USING COMPUTATIONAL FLUID DYNAMICS TO INVESTIGATE THE FLOW THROUGH AN OFFSHORE GAS METERING STATION

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Summary

The gas metering station on BP Bruce platform consists of four 16” orifice meter runs, with gas flowing through any 3 meters at one time. The system was originally designed to comply with ISO 5167[1], but an auditor expressed concern with the physical upstream layout of the pipework leading up to the inlet header to the metering system. He pointed out that there were a number of twists and turns in the upstream header that could have produced swirl and flow asymmetry at the plane of the orifice plate in the metering runs.

NEL was commissioned to run a series of computational fluid dynamics calculations to investigate the flow though the piping configurations. The results demonstrated, as would be expected, that the error in any one meter will depend on which streams are on line.

The estimated total system error compared with a system complying entirely with ISO 5167 related to the different streams on line is given below:

Streams online	Total system error
1-2-3	+0.4%
1-3-4	+0.7%
1-2-4	+0.4%
2-3-4	+0.3%

As can be seen, the flow measurement error is consistent positive and small in magnitude.

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1 INTRODUCTION

It is a known fact that asymmetric flow and swirl onto an orifice plate causes deviations from the flow predicted using ISO 5167. Although Bruce platform was originally designed to comply with ISO 5167, metering installations are usually designed taking no account of the real pipework configurations upstream of the metering installation. An auditor commented on the Bruce upstream pipework and suggested that its affect on the metering results be investigated.

The National Engineering Laboratory was requested to perform a Computational Fluids Dynamics study to model the flow through the Bruce metering installation. The aim of the study was to estimate the error, if any, caused by the upstream pipework on the flow rate indicated by the installation's orifice plate meters.

A sketch of the flow metering installation is shown in Figure 1.

