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NUMERICAL SIMULATION OF THE SMMI FLOW CONDITIONER

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1 Context and Introduction

Turbine meters and orifice plates are designed to operate in ideal conditions, downstream of straight pipe lengths and therefore turbine meters are calibrated in this configuration. The metering accuracy strongly depends on the flow conditions encountered at the meter inlet. Turbine meters are very sensitive to installation effects inducing flow perturbations like jet flow or swirling effects, generated by pressure regulators or pipe configuration in city gate stations. The error due to bad installation effects can reach more than 3%.

Consequently, in order to maintain a good level of accuracy, either the bad installation configuration has to be removed, or the meter has to be isolated from flow perturbations. However, the first solution is not suitable because other constraints like urbanization require a higher compactness of flow measurement systems. In addition it is not economically viable to modify the geometrical configuration of current delivery stations. So the second solution (which consists of making the meter less sensitive to bad configurations) is more suitable, and flow conditioners fulfill this goal. Flow conditioners (FCs) reduce flow perturbations like swirl or asymmetry in a much shorter pipe length than that usually necessary to a natural attenuation. Flow conditioners are more and more used on gas networks. As a proof, a certain number of FCs are quoted in international standards such as the ISO 5167 on differential pressure metering, acknowledging the efficiency of flow conditioners.

The International Organization of the Legal Metrology has a project of recommendations concerning flow measurement systems of combustible gas. This text defines three categories of users and a given level of permissible metering error for each category. The future national laws based upon these recommendations will make the requirements concerning the metering even more drastic, especially for category A meters which will be the biggest systems. It is more than probable that the use of flow conditioners will be necessary for existing delivery stations to match the new requirements. A certain number of flow conditioners are available on the market. Their efficiency but also their limits are well known. Gaz de France proposes a new version of its patented flow conditioner SMM10.

In addition to the experimental tests, numerical simulations were carried out on this new device under low-level disturbance conditions such as those produced by the configuration described in the ISO 9951 standard.
It represents the subject of this paper. This configuration is used in the qualification test of flow meters in order to assess the sensitivity of flow meters to installation effects. Simulations were carried out using the computer Fluid Dynamics code CFX which is widely used at the R&D Division of Gaz de France

2 Presentation of the SMMi

2.1 The design

The Gaz de France Research and Development Division has developed in 1988 a fully-integrated device, the PDIM, performing the functions of pressure regulation, flow straightening, metering, network protection and filtering. This integrated device is already being used successfully in the Gaz de France distribution network, allowing reduction of delivery station dimensions. Thus, the concept of the flow straightener used in PDIM proved to be efficient and maintenance -problem free during its utilization on the field. Therefore, five years ago, Gaz de France used this concept to develop an original flow straightener, specially designed for use in pressure reducing stations upstream of turbine meters (patent N°9803117). It is mainly composed of a perforated plate, which can be mounted against a second plate made out of a porous material as an option (Fig. 1).

The total length is then equal to one third of the nominal pipe diameter, which is very short. This conditioner can be mounted against the inlet flange of the meter, allowing the turbine meter to be mounted directly downstream of any type of pressure regulator. Its use gives the opportunity to drastically reduce the size of a station, while at the same time providing an excellent measurement accuracy.

Moreover, the density of the porous material can be adapted to various applications of the conditioner. The use or not of the porous material in addition to the perforated plate and choosing its adequate density will depend on the degree of perturbation to be dealt with and on the maximum pressure drop that can be afforded. For highly perturbed flows or very short installations, the use of a porous body may be relevant. Pressure reducing, wherever needed, may be conveniently shared between the porous body and the pressure reducer. The SMMi is designed for an insertion between flanges just upstream of the flow meter.

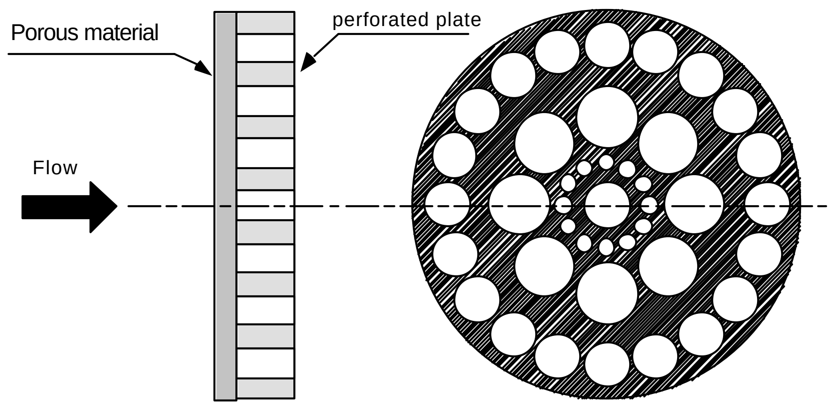


Fig. 1 : Scheme of the smm10 conditioner.

The SMMi new version (i stands for insertion) which is more compact, is designed to be inserted between the flanges just upstream of the flow meter (fig. 2). The necessary play between two flanges in order to insert the SMMi in an existing station is reduced to only one millimeter using specific spiral plate joint.

