CHARACTERIZATION OF A PNEUMATIC SPRAY NOZZLE BY 2D-PARTICLE IMAGE VELOCIMETRY (PIV-2D)

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Abstract.. *The use of PDA equipment for determining the drop size and flow field of spray flows is broadly applied, however, some characteristics of the flow field presents some lack of information, particularly, the complete flow field in the transverse area to the main flow. For this reason, it was decided to implement a test rig for getting a more detailed transverse flow field with the Particle Image Velocimeter technique in two dimensions in a pneumatic nozzle. The results obtained for the main (axial) flow show a very good agreement with the previously obtained with PDA, while the results for transversal sections cannot be properly resolved by the PDA method. The results of the PIV method from L/d0 = 17.4 to 60.9 show that even though there is a flow with more than one swirl for the average movement in sections closer to the nozzle exit, downstream this swirl flow appears to be vanished or more precisely, to be poorly averaged due to the relatively short number of 400 image-pairs. On the other hand, the image pairs for such regions shows a very complex swirl pattern, changing from more than two or three, to six or seven small swirls in the internal spray's zone.*

Keywords: spray nozzle, spray, swirl flow, eddies, PIV-2D, PDA, PLIF

1. INTRODUCTION

The use of sprays in a big diversity of applications, *e.g*., medicine, insecticide spraying, food engineering, farm, mechanical and steel industry, ink injection systems, internal combustion engines and turbo-reactors, and the fuel combustion in process and energy plants, between others, gives as result the big interest to know the detailed behavior of spraying nozzles in a big variety of conditions, for adjusting or optimum sizing design. At present, the spray flow fields follow experimentally studying with diverse methods, particularly the optical methods associated to the use of lasers as it is the case of the employment of PDA, PLIF, PIV, by light-diffraction according to the Lorenz-Mie theory, and of the use of ultra fast video cameras. In addition to serving directly in the design, the experimental information obtained help to improve the mathematical models that use in the prediction with CFD codes, being used frequently the droplet distribution functions, as in *e.g.* Beck and Watkins, (2004). Jin *et al*.(2004), used a combined technique of PLIF and Lorenz-Mie's theory to determine the Sauter diameter of a spray in transitory conditions, with the ratio of the luminescence intensities (PLIF) and Mie´s diffraction. Seneschal *et al.* (2003) with the goal of obtaining the characteristics of an injector of several orifices, developed a procedure of measurement using a high speed camera to determine the characteristics of the jet in terms of its pattern, the border speed and the angle of the high pressure spray. Davis and Disimile (2004), working with fire extinction sprays, found that the drop diameters measured with PDA are very sensitive to the specific optical configuration used, the results show that the speed measurements are almost not affected with the configuration changes, but the drop size measurements can considerably be., then the optimum configuration can be very difficult to choose without a previous knowledge of the rank of diameter that goes to be measured, they present an experimental methodology to determine the optimum configuration that provides the minor divert for a rank of diameters. Even small changes in the design of an spray nozzle can attain important effects in the behavior, by what the use of PDA is a clear option for designing, as in the case of Yang *et al*. (2003). Timm *et al*.(2002) used PDA and high speed to determine the effects in the characteristics of the spray caused by the temperature, pressure and fuel type, the high speed visualization of the flow patterns confirmed the results obtained with PDA. Serpengüzel *et al*. (2002) determined drop size by means of a LIF technique. Lacoste *et al*. (2002) and González (1998) have used -as many more- the PDA technique for spray transitory analysis of a diesel injector of internal combustion engines. The use of the information generated with PDA or other techniques is often used to develop models (Beck and Watkins, 2004) or calculation methods to feed the specific characteristics of heavy fuels into CFD codes to improve the numerical predictions of this type of sprays, as Takei *et al.* (2003). Kim *et al.* (2002) used PDA to get the characteristics

