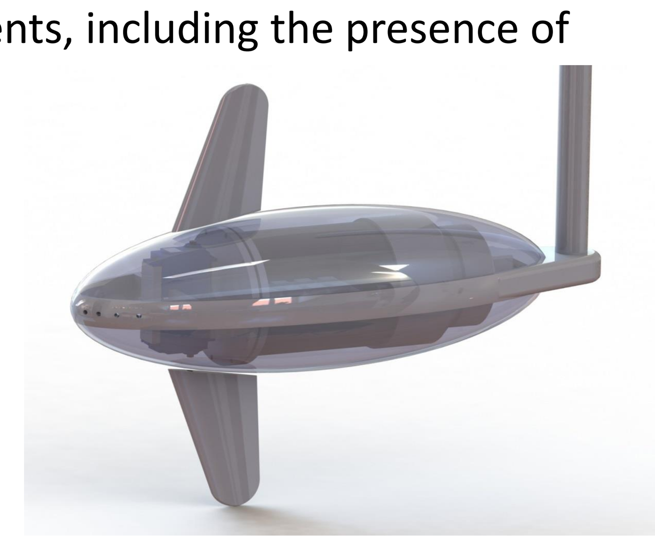

Fig. 3: CAD model of experimental vehicle.

Shape Change for Improved Maneuverability

We study two related cases of shape change in order to illicit fundamental vorticity creation and annihilation mechanisms that can add to our understanding of vortex creation and control for improved underwater vehicle maneuverability. Since vorticity creation and manipulation is the main control method exhibited by animals, especially in underwater creatures that must avoid costly drag penalties, we look to apply lessons from shrinking and retracting shapes to vorticity control methods.

Octopus, Squid, and Shrinking Cylinders

Octopus and squid are amazing animals that exhibit fast jetting responses when in need of escape from predators. These cephalopods intake a large amount of water into their mantle to prepare for the escape jetting maneuver. Interestingly, the initially bluff shape of the mantle does not prevent the animals from performing a fast escape. We are studying how the shape change of the mantle during the escape maneuver dictates and actually facilitates the fast escape maneuver, by modeling the shape change of the mantle as a shrinking cylinder.

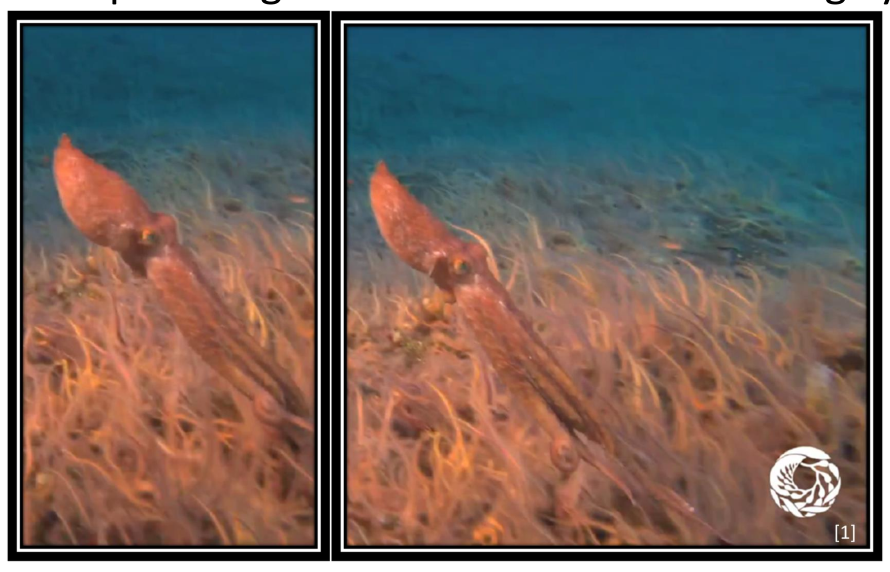

Fig. 1: A squid drastically changes the shape of its mantle as it jet-propels through the water.