This conditioner could be installed in an existing city gate station without any pipe work. It is also a low cost yet efficient method to dramatically improve the meter's accuracy.

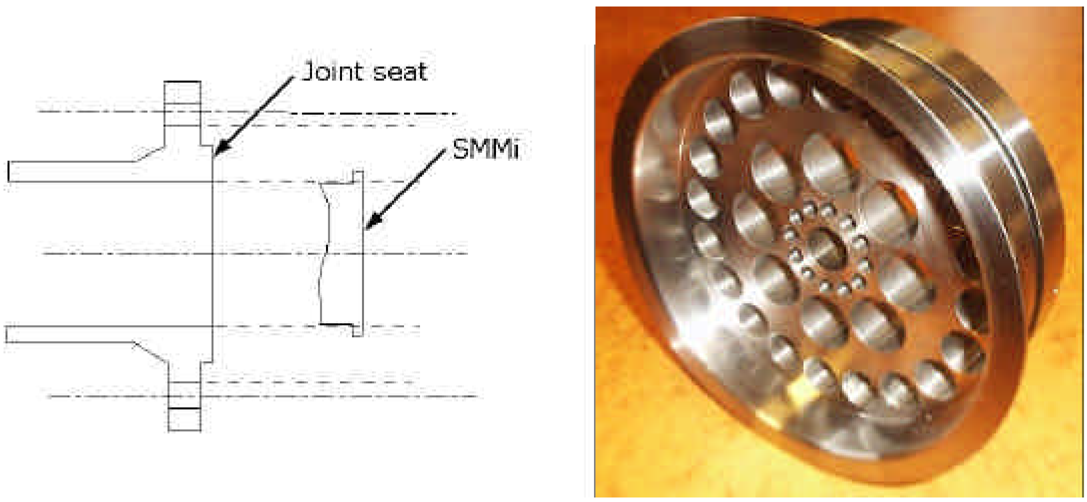


Fig. 2 : Scheme and photo of the SMMi conditioner.

The particularity of the SMM conditioner is the combination of a porous material with a perforated plate. The porous material removes the asymmetry of the axial velocity profile and the acoustic disturbances of the flow generated by the regulator of the delivery station. Due to its suitable design, the perforated plate removes the swirl with efficiency.

2.2 Its efficiency

In order to illustrate the efficiency of this new version figure 4 shows the impact of the SMMi on the turbine flow meter error curve in a critical configuration for the flow measurement . Those results are extract from an experimental study which was carried out on four geometries of delivery stations, well known for their negative impact on the metering accuracy.

The nominal flow rate of the meters was 1000 $m^3.h^{-1}$. Each delivery station configuration included one pressure regulator with a pressure reduction ratio of five. For this example, the geometrical configuration is short straight length (8D). The SMMi is positioned just upstream of the turbine flow meter.

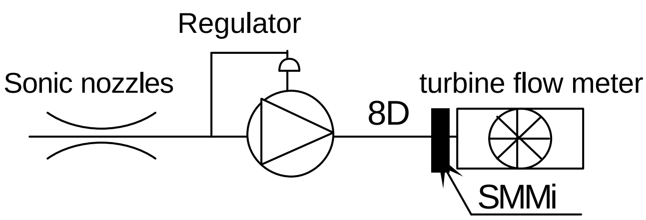


Fig 3 : geometrical configuration

The figure 4 represents the accuracy gains due to the SMMi conditioner located just upstream of the turbine flow meter :

- single conditioner,
- the porous associated to the perforated plate, compounded conditioner.