of new air-shrouded injector to improve its behavior diminishing the emissions from heavy fuel generated by the no uniformity in the spray drops and insufficient mixing. Although it is clear the advantages of PDA to get the drop size and distribution, the use of other techniques to complement the information are often used, for example, Valero and Ikeda (2002) used stereoscopic PIV to determine the three-dimensional structures caused by the interaction of the drops and the surrounding air flow, and even, have used multiple PIV layers of intensity to determine the behavior of the drops in the flow field.
In a recent work Medina *et al.* (2006), it was used a PDA system to know the behavior of a commercial pneumatic assisted nozzle for working in a very particular conditions, obtaining the relevant spray parameters, however, the information obtained in the transversal plane was limited since with the configuration used, only obtained one speed component, in the transversal plane, that depending of the conditions can be the tangential speed and for others, the radial component, this is useful information, but does not give a complete view of the spray swirling structure in transversal planes to the main flow direction. In this work in order to get a more detailed swirling structure in transversal planes, the particle image velocimetry in two dimensions technique was used since it can provide the information of the whole flow field plane.

2. EXPERIMENTAL SET-UP

For the development of the experiments, it was designed and built an experimental rig that consists of an acrylic box model that includes the pneumatic nozzle, together with the additional devices for controlling and moving the air-particles flow in and out to the box, and a fume generator. The control of the discharge conditions of the nozzle were done by adjusting of the pressure air feeding with an air regulator placed upstream, measuring to the same time, the conditions of temperature of the air used. To get the flow fields in the studying zone, the particle image velocimetry in two dimensions technique was used, with a Pulsed Nd:YAG Laser, double cavity, 200 mJ, 532nm, and cylindrical lens to get the green curtain, a CCD camera connected to the main acquisition and processing data unit through a synchronizing module, with the configuration and operation of all the system with the software of analysis in a PC. Previously, the main axial spray speed were obtained with a micromanometer to define the position of air-regulator. The positioning of the laser curtain and the CCD camera were done with a XYZ coordinate system, manipulated also from the PC. The Fig. 1, shows a diagram of the experimental installation.

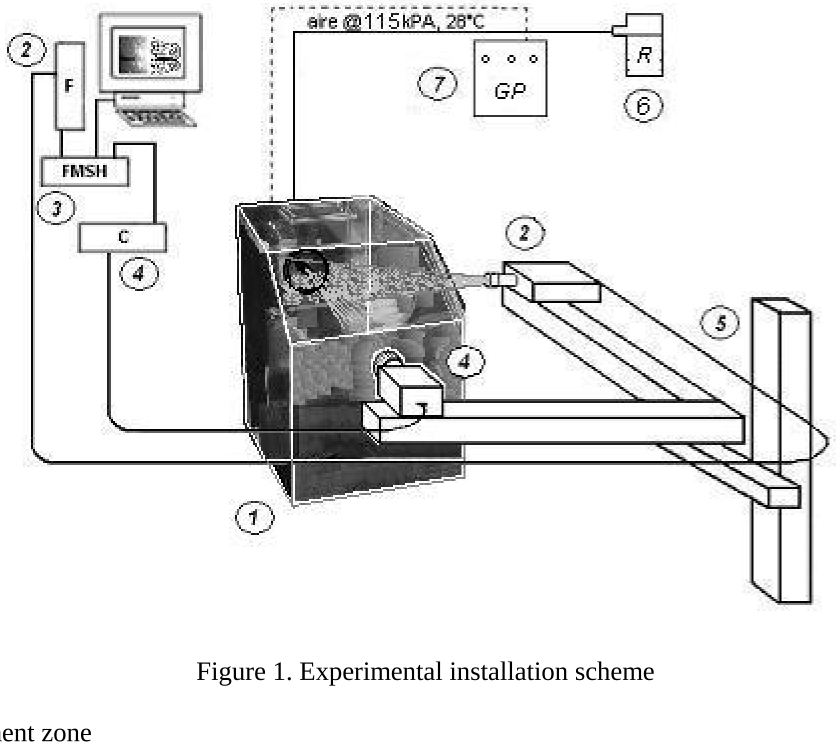

Figure 1. Experimental installation scheme

where
1. Model, measurement zone
2. Pulsed Nd:YAG Laser, double cavity and source (F), 532 nm (green curtain), 200 mJ
3. Process main unit FlowMap System Hub ® (FMSH)
4. Hisense Camera CCD 1024×1280 and synchronization unity for laser (C)
5. XYZ Coordinate system controlled from PC
6. Pressure regulator of air feed to the nozzle
7. Smoke generator (GP)
8. PC with Flow Manager Software ® for processing data

