Paper 6.2

The Effect of Varying Reynolds Number on a Zanker Flow Conditioner

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ABSTRACT

Perforated plate flow conditioners are widely used in the oil and gas sector to reduce swirl and flow asymmetry entering flow meters and hence improve their accuracy in non-ideal installations. These devices are typically developed and optimised in liquid (or low-pressure air) flow test facilities at relatively low Reynolds numbers. However, they are usually deployed in gas production metering systems that operate at higher Reynolds Numbers.

This paper describes work in which the velocity profiles were measured downstream of a Zanker flow conditioner plate in swirling flow and asymmetrical flow in oil (at a Reynolds number of 2.5×10^5) and in nitrogen (at a Reynolds number of 5.8×10^6). The velocity profiles measured were very similar in nitrogen and oil, suggesting that perforated plate conditioners developed and optimised in liquid flow tests will perform equally well in high pressure gas flow applications. The Zanker plate was found to pass the ISO 5167-1 test for velocity profile, but it did not satisfy the test for swirl.

The results of these tests and previous tests on an MHI flow conditioner were used to show that CFD methods can be used in the study and development of perforated plate flow conditioners. Further CFD simulation work demonstrated that flow conditioners that are optimised for use with orifice plate flow meters do not necessarily perform well with ultrasonic flowmeters.

1 INTRODUCTION

Perforated plate flow conditioners are now widely used in fiscal hydrocarbon measurement systems to improve flow conditions entering orifice plate and ultrasonic flow meters and thus reduce measurement uncertainty. A review of flow conditioner technology is given in Fletcher et al[1].

Historically, this type of flow conditioner has been developed for use with orifice plate meters and tested in low pressure water or air flows. The draft revision of ISO 5167-1 (ISO/FDIS 5167-1[2]) describes the use of Zanker flow conditioners with orifice plates. It also states that provided that the velocity profile entering a differential pressure flowmeter lies within a ±5% band of a fully developed profile and that the swirl angle is less than 2° no increase in uncertainty due to installation is required.

Although the flow conditioning requirements of differential pressure meters and ultrasonic meters are similar (i.e. that the flow entering the meter should be as close to fully developed as possible) they do differ. For example, the error due to swirl in a multi-path ultrasonic meter may well be less than that in an orifice plate experiencing the same conditions.

This paper describes test and computational work that addresses the following issues:

- Whether velocity and swirl data measured in relatively low Reynolds number liquid flows are representative of the high Reynolds number gas flows in which the conditioner is likely to be used.

- Whether a Zanker flow conditioner plate meets the ISO 5167-1 test for velocity profile skew and swirl
- The applicability of the ISO 5167-1 swirl and velocity profile criteria to a typical ultrasonic flowmeter
- Whether Computational Fluid Dynamics is a useful tool in the design and assessment of flow conditioners.

The project involved:

- Tests of a Zanker flow conditioner downstream of a swirler and a half plate in oil and high pressure nitrogen flows
- CFD simulations of the above tests and comparisons of predictions and the measurements.
- Simulation of a typical four path ultrasonic flowmeter upstream and downstream of the Zanker flow conditioner plate in the above tests
- Comparison of CFD predictions against previously published velocity profile data taken downstream of a Mitsubishi Heavy Industries (MHI) flow conditioner in water flow

2 EXPERIMENTAL PROGRAMME

A test package was assembled from a series of 6” SCH80 stainless steel spool pieces machined to an internal bore of 154.08 mm, as shown in Figure 1. By rearranging the components of this test section velocity profiles were measured at positions 2D upstream and 2D and 9D downstream of the flow conditioner. The flow upstream of the conditioner was disturbed by either a D-shaped half plate or a 12° fixed-bladed swirler. The test section was installed downstream of more than 60D of straight SCH40 6” nominal bore pipework in the NEL oil recirculating test loop and the NEL nitrogen recirculating test loop. Test conditions are summarised in table 1.

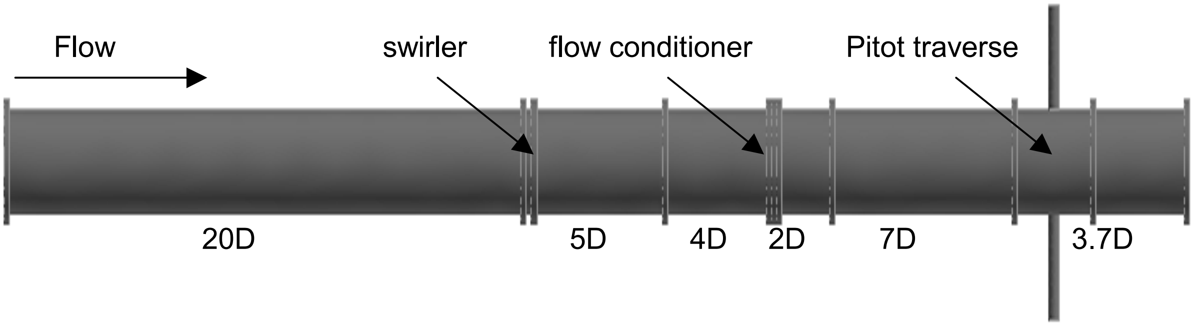


Figure 1 **The test section set up to measure the velocity profile 9D downstream of the Zanker flow conditioner plate with swirling inlet flow.**

