

Flow Conditioning and Effects on Accuracy for Fluid Flow Measurement

Rick Rans, RANSolutions
Blaine Sawchuk, Canada Pipeline Accessories
Marvin Weiss, Coanda Research & Development Corp.

1 INTRODUCTION

Inferential meters, such as orifice, turbine and ultrasonic meters, infer fluid flow based on an observed meter output combined with a number of fluid flow assumptions. Optimal flow conditions lead to optimal meter performance and in some cases “fully developed turbulent pipeline flow” is used to describe these optimal flow conditions. Unfortunately the length of long/straight/uniform/clean pipe required to produce “fully developed pipeline flow” often exceeds practical installation constraints. Although flow conditioning has been successfully used to create optimal flow conditions and reduce meter run lengths, problems can still exist if they are incorrectly applied. This overview presents material available from the literature which describes some of the installation effects that need to be managed.

2 WHAT IS “FULLY DEVELOPED TURBULENT PIPELINE FLOW”?

“Fully developed pipeline flow” occurs in long/straight/uniform/clean pipe when the pipe wall friction effects completely control the fluid flow characteristics. It occurs at the point where these characteristics no longer change as the fluid flows further downstream in long/straight/uniform/clean pipe. Figure 1 shows the pictorial development of pipeline flow. Even though flow enters the pipe with a uniform inlet velocity, the pipe wall boundary layer influence on the flow profile increases until it reaches the center of the pipeline flow. Reynolds Number and pipe wall surface roughness control the entrance length (L_e) required to cause fully developed turbulent flow. With uniform inlet conditions this length can be $>100D$. Add to this additional inlet flow perturbations and the required pipe length can increase.

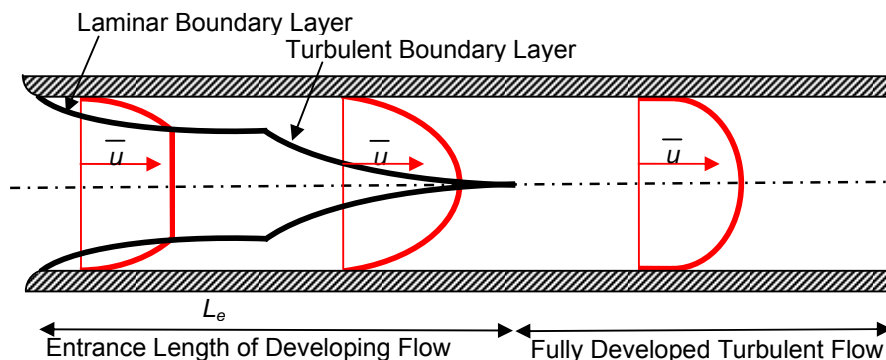


Figure 1 – Fully Developed Turbulent Pipeline Flow

Characteristics such as swirl, flow profile, and turbulence intensity can be used to describe pipeline flow. Some examples of these measurements are:

- Figure 2 is an example of full body swirl in bare pipe 10 diameters downstream of two 90° elbows out of plane. [1] The red arrows show the direction and magnitude of the swirl superimposed on the axial flow profile.
- Figure 3 shows measured and expected values of the axial/cross-flow velocity and turbulence profiles. The measurements were taken in a meter proving facility prior to the start of meter testing. [2]

This information can be used to help understand if the flowing conditions are stable and what the effect these instabilities and flow changes have on the meter performance.

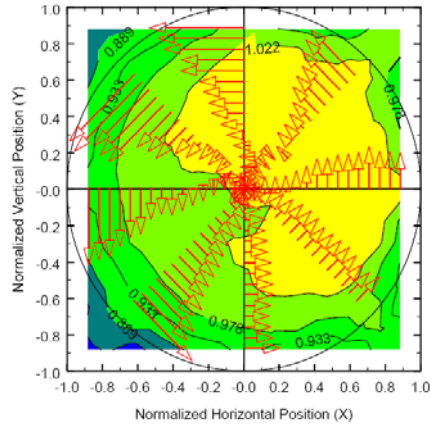


Figure 2 – Velocity Profile with Swirl

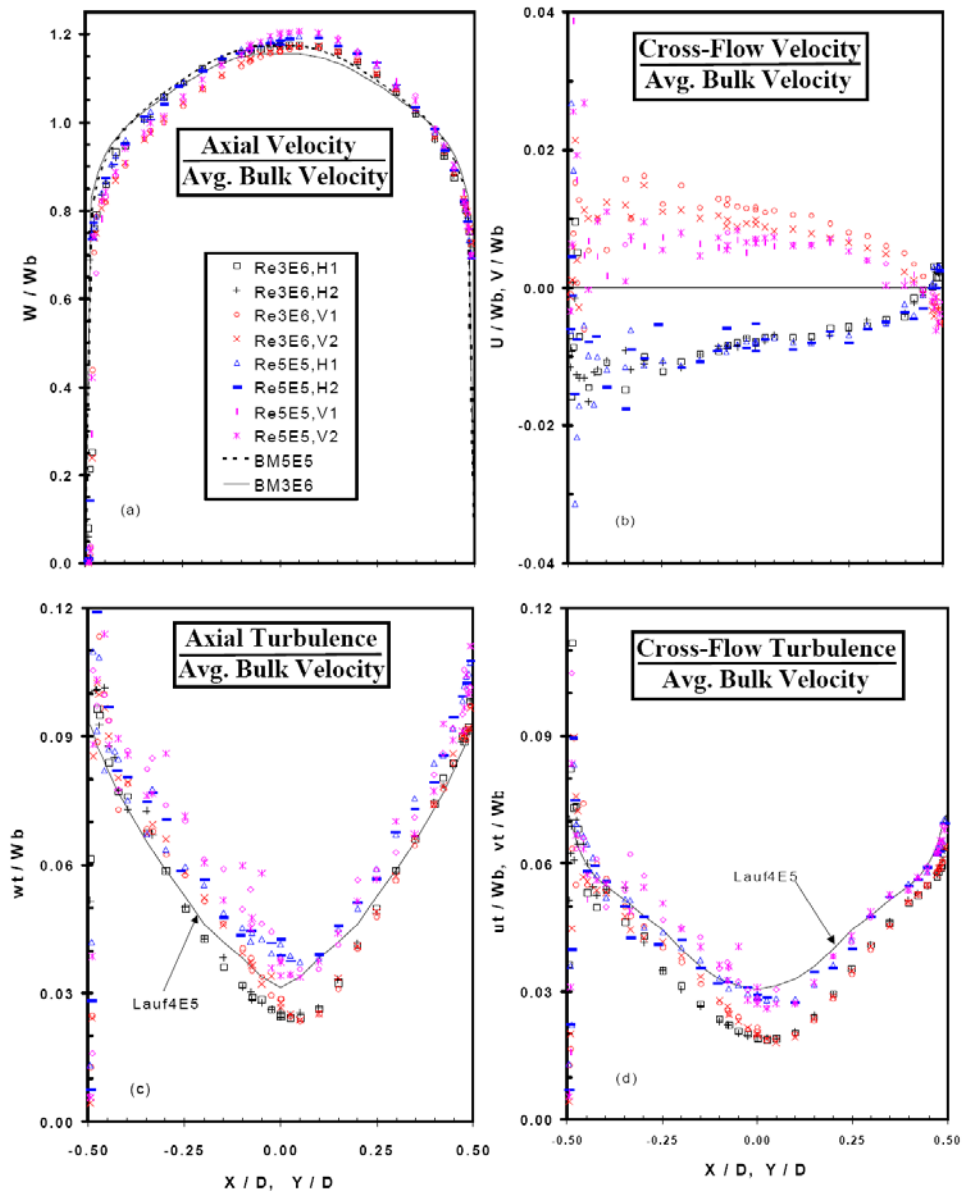


Figure 3 – Axial/Cross-Flow Velocity and Turbulence Measurements – “Good Flow”

3 EFFECTS OF FLOW CONDITIONS/CONDITIONERS ON METER PERFORMANCE

The effect of meter inlet velocity profile conditions has been discussed extensively and installation effect test results published in GRI test report for orifice [3], turbine [4] and ultrasonic meters [1]. GERG have also published ultrasonic meter installation effect test results [5]. Although swirl angle and velocity profile have been measured and their effects recorded, turbulence effects have often been over-looked.

3.1 Swirl and Velocity Profile

The detrimental effects of swirl on orifice and turbine meters have been known for many years. Once swirl has been created by a flow disturbance, the pipe wall roughness of long straight pipe only has a limited effect and only causes the swirl to slowly decay. As a result, swirl can propagate downstream for long distances and requires very long pipe length to control it and is the main reason for the use of tube bundle flow conditioners in orifice meter runs.

Tube bundle flow conditioners were designed prior to the availability of modern measurements of flowing conditions or simulation software. Orifice meter installation effect testing done in the late 1990's confirmed the tube bundle conditioners ability to control swirl but also showed a less than acceptable ability to control the pipe velocity profile. [3]

The meter inlet velocity profile affects the meter accuracy, if it differs from the conditions under which the meter was calibrated or the coefficient of discharge determined. Figure 4 shows a typical flow profile for fully developed turbulent pipeline flow normalized to the average bulk velocity. It will be used as a reference when discussing the effect of velocity profile on orifice, turbine and ultrasonic meters.

