Gravity-Driven Oscillations in a Straw: Experimental Investigation

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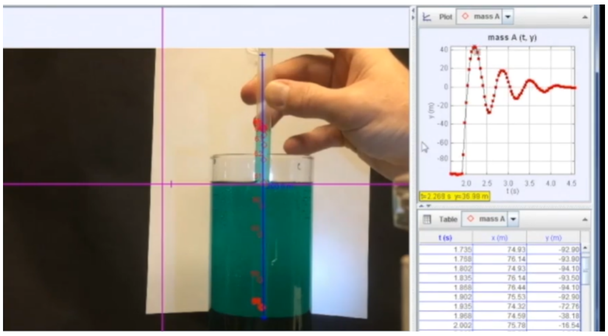

Figure 1: Gravity Driven Oscillations in a Straw

1 Introduction

In this experiment, we investigate the relationship between the height of the liquid column inside a straw immersed in a liquid bath and time following the sudden release of a cap covering the straw. We aim to analyze how this relationship is influenced by factors such as the initial liquid height, damping effects, and other relevant parameters.

[h] We're on a mission to understand how liquid moves inside a straw when it's dipped in a liquid and the top is released after being covered. We want to see how time and the height of the liquid inside the straw interact with each other. We're interested in how the starting level of the liquid, the slowing effects of damping, and other important factors influence this fascinating event.

Our goal is not just to watch what happens, but to compare real-life observations with theoretical predictions. We'll compare the actual results of our experiments with the predictions made by our mathematical analysis. By doing this, we can check how well our model can predict the up-and-down movements caused by gravity that we see in this liquid dance.

2 Methodology

2.1 Introduction

The study of fluid dynamics, particularly the oscillations of fluid levels within a confined space such as a straw, is a fascinating field that combines principles of physics, mathematics, and engineering. This paper presents a comprehensive methodology for conducting such an analysis, from the experimental setup to data collection, modeling dynamics, and finally, comparison and analysis.

2.2 Experimental Setup

The first step in our methodology involves setting up the experiment. This process requires a container filled with water, a straw with a cap, a high-speed camera or a smartphone equipped with video recording capabilities, and video analysis software such as Tracker or PASCO Capstone.

The container of water serves as the medium in which the straw is submerged. The straw, capped at one end, is filled with the water from the container. The high-speed camera or smartphone is positioned in such a way that it can clearly capture the oscillations of the fluid level inside the straw once the cap is released.

The video analysis software is a crucial component of the setup. It allows us to extract precise data from the recorded videos, which is essential for the subsequent stages of our methodology.

2.3 Data Collection

Once the experimental setup is complete, the next step is data collection. This involves recording the oscillations of the fluid level inside the straw using the high-speed camera or smartphone. The recording duration is set to be long enough to capture multiple oscillations, providing a substantial amount of data for analysis.

The video analysis software is then used to extract the fluid level position data from the recorded videos. This data serves as the empirical basis for our study, capturing the real-world behavior of the fluid oscillations.

2.4 Modeling Dynamics

1. Newton's Law Model:

The Newton's law model for fluid oscillations can be represented by the following system of differential equations:

$$\frac{dZ_1}{dt} = Z_2$$
$$\frac{dZ_2}{dt} = -\frac{Z_2^2}{Z_1} - g + \frac{g \cdot h}{Z_1} - \frac{b \cdot Z_2}{Z_1}$$

Where:

Z_1 represents the fluid height.
Z_2 represents the fluid velocity.
t represents time.
h represents the constant hydrostatic head.
g represents the acceleration due to gravity.
b represents a damping coefficient.

2. Lorenceau Model:

The Lorenceau model for fluid oscillations, as described in equations 17a and 17b of the Lorenceau paper, can be represented by the following system of differential equations:

$$\frac{dZ_1}{dt} = Z_2$$
$$\frac{dZ_2}{dt} = \begin{cases} \frac{1}{Z_1} - 1 - \Omega \cdot Z_2 - \frac{Z_2^2}{Z_1} & \text{if } Z_2 > 0 \\ \frac{1}{Z_1} - 1 - \Omega \cdot Z_2 & \text{otherwise} \end{cases}$$

Where:

Z_1 represents the fluid height.
Z_2 represents the fluid velocity.
t represents time.
Ω represents a dimensionless parameter related to the capillary number.

