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Dynamics of a Partially Fluid-Filled Sphere

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Dynamics of a Partially Fluid-Filled Sphere



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Killian, Truscott (APS Dallas)

Fluid Motion Inside a Spherical Boundary

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Introduction

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 - Ratio of Rebound Height and Weight
 - Viscosity Independence
- 3 The Model
 - Previous Work
 - Potential Flow Modeling
 - The Model
 - Validation with PIV
- 4 Future Work
 - Conclusions
 - Anticipated Applications

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.



Ratio of Rebound Height and Weight

• The same plot, yet simplified.



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Ratio of Rebound Height and Weight

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



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Ratio of Rebound Height and Weight

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



Change of Viscosity

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

▶ < Ξ >

Change of Viscosity

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



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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.



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Potential Flow

Fluid motion is defined by ϕ , a partial differential equation

- Potential flow theory utilizes an ideal fluid that is inviscid and irrotational.
 - $\phi = \frac{m}{2\pi} \ln r \rightarrow \text{source/sink} |m| = \text{magnitude of } \phi$
 - 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

$$\phi = \sum_{k=1}^{n} \frac{m_k}{2\pi} \ln r_k$$

$$[M] = 2\pi [V_0] [\ln r]^{-1}$$

$$V_0 = kgh, \ 0 < k << 1 \text{ except at}$$
the points within the impulse diameter.



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The Model

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



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Validation with PIV

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



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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

- 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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