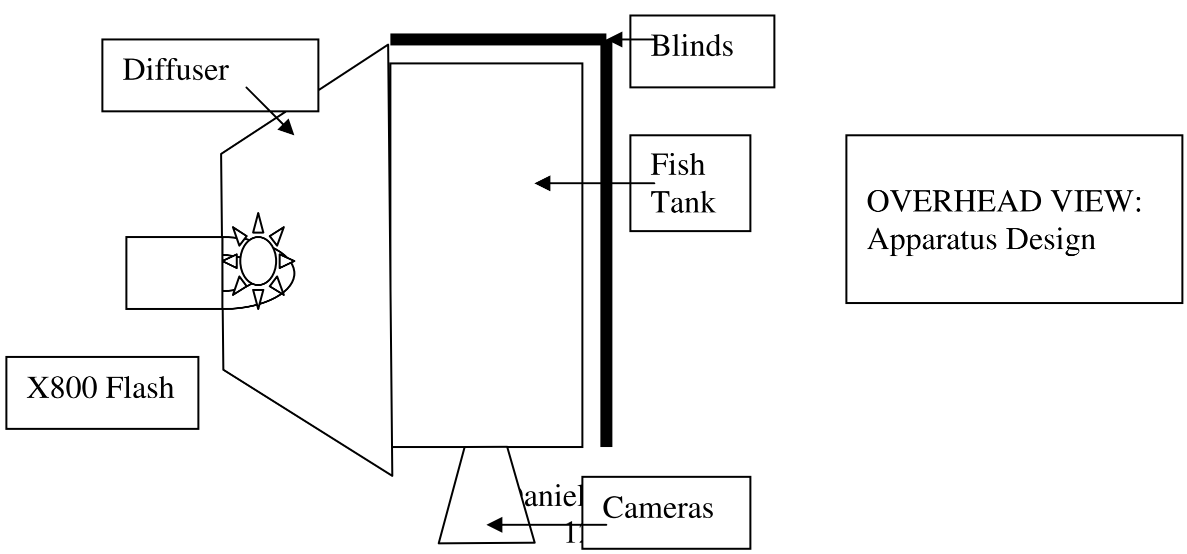
Flow Visualization
Group Project 3:
Dropped Object High Speed, Multi-Perspective Imaging

For the final group project our intent was to better utilize available equipment and perform an experiment utilizing high-speed photographic techniques to capture a set of crisp images from two different views, which clearly demonstrated a particular aspect of fluid interaction. The original expectation was to capture two views of a Worthington Jet, one from each side of the fluid surface. While we were successful in capturing Worthington Jets, a more interesting set of physics was captured in a large quantity of our images. These images captured a vortex like shape trailing behind a dropped object while a splash erupted above the surface. This phenomenon was captured for several objects, a billiard ball, a foose ball, a di, and was attempted for an asymmetrical polished rock.

To accomplish this image, a good deal of equipment and setup was required, however none of it is uncommon and can usual be found in the average household. A 12” wide X 20” tall X 30” long fish tank was partially filled with 11” of water and allowed to sit to room temperature. This fish tank was covered on two sides with black cloth and placed in a darkened room. A White Lightning X800 flash with square diffuser was placed on the remaining large side of the tank. One the remaining skinny side, two cameras were places on tripods, with their lenses on the same vertical axis, approximately 6” apart. This allowed one camera to see



above the water surface and the other below it. Padding was placed on the inside bottom of the tank to prevent damage to the glass from the dropped objects and to help block any remaining light.

This pair of images is of a 1″ diameter foosball being dropped from 18″ above the water surface. It has traveled almost 4 inches below the surface. At impact its speed was approximately 10 ft/sec based on the equation of motion Vf^2 = 2A*D. The Reynolds number immediately at impact is approximately 68000 and is highly turbulent. However the sphere almost immediately slows to a critical velocity of ½ ft/sec in the water due to high drag coefficients and being barely negatively buoyant. At these speeds the Reynolds number is approximately 3440 and is uniform for the areas where the ball is traveling at this speed (from around 1″ to 5″ below the surface. The boundary layer interaction between the entrapped bubble and the fluid ripples almost uniformly throughout this area. This rippling is similar to the results of Nagel and Keim from the University of Chicago in their study of bubble pinch-off singularity (abstract: EF.00007 of APS DFD 2007). It is possible that the rippling seen in this image is being caused by the attempt of the entrapped bubble vortex trying to separate from the ball and return to the surface. The buoyancy force of air in water drives this and soon after this image the vortex will collapse and the air will be driven back to the surface. This interaction between the air and water looks like cavitation as seen in marine propellers however based on a Reynolds number of 3400 and such a slow speed, the ball is not capable of producing a low enough pressure field behind it to generate vaporization and cavitation therefore confirming that this is indeed a entrapped bubble being dragged down in the void where water once was. If this were true it would also mean that the volume of the vertex or trapped air is very closely the volume of the displaced water visible in the spray at a steep wetting angle.

The wetting angle of the initial impact is not visible in this image however it is speculated that it was very nearly the angle of the top edge of the vertex in the below surface shot. This is supported by the nature of the coating on the ball and its texture. Large angles are produced by rough surfaces with hydrophobic surfaces, which this ball is, while smoother surfaces; such as a billiard ball produce a smaller angle. This supports two researchers at MIT, Truscott, and Techet, results on splash mitigation and the formation of trailing air cavities or vertices (Abstract: FC.00006 of APS DFD 2007).

In order to capture motion over a very short time duration and to ensure that two different cameras captured the motion at the exact same instant, the use of an incredibly short burst of light was required. To do this, both cameras were set to the same ISO and Aperture and set for an exposure of several seconds. Because the scene is dark except for when the flash is triggered no information is recorded during the majority of the time. The flash was set to a very low power setting to ensure its short duration. The White Lightning X800 has five different power modes and was set to the second lowest, T.4 for these images. The cameras were set to F8; this combination produced proper exposure for the amount of light given over approximately 1/3300th of a second at an ISO of 100. The surface camera used was a Nikon D200 with at CCD crop factor of 1.4, the underwater camera was a Canon 10D with a CCD crop factor of 1.6. Both cameras were mounted with 50mm macro lenses and independently focused 18” down tank from the lens to accommodate for the difference in refractions between air and water mediums. The images were cropped to maximize the viewing of the upper conical splash and provide the view with the most information without distraction. No other manipulations were performed. The initial pixel size of the surface image was 2600 x 3884 and 2040x 3072 for the below surface image. This difference is a combination of the difference between crop factors and between 8.0 and 6.3 Mega pixel CCD's. Both cameras used Adobe RGB 1998 color profiling and shared identical white balance points. Both images were captured at 10:58 AM MST on 12/5/2007.

This pair of images is inciting to me because it shows an interaction that is seen everyday by almost everyone, but it shows it frozen in time, making it look foreign and exotic. I also enjoy it because of the different viewpoints. This is a perspective, which cannot be captured by the human mind live. Technology allows this perspective to be easily analyzed and enjoyed by even a casual onlooker. If given the opportunity to study this further I would like to use an optical quality glass tank, bleached water, non-reflective inner surface of the tank, and use fog as the upper medium instead of regular air. This would allow a definitive answer as to whether or not cavitation is occurring as the cavitation would be clear as air while smoke or fog entrapped bubbles would appear hazy. A triggered release and delayed firing for the strobe unit would also be necessary to ensure repetitive identical results.