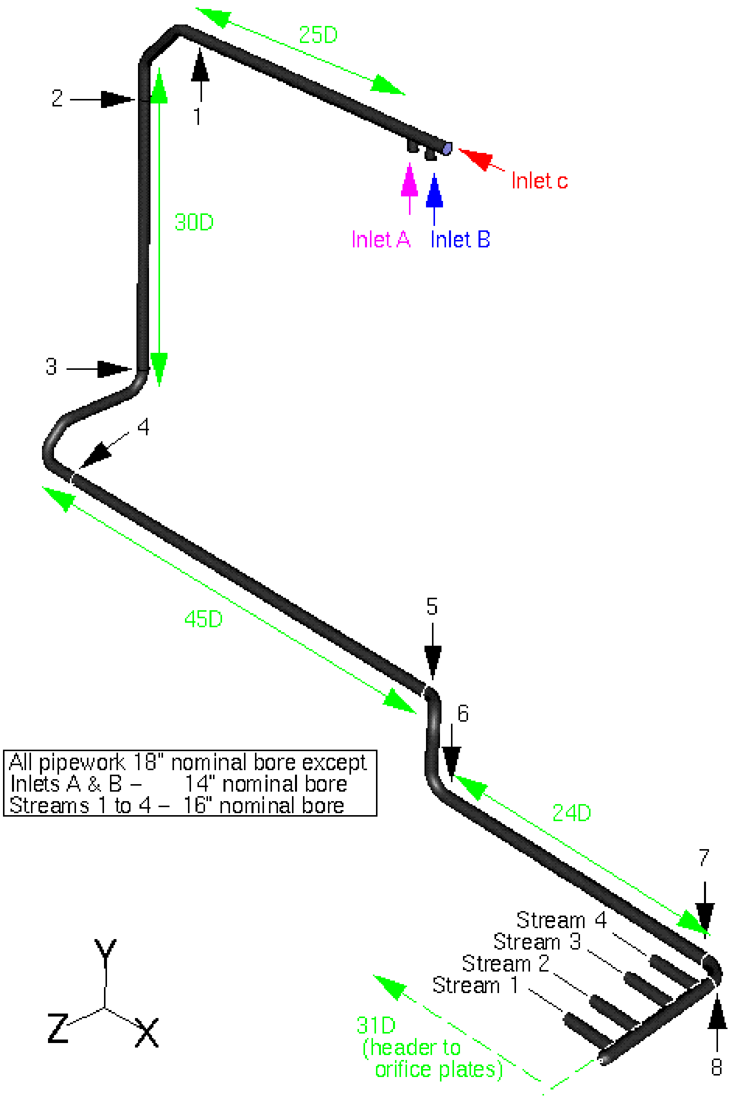

Figure 1. The Bruce Flow Metering Installation

Flow enters the pipework from three compressors at the inlets shown. The flow then passes through two 45^o bends between points 1 and 2 into a straight vertical section. Between points 3 and 4 are a 90^o elbow then an out-of-plane combination of 45^o and 90^o elbows. A second straight section follows leading to a 45^o elbow in the horizontal (x-z) plane closely followed by a 90^o elbow in the vertical plane and a second 90^o elbow. There is then a third straight section between points 6 and 7 leading to a 90^o elbow (in the horizontal plane) and a four-stream header. The header itself is 18" nominal bore, with each stream being 16" nominal bore. Each stream has an orifice plate (β = 0.6 and flange tappings) 31D downstream of the header. Three metering tubes are on-line at any one time, the fourth being shut off by a fully bore valve just downstream of the header.

2 FLOW MODELLING METHOD

2.1 Simulation Method & Parameters

The flow of gas through the installation was modelled using Fluent 5.4 Computational Fluid Dynamics (CFD) software[2].

The pipework was modelled in sections as shown in Figure 1; the inlet conditions for each section being derived from the predicted outlet conditions of the previous (upstream) section. An unstructured hexahedral mesh was used for each section. A typical mesh used to simulate sections of the pipework is shown in Figure 2 and the mesh used to model the flowmeters is shown in Figure 3.

The discretisation scheme used was the QUICK algorithm and turbulence effects were simulated using a Reynolds stress second order closure model.

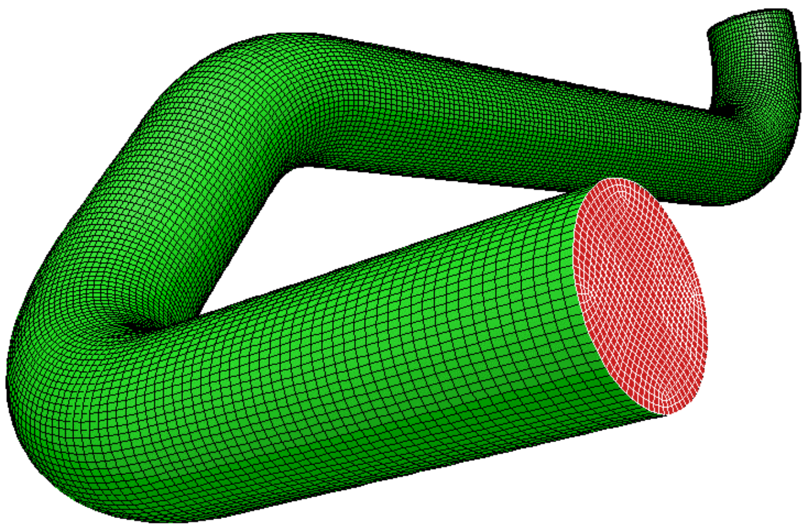

Figure 2. A typical section of the computational mesh used to model the pipework (between points 3 and 4 in figure 1)

