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Aerodynamic study and control of instabilities of the initial zone of the annular jet by acoustic excitations or modification of the central obstacle.

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Abstract: - The annular jet is an example of complex shear flow situations. Two axisymmetric shear layers, originating at the jet exit, one at the nozzle lip and the other at the centre body, eventually meet downstream or interact with each other. This study also proposes to apply P.O.D on P.I.V velocity fields. This article discusses especially about a control of an annular jet by acoustic excitations or modification of the central obstacle.

Key-Words: - Particle Image Velocimetry, Annular jet, control, acoustics excitations, POD.

1 Introduction

Annular jet is used in the industrial domain, in combustion (burners, bluff bodies...) or in industrial treatment processes. The geometry of the annular jet is determined by the ratio D_i/D_o , where D_i represents the internal diameter and D_o the external diameter. The flow characteristics of the initial region of an annular jet discharging into stationary air have been investigated previously. Chigier [1], in 1964, studied them as a limiting case of coaxial jets. Because the configuration of the annular jet often adopted by authors was without after body or bullet at the nozzle exit, an internal recirculating region is formed downstream of the interface. This recirculation zone is the result of the lack of any air supply in the center and the entrainment of air from the main stream of the annular jet. The interests of the flow here are the interaction between the jet and the recirculation zone near the nozzle of the annular jet. Many authors, like Ko [2][3], work on small diameter ratio annular jets, with a ratio D_i/D_o smaller than 0.7. Only the fully-developed merging zone of a diameter ratio larger than 0.7 have been studied by Aly [4] in 1991.

The scientific interest in the study of turbulence has led to the development of a P.I.V. post-processing, which is able to bring out the inner driving mechanism of the flow [5]. In other words, the structure responsible for the development or the maintenance of flow instability has to be reached. So, in this context, Lumley [6] [7] has proposed a method for identifying coherent and instantaneous structures in turbulent flow. The method is the Proper Orthogonal Decomposition (P.O.D.). This

method provides a base for the modal decomposition of a set of functions, such as data obtained in the course of the experiments. The most striking property of this decomposition is optimality : it provides the most efficient way of capturing the dominant components of an infinite-dimensional process with only a few functions. That is why the P.O.D. process has been applied in different turbulent flows to analyze experimental P.I.V. data with a view to extracting dominant features and trends : coherent structures[6][7][8][9]. P.O.D. provides an optimal set of basis functions for an ensemble of data. It is optimal in the sense that it is the most efficient way of extracting the most energetic component of an infinite dimensional process with only a few modes [5]. The present study relies on an experimental investigation of the initial zone of a large diameter ratio annular air jet by the use of Particle Image Velocimetry (P.I.V.). The first part relates to the study of the influence of the geometry of the internal obstacle (conical, spherical and disc) on the morphology of the jet. The other part presents the influence of acoustic waves on instabilities of stagnation point of an annular jet.

2 Experimental set-up

2.1 Annular jet

A diagram of annular jet is shown in fig 1. The annular jet is characterized by the outer diameter D_o , equal to 53.88 mm, and the inner diameter D_i , equal to 48.75 mm. The thickness of the jet e is thus equal to 2.565 mm. In our setup, D_i/D_o is equal to 0.90. The exit velocities U_o are equal to 8 m/s, 15 and 30m/s which respectively

correspond to the values of the Reynolds number Re , based on the thickness e , of 2048, 3840 and 7680. At a distance from the nozzle of $50 \mu\text{m}$, the cross sectional profile of the longitudinal, measured with hot wire anemometry, shows a “top hat” distribution.

