BOS AND PSV IN A SUPERSONIC JET

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We use Background Oriented Schlieren (BOS) and Particle Shadow Velocimetry (PSV) to study the shock structure and the flow field in a supersonic axisymmetric jet. We can visualize the regions of maximum density and those of maximum change in the density.

INTRODUCTION

We have been studying a supersonic axisymmetric air jet for several years with various techniques that give information about different aspects of the jet.

With Rayleigh scattering we visualized the shock structure and we obtained information about the local density fluctuations and the sound emission pattern inside and outside the flow. With Particle Shadow Velocimetry (PSV) we obtained the mean velocity field. With high-speed schlieren and shadowgraph we also visualized the shock structure and part of the turbulence, and through Background Oriented Schlieren (BOS) were able to determine the index of refraction field that is proportional to the density field. In this paper we emphasize the latest results obtained through PSV and BOS.

The jet is produced by the discharge of compressed air at about 5.5 atm into to the atmosphere (at Mexico City's altitude it is about 0.8 atm) through a 4mm axisymmetric straight duct with a length of 8cm; that is, the nozzle is not convergent-divergent. However, we have determined the mean transverse size of the flow and there is a contraction a few millimeters outside the nozzle.

PSV

PSV is a novel technique (proposed by Estevadiordal 2005). Similar to Particle Image Velocimetry (PIV) it consists in photographing moving seeds in a flow. Two photographs of a same group of particles at two different times are taken. The image is divided into interrogation areas, and through cross-correlation the mean displacement of an interrogation area is obtained. Finally, an instant speed of that area is obtained with the time between pictures.

The main difference between the techniques are:

PIV uses a pulsed light sheet, which is produced with high-power laser. Generally, the light sheet is a few millimeters thick and determines the volume of study. The technique depends on the Mie scattering properties of the seeded particles.

PSV uses a pulsed LED light, in this work a high power LED CBT-120. The technique depends on the shadow cast by the seeds, and the measurement volume is determined by the depth of correlation.

$$2z = 2\left[\frac{(1-\sqrt{\varepsilon})}{\sqrt{\varepsilon}}\left(\frac{f^{\#2}d_p^2 + 5.95(m+1)^2\lambda^2 f^{\#4}}{m^2}\right)\right]^{\frac{1}{2}}$$

m - Magnification
d_p - Particle diameter
$f^{\#}$ - f number
ε - Threshold parameter
λ - Wavelength

This notion is very important in micro PIV. It depends on the optics of the camera, the wavelength of the light and the size of the seeds. The light source is placed in front of the area to be studied (Figure 1), aligned with the optical axis of the camera.

