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APPLICATION OF Z-TYPE SCHLIEREN TECHNIQUE FOR FLOW VISUALIZATION AROUND HEATED CYLINDER

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ABSTRACT : *The flow around heated cylinders has already been investigated by many researchers. Object of the present examination is an electrically heated circular cylinder placed in a parallel flow in a wind tunnel. The experimental tests were carried out at low Reynolds numbers (Re<200), thus the flow field was approximately two dimensional (same flow in every normal plan of the heated circular cylinder). The relationship between the vortices and the heat transfer was determined by relevant numerical simulations. Experimental results showed that vortices are shed with a frequency almost identical to that of the heat transfer from the cylinder. this transfer takes place in 'heat packages'. Validation of numerical simulations (in case of velocity field) was done with the help of PIV (Particle Image Velocimetry). The main objective of the present experimental investigation is validating the temperature field results of numerical simulations. Two dimensional flow and the principle of Schlieren measurement technique were used to visualize the temperature field. The Z-type Schlieren technique was applied to measure the temperature distribution. The experiments were carried out at free and forced convection in a 0.5x0.5 m cross-section wind tunnel. The measurement technique and results were shown at different levels of forced convection.*

1 Introduction

Prismatic bodies being placed in a flow often have different temperature compared to that of the surroundings such as electrical transmission lines, cartridge heaters, pipes of heat exchangers, factory chimneys etc. The structure of the flow around prismatic bodies has been already examined for a long time. Also the z-type Schlieren measurement technique has also been investigated by many researchers [1-3]. One example for the use of the Schlieren technique is the visualization of shockwaves in a supersonic tunnel [4]. The system is basically adapted for 2D measurements, as there are many problems with 3D measurements [1]. Also the method has been used for general visualization of heat transport processes [1]. Our experimental tests were conducted at low Reynolds numbers (Re<200), thus the flow field was approximately two dimensional (same flow in every normal plan of the heated circular cylinder). In this work the adaptability of a Schlieren system is investigated to the described setup, which should be ultimately applicable in a wind tunnel in order to investigate free and forced convection flows. An electrically heated circular cylinder was placed perpendicular to the flow in a wind tunnel. The measurements were executed at free and forced convection in a 0.5x0.5 meter cross-section wind tunnel. The diameter of the heated circular cylinder was 10 mm. The temperature of the cylinder was 300 °C and the range of velocity was from 0-0.3 m/s.

2 Principle of Schlieren Measurement Technique

The basic optical Schlieren system uses light from a single collimated source shining on or from behind a target object. Variations in the refractive index, being caused by density gradients in the fluid, distort the collimated light beam. The light source is placed in the focal point of the first mirror (see Fig. 1). The knife-edge is placed in the focal point of the second mirror, so that it blocks about half of the light. In flows of uniform density this will make the photograph half as bright. However in flows with density variations the beam is deviated and focused in an area covered by the knife-edge and thus is blocked. The result is a set of lighter and darker patches corresponding to positive and negative fluid density gradients in the direction normal to the knife-edge. When a knife edge is used, the system is generally referred to as a Schlieren system, which measures the first derivate of density in the direction of the knife-edge. Temperature is determined from the density (refractive index) [1]. The principle of the Schlieren technique is shown in Fig. 1.

