Kármán Vortex Street Visualized With a Scale Model Car

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1. Introduction

This report will explain the experimental setup and scientific background behind this image of vortex rings trailing from a scale model LEGO® car, in airflow conditions similar to a wind tunnel. A green laser shining at a custom-built motorized beam splitter creates a laser sheet. The particle tracer is extremely fine titanium dioxide, generated from the chemical reaction of titanium tetrachloride (TiCL4) with moisture in the air. The titanium tetrachloride (liquid at room temperature) sits in a shallow dish, and air is blown over it, carrying the generated titanium dioxide particles with it. This air stream then passes over the model car.

This experiment visualizes the unstable flow that results from a flow encountering a blunt object. This image was taken to complete the final assignment for the University of Colorado Boulder course entitled "Flow Visualization" (ATLS 5519).

2. Scientific Background

When a laminar fluid flow encounters a blunt obstacle, the fluid flow separates into two parallel flows which then travel around the object. Depending on the viscosity of the fluid and its speed, when the split flows then meet once again on the opposite side of the object, the flow may become unstable and begin to oscillate. These oscillations yield vortices of oscillating rotational "polarity". This phenomenon is known as the "Kármán vortex street" [1]. Vortex streets occur both in nature and as a result of quickly-moving air interacting with synthetic objects (such as buildings, airplanes and cars).

We can predict whether these oscillations may occur by calculating Reynold's number for the flow after the object. Reynolds number quantifies the ratio of a fluid's inertial forces (due to an initial velocity) to its viscous forces (intermolecular interactions that make a fluid more or less "deformable"). Kármán vortex streets only occur within a limited range of Reynold's numbers. Spherical and cylindrical objects may yield vortex streets for fluids with Reynolds numbers between 40 and 1000, though values below 90 are more likely [2]. Reynolds number may be calculated as shown below in Equation 1:

$$Re = \ uL/\mu$$

Equation 1. *The Reynolds number, Re, is calculated from the fluid's density ( ), the fluid's velocity relative to the object (such as a pipe) containing it (u), the "characteristic linear dimension" (L), and the fluid's dynamic viscosity (μ).*

3. Apparatus and Visualization Technique

In **Figure 1**, air is injected via a plastic hose over a shallow dish containing titanium tetrachloride. Titanium chloride reacts with moisture in the surrounding air to produce an extremely fine mist of white titanium dioxide along with hydrogen chloride gas. At right is the green laser, whose beam is incident upon a fully-LEGO beam splitter. Within the same laser assembly, a LEGO EV3 Medium Motor powers a two-stage gear multiplier such that the beam splitter spins at approximately 3,750 rpm. This generates the sheet of green laser light that makes it possible to see the trailing vortices.

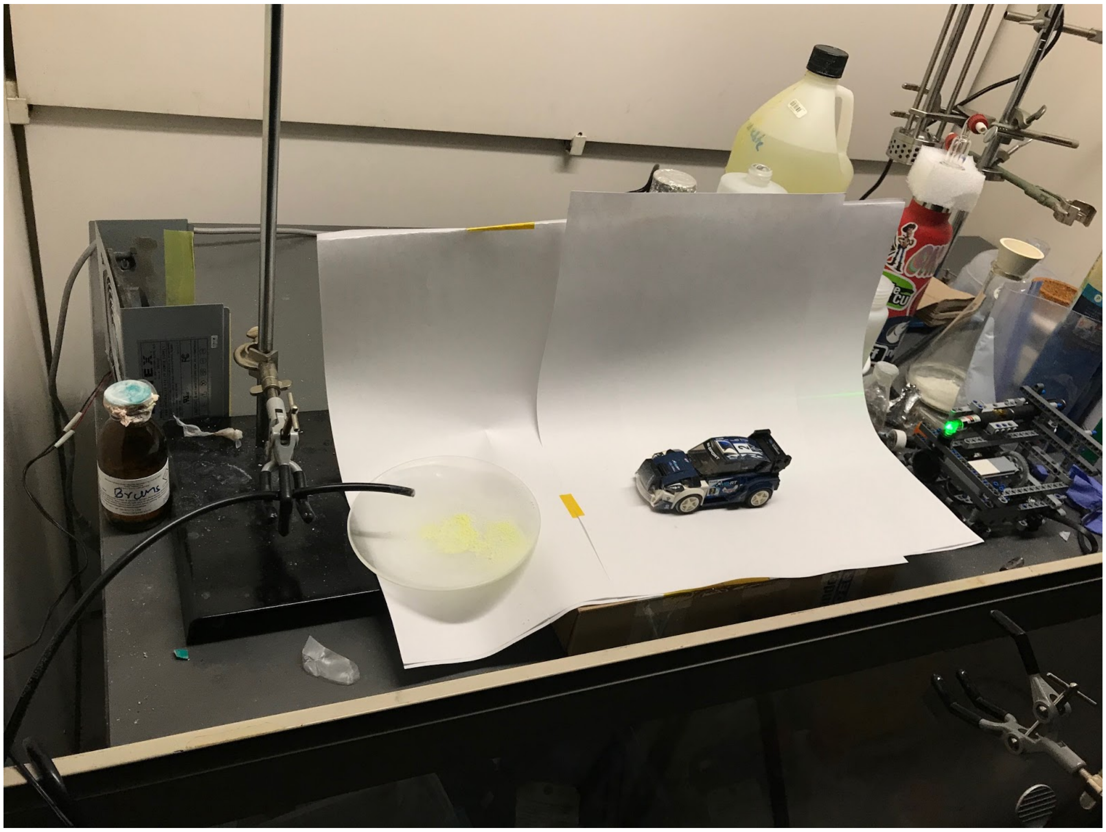

Figure 1. ***Experimental setup.***

4. Photographic Technique

The following camera settings were used for this image:

Camera and Image: iPhone 7, 1284 x 637 pixels (w x h)

Focal length: 4 mm

Exposure settings. ISO 1800, shutter speed 1/20 sec, f-number of 1.8.

Figure 1. *Final edited version of the image.*

Figure 2. *The original image.*

References

[1] "Various Views of von Karman Vortices" (PDF). https://web.archive.org/web/20160312145032/http://oceancolor.gsfc.nasa.gov/cmsdocs/educational_material/VariousViewsofvonKarmanVortices.pdf. *NASA page*. Archived from the original (PDF) on March 12, 2016.

[2] Tansley, Claire E.; Marshall, David P. (2001). "Flow past a Cylinder on a Plane, with Application to Gulf Stream Separation and the Antarctic Circumpolar Current" (PDF). https://wayback.archive-it.org/all/20110401142411/http://www.met.reading.ac.uk/~ocean/Dynamics/pub/tm01b.pdf. *Journal of Physical Oceanography*. **31** (11): 3274–3283. doi:10.1175/1520-0485(2001)031. Archived from the original (PDF) on 2011-04-01.