Ultrasonic measurement of the contact angle of a sessile droplet

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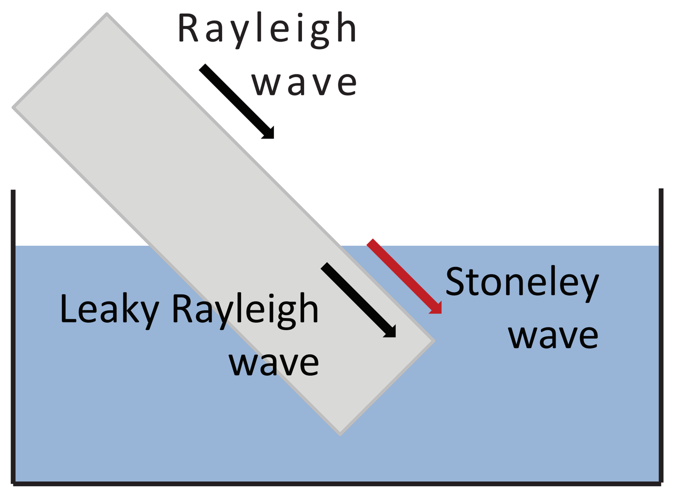
Introduction

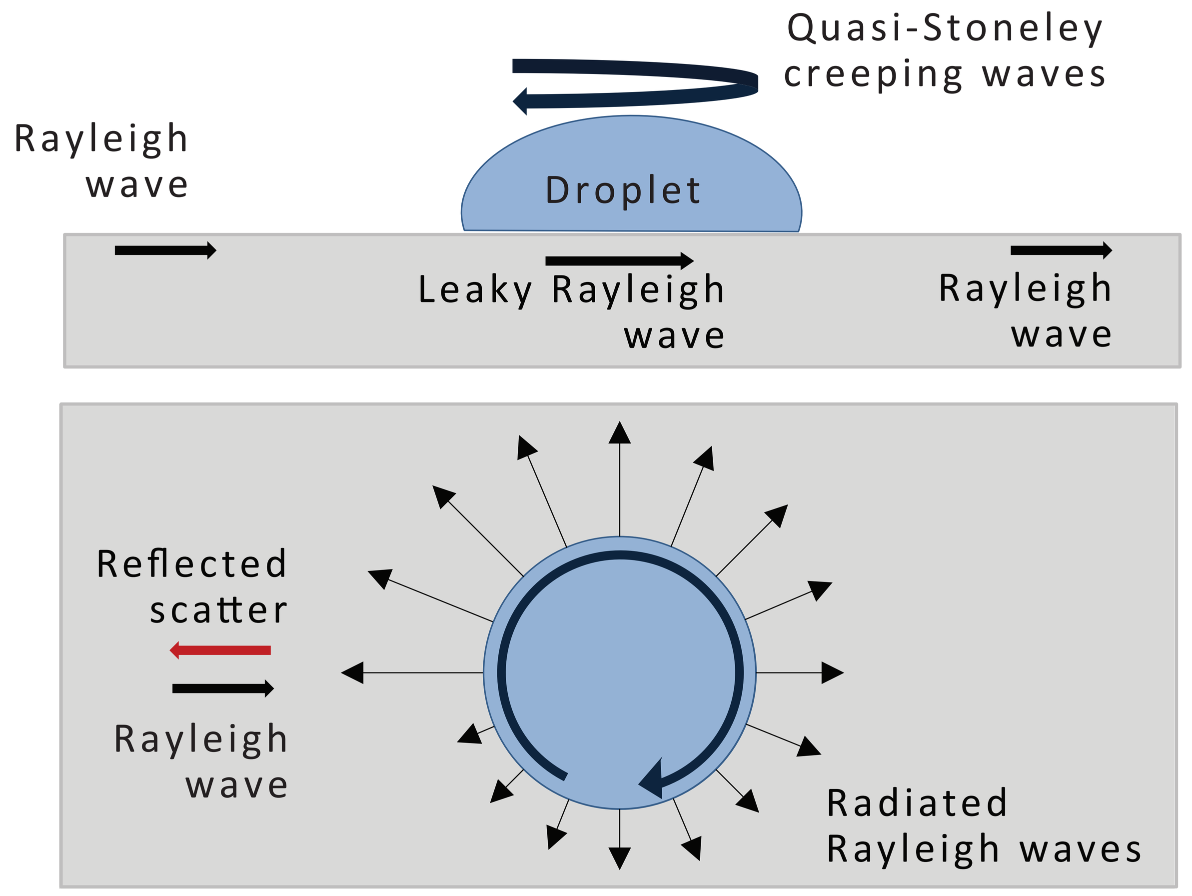
Techniques such as the drop-shape method are widely used to calculate surface tension by estimating the contact angle of liquid droplets deposited on solid substrates. However, they require complex optical systems and have limited accuracy in the case of small drops. This paper proposes a novel ultrasonic technique for the evaluation of the contact angle between a liquid droplet and a solid substrate that uses Rayleigh wave backscattering from the droplet.

