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BINARY MILLIMETRIC DROPLET COALESCENCE UNDER MICROGRAVITY CONDITIONS ON ISS

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ABSTRACT

The Droplet Coalescence (DropCoal) device operated aboard the ISS under residual gravity 10^{-5}-10^{-6} g, providing a unique platform to study inertial-capillary bridge dynamics and surface capillary wave propagation, free from buoyancy and convection. Water droplets (D = 2-5 mm, Oh ≈ 0.002-0.004) were generated at coaxial needles and brought into contact under controlled conditions; high-speed video at 8000 fps captured bridge formation for equal-size and asymmetric pairs, as well as capillary wave packets launched at the moment of contact and propagating along the droplet surface.

When two liquid droplets first contact, a liquid bridge forms and grows rapidly under surface tension. Theory predicts that in the inertial-capillary regime (Ohnesorge number Oh $\ll$ 1) the bridge neck radius follows $r(t) = CR(t/\tau)^{1/2}$, where $\tau = (\rho R^3/\sigma)^{1/2}$ is the inertial time scale. Testing this scaling law requires gravity-free conditions; on Earth, buoyancy deforms the droplets and drives convective flows that interfere with the measurement.

Eight experimental configurations were studied: four equal-size droplet pairs (D = 2, 3, 4, 5 mm) and four asymmetric pairs (size ratios up to 2.5:1), with up to eight replicates each. Power-law fits yield a universal exponent

n = 0.49 ± 0.03 across all eight configurations, in excellent agreement with the theoretical value of 0.5. The dimensionless prefactor C = 1.08-1.22 for all experiments, consistent with recent numerical simulations. For asymmetric pairs, normalising by the harmonic-mean effective radius $R_eff = 2R_1R_2/(R_1 + R_2)$ and the corresponding inertial time $\tau_eff = (\rho R_eff^3/\sigma)^{1/2}$ collapses all data onto the same universal curve as equal-size pairs, with no statistically significant dependence of C or n on size ratio up to 2.5:1. Capillary wave packets launched at the moment of coalescence are clearly resolved propagating along the droplet interface across all configurations, offering an independent probe of the inertial-capillary dynamics beyond the bridge region.

Volume-of-Fluid (VOF) simulations are performed with OpenFOAM (interIsoFoam) in an axisymmetric 2D geometry, using a 10 µm mesh resolution in the bridge region. A key feature is initialising each simulation from the experimentally measured pre-coalescence droplet contour rather than an ideal sphere, which is expected to improve quantitative agreement with experiment. Preliminary bridge-radius curves from simulation will be presented alongside the experimental results, providing a first validation of the numerical approach for microgravity binary pinned droplets coalescence.

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