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Numerical Simulation of a Flow Conditioner

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Summary

During the last decade, numerical techniques have been used for the simulation of flow conditioners, and therefore a validation based on experimental data is necessary. In this paper the finite volumes technique is employed to model the use of the New Zanker flow conditioner under low-level disturbance conditions, such as those produced by an out of plane double elbow configuration. The results obtained are compared to the experimental data available from literature in terms of the velocity profiles .

Introduction

Flow measurement is strongly influenced by the velocity profile. Since flowmeters are calibrated and characterised under completely developed flow conditions, perturbations such as swirl, cross-flow, and asymmetry can produce relevant systematic errors [1]. However, fully developed conditions can be hardly obtained in practice; in fact fluid-dynamic perturbations are caused by the elements of the piping itself, such as elbows, joints and valves. The influence of such perturbations my be reduced by using an adequate segment of straight pipe between the disturbance and the instrument. In practice, due to the reduced dimensions of the piping, it is useful to use proper flow conditioners [2].

Generally, flow conditioners efficiency is not based on the velocity profile produced, but on their effect on a particular flowmeter. This approach has certainly obstructed the development of a general theory and consequently the optimal design of flow conditioners [3]. Furthermore, the number and cost of experimental investigations does not allow a comprehensive characterisation of flow conditioners, although very interesting laser Doppler investigations were carried out during last years [4, 5]. The development of CFD in the last decades [6] has allowed researchers to use this technique for numerical analysis of installation effects [7, 8] and flow conditioners [9, 10]. However, a validation of the numerical tests presented is not easily found in the available literature. In this work the authors present a numerical study on the New Zanker flow conditioner, and validate the results obtained on the basis of the experimental data available in literature. The comparison is based on the evaluation of the velocity profiles and different fluid-dynamic parameters that describe the profile disturbance in a conduct, downstream of double bend out of plane, so called Low Level perturbation LL, according to OIML R-32 [11].

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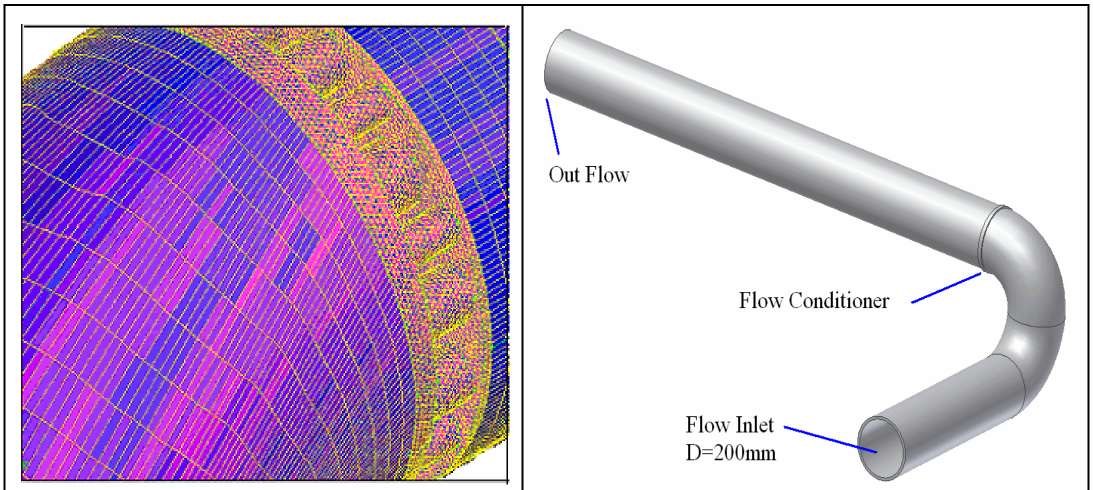
This work is a part of a wider research project for the set up of a procedure for numerical modelling of i) main fluid-dynamic perturbations (e.g. elbows, double elbows, etc) [12]; ii) most common flow conditioners [13] iii) flowmeters most sensitive to installation effects [14].

