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Image-Vid 3

Performance car aerodynamics visualized with fog

1. **Purpose**: For my third investigation into fluid phenomena, I wanted to capture aerodynamic airflow over a performance vehicle similar to wind tunnel testing. By constructing my own smaller version of a wind tunnel and utilizing a handheld fog machine, I wanted to visually demonstrate how cars are designed to cut through air and have it flow over the body in specific ways in certain areas. It took some trial and error to get the correct setup between lighting, fog density, and airflow, but with the help of some post processing I was able to capture smooth flow over the body of the car. Artistically, I wanted to use dramatic lighting and stark color differences to showcase the fog and make the car seem intimidating and advanced.

2. **Flow Apparatus and Discussion:** For this experiment, I had to create a wind tunnel structure as similar to car manufacturer's wind tunnels as possible. To do this, I used a 12-pack case of La Croix, the 15" x 11.5" glass from a Michael's picture frame, and an 8" Holmes window fan. I cut an 8.25" by 4" hole into the side of the case and secured the glass pane to it using masking tape. I then placed a 24:1 scale Ferrari Enzo model car by Maisto into the center of the "wind tunnel." The fan was setup at the rear of the wind tunnel facing the rear bumper of the car and was set to low to pull the air through the wind tunnel. Finally, I used a Wizard Stick handheld fog machine to release fog into the front of the wind tunnel, which would then be pulled over the car via the fan. To capture this, I placed my camera on a tripod perpendicular to the car and wind tunnel and about 11" away from the car. From this perspective, I was able to capture an ideal angle to visualize the fog traveling over the body of the car to simulate how the air would travel over the car at speed.

