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Team First Report

Introduction:

For the first group project our team wanted to experiment with dropping ball bearings in different mediums. Our initial intent was to capture the “Worthington Jet” with slow-motion video. With the help of Luke McMullan, Joanna Bugajska, and Quyncie Grenis, we tried a multitude of ball bearing sizes, various types of sand, water, glitter, and even paint. Although we never fully captured our initial intent, the results were incredibly fascinating and worthwhile to analyze.

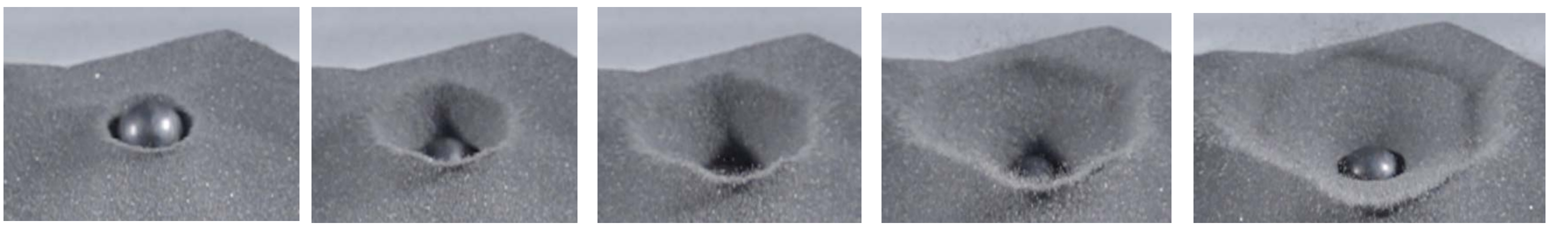

Figure 1-5: Ball Bearing Drop Stills (Taken from edited video)

Physics:

Upon initial viewing of this process it appears that there are multiple different phenomena happening. With the initial impact we see the ball creating a crown-like image, various waves being sent through the sand, and finally ending with a crater. [1] However, all of this can be attributed to a single phenomena called “Granular Eruption.” [2] What you see on the video is only half of this phenomena.

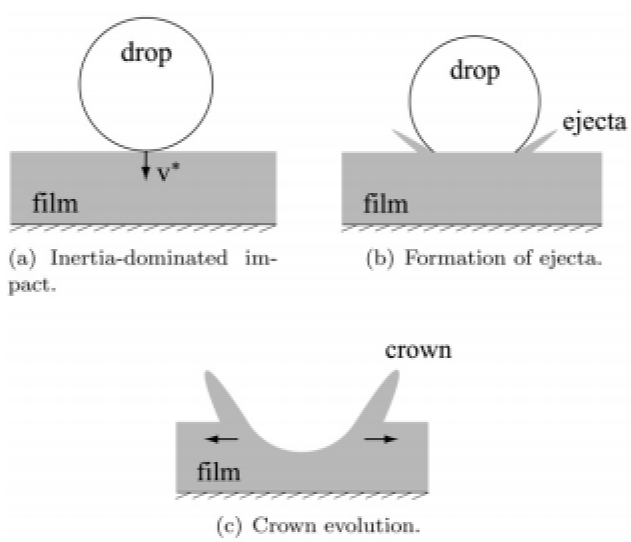

Figure 6: Crown Evolution [1]

Granular eruption occurs when a steel ball is dropped into loosely packed, fine sand. Upon impact the sand is blown in all directions forming the splash and crown-like image you see in the video. [5] However, for our experiment, at this point the force is transferred to neighboring sand particles and the bottom of the apparatus where the force eventually dissipates and settles. If our sand had been deep enough then we would've seen the completion of the granular eruption. After the impact a void is created in the sand and once this void collapses, a granular jet is formed. [3] This is the jet you see that pushes the sand particles straight up into the air, very similar to a Worthington jet when objects are dropped in liquid. [4] For high enough velocities, the void collapses towards the middle of the sand trapping air in the middle of the sand. This air bubble will eventually make its way to the top of the sand, completing the granular eruption. [5] From research and experiment it seems that the finer the sand, the better visual phenomena one can achieve.

Given that the ball dropped from approximately a foot, the velocity can be approximated to be roughly 2.45 m/s. According to some literature, a height of approximately 1.5 meters, or 5 feet, can produce the granular eruption. [6]This height would allow the ball to achieve greater velocities of more than double from our experiment. However, a simply higher height for our experiment would not achieve the granular eruption do to the shallow depth of sand. In some experiments for the granular eruption to be achieved, the depth of the sand has been recorded from 25-40 cm, or roughly 9-15 inches thick. [6]Our sand was only a few inches deep, and in other videos one can actually see the ball bouncing off the bottom of the dish. Unfortunately, this means no height or amount of velocity was going to yield this phenomena.

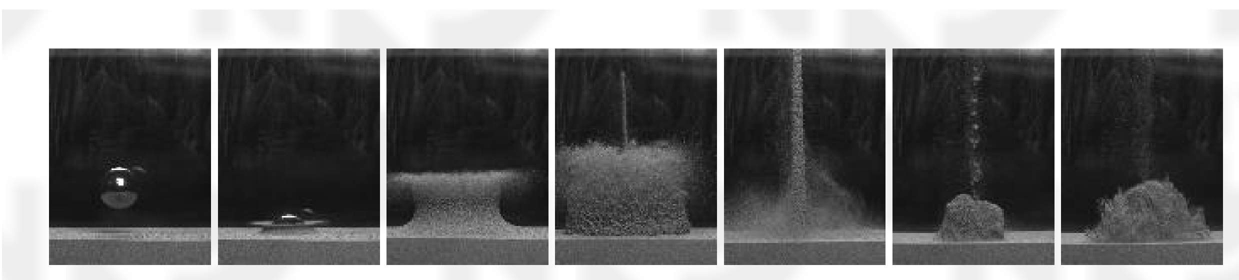

Figure 7: Granular Eruption [5]

Procedure & Technique: The following items were used to acquire the video.

