61st Annual Meeting | American Physical Society Division of Fluid Dynamics

FLOW FIELD around a Vertically SALTATING SPHERE

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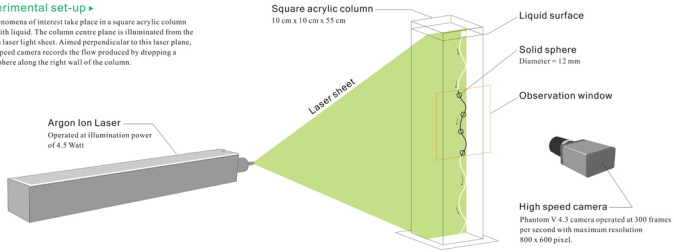
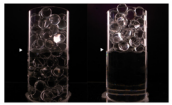
Experimental set-up

The phenomena of interest take place in a square acrylic column filled with liquid. The column centre plane is illuminated from the left by a laser light sheet. Aimed perpendicular to this laser plane, a high speed camera records the flow produced by dropping a small sphere along the right wall of the column.



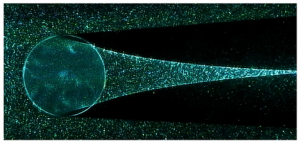
Multiple-exposure video image

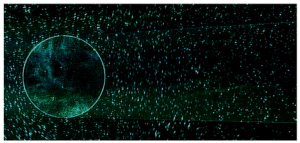
Touching the wall, the solid sphere (made of transparent acrylic) is released from rest approximately 1 cm below the surface of the liquid (here water to make the sphere visible). Interestingly, the sphere does not fall along a straight line but collides repeatedly with the wall during its vertical descent.



Refractive index matching

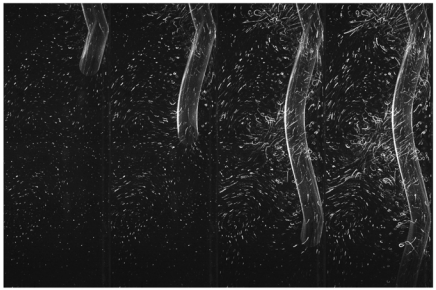
Refraction greatly influences the way light rays propagate through transparent solid-liquid media. When water is used (left), the acrylic spheres are visible both above and below the liquid free surface (marked by a white triangle). When immersed in the liquid para-cymene, by contrast, acrylic spheres become invisible (right). This is because, unlike water, para-cymene has the same index of refraction as acrylic.





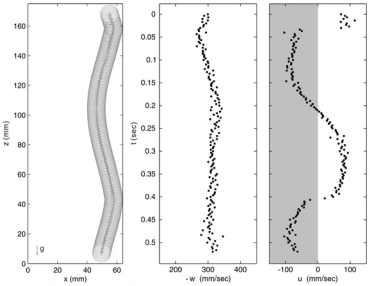
Shadows and caustics

Refractive index matching alleviates the light sheet distortion produced by liquid-solid boundaries (here the perimeter of an acrylic cylinder appearing as a bright circular halo). Our goal is to use a laser light sheet to visualize the motions of tracer micro-particles mixed with the liquid and surrounding the solid body. Whereas shadows and caustics are produced in water (top), they nearly vanish when acrylic is bathed in para-cymene (bottom). In that case, the liquid flow field can be evenly illuminated despite the presence of solid bodies, as exploited earlier by Hsu and Capart (2007).



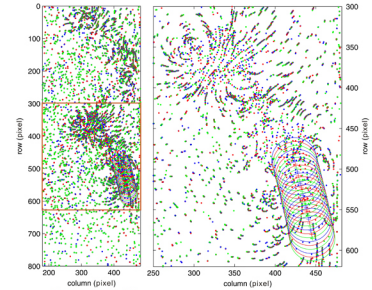
Pathlines of liquid and sphere

By processing the sequence of gray scale images acquired by the high speed camera, we can progressively accumulate a long exposure image of the sphere and tracer trajectories. Upon passage of the descending sphere, tracers along the sphere path are first pushed out then pulled in, forming looping pathlines.



Sphere path and velocity history

By identifying circular halos on the sequence of images, we can obtain the successive positions of the sphere (left), and the history of its vertical and lateral velocities. In the vertical direction (middle), the sphere rapidly reaches a nearly constant fall velocity of about 30 cm/s, corresponding to a Reynolds number of approximately 3000. In the lateral direction (right), the sphere undergoes a sudden velocity reversal at each collision, and a gradual velocity reversal between one collision and the next.



Tracer velocities

Liquid tracer velocities are measured by particle tracking velocimetry (PTV), using methods adapted from Capart *et al.* (2002). A criterion based on path regularity is used to match successive particle positions (shown here using a blue-red-green-blue coding scheme), and retrieve the particle velocities. The velocities are then transferred to a regular grid using natural neighbor interpolation.

ABSTRACT

We conducted experiments to characterize liquid motions around an immersed solid sphere in free fall near a wall. During its descent, the sphere repeatedly bounces off the vertical wall, much like a sediment particle saltating along a horizontal stream bed. To measure the flow around the sphere, we use refractive-index-matched materials and laser-illuminated tracers. We observe vortex rings released by the saltating sphere, and interpret the lateral sphere motions as the result of an attractive force between the sphere and the wall.

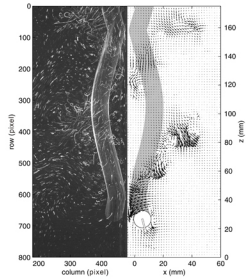
References

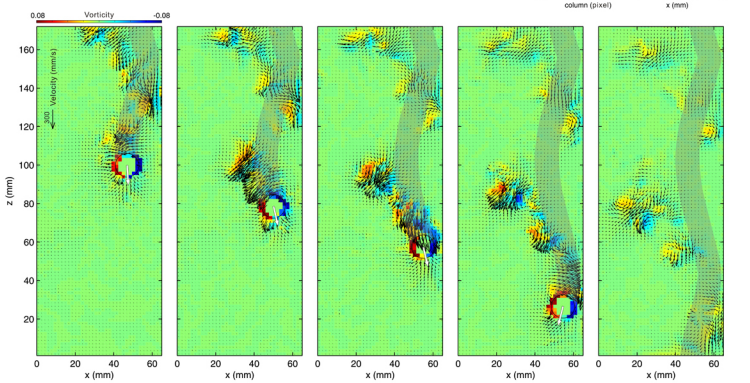
H. Capart, D.L. Young and Y. Zech, "Voronoi imaging methods for the measurement of granular flows," Exp. Fluids **32**, 121-135 (2002)

H. C. Hsu and H. Capart, "Enhanced upswing in immersed collisions of tethered spheres," Phys. Fluids **19**, 101701 (2007)

Sphere-wall attraction

By symmetry, the near-wall sphere descending in the liquid ambient can be approximated by a pair of spheres suspended in an ascending current. The constricted flow between the two spheres then generates a negative pressure that pulls the spheres together, before collisions push them apart again. An attractive force associated with negative liquid pressure thus acts like a spring pulling the saltating sphere towards the solid wall.





Velocity and vorticity maps

Time-resolved velocity and vorticity maps document successive states of the liquid flow around the saltating sphere. The wake shed by the sphere is composed of localized patches of clockwise (red) and counterclockwise vorticity (blue). The sphere releases an especially strong vortex ring at the apogee of its curved trajectory. Left behind by the sphere, the vortex ring follows an oblique path away from the wall, before gradually dissipating its energy.