Numerical Model

The flow regime for the cases studied in this work is turbulent, and the Reynolds number based on the pipe diameter is Re=70000**.** The governing equations are represented by the conservation of mass and momentum, averaged using the well known procedure introduced by Reynolds [15]. Since steady state incompressible flow is considered in this work, the Reynolds averaged Navier-Stokes (RANS) equations can be written as:

- mass conservation $$\nabla \cdot \mathbf{U} = 0 \qquad (1)$$
- momentum conservation $$\nabla \cdot (\mathbf{U} \otimes \mathbf{U}) = -\frac{1}{r}\nabla p + \nabla \cdot 2m\mathbf{D} - \nabla \cdot \mathbf{R} \qquad (2)$$

where **U**=[U, V, W] is the average velocity vector, $\mathbf{D} = 1/2\left(\nabla\mathbf{U} + \nabla\mathbf{U}^{T}\right)$, and $\mathbf{R} = \left(\overline{\mathbf{u'}\otimes\mathbf{u'}}\right)$ represent the well known turbulent or Reynolds stress tensor, due to fluctuating velocities **u’**=[u’, v’, w’]. One of the main problems in the solution of the RANS equations is certainly the description of the stresses in equation (2). Several turbulence models for the closure of the problem have been developed over the last fifty years [16], and some of them were already tested by the authors in the numerical simulation of internal turbulent flows [12].



Figure(1): Computational grid used for the flow conditioner and it is position

The so-called k-ε model [17] was found to give satisfactory results for the simulation of low level disturbance and some flow conditioners [9, 10, 13].

The code adopted for the numerical solution of the problem described above (FLUENT 6.1) is based on the finite volumes technique [18, 19], which allows to model complex geometry by using unstructured grids. This is essential for the simulation of the conditioners' geometry.

The discretized algebraic equations, obtained from the finite volume procedure, are solved using an implicit algorithm, SIMPLE, originally devised by Patankar [20]. Second order up-winding scheme is used for all velocity terms in the momentum equation, and second order interpolation was also used for pressure.

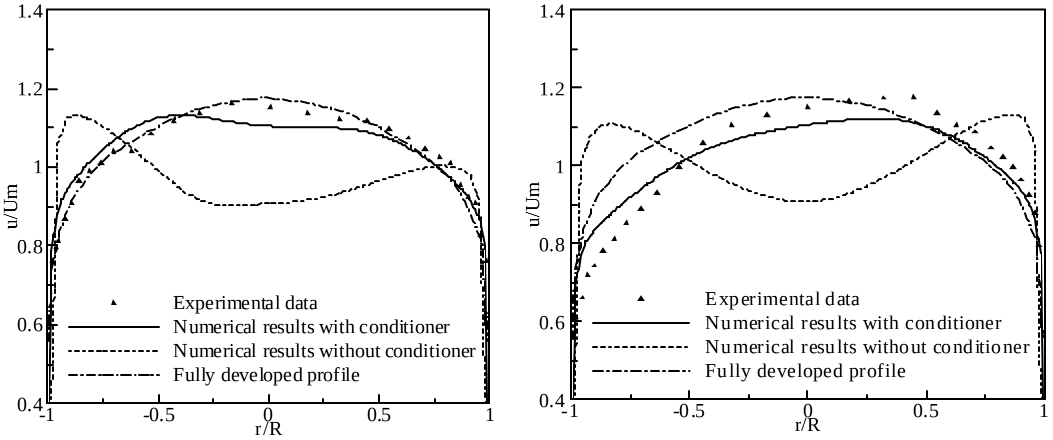
The geometry of the flow conditioners is discretized using unstructured grids. The mesh used for the flow conditioners is generated using advancing front type of procedure; Fig. 1 shows the geometry studied (a) and the grid used for the inlet section (b). The flow conditioner studied is positioned immediately downstream the second elbow, where the origin of the coordinate system is placed (Fig. 1). About 1.5 million cells have been used to discretise the computational domain. The boundary conditions considered include no slip velocity on all walls and fully developed flow at the exit. A fully developed flow profile was imposed at the inlet. This profile was obtained from the numerical simulation a 100D long straight pipe.

