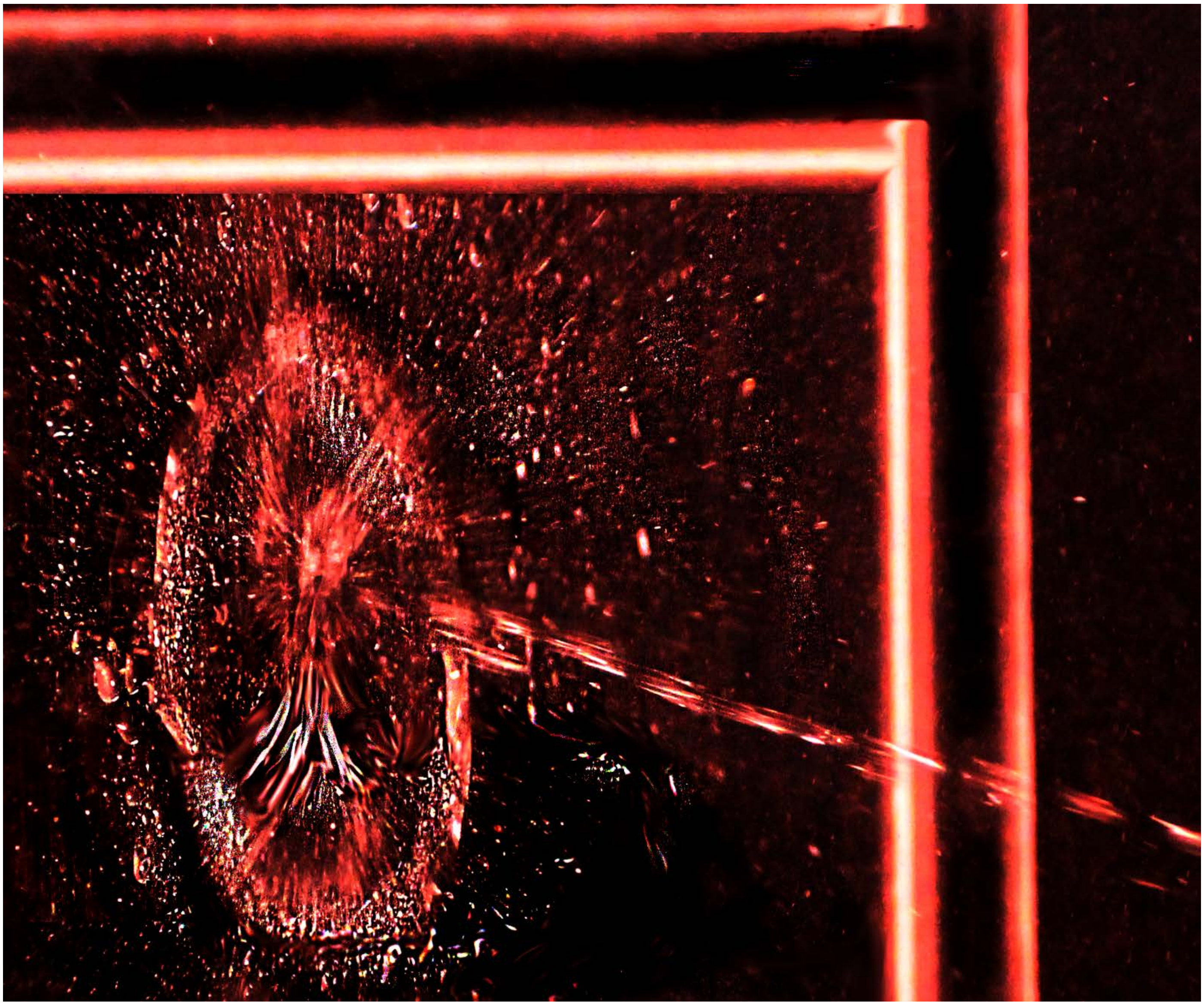
Neon Targets: A Study of the Impulse Reaction of Water



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MCEN 5151: Flow Visualization
Team Photo #3
April 27, 2014

