**Introduction**

Objects with rough surface texture creates underwater cylindrical air cavities on impacting water pools, greatly influencing the descent trajectories, structural integrities and drag forces associated with the impacting bodies. These cavities don’t persist for long with the cavity wall closing from the hydrostatic pressure of the pool sealing and dividing the cavity into two halves. A great deal of research has looked into finding the exact moment of this seal, popularly known as the pinch-off time. For a single sphere of known diameter, time to pinch-off has been found to stay consistent over a long range of drop heights. It could be of great hydrodynamic application interest to be able to vary this pinch-off time systematically. In this poster, we propose a novel simultaneous two-sphere drop on water, and show that doing so will prolong the time to pinch-off.

Figure 1: A 14 mm steel sphere (specific gravity 7.78) free falls onto a water pool from 20 cm (impact velocity $u_0 = 1.98$ m/s), creating an axisymmetric cylindrical air cavity in its wake as it falls through the water pool (0 ms – 26.8 ms). The sphere surface is rough, (roughness, $rz = 7.2$ which forces the flow around to separate from the sphere at impact. The cavity grows radially, until hydrostatic pressure forces the cavity to seal at mid-depth in what is known as a deep seal pinch-off (54 ms - 56.4 ms).

**Method**

Two $d = 14$ mm spheres were placed on a platform held over a water tank at height $H$ from the free surface. The horizontal distance between the spheres is $d_{x0}$, which is varied from $d_{x0} = 0$ d (the two spheres are touching each other, $d$ representing the diameter of the spheres used, 14mm for this study) to $d_x = 2d$ (the distance between the spheres is 3 times the diameter of the sphere), at 0.5d distance increment. The platform held at rest with a string pulley system, with the strings being clamped to hold the platform at tension. When the clamp is let go, the two spheres start free-falling and impacts the free surface with the same impact velocity $u_0$ and creates two separate cavities. The cavities grow radially, finally coming to deep seal pinch-off at time $t = t_d$. A Photon SA3 high speed camera captures the whole impact event at 2000 fps.

**Experimental Results**

![Figure 3: Evolution of two-sphere cavities over time until pinch-off.](image)

Each row of images shows the cavity formation for two spheres separated by a fixed horizontal distance $d_x$ of 0, 1d and 2d respectively. The time steps show the cavity evolving over time, and the images inside the blue boundary show the cavity pinch-off for each case. The pinch-off time depends on the sphere diameter and follows the rule $t_d \sim (H/d)^{3/2}$. For a 14 mm single sphere, $t_d \sim 54$ ms. But for two-sphere drops, pinch-off time varies, with $t_{d,2}$ as high as ~61 ms for a 0d distance. $t_{d,1}$ gets shorter with increasing $d_x$ between the spheres, clearly seen from the images inside the blue box. Another important observation is the warping of the shape of the cavity in relation to $d_x$. Compared to the single sphere drop shown in figure 1 it is clearly seen that the axisymmetric shape of the cavity is distorted on the inner cavity walls for two-sphere drops. The observation of distortion is important, because it proves that the flow fields around the cavities are compromised by each other due to the flow boundary interaction between both. This may work as the primary driving mechanism behind the elongation of cavity persistence or the pinch-off time. The distortion is quantified through calculating the cavity diameter over time through image processing, the method to which is shown in the next section and the data presented at figure 5b.

**Cavity Tracking:**

![Figure 4: (a) Raw image of two spheres creating an air cavity, taken from the captured high-speed camera video. (b) Image of left and right cavity, resized to prepare it for further processing. (c) Morphological operation on the raw images transforms the images from grayscale to binary, distinct boundary lines gets drawn throughout the edge of the cavity wall in the process. (d) Tracking the extreme points of the edge gives a numerical cavity diameter value along each pixel depth. The average of these diameter values are taken and presented as the average cavity diameter over time in figure 5b. All the image processing is done through MATLAB.](image)

**Conclusion**

The main takeaways from this study can be summarized in the points given below:

1. Simultaneous two sphere impact on water introduces interactive flow effects.
2. The deep seal pinch-off time shows incremental trend with shortened horizontal distances between the two spheres,
3. The cavity shapes for both the cavity gets distorted, indicating strong flow interaction at the boundary of the cavity walls.