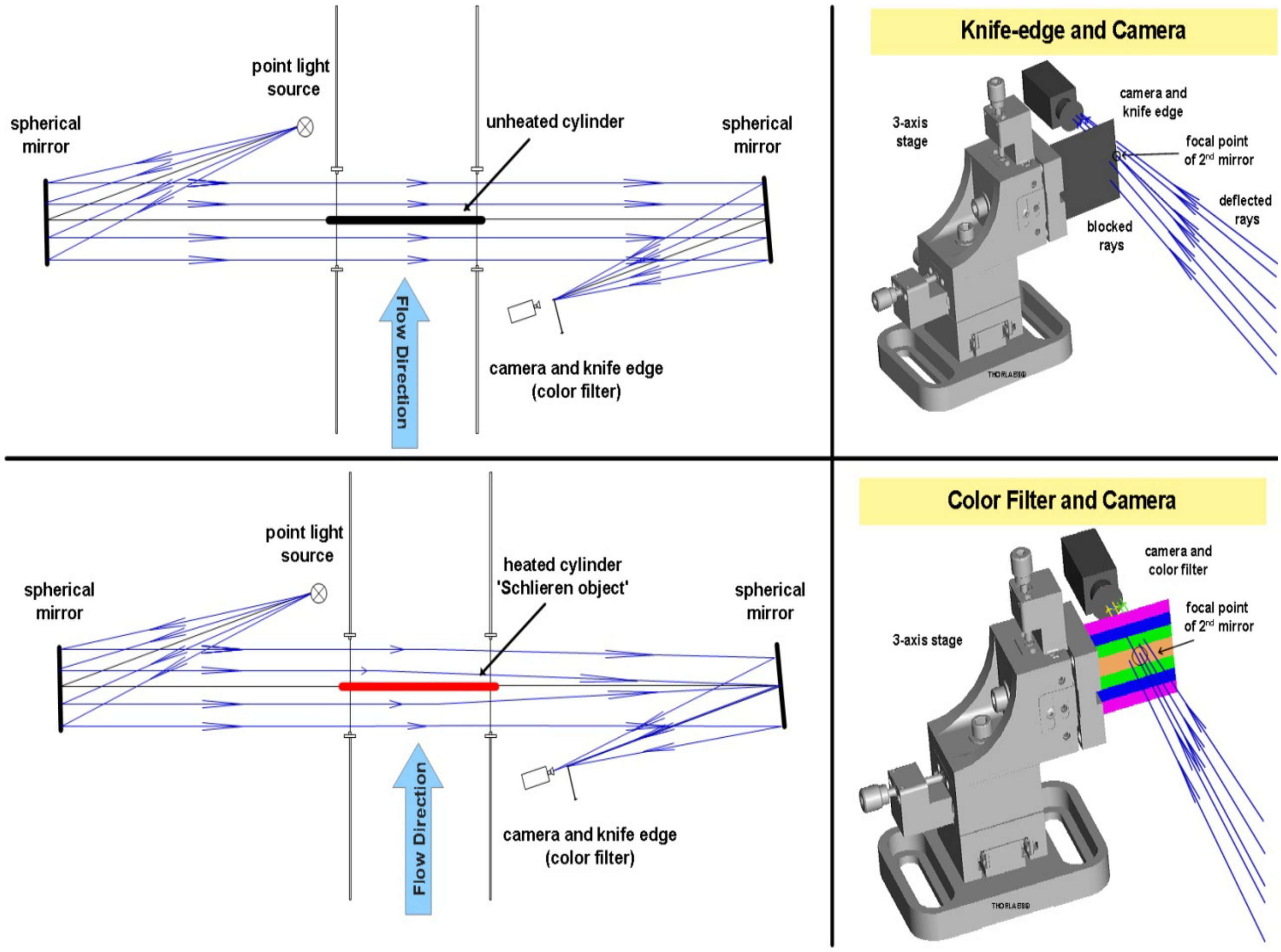

Fig. 1 Principle of Schlieren measurement technique (knife-edge and color filter)

The sensitivity of a measuring instrument is one of its basic characteristics, relating the output of the instrument and the input received. In the case of the here considered Schlieren optics, the output is a 2-D image in x and y – coordinates. More specifically, it is an array of picture elements characterized by their amplitude or grayscale contrast variations.

