Minimising errors FRom binary pressure sensitive paint

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Abstract

Pressure Sensitive Paint (PSP) has proven to be an effective technique for turbomachinery research applications. In flows with sufficiently large pressure ranges, it enables non-intrusive, full-field measurements of surface static pressure. By the mass transfer analogy, PSP can also be used to measure film cooling effectiveness even for low Mach numbers flows. Compared to traditional thermal methods of measuring effectiveness, the PSP technique has the distinct advantage of being unaffected by conduction errors.

One issue with conventional PSP is that the paint is sensitive to temperature as well as pressure, which can be difficult to account for. One solution is to use a binary paint, where an additional temperature-sensitive component is added. Temperature and pressure are then measured by examining the response at different wavelengths, allowing greater accuracy than conventional PSP.

However, since binary paints are relatively new, little information is available on how the details of the set-up can influence the paint response. This paper discusses a number of factors of influence, including: the time delay between painting and measuring; the influence of light intensity on photo-decay and emission band response; the effect of paint primer; and the effects of wide vs. narrow band excitation light sources. These factors are examined via a series of tests in a well-conditioned, calibration set-up. Ultimately the paper gives best-practice guidance on the set-up of binary-PSP.

introduction

Conventional pressure sensitive paint (PSP) consists of organic luminophores, such as Ruthenium complexes and metal porphrins, mixed with a polymer binder [1]. Once applied to a surface, the response of the paint to excitation light sources is used to visualize the surface pressure field by analyzing the relaxation emission spectra of the paint [2]. Unfortunately, conventional PSP is highly dependent on temperature [3]. Several methods exist to mitigate this issue, for example using surface thermocouples or a coupled IR camera [4], however these require instrumentation, which may not only be prohibitive in cases, but also adds additional inherent inaccuracies and complexity.

Binary pressure sensitive paint offers an alternative means to reduce temperature sensitivity, by including an additional component that is mostly pressure insensitive but highly temperature sensitive. This second component has a distinct relaxation emission band, allowing for the temperature variance to be accurately corrected [5], at the cost of requiring the light intensity at two wavelength ranges to be recorded per measurement.

This project aims to explain the pragmatic impacts of experimental set-up variations on the quality and reliability of binary PSP calibrations, exploring the impact of some common implementations and suggesting good practices. Whilst the described experiments employed binary PSP, the authors expect that the covered topics will be valid for other PSP types.

Test facilities consist of a calibration vessel with controlled pressurization, a thermal Peltier-based PID loop and an image acquisition system with a BigEye CCD camera. A filter switcher is used to change the camera filter between 570 and 660 nm ($\pm $10 nm FWHM). Utilized calibration coupons are 15 by 15 by 3 mm square Aluminum plates. The paint tested is the BinaryFIB from ISSI [6] and the calibration range is 0.15 to 2 bars at the temperatures of 10°, 30° and 50° C.

RESULTS and DISCUSSION

As a form of exemplification, figure 1 exposes the drastic changes in two example BinaryFIB PSP calibrations to what seems, at first, to be a mostly innocuous set-up decision: whether to employ LEDs with narrow (370 to 420 nm) or broad (340 to 470 nm) emission bands as excitation sources. Note that both LED arrays were low-pass filtered to the same wavelength, avoiding any contamination to the paint excitation bands. Likewise, the total emissive power was similar in both cases.

Narrowband light source

Broadband light source

Example measurement

**Potential error**

Intended output

**Figure 1. Difference between BinaryFIB PSP calibrations performed with narrowband and broadband LEDs. An example measurement and its potential error is plotted alongside.**

As can be seen, the measured light intensity ratio of the two paint components (ratio of ratios) is highly temperature dependent in the broadband light calibration case, with a percentage variation between the 10° and 30° C in excess of 50% at high pressure ratios. Contrastingly, the narrowband calibration is effectively converged around the expected calibration line, thus being adequately temperature insensitive at the tested ranges.

In practical terms, for a given measured output, for example a ratio of ratios of 0.92, the narrowband calibration would calculate a pressure ratio of 0.83, whilst the broadband light source calibration would give a ratio in the wide range of 0.8 to 1.49, depending on the temperature of the painted surface, which, depending on the accuracy of the temperature measurement (if available), could result in a high potential error.

This comparison shows how an inadequate choice of illumination source can negate the main reason to use binary PSP: its inherent ability to compensate for surface temperature differences. Thus, making it no more effective than its single-component variant, if used improperly.

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