Study of interfaces in an Axisymmetric Supersonic Jet using Background Oriented Schlieren (BOS)

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We have used several techniques to study a small axisymmetric supersonic jet: Rayleigh scattering, schlieren Toepler and PIV. Each technique gives different kind of information. In this paper, a BOS set-up is used to study the structure of the shock pattern. A shadowgraph of a dot matrix is obtained with and without a flow. The displacement field of the dots is related to changes in the index of refraction, which can be related, through the Gladstone-Dale equation, to changes in density. Previous results with this technique were not conclusive because of the relative size of the dots compared to the diameter of the nozzle. Measurements have been taken for three different exit speeds.

Introduction:

Shocks are high density regions in supersonic jets that can be visualized with appropriate techniques, like shadowgraph or schlieren (Figure 1).
Background Oriented Schlieren (BOS) allows to quantify the local density of a transparent medium, using the relative shift of the background due to local changes of the refractive index (Figure 2).
The technique compares a photograph of the background seen through still air with another photograph of the same background seen through the translucid medium. (Figure 3).
From a cross-correlation between the two pictures, the displacement field of the background can be calculated. The displacement field is related to the local density field through the Gladstone-Dale equation [Equation I]. Finally, a Poisson equation [II] is obtained that has been solved in this work with a Gauss-Seidel iterative method.
Local absolute values of the density can be calculated because of the previous calibration of the technique.

$$\frac{n-1}{\rho} = G(\lambda, T) \quad \text{... Equation I}$$

$$\nabla^2 \rho(x,y) = S(x,y) \quad \text{... Equation II}$$

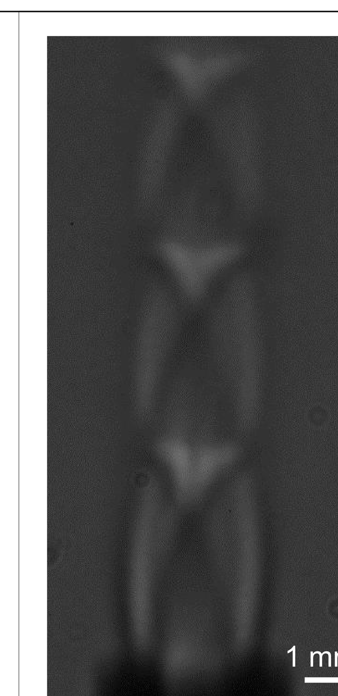

Figure 1.- Shadowgraph of the supersonic jet.