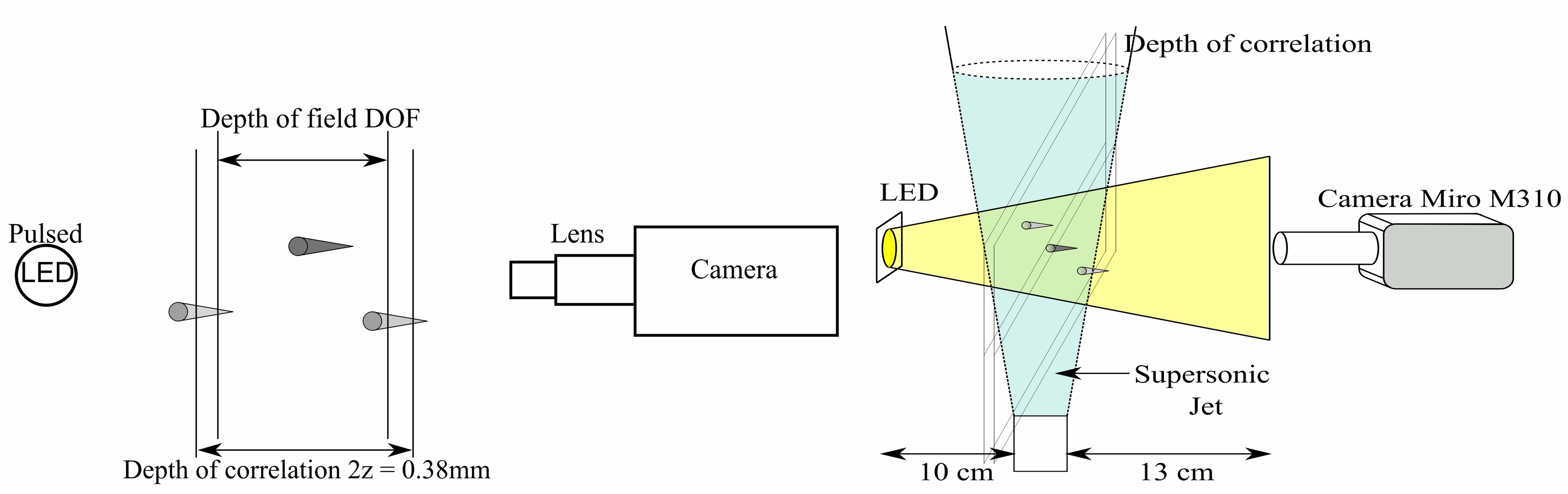

Figure 1.- Left: Depth of field and depth of correlation, right : PSV experimental set-up .

The light pulses are generated with a microcontroller MSP circuit 430g 2553 and a high-speed signal amplifier (Echeverría 2005).

In our experiment, the video camera recorded at 7200 fps, with a resolution of 778x776 pixels. The time interval between frames was 400 ns with an exposure time of 880 ns. We designed a device to inject the particles and were able, in spite of the speed and size of the flow, to obtain homogeneous seeding (Figure 2). The Mach number obtained with PSV is about 1.4.

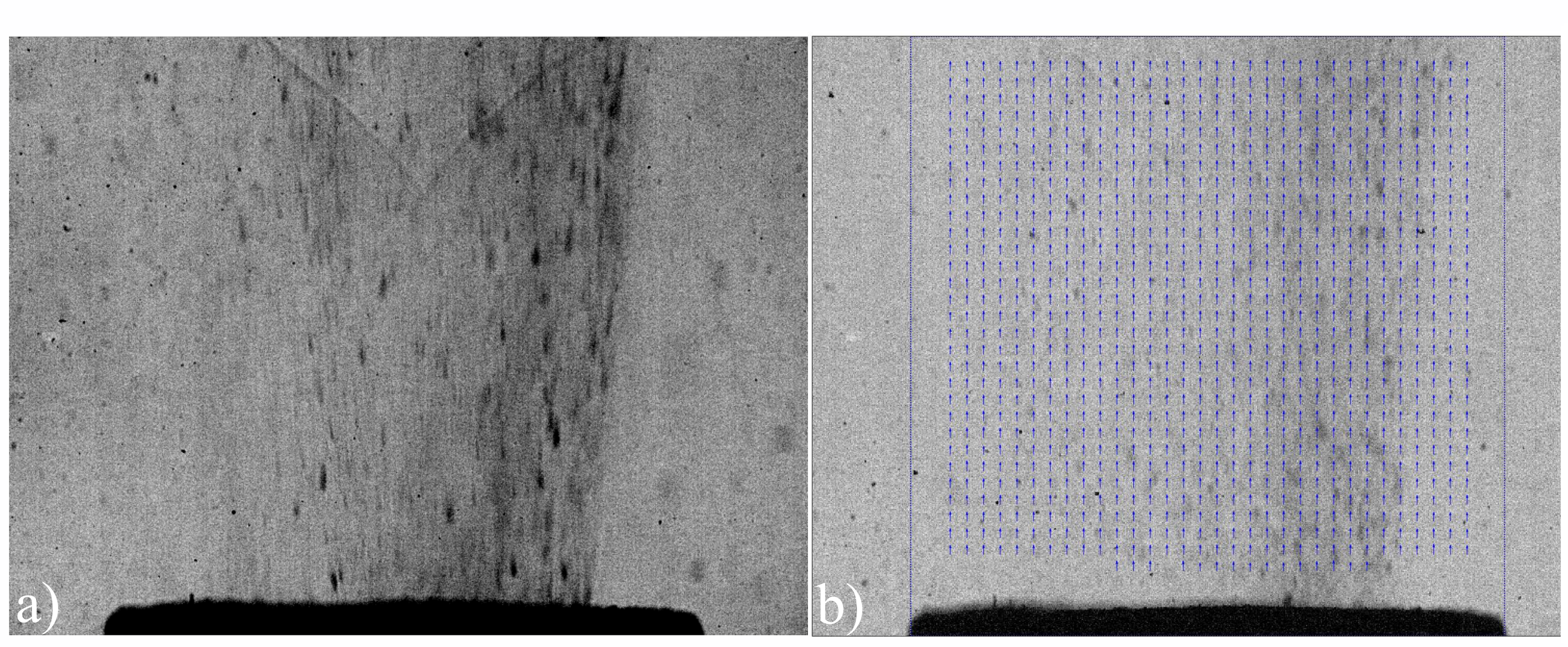

Figure 2.- a) Example of resulting frame and b) mean vector field.