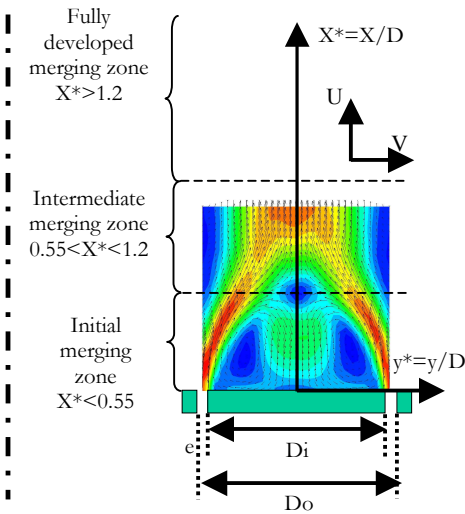


Fig 1: annular jet

2.2 cross correlation PIV set-up

The experimental setup of the P.I.V. measurements is presented in fig 2. A double pulsed Nd-Yag laser is used to set up the light sheet. The output energy is nearly 30 mJ for each laser pulse. The wavelength is 532 nm. The laser beams are focused onto a sheet across the median plane of the annular jet by one cylindrical lens ($f=0.02$ m) and one spherical lens ($f=0.5$ m). The time delay between the two pulses, which depends on the exit velocity U_o , is $8 \mu\text{s}$. The observation field is $2.8 \times 2.5 \text{ cm}^2$.

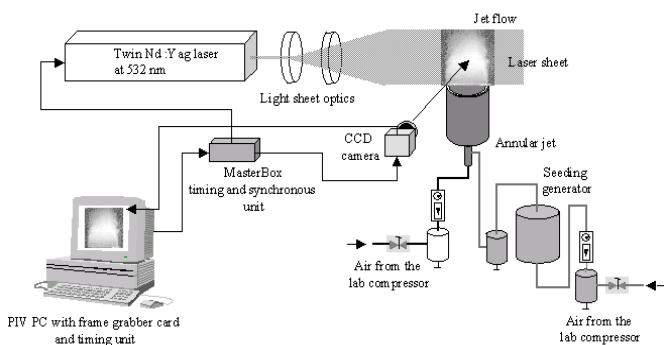


Fig 2: experimental PIV set-up

In this study, the video images are recorded by a LAVISION Flow Master 3S camera. The frame grabber, using a pixel clock, digitizes the analogue video signal to an accuracy of 12 bits. In the frame grabber, each field is digitized in 1280×1024 pixels with grey levels. The acquisition frequency is 4 Hz. Interrogation of the

recorded images is performed by two-dimensional digital cross correlation analysis using “Davis 6.2.2.” For all velocity fields, the sampling window has a size of 16 by 16 pixels (0.377 by 0.377 mm) and there is a 50 % overlap with the next window. 400 P.I.V. images have been recorded. We observed less than 1 % of false vectors calculated in the flow.

2.3 acoustics

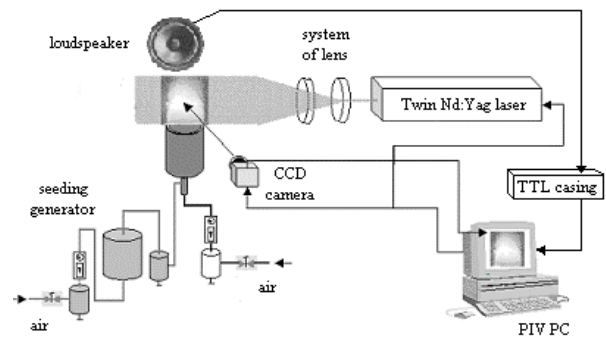


Fig 3: experimental set-up for the study of active control

The majority of works concerning the active control of the annular jets are carried out with measurements by hot wire anemometry or visualizations. Nakazano and Al [10], in 1991 work on basic annular jets of report/ratio of diameters ranging between 0,2 and 0,8. They discover that for a frequency of excitation equalizes at the frequency of formation of the swirls, the recirculation zone can be influenced and the length of this one can even decrease. Travnicsek and Tesar [11] work on an annular impinging jet of report/ratio of diameters 0,95 and notice that they can, in the absence of wall, influence the initial zone by using acoustic excitations of frequencies corresponding to frequencies of formation of the swirls. They note that the harmonic and double excitation harmonic cause the increase or the suppression of the appearance of the swirls. The Strouhal numbers for this study is between 0,38 and 2,47.

2.4 Flow seeding.

Flow seeding is one of the most important aspects of P.I.V. measurements. The intake air is seeded with 2-3 μm diameter olive oil droplets. These were generated in an atomizer by passing air through a bath of olive oil. The air pressure varied from 1.5 to 2.5 bars (fig 2). The particle seeding density was controlled by the flow rate of air through the atomizer.