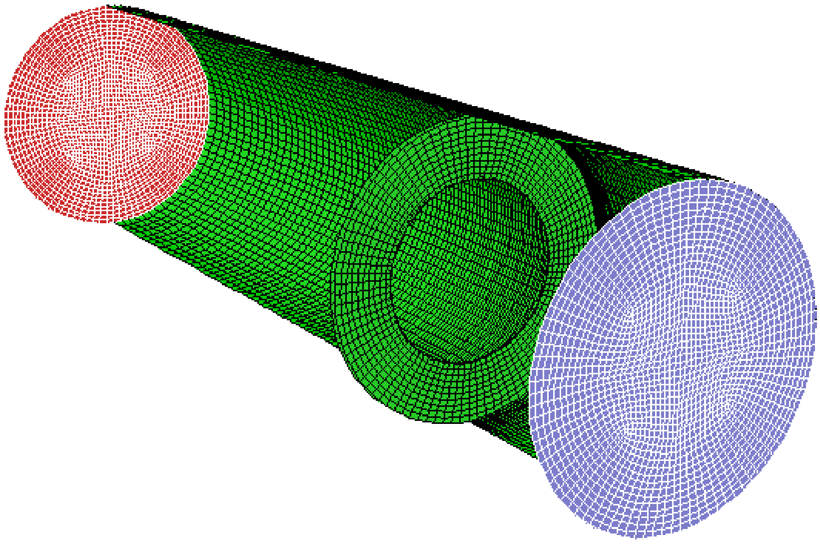

Figure 3. The computational mesh used for modelling the orifice plate flowmeters

2.2 Flow Parameters

The operational conditions were specified as 135 barg and 35°C. The flow rate through the installation was 17 million Sm^3/day. The following flow parameters were set within the CFD simulations:

- Gas density = 140 kg/m^3
- Gas viscosity = 1.82×10^{-5} Pa s
- Gas flow rate = 1.196m^3/s

A uniform velocity profile was set at the inlets A, B and C (marked on figure 1) such that one third of the flow was supplied by each compressor. The turbulence intensity at the inlets was set to 10%.

Simulations of the header used the flow splits shown in Table 1 to define the percentage flow through each stream. Operational experience from Bruce shows that these flow splits are quite repeatable and consistent.

Stream 1	Stream 2	Stream 3	Stream 4
39.4%	-	30.8%	29.8%
-	39.2%	30.8%	30.0%
28.1%	38.2%	33.7%	-
27.4%	37.2%	-	35.4%

Table 3. Percentage flow through each stream with different combinations of stream on-line

3 RESULTS OF THE SIMULATIONS

3.1 Predicted Flow Upstream of the Header

Figure 4 shows the predicted flow behaviour at selected points upstream of the header. The arrangement of the separator outlets and the two subsequent 45^{o} bends acted to generate and skewed velocity profile with a double vortex at point 2, similar to that seen downstream of a 90^{o} elbow. By point 3 the swirl had decayed but some degree of skewness remained, as shown in figure 4.

