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Dynamics of a Partially Fluid-Filled Sphere

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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.

Water: Ball Height = 10
The measured rebound heights of a 20cm drop: water filled.
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.
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
The dynamics of the cavity collapse and impulse-generated jet were modeled through a pressure-impulse model.
Fluid motion is defined by $\phi$, a partial differential equation

- Potential flow theory utilizes an ideal fluid that is inviscid and irrotational.
  - $\phi = \frac{m}{2\pi} \ln r \to$ source/sink  $|m| = \text{magnitude of } \phi$
  - When $m > 0$, $\phi$ represents a source (pushes fluid away).
  - When $m < 0$, $\phi$ 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**

\[
\phi = \sum_{k=1}^{n} \frac{m_k}{2\pi} \ln r_k \\
[M] = 2\pi \ [V_0] \ [\ln r]^{-1} \\
V_0 = kgh, \ 0 < k << 1 \text{ except at the points within the impulse diameter.}
\]
Then we calculate the velocity field using the source strengths and the distances of every point in the field to the parabolic boundary.
• PIV was performed to compare with model.
  ▶ Challenging due to internal flow, spherical shape and deformable surface.
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.
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.
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.
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