3 Proper Orthogonal Decomposition.

Coherent structures are present in turbulent flow and P.I.V. is able to highlight those on the largest scale at any given moment. The scientific interest in the study of turbulence has led to the development of P.I.V. post-processing, which is able to bring out the inner driving mechanism of the flow [5].

Lumley [6][7] has proposed a method for identifying coherent and instantaneous structures in turbulent flow. The method is Proper Orthogonal Decomposition (P.O.D.). P.O.D. provides an optimal set of basis functions for a set of data, Delville [12], Graftieux [13], Sirovish [13], Patte-Rouland [14]. It is optimal in the sense that it is the most efficient way of extracting the most energetic components of an infinite dimensional process with only a few modes. Each velocity fields can be decomposed as a linear combination of proper mode ϕ such that:

$$u_i(x,y) = \sum_{k=0}^{N-1} a_{i,k} \phi_k(x,y) \text{ and } \delta_{kk'} \lambda_k = \langle a_k a_k^* \rangle \quad (1)$$

where λ_k is the energy contained in the mode k. The computation has been done with 400 velocity fields. This number is sufficient for a good representation of the flow.

4. Velocity characteristics of annular jet.

4.1 Aerodynamic characteristics of the initial zone of annular jet.

For the annular jet, it appears that the stagnation point is put through important radial fluctuations and, axially, the maximal fluctuations are localized on the external-mixing layer. This was also observed by Ko and Chan [3], but they used a hot wire and this cannot measure null velocity. Therefore, for a spatial quantification, the P.I.V. technique has been used [9]. Fig 4 shows an example of the mean velocity field with the corresponding Reynolds decomposition fluctuation fields. The initial merging zone extends from the jet exit to the tip of the potential core. This zone contains a recirculating zone. The stagnation point which marks the end of the recirculating region is located at $x/Do=0.5$.

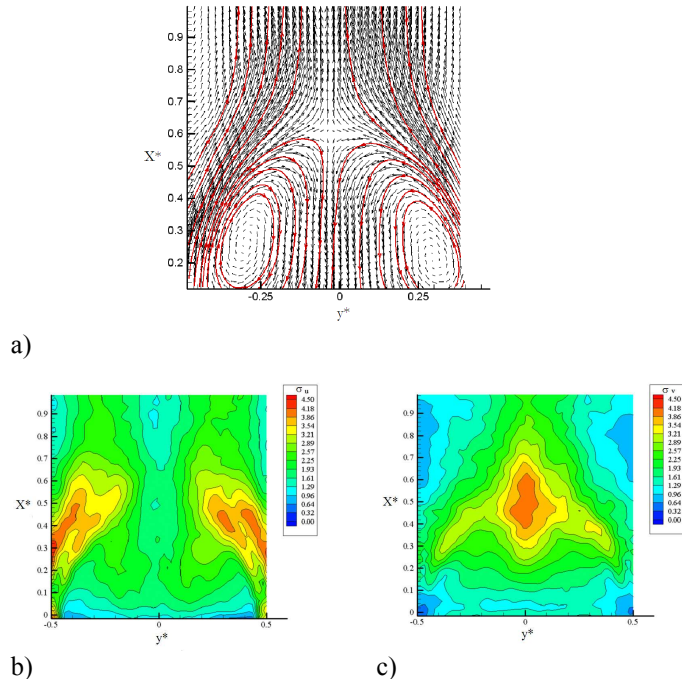


Fig 4 : Aerodynamic characteristics of the annular jet: $Re_c = 7680$. a) Average velocity field calculated with 400 P.I.V. fields. b) Reynolds decomposition radial velocities c) Reynolds decomposition axial velocities.

4.2 Results of Proper Orthogonal Decomposition application

In this study the P.O.D. is applied on P.I.V. velocity fields of the recirculation zone of this annular jet. Reynolds decomposition velocity fluctuations show two effects: the importance of oscillations for the stagnation point and the air entrainment in the annular jet. Thus, to evaluate the importance and the influence of each mode on an instantaneous velocity field, each instantaneous field reconstructed by choosing P.O.D. modes, and then the Reynolds decomposition radial fluctuations are calculated. A reconstruction with the first mode and the k^{th} mode, using the projection value of the instantaneous field on the modes, automatically shows what instability is represented by this k^{th} mode. Fig 5 shows the reconstruction of all the instantaneous fields with the first two modes and without mode 1. So, it is clear that with modes 0+1 the position and the intensity of the Reynolds decomposition radial fluctuations are the same as those calculated for all modes, contrary to the reconstruction without mode 1. So mode 1 is responsible for the radial fluctuations of the stagnation point.

