TEST CASE DOCUMENTATION
AND TESTING RESULTS

TEST CASE ID ICFD-BENCH-3.1

Turek & Hron's FSI Benchmark problem

Tested with LS-DYNA® v980 Revision Beta

Monday 30th July, 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-BENCH-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	The Turek test case: Strong FSI coupling problem
Test Case ID	ICFD-BENCH-3.1
Test Case Status	Under consideration
Test Case Classification	Benchmarking
Metadata	FSI

Table 1: Test Case Summary

3 Test Case Specification

3.1 Test Case Purpose

This test case features a FSI test case where strong coupling is needed in order to avoid the instabilities due to the so called ”added mass effect” that occurs when the density of the solid approaches the density of the fluid. The purpose of this test case will be to study the robustness of the solver as well as its accuracy compared to the monolithic solution provided by Turek & Hron [1].

3.2 Test Case Description

In this example we consider the flow in a 2D channel past a cylinder with an attached elastic ”flag”. This is the FSI benchmark problem proposed by Turek and Hron [1]. This problem combines the two single-physics problem of the flow past a cylinder with a ”flag” and the deformation of a finite-thickness cantilever beam due to its interaction with the fluid. It is a challenging problem as it tackles some of the main issues when dealing with fully coupled FSI problems namely large mesh deformations and the fluid's density being close to the density of the structure which usually results in critical instabilities.

Figure (1) offers a sketch of the problem. In consists of a 2D channel of height $H_{channel}$ and length $L_{channel}$ which conveys a parabolic inflow fluid and which contains a rigid cylinder of diameter d centered at (x_c, y_c) to which a linear elastic ”flag” of thickness H_{flag} and length L_{flag} is attached. The geometrical parameters are given in Table (2). All dimensions are given in non-dimensional units as this is a pure numeric benchmark test non representative of a ”real life” configuration. The setting is intentionally non-symmetric is order to prevent the dependence of the onset of any possible oscillation on the precision of the computation [2].

The present study will consist in a first series of preliminary tests where only the fluid will be considered. Several Laminar Reynolds numbers will be tried and results compared to those of [1]. After making sure that no significant error will be induced by the fluid results, several FSI configurations will be tested and results again compared to those of [1].

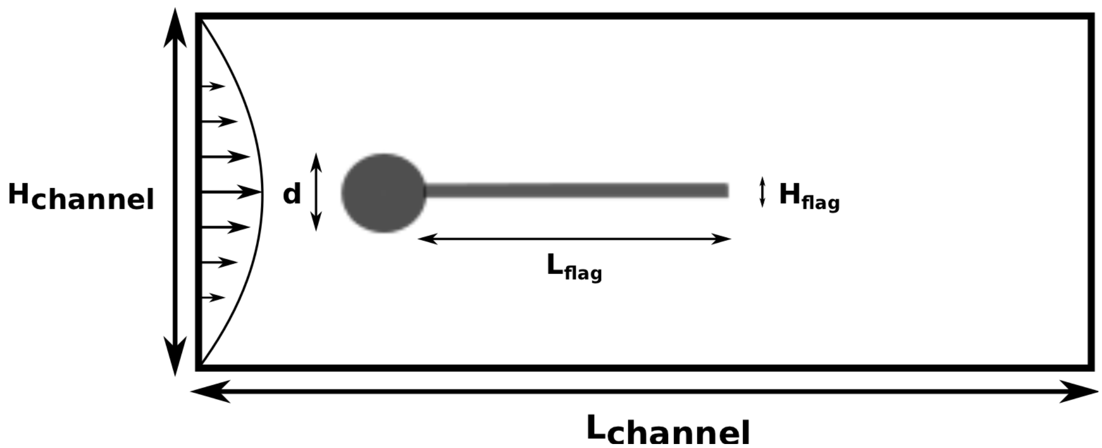

Figure 1: Test Case Sketch

Model Geometrical parameters	
$L_{channel}$	2.5
$H_{channel}$	0.41
d	0.1
x_c, y_c	(0.2,0.2)
L_{flag}	0.35
H_{flag}	0.02

