Peer Review Of "COMPUTATIONAL FLUID DYNAMICS (CFD) ANALYSIS OF ORIFICE PLATE METERING SITUATIONS UNDER ABNORMAL CONFIGURATIONS", Version 2.0, Dr W. Malalasekera, May 2013

A Report for

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For B Millington
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August 2013

EXECUTIVE SUMMARY

For the long model at any rate CFD grid independence has not been achieved; so the contention that the long model is required has not been proved.

There is generally quite good agreement between experiment and CFD, but grid independence remains to be achieved.

CONTENTS

1 INTRODUCTION

NEL have been tasked by Kelton Flow Measurement Consultants to undertake a peer review of a Computational Fluid Dynamics (CFD) report. The report title is “Computational Fluid Dynamics (CFD) analysis of orifice plate metering situations under abnormal configurations, Version 2.0” [1], authored by Dr W Malalasekera of Loughborough University, 2013.

The report describes a series of CFD calculations which have been used to predict the measurement error when an incorrectly installed orifice plate was used.

The aim of the review is to confirm that the recommendations made in report NEL 2013-98 have been undertaken and to state whether the CFD work is now technically robust.

2 MEETING THE RECOMMENDATIONS

The report in Version 2.0 [1] does not meet the recommendations made in the peer review [2] of the previous version of the report [3], although hexahedral elements have been used where possible (see e.g. p. 39 of [1], following Recommendation 2 of [2]).

It is stated that the orifice plate area is finely meshed (e.g. p. 39 of [1]), but the mesh spacing is not stated, and so it is not clear that it meets Recommendation 3 of [2] that it be a maximum of 0.1 mm around the orifice edge.

The quality of the mesh is still not reported (requested in 2.1.3 of [2]).

It is stated (e.g. p. 39 of [1]) that boundary layer meshes have been used at walls to maintain y+, but no values of y+ are given (the absence of y+ values was commented on in 3 of [2]).

In 2.2.2 of [2] NEL stated, ‘It is crucially important to show both the Reynolds number and computed discharge coefficients’.

‘It is also necessary to compare the base line discharge coefficient (i.e. the computed discharge coefficient for the orifice plate in the correctly installed location) with the Reader-Harris/Gallagher (1998) equation in ISO 5167-2:2003.

‘Studies must also be conducted to determine whether the computed shift in discharge coefficient (from baseline to test case) varies significantly with Reynolds number.

It should be stated that the CFD calculations are treated as incompressible. This is a reasonable method but it must be documented.’

These matters have not been addressed: the graph from Ben Kirkman confirms that the computed error in flowrate varies only weakly with Reynolds number, but still leaves the interpretation of the experimental data and the CFD results incomplete.

Mesh independence (Recommendation 4) has not been demonstrated: see below.

3 ANALYSIS

However, NEL has analysed some of the data: three analyses have been carried out.

3.1 Standard orifice plate

The differences between ISO 5167-2:2003 [4] and both the computed results and the experimental results are shown in Figure 1. These results are good in terms of agreement with experiment, especially given that the pipe is outside the roughness requirement for ISO

5167-2:2003, and the discharge coefficient at $Re_D = 10^7$ would be expected from [5] to be 0.84 % above the standard. However, they still lack grid independence.

