Elecdrip

Group 1 Image Report

Gage Henrich *gage.henrich@gmail.com*
Mechanical Engineering University of Colorado at Boulder

Instructor: Professor Jean Hertzberg
MCEN 5151 Flow Visualization

This report lists and describes the techniques performed to capture the photo *Elecdrip* as part of the first Team Flow Visualization assignment. The image attempts to depict shear effects on various fluids in a wind tunnel, and how fluids of different viscosity and density exhibit different flow. The intent of this assignment was to capture an image that effectively displays the beauty and complexity of fluid flow phenomena. The relevant fluid mechanics will be discussed and and used to analyze the image quantitatively. The final image was one of several captured during the project period, and it underwent severall steps of post-image processing to achieve the aesthetic intended.

The image was captured in the ITLL's wind tunnel at the University of Colorado (shown in Figure 1.) This is a high-speed (145 mph) Aerolab educational wind tunnel that is used to capture aerodynamic airfoil data such as angle of attack, pitch, air speed and air pressure. Rather than displaying the flow of fluid over an airfoil, as was originally intended for the project, the flow depicted in the final image is of drops of two different fluids on the floor of the wind tunnel.

Figure 1: The wind tunnel used during the project period

For this experiment, a UV light was positioned over the top of the wind tunnel to allow for fluorescent fluids to be seen in motion. Two fluorescent fluids of different viscosity were used: *All* Liquid Laundry Detergent, and a mixture of equal parts fluorescent dye and mineral oil. Droplets of varying diameter were placed linearly across the floor of the wind tunnel. The densities and dynamic viscosities of the liquids used in this experiment are displayed Table 1.

Substance	Density, ρ ($\frac{kg}{m^3}$)	Dynamic Viscosity, μ (cP)
All Laundry Detergent	~ 885	~ 120
Fluorescent Dye	~ 1000	~ 1.1
Mineral Oil	~ 800	~ 110

Table 1: Properties of selected liquids

From the values listed in Table 1, the kinematic viscositiy, ν, can be determined for each liquid.

$$\nu = \frac{\mu}{\rho} \tag{1}$$

Thus, the kinematic viscosity (in centistokes) for each liquid is:

$$\nu_{det} = 135.6 \qquad \nu_{dye} = 1.1 \qquad \nu_{oil} = 137.5 \qquad \text{(cSt)}$$

Assuming a constant temperature, kinematic viscosity of the oil-dye mixture can be estimated using the empirical Refutas equation, which is carried out in three steps [2]. The first step, shown in equation 2, is to determine the blending index, denoted as V, of each component in the mixture. Next, in equation 3 the blending index of the mixture is calcuated based on the mass fraction, x, of each component. Once the blending index of the mixture has been calculated using equation 3, the dynamic viscosity of the mixture can be determined from equation 4.

$$V = 14.534 \ln \ln (\nu + 0.8) + 10.974 \tag{2}$$

$$\bar{V} = x_{oil} V_{oil} + x_{dye} V_{dye} \tag{3}$$

$$\exp(\exp\left(\frac{\bar{V} - 10.975}{14.534}\right)) - 0.8 \tag{4}$$

Following equations 2 through 4, the kinematic viscosity of the oil-dye mixture is found to be:

$$\nu_{oil,dye} = 5.12 \text{ cSt} = 5.12\text{x}10^{-6} \ \frac{m^2}{s}$$

With the kinematic viscosities now known, the Reynold's number, Re, for each fluid can be calculated using equation 5. The Reynold's number is a measure of the ratio of viscous forces to inertial forces in a flowing fluid. Boundary layer is a layer adjacent to a surface where viscous eects are important. This is shown in Figure 2 for flow over a flat plate.

