TEST CASE DOCUMENTATION
AND TESTING RESULTS

TEST CASE ID ICFD-VAL-3.1

Flow around a two dimensional cylinder

Tested with LS-DYNA® v980 Revision Beta

Friday 1st June, 2012

Document Information	
Confidentiality	**external use**
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Contents

1 Introduction

1.1 Purpose of this Document

This document specifies the test case ICFD-VAL-3.1. It provides general test case information like name and ID as well as information to the confidentiality, status, and classification of the test case.

A detailed description of the test case is given, the purpose of the test case is defined, and the tested features are named. Results and observations are stated and discussed. Testing results are provided in section 4.1 for the therein mentioned LS-DYNA® version and platforms.

2 Test Case Information

Test Case Summary	
Confidentiality	external use
Test Case Name	Flow around a two dimensional cylinder
Test Case ID	ICFD-VAL-3.1
Test Case Status	Under consideration
Test Case Classification	Validation
Metadata	EXTERNAL FLOW

Table 1: Test Case Summary

3 Test Case Specification

3.1 Test Case Purpose

The purpose of this test case is to show the solver's ability to correctly reproduce the stationnary and the unstationnary incompressible laminar flow around a cylinder for a Reynolds number up to 160.

3.2 Test Case Description

The flow around a cylinder has been widely used both as a numerical validation test case as well as a research case (See [3], [1]). The behavior of the flow is characterized by the Reynolds number defined as :

$$Re = \frac{\rho L V}{\nu} \tag{1}$$

with ρ the fluid's density, L the characteristic length of the problem i.e the diameter of the cylinder, V the incoming velocity and ν the fluid's viscosity.

Depending on the Reynolds number, the following behaviors of the flow can be identified :

$Re < 50$	Steady laminar flow with symmetric separation (see Figure (1)).
$50 < Re < 160 - 190$	Karman Vortex street (see Figure (2)).
$190 < Re < 300$	Laminar with vortex street instabilities.
$300 < Re$	Laminar-Turbulent transition. Turbulent separation
and reattachment, Turbulent wake.	

This test case will focus on the laminar regime. The Reynolds number will be varied from 2 to 160. According to the available literature, this study will especially focus on two values of viscosity corresponding to the Reynolds number values of $Re = 40$ and $Re = 100$. For all cases, the values of pressure and lift will be compared to those available in the literature. For the $Re = 40$ case, the boundary layer separation point of the laminar stationary flow will be analyzed as well as the reattachment length. For the $Re = 100$ case, the frequency of the vortex shedding will be studied through the Strouhal number defined as :

$$St = \frac{DU}{T} \tag{2}$$

with D the diameter of the cylinder, U the incoming velocity, and T the oscillations' period.

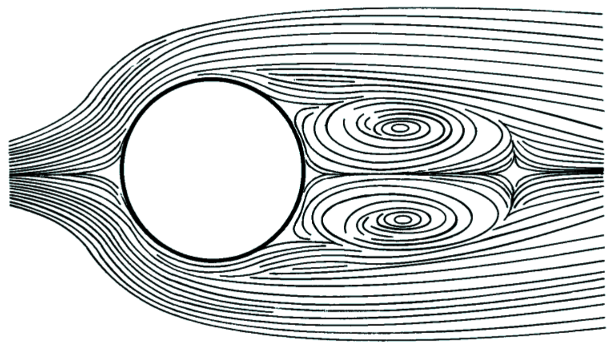

Figure 1: Graphical representation of the flow around a cylinder for Re=40

Figure 2: Graphical representation of the flow around a cylinder for Re=200

3.3 Model Description

The fluid environment consists of an inflow with a prescribed velocity, a outflow with a prescribed pressure, two free slip conditions for the remaining boundaries and a non slip condition on the cylinder. It also contains two meshing boxes which will allow a finer volume meshing around the cylinder and its immediate wake. A complete description of the model's geometry is depicted in Figure (3). A view of the resulting volume mesh after running the test case and a zoom to the zone close to the cylinder are shown in Figure (4) and Figure (5). Finally, Table (3) gives the physical parameters that will be used.