2.1 Temperature Calculation

A light ray passing through an inhomogeneous medium suffers a deviation in its trajectory in a certain angle [5]. This angle depends on the refractive index and the thickness of the medium under test. The equation of the ray path through an inhomogeneous medium is expressed as

$$\frac{d}{ds}\left(n_m \frac{d\vec{r}}{ds}\right) = \nabla n_m, \tag{1}$$

where $n_m = n_m(x, y, z)$ is the refraction index of the medium, ds is arc length and $\vec{r}$ is a position vector.
By considering the approximation of small angles of deviation, ε, the measured deviation at the observation plane (the exit focal plane) is $\Delta x = f_2 \tan\varepsilon \approx f_2\varepsilon$, where f_2 is the focal length of the focusing mirror in a two-mirror Schlieren system (in this type of system the first mirror serves to collimate the entering light). The equation (1) can be written as [5]

$$\varepsilon_\xi = \int_{\varsigma_2}^{\varsigma_1} \frac{\partial n_m}{\partial \xi} \cdot dz, \tag{2}$$

where ξ can be x or y, depending on the direction in which the knife blocks out the light.
Combining the Gladstone-Dale equation, $(n_m - 1) = K\rho$, where K is the Gladstone-Dale constant, and equation (2), leads to the following equation:

$$\rho_x = \frac{\partial \rho}{\partial x} = \frac{\Delta x}{f_2 h K}, \tag{3}$$

where ρ is the gas density and h is the thickness of the inhomogeneous medium under test, in the ray propagation direction. The Gladstone-Dale constant K depends on the medium composition and the wavelength.
Once ρ has been determined from equation (3) it can be substituted into equation (4) to obtain the corresponding temperature by [6]

$$T = \frac{\rho_0}{\rho_x} T_0 = \frac{n_0 - 1}{n_m - 1} T_0. \tag{4}$$

In equation (4), n_0 and ρ_0 are the refraction index and density at reference temperature T_0, and T is the value of the temperature of interest.

2.2 Calibration Curve

In a Schlieren system, the blockage of light by a knife-edge placed at the exit focal plane is due to the deviation of light by an inhomogeneous medium. This blockage can be similarly obtained in a homogeneous medium by a knife-edge which is allowed to be translated laterally by a quantity Δx. By considering this, we can establish a relationship between the light levels at the observation plane (the exit focal plane) to the corresponding transverse knife-edge position. This transverse position may cover the conditions from no cutoff of light (maximum intensity) to full cutoff of light (minimum intensity). Relationship between Δx and light intensity was determined by 3-axis stage (see in Fig. 2).

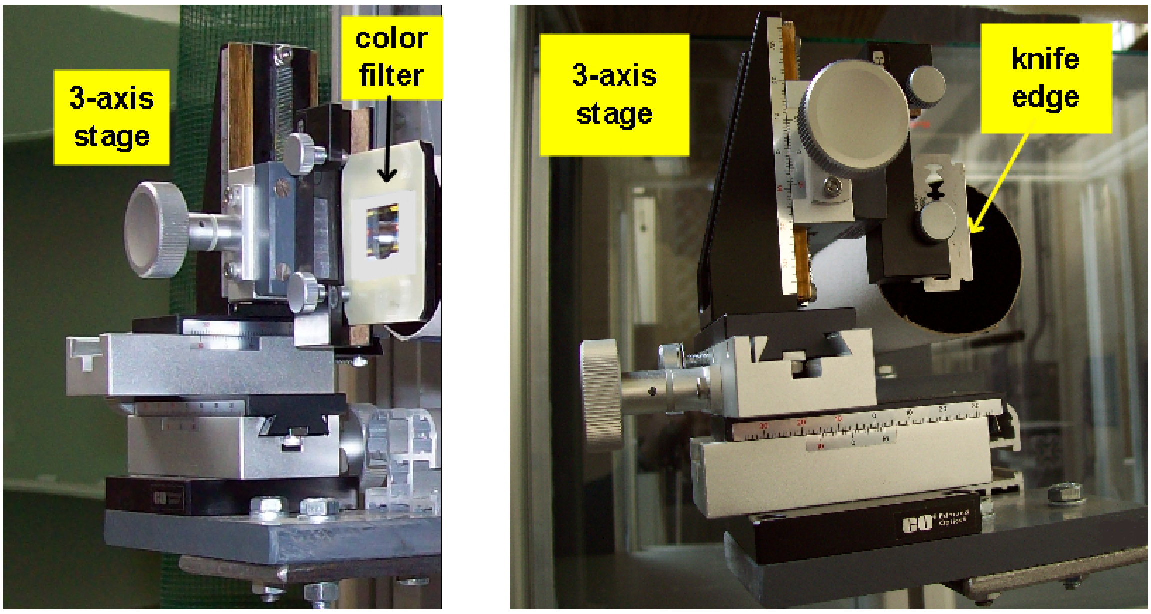

Fig. 2 Knife-edge and color filter with 3-axis stage

3 Application of the Z-type Schlieren System in the Wind Tunnel

General recommendation for the applications of a z-type Schlieren system [1]:

- According to an old rule, the mirror thickness ought to be 12-17% of mirror diameter for stability.
- To achieve good quality, the ratio of the mirror surface smoothness should be between $\lambda/8-\lambda/10$, where λ is the wavelength of the light and the ratio gives the deflection of the wave front, caused by the surface roughness of the mirror.
- A minimum distance between the field mirrors of about $2f$, is required to provide enough space for the test area, where f is the mirror focal length.
- The recommended process to minimize both astigmatism and coma is to limit to offset angles θ to their minimum practical values. Furthermore, mirrors with f/n number where n equal to 6 or greater are strongly recommended. The mirror power in z-type Schlieren system is usually between $f/6$ and $f/12$, where f/n expresses the ratio of the length and mirror or lens diameter.

Property	Value
Mirror thickness	25% of the diameter
Optical quality of the mirror	$\lambda/8$
Offset angle	$\theta = 3.81^o$
Power of lens	$f/10$
Distance between the mirrors	$L = 4500\ mm$

Table 1 Properties of the applied components in the z-type Schlieren system

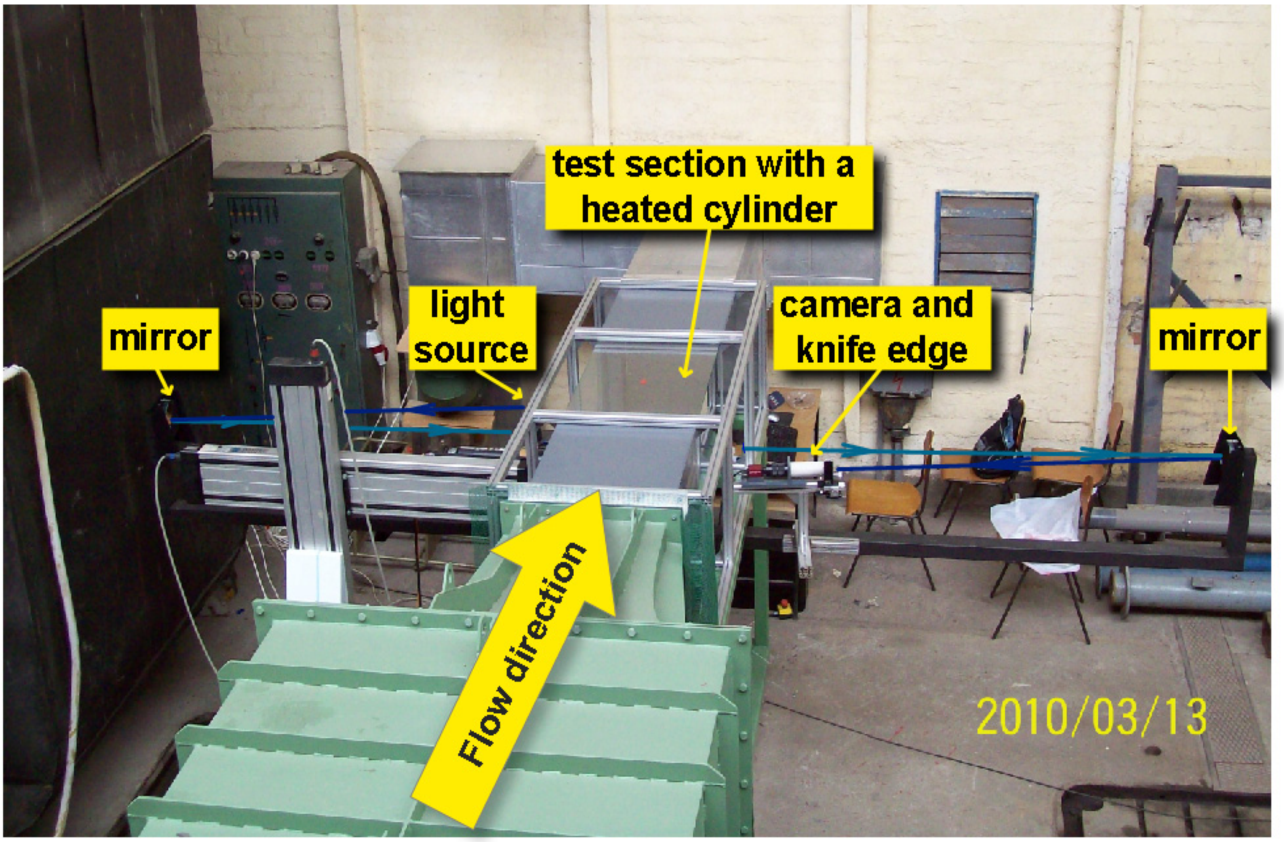

Fig. 3 Measurement setup of the z-type Schlieren system in the wind tunnel

4 Visualization of the Temperature Field

The temperature field was determined by z-type Schlieren system. Different types of color filters were made for the first test [7]. These color filters were made by hand (see in Fig. 4).

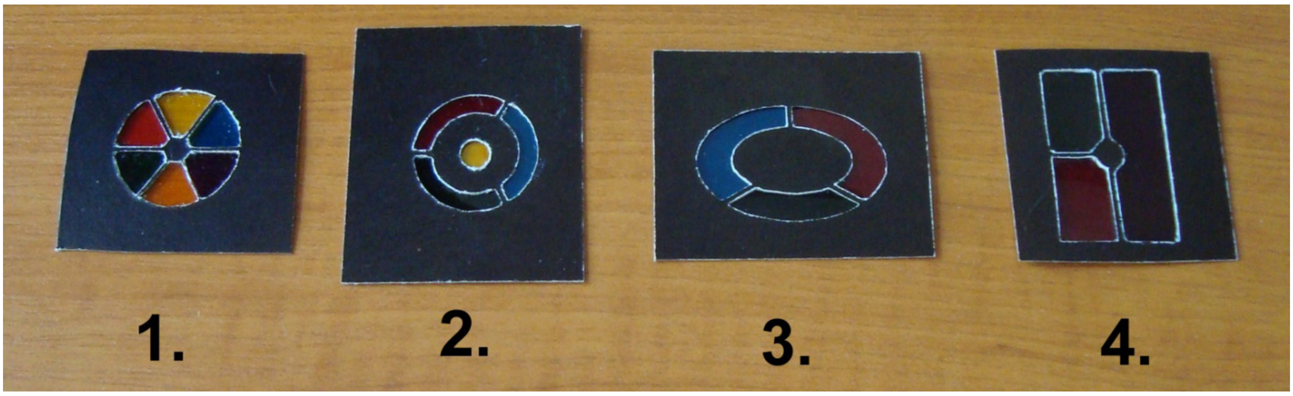

Fig. 4 Color filters

The second and third color filter did not good for the measurement, because the closed part of the color filter was too big so decrease the system sensitivity. First and fourth types of color filters were good for the measurements. In the first test: the diameter of the point light source was 5 mm, therefore the closed part of the color filters also 5 mm (only the deflected ray go through the color filter).

Best result was made by the fourth type of color filter (see in Fig. 4) and the real Schlieren pictures shown in the Fig. 5.