3. RESULTS

As it was mentioned in the previous paragraph, before taking the measurements with PIV, a micromanometer was used to determine the speed of a downstream defined point from the exit nozzle and to obtain a relationship between the axial speed at this point and the pressure in the air regulator; with this results the selected value for comparing and complementing the values previously obtained with PDA measurements in (Medina *et al.* (2006), was identified the value of the air pressure to use, however, in that conditions the smoke generator had problems to initially feed the particles to the system so it was taken a lower value corresponding to 88.2% of the reference value; this was considered as representative of the flow field, so the Reynolds number value of $Re_{do} = \rho u d_0/\mu = 2488.4$ was used in all the measurements. The Fig. 2, shows the comparison between the visualization that can be attained with the PIV, that shows one instantaneous frame (left) of the zone lighted by the laser curtain, the central plane of the spray, and the obtained with a regular digital camera that lights the outline, with a shutter speed some magnitude order lower.

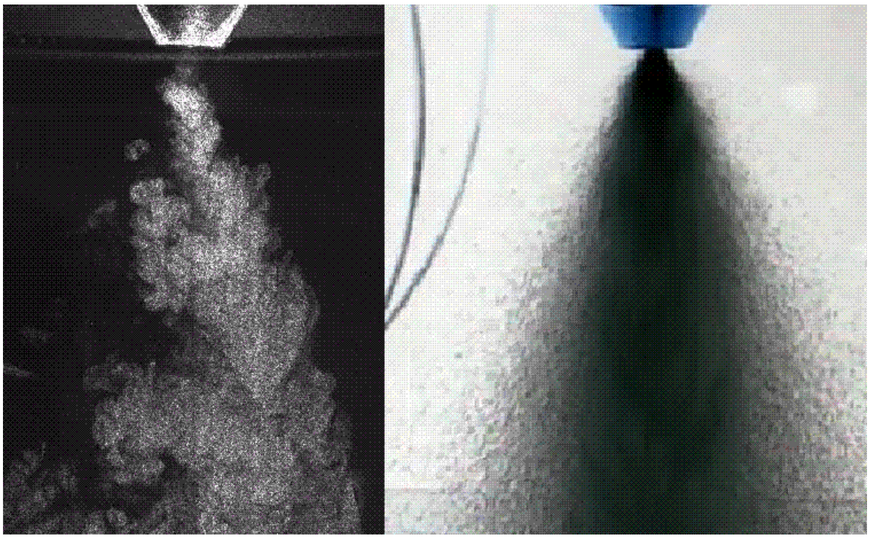

Figure 2. Visualization of the spray with PIV (left) and with conventional digital camera (right)

In order to confirm the results obtained with PDA, the rig was configured to determine the flow field of the spray central plane along the axial direction, the results shown in the figure 3 are satisfactory well compared with that obtained previously with PDA, to attain these results, it was used a total of 302 of image pairs.

