ME – PhD Thesis Defence

Experimental and Theoretical Insights into Impact phenomena of Small Scale Liquid Interfacial systems

Mr. Durbay Roy, PhD Student, Department of Mechanical Engineering, IISc, Bengaluru

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ABSTRACT

This work explores impact phenomena experimentally and theoretically for various interfacial systems ranging from medical diagnostics to drop impacts on solids and immiscible liquids. We study a hitherto unexplored impact phenomenon during an ophthalmology procedure called Non-Contact Tonometry. Using high fidelity experiments and theoretical modeling, we show that noninvasive ocular diagnostics demonstrate a propensity for droplet generation and present a potential pathway for pathogen transmission. The air puff-induced corneal deformation and subsequent capillary waves lead to flow instabilities (Rayleigh–Taylor, Rayleigh–Plateau) that lead to tear film ejection, expansion, stretching, and subsequent droplet formation. Effective cooling is one of the significant application areas of impact systems. In the context of cooling problems, we provide new insights using ab-initio scaling and boundary layer analysis of the integral and differential forms of the conservation equations. We have probed the limiting scaling regimes by incorporating the evaporative effects at the liquid-vapor interface. The dependence of liquid film thickness and Nusselt number on various non-dimensional numbers has been explored. We then investigate the class of drop impact problems where we study impacts on solids, bio-inspired substrates, and immiscible liquid pools at low to moderate impact energies. We explore impacts on glass, PDMS, and soft lithographically fabricated replicas of the lotus leaf and rose petals. Surprisingly, the rose petal and lotus leaf replicas manifest similar impact dynamics. The observation is extremely intriguing and counter-intuitive, as rose petals and their replicas are sticky in contrast to lotus leaves. Air entrapment in the micrometer features of bio-inspired surfaces prevents frictional dissipation of droplet kinetic energy, leading to contact edge recession and subsequent break-up modes of the droplet. We explore the air entrapment dynamics beneath an impacting droplet on an immiscible viscous liquid pool using high-speed reflection interferometry imaging and linear stability analysis. We have detected unique hydrodynamic topology in thin air film surrounding the central air dimple (peripheral disc). The pattern resembles spinodal and finger-like structures typically found in various thin condensed matter systems. We attribute the formation of multi-scale thickness perturbations, associated ruptures, and finger-like protrusions in the draining air film as a combined artifact of thin-film and Saffman–Taylor instabilities. We also investigate the air craters formed on the surface of the impacting droplet and attribute its formation to the rapid deceleration of the droplet due to viscous drag force. The droplet response to the external impulsive decelerating force induces oscillatory modes on the surface exposed to the air forming capillary waves that superimpose to form air craters of various shapes and sizes. We introduce a non-dimensional parameter (Γ) as the ratio of the drag force to the capillary force acting on the droplet to characterize the air craters. Further, we generalize the local droplet response with a global response model for low-impact energies based on an eigenvalue problem. We represent the penetrating drop as a constrained Rayleigh drop problem with a dynamic contact line. The air-water interface dynamics are analyzed using an in-viscid droplet deformation model for small deformation amplitudes. The local and global droplet response theories conform and depict that the deformation profiles could be represented as a linear superposition of eigenmodes in a Legendre polynomial basis. We further study air layer dynamics beneath an impacting droplet on a heated surface at various surface temperatures at low impact energy. The air layer thickness profile consisting of the dimple and the peripheral disc has been measured using high-speed reflection interferometric imaging. We decipher that a Gaussian profile can approximate the dimple height profile characteristics. The dimple thickness profile has a weak dependence on the substrate temperature and is a function of impact energy in general. The air layer rupture time scale and rupture radius increase with an increase in the substrate temperature. We characterize the air layer profile as a Knudsen field and show that a unified treatment, including continuum and non-continuum mechanics, is required to understand the air layer dynamics. The asymmetric wetting of the substrate by the impacting droplet initiates in the peripheral disc region. In the non-continuum regimes in the peripheral air disc, we discover intriguing asymmetric interface perturbations. These perturbative structures cause asymmetric wetting/contact between the droplet and the substrate. The sub-micron length scales of the structures exist due to the asymptotic effects of capillary and Van-der Waals interaction in the disc region. We extend our drop impact on immiscible systems to impact on immiscible stratified systems and show the existence of unique droplet deformation modes and penetration dynamics. The role of impact energy and stratification length scale has been explored experimentally using high-speed imaging techniques.

ABOUT THE SPEAKER

Durbar Roy is a Ph.D. student at the Department of Mechanical Engineering, Indian Institute of Science Bengaluru. He completed his Masters (M.Tech) in Mechanical Engineering from National Institute of Technology, Durgapur, in 2017, specializing in Fluid Mechanics and Heat Transfer. His research interests are broadly in Fluid and Thermal Sciences, Statistical Mechanics, Dynamical Systems, and physics-based machine learning in general. His dissertation is on "Experimental and Theoretical Insights into Impact phenomena of Small Scale Liquid Interfacial systems."