Report for Get Wet

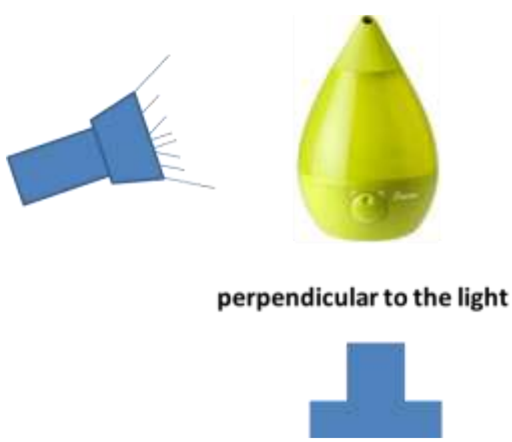
Qian Li

Department of Mechanical Engineering

Qian.Li@Colorado.edu

Flow visualization is an important approach to understand fluid flow mechanisms in a direct way. Light, controls of the camera, arrangement of all the components, and the tracer all play important role to obtain nice images. The purpose for this work is to get some experience about how to shoot pictures to present the transition from laminar flow to turbulent flow of a jet flow.

To create the desired flow pattern a Crane drop mist humidifier is used and water is the working liquid. The flow rate is adjusted to make the mist jet flow first in laminar flow when it leaves the nozzle and then turn into turbulent flow. The flow apparatus and the visualization components are shown in Fig. 1. The pictures are shot at a direction perpendicular to the light and the ambient light is turned off.



Due to the existence of the nozzle and the initial velocity, the mist jet is first in laminar flow with an increasing cross-section diameter. The increase results from the so-called entrainment of air from the ambience. Since there is difference between the mist and the stagnate air, the pressure in two parts are different. The pressure of the air is higher so that the air will be sucked into the mist jet flow. If we regard air as incompressible gas, the area of the mist jet flow has to increase to maintain mass balance. The mist humidifier has a capability to spray 2.3 gallon (8.71 L) in 10 hours (36000 s). Since the diameter of the nozzle exit is 1.5 cm, the estimated speed of the jet flow at the exit is

$$v = \frac{V}{t \times A} = 3 \times 10^{-3}\, m/s$$

where v is the speed, V is the volume of the water, t is the time consumption, and A is the cross-section area of the exit of the nozzle. However, the ejected mist jet is actually a mixture of small water droplets with a diameter of about 100μm and air. The velocity is much larger than the calculated value. By asking for data from the vendor the velocity is around 8cm/s. So the Reynolds number of the jet flow is

$$Re = \frac{v \times L}{\nu} = \frac{8 \times 10^{-2} \times 1.5 \times 10^{-2}}{1.5 \times 10^{-5}} = 80$$

where L is the characteristic length in the jet flow which is the diameter of the nozzle exit and ν is the viscosity of air at 1 atmosphere pressure and 20°C [1]. The transition number in external flow is at the order of 10^5. This low Reynolds number in the free space usually couldn't result in laminar-turbulent transition. So the chaotic motion is the result of interface instability. The shear force acting on the boundary of the mist jet flow could result in vortexes which are clearly shown right after the laminar flow. When the disturbance has a wavelength of $\sqrt{3}\lambda$, where λ is the critical Kelvin-Helmholtz wavelength, this disturbance will be amplified and finally break down the stability [2]. However, a prerequisite for the Kelvin-Helmholtz instability is the relative velocity between two fluids. Since the jet flow speed decrease when it is far away from the nozzle exit, the Kelvin-Helmholtz instability can't be developed. The literature reviewed a lot of instability mechanisms [3,4]. The base is the amplifying of the disturbance. Although the jet flow enters the turbulent flow regime, the base flow is still subjected to gravity. So the flow finally falls down when the velocity going up becomes zero.

The working liquid for the mist humidifier is just tap water. The mist consists of 100μm diameter tiny water droplets and air. The droplets which refract light can serve as tracer. However, compared with color dye, the mist can only deliver rather weak contrast. So the angle between the light and the camera becomes very important. I make them perpendicular to each other. The light is just a regular desk lamp. Besides, a black background that won't reflect light is really helpful. I choose a laptop which works quite well as background. Flash light is not employed since it makes the mist blur and mixed with the environment. The air flow in the room could affect the shape of the mist jet flow. So stay still before taking a picture.

The size of the field of view is about $30x40cm^2$. I cropped the image to get rid of the distractive stuff. The mist jet flow is approximately 20-30cm away from the lens. The focal length of the camera is 42mm and the maximum aperture is 4.98. This is a DMC-GF3 digital camera from Panasonic. The width and height of the original image are 3000x4000pixels while they are 2340x3462 in the final image. The f# is f/5.6, the exposure time is 1/400 sec, and the ISO speed is 6400.

The image reveals the flow dynamics of a free mist jet flow into air. I am quite satisfied with the image considered I don't have a camera and just have quite simple apparatus to use. The transition is clear and the vortex could be seen. However, the contrast is still limited. I am still a little confused about the real instability behind the transition. With more careful measurement of the dimensions and velocities this problem can be solved. So overall, I am pleased with my image and I am more interested in further tasks.

References:

[1] Cohen, I. M., Pijush K. K., Fluid Mechanics, Fourth Edition, New York, 2007.

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[3] Kendall, J. M., “Experiments on annular liquid jet instability and on the formation of liquid shells”, Phys. Fluids, **Vol** 29, **pp.**2086, 1986.

[4] Michalke, A., “Survey on Jet Instability Theory”, Prog. Aerospace Sci, **Vol.** 21, **pp**. 159-199, 1984.