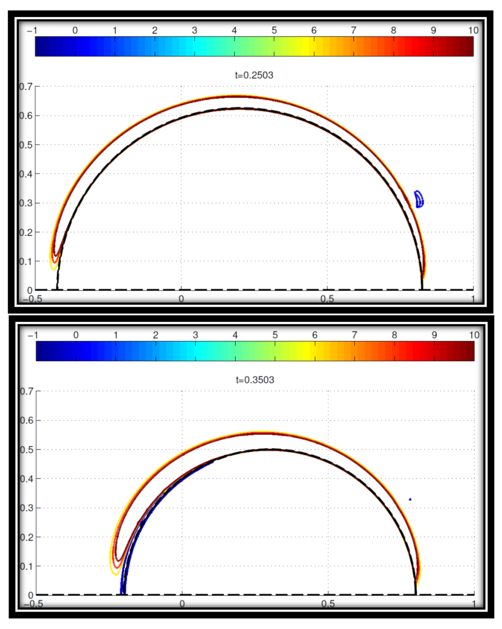

Fig. 2: We model the mechanics of shape-change-enhanced propulsion with a shrinking cylinder. Contours of vorticity are plotted.

Fig. 3: An octopus' initially bluff mantle does not prevent it from an extraordinary escape.

Vortex Creation by Retracting Foils

Additionally, we can create large vortices in the fluid by quickly retracting a foil at an angle of attack. We call this phenomenon *global vorticity shedding*, whereby the boundary layer vorticity on the foil is shed from the entire foil surface instantaneously. We have shown that global vorticity shedding occurs on a towed foil at an angle of attack when quickly retracted, leaving free vortices in the wake .

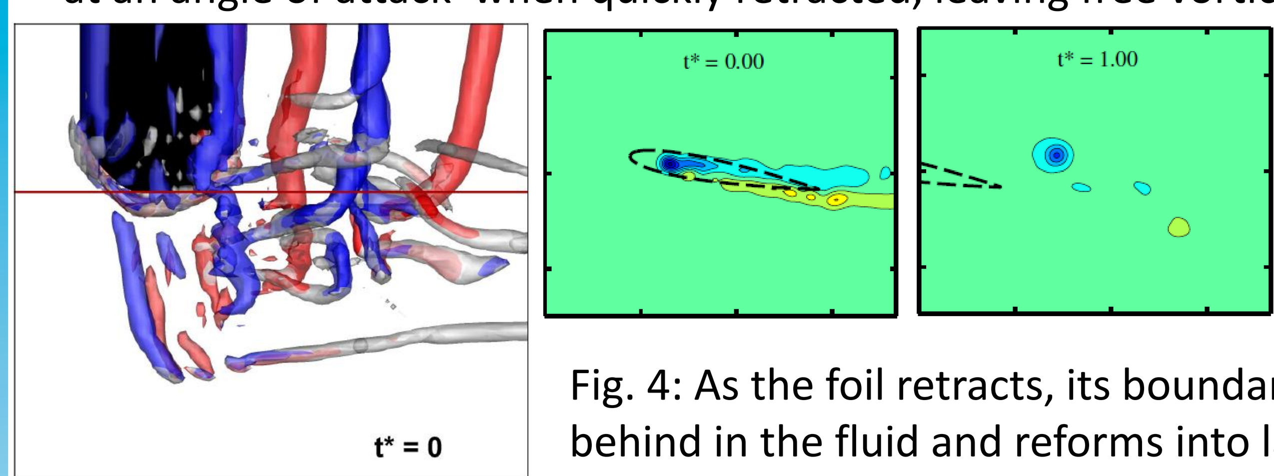

Fig. 4: As the foil retracts, its boundary layer vorticity is left behind in the fluid and reforms into large, lasting vortices.

References:

1. Cephalopods on the Move, Monterey Bay Aquarium, https://www.youtube.com/watch?v=PPYbjHwjNQc
2. Octopus vulgaris Camouflage Change, Roger Hanlon, https://www.youtube.com/watch?v=JSq8nghQZqA
3. Gao, A. Bio-inspired Pressure sensing for active yaw control of underwater vehicles. Masters Thesis, Mechanical Engineering Department, Massachusetts Institute of Technology, 2013.

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