Dynamics of two non miscible fluids inside a rotating cylinder

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We study the dynamical behavior of a two-phase vortex, namely a light fluid core embedded within a denser fluid flow environment. Such vortices can be seen in nature and in industrial applications, for example, cavitating helical vortices in the wake of ship propellers. Since such configuration is complex, we opt to investigate a simplified configuration where the vortex core is straight and confined. Two non-miscible fluids are placed within a rotating cylindrical container, with the axis of rotation oriented perpendicular to the gravitational field. When the rotation is sufficient, the centrifugal force maintains the lighter fluid around the axis of rotation with a slight shift of the bubble below the center of the tank. At the interface between the two fluids, waves are found to propagate.

Previous studies examined this configuration experimentally. The pioneering work by Phillips [1] proposed a linearized analytical solution to the problem of the base flow perturbed by gravity, together with a decoupled wave study in the axisymmetric configuration (without gravity); the problem was simplified by considering only the outer fluid in the inviscid framework, and the fluid surface as a free surface. Experimental results were given for the air-water system. Kozlov et al. [2] performed experiments with two non-miscible liquids, and derived an analytical dispersion relation for interfacial waves between the two fluids, yet neglecting gravity, viscosity and surface tension.

Our approach involves numerical simulations of the same system using the CFD Basilisk flow solver [3] in a two-dimensional configuration. The solver is well known for its efficiency in computing multiphase flows. We can vary the density contrast between the two fluids, their viscosity contrast, the surface tension and the confinement ratio (inner fluid radius divided by outer cylinder radius).

We choose parameters for which a stationary state exists, and focus on the establishment of this state: trajectory of the lighter fluid towards the equilibrium state, and interfacial wave motions. Following Phillips and Kozlov, we propose an analytical solution in the inviscid framework, now taking into account surface tension effects. Numerical simulations are compared to analytical solutions. Excellent agreement was found between numerical and theoretical steady states.

In addition to the above stable state, other regimes might occur, depending on the problem parameters (Froude number, Reynolds number, density ratio, confinement). These regimes observed experimentally can also be captured numerically. To understand them, an instability study has to be conducted.

References

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