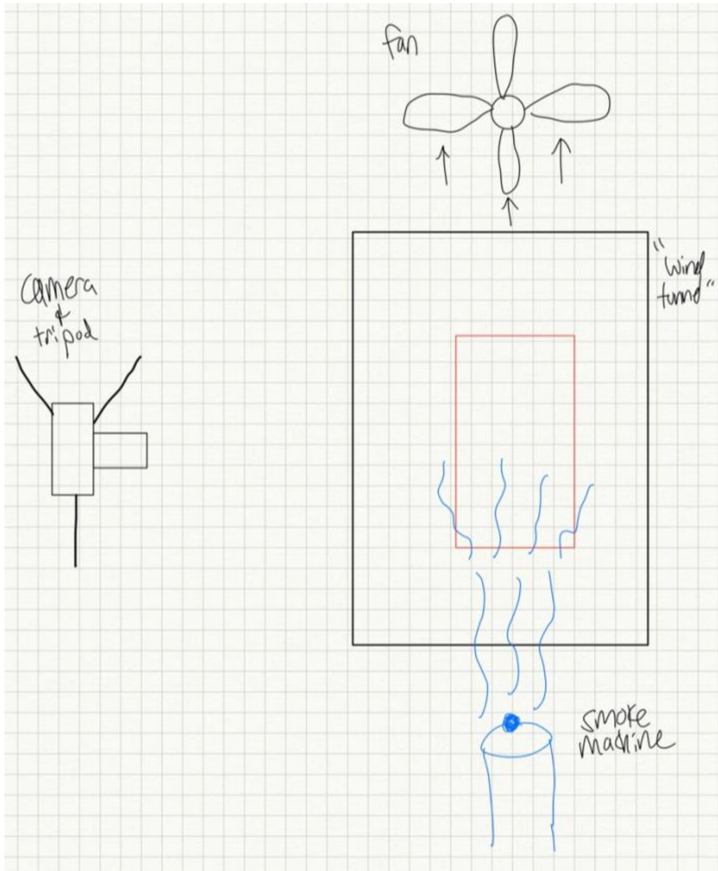

Figure 2: Overhead layout of subject and lighting

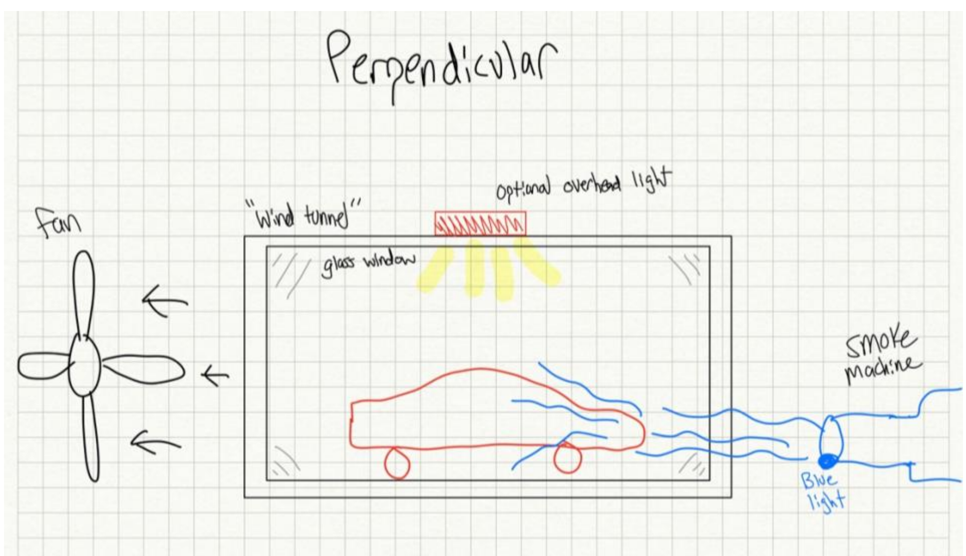

Figure 3: Perpendicular view of subject and lighting

In this investigation, the main fluid flow phenomena that is being analyzed is drag and turbulence in relation to a car's aerodynamics. Aerodynamics is "the study of a solid body moving through the atmosphere and the interaction which takes place between the body surfaces and the surrounding air with varying relative speed and wind direction" (1). Much research is done surrounding improving the aerodynamic efficiency of vehicles, as creating as little resistance as possible will improve fuel efficiency, acceleration times, and top speed (2). One of the key values that car designers seek to decrease is the drag coefficient, where drag simply acts as aerodynamic friction that opposes the intended direction of the vehicle (3). This can be shown in Figure 5 where air flows fast and smoothly over the hood, windshield, and roof, but the flatter front bumper creates higher-pressure slow-moving air that leads to drag. In terms of the Ferrari model in the image, it is very well designed with a low and smooth front bumper and hood area that lessen the drag as much as possible, but one can still see fog that makes hard turns to travel under the vehicle or around the sides which increases the drag. Another great aspect of this car that can be seen is that the fog is channeled above the front fenders smoothly to reduce drag and increase downforce on the front tire, but it is then directed into the rear air intakes behind the doors to be used in the high-performance rear engine. Even still, this car had a somewhat higher drag coefficient for supercars of 0.36, but as a rear-wheel-drive vehicle, the engineers prioritized rear downforce to improve handling and decrease lift (5). Using this value and Equation 2 below, one can determine the drag force at any velocity, but unfortunately this cannot be computed for this experiment as the simulated velocity in the simple wind tunnel cannot be determined. The other aspect of the car that should be minimized and is demonstrated in the image is turbulence. Figure 4 below demonstrates the airflow over the car where smooth laminar flow is found at the front and top of the car travelling over well-designed surfaces, and rough, turbulent flow is found at the rear of the car when the air moves away from these surfaces (1). The goal is to have laminar flow, which also helps reduce drag, and is represented by low Reynolds numbers and reduce turbulent flow in the cars wake, which is represented by high Reynolds numbers (6). Unfortunately, in this experiment the fog was not thick enough at the rear of the car to estimate the Reynolds number using Equation 1 below, but visually one can see that the fog travelling over the hood and front fenders appears to be laminar and therefore have a small Reynolds number. Clearly, vehicle aerodynamics is an immensely challenging area of research as many different factors need to be analyzed and extremely precise wind tunnels must be used to create and visualize airflow over a car. One cannot simply reduce drag and turbulence to reach a top speed or high fuel efficiency, as the body must be designed for safe and precision handling, cost, weight, and able to fit an average human person. As vehicles become more advanced and computer models become more complex, vehicle aerodynamics and airflow visualization will become more necessary and detailed as well.