Table 1 Summary of Experimental Test Conditions

Fluid	Oil (kerosene)	Nitrogen
Test Facility	NEL oil flow facility (line A)	NEL high pressure gas recirculating loop
Nominal Mean Flow Velocity	4 m/s	15.1 m/s
Nominal Fluid Density	820 kg/m^3	47.1 kg/m^3
Nominal Fluid Viscosity	0.002 Pas	1.89 x 10^{-5} Pas
Pipe Reynolds Number	2.5 x 10^5	5.8 x 10^6

Velocity profiles and swirl angle measurements were made using a specially designed high pressure beam-type Pitot tube (Figure 2) and instrumentation summarised in Tables 2 and 3. For each profile two sets of 11 point velocity measurements were taken across the pipe diameter. Point velocity measurements represented the average of a series of measurements sampled over a one minute period at a rate of 5 Hz. The resultant points were normalised against a mean flow velocity value derived from a reference flow rate measurement.

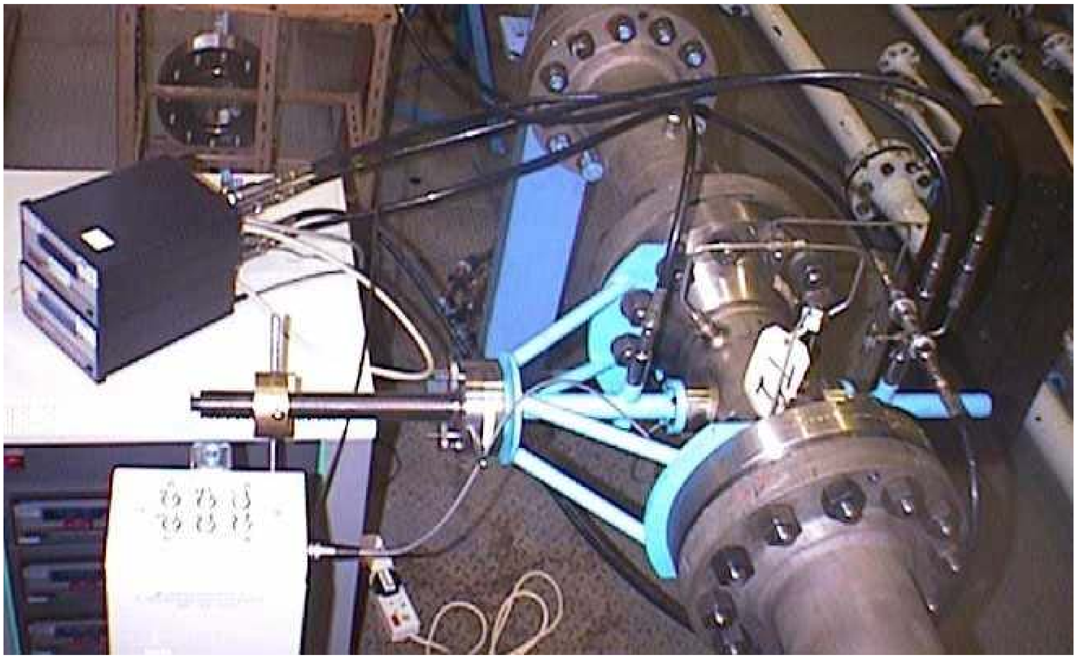


Figure 2. The Pitot Tube Spool

Table 2 Instrumentation for Oil Flow Tests

Measurement	Transducer	Range	Uncertainty
dP_1	Rosemount 1151	-150 to +150 mbar	0.2%
dP_2	Rosemount 1151	0 to 300 mbar	0.2%
reference flow rate	M21 PDM	40 to 90 l/s	0.08%

Table 3 Instrumentation for Nitrogen Flow Tests

Measurement	Transducer	Range	Uncertainty
dP_1	Mensor 14000	0 to 20 kPa	0.1%
dP_2	Mensor 15000	0 to 20 kPa	0.1%
Temperature	PRT - NOT 1590	0 to 25 ^{o}C	0.05%
reference flow rate	Turbine NOT 1739	0 to 1000 m^3/hr	0.4%

3 EXPERIMENTAL RESULTS

Figures 3 to 6 show velocity and swirl profiles measured 9D downstream of the flow conditioner for different inlet flow conditions. These are compared against an idealised fully developed profile (solid line) and a ±5% band about this profile (dotted lines). In general the oil and nitrogen velocity profiles were very close to each other and all axial velocity profiles fell within the ±5% band.