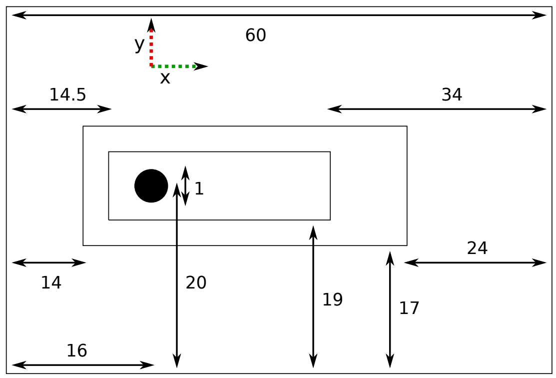

Figure 3: Test Case Geometry

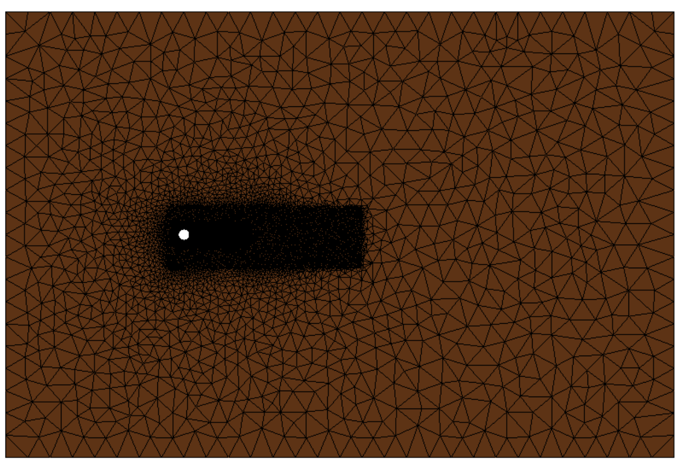

Figure 4: Test Case Mesh

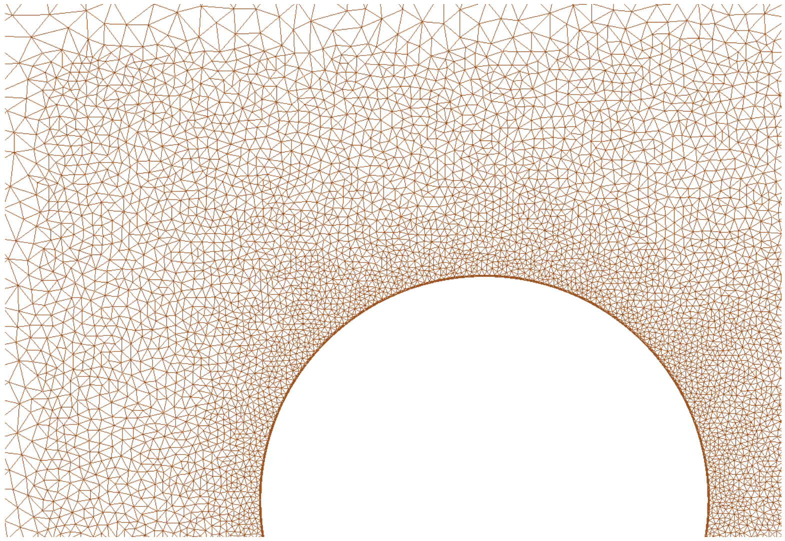

Figure 5: Zoom of the Mesh close to the cylinder

Model information	
Fluid boundaries element size	2
Cylinder element size	0.01
Meshing box 1 & 2 element size	0.1 & 0.025
Volume Nodes	45383
Volume Elements	88626
Anisotropic Elements added to the Boundary Layer	3

Table 2: Test Case Mesh Information

Model physical parameters	
Fluid Density	1
Viscosity	0.5 to 0.00625
Incomming velocity	1

Table 3: Test Case Parameters

4 Test Case Results

4.1 Test Case observations

Figure (6) shows the velocity vectors for a Reynolds number of 40 highlighting the steady laminar symmetric separation occurring behind the cylinder. Figure (7) shows the velocity vectors for a Reynolds number of 100 highlighting the periodic Von Karman vortex shedding. Table (4) gives the lift and drag results obtained for the various Reynolds numbers. The lift values correspond to the maximum lift values occurring during the vortex shedding. Starting from the Reynolds value of 60, the drag values given are mean drag values calculated after the vortex shedding is fully developed.

Figure (8) and (9) offer a comparison between the present analysis and the results given by [2]. It can be noted that the global behavior of the present analysis is in good agreement with the reference results. Starting from the Reynolds number of 40, the error regarding the total drag slowly expands going from 3.8% for $Re = 40$ to 7.5% for $Re = 2$ when comparing with the results given by [2]. This can be explained by the fact that, as the Reynolds number decreases and the viscosity increases, the hypothesis used by the Fractional Step method of the solver, (i.e the diffusion term of the solution due to the viscosity is small compared to the convection term) is slowly reaching its limits. It can also be noted that the the error regarding the lift coefficient slowly increases going from 4.1% for $Re = 80$ to 6.6% for $Re = 160$. In order to bring this error down, a finer mesh may be used. For illustration purposes, Table (5) offers a mesh grid convergence analysis for a Reynolds number of 100 using the reference result for error calculation given by [2].

