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Numerical Study on Shock/Droplet Interaction Before a Standing Wall

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Abstract. In this work, numerical simulations have been performed to study the shock/droplet interaction before a standing wall. The research efforts are directed to reveal the influence of the reshock on the flow features and interfacial dynamics. A five-equation model is applied to model the compressible multi-fluid flow with moving interface. The governing equations are solved under an axisymmetric assumption using a finite volume method. By varying the incident shock Mach number (M_S) and the distance (L) between the droplet and the wall, the wave motion and the droplet deformation are closely examined for four typical simulations. Also, the underlying physics of some salient flow features and interfacial behavior is discussed. Moreover, the maximum wall pressure is monitored in term that structural damage is possibly induced to the wall as a result of the shock/droplet interaction. The droplet kinematics is examined via the center-of-mass displacement and velocity, to clarify the integral effects of changing M_S and L.

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1 Introduction

The aerobreakup of liquid droplet has been widely studied because it has a great variety of relevant applications in industrial engineering, such as damage caused by rain droplets impinging on aircrafts in a high-speed flight, atmospheric dispersal of liquid

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agents released at supersonic speeds, combustion and detonation of multi-phase mixtures, sodium-water reaction in steam generators of fast breeder reactors, etc. In early studies, the aerobreakup mode of liquid droplets in a free field was classified into five typical regimes, which appears in sequence with the increase of the Weber number (We) as vibrational ($We \leq 12$), bag ($We = 12 \sim 50$), bag and stamen ($We = 50 \sim 100$), stripping ($We = 100 \sim 350$) and catastrophic ($We > 350$) regimes [1]. While recently, Theofanous *et al.* [2–5] claimed that those models could be re-classified into two regimes, namely ″Rayleigh-Taylor piercing″ (RTP) regime occurring for $10 < We < 100$ and ″shear-induced entrainment″ (SIE) regime for $We > 1000$, with transition occurring in the range $100 < We < 1000$. Although a large number of arguments were raised about the above classifications, it is commonly accepted that the droplet breakup mode is inherently dependent on the complex shock/droplet interaction at the early stage.

In fact, various experimental and numerical investigations have been focused on the early shock/droplet interaction [6]. Specifically, many recent research efforts have been devoted to the shock interaction with a water column (2D droplet). This is mainly due to the following factors: 1) For interface dynamics, the 2D water column demonstrates morphology changes (deformation and disintegration) similar to a 3D spherical droplet when impacted by an incident shock wave, thus could be extended to understand the basic physics of shock/droplet interaction [8]; 2) In experiments, well-shaped 2D water columns of large diameter (up to 22 mm) could be created more easily [9], so that effective visualization is allowed especially for the wave motion in the liquid medium by applying the traditional techniques such as shadowgraph, schlieren, and/or interferometry methods; 3) For numerical simulations, the 2D shock/water column interaction also serves as a classical test problem for development of robust numerical methods for studying interface dynamics in compressible multi-phase flows [10–13].

Two-dimensional numerical simulations have indeed provided many flow details behind the passing incident shock, for example the shock waves propagating inside and outside the droplet and the vortical structures generated along the interface. Igra and Takayama's simulations [14] reproduced the location and structures of the shock waves occurring outside the water column at the early stage. Their simulating results were consistent with previous experimental observations [15] for the stripping-type breakup of a water column with an initial diameter $d_0 = 4.8mm$ and an incident shock wave Mach number $M_S = 1.47$. It was suggested that formation of tips or ligaments on the water column periphery signatured the onset of a stripping process [7,8,16,17]. With a high-grid-resolution (of $\sim 0.002d_0$) simulation, Nourgaliev *et al.* [10] clearly captured the evolution of pressure wave refractions inside a 2D droplet of $d_0 = 6.4mm$. Recently, Sembian *et al.* [9] demonstrated in detail the propagation of the transmitted wave inside the water column. They found that the transmitted wave was reflected as a focusing expansion wave resulting in a negative pressure. It was also pointed out that the occurrence of negative pressure accounted for the cavitation bubbles observed in their experiments. Meng and Colonius [18] reported a transitory recirculation appearing at the 2D droplet's equator and a persistent upstream jet in the wake. These two flow features were verified to be the