When fully developed flow entered the flow conditioner the oil velocity profile was very close to the idealised fully developed profile, but the nitrogen flow profile was slightly skewed (Figure 3). When swirling flow entered the conditioner the downstream axial velocity profile was very close to the fully developed state (Figure 4). However, the swirl direction was reversed by the conditioner and a residual swirl with a maximum angle of about 4° was measured at both 2D and 9D (Figure 5). When skewed flow entered the conditioner all of the measured points 9D downstream fell within the ±5% band but the nitrogen velocity profile were slightly more skewed than the oil velocity profiles (Figure 6).

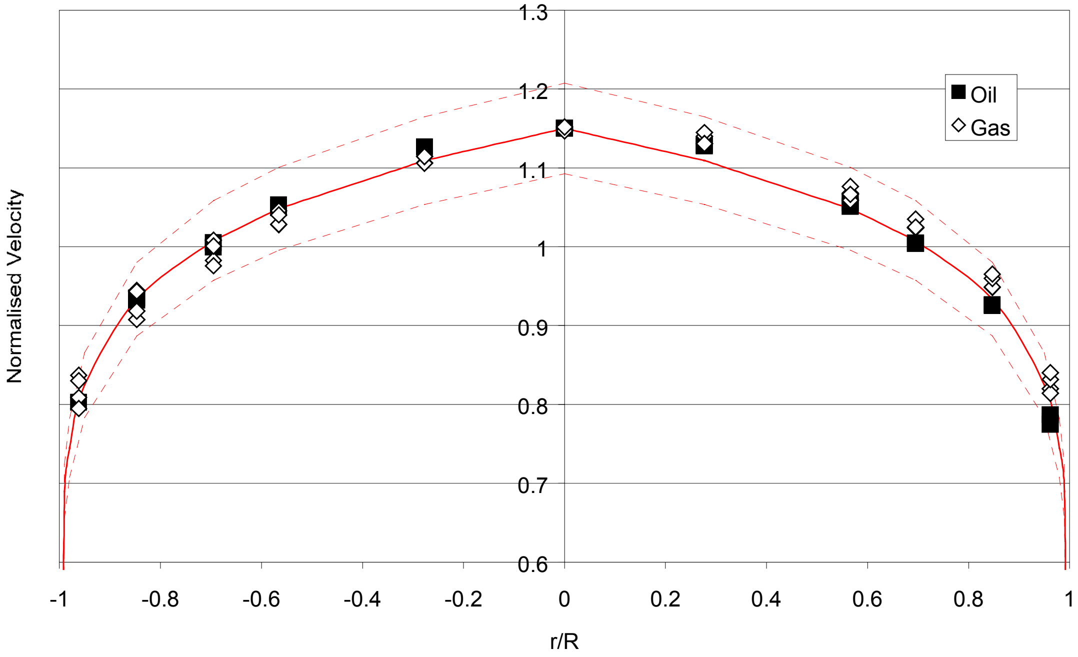


Figure 3 **Axial Velocity Profile Measured 9D Downstream of the Flow Conditioner with Fully Developed Inlet Flow**