Table 2: Test Case Geometrical Parameters

3.3 Model Description

For the preliminary CFD tests, three Reynolds numbers will be studied as shown in Table (3). The mesh size chosen is based on the Reynolds number and the results obtained during a mesh convergence analysis on a previously studied similar test case, "The Flow around a cylinder". A similar behavior will be expected i.e symmetric laminar boundary layer separation at low Reynolds numbers and Vortex shedding appearing at higher Reynolds values. Table (4) gives some information on the mesh.

For the FSI tests, again three configurations will be studied as shown in Table (5). For the FSI1 case, the main challenge regarding the stability of the analysis consists in the fact that the solid density is equal to the fluid density. For the FSI2 case, it is the large deformations that will result in mesh distortion and re-meshing. Finally, the FSI3 case combines those two features. Figure (2) offers a view of the solid mesh used.

For stability purposes, for the FSI cases, the suggested starting procedure suggested by Turek and Hron [1] will be adopted namely to use a smooth increase of the velocity profile in time as :

$$V(t,0,y) = \begin{cases} V(0,y)\frac{1-cos(\frac{\pi}{2}t)}{2} & \text{if } t \leq 2 \\ V(0,y) & \text{otherwise} \end{cases} \tag{1}$$

	CFD1	CFD2	CFD3
Density	1000	1000	1000
Viscosity	1	1	1
Average Inflow Velocity	0.2	1	2
Reynolds number	20	100	200

Table 3: Parameter settings for the CFD tests

Model information	
Cylinder Surface Element size	0.0025
Elements added to the Cylinder boundary layer	2
Volume Elements	125000
Volume Nodes	60000

Table 4: Test Case Mesh

	FSI1	FSI2	FSI3
Solid Density	1000	10000	1000
Poisson coefficient	0.4	0.4	0.4
Young Modulus	1.4e6	1.4e6	5.6e6
Fluid Density	1000	1000	1000
Fluid Viscosity	1	1	1
Average Inflow Velocity	0.2	1	2
Reynolds number	20	100	200

Table 5: Parameter settings for the FSI tests

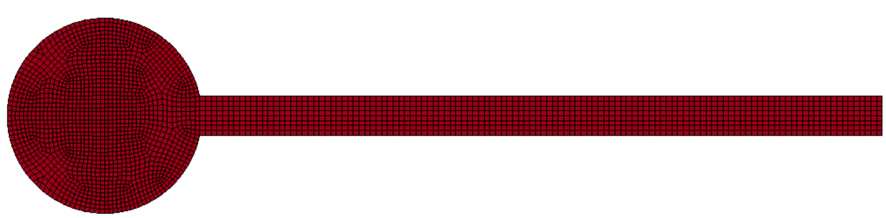

Figure 2: Cylinder and Flag mesh

4 Test Case Results

4.1 Test Case observations

Figure (3) shows the pressure and velocity fringes for the pure CFD cases. As expected, the periodic vortex shedding only starts for the highest Reynolds number of 200. It is also interesting to note for the $Re = 100$ case the pressure's slightly asymmetric behavior. This will be the cause of the flag's oscillations that will start in the FSI2 case. Table (6) and Figure (4) show the good agreement between the present results regarding the lift and drag values and the results obtained by [1].