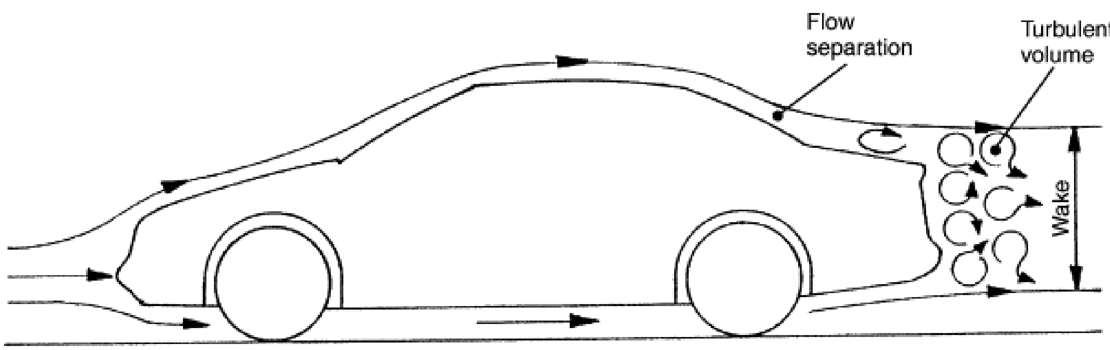

Figure 4: Airflow over a vehicle and the turbulent wake produced at the rear bumper. (1)

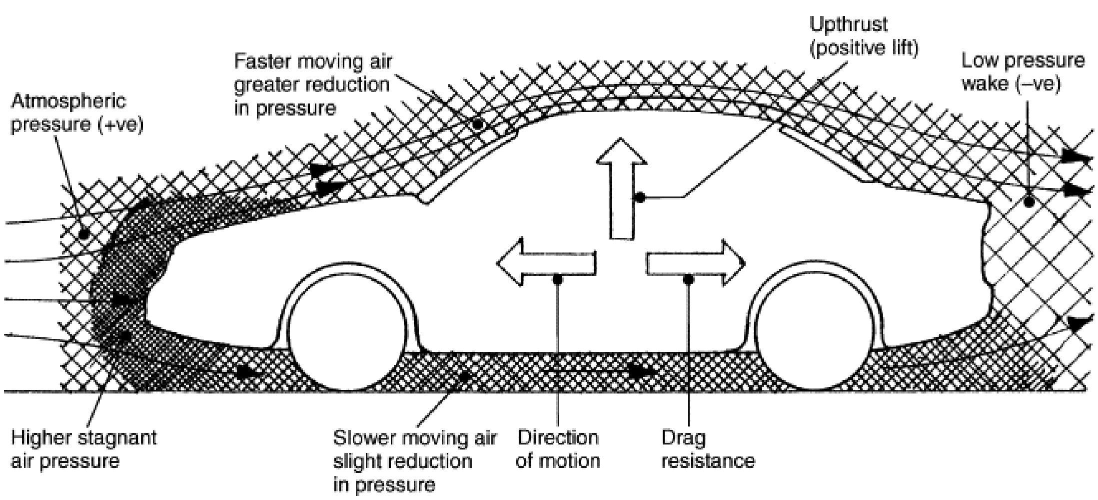

Figure 5: Car force diagram and air streamline visualization. (1)

$$R_e = \frac{Ud}{v}$$

Equation 1: Reynolds Number equation where U is velocity, d is distance, and v is kinematic viscosity. (6)

$$D = C_d * A * \frac{1}{2} * p * V^2$$

Equation 2: Drag equation where Cd is drag coefficient, A is area, p is density, and V is velocity. (4)