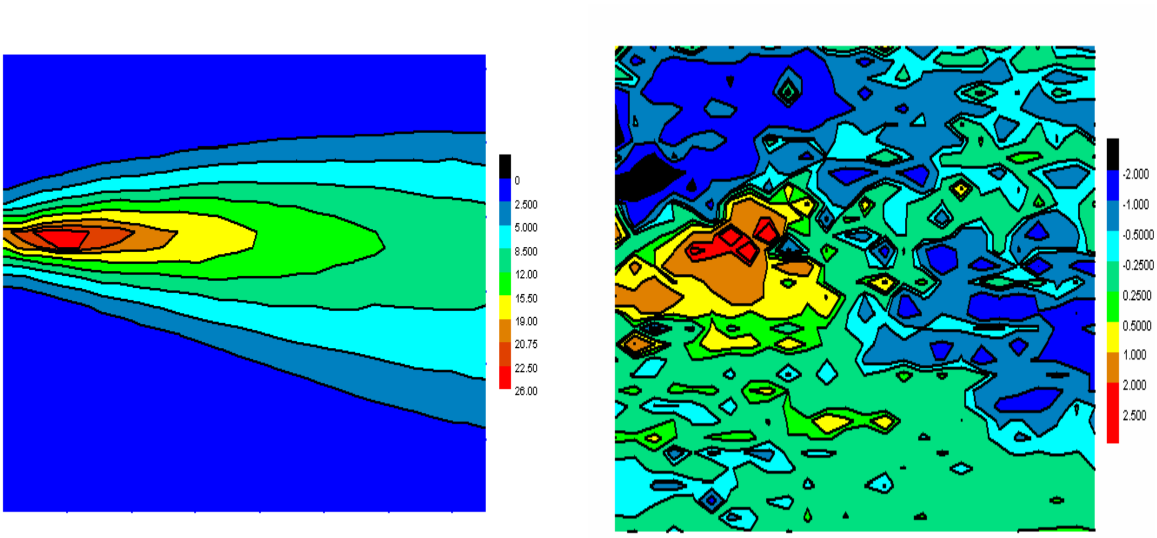

Figure 3. axial speed flow field u_z (left) and vertical speed u_y (right)

It can be seen that exists a small fall of the spray field in the axial direction caused by the characteristics of the model employed since the air flow is forced to leave the measurement zone turn down 180° to the exit just in the same wall of injector but in the bottom of model separated with a screen. The right part of the Fig. 3, shows the vertical speed component; it can observed distinctly the effect of air entrainment to the spray zone in the left part, and in the right, the predominant effect of the spray showing the speed to spread out, expanding it.

Once effected the first phase to obtain the whole flow field in the axial plane, it was modified the position of the model so that the laser curtain could be displaced along the spray axis to determine the flow field in the transversal plane positions defined. Using the results obtained with the initial experiment, it was decided to use a similar number of image pairs, averaging for this case a total of 390 image pairs for each one of the 11 positions, from Z = 40 mm (L/d_0 = 17.4) from the orifice's nozzle, to Z = 140 mm (L/d_0 = 60.9). The Fig. 4, shows a flow field map of the total speed in the transversal plane corresponding to L/d_0 = 17.4. In addition to being asymmetric, shows that the zones where the speed is maximum are separate, what could involve the presence of more than one swirl. The Fig. 5 to 7, show speed maps for L/d_0 = 17.4, 26.09, 34.8, 43.5, 52.2 and 60.9. In spite of lack of the detail wished in the central zone, it is evident that when L/d_0 grows, the influence of an apparent second swirl tends to disappear.

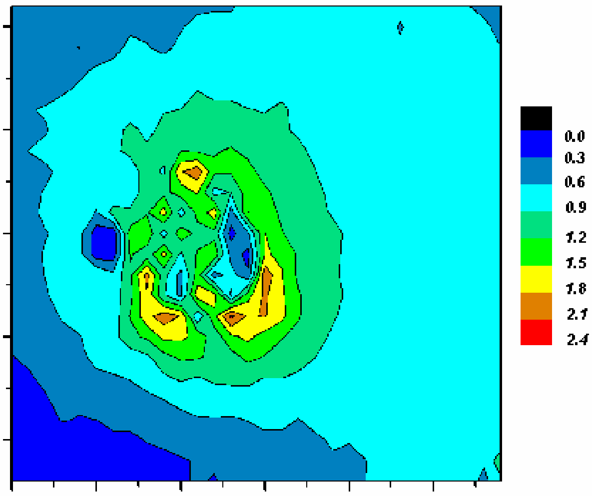

Figure 4. Average speed field in a transversal plane to the nozzle in Z= 40mm, (L/d_0 = 17.4)