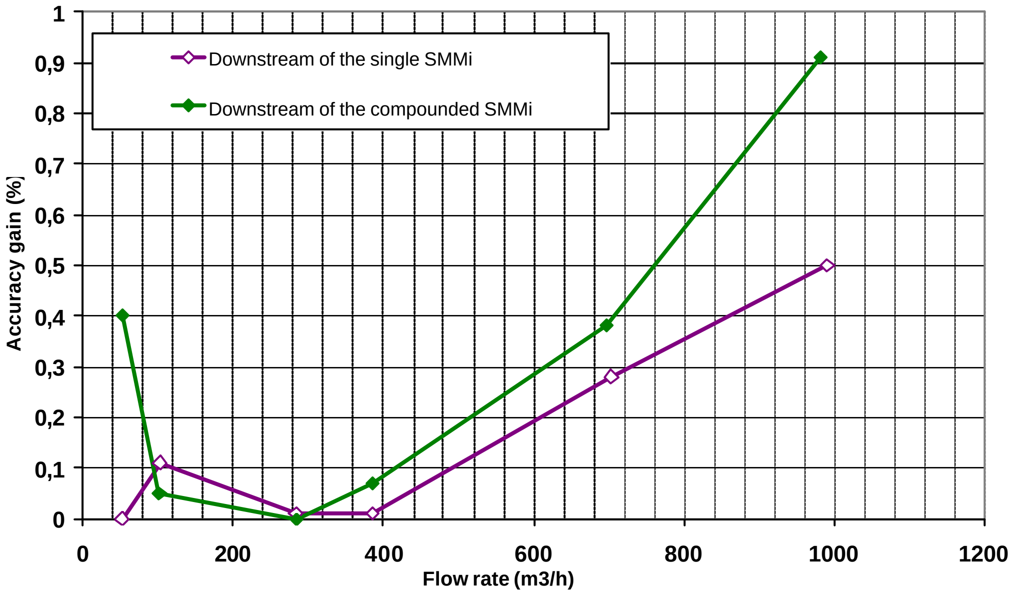


Fig. 4 : Accuracy gain due to the SMMi located upstream turbine flow meter

In order to estimate the efficiency of the SMMi, a numerical study was carried out with the Computer Fluid Dynamics code CFX. This study give us an insight into the complex phenomena inside the fluid flow at a very low scale and with a great level of details.

3 Numerical simulation description

3.1 Methodology of the study

The aim is the evaluation of the SMMi efficiency downstream of a flow under low-level disturbance conditions generated by a double-elbow out of plane and a divergent part such as described in the 9951 standard. So the flow downstream of the disturbing geometry without SMMi and with simple and compounded SMMi conditioner are compared. The SMMi is placed 8D from the disturbing geometry. This distance is likely to be found in metering critical configurations existing on the Gaz de France network.
The analysis consists in comparing axial and tangential velocity profiles provided by the calculation upstream the disturbance without and with the conditioner SMMi. In addition, to assess the quality of the velocity profile downstream of the conditioner, different parameters were calculated.

3.2 Calculation domain

Numerical studies were carried out on pipe diameter of 100 mm. The domain is subdivided into two entities to lighten calculation : the SMMi domain and the low level geometrical domain (ISO geometrical domain). The variables observed of the outlet section of the ISO geometrical domain at the end of the simulation are introduced in inlet condition for the SMMi computational domain.

Fig. 5 : Low-level computational domain
(5D straight length + double-bend + divergent part + 12D straight length)

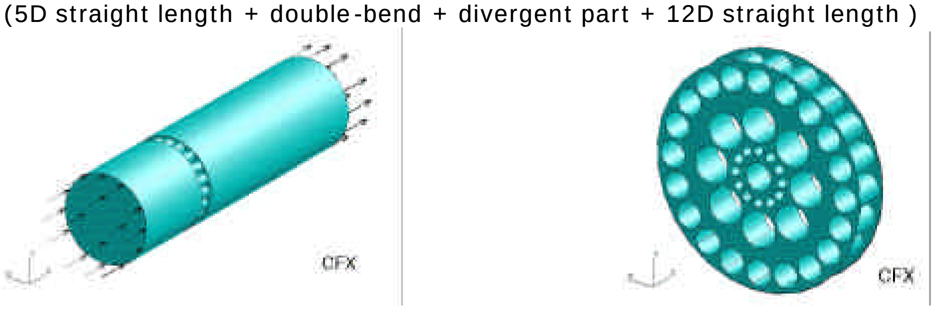


Fig. 6 : Respectively flow conditioner SMMi computational domain and numerical perforated plate representation (1D downstream the SMMi flow conditioner, 2D upstream the hole plate)

3.3 Meshing and numerical model

The code, named CFX, adopted for this numerical analysis is based on finite volumes technique. Finite volumes make possible to model complex geometry by using also unstructured grids, in respecting traditional finite difference schemes. This is essential for the simulation of geometry such as the flow conditioner design.
In this study, the interest is focused on the average values of velocity and other variables of turbulent flows, rather than their time fluctuant values. For this reason the governing flow

equations are averaged. Several turbulence models for the closure of the system of equations are available, and several of them were tested. The k-epsilon RNG model is widely used and it was found to give good results not only for analysis of flow conditioners.

For the simulation of viscous layer close to the walls, simplified models were used : a wall function approach. The viscosity-affected sublayer region is bridged by employing empirical formulas to provide near-wall boundary conditions for the mean flow and turbulence transport equations. These formulas connect the wall functions to the dependant variables at the nearest wall grid node which is presumed to lie in the fully-turbulent region of the boundary layer.
The wall function approach in CFX5 is an extension of the method of Launder and Spalding. In the log-law region, the near wall tangential velocity is related to the wall shear stress by means of a logarithmic relation. Assuming that the logarithmic profile reasonably approximates the velocity distribution near the wall, it provides a means to numerically compute the fluid shear stress as a function of the velocity at a given distance from the wall.

The alternative to wall functions is to actually fully resolve the details of the boundary layer profile with the mesh, but this requires a prohibitively fine mesh. Thus the advantage of the wall function approach is that the gradient shear layers near the wall can be modeled with relatively coarse meshes, yielding substantial savings in CPU time.

CFX-5 uses a coupled solver, which solves the hydrodynamic equations (for three components of the velocity and the pressure) as a single system. This approach uses a fully implicit discretization of the equations at any given time step. This reduces the number of iterations required for convergence.