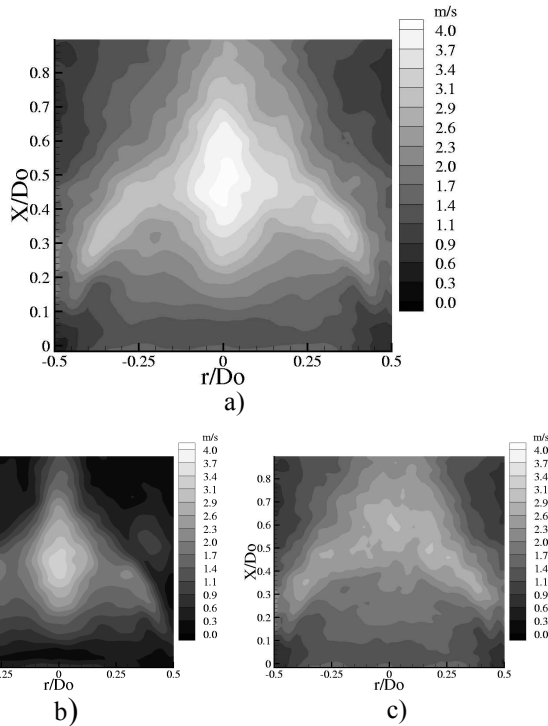


Fig 5 : Influence of mode 1 on Reynolds decomposition radial velocity fluctuations: a) Radial velocity fluctuations b) Radial velocity fluctuations reconstructed with mode 0 and 1. c) Radial velocity fluctuations reconstructed without mode 1.

5. Control of the radial fluctuations of the stagnation point.

5.1. Control of instabilities by modification of the central obstacle.

We used different geometries of obstacles: a disc, a cone and a spheroid. The last two obstacles have a length equal to the length of the zone of recirculation, which is $0,5D_o$. The profiles used are schematized on fig 6. For each form, measurements are taken for three values speed $U_o = 8 \text{ m.s}^{-1}$, 15 m.s^{-1} and 30 m.s^{-1} (which corresponds to Reynolds numbers Re_{D_o} calculated by using the external diameter D_o : 28736, 53880 and 107760). For each speed, 1000 pairs of images of the jet are recorded. The results presented in this article are obtained for $U_o = 30 \text{ m.s}^{-1}$

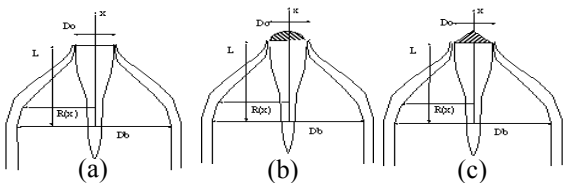


Fig 6 Profiles of the obstacles used for (a) basic annular jet, (b) spheroidal annular jet, (c) conical annular jet.

5.1.1 basic annular jet

The results of PIV measurements were compared with the basic annular jet (fig 7).

