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Experimental Investigation of the Flow Generated by a Flexible, Flapping Membrane based on a Soft Electromagnetic Actuator

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ABSTRACT

Biological systems have been inspired and mimicked by soft robot designs. Soft robots include soft actuators for multiple DOF movement and, when made from smart materials, possess the ability to respond dynamically to environmental stimuli like biological mechanisms. The application of soft actuators has permeated through numerous fields of study, especially liquid pumps. Soft actuator-based pumps with designs inspired by aquatic locomotion address the size and durability limitations of conventional pumps. Aquatic species generate a flow by periodically displacing the surrounding fluid for efficient propulsion. Each species exhibits different thrust-generating mechanisms primarily based on the body's shape, profile and musculature. Fluid-structure interactions (FSI) are then observed and characterized by flow patterns in the body's wake and hydrodynamic performance. Many studies have employed biomechanical prototypes, such as foils, panels or membranes, with findings indicating many similar characteristics as aquatic locomotion. Subsequently, soft robot pumps have adopted these deformable structures for fluid transport. Recently, the development of a new generation of Left Ventricular Assist Device (LVAD) incorporates an undulatory, elastic membrane to restore the output flowrate for heart failure patients. Numerical studies report optimal flowrate recovery and reduced hemolysis in comparison to other LVADs. Despite these encouraging results, there is still little understanding of the fundamental physics governing flow generation by such membrane and more generally on fully flexible, flapping structures in the absence of a freestream.

This study is inspired by the new generation of LVADs and aims at improving our fundamental understanding of pulsatile flow induced by flapping membranes. A prototype is developed based on a soft electromagnetic actuator. A 2D FSI experimental study is designed, implementing the prototype in a still, aquatic environment focusing on the wake's fluid dynamics when generating flow in a finite channel. Its design uses a 3D printed mold to cast the elastomeric membrane with internal channels for liquid metal; this smart material acts as the current-carrying coil. A control system and permanent magnet provide electromagnetic stimulus. The flow conditions are governed by the following parameters: actuation frequency, actuation current and channel width. A Particle Image Velocimetry investigation is conducted to quantify the effects of variations of the input parameters on the flow characteristics. The results highlight a highest streamwise velocity of 45 mm/s and a reversed unidirectional flow in some cases. The results provide a better understanding of the flow generated from a flapping membrane, while its design suggests further innovation for cardio-assist devices.