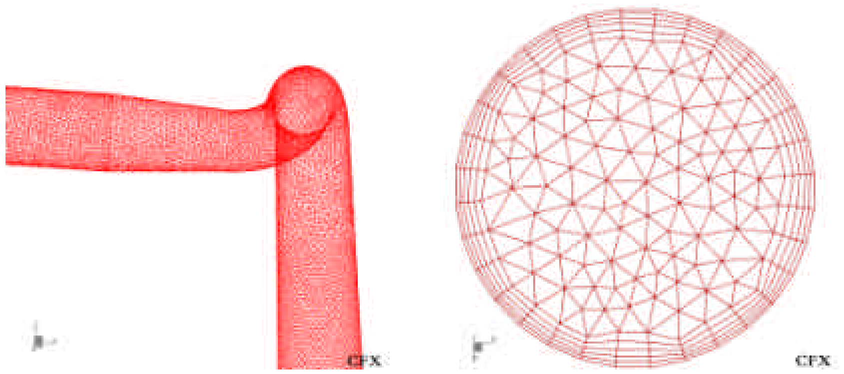


Fig. 7 : Meshing of the low-level computational domain and the boundary layer (630.000 cells).

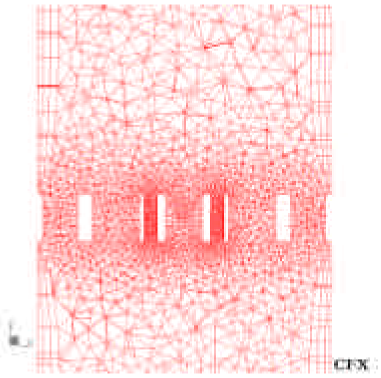


Fig. 8 : Meshing of the SMMi flow conditioner computational domain (290.000 cells).

Numerical results obtained by CFX with this model compared with experimental data showed a good agreement.

3.4 Modeling of the porous material

The modeling of porous material is based on experimental results describing the evolution of the pressure drop according to the volume flow. The pressure drop for a porous material, such as this used in the SMMi compounded is :

$$\Delta P = \frac{1}{2}.\xi.\rho.U^2 \qquad \text{eq. 1}$$

For a homogenous porous layer, the pressure drop coefficient ξ written as :

$$\xi = \frac{1{,}53}{\varepsilon'^{4,2}}.\left(\frac{30}{Re_{dg}} + \frac{3}{Re_{dg}{}^{0,7}} + 0{,}3\right).\frac{l_0}{d_g} \qquad \text{eq.2}$$

where ε' is the porosity of the material (vacuum ratio) :
. d_g is the average diameter of particles made up the porous material
. l_o is the thickness of porous material [m]
. Re_{dg} is the Reynolds number based on the characteristic quantity d_g :

$$Re_{dg} = \frac{0{,}45}{(1-\varepsilon').\sqrt{\varepsilon'}}.\frac{\rho.U.d_g}{\mu} \qquad \text{eq.3}$$

Consequently, d_g et ε' allow to calculate the theoretical pressure drop.
ε' is provided by the porous manufacturer.
d_g is obtained from the experimental results.

In this case, for Celmet® porous material grade n°3 and with a thickness of 10mm, dg=0,296mm et ε' =93,6% Redg=4300, thus ξ=21,55.

In order to model the porous material in CFX the Quadratic resistance option is used.

Resistance quadratic model provided by CFX expressed as : $\frac{\partial P}{\partial x} = aU^2$

where $a = \frac{1}{2l_o} x.r.$

3.5 Characterization of the velocity profile

Results of the numerical calculations were used to assess the efficiency of the SMM conditioner on flow perturbations. In order to assess the quality of the velocity profile downstream of the conditioner, different parameters were computed :

Turbine meters operate as integrators of the elementary momenta applied by the flow on each point of the rotor. Therefore it is best to describe the flow profiles with global flow parameters, resulting from the integration of local quantities on the entire section. We use 5 global parameters to quantify the flow perturbations with respect to a fully developed profile :

- K_U : axial momentum parameter.
- ΔK_U : difference between Ku of the disturbed profile and Ku0 of an undisturbed profile.
- K_V : tangential momentum parameter.
- K_A : asymmetry parameter.

The abbreviations used in the definitions hereunder are defined below :

A	Cross-section area
u	Axial velocity
u_m	Bulk velocity measured from the hot wire anemometer
v	Tangential velocity
r	radial position
R	Radius of the pipe
r	Flow density
y	Co-ordinate on the y-axis of the measured point
z	Co-ordinate on the z-axis of the measured point

3.5.1 Ku

K_U is the axial momentum number. It is the non-dimensional flux of radial moment of axial momentum. It gives an indication of the radial distribution of the axial velocity. The closer the location of the flow to the wall the higher the axial momentum K_U.

The definition of Ku is :

$$K_u = \frac{\iint_A r u^2 r dA}{p r u_m^2 R^3} \qquad \text{eq. 4}$$

A homogeneous flow would have $K_U=1$. For non-disturbed fully developed flows K_U is smaller than 1 and dependent on the Reynolds number. For Reynolds numbers of about 10^5, K_U is equal to 0,62. K_U increases when Reynolds number increases.

