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Vortex dynamics and trajectories of two pulsed jets: A DNS study

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ABSTRACT

Through the generation of vortex rings, pulsed jets display interesting fluid dynamics for propulsion. In nature, arrangements of multiple pulsed jets are observed in aquatic animals (e.g., salp and siphonophore colonies). In engineering, they can be leveraged for aquatic vehicle propulsion and active flow control devices. In this work, we study the vortex dynamics and propulsion characteristics of two synchronous pulsed jets ejected from circular nozzles. We use the Xcompact3D solver (Bartholomew et al., 2020; *SoftwareX* **12**, 100550) to conduct direct numerical simulations at a Reynolds number of 350. We use an immersed boundary method with cubic spline reconstruction (Giannenas & Laizet, 2022; *Appl. Math. Model.* **99**, 606–627) to model two thin nozzles extending from a wall. The pulsed jets are spaced a distance of 2 diameters apart and operate at vortex formation times of 4 and 8. In the initial stages, the two pulsed jets each form a vortex ring. The jets deflect toward each other due to the induced velocity and reduced pressure between them. The two vortex rings reconnect as they travel downstream, resulting in an irregular vortex ring that eventually splits into two distinct rings. The reconnection process occurs later for a formation time of 8 due to the added momentum from the longer pulse time. The variation of total circulation in time of individual vortices for both formation times are identical until the stopping time of the lower formation number. The calculation of circulation is generally sensitive to the selected boundaries, and can become rather ambiguous during vortex reconnection processes due to the presence of vortex stretching and the appearance of multiple vortices in the plane of interest. The Lagrangian-averaged vorticity deviation or LAVD (Haller et al., 2016; *J. Fluid Mech.* **795**, 136–173) is therefore used to identify the vortex cores and vortex boundaries as they translate, reconnect and ultimately decay downstream. We use the closed contours obtained from the LAVD approach to compute the circulation of the vortices. The maximum total circulation (nondimensional) for a single vortex in the plane of the nozzles was found to be 3.23 and 6.42 for formation times of 4 and 8 respectively. The circulation computed from the vortex boundaries is approximately half the total circulation. This study presents the characteristics of two pulsed jets at a larger formation time than previous studies, contributing to our understanding of pulsed jet interactions and their use for propulsion.