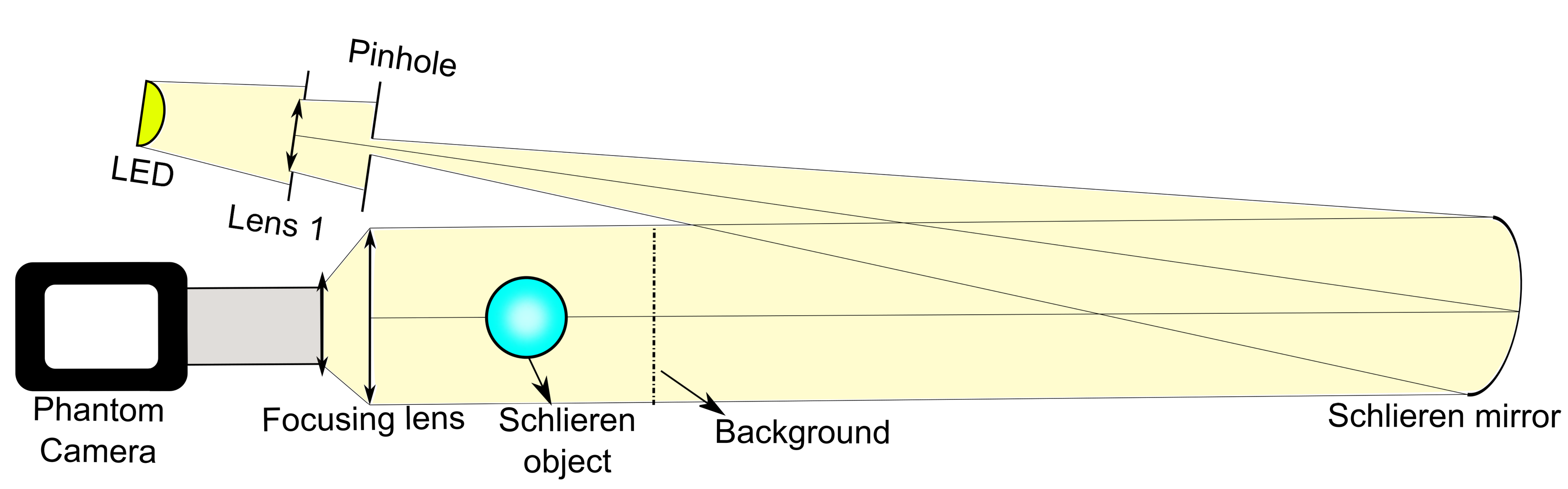

Figure 2 - Experimental setup, parallel ray shadowgraph.

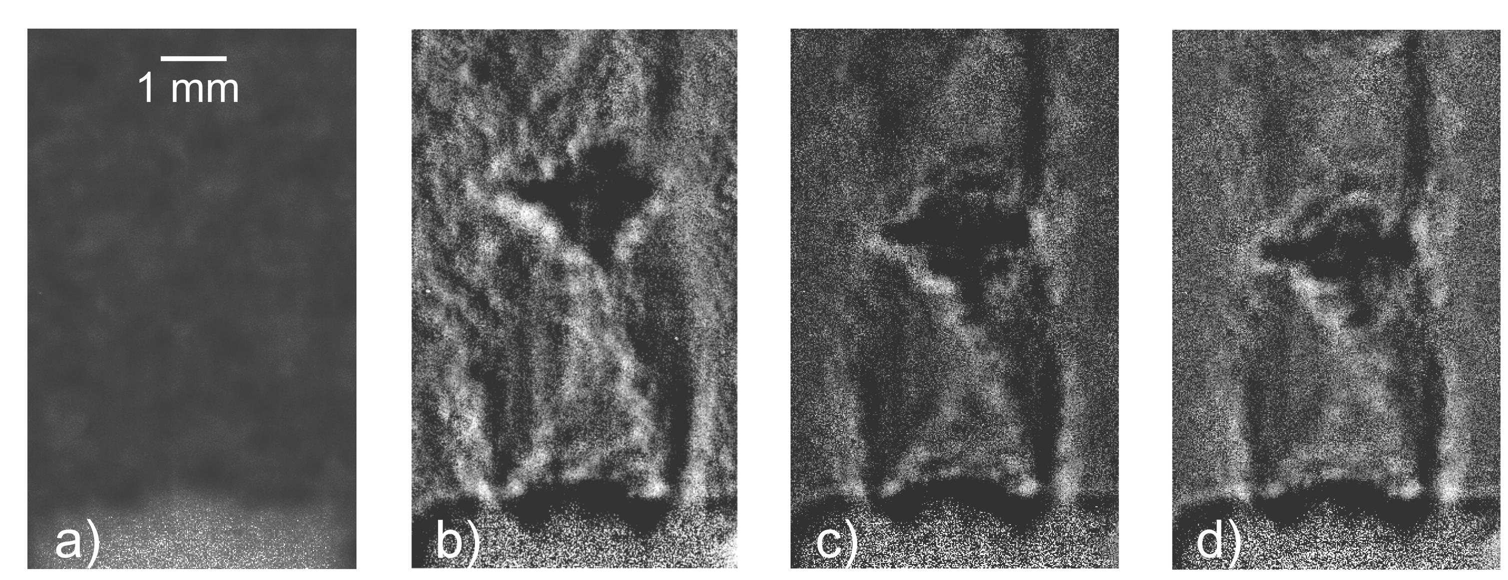

Figure 3 - a) background, b) supersonic jet M = 2.78 , c) supersonic jet M = 1.89, d) supersonic jet M = 1.79

