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Negatively buoyant fluid projectiles

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Abstract

An experimental study concerning the rise height and morphology of a negatively buoyant fluid projectile, produced when a finite volume of saline solution is forced vertically upwards into a quiescent and uniform fresh water environment, is presented. Unlike the much studied continuous injection of high Reynolds number negatively buoyant fluid giving rise to a turbulent fountain, the behaviour of a finite volume negatively buoyant release remains, until now, unstudied.

The work presented herein is based on the development of an experimental set up and methodology specifically tailored to the study of the negatively buoyant projectile. We commence by identifying the two source parameters governing the behaviour of the negatively buoyant projectile; namely the source Froude number Fr_D, expressing the ratio of source momentum to source buoyancy, and the aspect ratio of release L/D, relating the length L of the column of saline solution dispensed to the nozzle diameter D. In doing so, we note the link to turbulent fountains (continuous negatively buoyant releases) whose behaviour is governed solely by Fr_D and to vortex rings (finite volume neutrally buoyant releases), whose behaviour is governed solely by L/D.

Based on its differing rise height behaviour and morphology of release (for varying Fr_D and L/D), we classified the negatively buoyant projectile into one of three regimes: the weak-fountain regime, where the rise height behaviour of the negatively buoyant projectile adhered to very weak fountain predictions; the vorticity-development regime, where the development of an internal vortical structure within the head of the negatively buoyant projectile inhibited its vertical propagation; and the forced-release regime, where the rise height behaviour of the negatively buoyant release adhered, under certain source conditions, to forced fountain predictions.

This adherence of the rise height behaviour of negatively buoyant projectiles to fountain rise height predictions led to a study of the source conditions (in terms of Fr_D and L/D), separating finite volume behaviour (negatively buoyant projectile) from continuous behaviour (fountain), at least in terms of initial fountain rise heights. This study led to a classification of the Fr_D and L/D values marking the transition from finite volume behaviour to continuous behaviour for negatively buoyant releases, linking our work on

the negatively buoyant projectile to existing fountain literature.

Finally, we studied the time dependent volume of the head of the negatively buoyant projectile as it propagated, and identified two stages: a growth stage and a decay stage. We established that the volume of the head of the negatively buoyant projectile is subject to an absolute limit. This finding compares favourably with the absolute limit on the volume of fluid contained within a neutrally buoyant vortex ring (the formation number), as detailed in vortex ring literature. On comparing our findings on the negatively buoyant projectile to those on vortex rings, we developed a new method for estimating the formation number of negatively buoyant projectiles (possibly also for vortex rings), determined the dependence of the formation number on Fr_D, and linked our work on the negatively buoyant projectile to the existing literature on vortex rings.