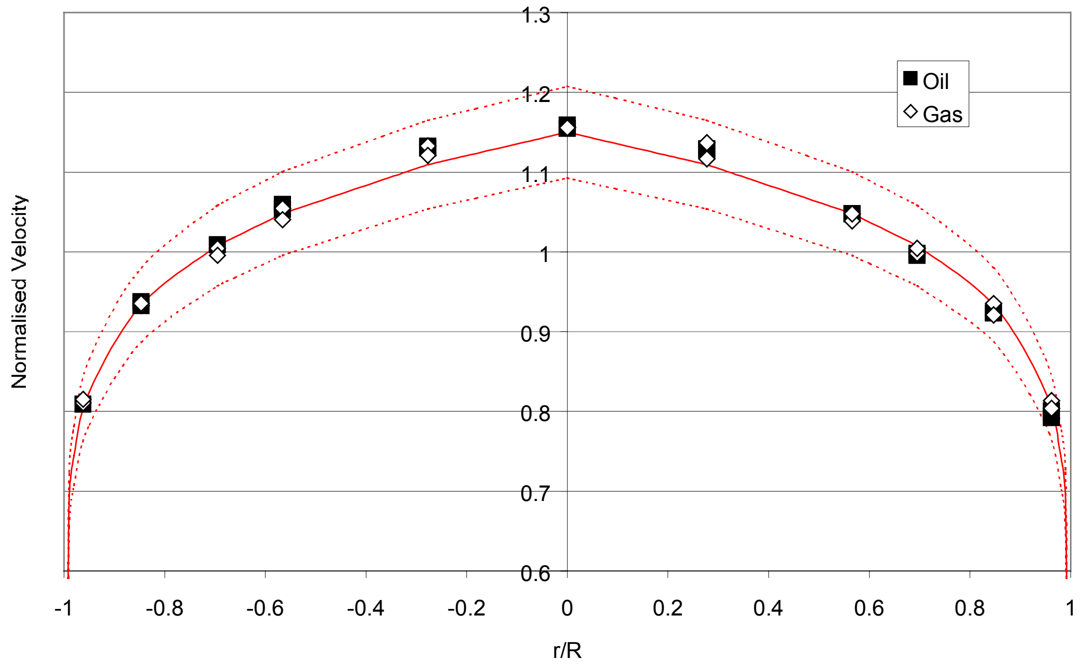


Figure 4 **Axial Velocity Profile Measured 9D Downstream of the Flow Conditioner with Swirling Inlet Flow**

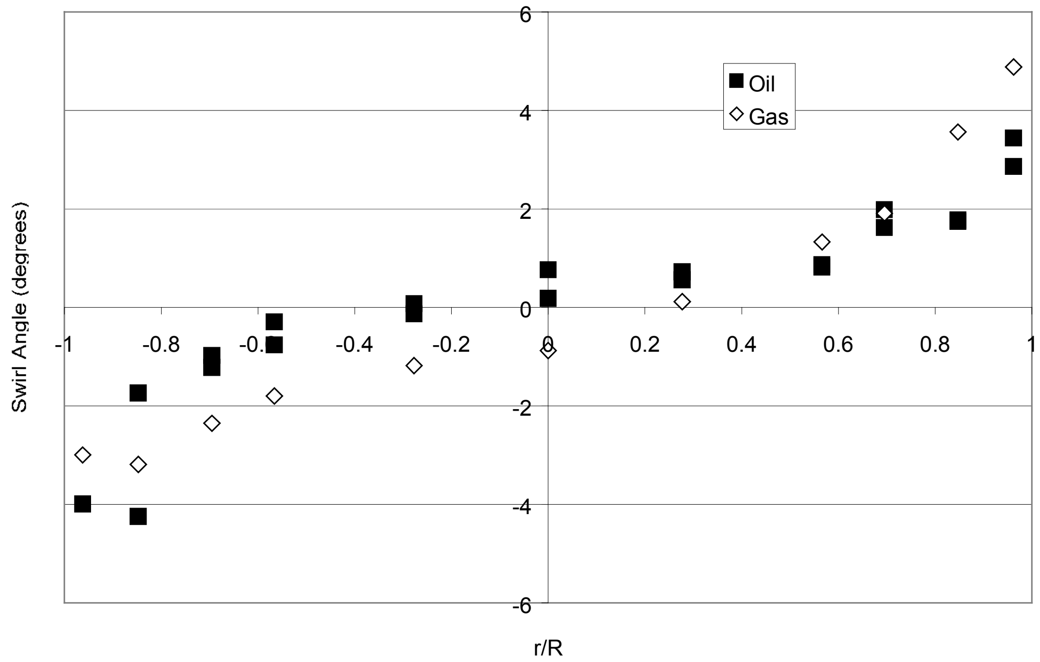


Figure 5 **Swirl Angle Measured 9D Downstream of the Flow Conditioner with Swirling Inlet Flow**

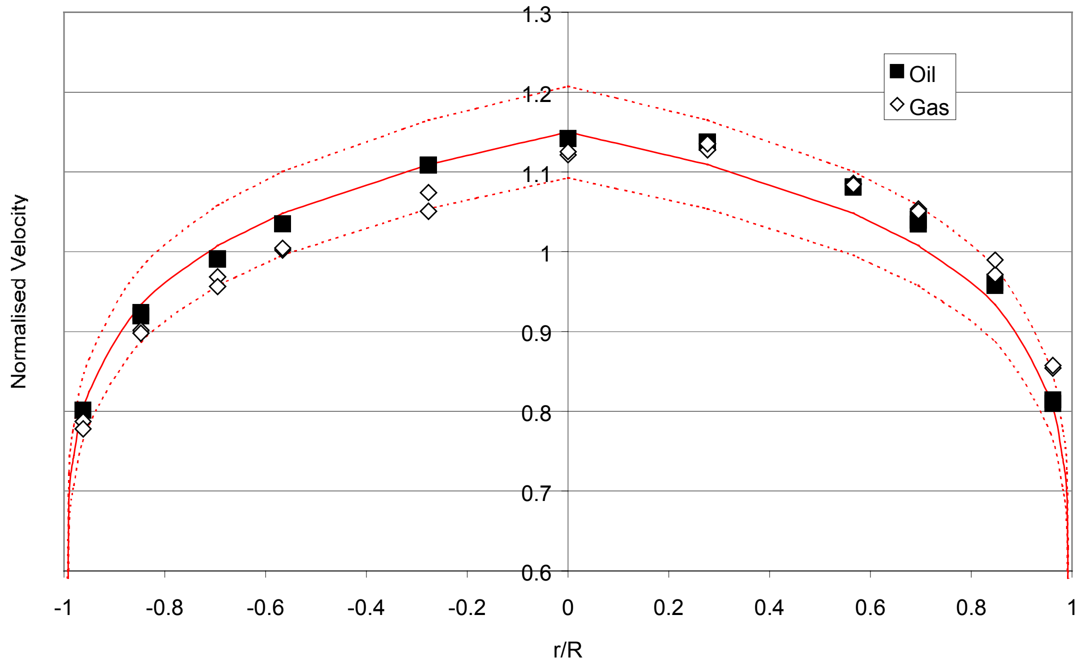
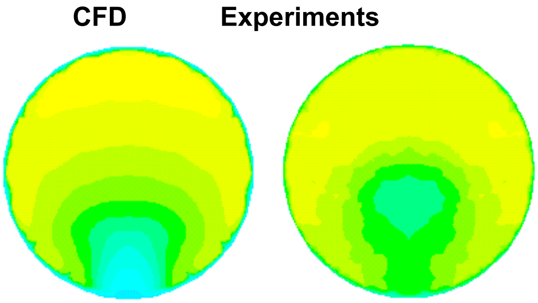


