WATER BOTTLE FLIPPING

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ABSTRACT

The current craze of water bottle flipping involves launching a partially filled plastic bottle into the air so that it performs a somersault before landing on a horizontal surface in a stable, upright position. Investigate the phenomenon and determine the parameters that will result in a successful flip. The secret behind a success flip of a water bottle into the air, is the distribution of mass, decreasing the angular velocity and finally landing like a shuttle cock, in this way for solving the problem easier we divided the hole system to 3 phases: Damping, Landing and Impact.

1 Introduction

In water bottle flipping as a challenge, the most important parameters which can result in the best and successful landing, are investigated.

First of all let's talk about the amount of water and how important it is. When the amount of water in a bottle is very little or almost full, most of the energy in hitting the ground will be transferred to the bottle then there is a bounce back without a success flip. But in a bottle with enough water, some of the energy will be transferred to the water and without a bounce back there is a successful flip.

When we throw a water bottle into the air, a success flip is because of the distribution of mass and decreasing the angular velocity . To solve the problem the hole system is divided to three phases: Damping, Landing and Impact (Fig. 1).

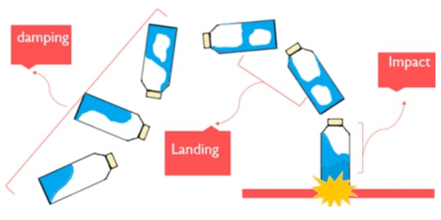

Fig. 1: 3 phases in throwing a water bottle

2 Theory

To find the moment of inertia around the center pf mass of the hole system (CM), the hole system is divided to 2 parts, water and bottle .

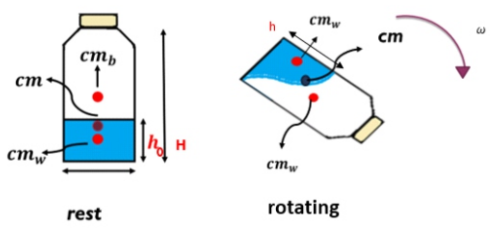

Fig. 2: Center of mass in two different situations, rotating and resting

In this case when bottle is completely empty or full the center of mass will be equal with H/2 .

$$\boldsymbol{h_{cm}} = \frac{\frac{H}{2}m_{b+}\frac{h}{2}m_w}{m_b+m_w} = \frac{H}{2}\left(\frac{m_b+m_w\frac{h}{H}}{m_b+m_w}\right) \tag{1}$$

$$I_b = \frac{1}{12}m_bH^2 + m_b\left(\frac{H}{2} - h_{cm}\right)^2 \tag{2}$$

$$I_w = \frac{1}{12}m_wh^2 + M\left(\frac{h}{2} - h_{cm}\right)^2 \tag{3}$$

$$I = I_{b+}I_w \tag{4}$$

According to the conservation of angular velocity, the minimum angular velocity is the angular velocity of the water plus the angular velocity of the bottle .

$$I_0 \times \omega_0 \approx I_{max} \times \omega_{min} \tag{5}$$

$$\omega_{min} \approx \frac{I_0}{I_{max}} \times \omega_0 \tag{6}$$

3 Modeling and Experiments

To decrease the errors and the same initial conditions, a mechanical setup was built to hit the bottle (Fig. 3).

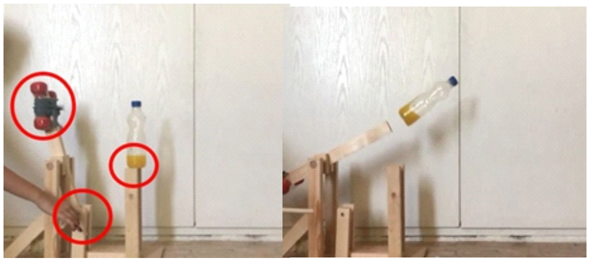

Fig.3: Mechanical device for throwing the bottle

The bottle with changing the amount of water acts as different objects, sometimes like a rigid object which moment of inertia is constant without having distribution of mass but in other occasions there is distribution of mass [1].

While bottle is flipping, the water needs a place to apply a force and support it from the centripetal force. In low amount of water, the bottom of the bottle is able to apply the force so water won't move a lot. In high amount again the walls and bottom of the bottle are able to apply the force and support it, so in this situation water won't move almost. But when it is partially full of water a free space is seen during flipping (Fig. 4)

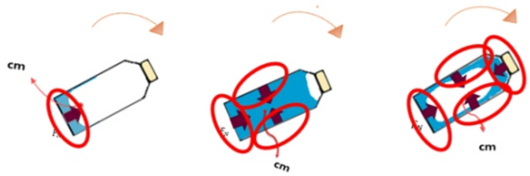

Fig. 4: Flipping with different amount of water

To decrease ω ,we can first decrease ω_0 but it is impossible because if we decrease it a lot we won't even have a flip so the best and maybe the only way is decreasing the amount of $\frac{I_0}{I_{max}}$ and as in figure (5) the minimum part causes flipping [1,2].

$$\frac{I}{I_{max}} = \frac{M^2f^4 + 4Mf^3 - 6Mf^2 + 4Mf + 1}{(1 + Mf)^2} \quad (7)$$

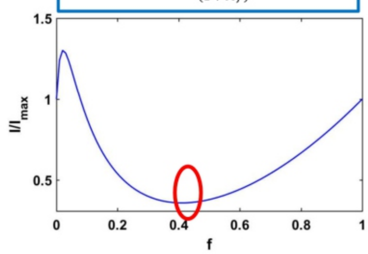

Fig. 5: The minimum part that rotational velocity is minimum

4 Results

Comparing to the theory, the rotational velocity of successful flip should decrease about 60% but in these experiments it decreased about 80% because the energy has been transferred to the water .