Hypothesis

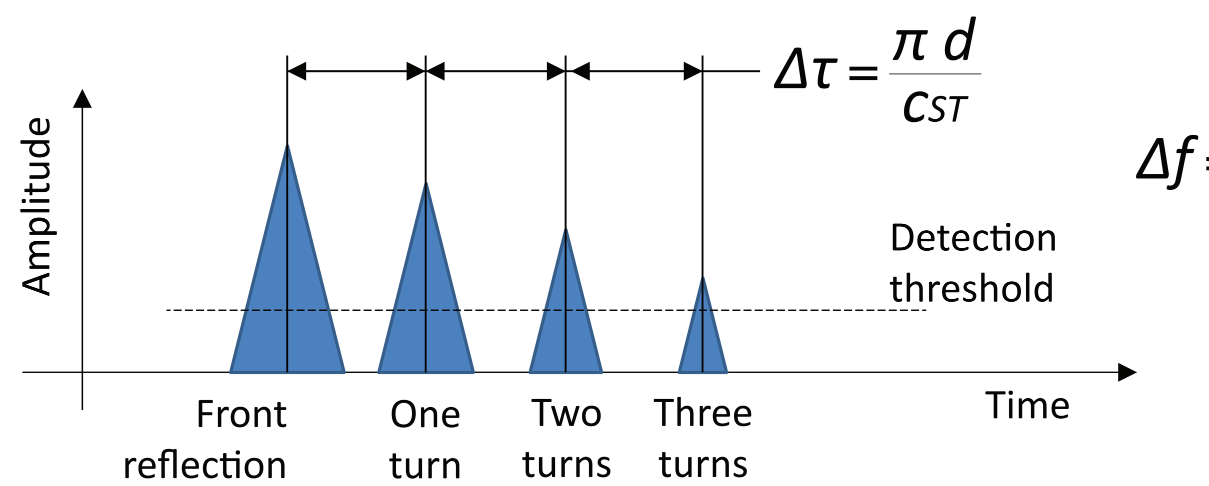
When a Rayleigh wave propagates along the free surface of a partially immersed plate, it is mode converted into a leaky Rayleigh and a Stoneley (also known as Scholte) wave



A similar phenomenon can occur in the case of a sessile droplet; however the circular contact line will force the Stoneley wave to creep around the droplet:



Therefore, the scattered field will be characterized by a train of pulses with repetition frequency Δf, dependent on the drop diameter d and the Stoneley wave velocity c_{ST}:

