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Projectile Velocity and Crater Formation in Water

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Abstract

The relationship between the velocity of impact and maximum crater diameter was found for two steel balls dropped into water using 300 fps video. The maximum diameter of the crater was found to be proportional to the impact velocity and independent of the diameter of the ball.

Introduction

When a metal ball is dropped into water, a circular crater temporarily forms on the surface. In this research, two metal balls with different diameters and masses are dropped from six different heights into a tank filled with water. The relationship between the impact velocity and the maximum diameter of the crater formed on the water surface is investigated.

An object falls with acceleration due to gravity. Increased drop heights will cause the impact velocity to increase. This is expected to cause an increase in the outward velocity of the crater wall, resulting in an increase in the maximum diameter of the crater.

Research conducted at the University of Bristol presents a general equation for determining the diameter of a planetary crater due to a meteor impact [1],

$$D = 0.07Cf\left(E \cdot \frac{\rho a}{\rho t}\right)^{1/3.4} \qquad \text{(Equation 1)}$$

where D is the diameter of the crater formed, C_f is the crater collapse factor, ρ_a is the density of the projectile, ρ_t is the density of the target surface rock, and E is the total energy of the meteor. Equation 1 describes the size and shape of the craters formed by meteors that collide at high speeds with the surface of the earth. From this equation, it can be seen that E has approximately a cube root relationship with the diameter of the crater formed. Given that dropping a steel ball into water at relatively low speeds is a very different situation than a meteor striking a planet, the validity of equation 1 for this situation is questionable. It is expected, however, that the relationship between impact velocity and maximum crater diameter will be similar to equation 1.

Methods

A Prosilica high-speed camera was fixed level with the surface of the water in a clear plastic tank as shown in figure 1. A meter stick was fixed above the surface of the water. A metal ball, with mass 0.067 kg and diameter 2.50 cm, was dropped from heights above the water surface ranging from 25 cm to 75 cm. The Prosilica high-speed camera then recorded the process at 300 fps. A total of five trials were done for each of the heights. A second metal ball, with mass 0.227 kg and diameter 3.71 cm, was dropped from heights above the water surface ranging from 20 cm to 70 cm with a total of 5 trials for each of heights. The impact velocity of the ball was calculated from the release height, assuming negligible air resistance. The maximum crater diameter was determined by Logger Pro Video Analysis, as shown in figure 2.

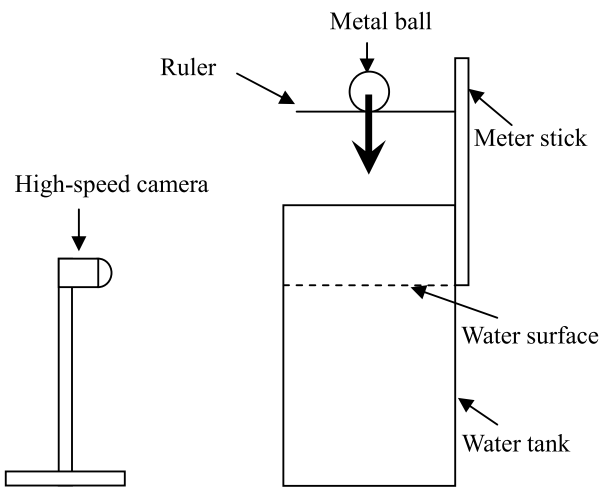

Figure 1 The experimental setup and the method used to drop the metal balls.

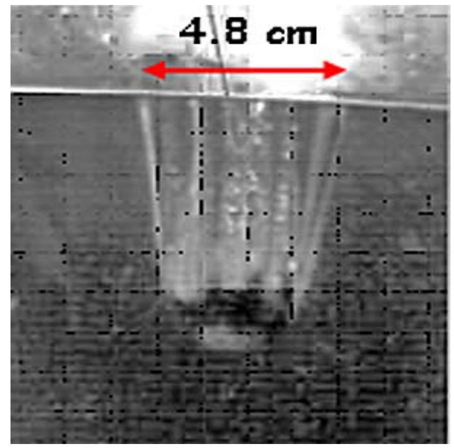

Figure 2 An image from the high speed camera showing the method for measuring the diameter of the crater.

Results and Discussion

From figure 3 the relationship between crater diameter and impact velocity is

$$D = 0.017\ (\pm 0.007\text{m/s})\ v \qquad \text{(Equation 2)}$$

where D is the maximum diameter of the crater formed, and v is the velocity at which the ball impacted the surface of the water. This relationship does not apply for impact velocities below 2.5 m/s. Below 1 m/s the ball formed no meaningful crater upon impact, and at speeds of between 1 m/s and 2.5 m/s, crater formation was inconsistent and unreliable.

It is interesting that the diameter difference between the balls of 1.21 cm had no measureable effect on the diameter of the crater formed.

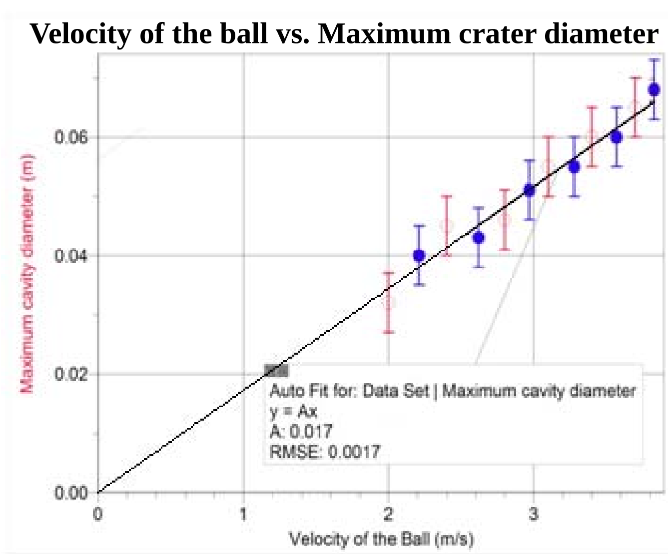

Figure 3: The relationship between the velocity of the falling ball and the maximum diameter of the crater formed in the water. The data for the 0.227 kg ball are in red and the 0.067 kg ball in blue.

There were several weaknesses in

the methods. First, due to time constraints, the water in the container was not allowed to become completely still before each drop. This would likely have increased the variability of the crater formation.

Second, the speed and resolution of the camera were limited as the higher the frame rate the lower the resolution. A frame rate of 300 fps with a resolution of 100 by 250 pixels was used as a compromise between the frame rate and resolution. Higher frame rates and resolution would give more accurate measurements of the maximum crater diameters.

It should be noted that the relationships for meteor formation on planets and for water crater formation are very different. The effect of the differences in projectile impact speed and target material characteristics should be investigated. Further research is suggested into crater formation in materials with a range of viscosity. In order to simulate meteor strikes in the ocean, objects with larger masses and diameter may be used at higher impact velocities. It would be interesting to find the effect of projectile diameter and mass on crater formation over a greater range of diameters and masses.

Conclusion

As shown in figure 3, the impact velocity of the ball is proportional to the maximum diameter of the crater formed on the water surface and is independent of ball mass or diameter for the two balls for velocities between 2.5 and 4.0 m/s.

References

[1] Brana, L. (n.d.). The Physics of Impacts. In *Impact Geology, Chemistry and Physics*. Retrieved June 16, 2009, from http://palaeo.gly.bris.ac.uk/communication/Brana/impact.html