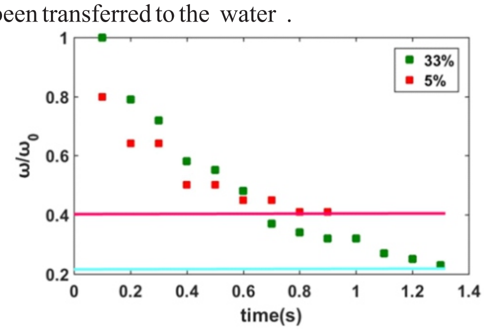

Fig. 6: The red line shows the amount that it should decrease according to the theory and the blue one shows the deduction according to the exp. And this difference shows transferred energy to the water

The second phase (Landing) is the same as shuttlecock. When we throw a shuttlecock without a rotational velocity, it comes down with its heaviest part and hit the ground in a stable upright position.

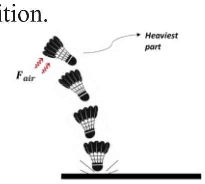

Fig. 7: Landing a shuttlecock considering air resistance

The amount of water and the center of mass will help the bottle to find a stable upright position in landing as the last phase (Fig. 8).

$$\frac{h_{cm}}{H} = \frac{1}{2}\left(\frac{1 + Mf^2}{1 + Mf}\right) \quad (8)$$

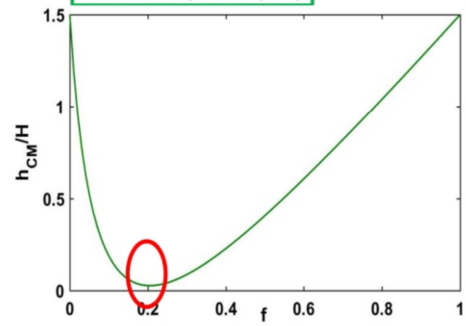

Fig. 8: The minimum shows the best position for landing

Bottle with M=14 shows two minimum parts, which is assumed the best situation and the most successful parts should be there because the rotational velocity is minimum and also the CM is very low too (Fig. 9)[2] .

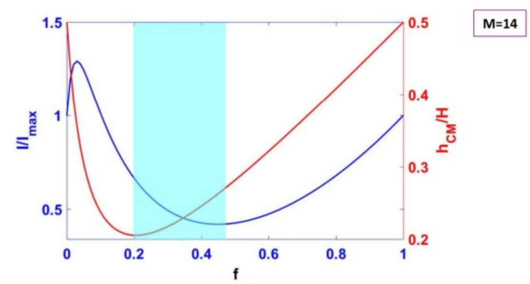

Fig. 9: Bottle with M=14 and two minimum parts

Let's compare the theory with our experiments . The best given results are exactly in that place but we have a little error because of our assumptions (Fig. 10)[2, 3].

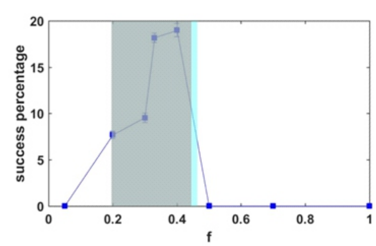

Fig. 10: The best situations comparing by theory and experiments

The other effective parameter is surface. Three different surfaces show the softer gives the better results because when it is hard, stone for example, we will have bounce back and a big amount of energy will be transferred to the bottle (Fig. 11).

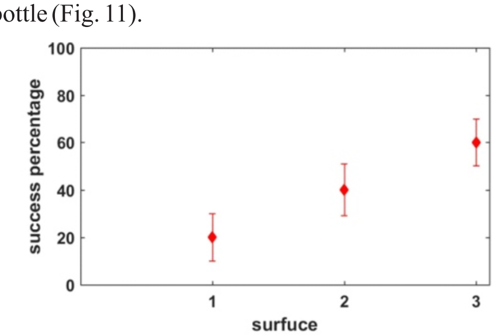

Fig.11: Success percentage in 3 different surfaces

Now by changing the amount of D/h, the diameter of the bottom to the height of the bottle, the results were examined. By increasing this amount, more successful was found because in the most situations CM isn't in front of the edge (Fig. 12).

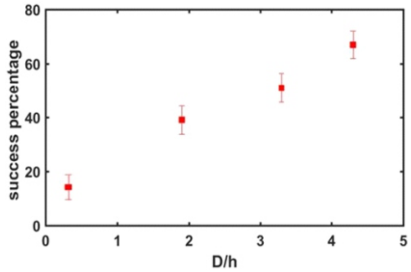

Fig. 12: Success percentage versus D/h

5 Conclusion

By investigating the phenomenon and comparing theory and experiments we found the best situations for having a successful flip:

1.we should decrease the rotational velocity
2.We should decrease the amount of center of mass
3.having an enough free space and movements of water by the centripetal force
4.having distribution of mass
5.increasing the D/h
6.making the surface soft
7.having optimal filling friction between 0.2 – 0.45
8.Landing like a shuttlecock

References

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[3] Dekker P.J. and L.A.G Eek et al, Flapper M.M., Horstink H.J.C., Meulenkamp A.R., Meulen J., Kooij E.S., Snoeijer J.H., Marin A. (2017). Water Bottle Flipping Physics, The Netherlands 2 Physics of Interfaces and Nanomaterials.