Figure 6 **Axial Velocity Profile Measured 9D Downstream of the Flow Conditioner With Skewed Inlet Flow. (The Open Half of the Half Plate Extends from R/R = 0 To 1)**

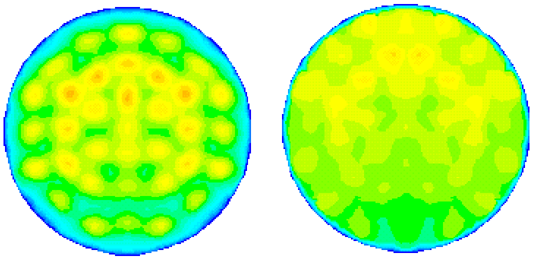
4 CFD SIMULATIONS

Three sets of CFD simulations were run representing the oil and nitrogen flow tests from this project and water flow tests of a Mitsubishi Heavy Industries (MHI) flow conditioner (Re = 9 x 10^5) described by Spearman[3].

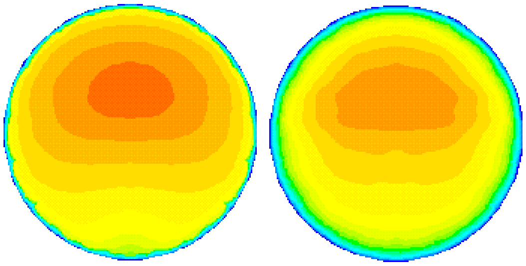
Figures 7 and 8 show the good agreement achieved between the CFD simulations and the water flow MHI test measurements. A vertical streak is seen in the experimental velocity profile in Figure 8c. This streak appears to be associated with a small offset in some of the LDV velocity data and is thought to be caused by an error in one of the velocity measurement traverses. This explains the main apparent discrepancy between the CFD and experimental data.



a) 1.125D upstream of the conditioner

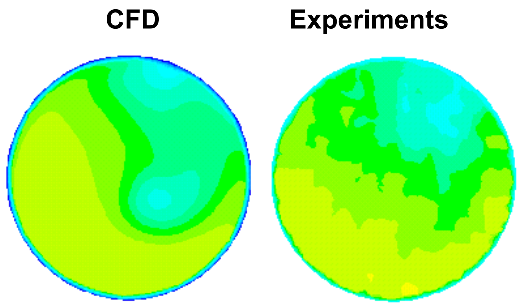


b) 0.625D downstream of the conditioner

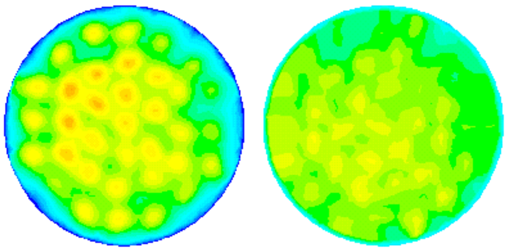


c) 6.75D downstream of the conditioner

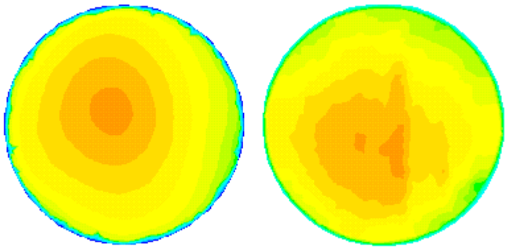
Figure 7 **Predicted and Measured Axial Velocity Profiles Downstream of a Bend (MHI In Water Flow)**



a) 1.125D upstream of the conditioner



b) 0.625D downstream of the conditioner



c) 6.75D downstream of the conditioner

Figure 8 **Predicted and Measured Axial Velocity Profiles Downstream of a Twisted Double Bend (MHI In Water Flow)**

Figures 9, 10 and 11 compare CFD predictions with measurements in the oil and nitrogen flow tests in swirling flow. The predictions agree well with the measurements 2D downstream of the conditioner (Figure 9) but diverge slightly at 9D (Figure 10). This was because of differences in the predicted and measured fully developed flow profiles (i.e. the simulated flow was decaying to a slightly different state to that in the experiments). This was probably because pipe roughness effects were not accounted for in the CFD simulations.