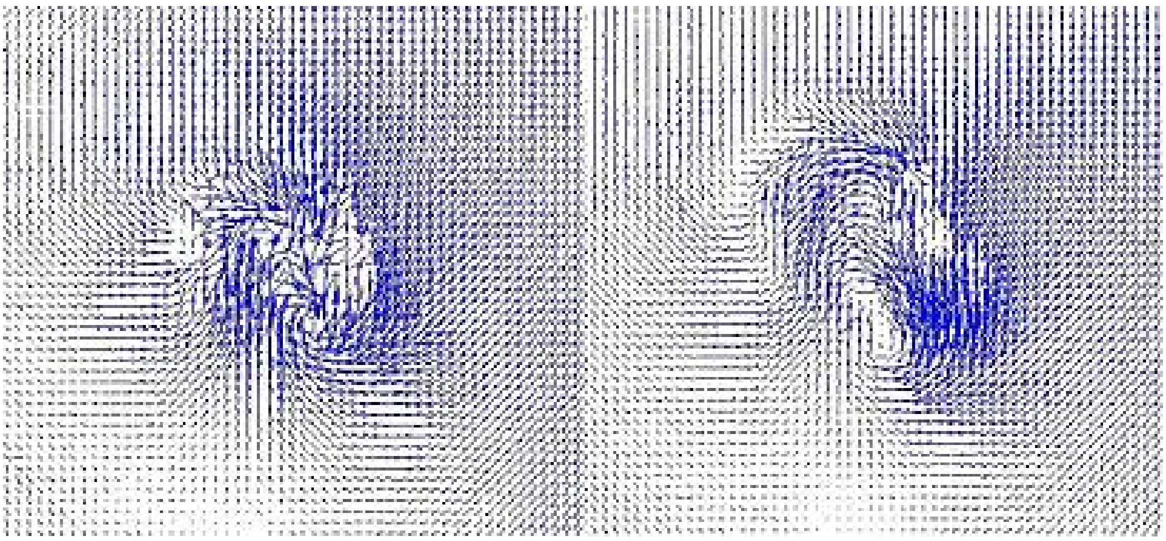

Figure 5. Average flow field in a transversal plane to the nozzle in Z = 40 mm and Z = 60 mm. (L/d_0 = 17.4 and 26.09)

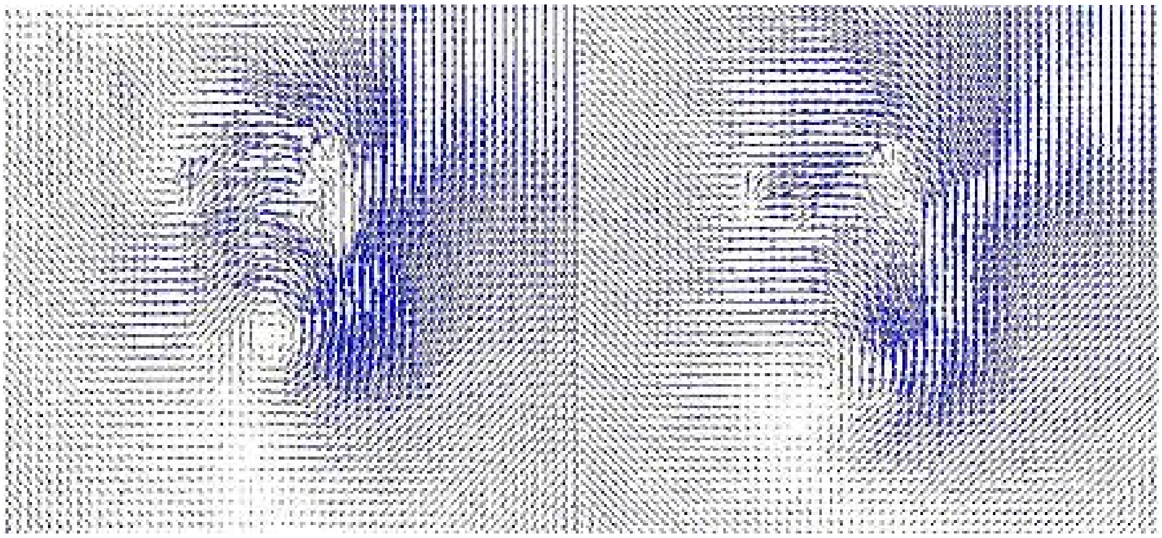

Figure 6. Average flow field in a transversal plane to the nozzle in Z = 80 mm and Z = 100 mm (L/d_0 = 34.8 and 43.5)