3.5.2 Kv

K_V quantifies the rotation of the flow in the pipe. It is the non-dimensionalized flux of radial moment of tangential momentum. The definition of K_V is :

$$K_V = \frac{\iint_A r u v r dA}{p r u_m^2 R^3} \qquad \text{eq. 5}$$

A positive value of K_V indicates a clockwise rotation when looking at the flow going. For a non rotating flow K_V is null.

3.5.3 K_a

K_A quantifies the asymmetry of the flow. It is relative position on the pipe radius of the centroid of mass flow. The definition of K_A is :

$$K_A = \frac{\sqrt{\left(y_S^2 + z_s^2\right)}}{R} \qquad \text{eq. 6}$$

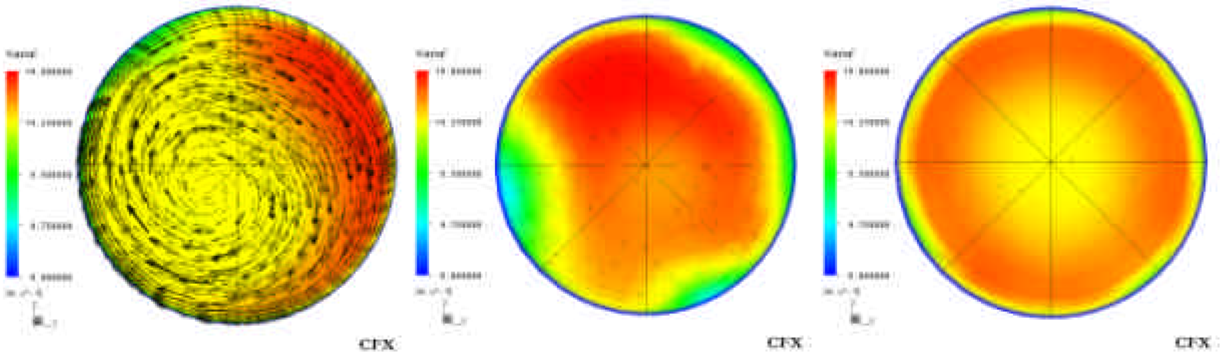
Where

$$y_s = \frac{\iint_A y r u dA}{p u_m R^2} \text{ and } z_s = \frac{\iint_A z r u dA}{p u_m R^2} \qquad \text{eq. 7}$$

Where y and z are the Cartesian co-ordinates of each point of the measurement section with the centre of the system in the centre of the section. For a symmetric flow K_A is null.

4 Results and analysis

4.1 Contour and cross flow vectors



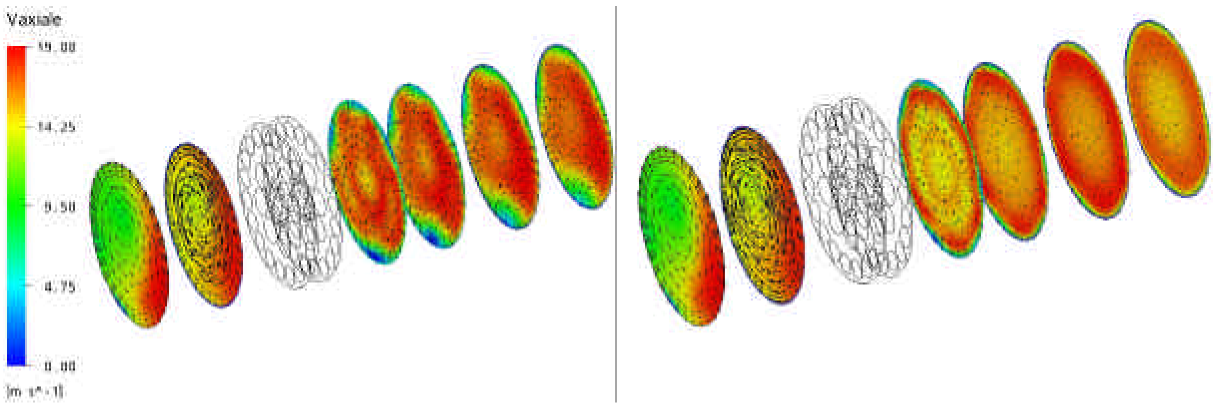
1. Without SMMi 2. single SMMi perforated plate 3. compounded SMMi

fig. 9 : contours axial velocity and cross flow velocity vectors
10D upstream of the Iso low-level obstacle.

Each contour, presented above, represent the flow obtained 10D upstream of the Iso low-level obstacle without and with the SMMi conditioner. On views 2. and 3. of the figure 9, a SMMi single and compounded are respectively placed 8D upstream of the Iso low-level.

These representations develop the positive impact of the SMMi straightener. Actually, the scale used to quantified the axial velocity contour and the cross velocity vector are the same for each configuration.

The swirl is almost completely removed by the single SMMi perforated plate. The plate also weakens the high asymmetry generated by the Iso. low-level geometry, but to a lesser extent.
As for the porous material, it haves a reduced effect on the swirl, but it increases considerably the symmetry of the flow.



single SMMi perforated plate compounded SMMi

fig. 10 : contours axial velocity and cross flow velocity vectors in the SMMi domain
(1D and 0.5D upstream of the SMMi perforated plate and 0.5D, 1D, 1.5D and 2D downstream the the SMMi perforated plate.

