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Dynamics of a Partially Fluid-Filled Sphere

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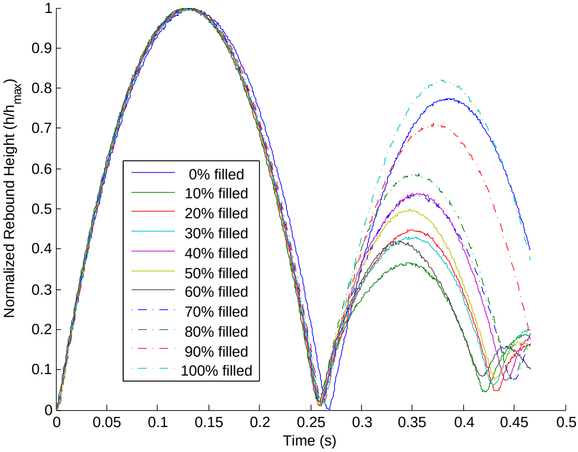
Objectives

Our objectives

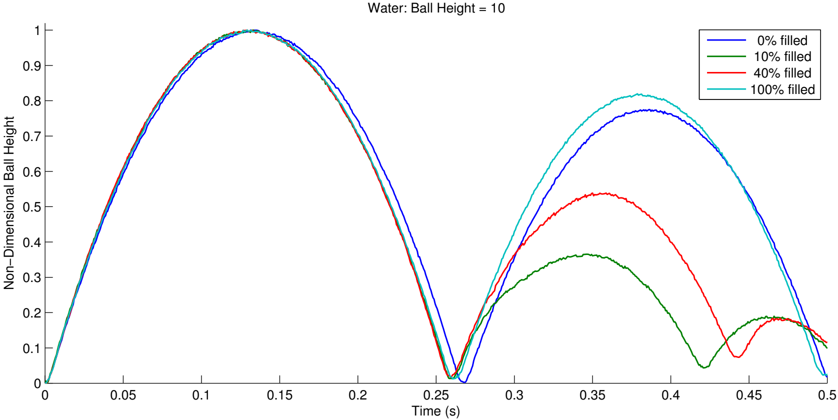
- Determine the cause of rebound mitigation.
  - Quantify the motion of the sphere.
  - Video analysis shows the formation of an internal jet at the same time as rebound mitigation.
- Determine the details of the internal energy exchange.
  - Determine the jet velocity and mass through PIV and numerical models.
  - Model the global effect of the energy exchange.

Observed Phenomena

- The measured rebound heights of a 10cm drop: water filled.

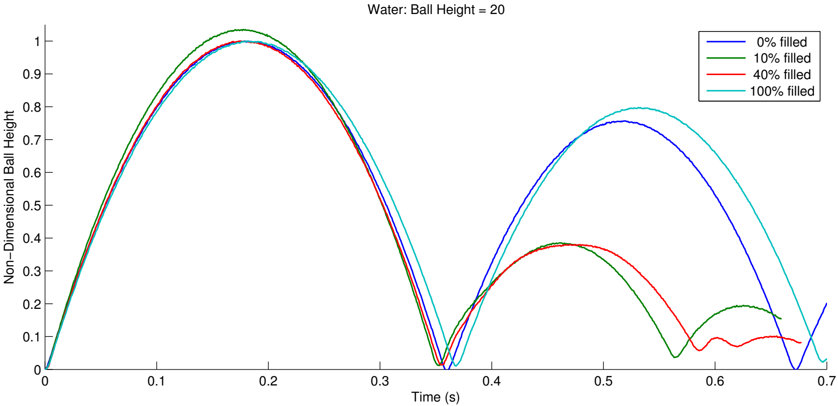


- The same plot, yet simplified.



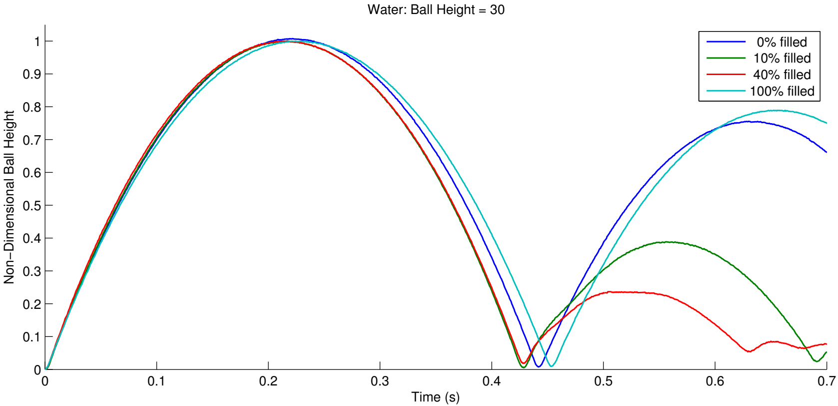
Ratio of Rebound Height and Weight

- The measured rebound heights of a 20cm drop: water filled.