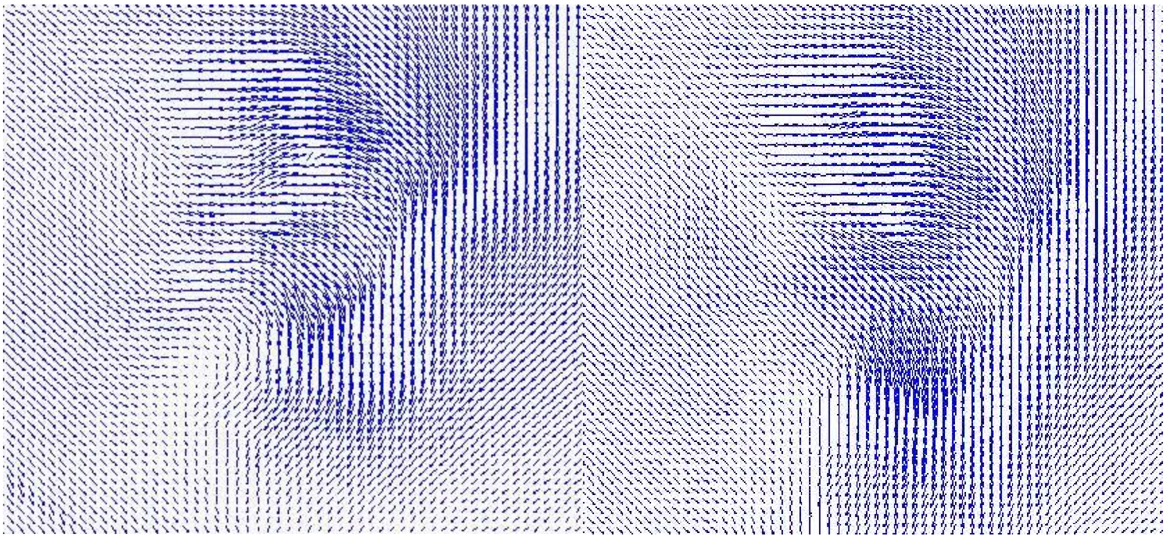

Figure 7. Average flow field in a transversal plane to the nozzle in Z = 120 mm and Z = 140 mm (L/d_0 = 52.2 and 60.9)

It is evident that the results obtained for the average flow fields in the transversal planes is not very clear, and especially, does not allow to establish with accuracy the characteristics of the mean flow, it is very likely that this owe to the limited number of image pairs used in the process for a complex field like which tried to know, contrasting with the number of samples used for each point in the case of PDA (10000); then, if it can be obtained general characteristics for the whole plane, the average values have a poor resolution with this number of image pairs. In spite of this, the analysis of image pairs that produce instantaneous fields in a transversal plane give a good idea of what occurs. The Fig. 8, shows a group of 6 fields of instantaneous flow fields for L/d_0 = 17.4 (Z = 40 mm). Although they are not in a sequential order, they are very representative of what occurs in the inside and outside of the spray: it can be seen clearly swirl structures in each one of them and these structures change very quickly, reviewing the generated instantaneous fields, is possible to measure from 2 or 3 in some case, until 7 or 8 swirl zones in others, there is a big activity inside the spray that helps to the drop mixing and distribution, it can be observed to the same time, the effect of the air entrainment into the spray. In order to get more information it is necessary a complementary analysis of the data obtained, this analysis was not included in this work, if it is a goal to get more data feasibility with the additional information, it is necessary to have a significantly bigger number of image pairs.

