Temperature Surface Measurements With A 3d Velocity Fluid Flow Measurements System Using The Same Laser Source And A Single Instrument

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ABSTRACT

The combination of flow velocimetry techniques and Temperature Sensitive Paints, (TSP), requires working with different laser beam intensities. Because velocity flow measurements (i.e. Particle Image Velocimetry, PIV) needs high level laser power compared with temperature surface measurement, where lower levels of laser power is required, is necessary to adjust the system to avoid the damage of the paint due to the high intensities in laser velocimetry measurements. The use of a paint of different grey levels, from white to black, as backgrounds above the TSP film deposition allows to make both, velocity and temperature measurements with the same laser power without damaging the TSP. This work is centered in the characterization, testing and calibration improvements of the temperature surface measurements using Temperature Sensitive Paints as a part of the 3D tunneling velocimetry system.

`Keywords`: temperature measurements, velocity measurements, Temperature Sensitive Paints.

1. INTRODUCTION

It has indeed been clear for some time that in the field of fluid dynamics there is a need for a robust single-access point diagnostic technique able to make 3D measurements. In order to describe the realities of unsteady flow, it is necessary to make three-dimensional, non-intrusive, instantaneous and simultaneous flow measurements of the four fluid variables: temperature, density, pressure, and velocity, sometimes together with body surface pressure/temperature distributions using the Temperature Sensitive Paints. A new technique has been developed which brings together much of the recent knowledge gained in optical metrology, diffraction theory, luminescence barometry, thin films, and data analysis. A single instrument has been developed [1,2], capable of making real-time 3D fluid velocity and near-surface temperature/pressure [3,4] optical measurements non-intrusively, simultaneously and instantaneously, using a single optical access point. This technique has been called Tunneling Velocimetry (TV).

A prototype velocimeter is shown schematically in Figure 1. A flow streams along a profile. The flow is seeded with particles, such as polystyrene spheres. A collimated laser beam – typically vertically polarised - introduced into the optical axis of a video detector by a polarisation-sensitive beam-splitter illuminates the flow field. A quarter-wave retarding plate is placed between the polarising beam-splitter arrangement and the volume of interest to circularise the polarisation of the illuminating beam on its way to the measurement volume, and also serves to make the particle-scattered light horizontally-polarised on the return path. Thus, the polarising beam-splitter arrangement transmits the scattered horizontally-polarised light onto the imaging lens and CCD camera. Hence the name of the technique: it is as if the camera was viewing the particles, from whose motion velocity is derived, inside a lit tunnel. The laser is pulsed and the CCD camera records multiple images of the light scattered back by the seeding particles.

Light power density falling on the particles is lower than for PIV, since power is being distributed over a volume rather than a light sheet. However, the resulting light intensity scattered by the particles in this arrangement is actually higher than for a comparable light-sheet because the efficiency of back/forward scattering is much higher for micron-sized particles. A further advantage of this arrangement is that the drop in power density allows the use of conventional optical components, many of which have a power threshold of 0.1 Joules/cm^2. A ½-wave retarding plate is placed in the beam path before the beam-splitter arrangement, to be able to adjust the power to be transmitted to the measurement volume, and to provide power level measurement through a photodiode. The flow field images, captured after passing

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through a filter which excludes all frequencies other than that desired, are then processed through a computer system to extract the motion information. The velocity field can be derived in 3D from the time separation between pulses of light combined with particle positions.

The colour-sensitive beam-splitter in front of the ¼-wave retarder plate is used to separate the fluorescent signal coming from the object, redirecting it to the back-surface parameter-sensing camera. TSP offers a unique and inexpensive means of determining temperature distributions, impossible to obtain using conventional measurement techniques at a comparable measurement density [5]. These paints can be excited either by the TV laser itself, or an external source such as an ultraviolet lamp.