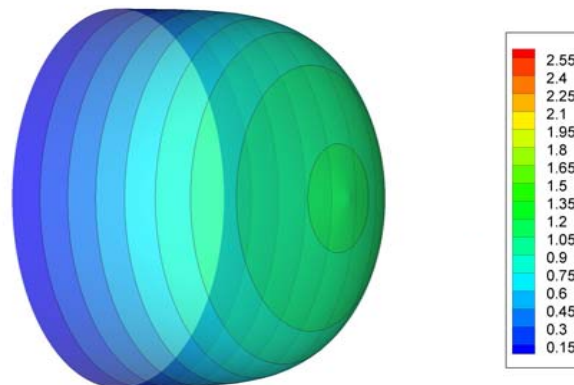


Figure 4 – Typical Velocity Profile (“Fully Developed Turbulent Pipeline Flow”)

3.1.1 Orifice Meter

The orifice meter measures the pipe wall pressure difference caused by a square edge orifice plate installed in the pipe flow. Because the meter measures pressure difference, the effect of a velocity profile that is different from Figure 4 – Typical Velocity Profile (“Fully Developed Turbulent Pipeline Flow”) is hard to visualize. The interaction of the inlet flow profile with the orifice plate altered flow profile, the effect of flow recirculation and the resultant pipe wall pressure requires flow lab testing.

Figure 5 shows a computer simulation of the velocity and pressure changes that occur under good inlet flow conditions and “Orifice Meter Installation Configurations with and without Flow Conditioners - White Paper Prepared for API 14.3 p.2” [3] provides measured installation effects for a number of inlet piping conditions.

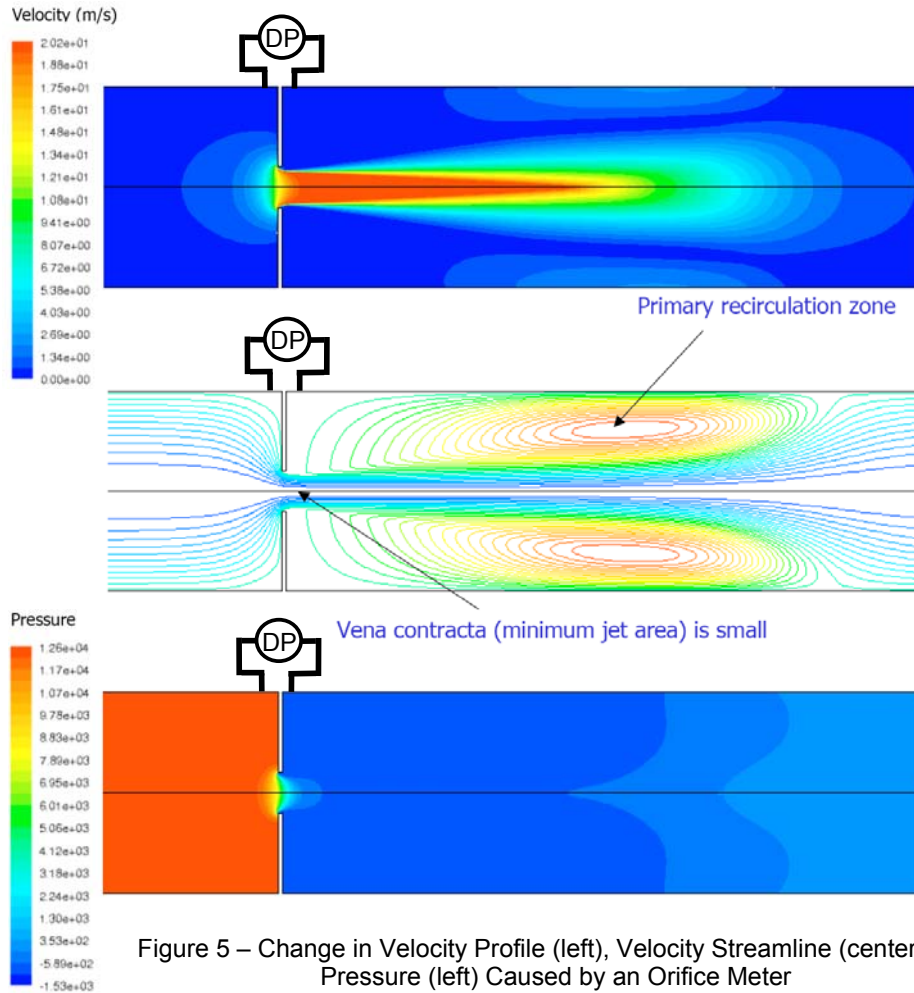


Figure 5 – Change in Velocity Profile (left), Velocity Streamline (center) and Pressure (left) Caused by an Orifice Meter

3.1.2 Turbine Meter

Most turbine meters in gas service use an inlet nose cone/flow conditioner to increase the gas velocity and reduce the effect of inlet flow conditions. Figure 6 shows the cross-section of a turbine meter with an inlet nose cone and flow annulus.

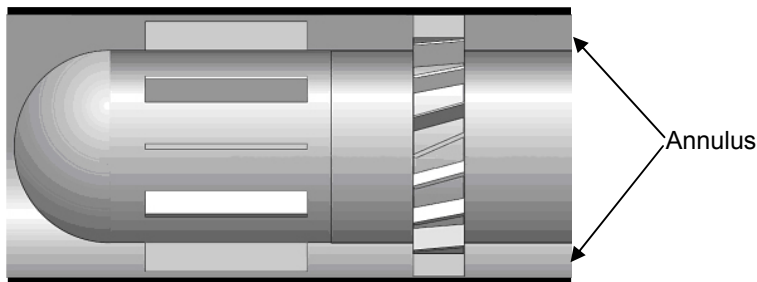
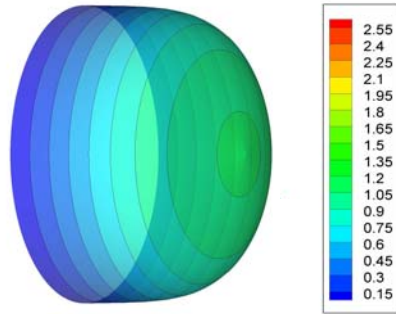


Figure 6 – Turbine Meter Showing Nose Cone and Flow Annulus

Figure 7 shows the inlet flow profile for a typical "fully developed turbulent pipeline flow" and the flow profile through the turbine meter annulus. It should be noted that the annulus area is ~50% of the pipe cross sectional area and would equate to a pipe flow restriction for an orifice with a beta ratio of ~0.7.

Normalized Pipeline Velocity



Normalized Turbine Annulus Velocity

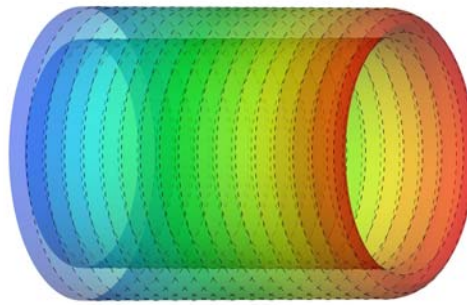


Figure 7 – Annulus Velocity Profile (Turbine Meter with Nose Cone)

Because the turbine meter infers the pipeline flow from the gas velocity it is easier to visualize the changes to a distorted inlet flow profile. The turbine meter rotor measures ~100% of the annulus flow but the effect of velocity imbalances on the turbine rotor can still cause a metering error. [4]

3.1.3 Ultrasonic Meter

Transit time ultrasonic meters measure differences in travel time when traversing a chordal path with the pipeline flow and against the pipeline flow. (Refer to AGA Report 9 [6] for a detailed discussion of its theory of operation and installation requirements.)

Figure 8 – Single Path USM Measures the Average Velocity Profile Along the Cord shows the normalized “fully developed turbulent pipeline flow” profile and the chordal path for a single path ultrasonic meter. The single path meter averages the velocity along the cord which represents <5% of the pipe flow. In this example the average velocity over the pipe cross-sectional area equals 1 while the average velocity along the center-line cord equals ~1.09.

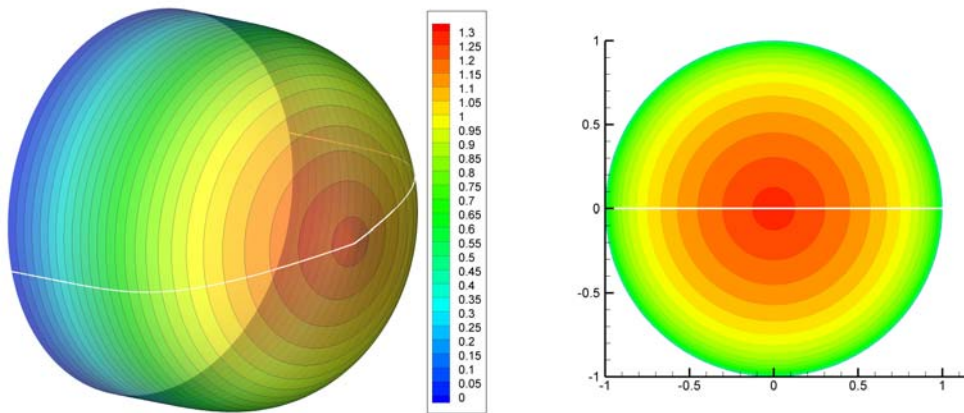


Figure 8 – Single Path USM Measures the Average Velocity Profile Along the Cord

Because the ratio of center-line averaged velocity to pipe cross section averaged velocity changes with Reynolds Number, this meter requires a Reynolds Number correction factor. Ideally the ultrasonic meter would measure the velocity along the cord times the pipe area that the velocity represents. For example the velocity of the center ¼ of the pipe only contributes ~6.25% to the total pipeline average velocity based on its area contribution while the outside ¼ of the pipe contributes ~43.75% to the total pipeline average velocity based on its area contribution.