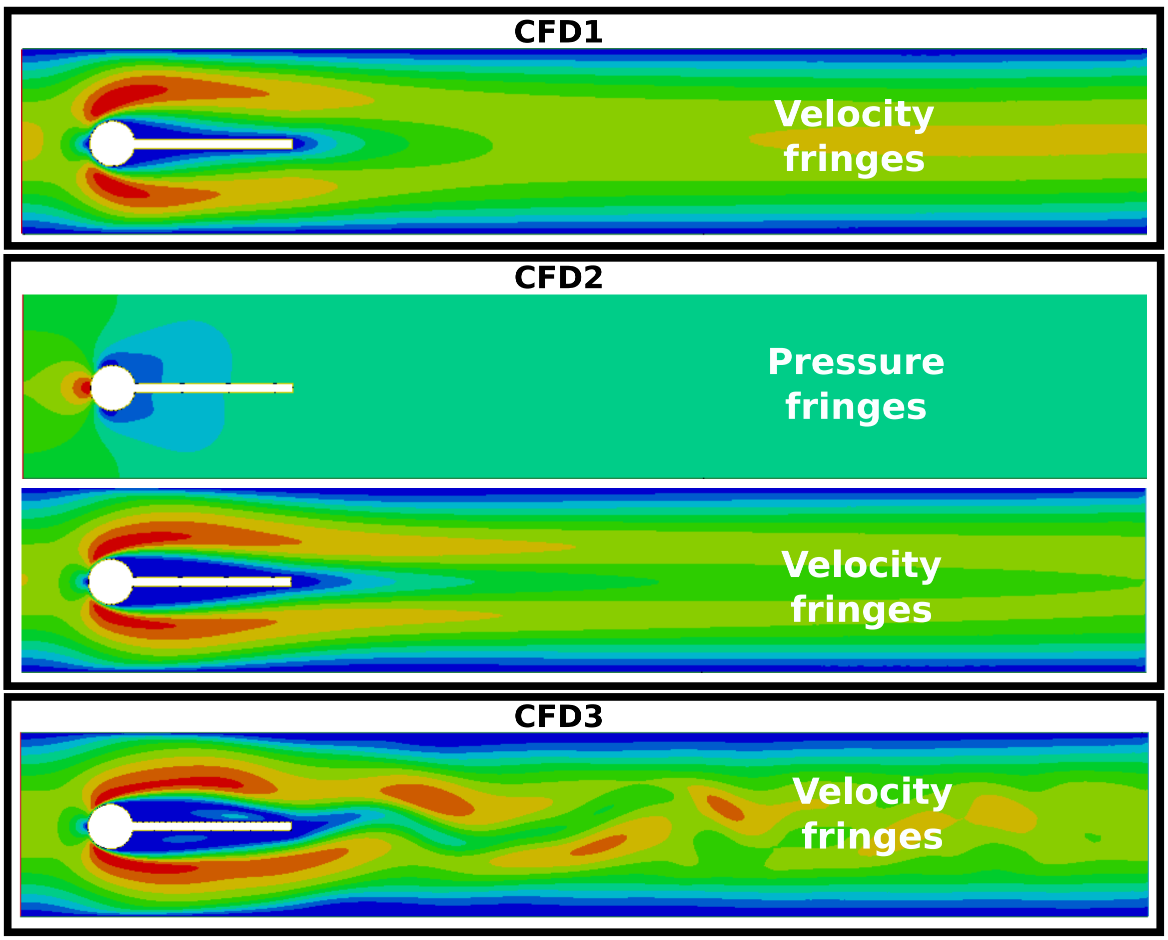

Figure 3: Test Case velocity and pressure fringes

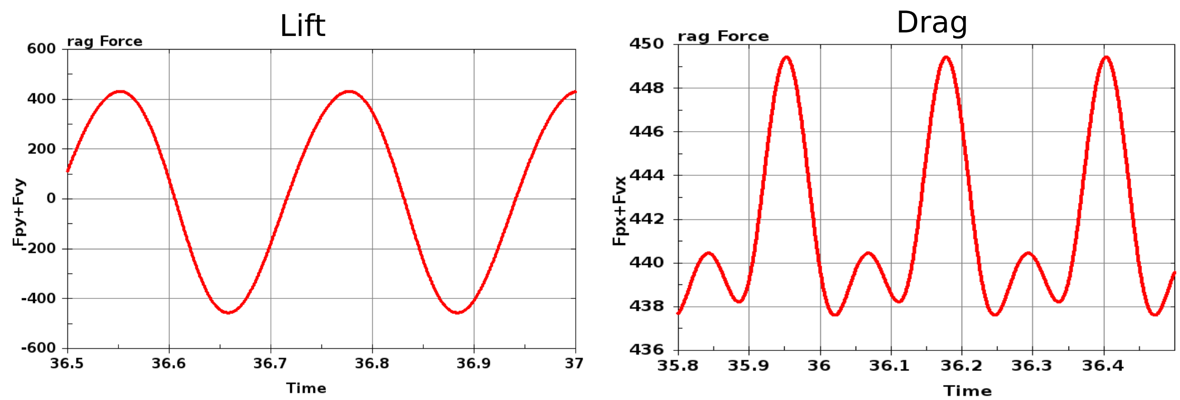

Figure 4: CFD3 Lift and Drag behavior

	CFD1		CFD2		CFD3	
	Drag	Lift	Drag	Lift	Drag	Lift
Present Analysis	14.22	1.119	137.0	10.55	443.5 ± 5.90	-13.73 ± 444.15
Reference results [1]	14.29	1.119	136.7	10.53	439.45 ± 5.6183	-11.893 ± 437.81

Table 6: Results for CFD tests

Table (7) shows the result for the FSI1 case regarding the lift and drag values. In the present analysis, the flag's displacement are negligible which explains that the results are very close to the CFD1 case and that the lift is slightly different from the reference result. For the FSI2 and FSI3 cases, periodic solutions can be