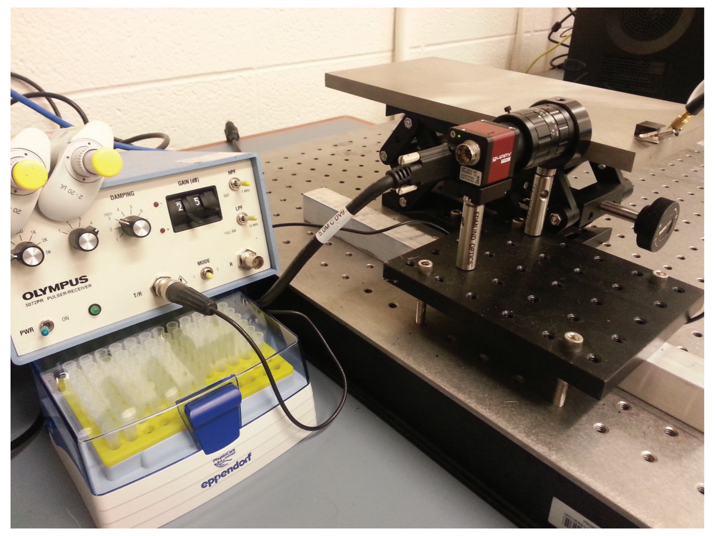


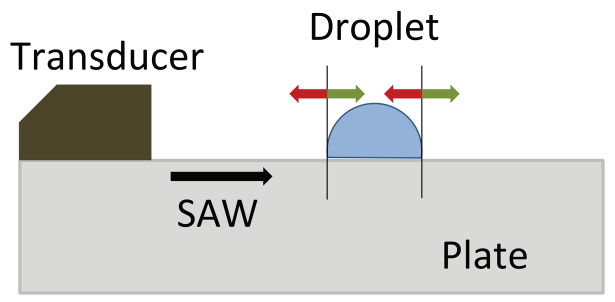
$$\Delta\tau = \frac{\pi d}{c_{ST}}$$

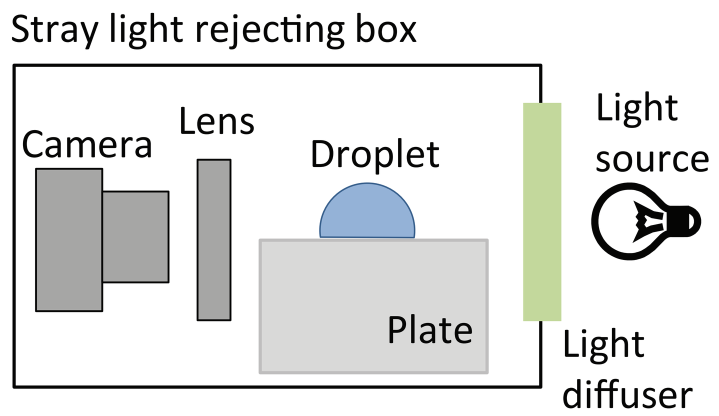
$$\Delta f = \frac{1}{\Delta\tau}$$

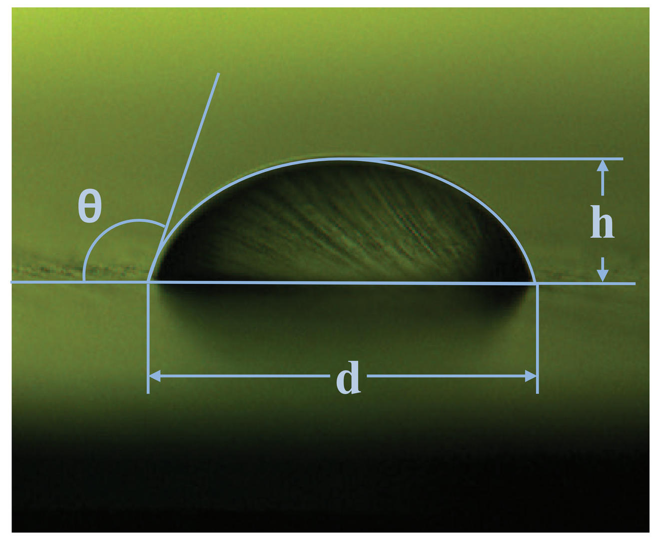
Experiments

To validate the hypothesis, water droplets of different diameters were deposited on a stainless steel substrate and monitored with ultrasonic and optic systems throughout the evaporation process







