Fluid Mechanics Group
Mechanical Engineering

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Bubbles Puzzles

- Understanding transient bubbles' behaviours via experiments and simulations

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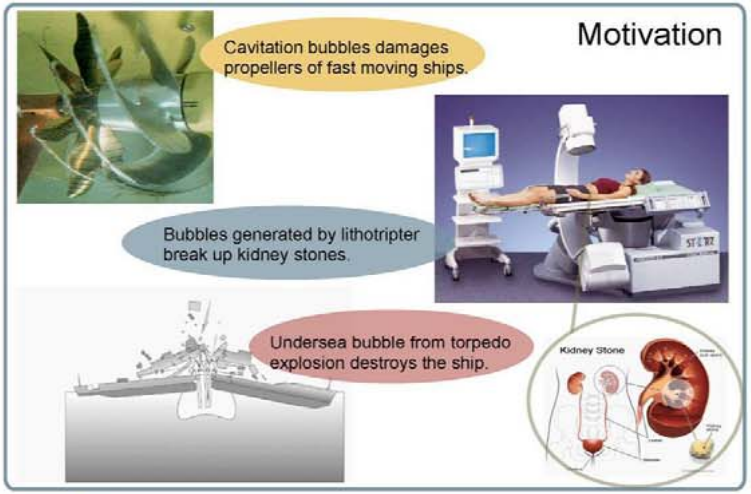
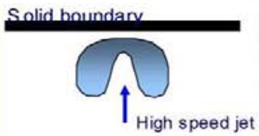
Motivation

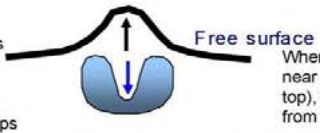


Bubble Dynamics



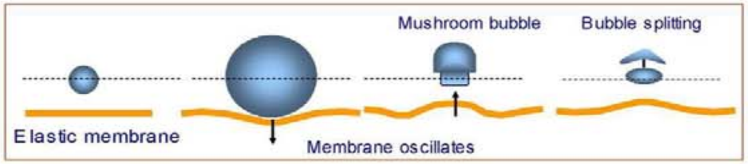
When a bubble collapses near a solid surface, it develops a high speed jet (about 100 m/s) towards the solid surface.

This is the cause for damages on propellers and the break up of ships in undersea explosion.



When a bubble collapses near a free surface (air on top), the jet is directing awa from the surface.

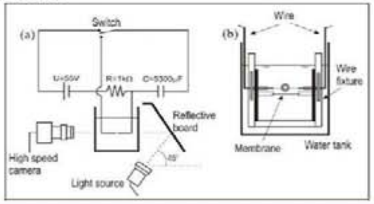
The surface forms a liquid jet. This jet is responsible for the flavour in champagne!



When a bubble collapses near an elastic membrane, e.g. the skin or muscle tissues, it behaviour is complicated. It pushes back the membrane as it expands to its maximum size, and then collapses into a mushroom shape. The membrane is attracted towards the bubble when it collapses. In certain cases, the bubble breaks into, with or without the formation of jets at its final stage of collapse.

Experimental Setup

- It has four main components:
  circuitry, water tank, high speed camera and light source.
- The circuitry consists of
  a 55 V DC supply, 5300 μF capacitors and a 1 kΩ resistor.
  At the wires' ends, copper-alloy electrodes (0.11mm in diameter) are used to generate transient bubbles.
- The tank is an open-top transparent tank of 17 cm × 17 cm × 17 cm.
- The frame rates of the high speed camera used are 12500 and 20000 frames per second.



Numerical Modeling and Simulations

- Boundary Element Method is used for the calculation of the Potential Flow modelled.
- Potential ϕ and the normal velocity $v_n = \mathbf{n} \cdot \nabla\phi = \partial\phi/\partial n$ on the bubble surface are solved using Green's second identity: $c(\mathbf{x})\phi(\mathbf{x}) + \int_S \left[\phi(\mathbf{y}) \frac{\partial G(\mathbf{x},\mathbf{y})}{\partial n(\mathbf{y})} - v_n(\mathbf{y})\, G(\mathbf{x},\mathbf{y}) \right] ds(\mathbf{y}) = 0$

  where x is a vector pointing to a location situated on the surface S of any of the bubbles; y is a vector pointing to an integration point (also on the surfaces of any of the bubbles); $G(\mathbf{x},\mathbf{y}) = \frac{1}{|\mathbf{x}-\mathbf{y}|}$ is the free space Green's function.
- The bubble's surfaces are divided in triangular linear elements. The potential on the bubble surface is updated for each time step using the unsteady Bernoulli equation