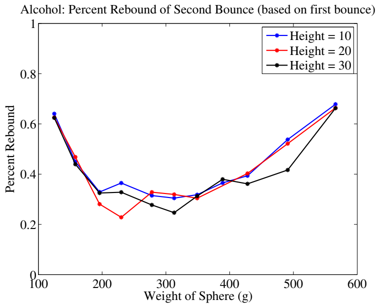
Ratio of Rebound Height and Weight

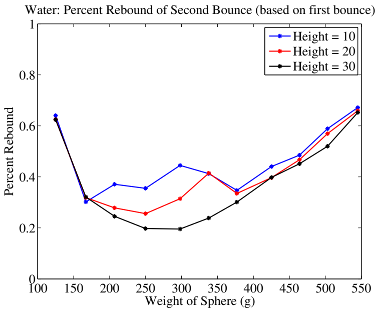
- The measured rebound heights of a 30cm drop: water filled.



- We considered different viscosities and observed different phenomena as seen in the video below.

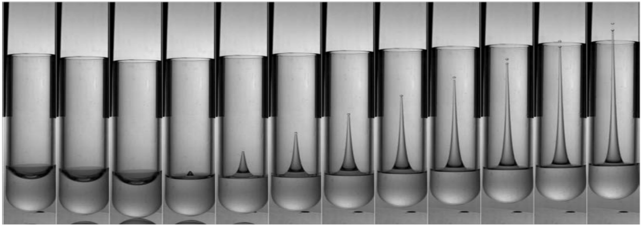
- Analysis of our data showed that the global effect of the sphere's motion is unchanged.



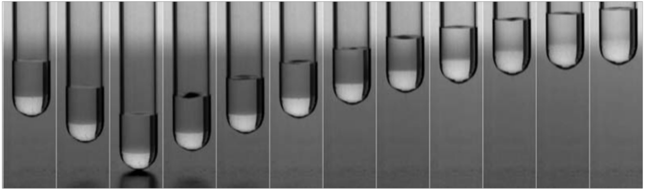


Previous Work

- In 2006, Antkowiak et. al. analyzed jet formation dependence on meniscus formation within a test tube.
  - Note the meniscus in the far left frames.

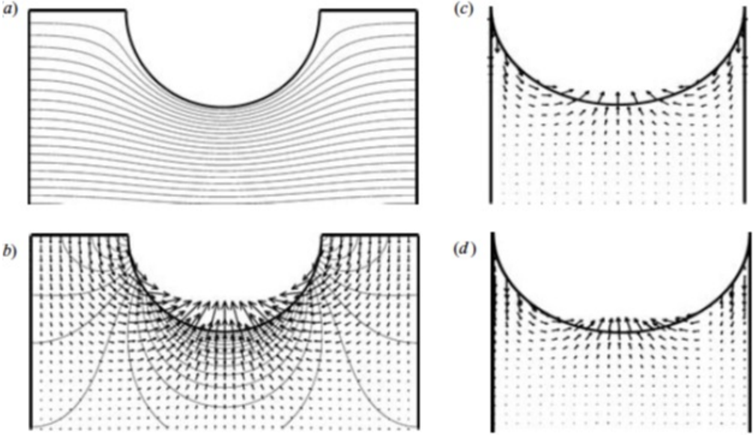


  - Treating the test tube so that no meniscus forms



Basis - Antkowiak et. al, 2006

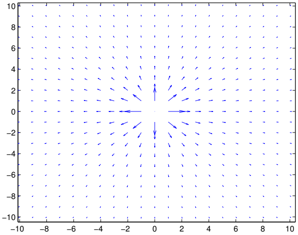
- The dynamics of the cavity collapse and impulse-generated jet were modeled through a pressure-impulse model.