Figure 10 illustrates the mixing role of the SMMi perforated plate, more accurately, its action on the jet effect of the flow and on the swirl generated by the ISOLL obstacle.

4.2 Velocity profiles

4.2.1 Axial velocity profiles

In order to quantify the impact of the single and compounded SMMi on the flow, the axial and tangential velocity profiles are analysed on five traverses in the section with 45 degrees between each of them.

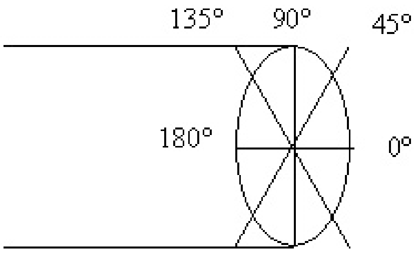


Fig. 12 : Scheme of the five studied traverses

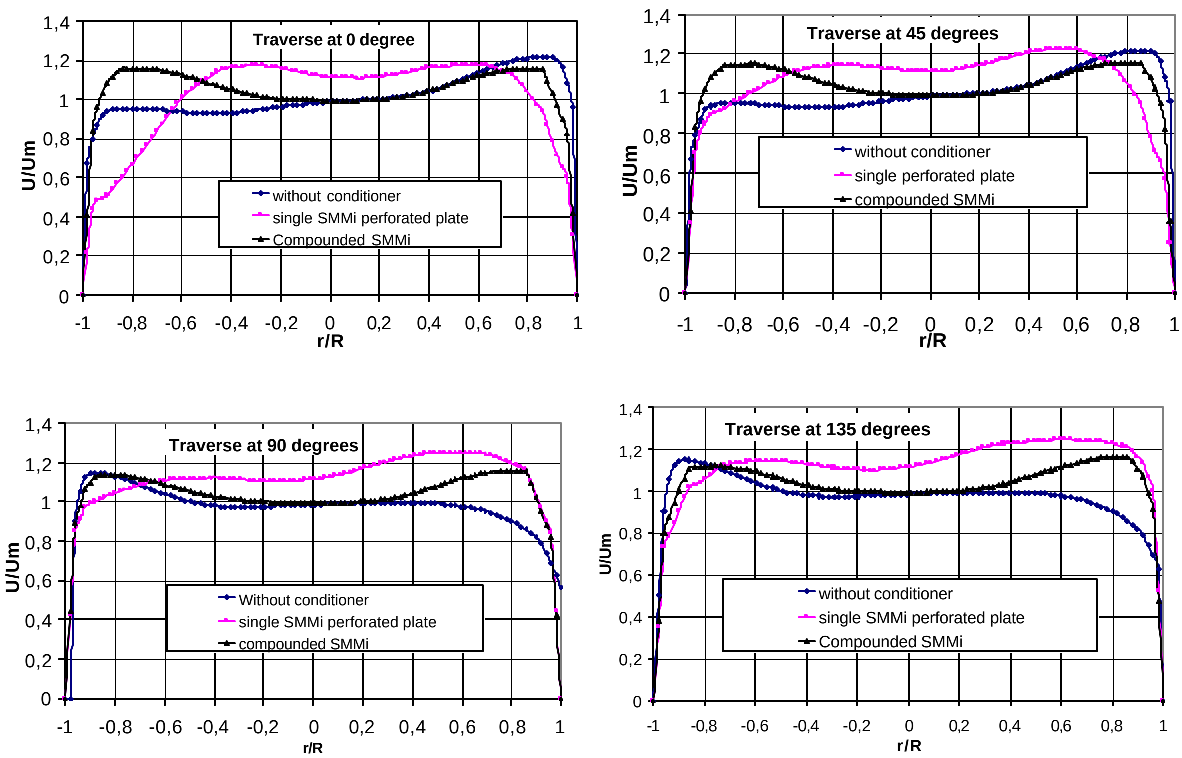


Fig. 11 : Comparison of the axial velocity profiles in the configuration with and without SMMi conditioner upstream the disturbance at different traverses
(single perforated plate or compounded SMMi).

The flow downstream of the Iso low-level obstacle is characterized by a deformation of the axial velocity profile due to the very low or even reverse flow downstream of the second bend at the inner curvature of the bend. The deformed axial profile rotates in the downstream direction due to the swirl developed in the second bend. The diffuser behind the second bend produces an adverse pressure gradient in the flow, resulting in a deceleration of the mean axial flow. Due to increasing pressure in the flow direction, such flows tend to separate easily forming re-circulation zones in the flow.

The design of the SMMi is such that the largest holes are placed on a central crown where the axial velocity values is lowest, and the thinnest holes are placed on the outer crown, where the velocity field is higher. Consequently, the maximum of velocity concentrated near to the wall, upstream of the SMMi, cross the perforated plate through the thinnest holes, while the central velocity filed cross the largest holes. Thus, the SMMi plate, to a lesser extent, acts as a reducer of velocity peaks by creating a mixing zone downstream of it. Actually, the SMMi plate increases the flatness of the flow, however, its action on asymmetry is almost inexistent.

