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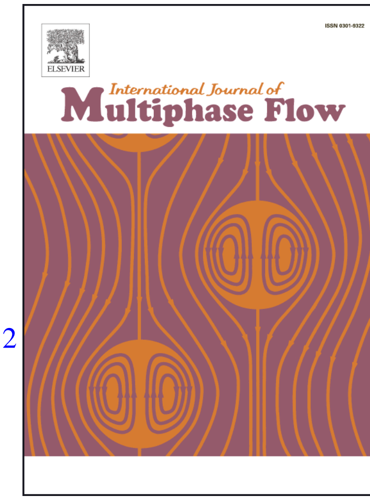

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Simulating air entrainment and vortex dynamics in a hydraulic jump

Adam Witt[1*], John Gulliver[1], Lian Shen[2]

[1]*St. Anthony Falls Laboratory, Department of Civil Engineering, University of Minnesota, 2 Third Ave SE, Minneapolis, MN 55414, USA.*
[2]*St. Anthony Falls Laboratory, Department of Mechanical Engineering, University of Minnesota, 2 Third Ave SE, Minneapolis, MN 55414, USA.*

*Corresponding author: *Tel:* 001 763 443 9221; *E-mail address:* witt0225@umn.edu

Abstract

The air entrainment characteristics of three separate Froude number hydraulic jumps are investigated numerically using an unsteady RANS, realizable k-ε turbulence model, with a Volume of Fluid treatment for the free surface. Mean velocity profiles, average void fraction, and Sauter mean diameter compare favorably with experimental data reported in literature. In all simulations, time-averaged void fraction profiles show good agreement with experimental values in the turbulent shear layer and an accurate representation of interfacial aeration at the free surface. Sauter mean diameter is well represented in the shear layer, and free surface entrainment results indicate bubble size remains relatively unchanged throughout the depth of the jump. Several different grid resolutions are tested in the simulations. Significant improvements in void fraction and bubble size comparison are seen when the diameter to grid size ratio of the largest bubbles in the shear layer surpasses eight. A three-dimensional simulation is carried out for one Froude number jump, showing an improvement in the prediction of entrained air and bubble size compared with two-dimensional results at a substantial increase in computation time. An analysis of three-dimensional vorticity shows a complex interaction between spanwise and streamwise vortical structures and entrained air bubbles. The jump is similar to a turbulent mixing layer, constrained by the free surface, with vortex pairing and subsequent fluctuations in free surface elevation. Downstream fluctuations of the toe are associated with a roll up of the primary spanwise vortex, fluctuations of the free surface, and counter-rotating streamwise vortex pairs. The action of these flow structures is likely responsible for the improvement in three-dimensional results.

Keywords: Air concentration, air entrainment, bubble dynamics, hydraulic jump, void fraction, vortex