The CFD correctly predicted the swirl reversal (Figure 11) but underestimated the maximum degree of swirl downstream of the conditioner (1° as opposed to 4°). The close agreement between the gas and oil velocity profiles was correctly predicted.

Downstream of the half plate the agreement between the CFD and the experiments was reasonable but not as good as in the swirler case. This was primarily because of discrepancies between the predicted and measured flow profile entering the flow conditioner. It is believed that a better match would have been achieved if more realistic inlet conditions had been defined at the conditioner inlet in the simulations.

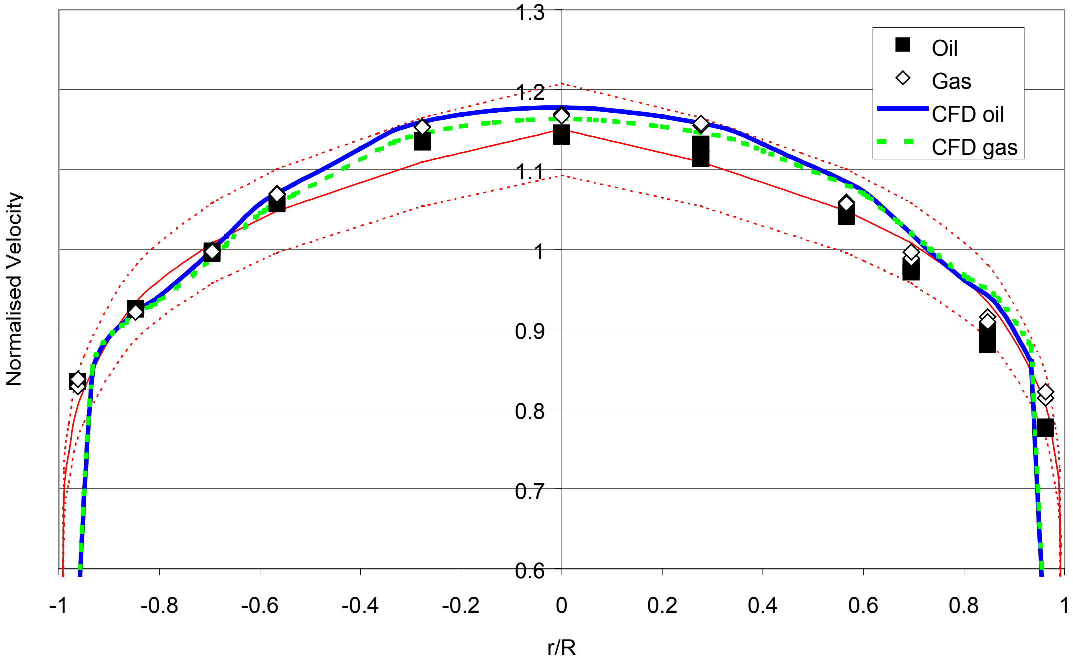


Figure 9 Comparison of Predicted and Measured Axial Velocity Profile Measured 2D Downstream of the Flow Conditioner with Swirling Inlet Flow