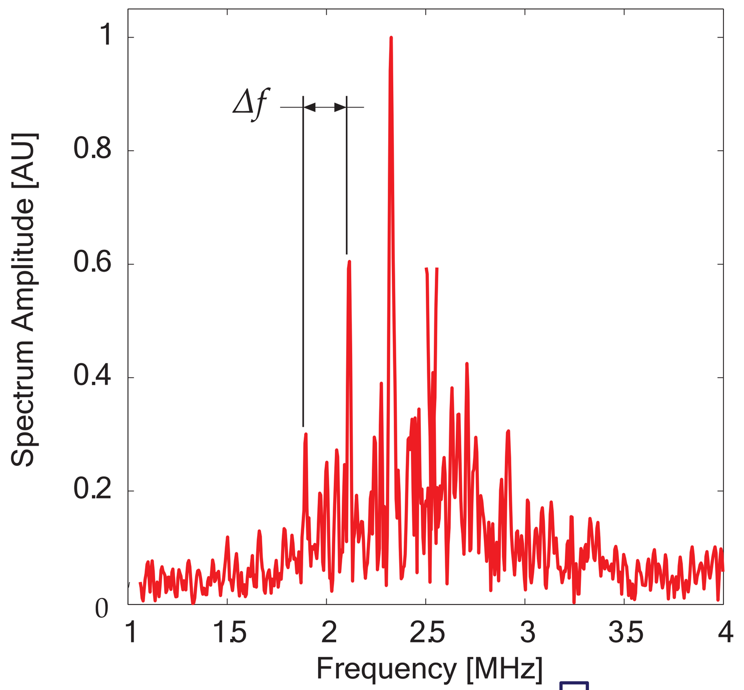


Results

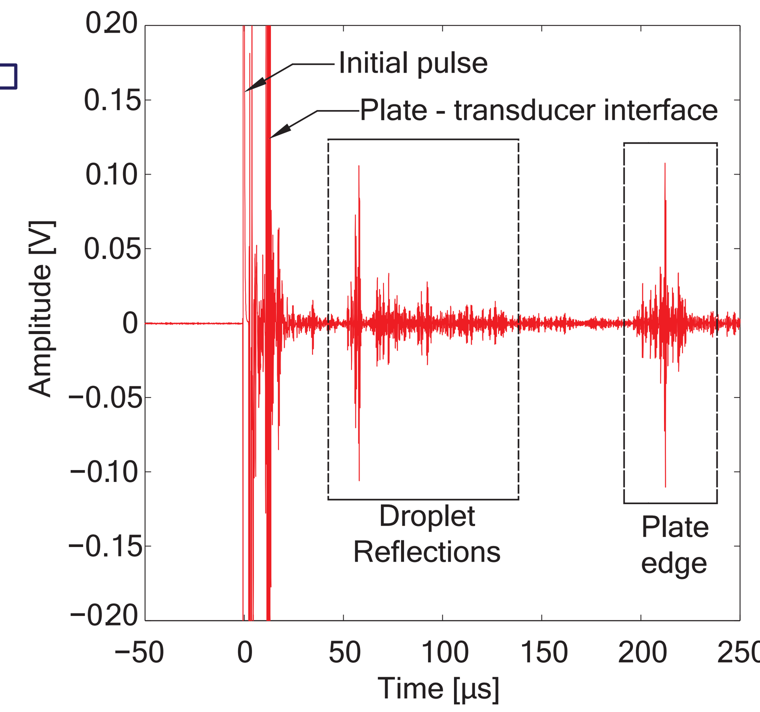
Diameter dependence

FFT

Spectrum characterized by the repetition frequency Δf

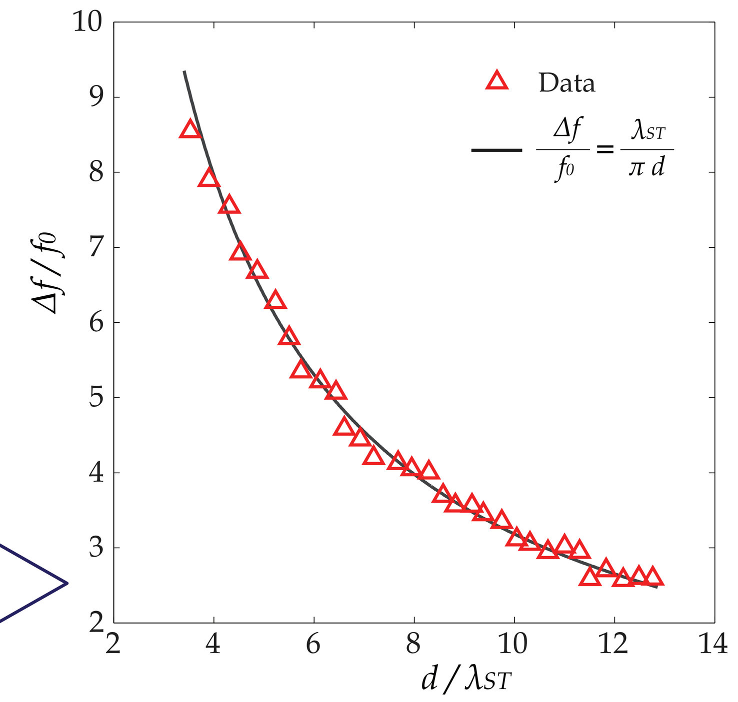


Typical time domain signal



Analysis of multiple droplets confirms the hypothesis

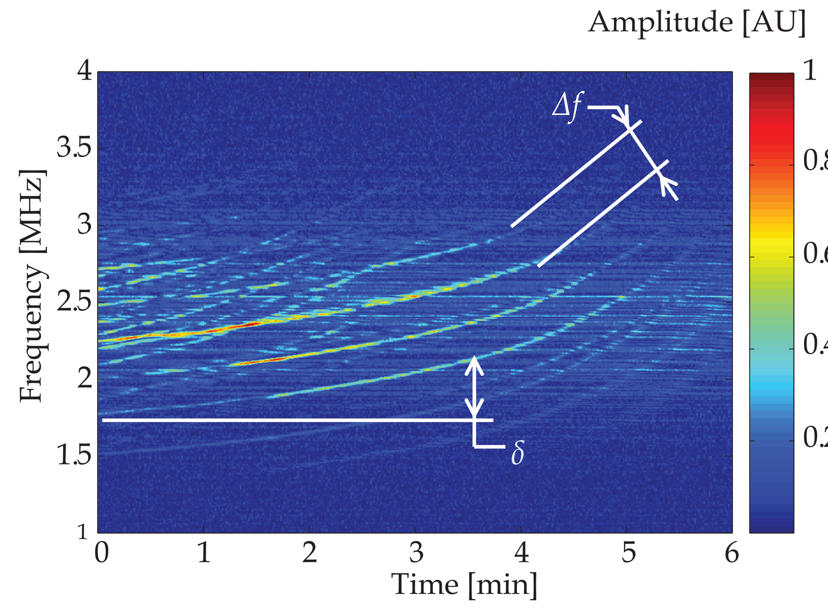
Dimensionless droplet diameter

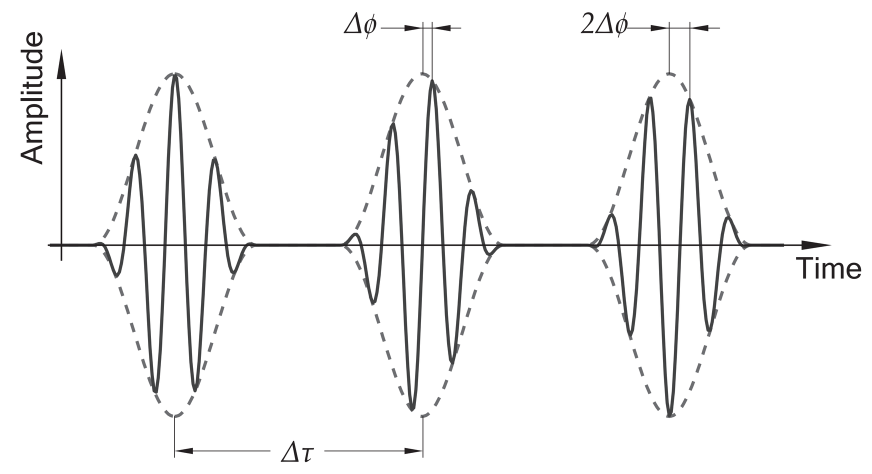


Results

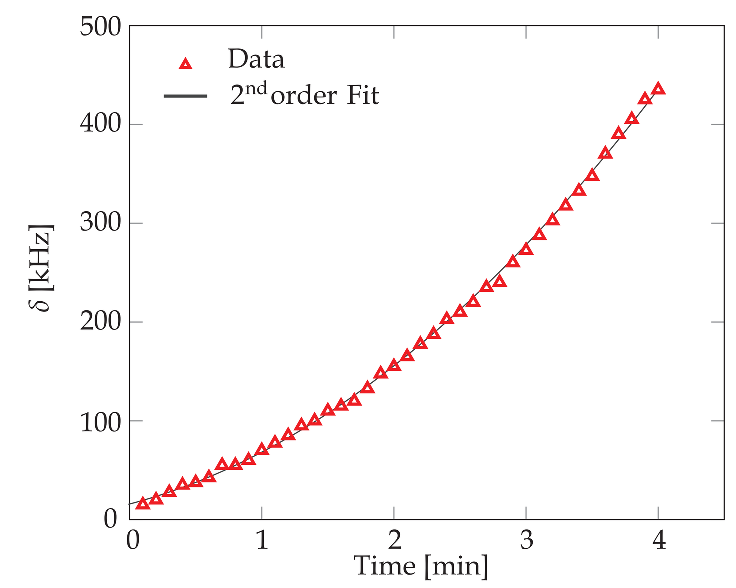
Contact angle dependence

The pulse repetition frequency Δf was monitored as the droplet evaporated. Results are shown on the right. The color of