By calculating the product of the velocity times its annulus area along the center line cord and normalizing the sum of these values to the average pipeline velocity, the ideal velocity

weighting for a single path ultrasonic meter can be calculated as shown in Figure 9. In this case the average velocity along the center-line cord would equal 1.

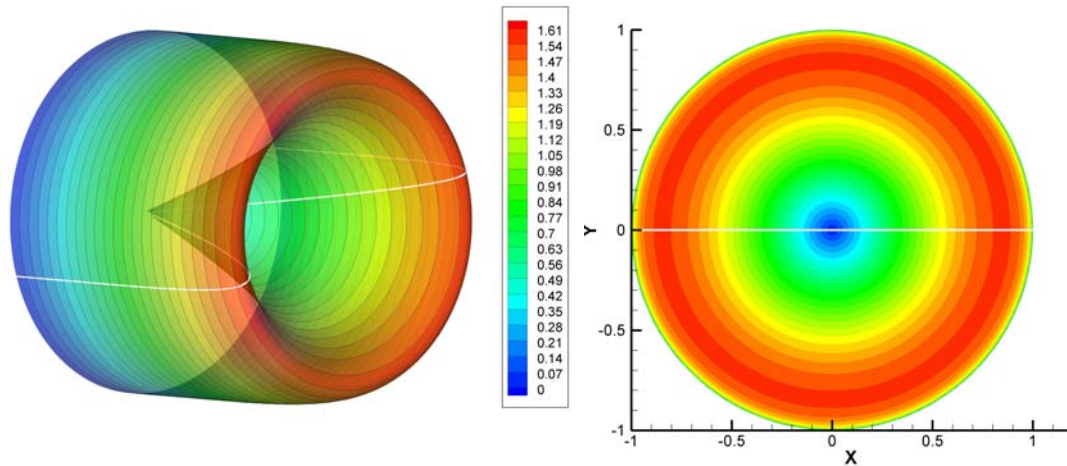


Figure 9 – Ideal Single Path Meter Would Measure the Annulus Weighted Velocity Along the Cord

Although this is an academic exercise, it does allow visualizing the effect of velocity changes on the meter performance. For example comparing Figure 8 to Figure 9 we see that a single path ultrasonic meter is over sensitive to the velocity changes at the center of the pipe and under sensitive to velocity changes toward the pipe wall.

For a single path meter the optimal location for the cord would be $0.5R$ [7] to minimize the meter's sensitivity to Reynolds Number. For multi-path meters, the optimal location may be based on Gaussian quadrature uniform velocity distribution methods [8] or proprietary designs.

The effects of velocity profile [9] [10] and installation effect/flow conditioner tests have been reported previously. [1] [5]

3.2 Turbulence Intensity

Review of literature and recent simulation work indicates that in addition to swirl and flow profile, turbulence can also have a significant, but less understood effect on meter accuracy.

3.2.1 Orifice Meter

Karnik et al. "Effect of Turbulence on Orifice Meter Performance" [11] measured flow profile and turbulence downstream of a tube bundle. The first set of tests measured these effects in good flow conditions. The second set of tests measures the effects of tube bundle location in a 19D meter run downstream of a 90° elbow. The third set of tests replaced the velocity/turbulence measuring apparatus with an orifice plate and measured the effect of tube bundle location on the upstream and downstream tap pressure, differential pressure and ΔC_D .

A number of observations can be drawn from these measurements and the paper:

1. The axial velocity profile downstream of a tube bundle in good flow conditions is distorted as it exits the tube bundle but returns to fully developed conditions within 4D.
2. The axial and radial turbulence intensities downstream of a tube bundle in good flow conditions are higher than "fully developed turbulent pipeline" flow at 2D, approximately the same as "fully developed turbulent pipeline" flow around 4D, lower than "fully developed turbulent pipeline" flow from 6D to >17D, and return to "fully developed turbulent pipeline" flow at a location significantly >17D.
3. The axial velocity profile downstream of a tube bundle at various locations in a 19D meter run is dependent on the distance of the tube bundle from the elbow.
4. The axial and radial turbulence intensities downstream of a tube bundle at various locations in a 19D meter run are under developed at 8D and 10D, at 4D the axial

turbulence intensity is flatter than “fully developed turbulent pipeline” flow with the centreline turbulence intensity being approximately the same and at 4D the radial turbulence intensity approaches “fully developed turbulent pipeline” flow with the exception of the turbulence intensity towards the pipe wall being overdeveloped.

5. “Although the mean velocity is the major contributor to metering error, it becomes important to examine the effects of the turbulent stresses in cases where no deviation is seen in the mean velocity, and yet there results a metering error.”

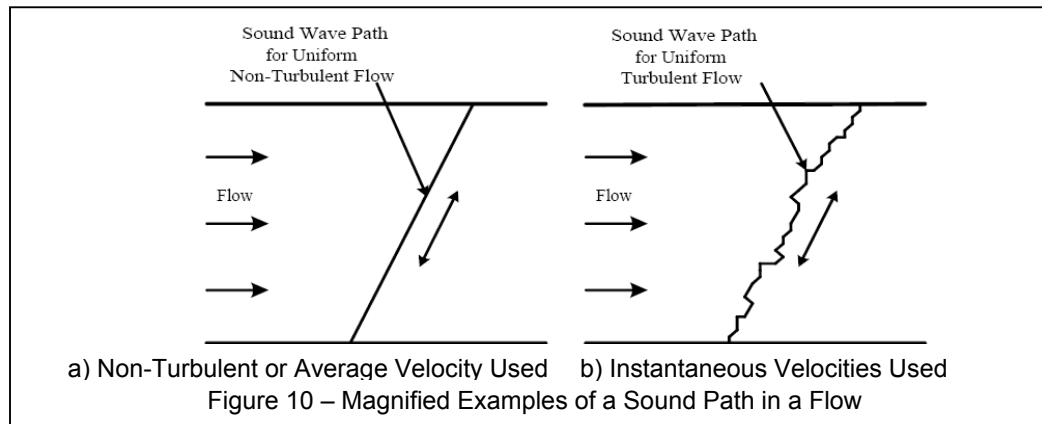
Although turbulence affects orifice measurement, it appears that flow conditioners may have addressed or minimized these problems as evidence by flow conditioner perturbation testing.

3.2.2 Ultrasonic Meter

Based on a literature search, turbulence can affect the performance of transit time ultrasonic meters in a number of ways.

1. Increased Path Length

“The path increase due to turbulence is caused by the random nature of fluid turbulence speeding up and slowing down the sound in the path, the result of which is a “crooked” path”
The crooked line representation in Figure 10 [12] is exaggerated to convey the concept.



To illustrate the change in sound path Figure 11 shows a sketch of a sound wave crossing a pipeline. The sketch on the left shows the sound wave with-out the effects of turbulent vortices and the sketch on the right shows the sound wave warping due to the interaction with a turbulent vortex.

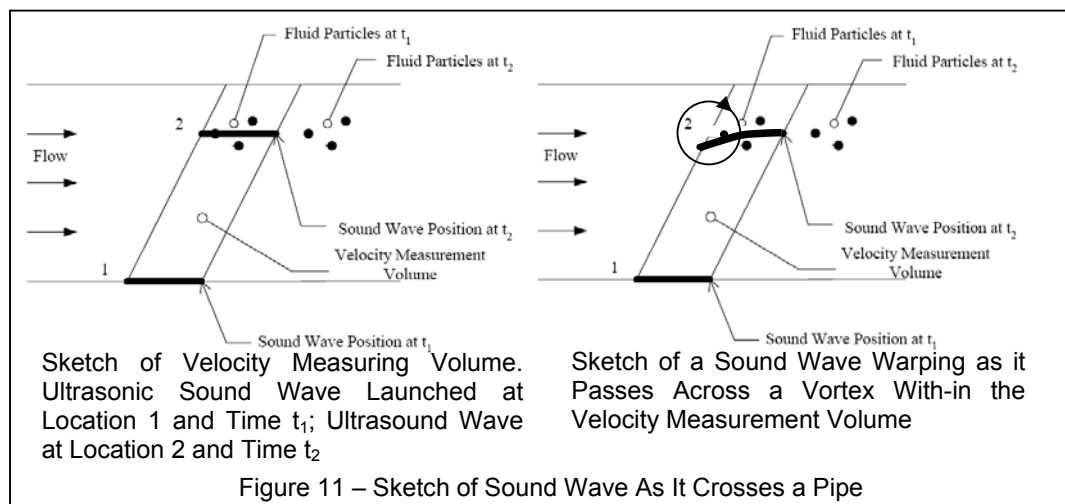
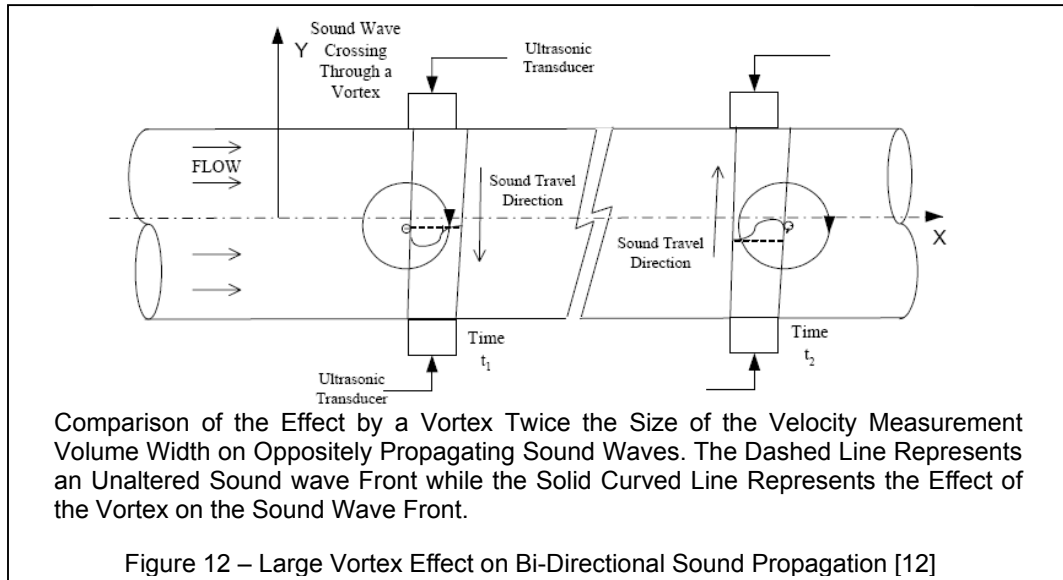
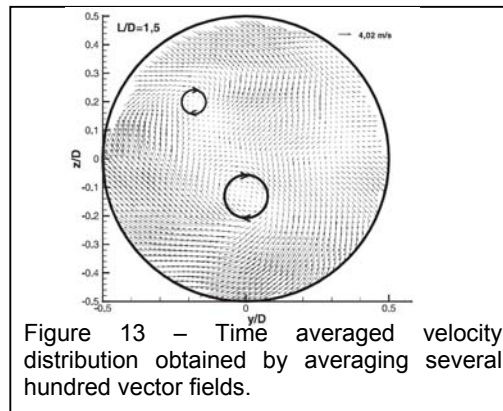