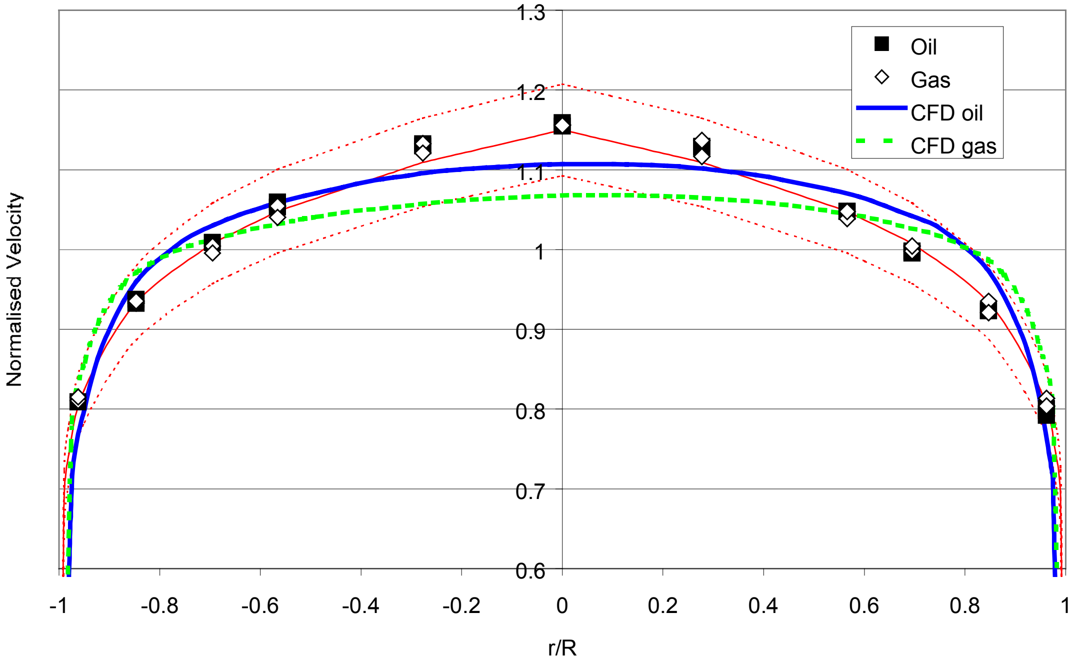


Figure 10 Comparison of Predicted and Measured Axial Velocity Profile Measured 9D Downstream of the Flow Conditioner With Swirling Inlet Flow

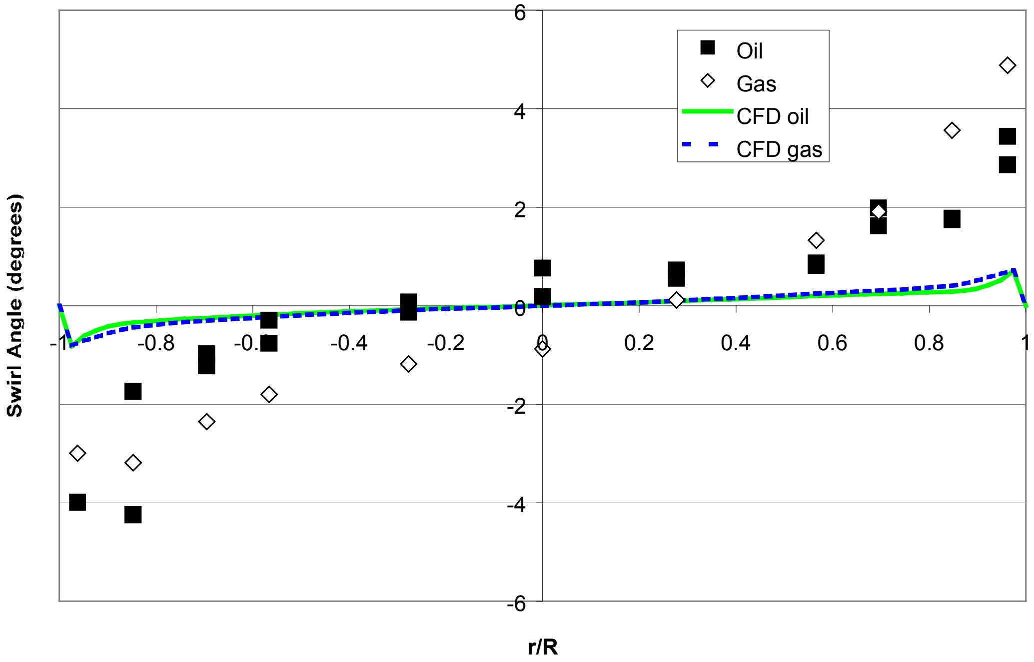


Figure 11 **Comparison of Predicted and Measured Swirl Angle 9D Downstream of the Flow Conditioner with Swirling Inlet Flow**

5 SIMULATIONS OF AN ULTRASONIC FLOWMETER DOWNSTREAM OF A FLOW CONDITIONER

Flow conditioners are generally optimised for use with orifice plate flowmeters. However, they are increasingly being used with ultrasonic flowmeters. They are usually assessed by calibrating an orifice plate downstream of a conditioner that is in turn downstream of a flow disturbance of some kind. Alternatively, velocity profiles and swirl angles may be measured downstream of the conditioner and compared against the ISO 5167-1 ±5% velocity profile and 2^o swirl limits. To assess whether these limits are relevant to ultrasonic flowmeters, the CFD nitrogen flow analysis was extend to include a simulation of a four path dual mid-radius meter. The methods used to model the meter's response are identical to those outlined in Coull et al[4].

Figure 12 shows that the skewed velocity profile generated by the half plate causes a significant metering error (up to -8%) upstream of the flow conditioner (i.e. for x<0). Downstream of the conditioner the error stabilises at about +2% despite the fact that the velocity profile downstream of the conditioner falls within the ±5% error band.

