Direct Numerical Simulations of Liquid Drops under Strong Shock Waves

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Liquid drops subjected to high-speed gas flows are subject to breakup by Rayleigh-Taylor (R-T) and/or Kelvin-Helmholtz (K-H) instabilities [Theofanous, Annual Rev. Fluid Mech., **43**, 661-90, 2011]. The problem has been studied extensively for nearly a hundred years, but the key physics have only recently been understood [Theofanous et al, Physics of Fluids, **24**, 022104, 2012 and **25**, 032101, 2013]. In these works, we find also the first glimpses of the power of numerical simulations to aid in understanding. In the present paper we bring forth a significant enhancement in this endeavor by employing the recently-developed Direct Numerical Simulation capability as documented in: Chang, Deng and Theofanous [J. Comput. Phys., http://dx.doi.org/10.1016/j.jcp.2013.01.014, 2013]. The method is conservative and consistent to 2nd order, embodies a sharp interface with exact treatment of the jump conditions, and is applicable to all flow speeds, and arbitrarily high material density ratios and acoustic impedance mismatches. The original publications demonstrated a broad range of validation, culminating with interfacial instabilities on liquid drops subjected to shock waves of various magnitudes. The latter were carried out with experiments carried specifically for this purpose at microsecond and micrometer resolutions. We made it evident in this publication that the viscous-K-H problem presents as special challenge for numerical methods, and also that this challenge had been somehow neglected in previous work. This we addressed by means of comparison to Orr-Sommerfeld results for low Mach number (incompressible flows), and direct comparison with experiments for high-Mach flows. In the present paper we close the gap by presenting comparisons with analytical results of K-H instability in high-Mach number flows, under the assumption that the gas in inviscid. We also revisit the experimental results of drops and draw implications about the prospect of a priori prediction of interfacial instabilities in complex geometries and arbitrary flow conditions. The results would be of great interest in combustion among many other applied fields of multiphase mechanics.

Keywords: Compressible Kelvin-Helmholtz instability, aerobreakup, direct numerical simulation of interfacial flows.