Figure 12 illustrates the effect of a large vortex on bi-directional sound propagation.



To date very little research has been done to measure the effects of turbulent vortex changes on ultrasonic meter calibration however a paper on pipe flow visualization [13] provides some interesting measurements at low pressure. Figure 13 shows a time averaged velocity distribution downstream of a 90° bend obtained by averaging several hundred instantaneous vector fields as show in **Error! Reference source not found.**



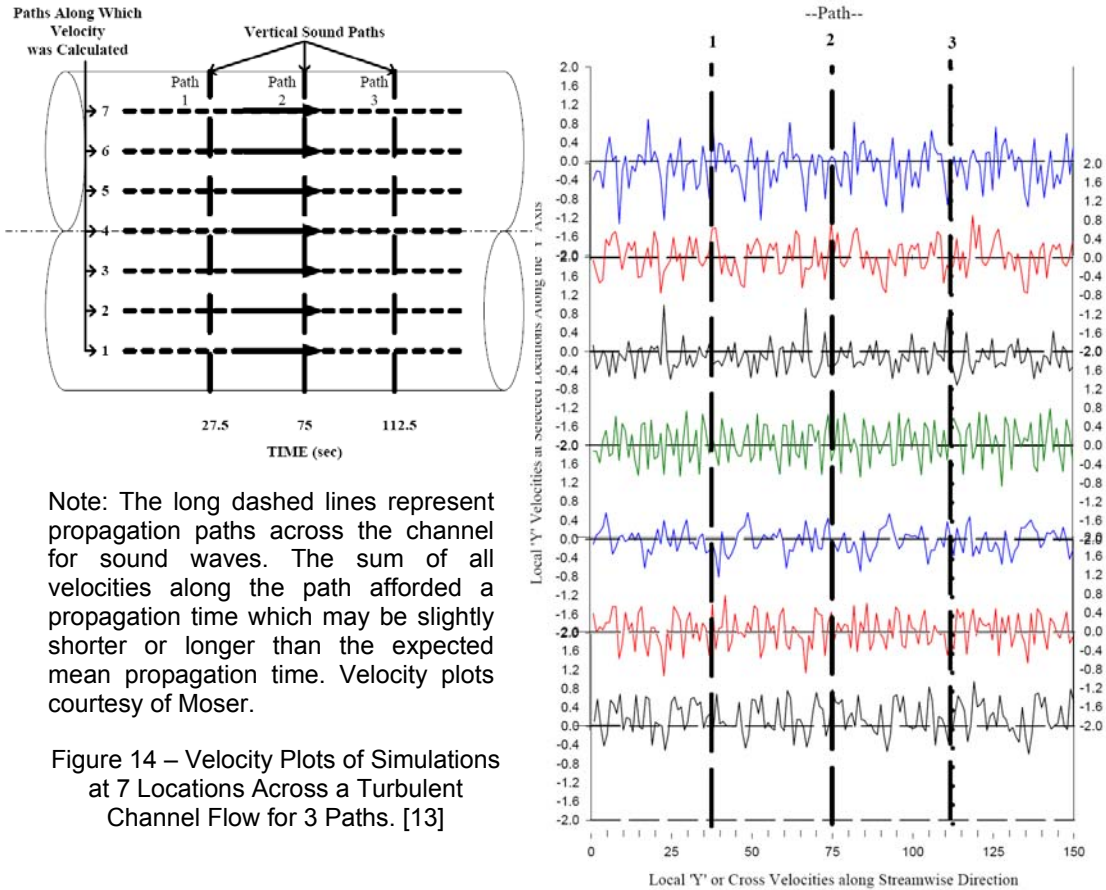
What is the impact of the turbulent vortices shown in Figure 13?

- The time averaged values indicate a systematic effect is possible.

2. Turbulence Induced Cross-Velocity [13]

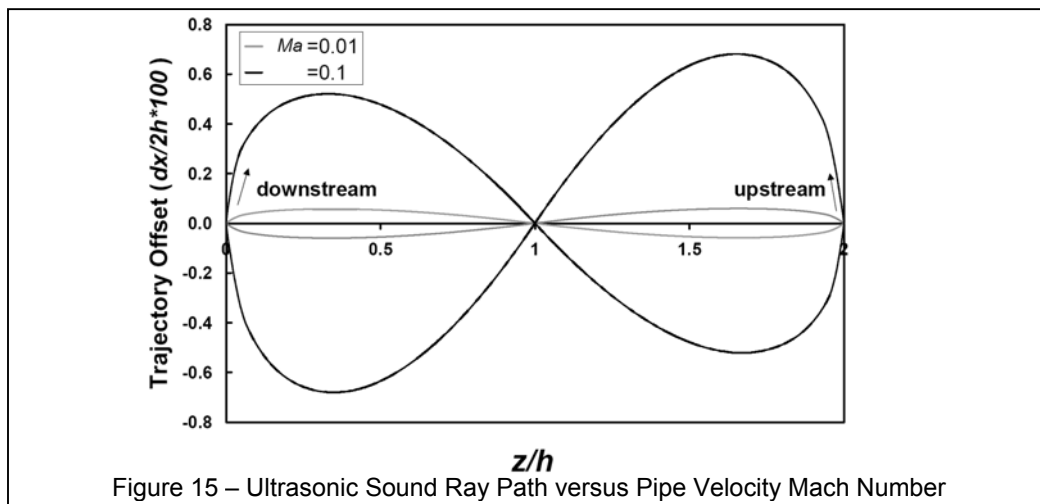
Turbulence induced cross-velocity can affect the average transmit time. To demonstrate this effect, three vertical ultrasonic paths are indicated by vertical dashed lines in **Error! Reference source not found.** In this example, the sound is propagating perpendicular to the flow so that, there is no average velocity in the sound travel direction. It would be expected, then, that the propagation time will always be the same; however, due to turbulence, there are small velocity perturbations in the direction of the sound propagation.

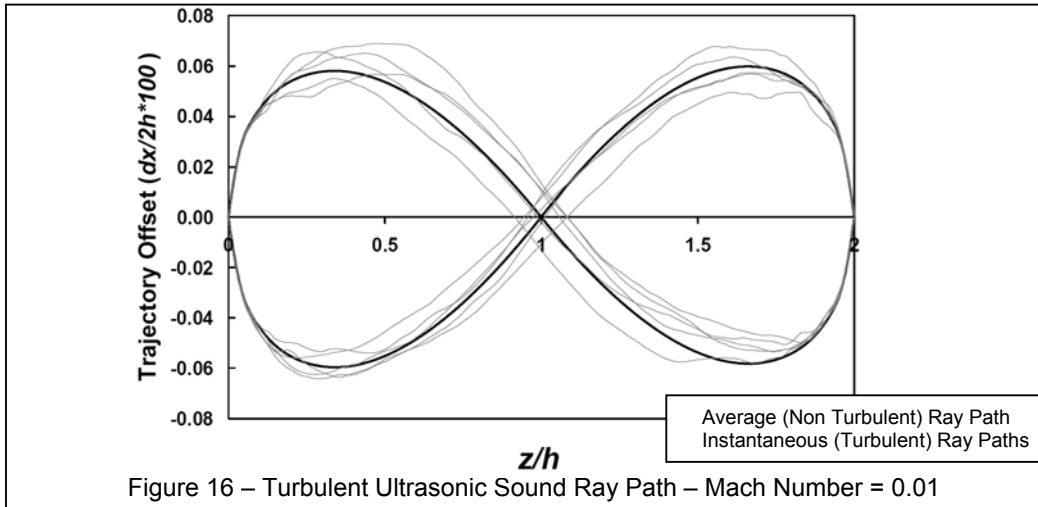
As the sound pulse propagates, it will be sped up and slowed down by these velocity perturbations or turbulent velocities as compared to the mean transit speed. Although the average cross-velocity is zero in “fully developed turbulent pipeline flow” (it is part of the definition of fully developed), it may not be zero downstream of pipeline fittings and flow disturbances.