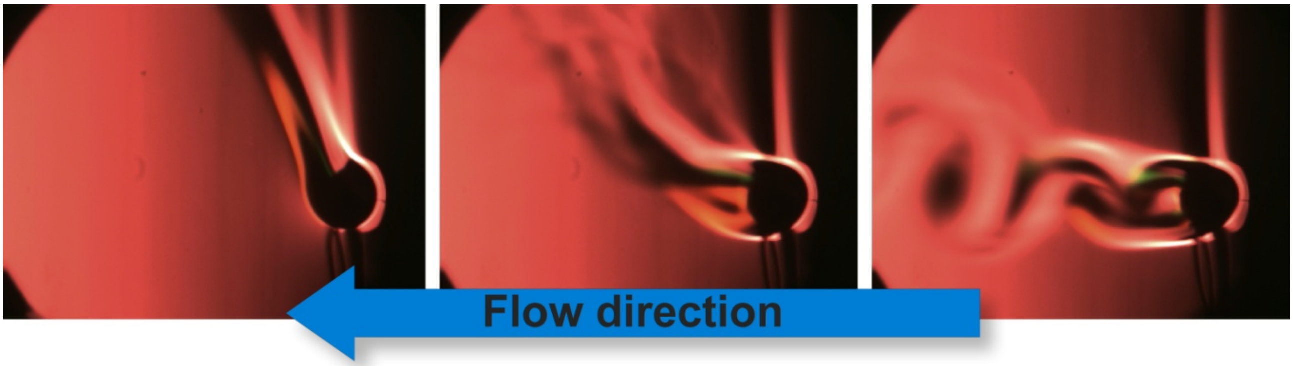

Fig. 5 First Schlieren pictures (300 ^{o}C and velocity range 0-0.3 m/s)

Simple knife-edge and striped color filter (see in Fig. 1 and Fig. 2) were applied to the next part of measurement. Calibration curve (determine relationship between light intensity and Δx) and reference picture were made in the first part of the measurement. Next part of process was to record a lot of picture from free convection to forced convection (until 0.3 m/s). Temperature field was determined from the calibration curve and recorded pictures. The results of temperature field only visualized the average value of the 3D flow (because the principle of Schlieren measurement technique). Calculated temperature field shown in Fig. 6.

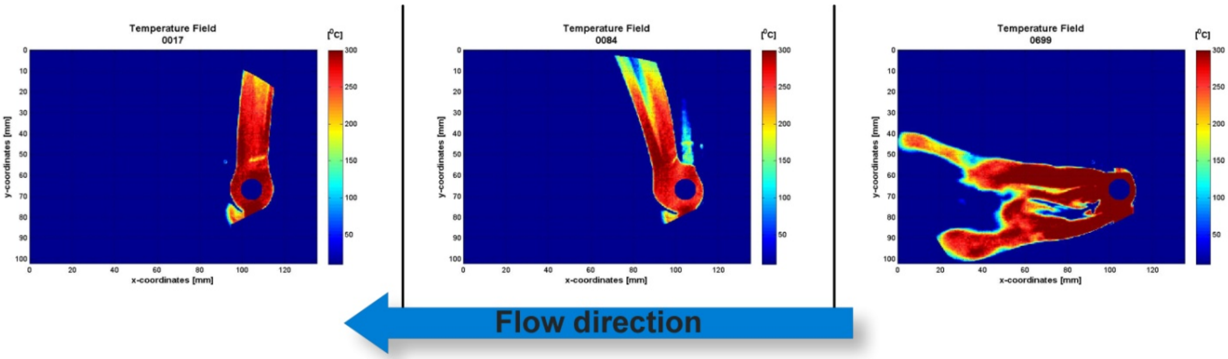

Fig. 6 Temperature field (300 ^{o}C and velocity range 0-0.3 m/s)

The new color Schlieren pictures were made by striped color filter (see in Fig. 1) and the calibration curve was determined the relationship between the Hue (one of the main properties of a color) and Δx). Temperature field was determined from the calibration curve and temperature field calculation process (see in Chapter 2.1).

4 Conclusion

The measurements results presented in this work confirm that the z-type Schlieren system is in principle suitable to visualize and quantitative analyze the temperature field in a wind tunnel. However, considerable improvement (such us precision color filter) is still required in the existing system to make more precise and really accurate measurements. In order to analyze the images in a further step, the recording quality must be increased to get more meaningful images. These temperature field results will be good to validate our results of numerical simulations (numerical simulations are made by own code and commercial software). First Schlieren results and numerical simulations are very similar; therefore our Schlieren system is suitable for validation of numerical simulation, but it is still required further development.

Acknowledgements

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