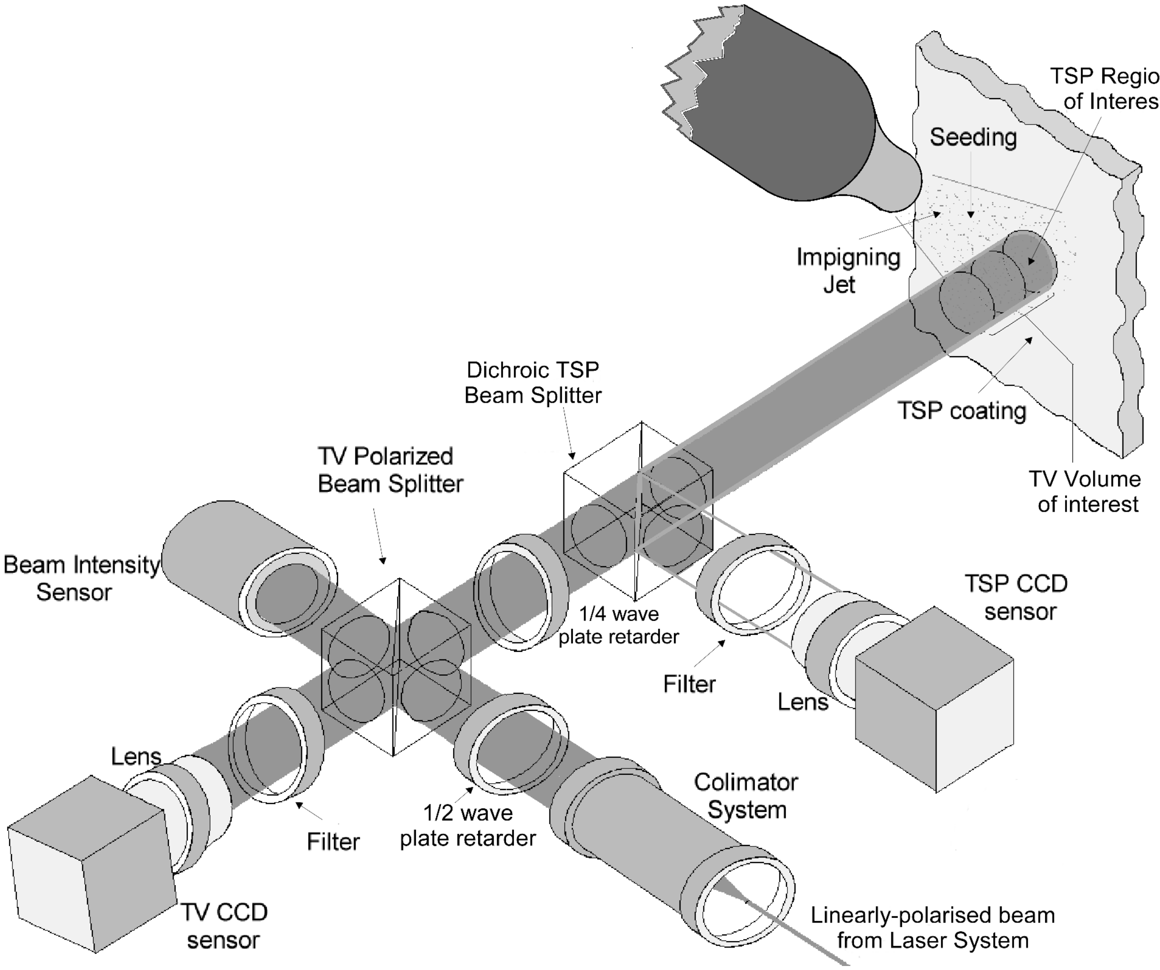

Figure 1. Tunneling Velocimetry Technique set up.

2. TEMPERATURE SENSITIVE PAINTS

The use of luminescent molecular probes for measuring surface temperature offers the advantage of enhanced spatial resolution at a lower cost compared with the traditional techniques. These new sensors are called Temperature Sensitive Paints (TSP). Normally, arrays of thermocouples have been used to obtain surface temperature distributions which make labor intensive and expensive. The TSP technique provides a way to obtain simple and inexpensive, full-field measurements of temperature with better resolution. That paints can be applied spraying over any model surface. TSP may be used for visualization of heat transfer rate, boundary layer transition, flow separation and flow reattachment on the models in transonic, supersonic and shock wind tunnels. The TSP have some disadvantages: the response of the luminescent molecules in the TSP coating degrades with time of exposure to the excitation illumination and the emission intensity is affected by the local pressure, but having that reference a calibration test would be enough.

Temperature Sensitive Paint, or TSP, is essentially a luminescent dye dispersed in an oxygen permeable binder (figure 2). The dye is excited by absorbing light, usually from the blue or UV portion of the spectrum, and it then returns to its ground state by emitting light, usually in the red or orange portion of the spectrum. There is an alternate process in which the dye can return to its ground state without emitting light by interacting with an oxygen molecule. This process is known as oxygen quenching. Thus, as the temperature of the oxygen above the TSP increases, the intensity of the emitted radiation will decrease.