3. Turbulence Effect on Ultrasonic Ray Trace Path

Ray tracing of the ultrasonic sound has been used to account for the change in the sound path length as the pipeline velocity increases, Yeh and Mattingly [14] and the effect of turbulence was added to this analysis by P. Moore, A. Johnson, P. Espina as shown in Figure 15 and Figure 16 which were copied from “Simulations of Ultrasonic Transit Time in a Fully Developed Turbulent Flow using a Ray-Tracing Method”. [15]





The paper concluded:

- The deviation of the calculated transit time increases with increasing Ma due to the enlarged change of the path trajectory from a straight line and the magnitude of the change in the down and upstream trajectories are generally not equal.
- The case of an ensemble of turbulent-like velocity profiles showed similar trends to the case of the average ray trace and can cause additional changes in the path lengths and ultrasonic transit time measurements.

Calibration of an ultrasonic meter at close to flowing conditions will account for changes in the average ray path length with pipeline velocity and for the turbulent conditions at the proving facility. If the turbulent vortex patterns/characteristics change from the conditions under which the meter was calibrated, the calibration of the meter may be affected. Additional research is required to quantify these effects.

4. Turbulence Effect on Velocity Profile

“Simulations of Ultrasonic Transit Time in a Fully Developed Turbulent Flow using a Ray-Tracing Method” [15] also provides the results of fluctuations and mixing length simulations for “fully developed turbulent pipeline flow” with and without instantaneous turbulence. (Figure 18 and Figure 17 - u is the pipeline axial velocity component, v and w are the non-axial velocity components)

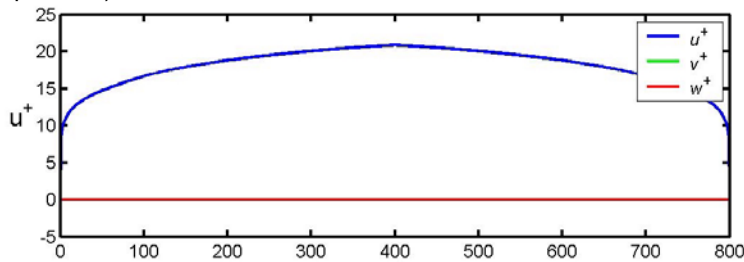


Figure 18 – Fully Developed Flow without Instantaneous Turbulent Fluctuations

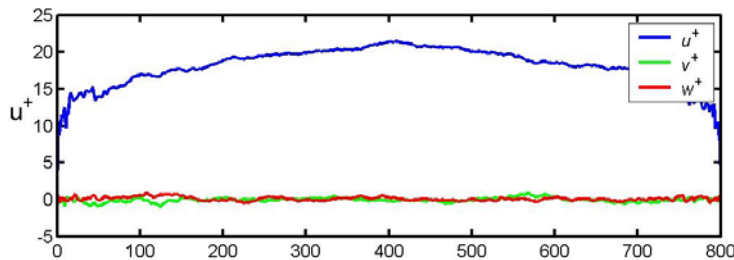


Figure 17 – Fully Developed Flow with Instantaneous Turbulent Fluctuations

4 HOW CAN FLOW CONDITIONERS HELP

4.1 Orifice Meters

The initial focus of flow conditioning was related to orifice measurement. Although proposals to use flow profile deviation and swirl limits have been tried, they have been unsuccessful to date. Flow profile, swirl and turbulence intensity can provide some insight into installation effects on orifice measurement but they cannot be directly related to orifice measuring principles. The orifice equation is ultimately based on empirical test data and requires empirical testing to demonstrate flow conditioner performance.

The API white paper “Orifice Meter Installation Configurations with and without Flow Conditioners” [3] documents installation effects and acceptance requirements for a number of installation configurations. It also recommended perturbation (performance) based testing of emerging technology flow conditioners meet these same requirements and this recommendation was incorporated into the AGA-3/API 14.3 part 2 in 2000 [16] as Appendix 2-D. (A number of flow conditioners have been tested against these requirements and the results are available from the manufacturer.)

4.2 Turbine Meters

The turbine meter design shown in Figure 6 incorporates a nose cone to condition the gas flow and a rotor that measures ~100% of the meter flow.

Although turbine meters are less sensitive to installation effects than orifice meters, these effects still exist. AGA Report 7 [17] provides the guidance on the need for flow conditioning and focuses on flow conditioners that control the effects of swirl and asymmetric flow.

4.3 Ultrasonic Meters

Ultrasonic meters are significantly different from orifice and turbine meters because they incorporate no flow conditioning. They rely on measurement of less than 5% of the flow (even with multiple paths) and a combination of assumptions and measurements of swirl, flow profile and turbulence structure/intensity. AGA-9 [6] requires that the ultrasonic meter be installed with a piping configuration or flow conditioning: “that will not create an additional flow rate measurement error of the meter more than 0.3% due to the installation configuration”.

GRI [18] and GERG [19] have published selected ultrasonic meter installation effects tests for bare tube and various tested flow conditioners. Summary tables of the test results are below.

4.3.1 GRI and GERG Published Bare Tube Installation Effects

GRI Test Results		Single Elbow		GERG Test Results		Single Elbow		
		0 Degrees	90 Degrees			12D	20D	30D
Daniel	10D Bare	-0.07%	0.02%	Daniel	0.18%	-0.24%	0.01%	
	20D Bare	-0.13%	-0.11%	FMC	-0.28%	-0.14%	-0.15%	
FMC	10D Bare	0.14%	0.29%	Instromet	-0.40%	0.04%	0.01%	
	20D Bare	0.03%	0.04%					
Instromet	10D Bare	0.11%	0.06%					
	20D Bare	0.33%	0.32%					

Table 1 – Single 90° Elbow

GRI Test Results		Elbows In Plane	
		0 Degrees	90 Degrees
Daniel	10D Bare	0.02%	0.24%
	20D Bare	0.11%	0.12%
FMC	10D Bare	-0.18%	-0.52%
	20D Bare	-0.10%	0.10%
Instromet	10D Bare	0.53%	0.76%
	20D Bare	0.51%	0.64%

Table 2 – Double 90° Elbows In Plane

7th South East Asia Hydrocarbon Flow Measurement Workshop
5th – 7th March 2008

GRI Test Results		Elbows Out of Plane	
		0 Degrees	90 Degrees
Daniel	10D Bare	0.53%	-0.04%
	20D Bare	0.05%	0.10%
FMC	10D Bare	-1.02%	-1.22%
	20D Bare	0.48%	0.12%
Instromet	10D Bare	0.53%	0.26%
	20D Bare	0.93%	0.84%

GERG Test Results		Double Elbows Out of Plane		
		12D	20D	30D
Daniel		0.95%	-0.04%	0.04%
FMC		0.34%	-0.02%	-0.02%
Instromet		-0.46%	-0.36%	-0.19%

Table 3 – Double 90° Elbows Out of Plane

Note: Only a portion of the test results meet the 0.3% uncertainty requirement of AGA-9 [6] and some of the meters show different effects depending on the meter orientation.

Note: These test results are a number of years old and ultrasonic meter designs have improved significantly. The information is provided for illustrative purposes only and the ultrasonic meter vendors should be consulted to obtain current meter performance data.

4.3.2 GRI and GERG Published Installation Effects Test Results with Flow Conditioners

GRI Test Results		Straigh Upstream Piping			
		CPA 50 E FC	Gallagher FC	Vortab	19 Tube Bundle
Daniel		0.17%	0.18%	-0.08%	0.17%
FMC		0.16%	0.04%	-0.02%	-0.05%
Instromet		-0.10%	-0.17%	0.37%	0.18%

GERG Test Results		Straigh Upstream Piping			
		CPA 50 E FC	Gallagher FC	Daniel Profiler	Instromet FS-3
Daniel		-0.11%	0.19%	0.11%	
FMC		-0.10%	0.01%		
Instromet		-0.06%	0.29%		-0.14%

Table 4 – Long Straight Inlet Piping

GRI Test Results		Single Elbow							
		CPA 50 E FC		Gallagher FC		Vortab		19 Tube Bundle	
		0	90	0	90	0	90	0	90
Daniel		-0.15%	-0.13%	0.04%	0.00%	0.10%	0.03%	-0.35%	-0.37%
FMC		0.16%	0.02%	0.04%	0.24%	0.05%	0.02%	0.33%	0.42%
Instromet		0.30%	0.30%	0.20%	0.12%	-0.07%	-0.11%	0.25%	0.05%

GERG Test Results		Single Elbow			
		CPA 50 E FC	Gallagher FC	Daniel Profiler	Instromet FS-3
Daniel		0.01%	0.35%	-0.12%	
FMC		-0.25%	-0.06%		
Instromet		0.03%	-0.26%		-0.21%

Table 5 – Single 90° Elbow

GRI Test Results		Double Elbow In Plane							
		CPA 50 E FC		Gallagher FC		Vortab		19 Tube Bundle	
		0	90	0	90	0	90	0	90
Daniel		0.03%	0.04%	0.36%	0.41%	0.07%	0.14%	-0.15%	-0.22%
FMC		0.16%	0.02%	0.06%	0.08%	-0.12%	-0.09%	0.11%	0.10%
Instromet		0.43%	0.50%	0.28%	0.26%	0.07%	0.13%	0.38%	0.39%

Table 6 – Two 90° Elbows In-Plane

GRI Test Results		Double Elbow Out of Plane							
		CPA 50 E FC		Gallagher FC		Vortab		19 Tube Bundle	
		0	90	0	90	0	90	0	90
Daniel		-0.23%	-0.30%	0.23%	0.30%	-0.02%	0.02%	0.13%	0.37%
FMC		With-in +/-0.3%		-0.13%	-0.11%	-0.19%	-0.19%	0.09%	-0.11%
Instromet		0.36%	0.33%	0.10%	0.05%	0.10%	0.09%	0.47%	0.52%

Note: Modifications of the meter's calculation algorithm made by the meter manufacturer after these tests would bring their results below the 0.3% specification.

