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Experimental and numerical studies of the cavity flows atlow Reynolds numbers

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Abstract

The paper is dedicated to the experimental and numerical studies of viscous flows in cavities. The present work investigates the formation of vortical structures in two configurations: (i) the flow inside a square cavity whose lid has constant velocity(a benchmark problem in fluid dynamics), and (ii) the free surface flow over a cavity weir. The experiments are performed in anopen channel, the flow rate and the fluid height upstream the body being controlled by the weir. Qualitative direct visualizations of the flow patterns are obtained in the cavity. The computations are performed in 3D flow configurations with the laminar steady and unsteady solvers implemented in Ansys Fluent. The VOF (Volume of Fluid) methodis used for the free surface geometry calculation and the interface between two fluids. The numerical solutions give precise descriptions of the experimental free surface line and the vortical structures and offer an evaluation of the mixing process inside cavity.

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Nomenclature

V_0	average velocity upstream the immersed broad crested weir (m/s)
ρ	density of fluids (kg/m^3)
η_0	viscosity of fluids (Pa·s)
g	gravitational acceleration (m/s^2)
Re	Reynolds number (-), $Re = \rho V_0 L_0 / \eta_0$
L_0	characteristic length (m)
B	width of channel (m)
H_0	height at the entrance in the channel (m)
Q	flow rate (m^3/s)

1. Introduction

The flow over square or rectangular cavities has many applications in the study of rivers and lakes (especially considering stratified flows), in the transport processes (toxic air, dispersion of pollutants, nutrients, sediment transport, aerosol, erosion) and maintenance of aquatic life, [1, 2]. However, the cavity flow represents a benckmark problem in fluid mechanics [3, 4,5].

Kyoungsik C et al. [2] examined the 3D incompressible flow past a rectangular shallow cavity immersed in a channel using the large-eddy simulation (LES) for the Reynolds number $Re < 5000$.

The flow inside a square cavity whose lid has constant velocity was solved with numerical approximations of second-order accuracy and multiple Richardson extrapolations (MRE) by Marchi et al. [6].The main objective of this work was to present the most accurate numerical solutions found to date for the problem of “singular driven cavity” at Re = 0.01, 10, 100, 400 and 1000.

Tuna and Rockwell [1]studied the self-sustained oscillations of shallow flow past sequential cavities. The primary aim of this investigation was to determine the flow patterns and mixing processes for successive cavities. Experiments were conducted in a recirculating free-surface water channel with a length of 4,87 m, a width of 0,927 m and an adjustable depth of 0,61 m. The goal of this investigation was to determine the flow structure along and within two successive cavities. The results indicate that highly coherent oscillations of the flow structure can indeed be generated, even from a nominally turbulent state. The physics has been pursued with a technique of high-image-density PIV in conjunction with unsteady pressure measurements.

In the present paper, two flow cases are investigated: (i) the free surface flow over cavity – weir of a viscous fluid (silicone oil at the temperature 25°C with density $\rho = 1200$ kg/m^3 and the viscosity $\eta = 0{,}3$ Pa·s) and (ii) the flow dynamics inside a square lid cavity using the same silicone oil, the cavity being half filled with dyed silicone oil (density $\rho = 1210$ kg/m3 and viscosity $\eta = 0{,}32$ Pa·s).

The investigated free surface flow corresponds to an immersed depth of the weir$H_0 = 65$ mm,and developed for one single case (which correspond to the $Re \cong 4$). The results of computations are compared with the experimentally free surface line and the vortex formation inside the cavity.

The lid flow cavity is investigated at $Re \cong 0{,}1$. The vortex formation is recorded experimentally and the visualized trajectories are compared with the non – stationary 3D solution. At the end, the evolution of the interface inside the cavity is determined.

2. Experimental set up

The experiments are performed in an open channel with constant flow rate, the fluid height upstream the immersed cavity - weir being controlled by a downstream weir. The average velocity upstream the broad crested weir is$V_0 = Q/BH_0$, where the flow rate Q is measured by volumetric method and height H_0 is kept constant, see Fig. 1.