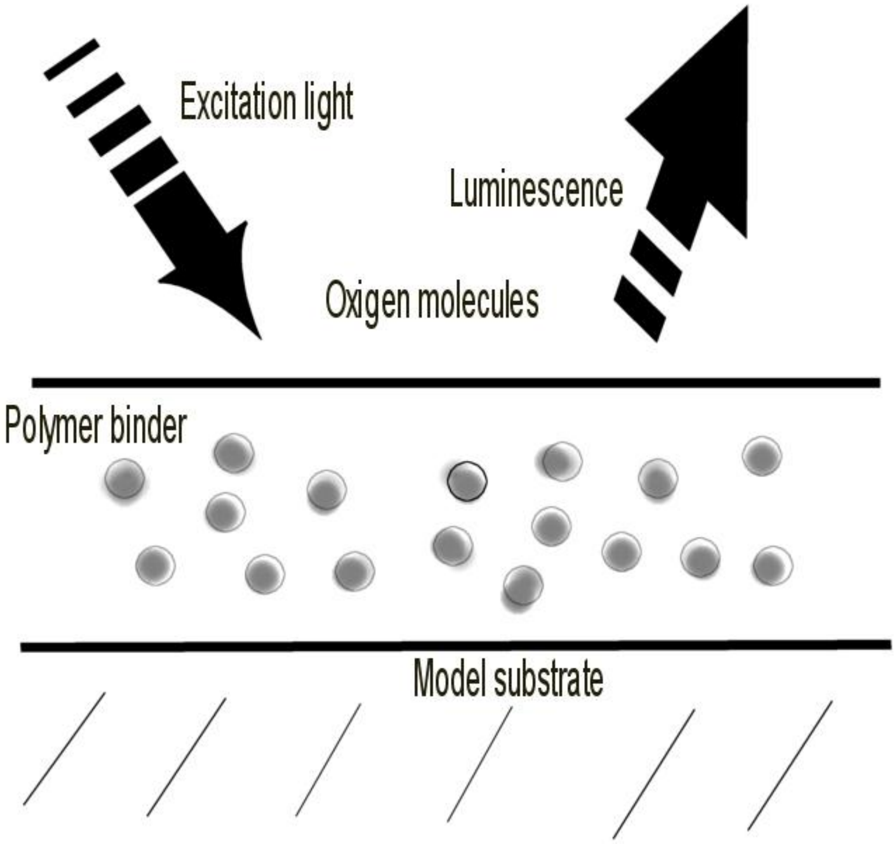

Figure 2. TSP principle

A simple representation of a typical TSP experimental setup is shown on figure 3. The model is covered with TSP, which is excited by absorbing light from the light source that has been passed through a red filter. The light emitted by the TSP is then passed through an orange filter and measured by a camera. The camera images are typically recorded by a computer which processes the data to measure the temperatures on the model.
When the temperature measurement need to be taken together with fluid velocity measurements, the standard TSP set up configurations should have some rearrangements. The TSP beamsplitter have a critical importance in figure 1, because the TSP measurements can be redirected to the camera. One more consideration is the intensity level of the laser source used. Because the paint has a limit response and also can be damaged for high intensities, is necessary to characterize the paint for different levels of laser power. After some test, it was concluded that that the laser power needs to be less than needed for velocimetry applications. A background grey level paint layer was placed over the model and over that paint was sprayed the TSP layer. Different background grey levels were tested and it was found that the response of the TSP was different according to the grey level. Figure 4 shows the comparative responses of the paint with the background and

also shows TSP response depending of the width of the TSP layer. 16 different grey levels were tested, from white to black and seven different TSP width layers. The layer 1 has less TSP and Layer 7 was saturated with TSP. According to figure 4, for high laser power the background paint can be chosen to be close to black color in order to avoid the damage.