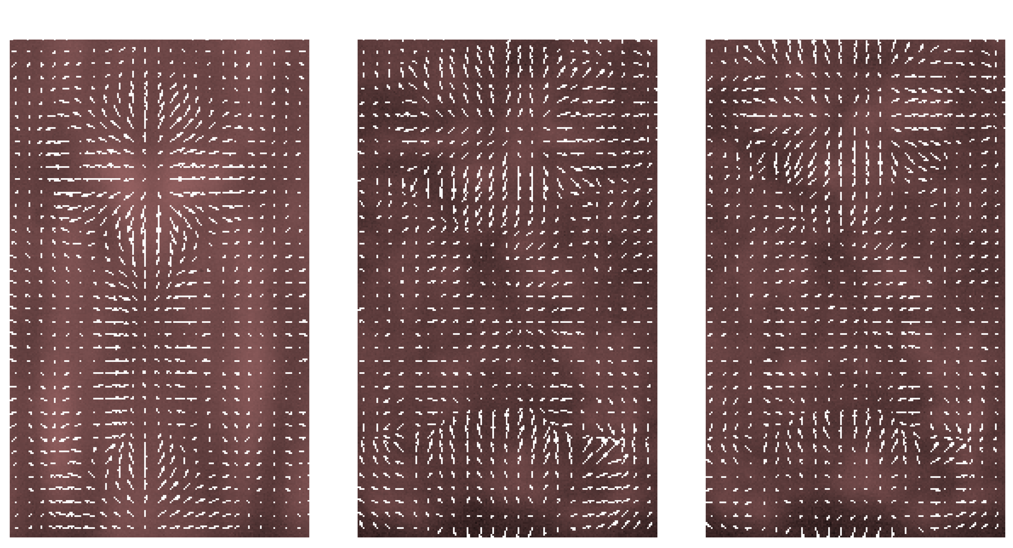
Figure 4- Displacement field of the jet at three different Mach numbers obtained through the cross-correlation between the images shown in Figure 3, a) with b), a) with c) and a) with d).

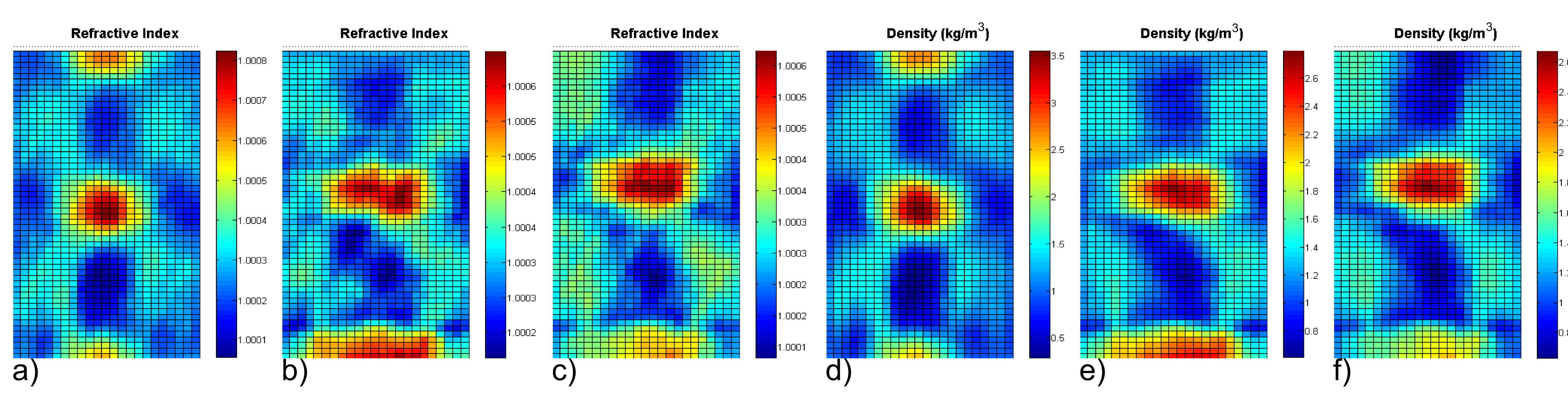

Figure 5- Results obtained by solving the Poisson equation for the refractive index and density for each of the displacement fields.
a) M = 2.78 , b) M = 1.89 , c) M = 1.79 , d) M = 2.78 , e) M =1.89 and f) M = 1.79

Conclusions

The displacement field of a random background pattern has been obtained in the central region of an axisymmetric supersonic jet.
Preliminary results on the density gradient inside the shock structure of a supersonic flow have been obtained using a BOS technique and a high speed camera. The spatial resolution is of 0.2 mm in the image that corresponds to 0.03 mm in the real flow.
The technique does not have enough resolution in the mixing layer region where density changes are small.

Future work

Modify the background pattern to obtain better resolution in the low density region.
Test other methods to solve Poisson's equation.
Compare results with those obtained with other techniques.

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Refernces

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