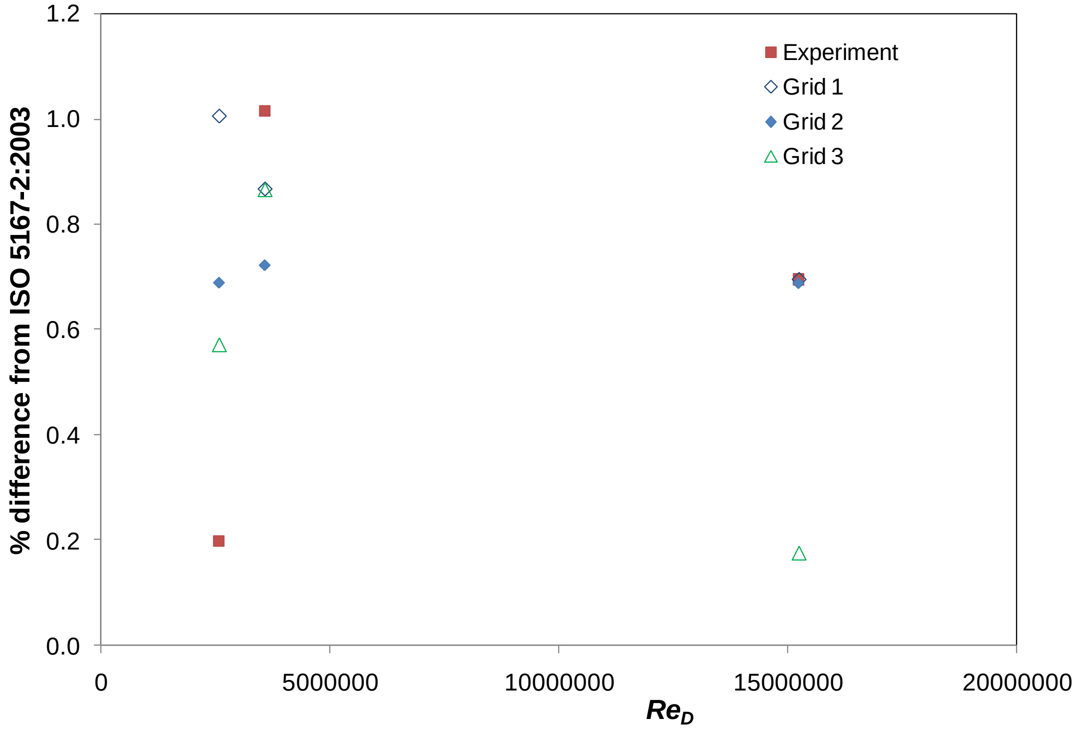

Figure 1 % difference in C for CFD and C_ε for experiment from ISO 5167-2:2003

Nevertheless, it is interesting that the pressure distribution downstream of the orifice is different from that given by experiment or other computational work. Both the experiments and the computations of Morrison et al. [6, 7] show that the pressure is constant from 6*D* downstream of the orifice, and NEL computations of the pressure recovery downstream of an orifice plate are shown in Figure 2, whereas Malalasekara [1] in Figures 13, 16 and 20 shows a continuing recovery after 6*D* downstream of the orifice plate (there is also a surprising kink in the pressure distribution just downstream of the orifice plate in Figure 20). It appears that poor computation of the downstream recovery has little effect on the discharge coefficient. It seems surprising that a thermowell 9*D* downstream would matter.

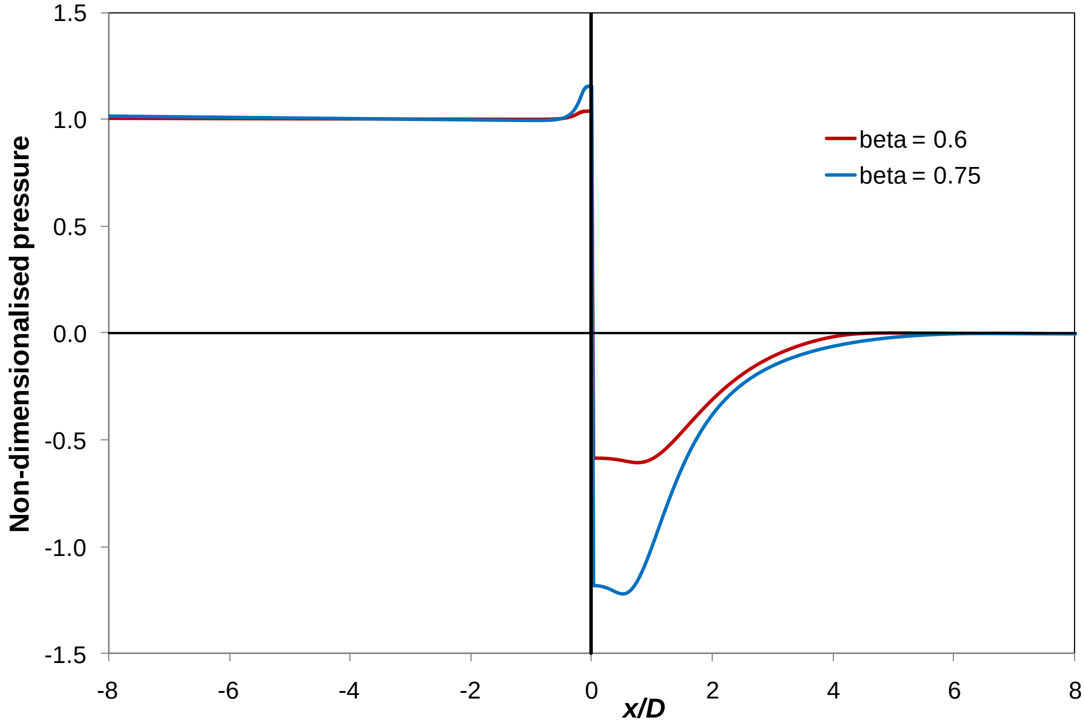

Figure 2 Non-dimensionalised pressure profile through an orifice plate: NEL computation: $Re_D = 10^7$

To establish whether the computations of flow through a standard orifice plate in [1] are grid-independent, axisymmetric computations could be performed and compared with the three-dimensional computations presented in [1].

