Drag of circular cylinders in turbulent flow at Reynolds numbers up to 1.3 x 10^6 (and why the AWES QAS manual has got it wrong)

Michael Eaddy, Bill Melbourne

MEL Consultants Pty Ltd, Victoria, Australia
eaddy@melconsultants.com

1 INTRODUCTION

It is well known that aerodynamic forces experienced by objects with curved surfaces, such as the circular cylinder, are dependent on Reynolds Number. There have been numerous papers published that show the dependency of the drag, lift, and fluctuating lift on Reynolds Number with significant changes occurring beyond a Reynolds number of approximately 1 x 10^5. However, even with the significant volume of published data we have reviewed a number of wind tunnel studies of forces for Reynolds number dependent shapes that do not consider the effects of Reynolds number. Many of these studies are undertaken to provide design wind load information for large structures that would experience Reynolds numbers well in excess of 1 x 10^5. The Reynolds numbers of these wind tunnel model studies are often well below 1 x 10^5.

Schewe [1] measured the standard deviation lift, Strouhal number, and the mean drag coefficient for a smooth circular cylinder in low turbulence flow for a Reynolds number range of 2 x 10^4 to 7 x 10^6 shown in Fig. 1. Although the measurements were performed on a smooth cylinder in low turbulence flow they clearly illustrate the dependence of the forces on Reynolds number. The wind tunnel studies for wind engineering applications are typically undertaken in turbulent wind flows, i.e. simulated turbulent boundary layers or grid generated turbulence. Cheung and Melbourne [2] published wind tunnel measurements of the total mean drag coefficient for a circular cylinder for Reynolds numbers up to 1 x 10^6, and the data is reproduced in Fig. 2. The data showed that the influence of free stream turbulence on the critical transition Reynolds number, and the Reynolds number dependence of the mean drag coefficient in turbulent flow. The mean drag coefficient continues to exhibit dependence on Reynolds number beyond 1 x 10^5 with turbulence, and does not appear to be approaching Reynolds number independence until about 6 x 10^5.

The Australasian Wind Engineering Society (AWES) has produced a Quality Assurance Manual (QAM) [3] to provide guidance as to the best practice for wind tunnel model measurements and refers to a minimum Reynolds number based on the minimum building width and mean wind speed at the top of the model. For sharp edged objects a minimum Reynolds number of 5 x 10^4, or greater, is recommended, and for a model with circular cross-section or corners with large radii where the points of separation may be dependent on Reynolds number a minimum Reynolds number of 1 x 10^5, or greater, which references the work of Cheung and Melbourne [2].

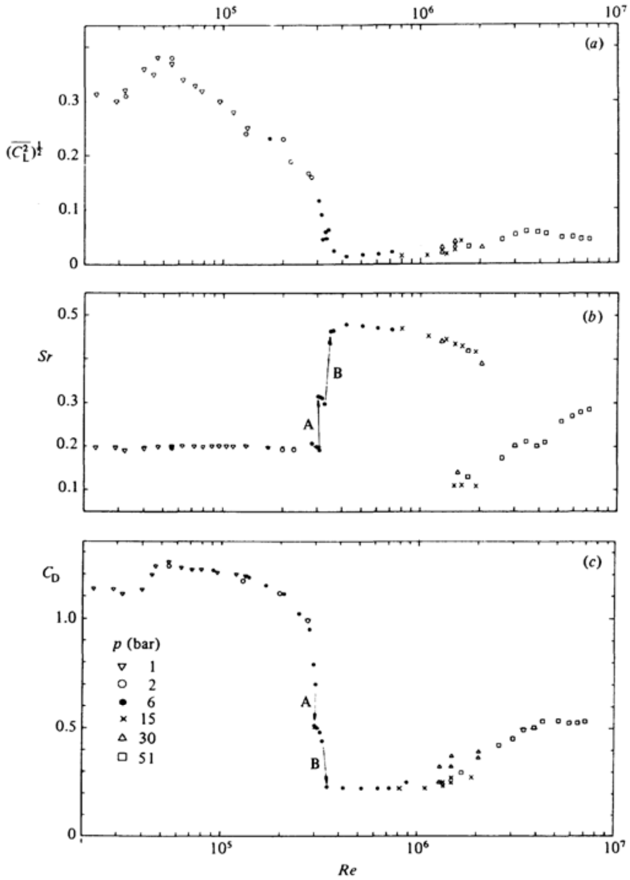

Fig. 1 Standard deviation lift coefficient, Strouhal number, and mean drag coefficient of a smooth circular cylinder as a function of Reynolds number in low turbulence flow [1]

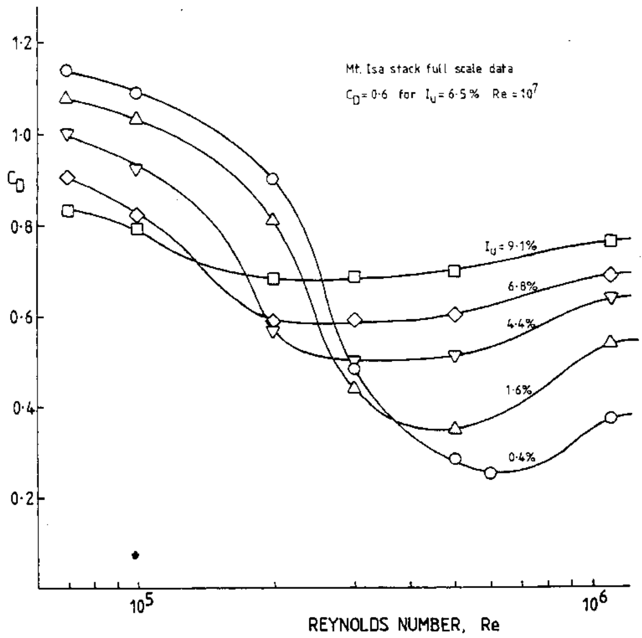

Fig. 2 Total mean drag coefficients as function of Reynolds number for a smooth circular cylinder for various turbulence intensities [2]