The SMMi plate effect is limited by comparison with the compounded SMMi action on the axial velocity field. With the compounded SMMi the homogenization of the axial velocity profile doesn't occur downstream of the SMMi plate, but upstream of it, in the porous material. The action of the compounded SMMi on the axial velocity profile consists to flatten it lightly, and more particularly to make it symmetric. The last point is particularly important for turbine flow meters installation. Actually, turbine flow meters are very sensitive to the asymmetry of the flow.

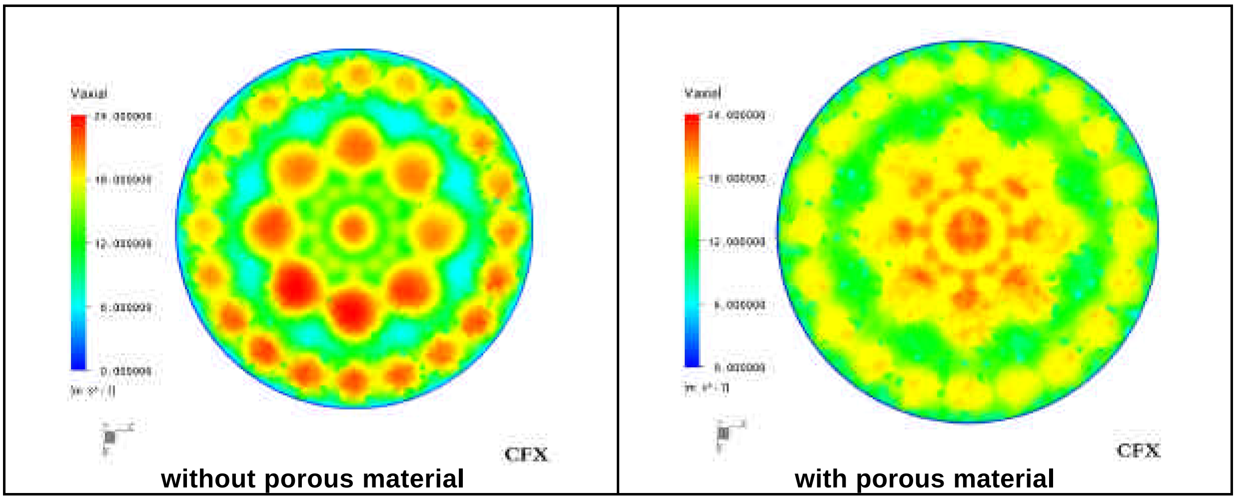


Fig. 12 : Contours of axial and tangential velocity at the middle of the porous material thickness (5 mm upstream of the SMMi perforated plate)

Figure 12 shows the impact of the porous material on the axial velocity profile upstream of the perforated plate. The axial velocity distribution near each hole is better and quasi equivalent. However, a concentration effect to the center of the SMMi is obvious, in opposition with the flow generated by the ISOLL, where the flow is concentrated on the outer section.

4.2.2 Tangential velocity profiles

The analysis of the tangential velocity profiles displays the action of the SMMi on the swirl. The swirl decrease, meanly, due to the perforated plate breaking the flow gyration. Downstream of the plate, tangential velocity is ten times lower than tangential velocity values without perforated plate.

The porous material has an impact on swirl, but in a lesser extent than the perforated plate. Actually, it removes any residual swirl. This action of the porous material is effective upstream of the perforated plate, flattening the velocity profile, by the reduction of the velocity peaks.