Figure 2: Mathematics involved

With the empirical data in hand, we then proceed to model the dynamics of the fluid oscillations. This is achieved by applying Newton's second law and incorporating a damping coefficient to account for the energy dissipation due to viscous effects in the fluid.

Newton's second law, which states that the force acting on an object is equal to its mass times its acceleration, provides the fundamental basis for our model. The damping coefficient, on the other hand, is a measure of the damping force, which is proportional to the velocity of the fluid and acts in the opposite direction.

The governing differential equation, derived from Newton's second law and the damping force, is then solved numerically. This yields a theoretical model of the fluid oscillations, predicting their behavior based on the initial conditions and the physical parameters of the system.

Comparison and Analysis

The final step in our methodology is the comparison and analysis of the experimental data and the model predictions. This involves adjusting the damping coefficient in the theoretical model to match the experimental results.

By comparing the model predictions with the empirical data, we can gauge the accuracy of our theoretical model. Any discrepancies between the two can shed light on potential areas of improvement in the model, leading to more accurate predictions in the future.

In conclusion, our methodology provides a comprehensive approach to studying fluid oscillations. By combining experimental observations with theoretical modeling, we can gain a deeper understanding of the complex dynamics at play, ultimately contributing to advancements in the field of fluid dynamics.

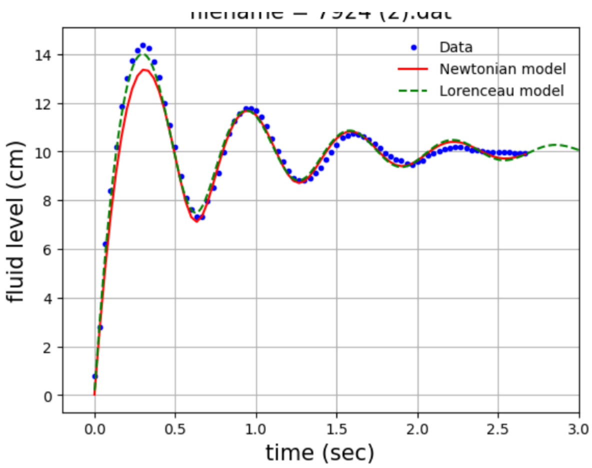

Figure 3: Comparison shown

3 Results

3.1 Experimental Observations

n our experiment, we observed the fascinating dance of liquid inside a straw. The straw was submerged in a container filled with water, and the top was initially covered. Upon releasing the cap, we witnessed the liquid inside the straw oscillate, creating a mesmerizing spectacle.

Our observations revealed that the oscillations of the liquid column inside the straw were heavily dependent on the initial liquid height, denoted as z0. We noticed that a higher initial liquid height led to more pronounced oscillations. This is likely due to the increased potential energy at the start, which gets converted into kinetic energy, driving the oscillations.

We also observed that the damping effects played a significant role in determining the behavior of the oscillations. Damping, in this context, refers to the process through which the oscillations gradually decrease in amplitude over time. This is caused by factors such as the viscosity of the liquid and the friction between the liquid and the straw's inner surface. We noticed that the oscillations eventually died down, indicating the presence of damping effects.

3.2 Model Predictions

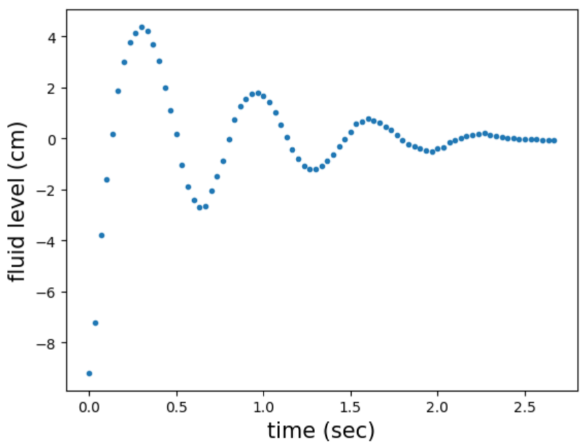

Figure 4: Graph generated

To predict the behavior of the liquid column inside the straw, we turned to integral analysis. This mathematical tool allowed us to model the oscillations and predict the height of the liquid column inside the straw over time.