BOS

The BOS technique allows to quantify local changes in the index of refraction of a transparent medium, based on the apparent motion of points of a pattern in the background produced by changes in the refractive index of the object of study. The refractive index is proportional to the density.

The technique consists in taking two photographs: the first with the background in absence of the flow and the second with the flow, the experimental set-up can be seen in Figure 3. The mean displacement is obtained via cross-correlation of the two images. The index of refraction is obtained from the displacements through a Poisson Equation, the source term is the derivative of the vector displacement field.

$$\frac{\partial^2 n}{\partial x^2} + \frac{\partial^2 n}{\partial y^2} = \frac{n_0}{MZ_D h}\left[\frac{\partial \xi_x}{\partial x} + \frac{\partial \xi_x}{\partial y}\right]$$

The relationship between the refractive index and the density is given by the Gladstone-Dale equation $n - 1 = k\rho$. However, it is necessary to know the correct value of a constant for the specific material and the incident light.

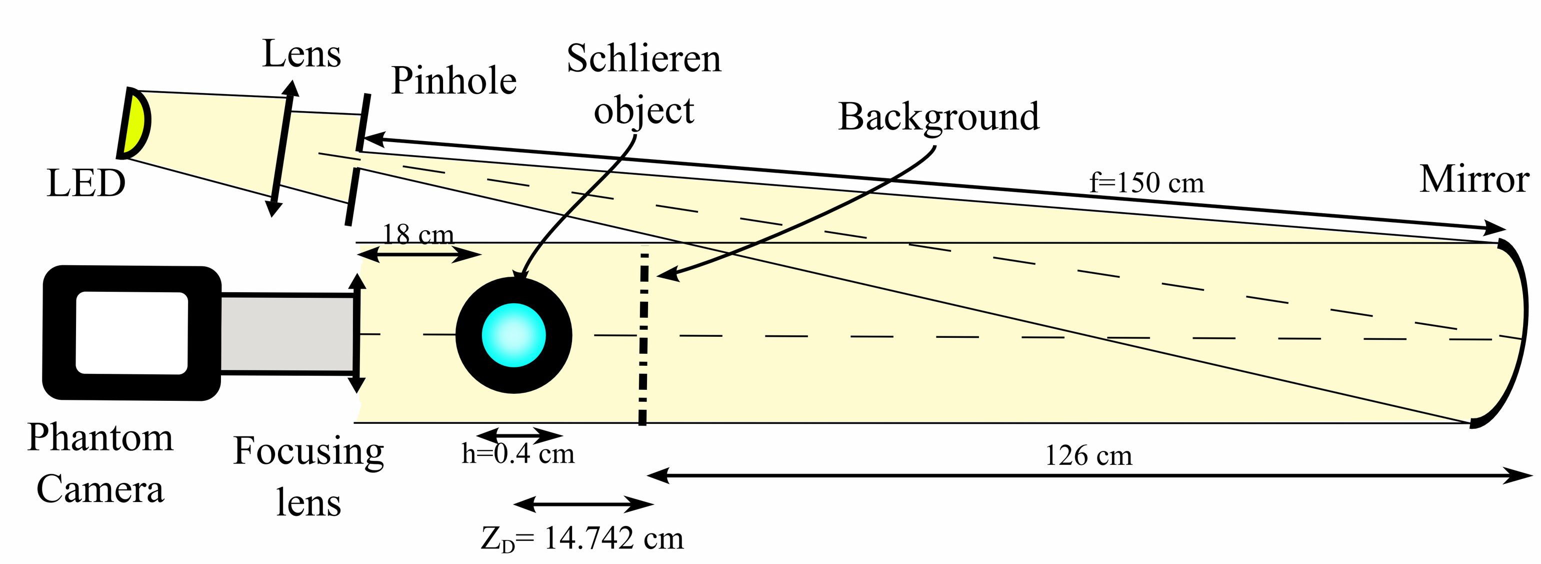

Figure 3.- BOS experimental set-up (Porta 2015).

Figure 4a shows a shadowgraph of the jet flow. The dark areas correspond to regions of highest density gradient. Figure 4b are the results obtained from BOS. The red areas correspond to regions where the index of refraction is maximum, and thus the density is largest. Figure 4c is the superposition of both images.