3.2 Test cases 99985 – Tests 01 to 11

The CFD and the experimental data are plotted in Figure 3. Throughout the analysis here the orifice diameter has been used in the definition of discharge coefficient. It might be better to calculate a diameter based on the open area at the orifice, but the conclusions would be the same.

Both sets of CFD calculations show that there is very little effect of Reynolds number on the discharge coefficient. The variation in the experimental data with Reynolds number is largely due to higher uncertainty at lower differential pressure. The 'long model' calculations are not grid-independent: the two sets differ by about 0.8%. The 'short model' calculations are much closer to grid independence, differing by about 0.2% on average. NEL's expectation is that the difference between the 'long model' and the 'short model' calculations is due to lack of grid independence (especially for the 'long model') rather than to the fact that the downstream thermowell and bend are modelled in the 'long model'. For a correctly installed orifice plate Goldsmith et al. [8] showed that the effect of thermowells 1.63D to about 2D downstream on the measured flowrate was small, and that an oversized thermowell only 1.63D downstream of a plate had no effect at all. It would, therefore, be expected that a thermowell 9D downstream of an orifice plate would have no effect at all. ISO 5167-2:2003 requires 7.3D before a downstream bend; the bend here is 18D from the orifice; again it should have no effect at all. To demonstrate that the downstream effect captured in the long model is real it is necessary that the same grid be used until 8D downstream of the orifice plate and then two alternative downstream grids used and the discharge coefficients compared.

Considering the three experimental points for which Re_D is around 1.5×10^7, the highest of the points appears to have an error much larger than the stated uncertainty.

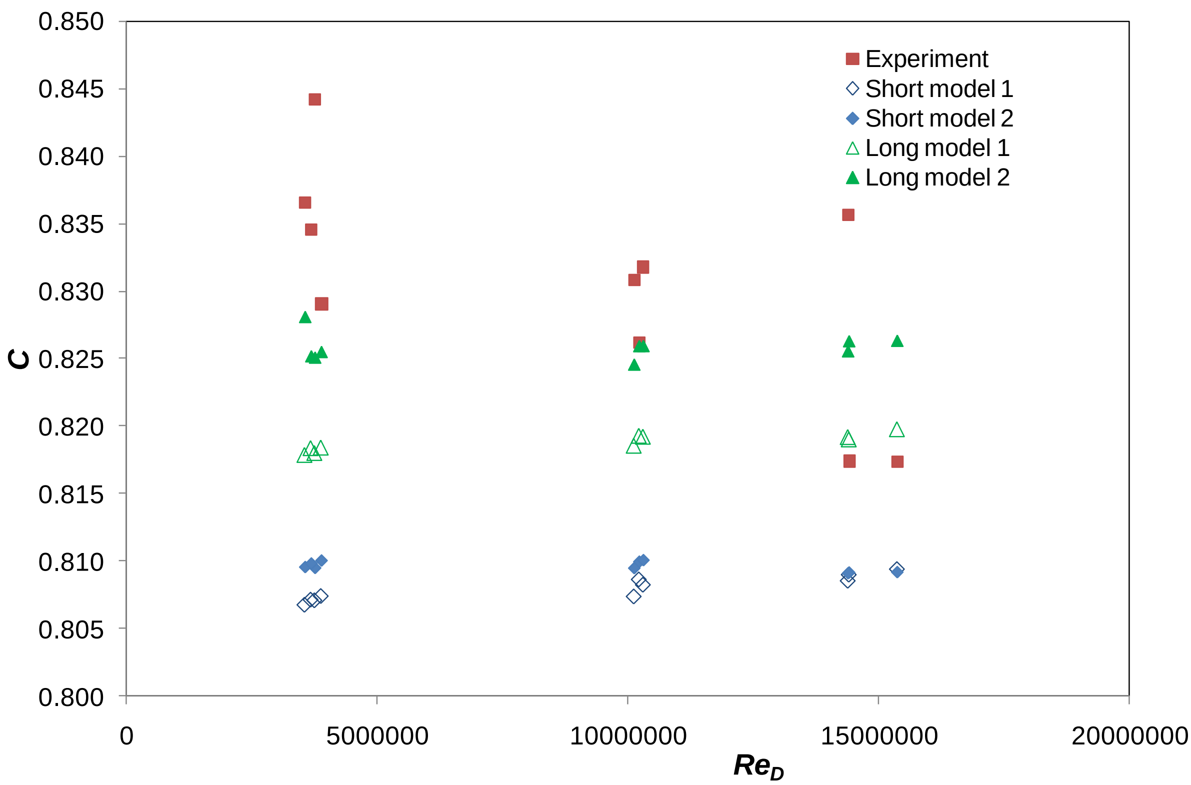

Figure 3 Data for test cases 99985: for the CFD *C* is plotted, for the experiments *Cε*