GERG Test Results		Double Elbow Out of Plane			
		CPA 50 E FC	Gallagher FC	Daniel Profiler	Instromet FS-3
Daniel		0.22%	0.10%	-0.17%	
FMC		-0.25%	-0.06%		
Instromet		0.23%	-0.29%		-0.07%

Table 7 – Two 90° Elbows Out-of-Plane

Note: Most of the test results meet the 0.3% uncertainty requirement of AGA-9 [6] and some meters show different effects based on meter orientation.

Note: These test results are a number of years old and ultrasonic meter designs have improved significantly. The information is provided for illustrative purposes only and the ultrasonic meter vendors should be consulted to obtain current meter performance data.

4.3.3 Understanding the Interaction between Flow Conditions and Ultrasonic Meters

As described in 3.2.2, ultrasonic transit time can be affected by swirl, flow profile and turbulence structure/intensity. To address these effects, the meter manufacturers have developed various designs and algorithms for use in combination with and with-out flow conditioners. The results of the interaction of flow conditioners with ultrasonic meters in good flow conditions (Table 4) are generally less than 0.1% to 0.2% and are approaching the repeatability of the test facilities. Why then does the addition of piping configurations upstream of the flow conditioner cause the ultrasonic meter output to be affected?

A hint may lie in simulation results presented in a student thesis “Numerical and experimental evaluation of flow through perforated plates”. [20] It shows that all flow conditioners are not created equal and that even flow conditioners with a similar design can have significant differences. Pipe flow is simulated for four variations of a perforated plate (Figure 19) downstream of a 50% closed gate valve.

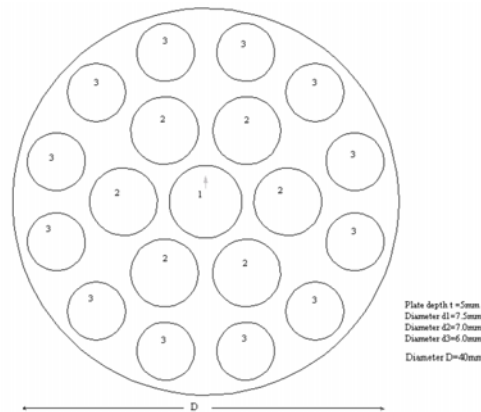


Figure 19 – Perforated Plate Design Used In Pipe Flow Simulations

The four variations of the perforated plate are:

- Model C: 19 Hole (geometry 1-6-12), porosity = 48.9%, thickness = 5mm
- Model E: Similar to model C except chamfered $0.5\text{mm}@45^\circ$ on upstream side of holes
- Model F: Similar to model C except chamfered $0.5\text{mm}@45^\circ$ on downstream side of holes
- Model H: Similar to model C except thickness = 2.5mm

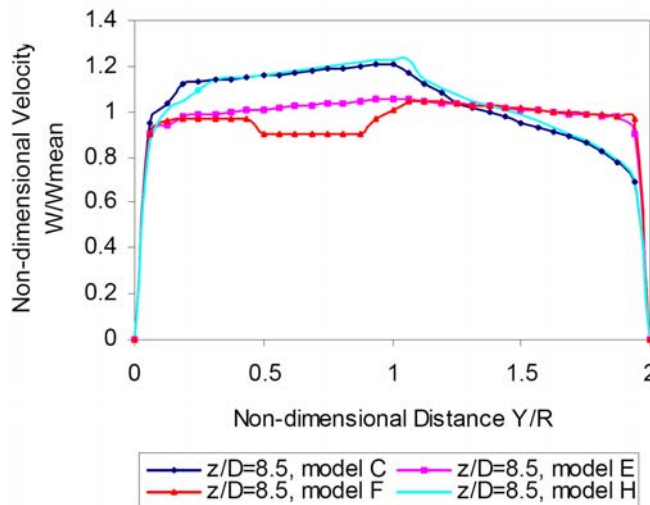


Figure 20 – Velocity Profile 8.5D Downstream of Perforated Plate Flow Conditioner

Figure 20 shows significantly different velocity profiles can be achieved by chamfering the holes, while plate thickness had little effect. However, it is not just the velocity profile that can affect an ultrasonic meter. Figure 21 shows the velocity profiles at 20D are nearly fully developed:

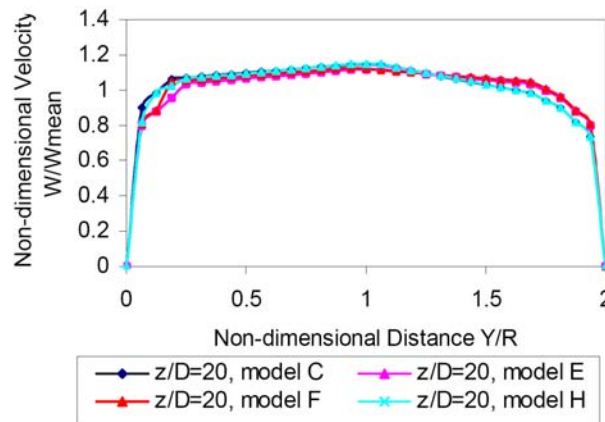


Figure 21 – Velocity Profile 20D Downstream of Perforated Plate Flow Conditioner

but Figure 22 shows the turbulence intensities at 20D are still quite different.

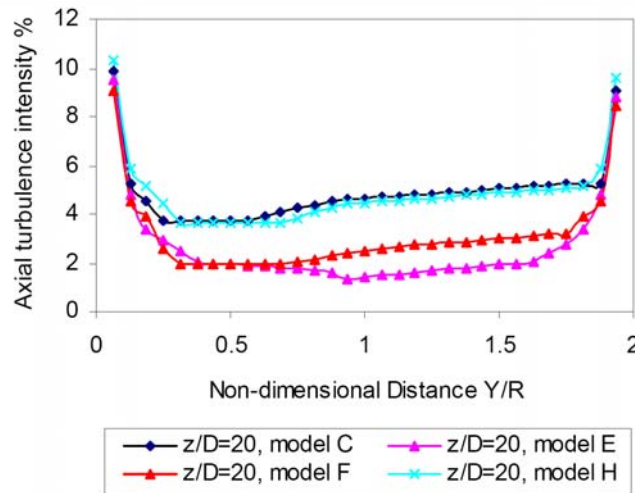


Figure 22 – Turbulence Intensity 20D Downstream of Perforated Plate Flow Conditioner

4.4 Turbulence Intensity Simulations - Commercial Flow Conditioner

The turbulence simulations in the previous section raise some interesting questions but are for a hypothetical flow conditioner and a location almost twice as far downstream as meters are normally installed. To gain additional understanding of turbulence conditions downstream of a commercial flow conditioner, a series of simulations under good and disturbed flow conditions were performed.

Fluent® was used to analyze the steady-state flow of natural gas through a straight Ø12" pipe (0.3 m) with a CPA-50E flow conditioner. The common simulation configuration parameters are shown in Figure 23.

As a reference, the % turbulence intensity for "Fully Developed Pipeline Flow" is shown in Figure 24.

The geometry of the flow conditioner used in the simulations is shown on the right.

The CFD Model Parameters and Settings

- the RSM turbulence model was used
- gas density = 40 kg/m³
- gas viscosity = 1.2×10^{-5} Pa s
- flow rate = 33.93 kg/s (12 m/s bulk velocity)

