DEVELOPMENT OF A HIGH-FREQUENCY PRESSURE SENSITIVE PAINT (PSP) TECHNIQUE TO INTERROGATE UNSTEADY SEPARATED FLOWS

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ABSTRACT

This paper describes the development of a high-frequency pressure sensitive paint technique, specifically developed to provide high spatial and temporal resolution in regions of unsteady separation in both subsonic and supersonic applications. The frequency response of the paint is characterized with a blue LED (450 nm) and a Hyper Vision HPV-X2 Shimadzu camera (10 MHz, 50,000 pixels). The luminescence lifetime of the PSP paint exposed to a blue pulsed LED is monitored by a Photron Fastcam SA-Z camera (20 kHz, 1024x1024 pixels). Additionally, the PSP sample is calibrated to provide a Stern-Volmer relation to convert the intensity signal to pressure. A balloon burst experiment is used to assess the paint response to a pressure step of about 1ms. A fast responding pressure transducer (Kulite XCQ-062), is used as a reference pressure sensor. A pixel-by-pixel approach is implemented to evaluate the uniformity of the luminescence lifetime, response signal, and calibration at 4x4 pixel bins as well as at different time steps. A correction for luminescence deviation due to non-uniform illumination, reflections, and self-illumination is applied [1]. In-situ calibration and application of the PSP for unsteady flow measurements on different geometries is set-up in a unique blow-down wind tunnel facility [2] with complete optical access at the Purdue Experimental Turbine Aerothermal Lab (PETAL). The high-frequency PSP measurement is used to measure and provide unique qualitative (global surface pressure) and quantitative (pixel-by-pixel) insights of the unsteady separation bubble, reattachment location, and shock-boundary layer interactions. Additionally, the PSP experimental data is used to validate high-fidelity CFD results.

METHODOLOGY

Bathophen Ruthenium Dichloride (Ru(dpp)) was selected as a luminophore because its short lifetime allows for application to time-varying flows. The porous binder selected in the measurements with the Ru(dpp) was a TLC binder (Aluminum Oxide deposited on Polyester). Unsteady Pressure Sensitive Paint data was acquired with a combination of a porous binder (TLC - Aluminum Oxide deposited on Polyester) and Bathophen Ruthenium Dichloride (Ru(dpp)) luminophore. Static calibration of the TLC-PSP was performed in-situ in a linear blow down wind tunnel as well as apriori in a calibration chamber. The dynamic calibration of TLC-PSP was achieved in a calibration chamber using a balloon burst experiment. Both a conventional static pressure tapping, and a fast response pressure transducer were used as a reference pressure signal to the response of the paint. The effect of paint layer thickness on the response of the paint was characterized at different pressures and temperatures. The method of illumination source used in testing was an LED blue light with the required wavelength to excite the TLC-PSP luminophore molecules. Preliminary data using an s-CMOS camera (Andor Zyla 5.5) and a blue LED light is provided in the results and discussion section.

RESULTS AND DISCUSSION

- Anticipated results:
    - Static and Dynamic calibration results
    - ~~Wavy surface test case [3]~~Supersonic shock test case
        - Unsteady surface pressure map
        - Shock formation and location
    - Wall mounted hump test case
        - Unsteady surface pressure map
        - Detection of vortex structures and separation effects
        - Separation bubble structure

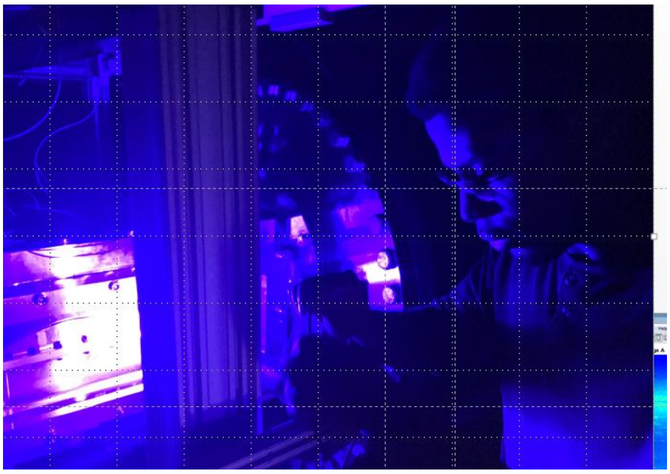

Figure 1: Application of the paint

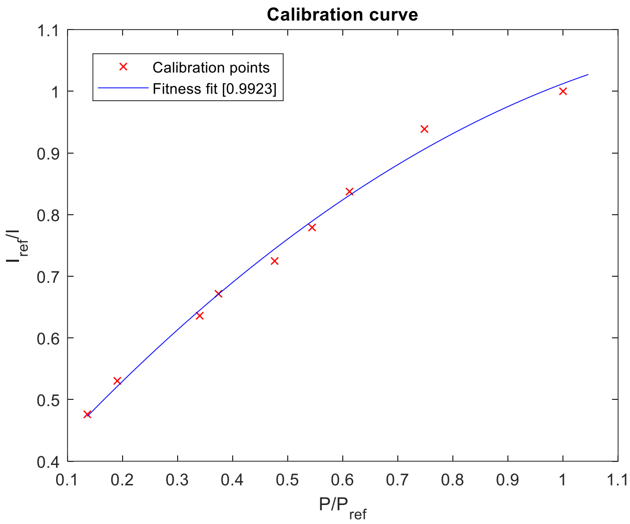

Figure 2: Calibration data

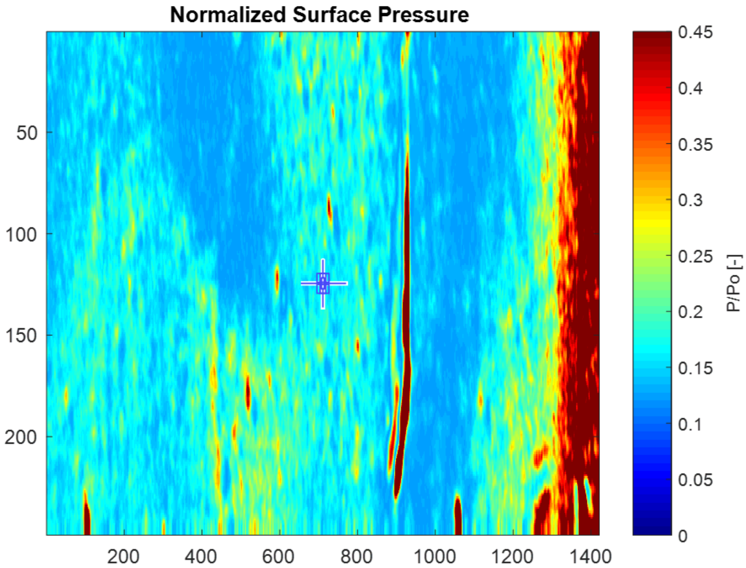

Figure 3. Preliminary results

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