each pixel corresponds to the normalized amplitude of the signal spectrum measured at time t during the experiment.

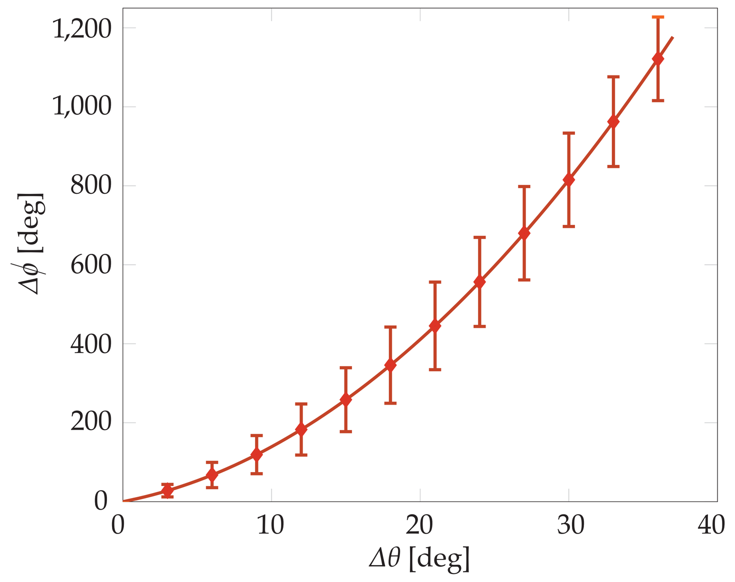




The repetition frequency between echoes Δf remains constant, but the interference pattern undergoes a shift δ caused by a continuous phase increment $\Delta\phi$ between pulses:



$$\delta = \frac{\Delta\phi\,\Delta f}{2\pi}$$



Data from different droplet sizes reveals a quadratic dependence between the contact angle increment $\Delta\theta$ and the phase increment $\Delta\phi$.

$$\Delta\phi = 38\,\Delta\theta^2 + 7.25\,\Delta\theta + 0.0037$$

Conclusions

- We have demonstrated the existence of quasi-Stoneley waves (QSTWs) circling around sessile droplets deposited onto rigid substrates
- QSTWs induce resonances that lead to surprisingly large Rayleigh wave (RW) backscattering
- Receding contact angles cause the interference spectrum of reflected RWs to shift to higher frequencies whilst retaining the same repetition frequency.
- Spectral shifts are related to contact angles changes by a quadratic law
- Inversion of the quadratic law can be used to measure the contact angle and opens the possibility for ultrasonic measurement of surface tension.