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Introduction

The collision of any projectile, specifically a fluid, with a significantly harder object generally results in a reflection of the projectile at an angle in the opposite direction. This phenomenon is called impulse, in which the momentum of the object is changed due to an opposing force by the striking surface applied for a specific period of time. In the following experiment, a super soaker water gun with a pressurized chamber was shot at a plexiglass surface in order to analyze the collisional effects. Although the original intent of this photograph was mainly scientific, my modifications during post processing created a “techno” theme to the project which resulted in a much more dynamic photo than the original. Figure 1 below is the post processed photo:

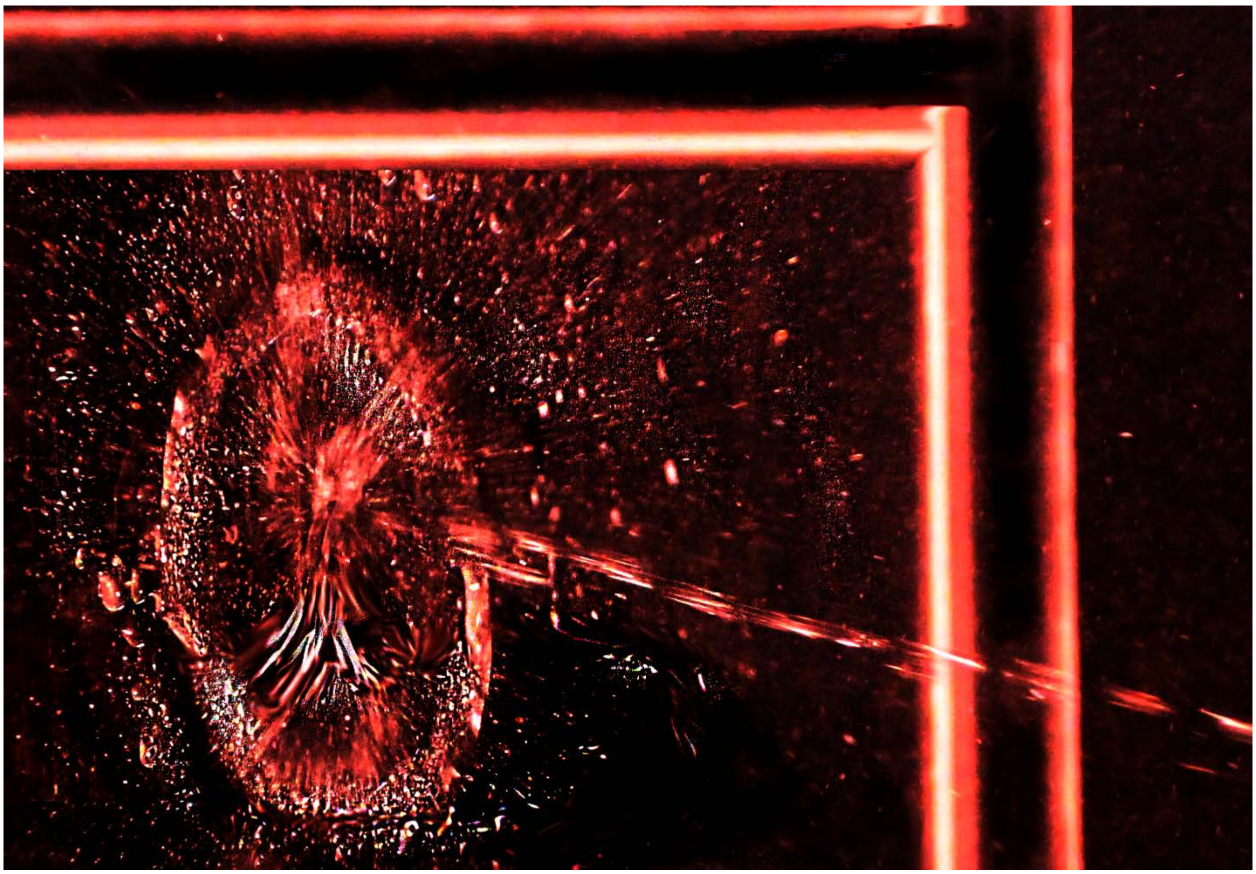

Figure 1-Impulse of water striking a plexiglass surface. Neon effects created in post-processing.

During the execution of this experiment, several team members in addition to myself were involved in the equipment setup, gun operation, reset operations, and camera and video operations. Consequently, I would like to acknowledge Andre Molchanov, Gregg Potts, Da Zhou, and Zach Stein for their work in helping me create this photo.

