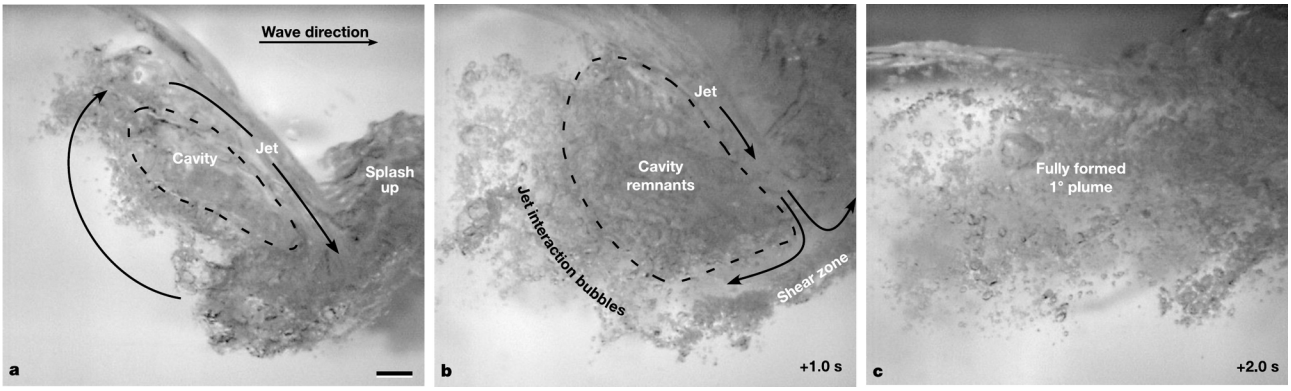
Universality of bubble size distributions in pulsed plunging jets

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Abstract
In a pioneering work Deane and Stokes (2002) identified two mechanisms: Jet and drop impacts create small bubbles, while turbulent fragmentation shapes larger bubbles in oceanic breaking-waves. Field measurements within breaking waves are rare and extremely difficult because the flow is transient, turbulent and densely aerated. Motivated by very recent plunging-jet simulations, we propose a repeatable inclined-jet experiment to test their universality. A Doppler-effect based optical probe will measure void fraction and bubble size distributions at successive depths. Time windows averaged across repeated impacts will resolve entrainment and decay. We will then repeat the protocol in salt-saturated water to investigate how ionic effects on bubble coalescence alter these statistics. Establishing universality between tabletop experiments and oceanic observations would provide an accessible experimental model for studying bubble populations and improving descriptions of air entrainment in hydraulic systems.

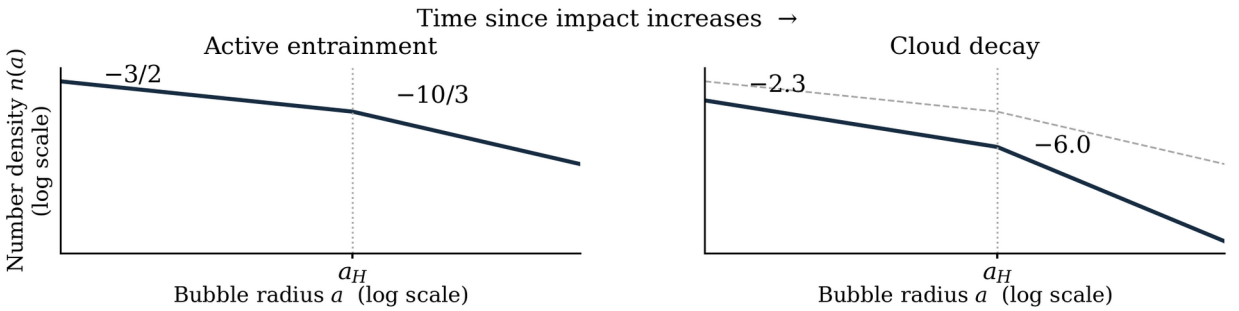


Breaking-wave evolution: (a) jet impact, (b) cavity fragmentation after 1 s, (c) fully formed plume after 2 s. Panels from Deane and Stokes [1], Fig. 2. Scale bar: 1 cm.

Context and motivations

Deane and Stokes [1] distinguish active air entrainment from the subsequent decay of the bubble cloud, as illustrated in the photographs above and the spectral schematic below. During active breaking, jet and drop impacts create small bubbles, while turbulent fragmentation produces larger ones. Their contributions yield number densities proportional to $a^{-3/2}$ and $a^{-10/3}$, respectively, where a is the bubble radius. The Hinze radius is the crossover scale below which surface tension stabilises

bubbles against turbulent breakup. Once active production ceases, buoyant escape and dissolution deplete the cloud and the spectrum steepens. Similar spectra in plunging-jet simulations [2] motivate testing whether these oceanic bubble statistics can be reproduced in a controlled tabletop experiment. An inclined plunging jet isolates the active entrainment phase; stopping injection then gives access to cloud decay.



Schematic spectral evolution based on [1]. Late slopes −2.3 and −6.0 are examples reported for one plume 1.5 s into decay. The dashed line repeats the active spectrum.

Experimental technique

An inclined nozzle and timed valve will inject water into a transparent pool in pulses of prescribed duration at regular intervals, allowing bubbles and circulation to decay between trials. Imaging will determine impact velocity, jet diameter, cloud shape and penetration depth. For fixed jet velocity, inclination and injection duration, we will acquire data from repeated impacts at several depths along the cloud centreline.

Using an in-house setup with a fiber-optic probe as in Dev et al. [4], we will measure void fraction, bubble velocity and bubble size distributions. Short windows synchronised to impact will resolve active injection and subsequent cloud decay. Averaging within each window and across identical trials will yield ensemble statistics at each time and depth. Thereby, we will measure spectral slopes and crossover radius over the resolved size range and compare their evolution with breaking-wave measurements [1,3]. Measurements at successive depths will reveal how transport, buoyant escape, breakup and coalescence transform the distributions. So these comparisons will not only identify when a simple plunging jet reproduces the bubble statistics measured in breaking waves, but also help understand bubble clouds in plunging jets.

Surfactants modify wave dynamics through surface tension and Marangoni stresses [5]. Dissolved salts can also affect interfacial film drainage and inhibit coalescence through ion-specific effects [6]. Repeating the protocol in salt-saturated water will test changes in slopes, crossover size and cloud evolution. Concentration, temperature and liquid properties will be documented, with matched impact conditions and probe calibration. The student will deliver a reproducible protocol, a dataset resolved in time and depth, and an assessment of universality and salt effects relevant to oceanic bubbles and hydraulic aeration.

References

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