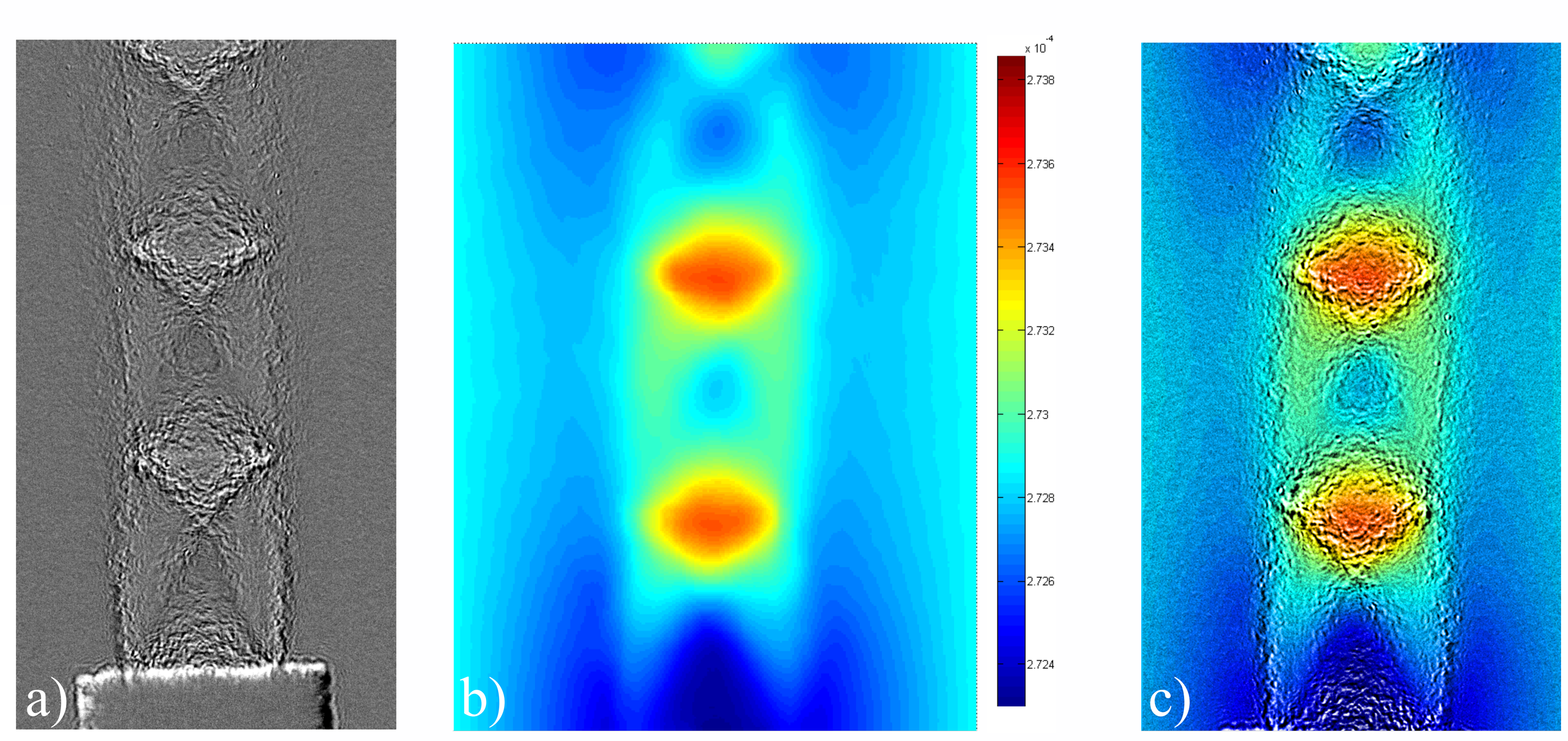

Figure 4.- a) Scalar field of the Index of refraction , b) Shadowgraph of the jet and c) superposition of a) and b)

We have implemented two novel techniques that give information about the velocity and the index of refraction as a function of position inside a supersonic flow. Also, the PSV technique, which has the same set-up of a shadowgraph, can be used to localize the position of the shock structure inside the flow. High-speed videos show that the shock structure is actually fluctuating but more studies have to address this question.We have not found any other study that can show the velocity field and the shocks at the same time.

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