Team Project 3[1]

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The behavior of high velocity air ejected from a BB gun is examined using a water tank and food dye to help visualize the flow. Firing the BB gun into an aquarium helps allow the air ejected from the gun's barrel to be easily visualized. The images generated reveal rings of air ejected from the barrel even when the barrel is completely filled with water, providing evidence of a highly turbulent vortex that forms when the gun is fired.

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The images were created in order to observe the fluid physics that occur when a small BB gun is fired. In order to allow for easier visualization of the air ejected from the barrel, the gun is held and fired under water in a small aquarium. The air ejected from the gun moves quite quickly and begins to ascend upward to the surface after exiting the barrel so capturing images that detail the actual physics of the firing gun proved to be rather difficult. Numerous techniques were attempted to capture the most vivid images; originally, the gun was fired while loaded with a BB and full of air but this proved difficult as air quickly leaked out of the gun and when this air leaks out of the gun only water is ejected from the barrel upon firing of the gun so visualization of fluid physics is no longer possible. To counteract the problem of water infiltration, the barrel is prepared prior to immersion in the aquarium by placing a few drops of food dye into the barrel of the gun. Thus, as water infiltrates the barrel it is dyed a different color and can be easily visualized when ejected upon firing.

The physical setup of the system used to visualize the fluid flow was quite simple. The BB gun used was a Smith and Wesson model 5906 air soft pistol. The gun is called "air soft" because the pistol fires 6mm plastic BBs rather than 5mm metal BBs. This type of gun was chosen because it fires the BBs at 176fps (feet per second) rather than the typical values of 500fps or more seen with guns that fire metal BBs. This slower projectile speed means that it will travel a shorter distance during the photograph exposure time, increasing the chances of a usable image that reveals understandable physics. For a tank to fire into, a ten gallon fish aquarium was filled with water and a black sheet draped behind it to ensure a uniform background. The gun was held and fired by hand under water and images are generated with a camera placed approximately three feet away from the tank upon a tripod. The images were generated out of doors on a very sunny day so no artificial lighting was used; the only lighting for the image is from sunlight.

Figure 1: BB gun and aquarium setup

The physics observed in the final image are relatively simple. As high velocity colored fluid is ejected from the barrel of the gun, a vortex ring is generated. At the center of the ring, the small amount of air bubbles released from the gun congregate in a ring in the area of highest shear. Two main phenomenon are occurring as the water is ejected from the barrel of the gun; a vortex ring is generated and cavitation takes place to create a ring of air bubbles that makes it possible to see the region of highest shear in the vortex ring.

As simply stated by Niota et al. "a vortex ring is formed by ejecting a blob of fluid from a circular orifice or nozzle in a short time." Obviously for us, this circular orifice is the exit of the barrel of the BB gun and the fluid is indeed ejected in a short time because we are shooting our "blob" of fluid out of the barrel near the gun's listed specifications of 176 fps. Assuming a barrel diameter equal to our BB diameter of 6mm, the speed of 176 fps, and a kinematic viscosity for water of 0.884E-6 m/s, we arrive at a Reynolds number of approximately 360,000;

we are quite clearly in the turbulent regime so the formation of vortices is quite possible. The vortex rings form because as the high speed jet of water leaves the barrel, viscous forces from the water into which it is injected causes the fluid to slow. The fluid that follows out of the barrel an instant later, however, is still moving quickly and therefore pushes the slow moving fluid ahead of it outward. As this process continues, fluid is continually pushed outward while more fluid passes through the center; the fluid in the center also causes the fluid near it to begin to move as viscous forces cause fluid to be entrained in the jet. Eventually, this forcing of fluid outward combined with the entrainment of nearby fluid causes rotation to occur and a vortex ring is born.

The second important set of physics is the existence of the ring of bubbles that allows us to actually observe the vortex ring that is formed as the gun is fired. The cavitation occurs due to the stresses upon the liquid in the low pressure region in the center of the rotational region of the vortex ring. As Wikipedia.com states "A liquid when it is subjected to a low pressure (tensile stress) above a threshold it ruptures and forms vaporous cavities." These vaporous cavities are the bubbles seen in the ring in the left hand side of the final image.

The visualization technique used for this image is boundary marking. One would initially assume, by looking at the image, that the boundary referred to is between the colored and uncolored fluid. This boundary, however, does not provide very much information about the actual fluid physics that are occurring. The more important boundary is that between the ring of air bubbles and the water. It is this boundary which allows us to see the existence of the vortex ring generated by the firing of the BB gun. As mentioned earlier, there was no artificial lighting used for generating this image; all of the photographs were taken out of doors in direct sunlight.

The camera used was a Pentax ZX-5N with a 28mm to 200mm lens set at about 75mm and the shutter speed was set at 1/2000th of a second with an aperture of f/5.6 and the film used was 400speed Fuji Superia X-tra. The camera was mounted on a tripod with the subject approximately three feet away resulting in a field of view of about fifteen inches by ten inches. A minimal amount of editing was done with Adobe Photoshop in order to crop the photo to its' current dimensions and the contrast was increased slightly to add more definition to the edges of the colored water.

The final image has proven to very interesting; when the images were taken, the gun was fired approximately one hundred times yet our group only observed the ring of air bubbles one or two times. When the photos were developed however, they revealed a ring of air bubbles in nearly fifty percent of the images. Evidently, the formation of a ring of air bubbles is quite common but this ring must move too quickly or last only a short amount of time and therefore is difficult to observe with the naked eye. The main problem with most of the images is the amount of distracting elements such as bubbles not associated with the gun, drips on the outside of the glass, and glare on the glass. This resulted in quite a few unusable images and the few decent images are still not without defects. Thus, although the images are quite interesting due to the existence of the ring of air bubbles, there is some disappointment associated with the small amount of defects present in the final image.

References:

Wikipedia-online encyclopedia: http://en.wikipedia.org/wiki/Cavitation

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