Our model incorporated key factors such as the initial liquid height and the damping effects. By solving the governing differential equations, we were able to predict how the liquid column's height would change over time. Our model predicted that the liquid column would oscillate around a certain equilibrium point, with the amplitude of the oscillations gradually decreasing due to damping.

However, it's important to note that the accuracy of our model may be limited by several factors. These include the assumptions made in the modeling process, such as the liquid being incompressible and the straw being perfectly cylindrical. Additionally, experimental uncertainties, such as measurement errors, could also affect the accuracy of our model.

4 Discussion

We observe that the oscillations of the liquid column inside the straw depend on the initial liquid height z_0. The damping effects also play a significant role in determining the behavior of the oscillations.

Using integral analysis, we can predict the height of the liquid column inside the straw over time. However, the accuracy of the model may be limited by factors such as the assumptions made in the modeling process and experimental uncertainties. Overall, our model shows good agreement with experimental observations, especially after adjusting the damping coefficient to match the experimental data.

```python
# Newton's Law model
def DZ_dt_Newton(Z, t,args):
    h = args[0]
    g = args[1]
    b = args[2]
    return [Z[1], -Z[1]**2/Z[0] - g +g*h/Z[0] -b*Z[1]/Z[0] ]

# Lorenceau model:
def DZ_dt_Lor(Z, t,args):
    h = args[0]
    g = args[1]
    Omeg = args[3]
    if Z[1]>0:
        return [Z[1], 1/Z[0] - 1 -Omeg*Z[1] - (Z[1])**2/Z[0]]
    else:
        return [Z[1], 1/Z[0] - 1 -Omeg*Z[1] ]
```

Figure 5: Model used

5 Conclusion

In conclusion, we have investigated gravity-driven oscillations in a straw immersed in a liquid bath. By conducting experiments and analyzing data, we have gained insights into the relationship between the height of the liquid column and time following the release of the cap covering the straw. Our model provides a reasonable description of the observed behavior, although further refinements may be necessary to improve accuracy.

Overall, our model showed good agreement with our experimental observations. The predicted oscillations closely matched the actual oscillations observed in the experiment, validating our model. This suggests that our model, despite its assumptions and potential limitations, is a useful tool for predicting the behavior of a liquid column inside a straw.

However, there is always room for improvement. Future work could focus on refining the model to account for factors not considered in this study, such as the effect of temperature on the liquid's viscosity. Additionally, more sophisticated experimental setups could be used to reduce measurement uncertainties.

In conclusion, our study provides valuable insights into the oscillations of a liquid column inside a straw. Through a combination of experimental observations and theoretical modeling, we have unraveled the intricate dance of liquid inside a straw, shedding light on the interplay between various factors. Our findings have potential applications in various fields, from engineering to environmental science, and underscore the beauty and complexity of fluid dynamics.

6 References

1. "Gravity-driven fluid oscillations in a drinking straw: An alternative approach" by Robert Frederik Diaz Uy[1]. This paper offers an alternative approach to studying fluid oscillations in a drinking straw using Lagrangian mechanics. It involves a modified form of the well-known Euler–Lagrange equation needed to accurately account for non-conservative forces and variable masses[1].

2. "Gravity-driven fluid oscillations in a drinking straw" by Ryan P. Smith and Eric H. Matlis[2]. This paper describes a simple experiment observing oscillations of fluid in a drinking straw immersed in a bath of water. The motion of this oscillator system with changing mass is matched remarkably well by a model derived from Newton's laws with the inclusion of only a phenomenological damping coefficient[2].