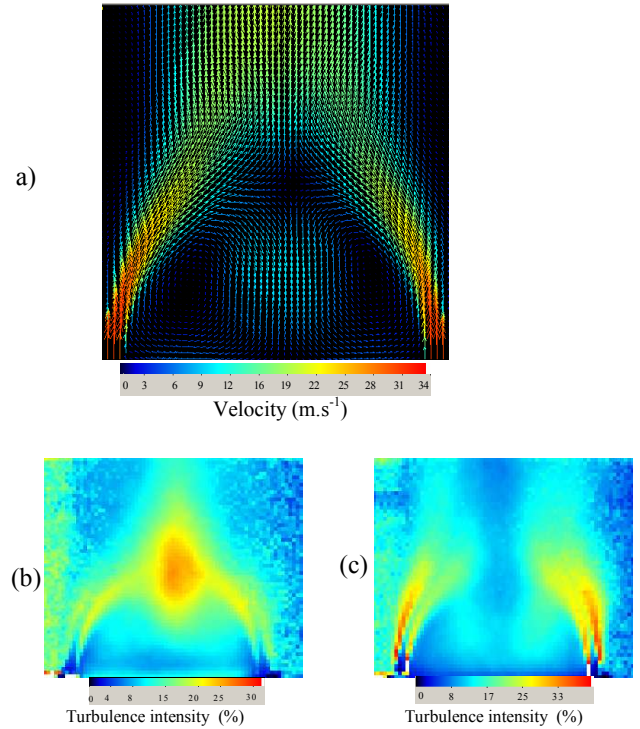


Fig 7: disc annular jet: (a) field mean velocities, (b) field of Reynolds decomposition radial velocities (c) field of Reynolds decomposition axial velocities.

5.1.2 Spheroidal annular jet

The field of mean velocities notes a complete disappearance of the zone of recirculation in the initial zone (fig 8).

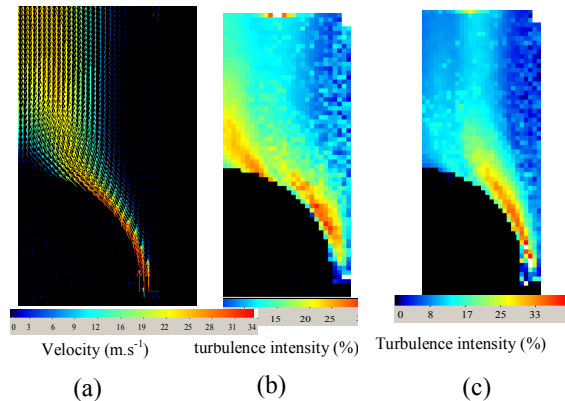


Fig 8: spheroidal annular jet: (a) field mean velocities, (b) field of Reynolds decomposition radial velocities (c) field of Reynolds decomposition axial velocities.

The field of mean velocities notes a complete disappearance of the zone of recirculation in the initial zone (fig 8). The transverse fluctuations are not any more on the level of the point of stagnation but rather on the level of the point of separation. A new zone of transverse fluctuations appears on the edges of the jet. These fluctuations are generated by the formation of the Kelvin-Helmholtz swirls in the external mixing layer. The axial fluctuations show that there is no more, in the case of a spheroid obstacle, that only one zone of shearing. This result is a direct consequence of the disappearance of the recirculation zone. In fact, the air which is located downstream from the disc for the basic annular jet is, for the spheroidal annular jet, is replaced by the obstacle.

5.1.3 Conical annular jet

The results are different when the obstacle used is a cone, as figure 9 shows it.

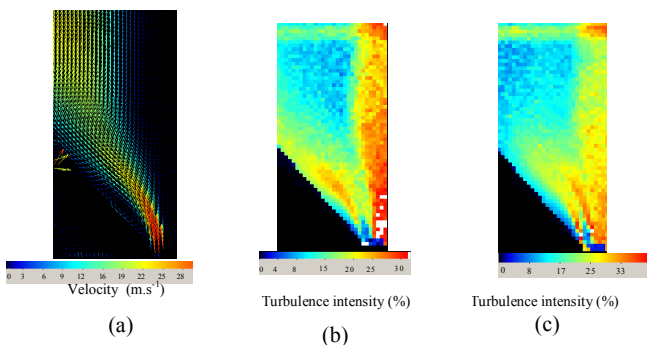


Fig 9: conical annular jet: (a) field mean velocities, (b) field of Reynolds decomposition radial velocities (c) field of Reynolds decomposition axial velocities.

The fields mean velocity shows a reduced recirculation zone at the exit of the jet. The radial fluctuations show that there are no more fluctuations on the level of the point of stagnation. This configuration seems to allow a passive control of this area of the jet. On the other hand, this annular jet also induced radial fluctuations on the edges of the jet. The obstacle does not allow the recirculation to become deformed towards the interior of the jet. This deformation thus occurs on outside and the radials fluctuations of the point of stagnation are transferred on the edge of the jet. The axial fluctuations show the presence of the two shearing layer as in the case of the basic annular jet.

5.2 Control by acoustics excitations

For industrial applications, a modification of the geometry of the jet is not easily possible. The second part of this study has the ambition to establish another control method of instabilities of an annular jet, by

applying acoustic waves created by a loudspeaker placed outside of the jet.