2 RECENT WIND TUNNEL DATA

The recent wind tunnel measurements of the sectional mean drag coefficient for a smooth cylinder in turbulent flow are shown in Fig. 3. The data shows that the mean drag coefficients are beginning to become independent of Reynolds number only at the highest Reynolds numbers investigated. The data are showing a trend towards a sectional mean drag coefficient of 0.6 at the highest Reynolds number, with the mean drag coefficient reaching 0.5 at approximately 6×10^5.

The AWES QAM [3] has stated that a Reynolds number of 1×10^5 should be achieved when wind tunnel testing a model with Reynolds Number dependence. Given that the wind tunnel velocities hence fan power necessary to achieve these Reynolds numbers it would be expected that testing would be carried out at the minimum recommended Reynolds number. The data shows that by testing at the minimum Reynolds number recommended by the AWES QAM the wind tunnel model measured drag coefficients would be significantly lower than those experienced by a large full scale structure. Therefore, the minimum recommended Reynolds number in the AWES QAM should be increased to at least 6×10^5, but wind tunnel model measurements should aim to be well in excess of this value.

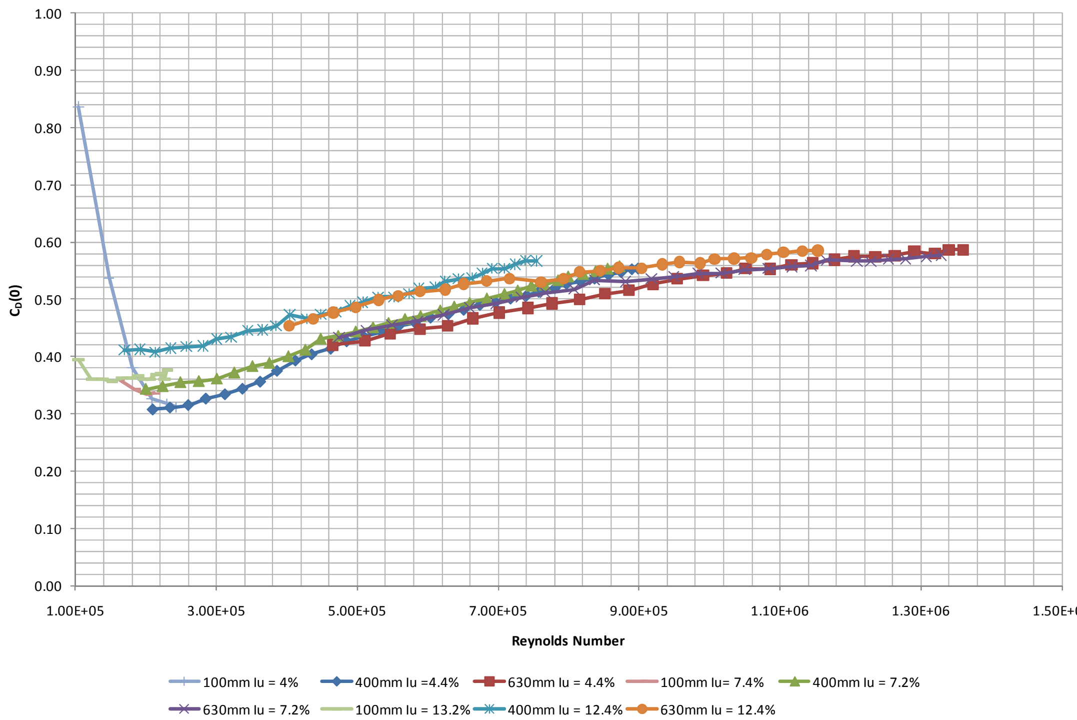

Fig. 3 Sectional mean drag coefficient as a function of Reynolds number for smooth cylinders in various turbulence intensities

3 CONCLUSIONS

Based on the recent wind tunnel measurements the guidance provided by the AWES QAM [3] for wind tunnel testing of models, with correctly scaled turbulence intensity greater than 10%, that have a Reynolds number dependence should be increased to a minimum of 6 x 10^5, and for wind tunnel testing should aim to have the Reynolds number well in excess of this value.

It is noted that for fluctuating lift forces the independence Reynolds number is higher, particularly where roughened cylinders are concerned.

4 REFERENCES

[1] Schewe (1983). “On the force fluctuations acting on a circular cylinder in crossflow from subcritical up to transcritical Reynolds numbers ”, J. Fluid Mech.,133, pp 265-285.

[2] Cheung J. C. K. And Melbourne W. H. (1983). “Turbulence effects on some aerodynamic parameters of a circular cylinder at supercritical Reynolds numbers”, J. Wind Eng. Ind. Aerodyn., 14, pp. 399-410

[3] Australasian Wind Engineering Society AWES-QAM-1-2001 (2001). Wind Engineering Studies of Buildings, ISBN 0-9750376-0-9.