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The oscillation and rupture of a water-filled balloon

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ABSTRACT

Experimental observations of the impact and rupture of a water-filled balloon on a rigid surface have revealed that the initial stages of the impact are analogous to those for a water droplet of constant surface tension impacting a rigid, hydrophobic boundary. Upon collision, upward-travelling capillary-like waves are created on the membrane, with the tension in the membrane playing a similar restorative role to surface tension. The velocities and wavelengths of these waves are in approximate agreement with linear potential theory for an oscillating sphere of water with constant surface tension. Should the balloon membrane remain intact during the impact, it will evolve in a similar way to the surface of a *bouncing* droplet, with the membrane's elastic energy acting analogously to the surface energy of a water droplet.

However, if the membrane ruptures during impact, any similarities are quickly lost. The rapid retraction of the membrane creates a small-scale shear instability on the air/water interface. On a larger scale, as the restoring force for the capillary-like waves is lost while their kinetic energy within the water remains, growth of the interfacial amplitude occurs (as demonstrated in figure 1). Eventually gravity comes to dominate the flow, leading to the slumping and spreading of the water.

A water-filled balloon that is held, forcibly oscillated then ruptured with a sharp object displays the same three distinct phenomena. In air, the large-scale growth of the interfacial amplitude becomes asymmetric, leading to the formation of so-called bubbles of the less dense, air phase and spikes of the denser water phase. For such a balloon held underwater, the interfacial amplitude grows in a symmetric way.

In this paper, we present examples of the phenomena described above. Further, we explain why the late-time growth of the interfacial amplitude is a manifestation of the Richtmyer-Meshkov instability, while demonstrating that unlike classical Richtmyer-Meshkov instability, growth may occur even when there is no density difference across the interface. At late-time, measurements of the displacement of the maximum amplitude of the interface suggest a power law of the form t^{θ}, where t is time and θ is around 0.6.

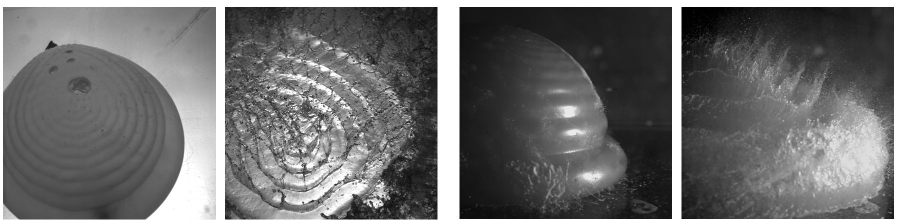

Figure 1: The impact and rupture of a water-filled balloon on a rigid surface in air.