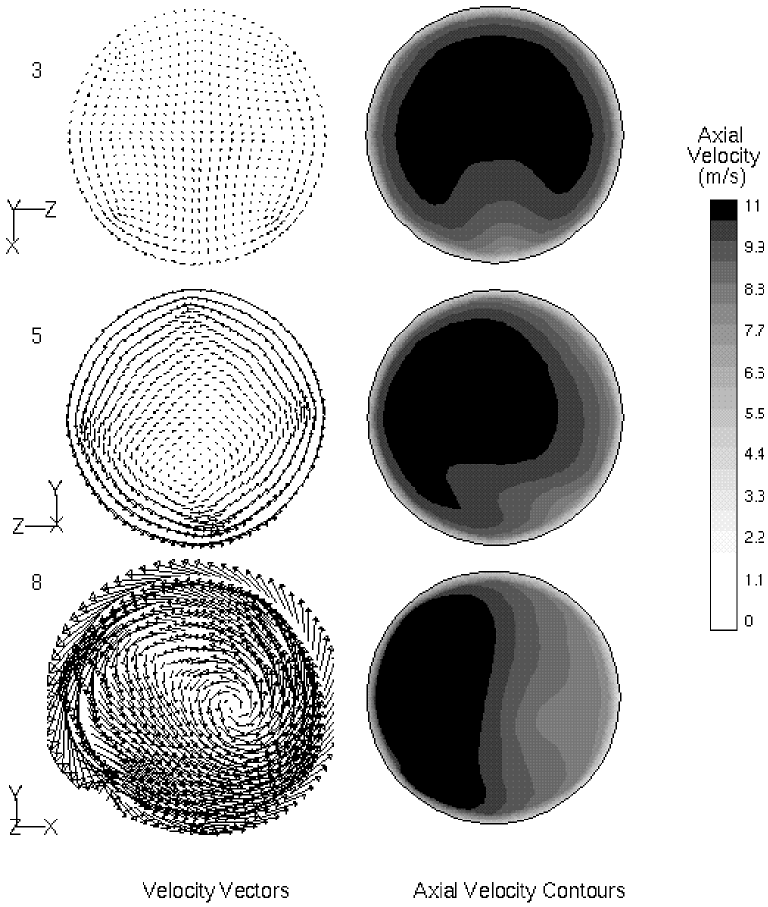

Figure 4. Predicted Flow Behaviour Upstream of the Header

The triple bend combination between points 3 and 4 caused a single vortex swirl that decayed to a magnitude of about 4^{o} by point 5 (see figure 4). The triple bend combination downstream of point 5 caused further swirl that was sustained through the bend between points 7 and 8. The flow entering the header at point 8 was skewed towards the inside of the bend with single vortex swirl of a magnitude of about 14^{o}.

3.2 Predicted Flow in the Header

Two simulations were run of the header, the first with streams 1,3 and 4 on-line. The second with streams 1,2, and 3 on-line. Figure 5 shows the velocity vectors and contours 1.5m downstream of the header with streams 1,3 and 4 on-line. On first inspection all of the streams show a similar behaviour, with the velocity profile skewed to one side and a double vortex swirl reminiscent of that seen downstream of a single bend. However, the swirl entering the header has distorted the swirl pattern in Stream 4, one vortex being marginally bigger than the other with the velocity profile twisted around about the pipe axis. Previous experience suggested that this indicated that single vortex swirl was likely to develop in Stream 4.

