AerE545/AerE445: Experimental Fluid Mechanics and Heat Transfer

Lab # 03: Pressure Distribution Measurements of a Transonic Impinging Jet onto a Flat Plate by using PSP technique

Objectives:

1. To understand the fundamental basis of pressure sensitive paint (PSP) technique and identify the common error sources in PSP uncertainty analysis

2. To get "hands-on" experience on how to map the pressure distribution of impinging jet onto a flat plate by using pressure sensitive paint (PSP) technique.

Instructor: Dr. Hui Hu

Department of Aerospace Engineering
Iowa State University
Office: Room 2251, Howe Hall
Tel: 515-294-0094
Email: huhui@iastate.edu

The experimental setup and test model:

The experiments will be performed in the Transonic speed, open-circuit wind tunnel located at the Department of Aerospace of Iowa State University. With a relative large settling chamber located at the upstream of a converging nozzle (i.e., with a diameter of D = 25.4 mm), it has the capability of providing stable and high Mach number jet flow. The total upstream pressure (P_0) can be adjusted through a series of the sophisticated pressure regulator. It is worth noted that the compressed air is supplied by using three big pressurized tanks, which is about 8.0 m^3 in volume and 150 psi in pressure at full capacity.

Figure 1 shows the schematic of the experimental setup for the PSP measurements. A constant UV light (LM2X-DM, ISSI) with a wavelength of 390 nm was used as the excitation source for the PSP measurements. A 14-bit (1600 pixel × 1200 pixel) charge-coupled device (CCD) camera (PCO2000, Cooke Corp.) with a 610 nm long-pass filter was used to records the photoluminescence light emitted by excited PSP molecules. The PSP paint used in the present study is Uni-FIB provided by ISSI, which has a low sensitivity to temperature variation (~0.5%/◦C).

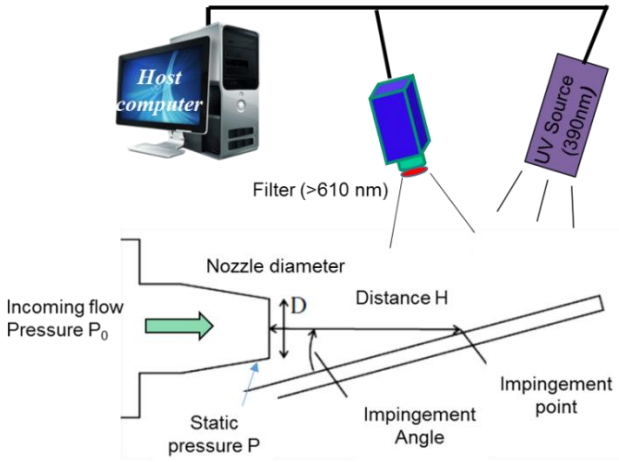

Figure 1. Experimental setup for PSP measurement

During the test, the high-speed air stream will inject out of the circular nozzle (D=25.4 mm) and impinge onto the flat test plate. The plate is inclined at an angle of 45 degrees with respect to the axis of nozzle jet. It is made of aluminum, 304.80 mm in length, and 107.95 in width. A total amount of 8 pressure taps with 0.7 mm in diameter were distributed on the surface of the inclined plate, which is shown in Figure 2. These 8 pressure taps were connected to a DSA (100 psi) pressure transducer to acquire the pressure at each tap location. The acquired pressure information from these 8 pressure taps will then be used to make quantitative comparison with the measured pressure by using PSP technique.