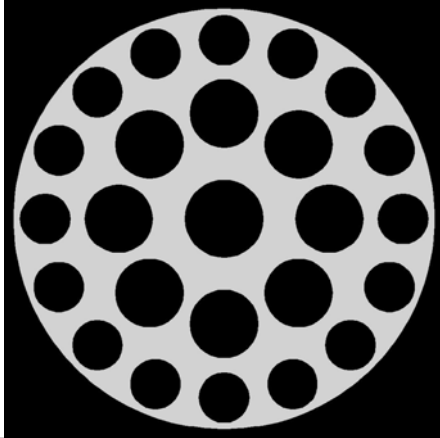
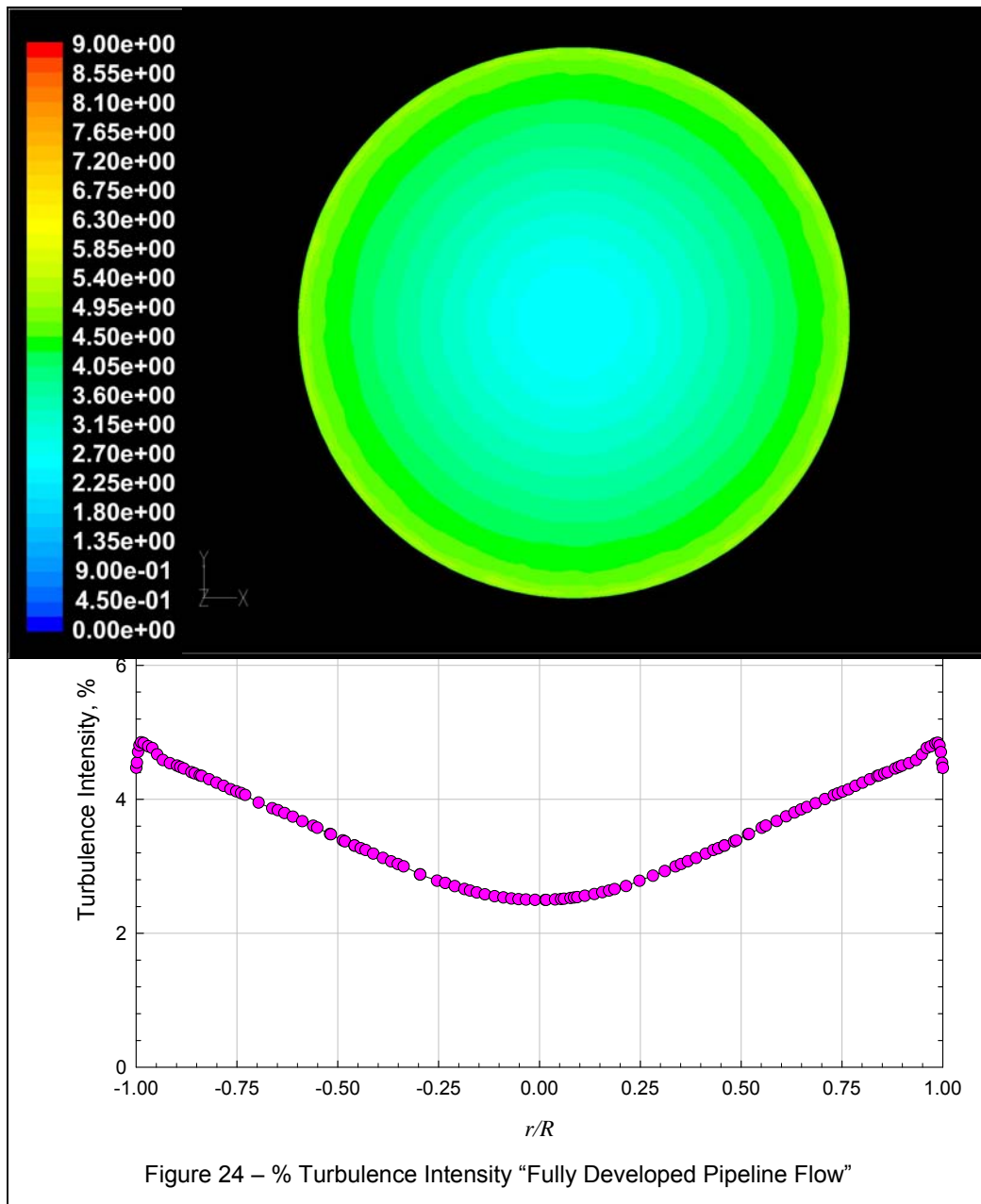


Figure 23 – Common Simulation Conditions



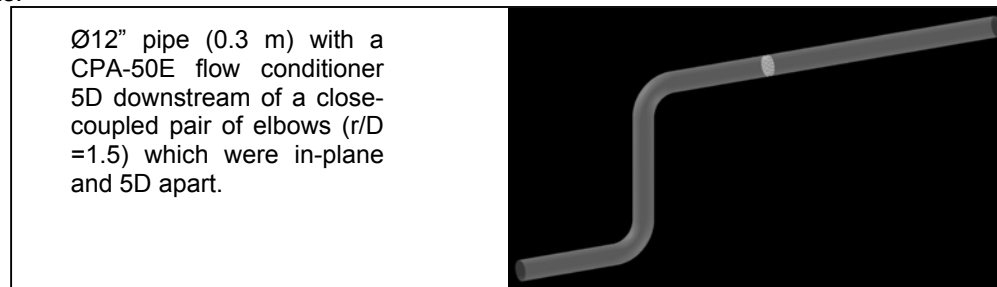
The four inlet conditions investigated were:

Inlet condition 1 - CFD for straight pipe inlet, each model has more than 1 million grid cells.

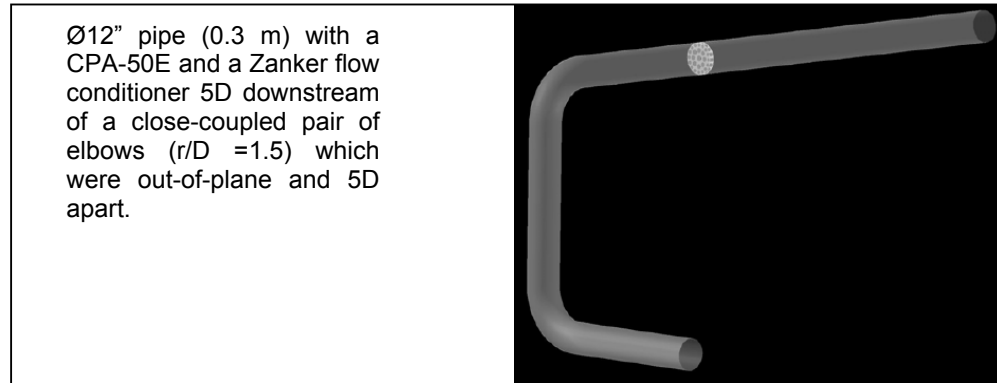
Inlet condition 2 - CFD for single 90° elbow inlet, each model has more than 1.8 million grid cells.



Inlet condition 3 - CFD for two 90° elbows in plane, each model has more than 2.5 million grid cells.



Inlet condition 4 - CFD for two 90° elbows out of plane, each model has more than 2.5 million grid cells.

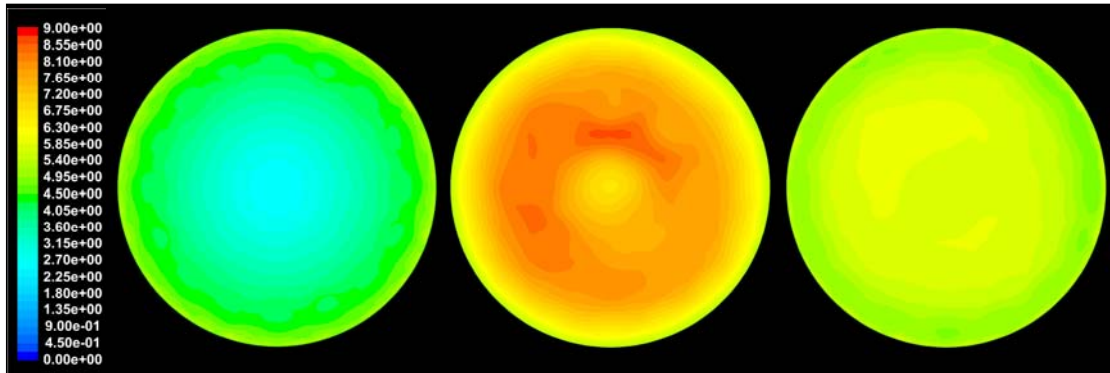


The results of the simulations are shown in below.

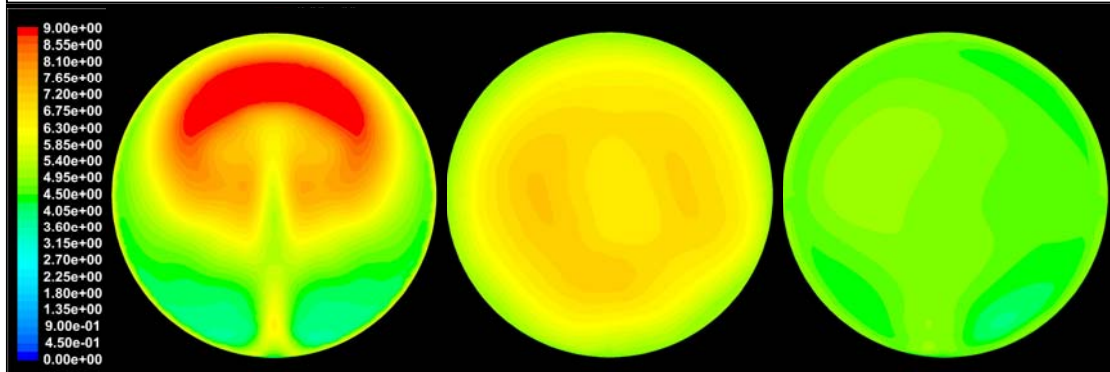
Figure 25 to Figure 28 show the % turbulence intensity 1D upstream of the flow conditioner, 6D downstream and 12D downstream.

Note:

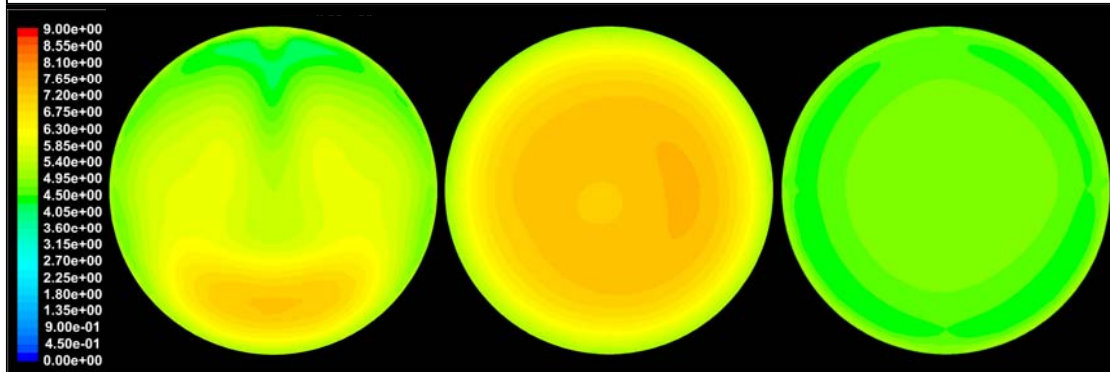
- The differences in the % turbulence intensity upstream of the flow conditioner, caused by the different inlet piping conditions. The straight pipe 1D upstream condition in Figure 25 is similar to “fully developed pipeline flow” shown in Figure 24, but is starting to be affected by the flow conditioner.
- The turbulence intensities downstream of the flow conditioner are similar but significantly different from “fully developed pipeline flow”. This is easier to see by comparing the horizontal and vertical cross sectional plots in Figure 29 to the cross section of “fully developed pipeline flow” in Figure 24.