Results

The results obtained from the numerical simulation are presented in Figures 2 in terms of velocity profiles downstream the flow conditioner. In particular, the figure shows the axial velocity profile on a vertical section and a horizontal lines of the section placed 2.5 and 10 diameters downstream the flow conditioner. The numerical results produced with the present model are compared with the experimental results obtained by Zanker [21, 22]. The calculated profiles compare quite well with the experimental data from a qualitative point of view. The same comparison was performed also for sections of the pipe placed 5 diameters downstream from the conditioner. Table 1 presents a quantitative parameter that measures the difference between the value of the axial velocity calculated numerically and experimentally. The parameter shown in this table is defined as:

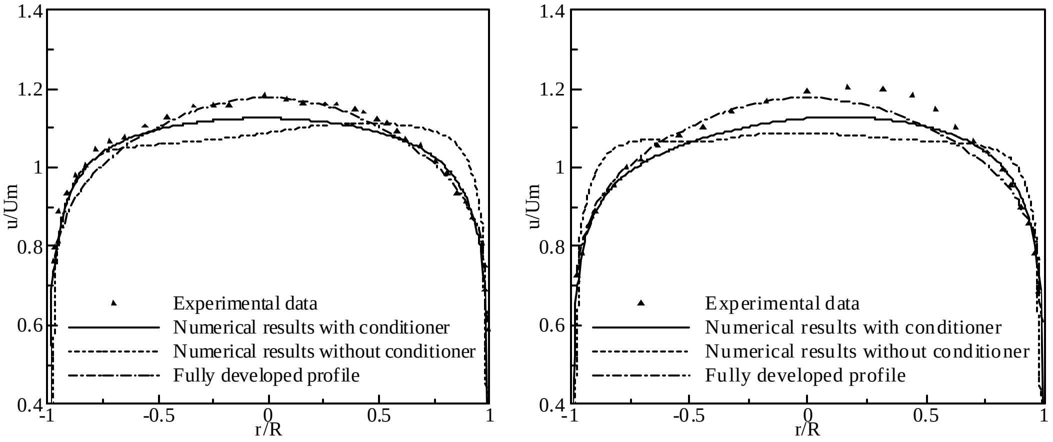
$$\sigma = \frac{1}{U_m}\sqrt{\frac{\sum_N \left(u_{num} - u_{exp}\right)^2}{N}} \cdot 100 \qquad (3)$$

where Um is the average velocity in the section, while u_{num} and u_{exp} are the values of the axial velocity calculated numerically and experimentally respectively. It can be noticed from the table that the most critical section is the closest to the conditioner, as it was expected. The agreement between the result improves as we move far from the conditioner (<1.5%). The comparison does not include the uncertainty of the numerical data, that are not known at the moment of writing.



a) horizontal

b) vertical



c) horizontal

d) vertical

Figure. 2: Comparison of the axial velocity profiles calculated numerically and experimentally 2.5 and 10 diameters downstream the New Zanker flow conditioner

Furthermore, Table 2 reports the values of three non-dimensional flow field parameters for the velocity profiles produced downstream the New Zanker flow conditioner. The definition of these parameters can be found elsewhere [3, 13] and it is not reported here for the sake of brevity. These are well know parameters, the momentum number K_u, the swirl number K_v and the asymmetry number K_a, that measure the difference between the velocity profile produced downstream the conditioner and a fully developed velocity profile.

Table.1: Percentage difference between the experimental and numerical results at different sections of the pipe

Velocity \σ	2.5D	5.0D	10D
Axial (horizontal)	0.84	0.72	0.60
Axial (vertical)	1.07	1.33	0.74

The reduction of the values presented in Table 2, as the flow moves into the pipe away from the conditioner confirms the decay of the disturbance along the pipe.

Conclusions

The work presents a validation of the numerical simulation of the New Zanker flow conditioner under low-level disturbance conditions produced by an out of plane double elbow configuration. The results obtained have shown that using the proper number of degrees of freedom for the domain discretization, the simulation can produce results that compare very well with the experimental data, and that can therefore be used for the development of a more general theory about flow conditioners. The numerical model will be further used for the simulation of high level flow disturbances.

Table.2: Non-dimensional flow field parameters for the velocity profiles produced downstream the New Zanker flow conditioner

Distance form flow conditioner	ΔK_u	K_v	K_a
2.5D	0.0144	-0.00348	0.0122
5.0D	0.0135	-0.00340	0.0098
10D	0.0120	-0.00320	0.0068

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