Pressure-Sensitive Paint

Traditional measurement techniques for acquiring surface pressure distributions on models have utilized embedded arrays of pressure taps. This requires extensive construction time while producing data with limited spatial resolution. An alternative approach is to use Pressure-Sensitive Paint (PSP) to measure surface pressure. Pressure measurements using PSP[1] have been demonstrated in several challenging flow fields such as on the suction surface of an advanced compressor blade[2] and an aircraft wing[3] in flight. The advantages of PSP include non-intrusive pressure measurements and high spatial resolution when compared to conventional measurement techniques.

The PSP method is based on the sensitivity of certain luminescent molecules to the presence of oxygen. A typical PSP is comprised of two main parts, (Figure 1) an oxygen-sensitive fluorescent molecule, and an oxygen-permeable binder. When a luminescent molecule absorbs a photon, it is excited to an upper singlet energy state. The molecule then typically recovers to the ground state by the emission of a photon of a longer wavelength. Pressure sensitivity of the luminescent molecules results when an excited luminophore interacts with an oxygen molecule and transfers some of the excited state energy to a vibrational mode of the oxygen molecule. The resulting transition to the ground state is radiationless, this process is known as oxygen quenching. The rate at which the quenching process competes with the radiation process is dependent on the partial pressure of oxygen present, with a higher oxygen pressure quenching the molecule more, thus reducing fluorescence.

Conceptually a PSP system (Figure 1) is composed of a PSP, an illumination source, a detector, and a long-pass filter. The PSP is distributed over the model surface and the surface is then illuminated by the excitation source causing the PSP to luminesce. The luminescent intensity from the PSP is recorded by the detector and converted to pressure using a previously determined calibration. Unfortunately, the luminescent intensity from a pressure-sensitive coating can be a function of several parameters such as; spatial variations in excitation illumination, pressure-sensitive luminophore concentration, paint layer thickness, and camera sensitivity. These spatial variations are minimized by ratioing the luminescent intensity of the paint at the test or ***wind-on*** condition (I_T T_T) with the luminescent intensity of the paint at a known reference or ***wind-off*** condition (I_{ref}, T_{ref}).

A final issue of concern for PSP is the dependence of luminescence on temperature. Temperature sensitivity of a PSP is generated by two mechanisms, thermal quenching of the luminescent probe and temperature dependent oxygen permeability within the polymer matrix that holds the pressure-sensitive probe. Regardless of the mechanism, temperature sensitivity must be considered a major source of error[4], particularly for low-speed measurements. Generally a pressure sensitive paint is calibrated at a series of temperatures (as demonstrated in Figure 2 and Figure 3) and the appropriate calibration is applied in the data reduction process. The topic of minimizing errors in pressure sensitive paint measurements caused by variations in temperature and illumination is discussed in more detail in the document titled **Binary Pressure-Sensitive Paint**.

Calibration of Pressure Sensitive Paint

The functional relationship between luminescent intensity from a paint and the pressure and temperature experianced is determined using the PSP calibration chamber (Figure 4). A small aluminum coupon is painted with the PSP to be calibrated and this coupon is mounted onto a Peltier thermo-electric cooler and mounted inside the calibration chamber. The pressure inside the calibration chamber is controlled using a Ruska pressure controller while the temperature of the sample is controlled using an Omega temperature controller. The sample is illuminated using an ISSI LM-2 Lamp, this lamp uses an array of 76 LEDs to produce excitation at 405 ± 10 nm . The luminescence from the sample is collected through a long-pass filter onto a PCO Series 1600 CCD camera. The calibration is begun by recording the luminescence of the sample at 298 K and 14.696 psia, this serves as the reference condition. The temperature and pressure within the chamber are then varied over a range of temperatures and pressures. The luminescence from the sample is recorded at each condition and the ratio $I(T_{ref},P_{ref})$ over $I(T,P)$ is computed and plotted versus pressure. Calibrations for two PSP formulation are shown in Figure 2 and Figure 3. A quick description of each paint formulation is included.

