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Experimental study on the starting jet through the flexible circular nozzle

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ABSTRACT

In the present study, we experimentally investigate the flow-structure interaction of the starting jet through the flexible nozzle while varying the nozzle morphology and jet flow. The water slug is impulsively accelerated through the cylindrical nozzle, fabricated with silicon rubber, with different flexibility. Analytically, we also formulated the governing equations to describe the fluid-structure interaction by combining the hydrodynamic conservation equations and the linearized shell theory, by which we extracted two dominant dimensionless parameters: the effective acceleration time of the jet (Π_0) and the effective nozzle stiffness (Π_1). For the continuous jet, the flexible nozzle augments the thrust by the starting jet, which is accompanied by the modification of the jet vortical structure. The measurement of nozzle surface deformation reveals that the back-and-forth wave propagation on the nozzle surface is responsible for the jet-vortex evolution augmenting the thrust. The asymptotic analysis of the governing equation shows that the dimensionless wave speed ($\hat{c}$) is expressed as $\hat{c} = (\Pi_0^2 \Pi_1/2)^{0.5}$, and it is further noted that the jet momentum is maximized at $\hat{c} = 3.0$, the condition at which the release of elastic energy stored during the nozzle contraction to the jet is synchronized with the instant of termination of jet acceleration. Using this theoretical argument, it is found that the proposed model accurately predicts the optimal condition for the maximum thrust by comparing the hydrodynamic impulse depending on the nozzle and jet conditions. For the pulsed jet, the flow structure and kinematics of the vortex ring are studied, and, especially, it is confirmed that the same optimal condition for the maximum thrust holds for the pulsed jet, although the deceleration of the jet substantially affects the jet evolution.

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