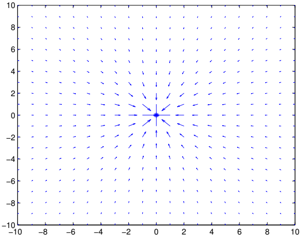


Potential Flow

Fluid motion is defined by ϕ, a partial differential equation

- Potential flow theory utilizes an ideal fluid that is inviscid and irrotational.
  - $\phi = \frac{m}{2\pi}\ln r \rightarrow$ source/sink $|m| =$ magnitude of ϕ
  - When $m > 0$, ϕ represents a source (pushes fluid away).
  - When $m < 0$, ϕ represents a sink (pulls fluid in).
  - m is found by the localized use of $m = V_r 2\pi r$





The Model

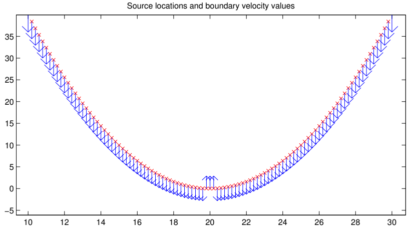
- We approximate the free surface as a parabola and set the sources and sinks along the parabolic interface.

Theory

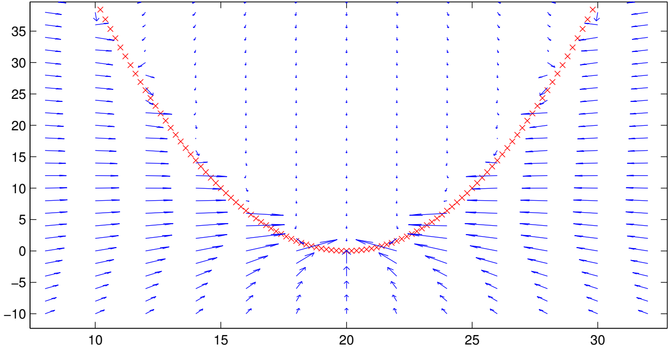
$$\phi = \frac{m}{2\pi} \ln r$$
$$m = V_r \, 2\pi r$$
$$V_r = \sqrt{u^2 + v^2}$$

Implementation

$$\phi = \sum_{k=1}^{n} \frac{m_k}{2\pi} \ln r_k$$
$$[M] = 2\pi \, [V_0] \, [\ln r]^{-1}$$
$V_0 = kgh, \; 0 < k << 1$ except at the points within the impulse diameter.

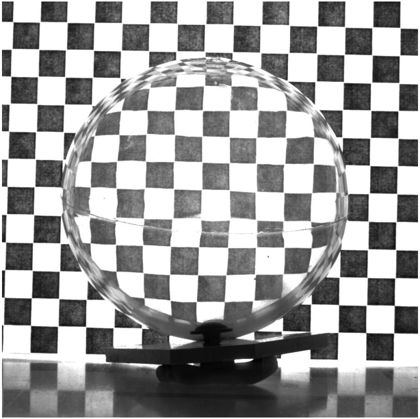


- Then we calculate the velocity field using the source strengths and the distances of every point in the field to the parabolic boundary.



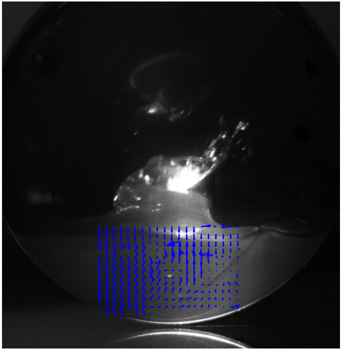
Validation with PIV

- PIV was performed to compare with model.
  - Challenging due to internal flow, spherical shape and deformable surface.

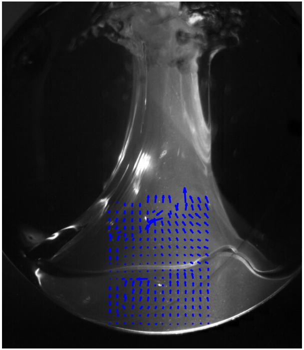


Validation with PIV

- PIV was performed to compare with model.
  - Challenging due to internal flow, spherical shape and deformable surface.
  - 32x32 pixels interrogation on a portion of the total image, 3 passes, nearest neighbor filtering.



Just after impact



Fully formed jet

Future/Continued Work

- Implement a 2D Spherical Boundary Condition.
- Expand model to 3D.
- Analyze the rebound coefficient and mass removal dynamics.
- Verify numerical results with experimental results.
- Begin exploring the elasticity of the sphere.

Anticipated Applications

Future application of our findings could lead to:

- More efficient methods of damping the shock incurred while traveling over water at high speed.
- A cheaper and more effective way to stabilize oil during transport, reducing oil spills.

Conclusions

- Rebound suppression depends on drop height and fill volume.
- There is an exchange of energy from the sphere to the fluid.
- The collapse of the cavity can be shown using a potential flow model.

Acknowledements

Department of Mathematics, *Department of Mechanical Engineering
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