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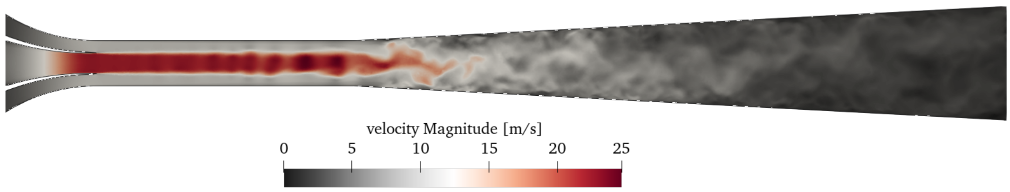
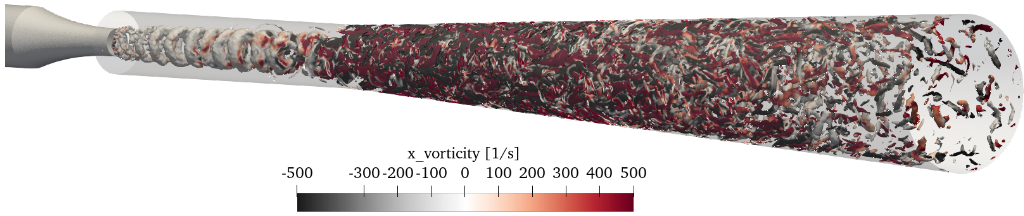
Turbulent Mixing in Water Jet Pump Using the Stress-Blended Eddy Simulation (SBES) Model

Akbar Ravan Ghalati*, Jay Lacey*, Sébastien Poncet†

A jet pump is a versatile hydraulic device with no moving parts used in a variety of applications (refrigeration, water treatment, . . .). It operates based on the energy of a primary fluid and consists of four main components, namely: nozzle, suction chamber, mixing throat and diffuser. Discharging the primary fluid into the mixing throat through a nozzle forms a low-pressure region at the beginning of the mixing section. The created vacuum forces the secondary fluid into the pump. In the mixing throat, the primary fluid transfers part of its kinetic energy to the secondary fluid while the two flows are mixing together.
Numerical analysis of jet pumps using Scale-Resolving Simulation (SRS) approaches are prohibitively computationally expensive due to high Reynolds numbers and complex interactions within the wall-bounded domain. Therefore, the present study employs Stress-Blended Eddy Simulations (SBES)[1] which is a hybrid RANS-LES turbulence model offering a clear distinction between RANS and LES regions and rapid transition to resolved turbulence in separating shear layers. The numerical domain is designed based on the jet pump used in the experiments of Sanger[2], which used water for both the primary and secondary flows.
Figure 1a depicts the instantaneous velocity magnitude contours on the mid-plane of the jet pump which is operating with a flow ratio equal to $M = \frac{Q_{sec.}}{Q_{prim.}} = 1.6$ (where $Q_{sec.}$ and $Q_{prim.}$ are volume flowrates of the secondary and primary flows, respectively). The formation of mixing layers is observed at the boundary of the primary jet as it exits the nozzle. These mixing layers exhibit a wavy pattern due to the appearance of Kelvin–Helmholtz instabilities. Figure 1b shows isosurfaces of the positive Q-criterion, revealing the formation of ring-like vortex structures caused by these instabilities, their pairing, and the subsequent transition to fully three-dimensional turbulence.



(a)



(b)

Figure 1: (a) Contours of the instantaneous velocity magnitude and (b) iso-surfaces of the Q-criterion colored by the streamwise vorticity achieved using the SBES model for a flow ratio equal to M=1.6

Analyzing the effects of the flow ratio on the internal flow field of jet pumps reveals that higher flow ratios cause the primary jet breakup to occur further downstream. Additionally, quantitative characterization of turbulent mixing within the jet pump is conducted by solving a passive scalar transport equation, offering new insights into the mixing efficiency and flow structure of these devices.

*Civil Engineering Department, Université de Sherbrooke, Sherbrooke, Canada
†Mechanical Engineering Department, Université de Sherbrooke, Sherbrooke, Canada
[1] Menter et al., *Applied Sciences* **11**, 2459 (2021)
[2] Sanger, *NASA Technical Report*, (1968)