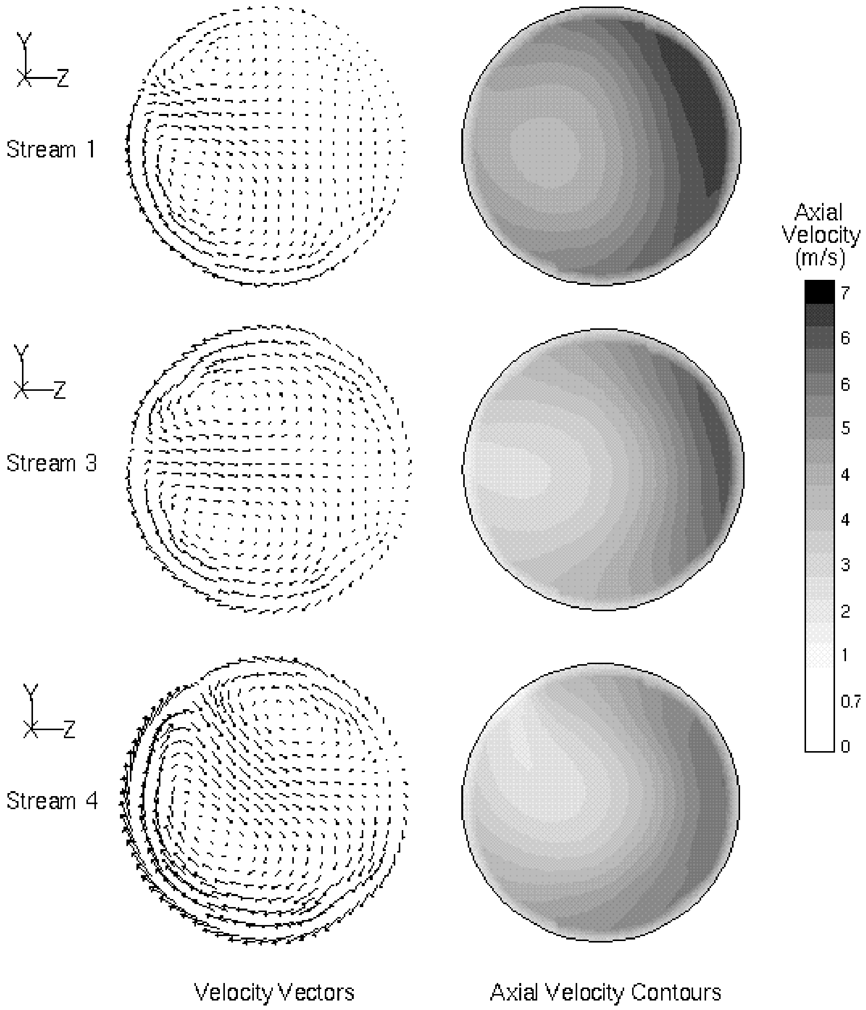

Figure 5. Predicted Flow Behaviour 1.5m Downstream of the Header with Streams 1, 3 and 4 on-line

Figure 6 shows vectors and contours downstream of the header with streams 1,2 and 3 on-line. The flow in stream 3 (figure 6) is very similar to that seen for stream 4 (figure 5). This implies similar behaviour will be seen in the upstream branch for other configurations.

Stream 2 (figure 6) has similarities to streams 1 and 3 (figure 5), with a skewed axial velocity profile and weak double vortex swirl

The flow pattern in stream 1 (figure 6) differs significantly from that in figure 10, with single vortex swirl (about 11^{o} in magnitude) and a skewed axial velocity profile.

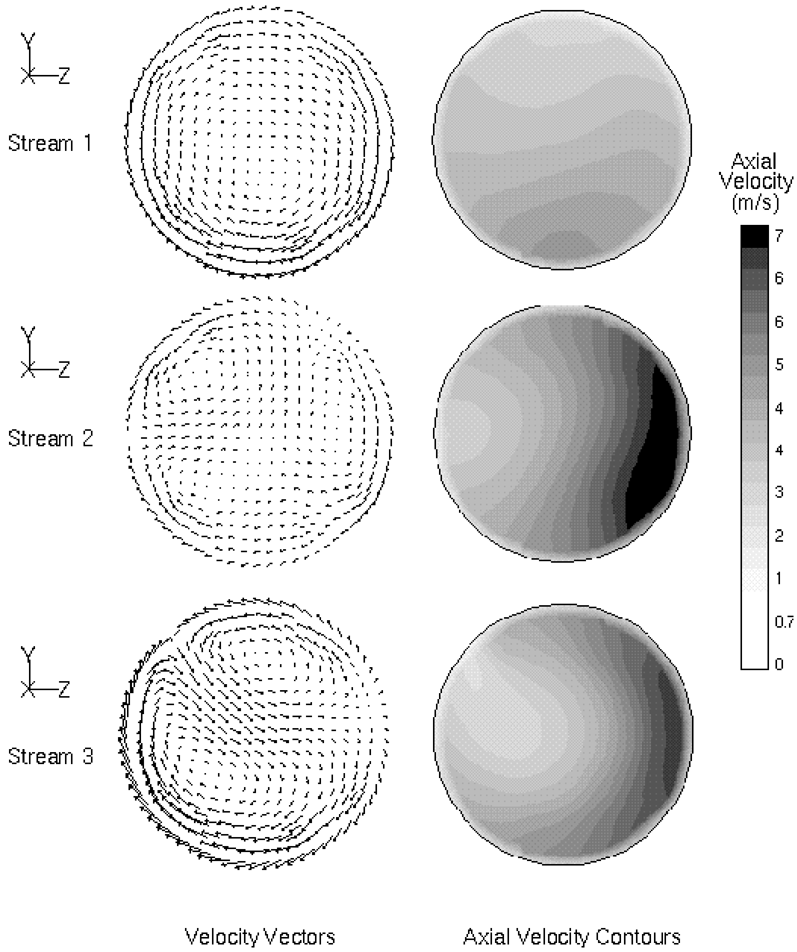

Figure 6. Predicted Flow Behaviour 1.5m Downstream of the Header with Streams 1, 2 and 3 on-line