Experimental Setup

For this experiment, a plexiglass sheet was used as a striking surface for the gun. To protect the camera from any water damage, the body was incased in plastic wrap. A photograph of the camera itself is displayed below in Figure 2:

Figure 2-Olympus High Speed Camera used for the experiment. Camera was protected with plastic wrap.

In addition to the plastic wrap, a plexiglass sheet was placed between the experiment and the camera itself to act as a blast shield. This prevented any direct contact between the camera and the water. Figure 3 below is the schematic of the experiment from the camera's point of view:

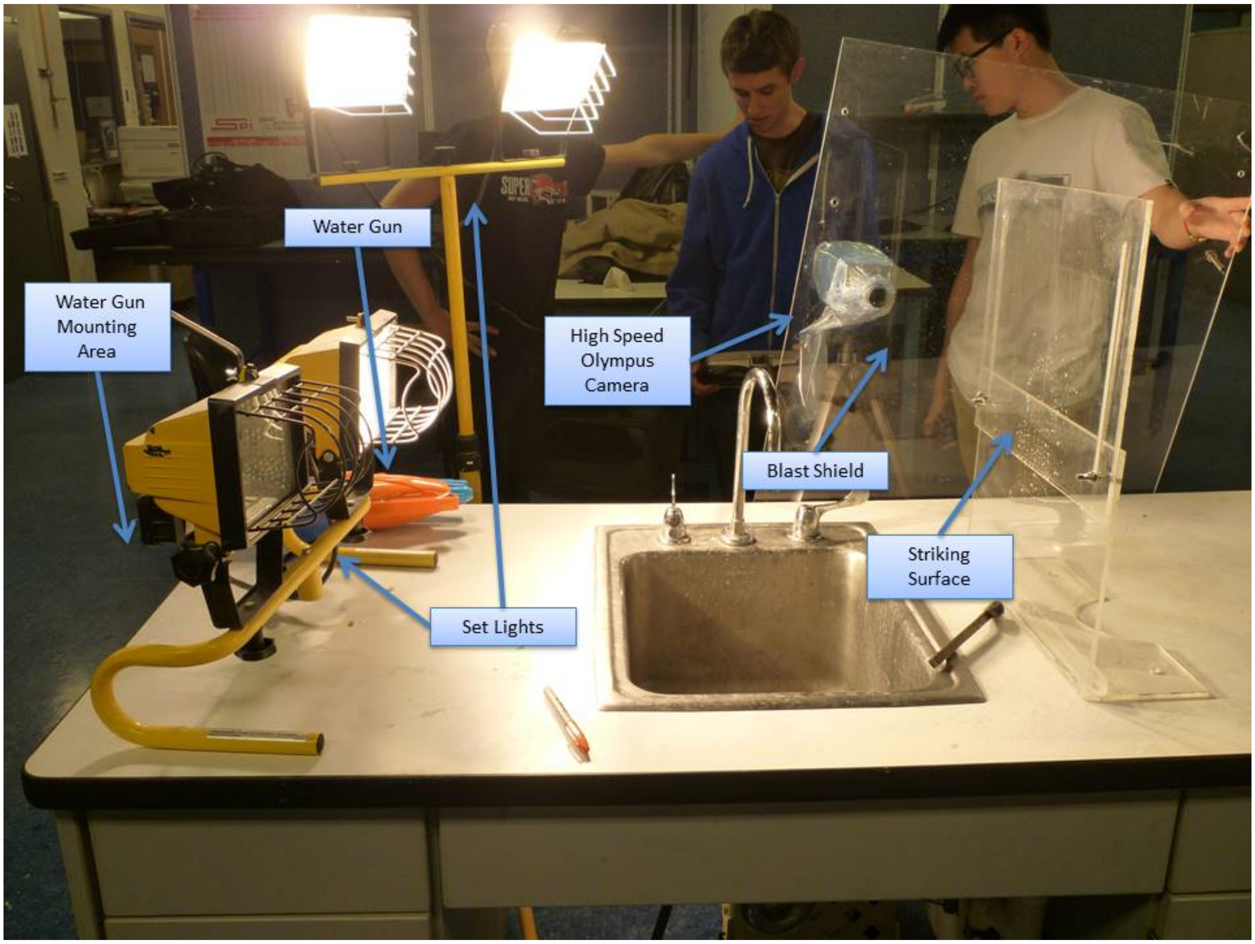

Figure 3-Layout of experimental setup during reset operations. All key components labeled.

