Exploring what happens when different spherical objects hit the water

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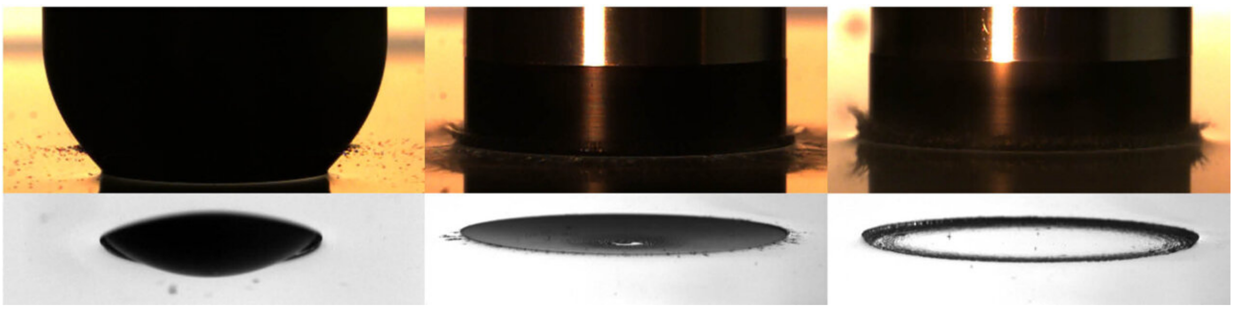

Images of a hemispherical (left), convex (middle) and flat (right) nose-tipped bodies impacting the water. Credit: Jesse Belden.

When an object hits a body of water vertically, it is accompanied by a strong hydrodynamic force fueled by the flow of water around it, which propels it forward. The magnitude of this force is known to vary depending on the mass of the object hitting the water.

While this general rule is known to be true for both flat and spherical objects, the force that accompanies flat objects is influenced by an additional factor. Specifically, the presence of a trapped gas layer in flat objects alters their hydrodynamics, resulting in peak pressures that are below those predicted by water hammer theory.

Water hammer theory is a physical construct that describes what happens when a moving fluid is suddenly brought to a halt or swayed in a different direction. The theory suggests that this halt or sudden change in motion produces a surge in pressure or wave within the fluid, also referred to as the water hammer effect.

While water hammer theory can be used to predict the pressures that emerge in different fluid systems, it does not predict the hydrodynamic forces that accompany flat objects vertically hitting water. Interestingly, some spherical objects with a lower curvature, such as oval-shaped spherical pebbles, can sometimes behave as flat objects after impact with a water body.

Researchers at Naval Undersea Warfare Center Division Newport , Brigham Young University and King Abdullah University of Science and Technology (KAUST) carried out a study aimed at delineating the curvature at which spherical objects start to behave as flat objects. Their paper, published in *Physical Review Letters*, presents evidence that challenges the well-established belief that flat objects are accompanied by the highest impact forces in water.

"We were interested in measuring the water impact force of a flat-nosed body impacting flat water," Jesse Belden, co-author of the paper, told Phys.org.

"There was a long-standing belief in the literature that this scenario would yield the largest impact force (as opposed to other nose geometries). However, in this paper we found that putting a very slight positive curvature on the nose increased the impact force significantly beyond those measured for flat-nosed bodies."

To carry out their tests, Belden and his colleagues designed a unique experimental body, which they then attached to objects with different shapes. This body had an accelerometer embedded in it, which allowed the researchers to directly measure the objects' water impact forces.

"We then designed several different nose shapes ranging from hemispherical to flat, which could be attached to the test body," Belden explained. "We compared our measured impact forces to existing theories that predict impact forces on spherical nose shapes and found the nose radius at which our experiments departed from these theories."

The findings gathered by Belden and his colleagues contradict the assumption that when hitting water vertically, flat objects experience greater hydrodynamic forces than spherical objects. Instead, the researchers found that the curvature of spherical objects could greatly influence the extent of the impact forces accompanying them.

"We observed that as the nose becomes flat, an air layer is trapped between the nose and the water at the moment of water impact," Belden said. "The height of this air layer depends heavily on the nose curvature. Furthermore, the air layer significantly 'cushions' the impact. A slightly curved nose induces a shorter air layer height, which results in less cushioning relative to a flat nose."

The findings gathered by Belden and his colleagues could have valuable implications for the future development of objects and technologies designed to move quickly in water. In addition, their work could inspire other research groups to perform similar experiments aimed at exploring the hydrodynamics of spherical objects with different curvatures further.

"In our next studies, we would be curious to investigate whether biological divers (i.e., humans or birds) ever suffer impact forces as large as those we have revealed in our laboratory experiments," Belden added.

More information: Jesse Belden et al, Water Impact: When a Sphere

Becomes Flat, *Physical Review Letters* (2024). DOI: 10.1103/PhysRevLett.133.034002

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