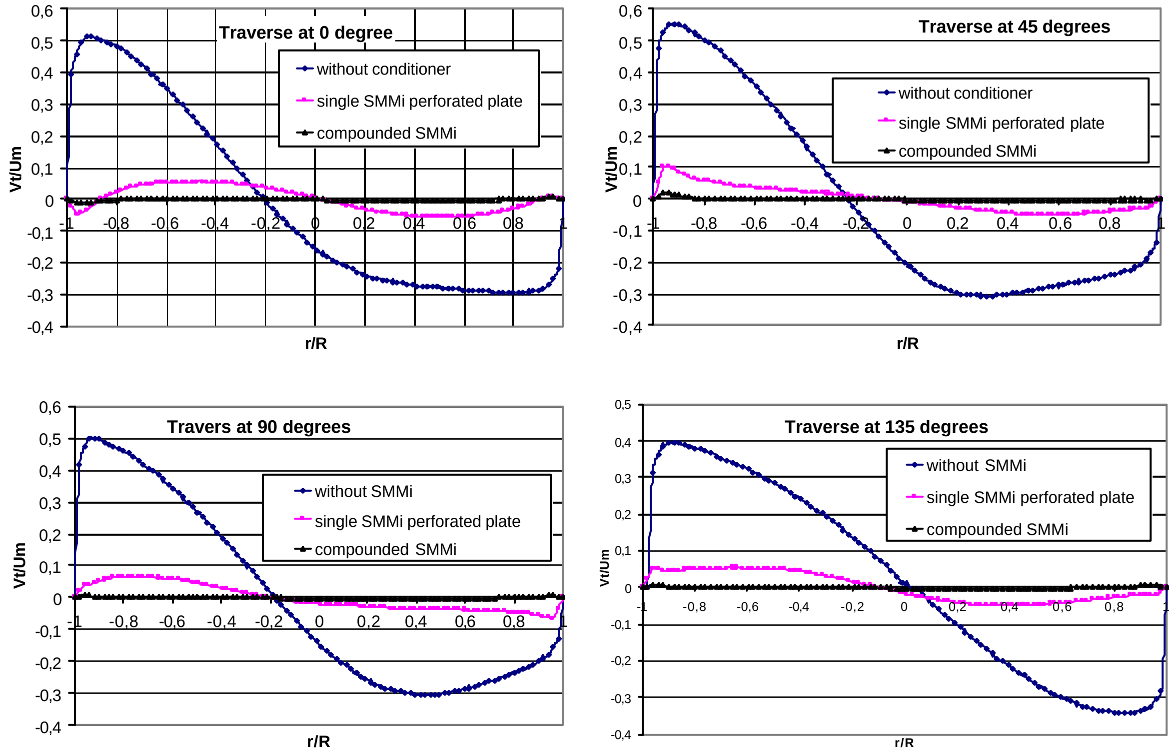


Fig. 13 : Comparison of the tangential velocity profiles in the configuration with and without SMMi conditioner, (single perforated plate or compounded SMMi) upstream of the disturbance at different traverses.

4.3 Flow parameters

In order to characterize the flow, typical integral values, described above, are calculated.

4.3.1.1 Values of flow parameters downstream the iso low level configuration

x/D	Ku	Kv	ka
0	0.758	0.236	0.168
1	0.744	0.237	0.153
2	0.711	0.241	0.147
3	0.687	0.24	0.144
4	0.675	0.237	0.142
5	0.67	0.233	0.139
6	0.668	0.229	0.134
7	0.668	0.225	0.127
8	0.667	0.221	0.118
9	0.667	0.217	0.109
10	**0.666**	**0.212**	**0.103**

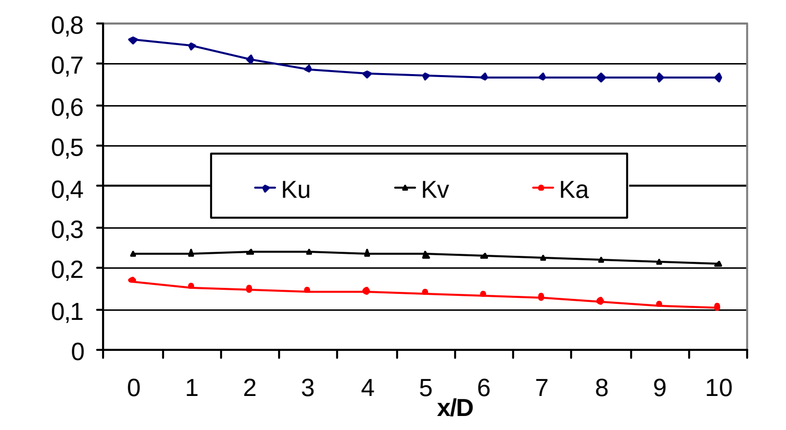


Fig. 14 : Table and graph of values of flow parameters upstream the Iso low level configuration

4.3.1.2 Values of flow parameters downstream the SMMi conditioner

	Ku	Kv	ka
Without conditioner	**0.666**	**0.212**	**0.103**
Single SMMi perforated plate	**0.612**	**0.024**	**0.030**
SMMi compounded conditioner	**0.658**	**0.0007**	**0.007**

Fig. 15 : Comparison of values of flow parameters.

These values highlight the positive impact of the SMMi straightener on the flow downstream of the low-level configuration. The SMMi generates, upstream of the potential turbine flow meter, a symmetric flow almost without swirl effect.

5 Conclusion

This first numerical study carried out by Gaz de France on the SMMi flow conditioner has increased our knowledge on the flow phenomena. The results achieved show that the performance of this straightener depends on its configuration, single SMMi or compounded SMMi :

- The perforated plate presents good characteristics in term of swirl and flatness, but asymmetry efficiencies are not very high
- the compounded SMMi, integrating a porous material upstream of the perforated plate, is very good in terms of symmetry and of swirl removal. The porous material acts as a mixing zone upstream of the perforated plate.

The compounded SMMi presents two drawbacks, one being the pressure drop and the other the clogging of the porous material. The porous material integrated in the compounded SMMi significantly increases the pressure drop of the device. The pressure drop coefficient goes from 1.5 for the single SMMi, to 22 for the compounded SMMi ($Cd=2*\Delta P/\rho v^2$).

The first may be solved by a new adjustment of the upstream pressure. The second requires that compounded SMMi be placed in a part of the network where gas is free of particles and oil. G.D.F. continues to study a new device to overcome the problem of clogging. Another numerical study will be carried out on flow conditioners to compare different types of conditioners, including the SMMi.

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