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PROPOSITION DE SUJET DE THESE

Intitulé : New binary pressure sensitive paints for unsteady pressure field measurements with high sensitivity.

Référence : **MFE-DAAA-2022-11**
(à rappeler dans toute correspondance)

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Mots clés

Pressure Sensitive Paint (PSP), Temperature Sensitive Paint (TSP), metrology, optical techniques, aerodynamics

Profil et compétences recherchées

Master 2/diplôme d'ingénieur en mécaniques des fluides et/ou capteurs. Expérience en dispositif expérimental pour la mécanique des fluides souhaitée

Présentation du projet doctoral, contexte et objectif

ONERA has a wide variety of wind tunnel facilities dedicated to the evaluation of industrial aeronautical programs and to the scientific study of flow phenomena. Nowadays, dense and unsteady measurements are essential to characterize complex dynamics of fluid flow and further improve aerodynamical performances by reducing drag, noise footprint or improving the maneuverability of aircrafts. They are also of great interest for validating simulations or enhancing them with data-assimilation techniques. With the progress made in cameras and illumination devices (laser, LED, ..), optical techniques are undergoing constant development while offering very good spatial resolution and low intrusiveness. Since the pressure in a turbulent flow varies in space and time, fast distributed measurements over a surface are required. Pressure sensitive paint (PSP) is such a pressure imaging technology developed and used since the 1980´s. It makes use of luminescent molecules embedded into a painted surface. The interaction of oxygen molecules present in the air and the luminescent molecules of the paint affects the intensity of the luminescence emission, a phenomenon called oxygen quenching [1]. At fixed oxygen mole fraction in airflows, the number density of oxygen molecules is directly related to the local static pressure of the flow so this technique delivers pressure information. Providing dense pressure fields, PSP has known a great success which led to its widespread use in aerodynamics research with applications on fast rotating surfaces such as turbine or compressor blades or on the entire wing of a commercial aircraft as shown on the Figure. Since two decades, the attention has been focused into the formulation of porous fast-responding paints to transmit pressure information at several thousand images per second [2] [3], which allow to closely study flow dynamics. However, resolving pressure fluctuations over short time scales raises new challenges in terms of signal levels and dynamical corrections.

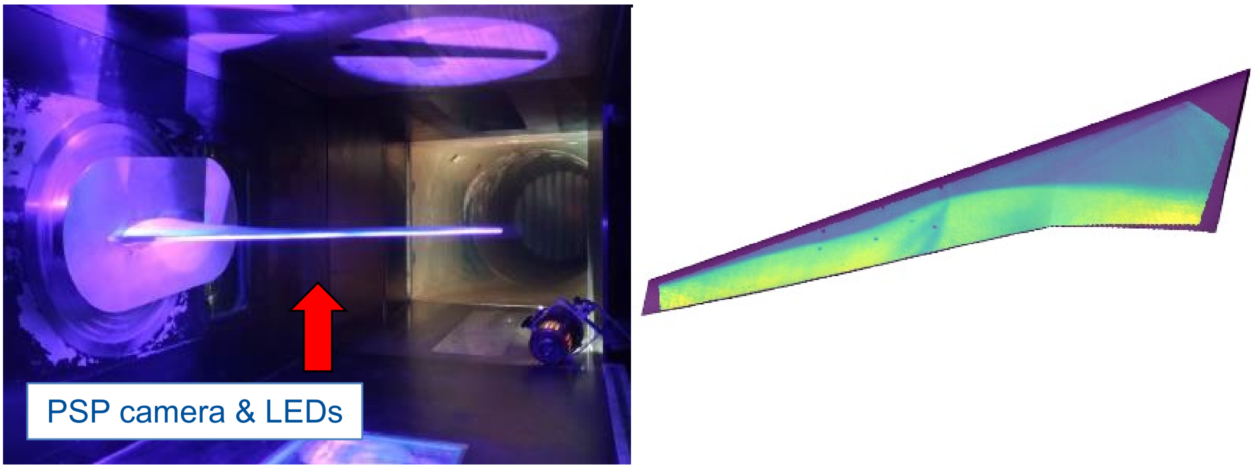

Figure: Pressure field measurements in transonic conditions using unsteady PSP in ONERA S3Ch wind tunnel: photograph of illuminated PSP painted wing in wind tunnel (left), pressure map measured on the suction side by PSP (right)

The standard PSP method, referred to as “intensity method”, consists of exploiting the decrease in luminescence caused by oxygen quenching. The luminescence emission of the paint under illumination by excitation light, often a blue LED, is imaged by a camera. This image is divided by the image under uniform pressure conditions, i.e. under no flow also called wind off to account for non-uniformity in illumination intensity and luminophore concentration. While such method is able to provide useful pressure variations in flows with significant pressure differences such as medium and high speed flows, its ability to correctly measure small pressure variations is limited by three main sources of image intensity variations, which do not result from pressure variations.

- The first source is related to the deformation and displacement of the observed surface under the wind on conditions, which causes not only a distortion of the image but also variations in illumination and detection. As a result, the division by the wind off-image no longer accounts for the illumination non-uniformities.
- The second error source originates from the influence of temperature on the luminescence intensity, called thermal quenching. Small variations in temperature, which are unavoidable in wind tunnels, cause variations in the measured pressure fields.
- Measurement noise creates random intensity variations, which also limit the minimum resolvable pressure variations. This influence of this noise on the measurement depends on the strength of the luminescence signal and the detector sensitivity.

This thesis aims at improving the reliability and detection limit of pressure sensitive paints by developing methods to correct for deformation-induced and temperature-induced variations and for maximizing the signal to noise ratio.

To address those problematics, different approaches will be investigated:

- Some advanced PSP methods use “self-referencing”, which instead of exploiting the decrease in absolute emission intensity, exploits pressure-induced variations in the shape of the emission spectrum or in the persistence time of the luminescence emission. Two images, either separated in spectral range (two colours) or in time are taken within a very short time, and the ratio between those images allows to cancel off variations in illumination, local paint concentration or thickness, and detection efficiency.
- To tackle the effect of temperature variations, an additional luminescent component, which is temperature-sensitive but pressure-insensitive, can be added to the paint. This way the temperature field can be measured and then used to correct the pressure image.
- Finally, the signal to noise ratio is conditioned to the radiative energy reaching the camera. Resolving fast-pressure variations requires short camera exposures, which limit the energy delivered by LED light sources during that time. Short laser pulses may offer orders of magnitude higher energies but photo degradation processes must be considered.

This thesis will address the key developments necessary to bring the unsteady PSP technology at ONERA to a higher level of pressure precision, thereby widening its use. It will involve the benchmarking of self-reference techniques in terms of measurement precision; the formulation and testing of binary paint systems for dual correction; and the optimization of the excitation source and detection system. The PhD student will also develop robust image analysis algorithms for the new pressure readout methods, together with deriving uncertainty budgets.

The development will follow three phases: 1) benchtop testing to characterize the paint luminescent properties, 2) demonstration testing in wind tunnels of the DAAA department, 3) application to study new flow instabilities.

References.

[1] J. I. Peterson et R. V. Fitzgerald, «New technique of surface flow visualization based on oxygen quenching of fluorescence,» *Review of Scientific Instruments,* vol. 51, p. 670–671, 1980.

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[4] M.-C. Merienne, P. Molton, R. Bur et Y. Le Sant, «Pressure-sensitive paint application to an oscillating shock wave in a transonic flow,» *AIAA Journal,* vol. 53, p. 3208–3220, 2015.

Collaborations envisagées

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