Due to the complexity of this experiment as well as the low resolution of the high speed camera, significantly more lighting than normal was needed in order to completely capture the impulse at a high enough frame rate.

Impulse and Momentum Changes

The primary physical phenomenon in this experiment is impulse. By definition, impulse is the change or shift in linear momentum that a body undergoes during a collision. In general, impulse can be calculated as follows [1]:

$$J = F_{average}(t_2 - t_1) \qquad \text{Eq (1)}$$

$$J = \int F dt \qquad \text{Eq (2)}$$

Eq (1) is a simplification of Eq (2), with Eq (2) being the more generalized mathematical expression for the calculation of impulse [2].

In our water impulse experiment, the water gun was pressurized and fired at the plexiglass surface. As a result, due to the high pressure, it was assumed that the water had a significantly greater momentum than at resting state. One of the main considerations when examining impulse is the momentum of the incoming object versus that of the striking surface. Under the assumption that the plexiglass board was not moving, its momentum could effectively be denoted as zero. However, this is not the case with the water. Consequently, the water had a significantly higher momentum than that of the plexiglass. In this sense, once the plexiglass was struck with water, it applied a significant force for a given time as to redirect the water in the opposing direction at a mathematically random angle [1].

An interesting phenomenon that was observed after several seconds was that the deflection of water droplets became significantly lower. While at first unclear, an examination of the properties of water provided a relatively simple explanation. Water inherently possesses adhesive properties [3]. Note however, that plexiglass, or rather PMMA, is not hydrophilic [4]. In this sense, water will not be absorbed by PMMA and will collect on the outside layer of the plexiglass [4]. However, it is this pool of water that is our primary point of interest. As the water continually strikes, it forms a greater and greater pool that eventually begins to drip down the plexiglass. The slower the flow rate of the dripping portion, the greater the size of the pool. As water continues to strike the plexiglass, it will be colliding with other water molecules rather than the actual plexiglass surface. This implies that midway through the experiment, the striking surface will change. As a result, the momentum change is not due to impulse anymore, but rather, the trapping of molecules by the cohesion and surface tension of water [5]. Physically, this will result in more dripping motion (a faster flow rate of water running down the striking surface). The collision phenomenon then becomes based on energy transfer from the moving water to the “pooled” water on the surface of the plexiglass. Note that gravity will eventually pull the water downwards on the plexiglass surface resulting in a constant pooled volume of water so long as the flow rate of the water gun is constant. This phenomenon is known as conservation of energy [6].

As a general summary of the physics described, initially the water fired from the gun will create impulse driven behavior. This will result in the water being reflected off the surface of the plexiglass due to the reaction force applied by the plexiglass for a specific moment of time. However, once a sufficient amount of water has pooled onto the surface of the plexiglass, the mode of collision will change. Instead of striking the plexiglass, the projected water will contact water molecules rejected from the striking surface due to its hydrophobic properties. As a result, the collision becomes based on energy transfer rather than impulse.

Visualization Techniques

To produce the image in Figure 1, a high speed camera was used to capture the behavior of the fluid as it struck the surface of the plexiglass. Note however that the complexity of this increased with the higher frame-rate setting. In other words, the frame-rate would decrease the resolution of the camera, resulting in a darkened photo. Consequently, a significant amount of stage lighting was needed in order to ensure that the photo would retain a high enough resolution for analysis while capturing the entirety of the collision. As mentioned earlier, a plexiglass blast shield was used to protect the camera from the water hitting the striking surface. However, this created a complication in which small imperfections on the glass were captured in the photograph. Initially, this presented a problem as it became difficult to find a perfect surface on the blast shield. Despite this, once the frame-rate was increased, these imperfections no longer became visible, resulting in an accidental solution to this problem.