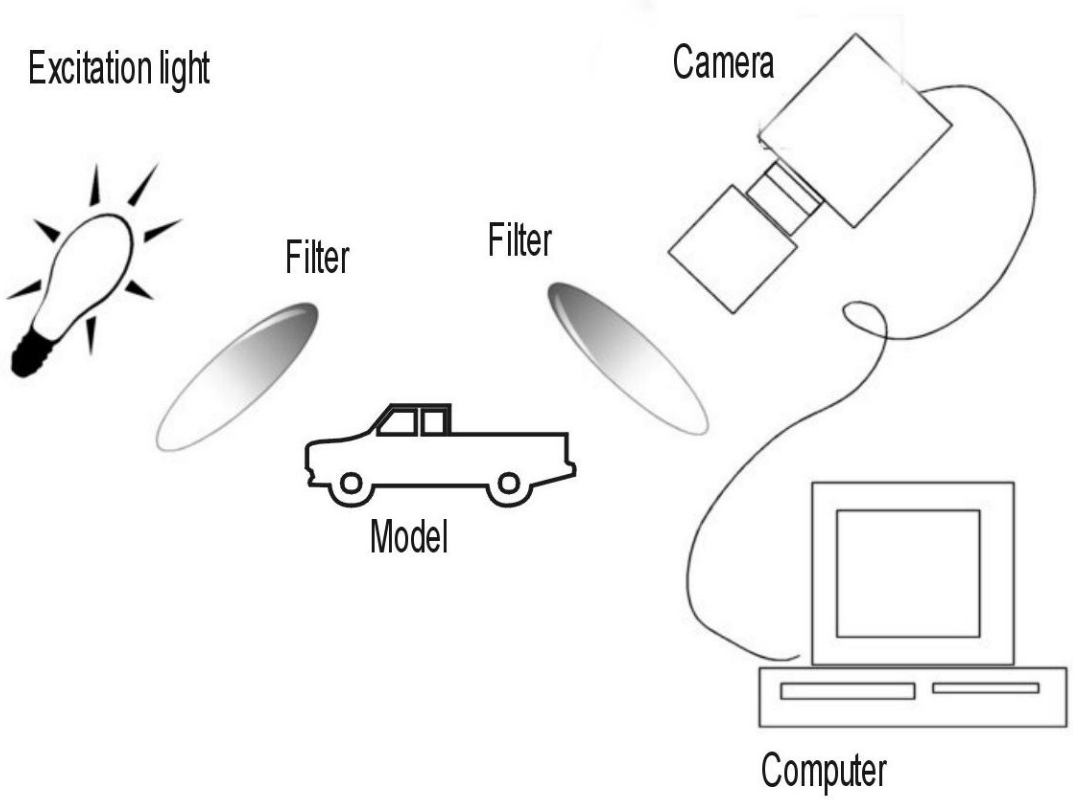

Figure 3. Standard set up for TSP measurements.

3. CONCLUSIONS

There is a lot of work that remains to be done, but the results show that the development of the Pressure Sensitive Paints for temperature measurements in addition to velocity using a single instrument is robust and cost effective for applications in fluid mechanics. The response of the TSP paint to the background grey levels needs to be calibrated for setting up the temperature range. Other TSP paints can be used for other temperatures ranges.

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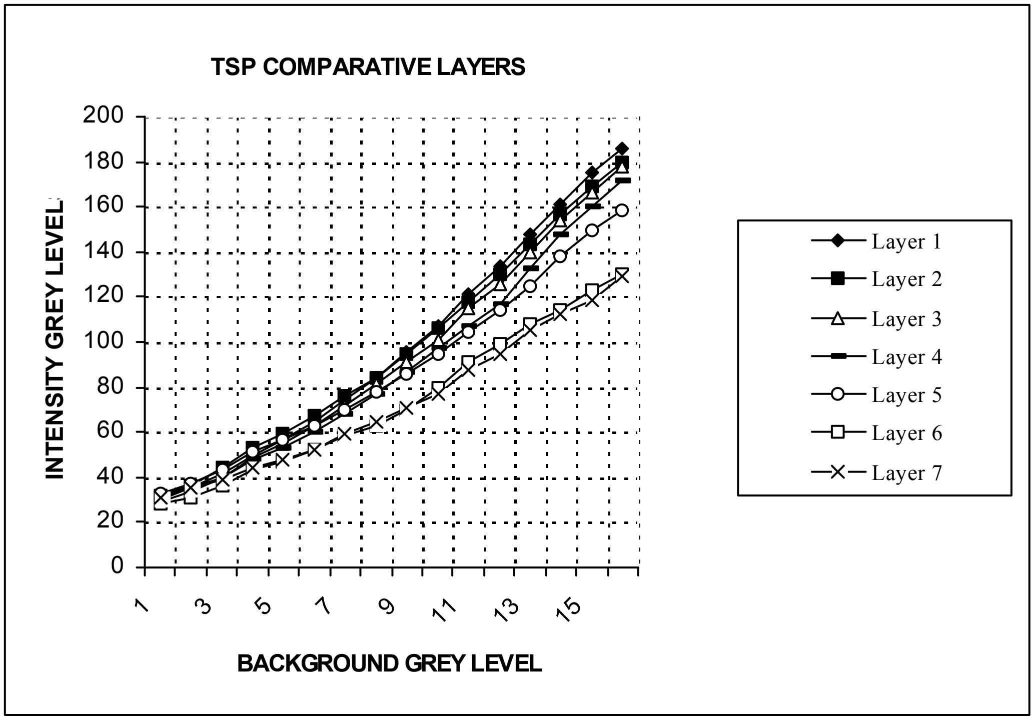

Figure 4. TSP response to intensity for different background grey levels and different width of the sprayed TSP.

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