Downstream of the swirler the metering error fluctuates about a mean value of about -1.65%. This is less than the error in the half plate case (either up or downstream of the conditioner) despite a (maximum) swirl angle of 12^o. Note that the fluctuations in the error characteristic are caused when wakes from the swirler blades intercept individual paths. Downstream of the flow conditioner the axial velocity profile is close to fully developed, the swirl angle is reduced to about 1^o, and, as would be expected, the error is very close to zero.

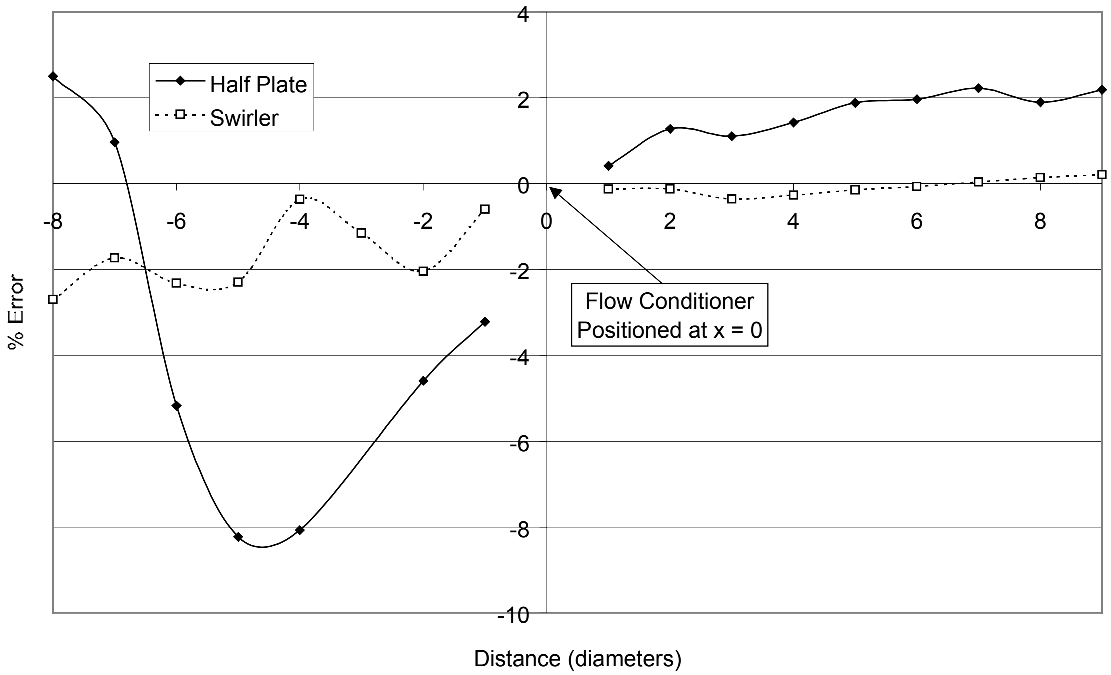


Figure 12 **Simulated Error Response of a Dual Mid-Radius Ultrasonic Flowmeter Upstream and Downstream of the Zanker Flow Conditioner in the Test Package Described in this Paper (Oil Flow)**

This exercise demonstrates that this design of meter is quite tolerant of swirl, but that it is sensitive to velocity profile distortion. In this case, a flow conditioner that exceeds the ISO 5167-1 requirements for velocity profile is likely to reduce the meter uncertainty, even if it fails the swirl requirements. Meters with other path configurations are likely to respond in a different manner and have different flow conditioning requirements.

6 CONCLUSIONS

Experimental tests have shown that the performance of a Zanker flow conditioner at a low Reynolds number (2.5×10^5) is representative of its performance at a higher Reynolds number (5.8×10^6). ISO 5167-1[3] states that provided that the velocity profile entering an orifice plate flowmeter lies with a ±5% band about a fully developed profile and has a swirl angle of less than 2^o no increase in uncertainty due to the installation is required. The Zanker conditioner was found to fulfil the velocity profile criterion but it fails the swirl criterion in both oil and nitrogen.

CFD has been shown to be a useful tool in the study of flow conditioners. Subtle effects, such as swirl reversal can be captured using CFD and agreement with test data is generally very good. However, there were small differences between the real and the simulated fully developed state to which the flow decays downstream of the flow conditioner. Care is needed to take this into account when using CFD to model flow conditioners.

Flow conditioners are generally developed to reduce measurement uncertainty in orfice plate flowmeters and to meet swirl and velocity profile criteria outlined in ISO 5167-1. Simulations have demonstrated that conditioners optimised for use with orifice plates do not necessarily perform well with ultrasonic flowmeters. Ideally, a flow conditioner should be selected to match the characteristics of the ultrasonic meter with which it is to be used.

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CONTACT FOR FURTHER INFORMATION

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