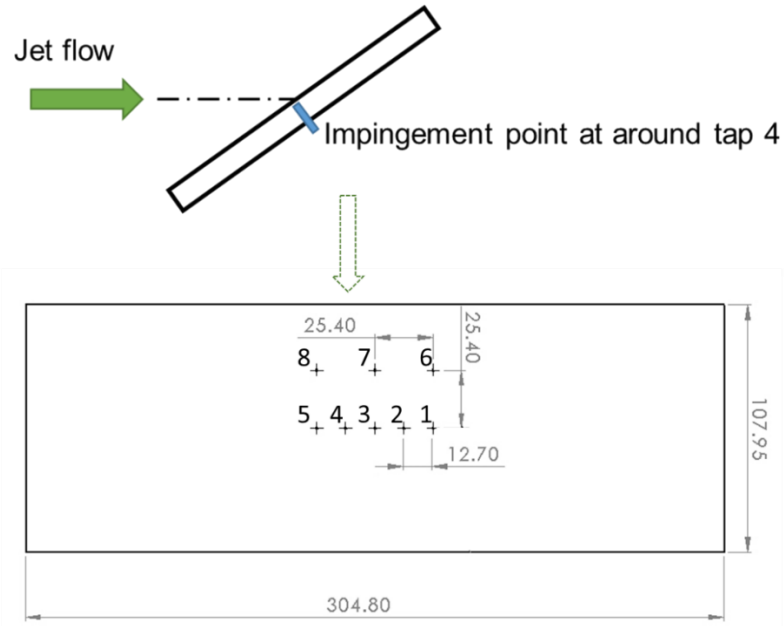

Figure 2. Detailed geometry of the flat test plate, unit (mm).

PSP calibration curve:

For the PSP measurements, the surface of interest is coated with an oxygen-sensitive layer of paint, which consists of luminophores molecules held bound within a gas-permeable polymeric binder. When excited by certain UV light, the luminophores molecules would emit light. However, the excited molecules may return to the ground state via a reduced or non-radiational emission in the presence of oxygen molecules, which is called oxygen quenching, and the intensity of the photoluminescence is inversely proportional to the concentration of local oxygen. Consequently, the concentration of oxygen over the interested surface can be calculated based on the recorded light intensity through the using of a calibration curve. The calibration curve for the present study is:

$$\frac{P_{jet}}{P_{ref}} = -0.053032170 + 0.922217040 * \frac{I_{ref} - I_b}{I_{jet} - I_b} + 0.135149696 * \left(\frac{I_{ref} - I_b}{I_{jet} - I_b} \right)^2 - 0.008236630 * \left(\frac{I_{ref} - I_b}{I_{jet} - I_b} \right)^3 ,$$

where P_{ref} is the reference pressure (~ one atm in the present test); P_{jet} is the measured pressure on the test plate; I_{ref} is the captured light intensity at reference condition; I_{jet} is the recorded light intensity on the test plate, I_b is the background noise intensity with recorded with both the UV light and jet off.

Experimental procedure:

1. Set the Mach number of the jet flow. It can be achieved by adjusting the opening size of ball valve, which is located right upstream of settling chamber.
2. After setting the incoming flow speed, let the tunnel run approximately 40 secs to minimize the temperature difference within the test plate.
3. Turn on UV light and wait ~10 seconds to achieve stable light emission from coated test plate. Run the camera and collect 100 images with the tunnel and UV light on.
4. Shut down the wind tunnel and collect another 50 images.
5. Turn off UV light and take 20 images, which will be used to isolate the background noise during the image processing later.

What you need to know before you came to the lab:

1. You should review and understand the basis of PSP technique.
2. You should review and know how to compute the Mach numbers based on the stagnation to static pressure ratios.

The test conditions for the PSP experiments:

Each group needs to perform the PSP experiments with jet flow at flowing Mach number,

1. Mach = 0.5
2. Mach = 0.7
3. Mach = 0.9

Requirements of the lab report

Each group is required to prepare a formal lab report with following results included:

1. It should include a quantitative comparison of the measured pressures by using PSP technique with those of traditional pressure taps measurement results. Based on the results, you are required to analyze error sources during the PSP measurement.
2. Plotting the contours of spatial pressure distribution at different test conditions.
3. Abstracting the pressure values along the centerline of the impingement jet and making quantitative comparisons between them.