DANCING BALL

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ABSTRACT

A Styrofoam disc or ball can be levitated by a water jet. In this phenomenon lots of principles take part and totally they cause the disk to remain stable for some time. In this paper, the most effective parameters are investigated such as the mass and volume of the ball, the flow rate of the water and the shape of the object (disc/ball). Depending on optimum parameters the object can withstand air turbulence, switching the objects, sudden water pressure drop and tapping the object, as external disturbances.

1 Introduction

When a light object, such as a Styrofoam disk is placed on a water jet, under certain conditions, the object will start to spin while being suspended. This phenomenon and its stability to external perturbations are investigated. Through the observations and experiments, theory of momentum and instabilities, and several parameters such as angel ,flow rate and hydrophobicity versus rotational speed are studied (Fig. 1) [1 &2].

Fig. 1: Rotation of a Styrofoam disk on a water jet

2 Theory and Experiments

By placing a Styrofoam ball in different masses and volumes on the edge of water jet various behaviors of ball are observed such as creating a sheet of water or drop ligaments. The experimental setup contains a tube which provides water jet and a ruler that measures how much the water jet can rise up and the alternation of ball's height in this experiment. The effective parameters namely mass, object's geometry (shape, diameter), properties of the water jet, object's roughness (friction) and external disturbances (switching the objects, air turbulence, sudden water pressure drop, tapping the object) were investigated (Fig. 2). A small part of the water jet which has an efficient area and a displacement is considered so a small part of this volume of the water jet is equal to (Eq. 1 and 2):

$$dV = Avdt \tag{1}$$

$$dp_{in=v\times}\rho dV \tag{2}$$

So (Eq. 3):

$$\frac{dp_{in}}{dt} = \rho A v^2 \tag{3}$$

Fig. 2: Experimental setup

We assume the momentum of the water jet and drops throwing out of the ball are propulsion with each other (Eq. 4) (Fig. 3).

$$\frac{dp_{out}}{dt} = \alpha' \frac{dp_{in}}{dt} \tag{4}$$

So the force applied to the system is equal to (Eq. 5):

$$F = (1-\alpha')\frac{dp_{in}}{dt} = \alpha\frac{dp_{in}}{dt} = \alpha\rho A v^2 \tag{5}$$

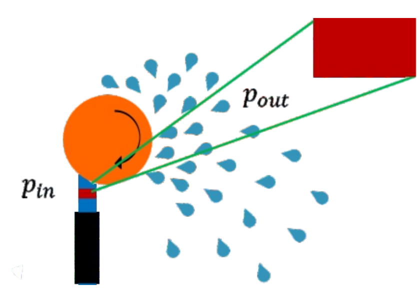


Fig. 3: Momentum of the water jet and drops throwing out

In steady state the applied force to the ball by the water jet is equal to the weight of the ball so the coefficient which is related to the properties of the ball and is calculated (Eq. 6-10).

$$AV = D \qquad \rho A v^2 = \rho D v = \rho D\sqrt{v^2_{-2gy}} \tag{6}$$

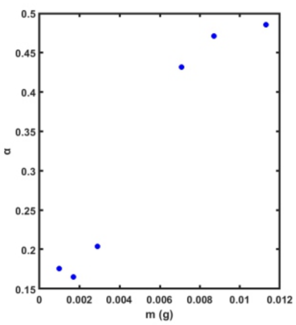
$$F = \alpha \rho D \sqrt{\frac{D^2}{A^2} - 2gy} = mg \quad (7)$$

$$D^2 y = \frac{D^4}{2gA^2} - \frac{m^2 g}{2\alpha^2 \rho^2} \quad (8)$$

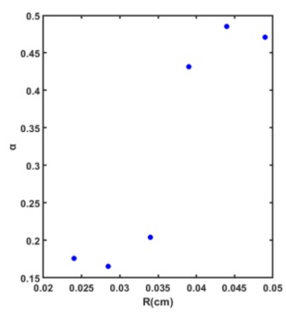
$$D^2 y = X \frac{1}{2gA^2} - \frac{m^2 g}{2\alpha^2 \rho^2} \quad (9)$$

$$\alpha = \sqrt{-\frac{m^2 g}{2A\rho^2}} \quad (10)$$

Now the relation between α and mass of the ball and also in different radius are plotted . (Fig. 4a and b).