Table 1 - Items Used
Black Fine Sand (Approximately 2 Cups)
.25" Diameter Steel Ball Bearing
9x13 Clear Pyrex Dish
High Speed Camera
Tri-pod
250 Watt Lowel Pro-Light Focusing Floodlights (2) (Tungsten Balanced)
Sony NEX-FS700 Camcorder with 18-200 mm Power Zoom Lens

Figure 8: Setup

By utilizing the lighting studio on the Colorado University campus, we were able to work in an open environment that let use control many of the variables. In the above picture you can see the setup we used for each trial. With the back-drop in place, we didn't have to worry about in unnecessary images appearing in the background. Additionally, the two lamps provided adequate lighting for our experiments. These 250 watt lamps were set at approximately 45 degrees from our setup. We felt this would illuminate the image the best. Our experiment began with piling approximately 1.5 cups of sand into the Pyrex dish. Once we had the camera in focus and the sand piled to significant height, we dropped the ball bearing from approximately 12 inches. Once we were satisfied with our results we tried several different ball sizes, sand types, water, and even glitter.

Camera Configuration & Processing:

The following were used for the camera Settings (Adapted from Joanna Bugajska)

Table 2 : Camera Settings

ISO	2200
F-stop	5.6
Shutter speed	Auto (only option in high speed mode)
HD Format:	1080p30 video*
Frame rate:	480 fps and 960 fps*

We performed experiments at two different frame rates: 480 fps and 960 fps. The way the FS700 camera operates for slow motion video is that it records the frames to the memory for up to 12 seconds for 960 fps and 20 seconds for 480 fps, then the frames are transcoded as 1080p30 video (30 fps). Average duration of the video clips recorded per take was between 1 min to 4 min.

Table 3 : Frame Rate

Frame rate buffered	**Frame rate when recorded**	**Duration**
960 fps	30 fps	32 sec
480	30 fps	16 sec

There was minimal post-processing done to the video as a whole. Utilizing Windows Movie Maker I was able to shorten the clip of the original video by over a minute. With the camera setting of 960 frames per second, this meant there was a lot of unnecessary footage on the original clip. Beyond adding two slides at the beginning of the video there were no other changes made.

Analysis & Opportunities for Improvements:

After a substantial amount of research following our experiment I see one immediate correction that could've improved our results drastically. This improvement would be to increase the amount of sand we used. Using a clear jar or vase we could've filled the apparatus approximately half-way with sand and then we would've been able to capture the granular jet we had hoped for. One other improvement would be to setup a releasing apparatus to release the ball at a consistent height every time. This also could have affected our results. With that said, our resulting videos still show an assortment of projectile motion, wave motion, force transfer, and gravity phenomena. With the assistance of the high-speed camera we were able to capture these phenomena well, even if they weren't the initial desired result we had hoped for.

If we were to try this experiment again I would want to make the two improvements mentioned previously as I believe these would remedy any force transfer into any medium besides the sand.

Sources Used:

[1] Krechetnikov, Rouslan, and George M. Homsy. "Crown-forming Instability Phenomena in the Drop Splash Problem." *Journal of Colloid and Interface Science* (2008): 555-59. Web. 26 Oct. 2015. http://www.engineering.ucsb.edu/~rkrechet-lab/files/publications/jcis2009.pdf

[2] Mikkelsen, René, Michel Versluis, Elmer Koene, Gert-Wim Bruggert, Devaraj Van Der Meer, Ko Van Der Weele, and Detlef Lohse. "Granular Eruptions: Void Collapse and Jet Formation." Physics of Fluids. Web. 26 Oct. 2015. http://doc.utwente.nl/57533/.

[3] Thoroddsen, S. T., and Amy Q. Shen. "Granular Jets." *Physics of Fluids Phys. Fluids*: 4. Web. 26 Oct. 2015. http://citeseerx.ist.psu.edu/viewdoc/download?rep=rep1&type=pdf&doi=10.1.1.222.5612.

[4] McKown, Jenna. "DSpaceMIT." *An Experimental Study of Worthington Jet Formation after Impact of Solid Spheres* (2011): 13-15. Print. http://dspace.mit.edu/handle/1721.1/67750.

[5] Mikkelsen, Rene, Michel Versluis, Elmer Koene, Devaraj Van Der Meer, Ko Van Der Weele, and Detlef Lohse. "Granular Matter Homepage." *Granular Matter Homepage.* 1 Sept. 2002. Web. 26 Oct. 2015. http://stilton.tnw.utwente.nl/people/rene/Granular.html.

[6] Lohse, Detlef, Raymond Bergman, Rene Mikkelsen, Christiaan Zeilstra, Devaraj van der meer, Michel Versluis, Ko van der weele, Martin van der Hoef, and Hans Kuipers. University of Twente, Netherlands. "Impact." (2008): 1-5. Web. 11 Dec. 2015. http://arxiv.org/pdf/cond-mat/0406368.pdf.