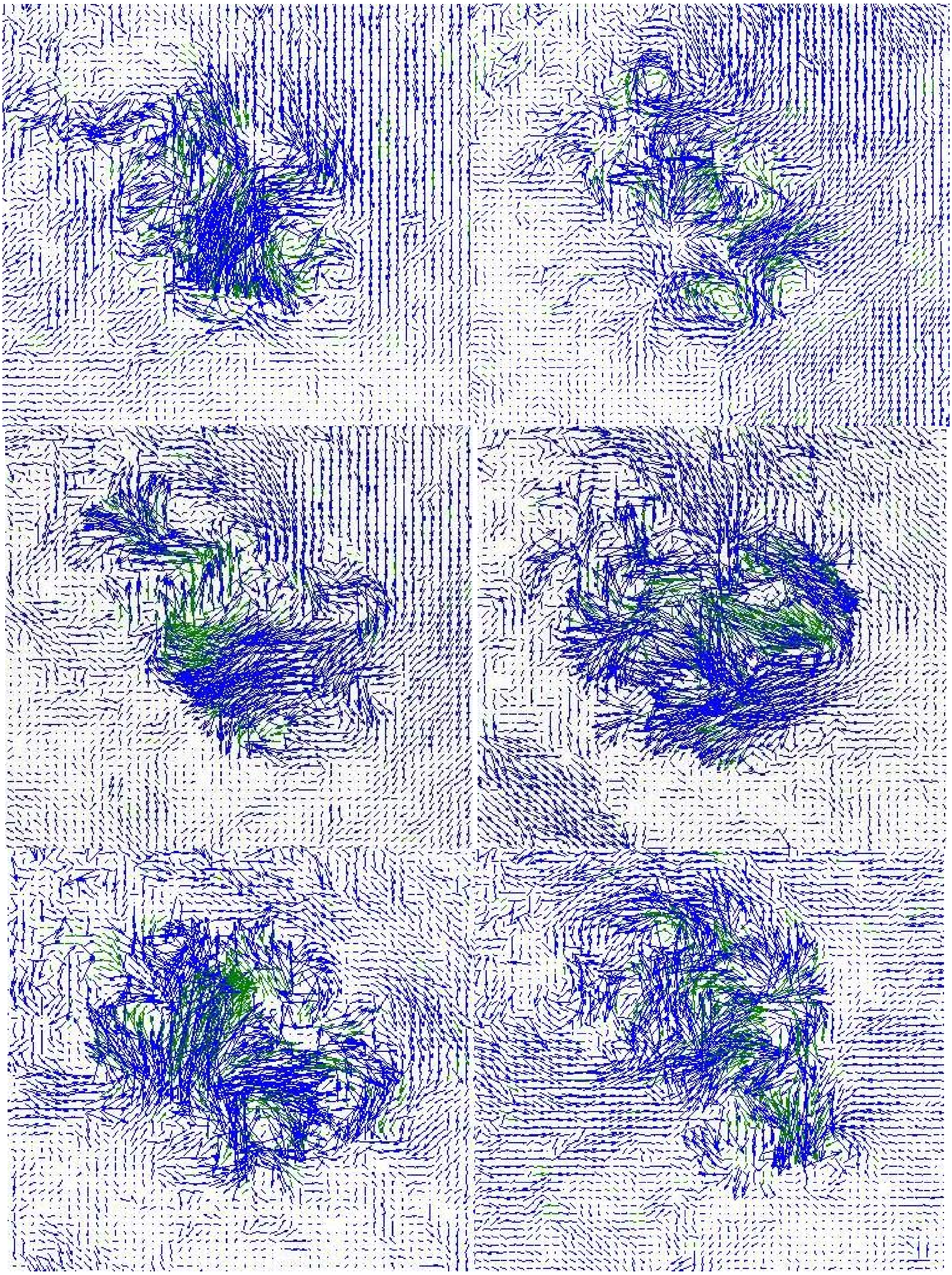

Figure 8. Instantaneous flow fields in a transversal plane to nozzle in Z = 40mm, (L/d_0 = 17.4)

4. CONCLUSIONS

In spite of the limited extent of this study, it could be obtained additional information that complements the previous one. It is evident that in regard to the main interest of this work, it was obtained more detail of the flow field structure, is clear that the nozzle produces a set of eddie filaments that develops downstream but that are fluctuating of intermittent way, then this eddies only can be seen when they coincide with the shot of the CCD camera. The presence of a second swirl in the average images seems to be more well caused by the limited number of image pairs, probably the flow would have an appearance more uniform using more image pairs, although this could not shown in this case. Regarding the use of the PIV technique for the analysis of sprays, shows his main advantage so it can be seen a complete planes with complex structures, but that has the intrinsic limit of the zones defined, is to say, can not resolve smaller scales. Is important to point out that where there are complex structures is of fundamental importance to determine the appropriate number of image pairs if you wish obtain solid conclusions on the flow field, the trivial solution is not applicable in a practical way because carry on a experiment to thousand of image pairs involve a substantial increase in the required capacity for the storage and still more work for the manipulation of the files in a post processing stage.

5. ACKNOWLEDGMENTS

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