(a)



(b)

Fig. 4: a) α in different mass of the ball, b) in different radius of the ball

What is the reason of observing these kind of the reactions of the ball? Due to Kelvin Helmholtz instability when two different fluids want to move on each other, it causes some waves and due to Rayleigh-Taylor instability these waves because of two different accelerations: gravity and centrifugal force, grow and become to ligaments or water drops (Fig. 5). These different situations depend on different parameters such as mass or flow rate of the water jet or other parameters which will causes different reactions of the object. If the centrifugal force is larger than surface tension, these waves will grow and if vice versa happens, waves could just be damped by the surface tension.

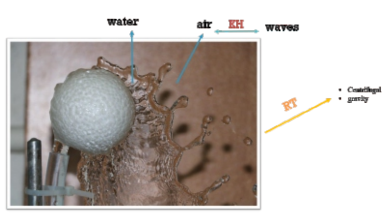
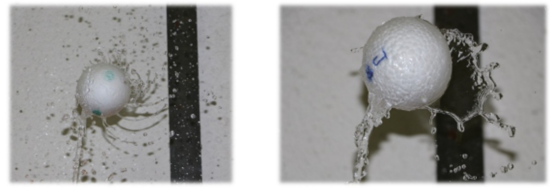


Fig. 5: growing of ligaments

So as we already mentioned based on the different properties of the ball different reactions could be observed (Fig. 6).



(a) (b)

Fig. 6: a) Ligaments in Drops, b) Sheet of water

Now we change the hydrophobicity of the ball by changing the contact angle of the surface of a disk and a ball (Fig. 7). So different contact angles have been observed (Fig.8) , so with the less contact angle, the object is less hydrophobic and water likes to stay on the surface of the ball and it causes much more rotational speed and the same result was observed for the ball that the hydrophobic one has more ligaments because the drops don't like to attach on the ball so they have inverse relation with each other (Fig. 9)

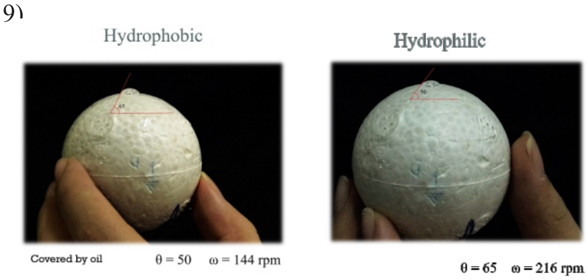


Fig. 7: The behavior of two different hydrophobic and hydrophilic balls

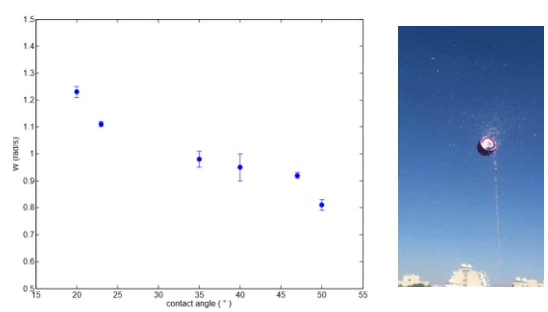
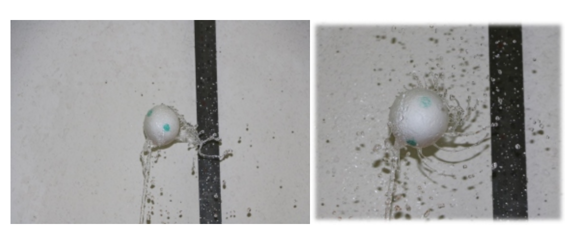


Fig. 8: The rotational speed versus contact angle



(a) (b)

Fig. 9: a) Hydrophilic, b) Hydrophobic patterns

The other parameter that we've changed was the flow rate of the water jet and its effect on the angular velocity of the ball or disk. It is observed that if the flow rate changes, it won't cause any differences to the rotational speed of our ball because the weight of the ball is constant so it needs the

same force of the water jet. If we increase the flow rate, the object will stay in a higher position to be stable . If the weight of the ball is increased, the force of the water jet should increase too, so the ball stays in lower height to get much more force from water jet. In overall the velocity of the collision of the water jet on the ball is important which in different flow rates it will be the same.
Now the external perturbation is considered in our experiments. If we apply a force with a pin, it could easily be observed that the momentum of the right side of the object should be the same with the momentum of the left side , so the momentum of the opposite direction will push the ball to its first place.

Fig. 10: External perturbation

3 Conclusions

To investigate this phenomenon instabilities of the Styrofoam ball in different masses and volumes on the edge of water jet was studied. Creating a sheet of water or drop ligaments depending on hydrophobicity of the ball which causes the change of contact angle of the surface of a disk or a ball was observed too. The flow rate of the water jet and its effect on the angular velocity showed that if the flow rate changes, it won't cause any differences to the rotational speed.

References

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