3. **Visualization**: This image tried to capture how air would flow over a car like how manufacturers test cars in precision wind tunnels. The primary fluid in this experiment was the fog created by the handheld fog generator, which is mainly comprised of water and propylene glycol. Based on how the device operates, the exact amount to produce each burst of fog is unknown but the trigger for the heating element was activated for about 10 seconds for each burst. This fog was then pulled over the car via the fan in the back and multiple attempts were conducted to get the fog density to produce a good image. For lighting, the main light source for the fog image was the blue LED light at the end of the Wizard Stick fog device pointing toward the front of the car, and the Aputure AL-MX on-camera LED light was used as an overhead light on top of the wind tunnel to capture the full body of the car for the image blending portion of the post processing.
4. **Photographic Technique:** For the specific photographic goal of this image, I wanted to capture a perfect side body view of the car and the fog travelling over in the same way that car manufacturers utilized wind tunnels for testing and marketing material. I used my Sony A7iii full frame 24MP camera and a Tamron 28-75mm f2.8 lens that is very good at capturing sharp details in close range. I set the camera up on a tripod level with the car and the wind tunnel structure, set the aperture to f5.6 to capture sharp detail with a wider range of focus, and adjusted my shutter speed to 1/25 and ISO to 1250 to gain some more exposure. As you can see in the raw image in Figure 6, this was dark still, but the full frame sensor is very good at retrieving details in the shadows. After editing the image though, I still did not feel happy with how much of the car was still in shadow, so I used Photoshop and then combined the fog image with another image that had more lighting on the car body. This photo had the same settings, except the ISO was brought down to

200 due to the additional lighting, so the final image had more of the car body displayed and helped decrease the ISO noise. From here I was able to raise the exposure, shadows, highlights, and whites to make the fog and the car standout more without losing too much detail or losing contrast. I also increased the saturation of red and blue in the image to make it more vibrant and emphasize the two-tone nature of the image. Lastly, I raised the exposure and highlights in targeted areas of the image, like the wheel and headlights, to make them appear more visible and add to the advanced look of the car.

Fog Photo - Photographic Details Overview

- **Object Distance:** 11in
- **Lens:** Tamron 28-75mm f2.8 set at 39mm
- **Camera:** Sony A7iii
- **Resolution:** 6000 x 4000 Original, 5213 x 2962 Final
- **Aperture:** f5.6
- **Shutter Speed:** 1/25
- **ISO:** 1250

Car Photo - Photographic Details Overview

- **Object Distance:** 11in
- **Lens:** Tamron 28-75mm f2.8 set at 39mm
- **Camera:** Sony A7iii
- **Resolution:** 6000 x 4000 Original, 5213 x 2962 Final
- **Aperture:** f5.6
- **Shutter Speed:** 1/25
- **ISO:** 200

Figure 6: RAW Image 1

Figure 7: RAW Image 2

Figure 8: Raw Image vs Final Image

5. **Self-Assessment:** This image shows how well car aerodynamics need to be designed to create a vehicle that reduces drag, reduces turbulence, and increases handling as much as possible. The interactions between the car body and air at high speeds is a huge field of research and a high precision wind tunnel is a necessity for any real analysis to be done. What I like about this image is that through a fairly simple setup I was able to capture the general flow of air over a performance car and how it is designed make these interactions occur. I was also able to artistically show this through simple color choices and dramatic lighting that help emphasize the incredible design and power of this Ferrari. Still, I do have some areas that I wish could have been improved, such as having a denser and more streamlined fog that travelled over the entire length of the car to better demonstrate how the air moves over individual portions of the car. Overall, this is still a great image that demonstrates car aerodynamics in a beautiful way and only makes me more amazed at how well engineered large scale wind tunnels are.

References:

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