3.3 Predicted Flow in the Metering Streams

The next step in the analysis was to model the flow from the header to the flowmeters and the flow through the meters themselves. The flow from the header to the flowmeters was modelled for three streams (designated Cases A, B and C). ISO 5167 states that the velocity profile entering an orifice plate flow meter should be within a +/-5% band of a fully developed profile and that the inlet flow swirl angle should be less than 2^{o}. The predicted flow behaviour was compared against these criteria, as discussed below.

<u>Case A - Stream 3 with streams 1,3 and 4 on-line</u>
This stream was selected as the flow entering it shared common features with other streams, i.e. stream 1 (1,3 & 4 on-line, figure 10) and stream 2 (1,2 & 3 on-line, figure 6).

The double vortex swirl entering stream 3 almost completely decayed by the time the flow reached the flowmeter. The velocity profile was slightly flattened but within the ISO 5167 +/-5% limit.

Case B - Stream 4 with streams 1,3 and 4 on-line

This stream was selected because there were strong indications that further downstream of the header single vortex swirl was likely to develop. Single vortex swirl is known to persist for long distances and is detrimental to the accuracy of orifice plate flowmeters.

This was indeed the case with swirl of about 4^{o} being predicted at the flowmeter inlet. This exceeds the ISO 5167 limit of 2^{o}. The velocity profile was also slightly distorted, but close to being fully developed and lay within the ISO 5167 limits.

Case C - Stream 1 with streams 1,2 and 3 on-line

This was also selected because single vortex swirling flow was predicted at the header. This swirl decayed to about 5^{o} at the flowmeter inlet, again, this is in excess of the 2^{o} limit. As in previous cases the axial velocity profile entering the flowmeter was close to being fully developed, just failing the ISO 5167 criteria for velocity profile.

3.4 Predicted Flow Metering Error

Four simulations were run of flow through an orifice flowmeter: a baseline case with fully developed inlet conditions and three cases using the disturbed inlet conditions described in section 3.3. The difference between the baseline and disturbed flow cases was used to predict the installation error of individual flowmeters in the Bruce installation, as summarised in table 2.

Case	Streams On-line	Flowmeter	Predicted C	Shift in C	Measure-ment Error
	Fully Developed	-	0.6249	-	-
A	1-3-4	3	0.6187	-0.97%	+0.97%
B	1-3-4	4	0.6236	-0 .18%	+0.18%
C	1-2-3	1	0.6254	+0.11%	-0.11%

Table 2. Predicted flow measurement error

The predicted discharge coefficient for fully developed flow was 0.6249. This is 3.6% greater than the value given in ISO 5167 of 0.603. This confirms the findings of similar previous work[3] that showed calculation errors of the order of 5% in the three-dimensional simulations of orifice plates. However, it has been shown that this calculation error is very similar in fully developed and disturbed cases, Thus, subtracting two predicted values of discharge coefficient (as in equations 2 or 3) effectively eliminates most of the calculation error associated with the CFD predictions.

4 DISCUSSION

4.1 Validity of the Predictions

Case A

The double vortex swirl and skewed velocity profile entering stream 3 (see figure 5) is very similar to that seen downstream of a single bend. A comparison of CFD predictions of an orifice plate downstream of a single bend with published test data (figure 7) suggests that the predicted error of +0.97% 31 diameters downstream of the header is likely to be a slight over-estimate.