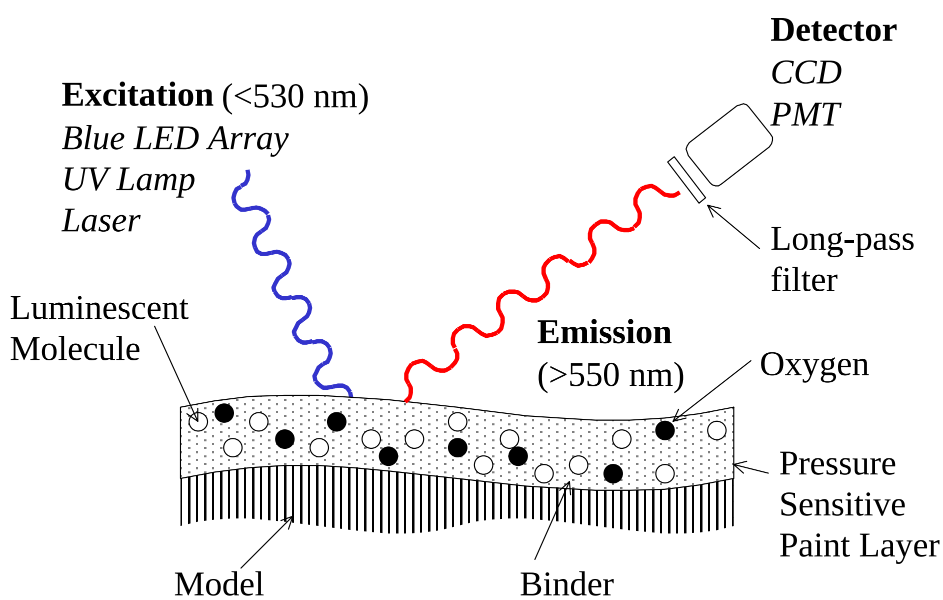

Figure 1 Basic Pressure-Sensitive Paint system.

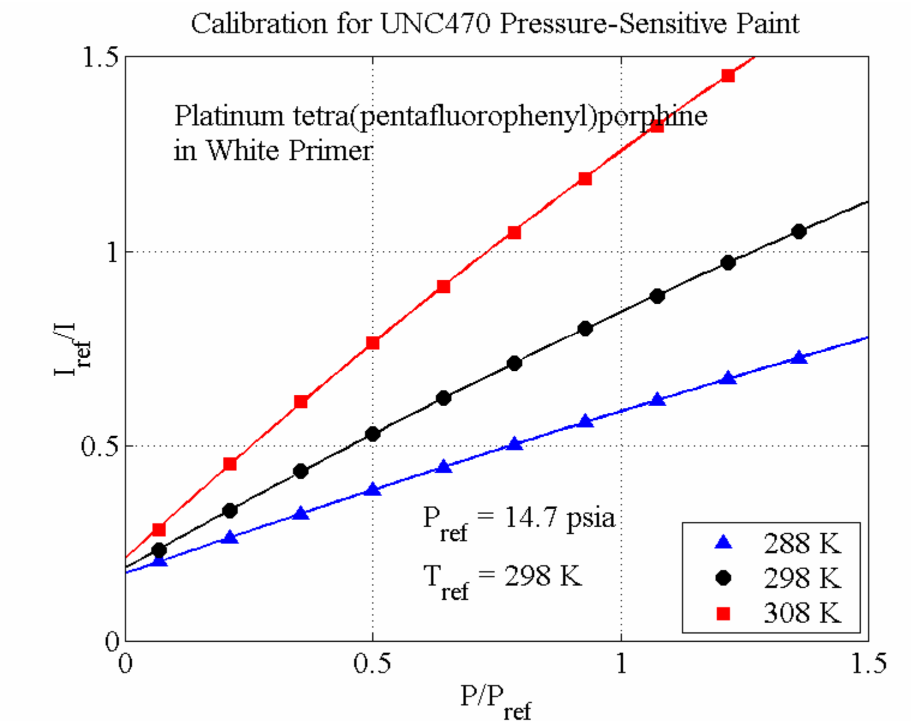

Figure 2 ISSI Unicoat. Simple application and storage (shipped in a spray paint can) and long shelf life. Exhibits good pressure sensitivity (4% per psi) but is also very sensitive to temperature (2% per K) Recommended for entry level PSP studies.

