Symmetry breaking during flapping generates lift

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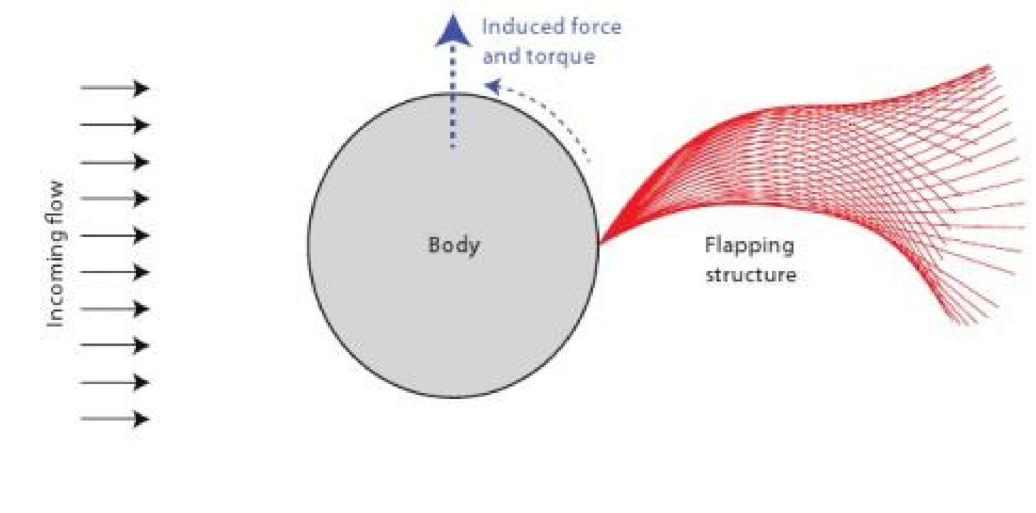
A translucent sea slug called Clione Antarctica, or “sea angel,” moves by flapping its wings. Its cilia can either be motile or non-motile, but when they're non-motile they may still contribute to the animal’s locomotion through the symmetry breaking mechanism described in the new study. Image credit: NOAA

(Phys.org)—A small, translucent sea slug called *Clione antarctica* swims through the cold waters near the polar regions by flapping its wings. At the same time, tiny cilia that circle the sea slug's body in three bands may flap passively and assist in movement. In this mode, the cilia are inert – unable to move themselves – and scientists don't fully understand what role they play in the sea slug's locomotion. Now in a new study, scientists have found a clue to how passive flapping elements generate movement: through a process commonly found in many areas of science called symmetry breaking.

The University of Genova researchers, Shervin Bagheri (now at KTH Mechanics in Stockholm, Sweden), Andrea Mazzino (also at the INFN and CINFAI Consortium in Genova, Italy), and Alessandro Bottaro, have published their study on how symmetry breaking of a flapping filament on a body moving in air or water can generate lift without increasing drag. Their study is published in a recent issue of Physical Review Letters.

"We demonstrate that a short flexible filament attached on the body flaps at an angle of 20-40 degrees either to the right or left of the incoming stream of flow, thus inducing a net force on the body which may move transversely at no additional cost," Bagheri tod *Phys.org*. "This discovery is an example of how the mere presence of appendages on animals contributes to locomotion via the interaction with the surrounding fluid flow, without any effort whatsoever from the animal."

In previous studies, researchers have modeled what happens when a two-dimensional circular cylinder is placed in a stream of fluid flowing from its front to its rear, and found that the flow behind it consists of swirling vortices or eddies. Importantly, the upper eddies above the cylinder are mirror images of the lower eddies beneath it – that is, the vortices have an up-down symmetry. When placing an elastic filament (which in real life might take the form of cilia, feathers, scales, or other passive appendage) in the stream alone, the same thing happens: the up-down symmetry of the eddies is preserved as the filament undergoes a regular flapping motion.



In the presence of a flow, a passive filament attached to a cylindrical body will passively flap in an asymmetric way: red lines depict the filament position at different times. The broken symmetry may explain how the passive flapping filament generates lift and torque in the body. Image credit: Bagheri, et al.

Here, the researchers investigated what happens when the two symmetry-preserving systems interact. When they attached a short filament to the rear of a cylinder, they found that the filament passively oscillates in either the upper or lower part of the cylinder's wake. As a result, symmetry breaking occurs, since the upper eddies and lower eddies are no longer mirror images.

The scientists found that this symmetry breaking generates lift and torque while reducing drag, which causes the system to rotate and self-propel itself upwards. The bulk of the paper deals with finding the underlying physical mechanisms that explain exactly how this happens.

"The symmetry breaking induces an asymmetric pressure distribution around the body, which in turn results in a non-zero net force and a non-zero net torque on body," Bagheri said. "There is a transition (or bifurcation) from symmetric flapping to asymmetric flapping as one decreases the length of the elastic filament. A very long flexible filamentous structure attached to a hind end of a body will flap – similar to the fluttering of a flag attached to a pole – in the same direction as the incoming stream of flow. We have shown that this not the case if the filament is shorter than a critical value."

This is not the first time that research has found that symmetry breaking can generate locomotion in animals, but the previous studies focused on different scenarios. For example, one study found that symmetry breaking of flagella movement has a significant impact on the waveform and swimming trajectory of sperm. Beyond animal locomotion, symmetry breaking can explain a wide variety of unexpected properties in areas from physics to biology to economics because it results in a phase transition.

The results from this study could help explain why many animals, such as the sea slug, have short, passive filaments that seem to improve their hydro- or aerodynamic behavior. The mechanism could also help improve man-made applications.

"These findings may become useful in technological applications where it is of interest to generate a side/lift force on a moving body without increasing the drag from the surrounding fluid," Bagheri said. "The unexpected feature is that the drag on the body is not increased in the presence of the elastic structure, compared to the body without any elastic structures."

More information: Shervin Bagheri, et al. "Spontaneous Symmetry Breaking of a Hinged Flapping Filament Generates Lift." *PRL* 109, 154502 (2012) DOI: 10.1103/PhysRevLett.109.154502