Finally, for the Reynolds numbers of 40 and 100, some further observations can be made. For the Reynolds number of 40, the boundary layer separation angle occurs at an angle of $54°$ and the distance between the flow reattachment point and the cylinder is equal to 2.3 which is in good agreement with the results given by [2]. For the Reynolds number of 100, the Strouhal number is equal to 0.165 which is in the vicinity of the results given by [2] and [3] (see Table (6)).

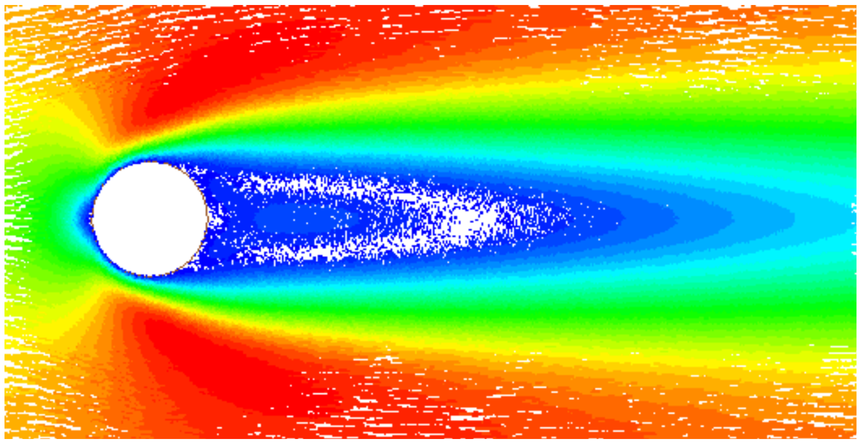

Figure 6: Velocity vectors for $Re = 40$

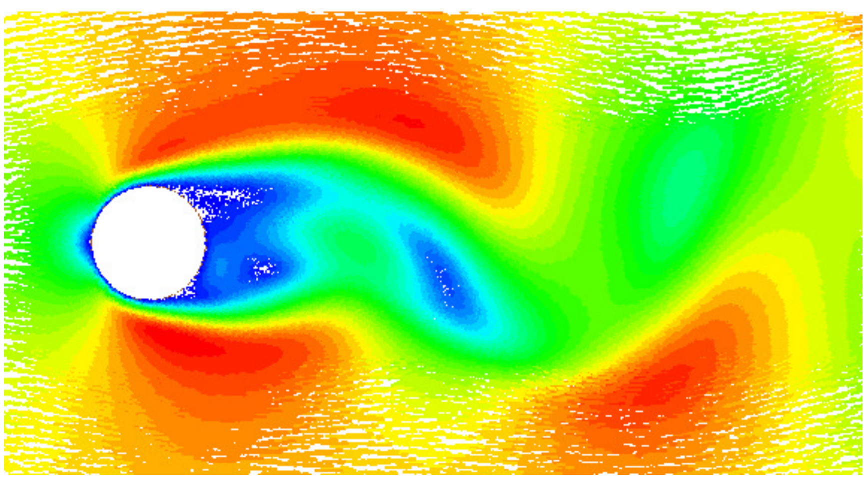

Figure 7: Velocity vectors for $Re = 100$

Results for the Drag and Lift coefficients						
Reynolds	Cd_{tot}	Cd_{pres}	Cd_{fric}	Cl_{tot}	Cl_{pres}	Cl_{fric}
2	7.36	3.74	3.62			
4	4.83	2.54	2.29			
10	2.92	1.63	1.29			
20	2.10	1.25	0.84			
40	1.57	1.02	0.55			
60	1.44	0.99	0.45	0.14	0.12	0.0250
80	1.40	1.00	0.40	0.25	0.22	0.0396
100	1.38	1.02	0.36	0.35	0.30	0.0480
120	1.37	1.03	0.33	0.43	0.37	0.0562
140	1.37	1.05	0.31	0.51	0.45	0.0620
160	1.37	1.07	0.30	0.59	0.52	0.0674

