



Bouncing Liquid Jets

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Abstract

The project "Bouncing Liquid Jets" involves studying the phenomenon that occurs when viscous oil is poured into a bath of the same oil. Under the right circumstances, the incoming jet will rebound off the bath back into the air in a parabolic trajectory. In the experimental setup, canola oil is pumped into a long vertical tube. By varying the oil level and output nozzle size, the speed and incident angle of the jet can be controlled. This allows the production of mostly stable bounces with little outside interference. Using a high speed camera, the bounce has been photographed and viewed at up to 600fps. Using a photo analysis program the energy loss during the rebound has been studied. The results of this study are presented as well as a "slingshot effect" that has been noted to occur when the bounce is disrupted.

Bouncing Jet Mechanics

In most cases when two identical fluids meet, they will mix together. This is not the case for a bouncing jet. As the jet plunges into the bath, it also pulls in the surrounding air. The incoming jet remains separated from the oil bath by this thin air layer. The air layer provides a very low friction surface for the incoming jet. The upward force from the surface tension deflects the incoming jet causing it to be reflected upwards. The bounce will continue until the air layer is disturbed.⁽¹⁾

The bounce will only occur for a certain range of incident angles and speeds. Near the middle ranges of angle and speed, the bounce is stable and can continue for minutes at a time. Near the edges of the range it becomes increasingly unstable until the air layer breaks and the bounce stops. If the incoming speed or angle is too large, the jet plunges into the bath because the surface tension does not provide a large enough force to reflect the jet. If the incoming speed or angle is too small, the jet will ride along the surface of the bath.

Apparatus

In our experimental setup (Fig. 2), canola oil is pumped into a long vertical tube. The oil exits the tube through a nozzle at the bottom. By controlling the level of the oil in the tube and nozzle size, we are able to control the speed of the incoming jet. The nozzle angle is also adjustable. The oil exits into a glass container where the bounce occurs. The flat glass sides of the container allow us to take close range pictures with little distortion. One end of the container is lower than the other sides, allowing oil to spill out into a collection dish. This keeps the surface of the bath at the same height relative to the camera. A black background and desk lamps provide the contrast needed to capture the bounce with a camera.



Fig. 2. Experimental setup

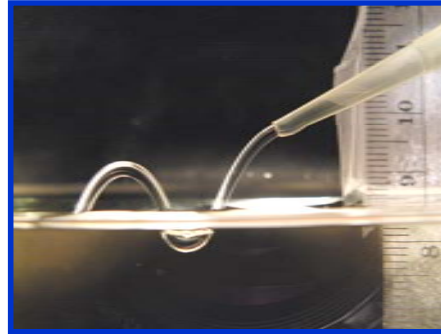


Fig. 1. An incoming jet reflects off the surface of a bath of canola oil.

Objectives

- To understand the mechanics of the bounce.
- To study the energy lost by the jet in deforming the surface of the bath.
- To determine what effect incident angle has on energy loss.
- To study the "slingshot effect" and the energy transferred to the jet.

Data Collection

Our experimental setup allows us to take high quality digital photos from a close range using a Casio EX-F1 digital camera. After thresholding the photo to separate the background and the jet, the image is converted to binary.⁽²⁾ This allows us to use a function called "skeletonize" which traces along the center of the bouncing jet. Pasting the skeletonized photo on top of the original allows us to follow the path of the bounce and obtain data points. Using Microsoft Excel each set of points is then broken into the incident and reflected parts of the bounce. The reflected part has a complete parabolic trajectory. The incident part is measured beginning as soon as the jet leaves the nozzle. The starting X position of each piece is set to zero to allow comparison (Fig. 3). Using a 2nd degree polynomial the two pieces are fit with parabolic curves.

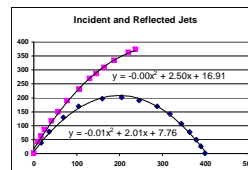


Fig. 3. The starting position of the incoming and reflected jets are set to zero to allow comparison. Each piece is then fit with a 2nd degree polynomial.

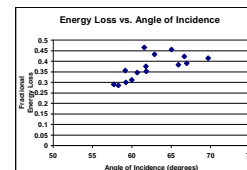


Fig. 4. The fractional energy loss is plotted according to incident angle.

Calculations

Using the standard equations of motion,

$$x = x_0 + v_{0x}t \quad y = y_0 + v_{0y}t - \frac{1}{2}gt^2 \quad (1)$$

a formula for the path of the bounce was derived.

$$y = y_0 + \tan(\theta_i)x - \frac{g}{2v_i^2 \cos^2(\theta_i)}x^2 \quad (2)$$

Taking the coefficients of x and x^2 from the Excel curve fit, we were able to first solve for θ_i and then for the velocity. The incident angle θ_i used in the formula is the angle between the bath and the jet.

The fractional energy loss of the reflected bounce was computed using the formula

$$\frac{v_r^2 - v_i^2}{v_i^2} \quad (3)$$

Results and Conclusions

It was determined that the fractional energy loss for the reflected portion of the bounce ranged between approximately .30 and .45. The smaller loss corresponded to a smaller incident angle (Fig. 4). The measurements were taken in the middle range of angles and jet speeds where the bounce was the most stable.

Nearly all the energy loss takes place when the incoming jet is reflected by the bath. This energy loss is due to a frictional force as the jet is reflected by the surface plus the energy required to deform the surface of the bath (Fig. 1.). The frictional force is small because the trapped air layer provides a low coefficient of friction. The majority of the energy loss comes from deforming the surface of the bath. This can be seen in the "slingshot effect."

Slingshot Effect

In Fig. 5-7, a disturbance is created in the jet. This causes the surface of the bath to return to its normal undeformed state. A large portion of the energy lost by the jet in deforming the surface is given back to the trailing end of the jet. This end of the jet travels roughly one third farther than the normal path. The photos below are part of a 300fps movie of the slingshot. The red is the normal path taken by the jet. The green is the path of the disturbed jet and the resulting slingshot.



Fig. 5.

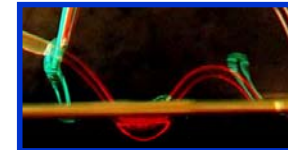


Fig. 6.



Fig. 7.

Fig. 5-7. The bounce is disturbed and the end is thrown forward. The red is the normal bounce. The green is the disturbed jet.

References

- (1) Thrasher, Matthew, et al. "Bouncing Jet: A Newtonian liquid rebounding off a free surface." *Physical Review E* 76, 056319 (2007).
- (2) All image processing was done using ImageJ, a public domain Java image processing program available from <http://rsb.info.nih.gov/ij/download.html>.

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