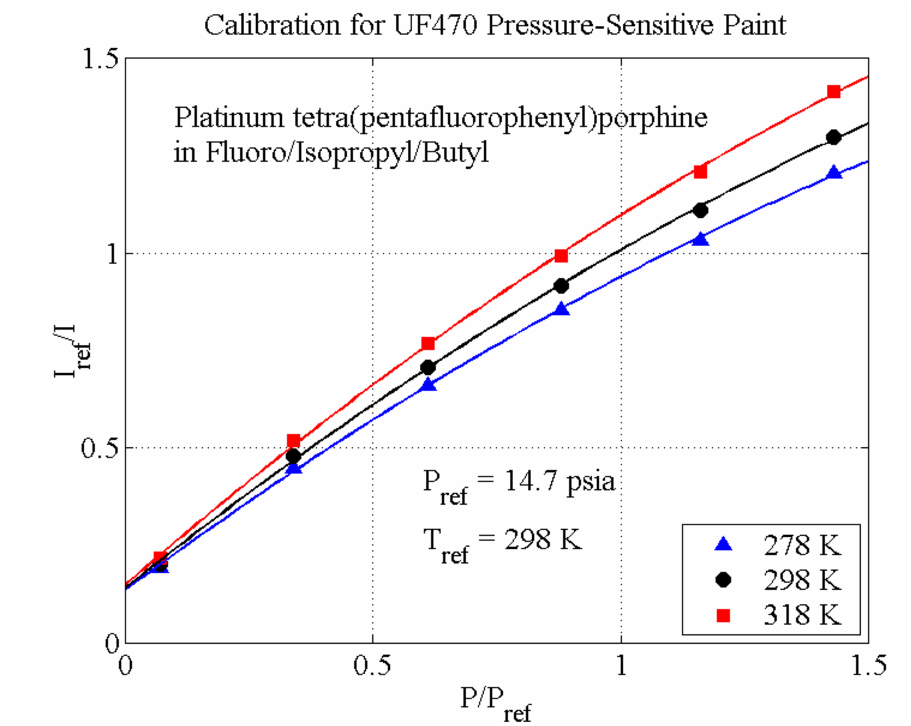

Figure 3 ISSI UniFIB. Exhibits good pressure sensitivity (5.5% per psi) and low temperature sensitivity. (0.5% per K) Temperature sensitivity is not a function of pressure; this an ideal paint as defined by Ponomarev and Gouterman[5]. Advantages are single coat application, high pressure sensitivity, and low temperature sensitivity. Reccomended for high quality quantitiative PSP studies.

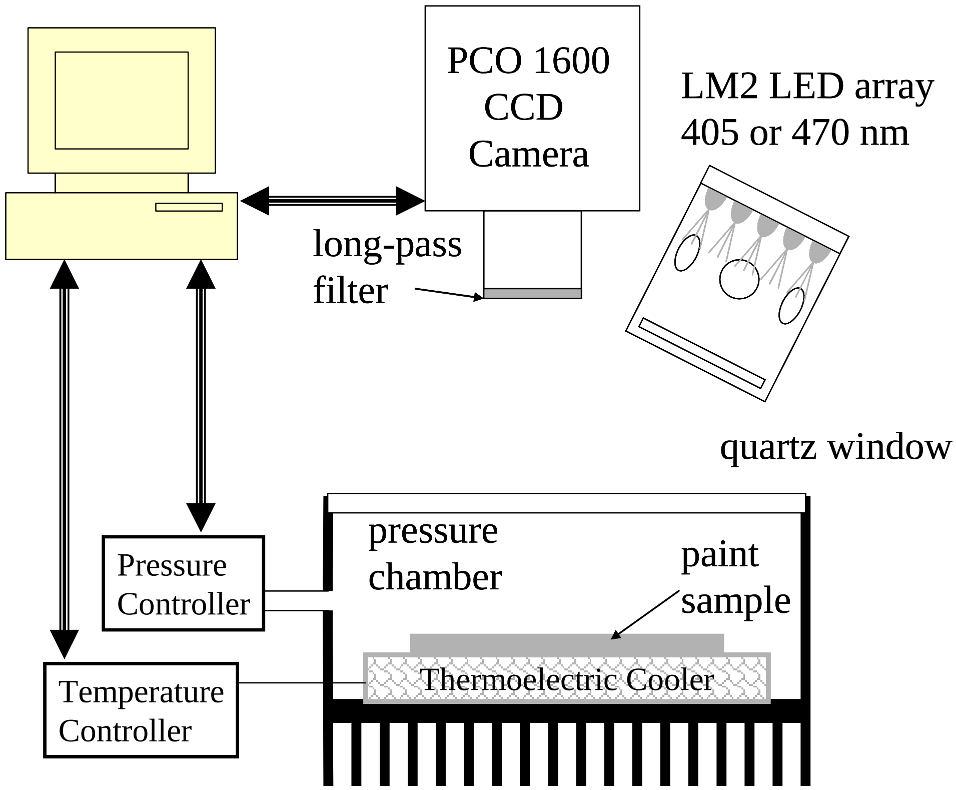

Figure 4 Pressure-Sensitive Paint calibration system.

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