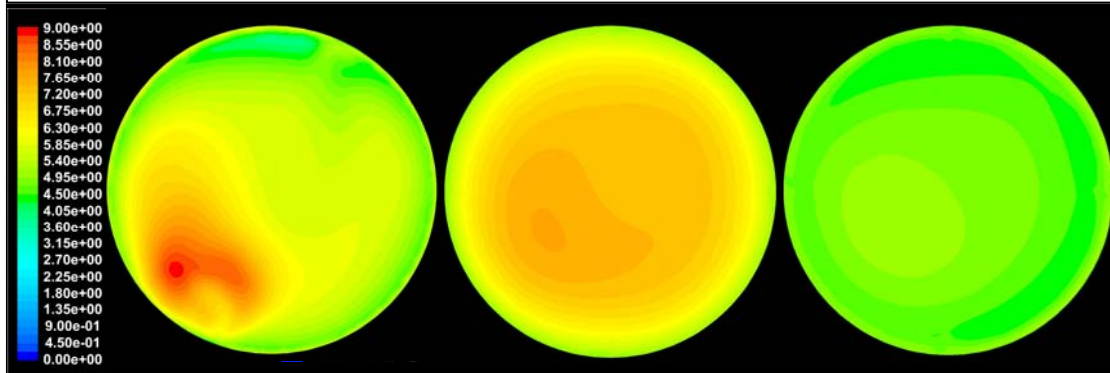
1D Upstream 6D Downstream 12D Downstream
Figure 25 – % Turbulence Intensity Upstream/Downstream of Flow Conditioner – Straight Pipe



1D Upstream 6D Downstream 12D Downstream
Figure 26 – % Turbulence Intensity Up/Downstream of Flow Conditioner – 90° Inlet



1D Upstream 6D Downstream 12D Downstream
Figure 27 – % Turbulence Intensity Up/Downstream of Flow Conditioner – Double Elbow In Plane



1D Upstream 6D Downstream 12D Downstream
Figure 28 – % Turbulence Intensity Up/Downstream of Flow Conditioner – Double Elbow Out of Plane

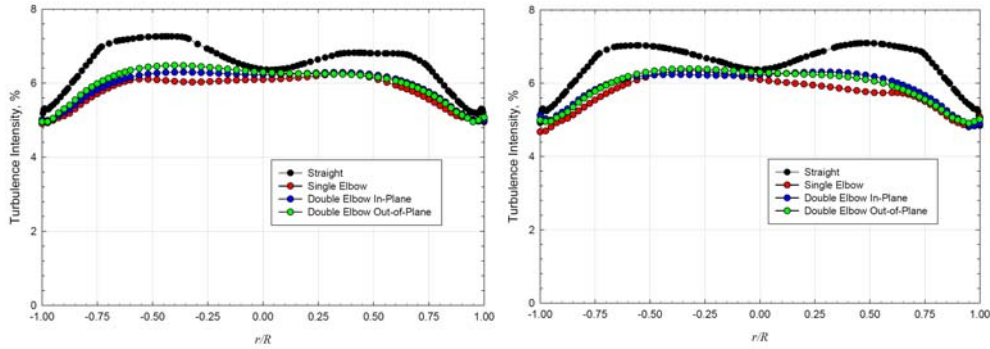


Figure 29 - Profiles of % Turbulence Intensity along a Horizontal (Left) and Vertical (Right) Diameter at 8D Downstream of Flow Conditioner

5 CONCLUSION

A turbulence intensity profile that does not change as flow moves down the pipe is required to have “fully developed turbulent pipeline flow”. The simulations presented show this profile has not been reached at distances 6D-12D downstream of the flow conditioner and may require more than 20D to develop.

Review of literature indicates that turbulence can affect orifice and ultrasonic metering. To date the explanation of metering anomalies has been primarily focused on velocity profile and swirl.

Could changes in turbulence intensity between meter calibration and final installed conditions or turbulence intensity/intensity changes in combination with the ultrasonic meter algorithms/design be causing metering errors? What is required to control and minimize the difference from meter calibration to final installed conditions? Additional research on turbulence related installation effects is needed to help define their effect on meter performance.

6 REFERENCES

- [1] T. A. Grimley. “Performance Testing Of 12-Inch Ultrasonic Flow Meters And Flow Conditioners In Short Run Meter Installations”, Gas Research Institute Topical Report GRI-01/0129
- [2] T. T. Yeh, G. E. Mattingly. “Ultrasonic Technology: Prospects For Improving Flow Measurements And Standards”, Proceedings of the 4th International Symposium on Fluid Flow Measurement (Denver, CO: NAFFMC 1999), and Proceedings of FLOMEKO 2000 (Salvador, Brazil: IPT 2000)
- [3] W. Studzinski, U.Karnik, P. LaNasa, T. Morrow, D. Goodson, Z. Husain, J. Gallagher. “Orifice Meter Installation Configurations with and without Flow Conditioners - White Paper Prepared for API 14.3 p.2”, Gas Research Institute Topical Report GRI-99/0262
- [4] D. L. George. “Metering Research Facility Program: Turbine Meter Research in Support of the Planned AGA Report No. 7 Revision”, Gas Technology Institute, GRI Topical Report GRI-01-0226
- [5] B. Delenne et al. “Evaluation Of Flow Conditioners – Ultrasonic Meters Combinations”, North Sea Flow Measurement Workshop, St Andrews, Scotland, October 2004
- [6] “Measurement of Gas by Multipath Ultrasonic Meters”, American Gas Association Report No.9, 2007
- [7] S.E. Smørgrav, A.K. Abrahamsen. “Wet Gas Experience with a Single Path Ultrasonic Meter”, American Gas Association Operating Section Proceedings Chicago Illinois, April 27 - 29, 2005

- [8] T. Tresch, P. Gruber, T. Staubli. "Comparison Of Integration Methods For Multipath Acoustic Discharge Measurements", 6th International Conference on Innovation in Hydraulic Efficiency Measurements, July 30 - August 1, 2006, Portland, Oregon, USA
- [9] G. Brown, D. Augenstein, T. Cousins. "Velocity Profile Effects on Multipath Ultrasonic Meters", 6th International Symposium on Fluid Flow Measurement Querétaro, Mexico, 16 - 18 May 2006
- [10] P. Lunde, K.E. Frøysa, M. Vestrheim. "GERG Project on Ultrasonic Gas Flow Meters, Phase II", Groupe Européen de Recherches Gazières, GERG TM 11
- [11] U. Karnik, W.M. Jungowski, K.K. Botros. "Effect of Turbulence on Orifice Meter Performance", Journal of Offshore Mechanics and Arctic Engineering May 1994, Vol. 116/77
- [12] F. J. Weber, Jr.. "Ultrasonic Beam Propagation in Turbulent Flow", PhD Dissertation Submitted to the Faculty of the Worcester Polytechnic Institute December 16, 2003
- [13] W. Merzkirch L. Strömungslehre. "Flow metering in non-developed pipe flow", 6th Asian Symposium on Visualization, Pusan, Korea, May 2001
- [14] T. Yeh, G. Mattingly. "Computer Simulations Of Ultrasonic Flow Meter Performance In Ideal And Non-Ideal Pipeflows", 1997 ASME Fluids Engineering Division Summer Meeting (FEDSM'97) June 22 - 26, 1997
- [15] P. Moore, A. Johnson, P. Espina. "Simulations of Ultrasonic Transit Time in a Fully Developed Turbulent Flow using a Ray-Tracing Method", North Sea Flow Measurement Workshop 22nd – 25th October 2002
- [16] "Orifice Metering of Natural Gas and Other Related Hydrocarbon Fluids", American Gas Association Report No.3 - 2/American Petroleum Institute API 14.3.2/Gas Processors Association GPA 8185-00, Fourth Edition, April 2000
- [17] "Measurement of Natural Gas by Turbine Meters", American Gas Association Report No.7, February 2006
- [18] "Measurement of Natural Gas by Turbine Meters", American Gas Association Report No.7, 2007
- [18] T. Grimley. "Performance Testing Of 12-Inch Ultrasonic Flow Meters And Flow Conditioners In Short Run Meter Installations", Gas Research Institute Topical Report GRI-01/0129
- [19] B. Delenne, et al – "Evaluation Of Flow Conditioners – Ultrasonic Meters Combinations", North Sea Flow Measurement Workshop, St Andrews, Scotland, October 2004
- [20] Z. Shao. "Numerical and experimental evaluation of flow through perforated plates", A dissertation submitted in partial fulfillment of the requirements for the degree Magister Ingenieriae in Mechanical Engineering at the Rand Afrikaans University