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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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Our objectives

- Determine the cause of rebound mitigation.
	- \triangleright Quantify the motion of the sphere.
	- \triangleright 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.

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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.

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Change of Viscosity

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

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Change of Viscosity

Analysis of our data showed that the global effect of the sphere's \bullet 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.
	- \triangleright Note the meniscus in the far left frames.

 \triangleright 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.
	- $\phi = \frac{m}{2\pi} \ln r \rightarrow$ source/sink $|m|$ = magnitude of ϕ
	- **IVhen** $m > 0$, ϕ represents a source (pushes fluid away).
	- \triangleright When $m < 0$, ϕ represents a sink (pulls fluid in).
	- \triangleright m is found by the localized use of $m = V_r 2\pi r$

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The Model

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

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

Implementation

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

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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.
	- \triangleright Challenging due to internal flow, spherical shape and deformable surface.

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Validation with PIV

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

- Implement a 2D Spherical Boundary Condition.
- Expand model to 3D.
- Analyze the rebound coefficient and mass removal dynamics. \bullet
- 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.

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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

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