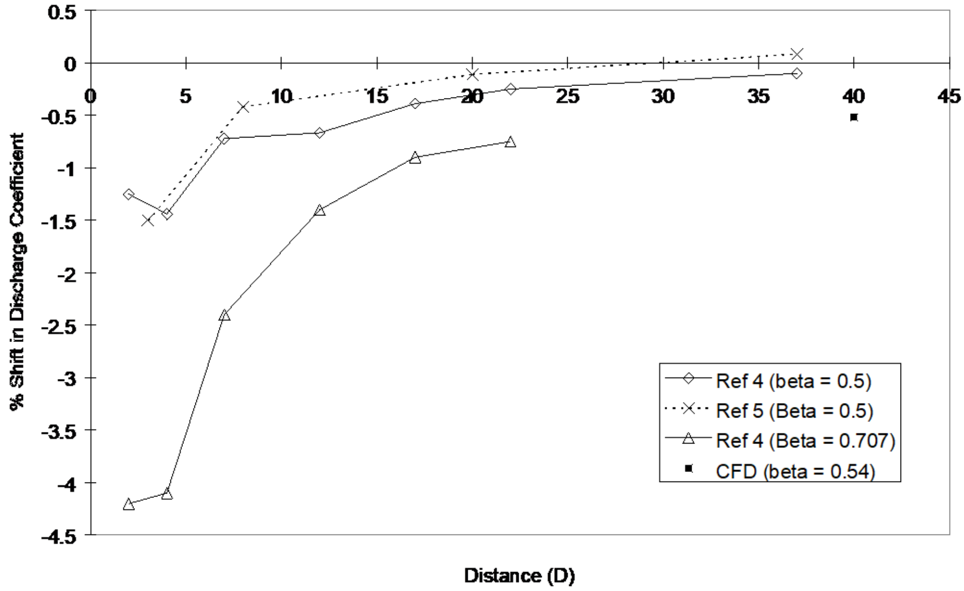

Figure 7. Comparison of Measured and Predicted Shifts in Discharge Coefficient of an Orifice Plate Downstream of a Single Bend

Cases B & C

The single vortex flow pattern entering the flowmeters in Cases B and C is analogous to that seen downstream of twisted double bends. Examination of test data from orifice plates (such as that shown in figure 8) shows that flowmeters with a β ratio of about 0.6 at 31 diameters produce small measurement errors. This suggests that the estimated errors of +0.18% and –0.11% for Cases B and C are realistic.

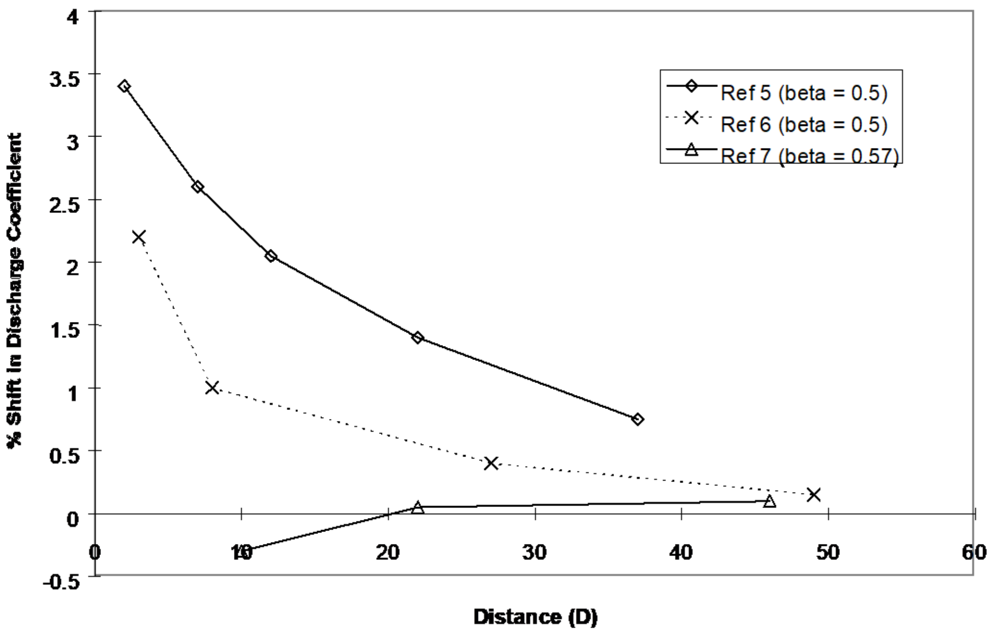

Figure 8. **Measured Shifts in Discharge Coefficient of an Orifice Plate Downstream of a Twisted Double Bend**

