ME – PhD Thesis Defense

Axisymmetric Starting Jet with Passive Flexibility at the Exit with and without Co-flow

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ABSTRACT

Starting jets are encountered in a wide range of natural and engineering systems, from blood discharge in the human heart to the propulsion mechanisms of aquatic organisms such as jellyfish and squids. These organisms possess highly flexible body structures, suggesting that flexibility plays an important role in achieving efficient propulsion. Motivated by this observation, the present study experimentally investigates the influence of passive flexibility at the nozzle exit on the formation of axisymmetric starting jets and their propulsive characteristics. The investigation is carried out under two ambient conditions: a quiescent environment, representative of the initial phase of jellyfish propulsion, and a uniform background co-flow, representative of sustained swimming conditions. We generate a starting jet using a piston-cylinder arrangement that drives flow through a circular nozzle with an impulsive piston motion. Passive flexibility is introduced by attaching overlapping elastic flaps around the nozzle exit. The effects of the piston parameters, namely piston speed (U_p) and normalized stroke length (L_m/d), together with the flap parameters, flap flexural rigidity (EI) and normalized flap length (L_f/d), are systematically investigated. The resulting flap motion and vortex dynamics are analyzed to understand the underlying fluid-structure interactions and their implications for propulsion.

As the piston moves impulsively over a finite stroke length to generate a starting jet, the flexible flaps undergo a characteristic sequence of opening, return, collapse, and recovery phases, governed by the interplay between fluid forcing and elastic restoring forces. Piston speed, flap stiffness, and flap length strongly influence the magnitude and timing of flap deformation, while stroke length primarily affects the timing of flap collapse. A nondimensional flexibility parameter, EI^*, is introduced to combine the effects of flap stiffness and piston speed, enabling a unified characterization of exit flexibility over a wide range of conditions. Flap deformation is found to significantly modify the vorticity field. In particular, the rapid flap collapse generates an additional vortex that enhances the circulation and hydrodynamic impulse of the starting jet relative to a rigid exit. The study further identifies optimal flexibility conditions in conjunction with flow parameters, that maximize these enhancements and shows that they are closely linked to a specific flap kinematic response.

To examine propulsion under swimming conditions, the study is extended to jets issuing into a uniform background co-flow. While the flap kinematics remain largely unaffected by the imposed co-flow for the piston speed profiles investigated, vortex formation is weakened through interactions between the jet shear layer and the oppositely signed wake vorticity associated with the background flow. Despite this adverse effect, flexible exits consistently generate higher circulation and impulse than their rigid counterparts, as the collapse-induced vortex remains comparatively less affected by the co-flow.

Overall, the results demonstrate that passive flexibility can substantially enhance the robustness and propulsive performance of starting jets. These findings provide physical insight into biological propulsion and offer useful guidelines for the design of bio-inspired underwater vehicles employing pulsed-jet propulsion.

ABOUT THE SPEAKER



B Ashok is a PhD scholar at the Flow Physics Lab, Department of Mechanical Engineering, Indian Institute of Science, Bengaluru, working with Prof. Raghuraman N. Govardhan. He received his Bachelor's degree in Mechanical Engineering from VSSUT, Burla, Odisha, and Master's degree in Mechanical Engineering from Indian Institute of Science, Bengaluru. His research broadly focuses on fluid structure interactions, vortex dynamics, and bio-inspired propulsion systems.