A first series of measurements by hot wire anemometry made it possible to carry out a preliminary study of this control.

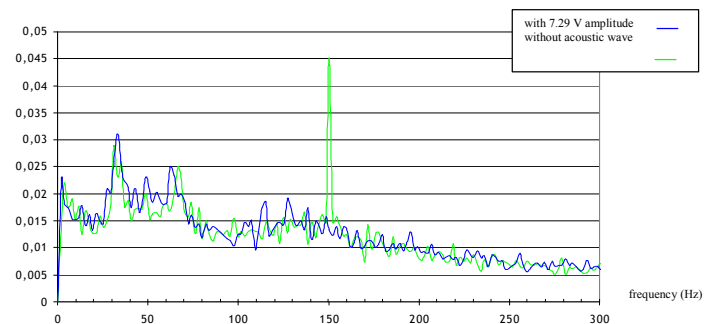


Fig 10: Frequency spectrum obtained by hot wire anemometry at the stagnation point for a jet subjected to an acoustic wave of 150 Hz and 7.29V.

The parameters of the experimental device were the same ones as those presented previously (frequency of excitation equal to 150Hz, amplitude of the wave equal to 1,89V or 7,29V). A removal of the peak of frequency of 150 Hz, present in the unexcited jet at the stagnation point, is obtained by applying a frequency of excitation equal to this frequency inherent in the jet (fig 10). So we wanted to look further into these promising results for an active control of instabilities.

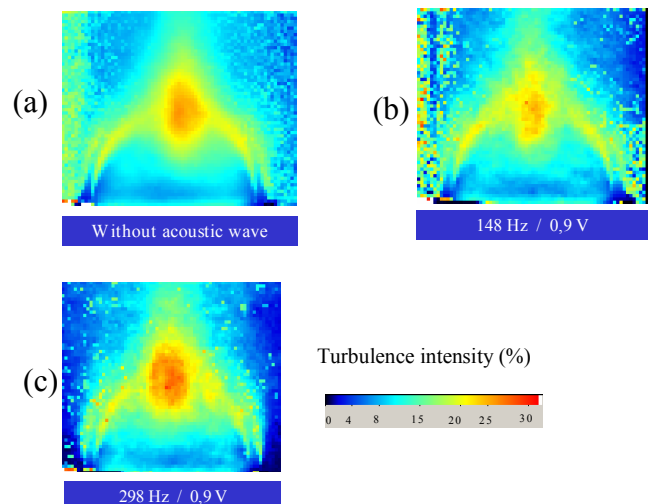


Fig 11 : field of Reynolds decomposition radial velocities: (a) without acoustics, (b) with acoustics excitations ($f=148\text{Hz}$) (c) with acoustics excitations ($f=298\text{Hz}$)

The fields of radial fluctuations calculated for the various phases with amplitude, frequency and position of the loudspeaker fixed, show significant differences:

the radial fluctuations of the stagnation point are more or less strong according to the studied phase. The comparison of the radial fluctuations, for a given position of the loudspeaker, and different frequencies of excitation enables us to see that the radial fluctuations of the stagnation point are considerably reduced when the frequency of the acoustic wave is 148 Hz and are, on the other hand, larger for a frequency of 298 Hz. An example of these comparisons is illustrated on fig 11.

6 Conclusions

This study directed around two principal axes, the common ambition of which is to establish a method of control, effective and easy to set up on industrial devices, of annular jet instabilities.

The modification of the geometry of the central obstacle is a possibility of passive control of the transversal stagnation point fluctuations by using for example a conical annular jet. But this modification of the geometry of the jet is accompanied by new zones of fluctuations located on the edges of the jet. The study of active control by acoustic excitations is delicate with PIV measurements : it's necessary, in this case, to find a relation between the beat jet frequency, the frequency of the acoustic wave and the frequency of the images acquisition in order to know the real influence of the excitation on the flow. By putting the system of illumination and acquisition in phase with the acoustic wave, we can observe the response of a basic annular jet subjected to excitations of frequency equal to the natural frequency of stagnation point beat. These transversal oscillations are reduced for this frequency of excitation. A series of measurements coupling the techniques of P.I.V. and of hot wire Anemometry is considered by sweeping a frequency band.

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