Table 4: Test Case Lift and Drag results

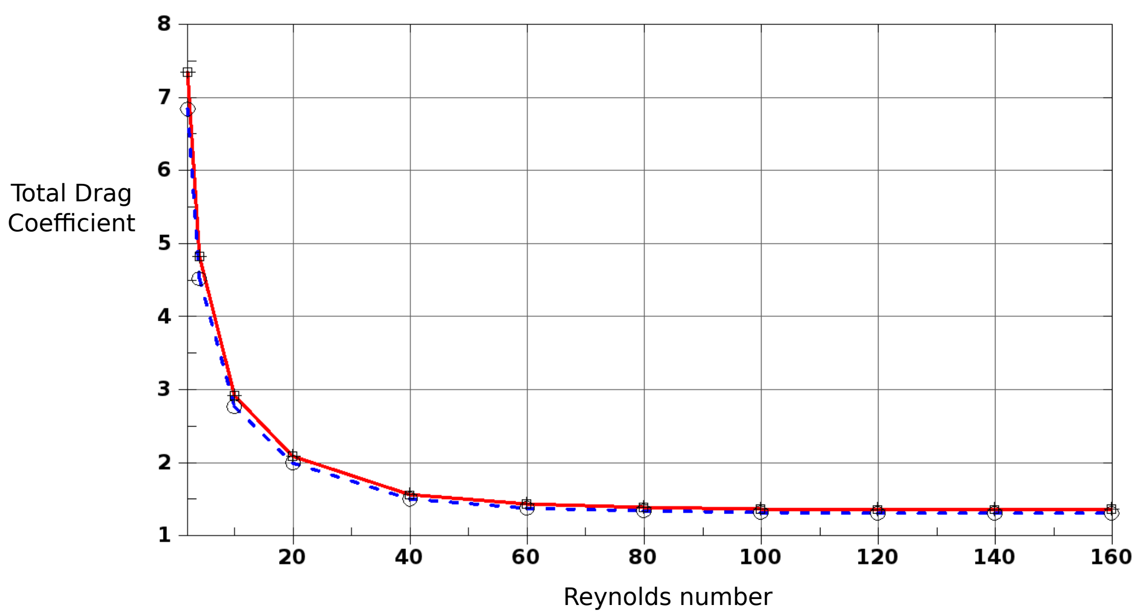

Figure 8: Comparison of the Total Drag between the present analysis (in red) and the results (in blue) given by [2]

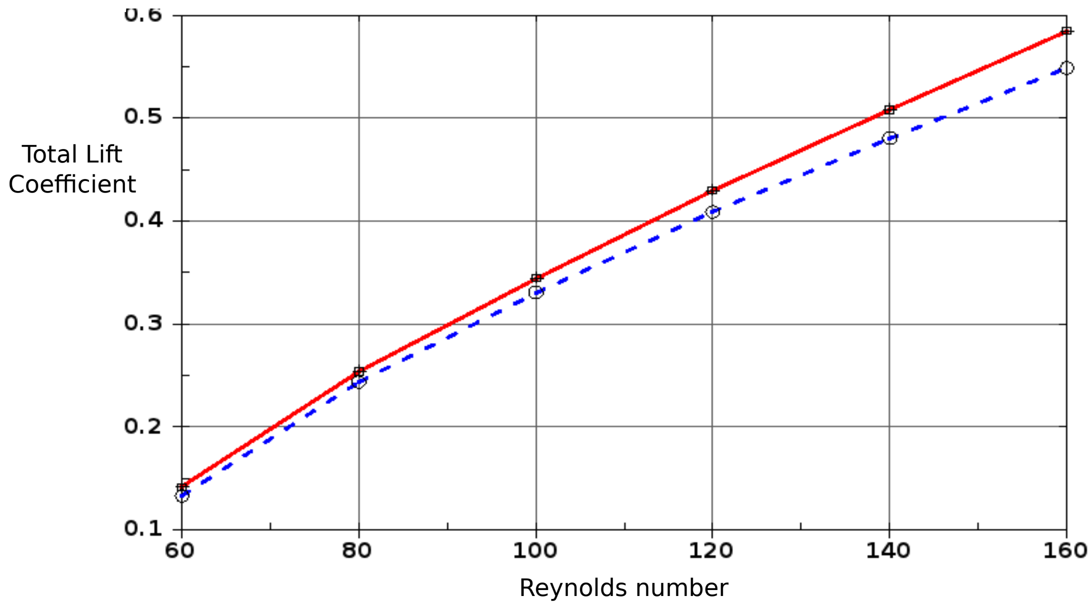

Figure 9: Comparison of the Total Lift between the present analysis (in red) and the results (in blue) given by [2]

Cylinder surface element size	Cl_{tot}	$Error$
0.02	0.357	7.6%
0.01	0.346	4.2%
0.005	0.337	1.4%
0.0025	0.336	1.2%

Table 5: Mesh grid analysis for $Re = 100$

	Simo, Armero (1994)	Tezduyar et al.(1991)	Choi et al. (1997)	Mittal (1993)	Brooks,Hughes (1982)	Behr et al. (1995)
St	0.167-0.178	0.156-0.170	0.164	0.167	0.167	0.162-0.171

Table 6: Results given by different authors for the Strouhal number and $Re = 100$

References

[1] J. G. C. Y. Zhou, *A numerical study of cylinders in waves and currents*, Journal of Fluids and Structures, 14.

[2] H. C. Jeongyoung Park, Kiyoung Kwon, *Numerical solutions of flow past a circular cylinder at reynolds numbers up to 160*, KSME International Journal, 12.

[3] W. A. Wall, *Fluid Struktur Interaktion mit stabilisierten Finiten Elementen*, PhD thesis, Universität Stuttgart Institut für Baustatik, 1999.