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Multiphase Turbulence Mechanisms Identification from Consistent Analysis of Direct Numerical Simulation Data

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Abstract – *Direct Numerical Simulation (DNS) serves as an irreplaceable tool to probe the complexities of multiphase flow and identify turbulent mechanisms that elude conventional experimental measurement techniques. The insights unlocked via its careful analysis can be used to guide the formulation and development of turbulence models used in multiphase computational fluid dynamics (M-CFD) simulations of nuclear reactor applications. Here, we perform statistical analyses of DNS bubbly flow data generated by Bolotnov (Re_τ=400) and Lu & Tryggvason (Re_τ=150), examining single-point statistics of mean and turbulent liquid properties, turbulent kinetic energy budgets, and two-point correlations in space and time. Deformability of the bubble interface is shown to have a dramatic impact on the liquid turbulent stresses and energy budgets. A reduction in temporal and spatial correlations for the streamwise turbulent stress (uu) is also observed at wall-normal distances of y^+=15, y/δ=0.5, and y/δ=1.0. These observations motivate the need for adaptation of length- and time-scales for bubble-induced turbulence models and serve as guidelines for future analyses of DNS bubbly flow data.*

Keywords
M&C2017, DNS, Bubble-Induced Turbulence, Budget Equations, Multiphase CFD

I. INTRODUCTION

Understanding and predicting the fundamental two-phase flow and boiling heat transfer phenomena is instrumental to the thermal-hydraulic design and safety analysis of light-water reactors. Multiphase computational fluid dynamics (M-CFD) modeling techniques can be utilized to obtain predictions for these quantities. Such modeling approaches typically adopt the Eulerian-Eulerian two-fluid formulation [1] [2], which consists of solving a system of spatially and temporally averaged governing equations. By virtue of the averaging processes, additional terms arise that must be accounted for through prescription of suitable momentum and multiphase turbulent closure relations. The lack of consensus for the formulation of the multiphase turbulence closure relation comes as direct consequence of the incomplete understanding of the underlying physical phenomena. Therefore, before developing an advanced closure relation it is first necessary to identify the key multiphase turbulence mechanisms at play, which can be achieved by leveraging the volumes of statistics and data obtained from Direct Numerical Simulation (DNS) results.

The canonical multiphase turbulence model comprises the single-phase transport equations (e.g. *k-ε*, *k-ω*, SST) scaled by the liquid volume fraction. Notable efforts have been made to develop bubble-induced turbulent closure relation source terms in the turbulent transport equations [3] [4] [5] [6] [7]; however, in most cases these additions lead to worse predictions than the original formulations, and it is common practice in the industry to neglect such terms entirely. An effective multiphase turbulence model must revert back to the single-phase equations in the absence of vapor volume fraction; consequently, when searching for multiphase turbulence mechanisms one must be cognizant of how to incorporate these features into the model equations. Quantities that become of interest include turbulent time- and length-scales, as well as the turbulent kinetic energy budgets.

Experimental and DNS observations reveal several complex and interesting phenomena associated with multiphase turbulence that are lacking from current bubble-induced turbulence model formulations. While interfacial interactions generally act to augment the liquid turbulence profile, in high liquid flux / low gas flux flows liquid turbulence suppression has been routinely observed [8] [9] [10] [11] [12]. Further, spectral analyses of the liquid energy