3.3 Test cases 99950 Tests 01 to 11

The CFD and the experimental data are plotted in Figure 4. Except for the first computation the computed values of discharge coefficient vary little with Reynolds number. The uncertainty of the experimental data is much higher than the values given in Table 12 of [1], where the uncertainty in measurements (presumably in differential pressure) is stated never to exceed 6 % (there are also errors in the calculated difference in error). Table 12 appears inconsistent with Figure 10. The discharge coefficients using Grid 2 and Grid 3 differ very little from each other; those using Grid 1 differ from the other two by a little over 2%.

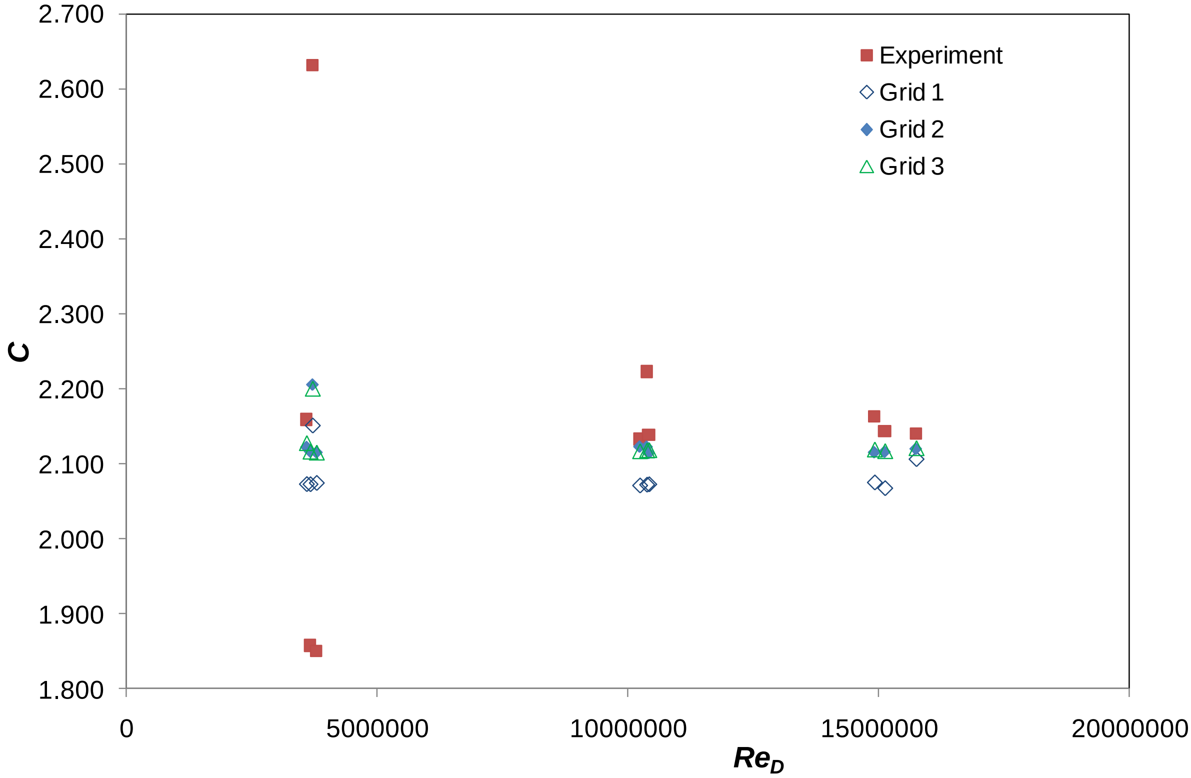

Figure 4 Data for test cases 99950: for the CFD *C* is plotted, for the experiments *C*ε

4 CONCLUSIONS

For the long model at any rate CFD grid independence has not been achieved; so the contention that the long model is required has not been proved.

There is generally quite good agreement between experiment and CFD, but grid independence remains to be achieved.

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