4.2 Estimation of Error in the Metering System

The flow patterns generated at the header outlets depend on the combination of streams that are on-line, as can be seen when comparing figures 5 and 6. However, similarities can be seen between flow patterns generated by different combinations. For example, the flow pattern in Stream 4 shown in figure 5 is similar to that seen in Stream 3 in figure 6. As a first estimate, we could therefore say that the flowmeter on Stream 3, with streams 1, 2 and 3 on-line, is likely to be in error by about +0.18%.

Using this general approach the metering error for the entire metering system was estimated, as summarised in Tables 3, 4 and 5. Initially streams that had not been modelled were equated to those that had been modelled (Table 3) and corresponding metering errors allocated to each stream (Table 4). These errors were then scaled to account for the flow splits given in Table 1 and a total system metering error calculated (Table 5).

Stream 1	Stream 2	Stream 3	Stream 4
c	**A**	**B**	-
A	-	a	b
C	**A**	-	**B**
-	**C**	**A**	**B**

Table 3. **Estimation of the flow conditions in different streams. Lower case text shows values where conditions have been simulated using CFD, bold text shows estimated equivalents.**

Stream 1	Stream 2	Stream 3	Stream 4
-0.11%	**+0.97%**	**+0.18%**	-
+0.97%	-	+0.97%	+0.18%
-0.11%	**+0.97%**	-	**+0.18%**
-	**-0.11%**	**+0.97%**	**+0.18%**

Table 4. Estimation of the flow measurement errors in different streams. Bold text shows estimated values.

Stream 1 Weighted	Stream 2 Weighted	Stream 3 Weighted	Stream 4 Weighted	Total Error
-0.031%	**+0.371%**	**+0.061%**	-	+0.400%
+0.382%	-	+0.299%	+0.054%	+0.735%
-0.030%	**+0.361%**	-	**+0.064%**	+0.394%
-	**-0.043%**	**+0.299%**	**+0.054%**	+0.310%

Table 5. Estimation of the total flow measurement error of the metering system based on values in table 4 weighted to account for the flow rate through each stream.

Table 5 suggests that the total error of the system is generally small in magnitude and depends on which streams are on-line. As most of the errors tend to be positive in sign, the meters with negative errors tend to act to cancel these errors out, reducing to the total error.

5 CONCLUSIONS

The flow through Bruce flow metering installation has been simulated using CFD software.

Predictions show that significant amounts of swirl and velocity profile distortion are generated by the pipe bends upstream of the header. Swirling flow enters the header.

Two simulations of the header have been run. These show that the flow pattern in each outlet stream varies, depending on which combinations of streams are on-line. Consequently, the flow metering error in each of the orifice plate meters will vary depending on which streams are on-line.

The flow through three of the flow meters has been modelled. Only one of these three cases (simulation A) the predicted inlet conditions complied with the requirements of ISO 5167 for velocity profile distortion and swirl. The predicted installation error for this meter was +0.97%. Comparison against published experimental data suggests that this prediction may be a slight over estimate.

The two other flow meter simulations (B and C) failed the ISO 5167 criteria for suitable inlet flow conditions. In these two cases errors of +0.18% and –0.11% were predicted. Comparisons with experimental data suggest that these predictions are realistic.

Using the CFD error predictions a rough estimate of the installation error of the flow metering system has been calculated as being between +0.3% to +0.7% depending on which streams are on-line. Since these values lie within the ±1% uncertainty of a metering system built to ISO 5167, then no modifications will be performed on the present metering system.

6. REFERENCES

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