Bubble simulation: Model improves prediction of cavitation nuclei

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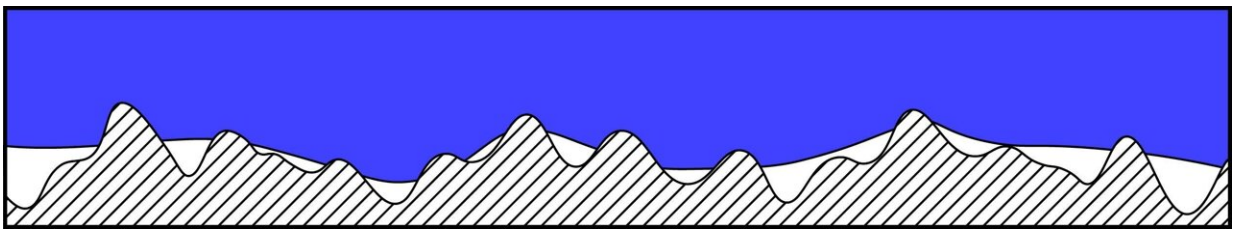

A schematic representation of a close up view of a liquid droplet (blue) on a solid substrate (striped) where surface roughness is apparent. The liquid-solid contact shows where air pockets (white) develop, introducing nucleation. Credit: Karim Alamé et al. 2020

Small gas bubbles that form and collapse in a liquid—a process known as cavitation—can cause big problems for equipment like ship propellers. Imploding bubbles create noise and vibration, interfering with acoustic sensors, and even erode metal over time.

Just as any solid material has defects, water contains defects in the form of very small regions of dissolved gas called nuclei. Cavitation occurs when water flows to regions of low pressure, and these nuclei grow and collapse.

"When you design a propulsor, being able to predict and prevent cavitation is huge," said Krishnan Mahesh, a professor of naval

architecture and marine engineering at the University of Michigan.

To predict cavitation, you have to account for nuclei. In the past, the fluids community treated nuclei empirically, entering the level determined from experimentation into calculations.

In a paper in the *Journal of Fluid Mechanics*, co-authors Krishnan Mahesh and Karim Alamé developed an approach to predict nuclei levels from first principles for the first time.

"A core problem that we solve is that if you can scan a surface, we can predict the shape of this equilibrium interface, or how much nucleation the surface will introduce," said Mahesh.

This physics-based approach and analytical solutions based on Gibbs free energy gives a more comprehensive view of cavitation nucleation in the presence of gas. Their model agreed with a compilation of experimental data collected over 60 years from the ocean and a water tunnel in Launceston, Tasmania, validating the analytical solution.

Surfaces like metal that appear smooth have a rough texture up close. When immersed in water, the textured surface can trap gas in crevices, introducing nucleation. The approach can inform the design of quieter propulsors and erosion-resistant coatings for ship rudders and other control surfaces.

The ability to predict the equilibrium liquid-gas interfaces over arbitrary solid surfaces can also be applied to develop and characterize superhydrophobic surfaces, which could lead to more energy-efficient designs. A submerged surface in direct contact with gas rather than water has greatly reduced hydrodynamic drag.

"Moving forward, our model sets the foundation to predict the effect of

walls, depth, surfactants or biological materials on nuclei and cavitation," said Mahesh.

More information: Karim Alamé et al, Effect of gas content on cavitation nuclei, *Journal of Fluid Mechanics* (2024). DOI: 10.1017/jfm.2024.79

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