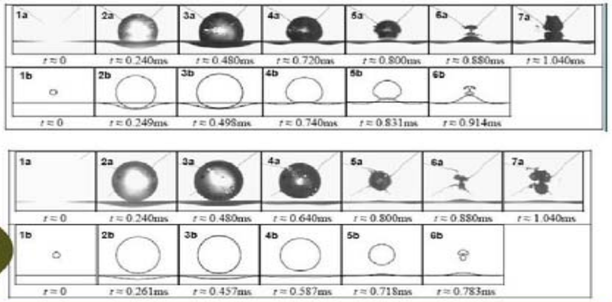
  $$\rho \frac{D\phi}{Dt} = p_{ref} + \frac{1}{2}\rho|\nabla\phi|^2 - p_b$$

  with D/Dt the material derivate.
- The gas inside the bubble is assumed to behave adiabatically.

Single Bubble

Near Elastic Membrane

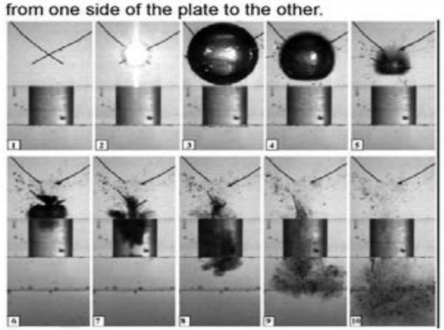
- The interaction between a membrane and a submerged oscillating bubble is studied.
- The spark bubble is generated near an elastic membrane.
- Numerical simulations are performed to provide better understanding on the phenomena. Excellent matches between experimental and numerical results are obtained as shown below.
- The interaction induces a perturbation that propagates on the surface of the bubble and leads to the bubble mushroom formation, bubble pinching and bubble splitting.
- The numerical model can be utilized as a guideline to predict the interaction of transient bubbles with biological tissues that are difficult to observe experimentally.



Significance:
Understanding bubble behaviour in bio-medical systems where elastic materials are involved.

Near Perforated Wall

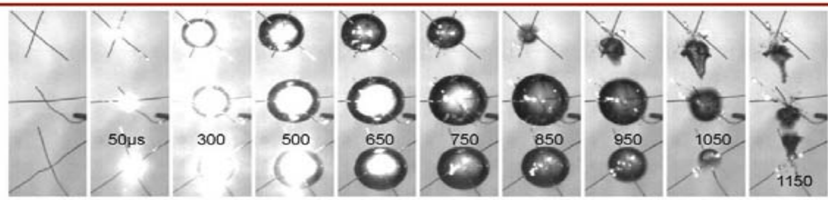
- It is well known that a jet develops in a (non-equilibrium) oscillating bubble near a solid wall. The jet is directed towards the wall and is usually of very high speed (~100 m/s).
- Experiments of a pump based on this principle are performed for a bubble collapsing near a plate with a small hole in it.
- It is verified that this pump design is effective as the collapsing bubble jet sends liquid from one side of the plate to the other.

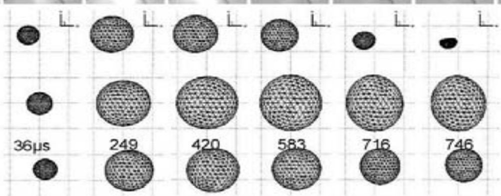


Application:
Micropump with no mechanical parts for bio-medical applications.

Multiple Bubbles

- Interactions between several non-equilibrium bubbles are studied using high speed photography.
- Corresponding simulations are performed using a three dimensional BEM code.
- Complex interactions are observed depending on the bubbles:
  - Relative spatial arrangement,
  - Time of inceptions,
  - Relative distances, and
  - Maximum sizes.
- In the left figure, the three bubbles arranged in-line and created at the same time. Both top and bottom bubbles collapse with a jet towards the center, slightly elongated bubble.





Significance:
In real applications, multiple bubbles are often involved. The dynamics of these bubbles differ from that of the commonly studied (due to its simplicity) single bubble dynamics. We hope to understand multiple bubbles dynamics better for improving instrumentation designs and developing innovations.

This work is done in collaboration with Ong Geok Pei, Kelly Liew Siew Fong, and Deepak Adhikari.

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