$$Re_\infty = \frac{U_\infty L}{\nu} \tag{5}$$

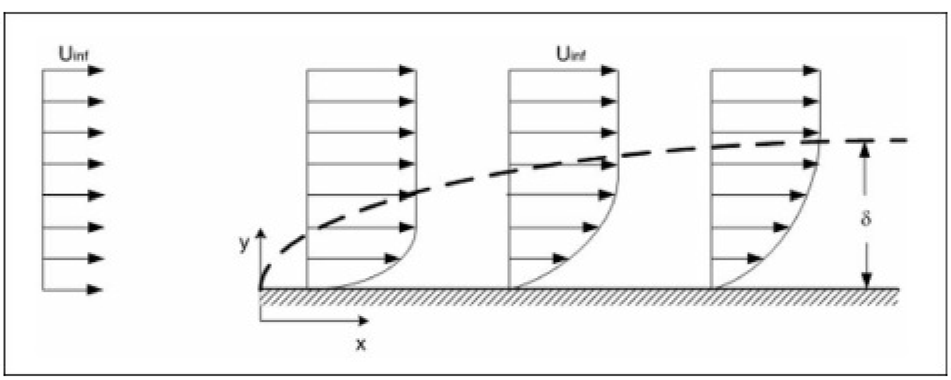

Figure 2: Flow over a flat plate

where U_∞ is the free stream velocity of the fluid, and L is the characteristic length, measured from the leading edge of the at plate at which the boundary layer distributions are being evaluated. U_∞ for the flow of fluid over the wind tunnel floor (flat plate flow) is assumed to be equal to that of the air measured in the tunnel, and L is the diameter of the individual drops. Thus,

$$U_\infty = 21.04 \ \frac{m}{s} \qquad L_{det} = 2.54 \ \text{cm} \qquad L_{oil,dye} = 1.50 \ \text{cm}$$

Substituting the respective values (with ν in m^s/s), into equation 5 yields:

$$Re_{det} = 3886.7 \qquad Re_{oil,dye} = 61640.6$$

Since their Reynold's numbers are less than 3.4x10^5, the flow for both fluids is considered laminar [1]. The drops in the image that are being analyzed are the two middle drops, with the orange drop being the oil-dye mixture and the blue/green drop being the detergent. The analysis provides a quantitative explanation of the fluid behaviors: the detergent has a lower Reynold's number, thus it is more dominated by viscous forces. This is seen in the image because the detergent drops do not flow as far as the oil-dye mixture drops.

The image was captured on March 5, 2013 with a Nikon D5000 SLR 12.3 megapixel camera. The image specifications are shown in Table 2 below.

Specification	Value
F-number	4.2
Exposure time	1/10
Focal Length	26
ISO	1000

Table 2: Image specifications

The area of the field of view was approximately 32.1 x 16.2mm. The spatial resolution is estimated to be 3mm. The image was post-processed in Photoshop after initial capture. The curves and exposure were adjusted to rid the image of any distracting background elements. Then, the contrast and saturation were adjusted heavily.

Although the noise in the image was increased as a result of saturation and contrast adjustments, I felt it added a gritty aesthetic to the shot. The image was rotated 90° clockwise to make it seem the droplets were dripping down a wall. Overall, I am extremely satisfied with my final image. The wind tunnel and UV lights combined to achieve an aesthetically-pleasing work of art that also effectively conveys the physics of fluid flow. The original and final shots are shown in Figure 3 and Figure 4 on the following page.

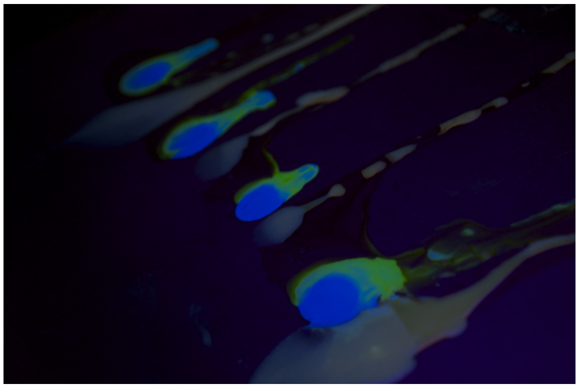

Figure 3: Original image

Figure 4: Final image

References

[1] Li, J. and Renardy, Y. Numerical Study of Flows of Two Immiscible Liquids at Low Reynolds Number. SIAM Review, 2000, Vol. 42, No. 3 : pp. 417-439

[2] Robert E. Maples (2000). Petroleum Refinery Process Economics (2nd ed.). Pennwell Books. ISBN 0-87814-779-9.