Lighting for this photograph was provided by two sets of work lights. Although initially considered, a white background was not implemented into the photograph as the striking surface provided an appropriate contrast allowing for clear visualization of the collisional effects. While the initial problem of glass imperfections was resolved through higher frame-rate settings, as a precaution the plexiglass blast shield was cleaned thoroughly to remove fingerprints, grease, and any other temporary obstructions. To obtain a consistent frame, a small target dot was marked on the plexiglass striking surface as a guiding point for the water gun operator. This enabled consistent shots within the camera's visual field, allowing for a clear picture during each run. Additionally, continuous stream pumping methods were seldom used as re-pressurization of the water gun would result in slight deviations from the target mark, resulting in a non-centered photograph.

Photographic Technique

The image in Figure 1 was captured using a Canon EOS Rebel T5i. A tripod was used to position the camera as to ensure that the marked target on the plexiglass would be centered in the frame. Several practice runs were performed to solidify the procedure and to verify that the point of interest was indeed in the center of the camera's field of view. While no true danger was present during this experiment, all electronics were protected with either plastic wrapping or a blast shield to prevent any contact with water. To capture the impulse phenomenon as well as the energy transfer phenomenon, an exposure time of 1/2000 sec was used with an ISO speed of ISO 6400, and a focal length of 40 mm. Due to the higher degree of lighting in the photograph, additional lighting was not needed by the camera. Furthermore, the reflective surfaces of both the blast shield in addition to the plexiglass striking made any flash unusable. The distance between the target and the water gun was approximately 4.27 ft. The elevation of the water gun was adjusted to around 19.5^{o} as the water had a tendency to arc. The plexiglass striking surface was

1.97 ft tall and 1.27 ft wide. Due to the desire for a greater blast shield, the largest piece of plexiglass available at our disposal was chosen. As its length was variable across its width, so long as the blast shield could stand at least 6 ft tall, it was deemed suitable for use as a blast shield.

In its original form, the photograph was 5184 x 3456 pixels for a setup that captured a 12” by 6” framed image. The original photograph is shown below in Figure 4:

Figure 4-Original unedited photograph of water striking a plexiglass surface.

The photo was post processed in Adobe Photoshop CS5. While the draining behavior was interesting from a scientific perspective, I was more interested in the splash pattern at the top of the photograph. Consequently, I decided to copy the radial splash pattern and transpose it to the bottom of the photograph to remove the stream-like flow. While initially complicated, I managed to create a symmetrical image through the blur tool and the smudge tool. In order to remove the frame of the transposed section, I used the smudge tool to combine the border with that of the plexiglass background. Some additional color modifications allowed the radial splash to be smoothly integrated to the bottom of the photograph. Afterwards, I cropped the photograph such that the edge of the plexiglass at the base was not visible. Using the curves tool, I adjusted the coloring such that the radial splash pattern was emphasized in more detail. A side effect of this was the washing out of the background. However, this was preferable as there were several distracting elements in the background. Some modifications to the saturation of the photograph created a neon sign like effect that can be seen below in Figure 5:

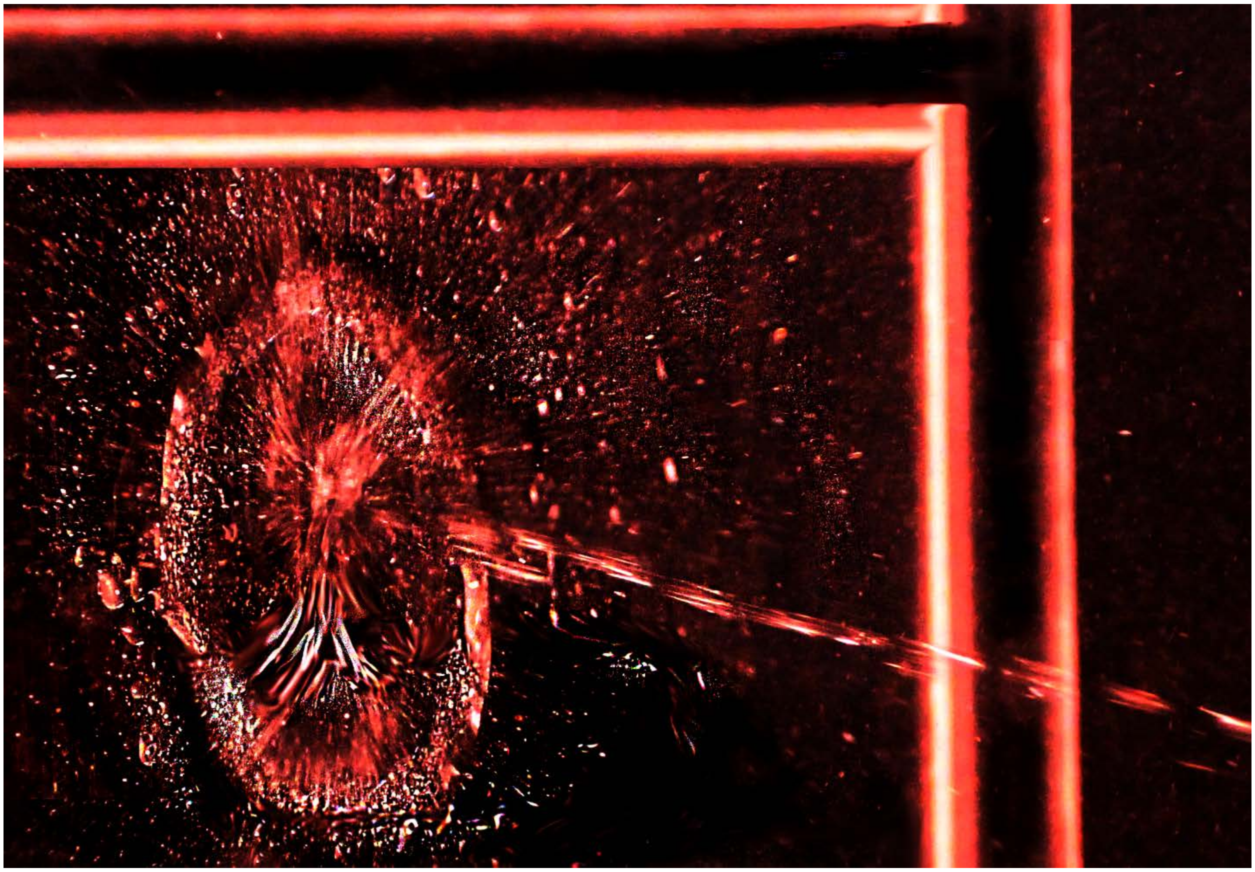

Figure 5-Modification of impulse on a glass to create a symmetric splash pattern

As seen from Figure 5, the edges of the plexiglass were emphasized with a neon-like red glow. While originally only the right side of the photograph had the double lined red edge, a quick transpose, blur, and merge allowed me to create a similar border at the top of the photograph. Once this was performed, several burn operations were done on the photograph to disguise the transpose. This created the illusion that this photograph was done with phosphorescent liquid. Some additionally smudging was performed along the edges of the radial splash to create a more symmetrical shape. The final dimensions of this photograph were 2166 x 1498 pixels.

<u>Overall Analysis</u>

As a summary, the following experiment was more scientific as it focused primarily on the impulse effects of water when colliding with a hard surface. However, I did not anticipate the sudden change in collision mechanism due to the pooling of water. This made the analysis of this photograph more challenging as I was not aware of the change in mode until after I observed the photograph in more detail. While the primary scientific interest of this project revolved around physical phenomenon, I was pleasantly surprised by the need to research the material properties of PMMA in order to understand the change in collision modality. In terms of the artistic approach, my original post processing was plagued by severe issues due to hardware limitations. While attempting to transpose the radial splash pattern, I found it difficult to prevent photoshop from crashing as the transpose was performed on a relatively high resolution photograph of a significant size. In addition, the blending operations of the transposed portion with the surrounding areas of the photograph proved to be a great obstacle as the difference in background was clearly visible. However, once changes using both the curve and saturation tools were implemented, it became easier to blend the image as the background became obscured. Photoshop's layer tool was also immensely helpful as it allowed constant merging which permitted continuous changes in color, enabling a better merging effect between the transposed section and the original background layer. While at first I designed the photograph's main color to be neon blue, I chose red as it provided a much greater contrast between the black background and the radial splash behavior that I was trying to emphasize. Overall, while the post processing was extremely frustrating at times, I am very satisfied with this photograph as the neon effects were an unintentional bi-product of my attempt to blend the transposed images. If I were to repeat this experiment, I would examine the effects of both oil as well as deionized water when striking plexiglass.

References

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