AN ANALYSIS OF INTERFACIAL WAVES AND AIR INGESTION MECHANISMS

by

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ABSTRACT

This research was focused on developing analytical methods with which to derive the functional forms of the various interfacial forces in two-fluid models [Galimov et al.,2004], and on the Direct Numerical Simulations (DNS) of traveling breaking waves and plunging liquid jets.

Analytical results are presented for a stable stratified wavy two-phase flow and the associated interfacial force densities of a two-fluid model. In particular, the non-drag interfacial force density [Drew & Passman, 1998], the Reynolds stress tensor, and the term $\left(\tilde{p}_{cl_i} - \overline{p}_{cl}\right)\nabla\alpha_{cl}$, which drives surface waves, were derived, where $\tilde{p}_{cl_i}$ is interfacial average pressure, $\overline{p}_{cl}$ is the average pressure, and α_{cl} is the volume fraction of the continuous liquid phase. These functional forms are potentially useful for developing two-fluid model closure relations for computational multiphase fluid dynamics (CMFD) numerical solvers. Moreover, it appears that this approach can be generalized to other flow regimes (e.g., annular flows). A comparison of the analytical and ensemble-averaged DNS results show good agreement, and it appears that this approach can be used to develop phenomenological flow-regime-specific closure laws for two-fluid models [Lahey & Drew, 2004], [Lahey, 2005].

A successful 2-D DNS of breaking traveling waves was performed. These calculations had periodic boundary conditions and the physical parameters for air/water flow at atmospheric pressure, including a liquid/gas density ratio of 1,000 and representative surface tension and viscosities.

Detailed 3-D DNS was also made for a plunging liquid jet. The processes of forming the liquid jet, the associated air cavity, capturing an initial large donut-shaped air bubble, and developing and breaking-up this bubble into smaller bubbles due to liquid shear, were shown. These simulations showed that the inertia of the liquid jet initially depressed the pool's surface and the toroidal liquid eddy formed subsequently resulted in air cavity collapse which, in turn, entrained air into the liquid pool from the annular region formed around the liquid jet. It is significant that the observed physics of the air entrainment processes is quite different from that previously proposed [Zhu et al., 2000],[Bonetto et al.,1994], [Lorenceau et al.,2007].