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
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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

<table>
<thead>
<tr>
<th>confidentiality</th>
<th>external use</th>
</tr>
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<tbody>
<tr>
<td>Test Case Name</td>
<td>Flow around a two dimensional cylinder</td>
</tr>
<tr>
<td>Test Case ID</td>
<td>ICFD-VAL-3.1</td>
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<tr>
<td>Test Case Status</td>
<td>Under consideration</td>
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<td>Test Case Classification</td>
<td>Validation</td>
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<tr>
<td>Metadata</td>
<td>EXTERNAL FLOW</td>
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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 stationary and the unstationary 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:

\[ Re = \frac{\rho LV}{\nu} \]  \hspace{1cm} (1)

with \( \rho \) the fluid's density, \( L \) the characteristic length of the problem i.e the diameter of the cylinder, \( V \) the incoming velocity and \( \nu \) 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:

\[ St = \frac{DU}{T} \]  \hspace{1cm} (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](image1)

![Figure 4: Test Case Mesh](image2)
Figure 5: Zoom of the Mesh close to the cylinder

<table>
<thead>
<tr>
<th>Model information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluid boundaries element size</td>
</tr>
<tr>
<td>Cylinder element size</td>
</tr>
<tr>
<td>Meshing box 1 &amp; 2 element size</td>
</tr>
<tr>
<td>Volume Nodes</td>
</tr>
<tr>
<td>Volume Elements</td>
</tr>
<tr>
<td>Anisotropic Elements added to the Boundary Layer</td>
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Table 2: Test Case Mesh Information

<table>
<thead>
<tr>
<th>Model physical parameters</th>
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<tbody>
<tr>
<td>Fluid Density</td>
</tr>
<tr>
<td>Viscosity</td>
</tr>
<tr>
<td>Incomming velocity</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Reynolds</th>
<th>$C_{d_{tot}}$</th>
<th>$C_{d_{pres}}$</th>
<th>$C_{d_{fric}}$</th>
<th>$C_{l_{tot}}$</th>
<th>$C_{l_{pres}}$</th>
<th>$C_{l_{fric}}$</th>
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<tbody>
<tr>
<td>2</td>
<td>7.36</td>
<td>3.74</td>
<td>3.62</td>
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<tr>
<td>4</td>
<td>4.83</td>
<td>2.54</td>
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<tr>
<td>10</td>
<td>2.92</td>
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<td>1.29</td>
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<tr>
<td>20</td>
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<td>1.25</td>
<td>0.84</td>
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<tr>
<td>40</td>
<td>1.57</td>
<td>1.02</td>
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<td>60</td>
<td>1.44</td>
<td>0.99</td>
<td>0.45</td>
<td>0.14</td>
<td>0.12</td>
<td>0.0250</td>
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<td>80</td>
<td>1.40</td>
<td>1.00</td>
<td>0.40</td>
<td>0.25</td>
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<td>100</td>
<td>1.38</td>
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<td>140</td>
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<td>0.31</td>
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<td>1.07</td>
<td>0.30</td>
<td>0.59</td>
<td>0.52</td>
<td>0.0674</td>
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</table>

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]](image-url)

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]

<table>
<thead>
<tr>
<th>Cylinder surface element size</th>
<th>$C_{l_{tot}}$</th>
<th>Error</th>
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<tbody>
<tr>
<td>0.02</td>
<td>0.357</td>
<td>7.6%</td>
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<td>0.01</td>
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<tr>
<td>0.005</td>
<td>0.337</td>
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</tr>
<tr>
<td>0.0025</td>
<td>0.336</td>
<td>1.2%</td>
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Table 5: Mesh grid analysis for $Re = 100$

<table>
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<tbody>
<tr>
<td>Strouhal (St)</td>
<td>0.167-0.178</td>
<td>0.156-0.170</td>
<td>0.164</td>
<td>0.167</td>
<td>0.167</td>
<td>0.162-0.171</td>
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Table 6: Results given by different authors for the Strouhal number and $Re = 100$
References