observed with the largest deformation occurring in the FSI2 case as can be observed on Figure (5). Frequent re-meshing is needed. The oscillation period is of 0.5 and 0.19 for the FSI2 and FSI3 cases respectfully which is in good agreement with the results of [1]. Figure (6), Figure (7), Figure (8), Figure (9), Table (8) and Table (9) show the good agreement between the present analysis and the reference results. It is interesting to observe that a better agreement is found in the FSI3 case regarding the lift values. One possible explanation could be that the wall effects become more important in the FSI2 case.

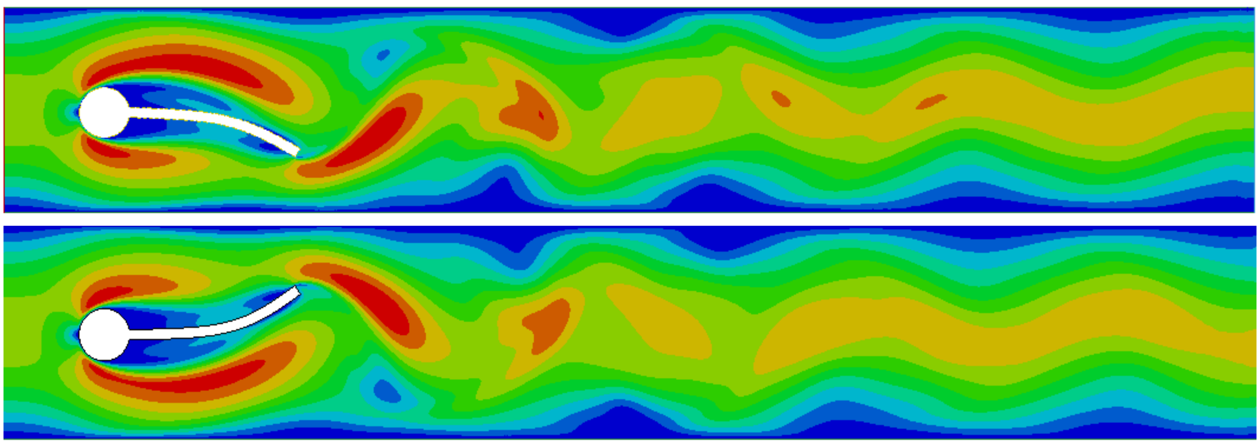

Figure 5: Flag deformation in the FSI2 case

	Drag	Lift
Present Analysis	14.22	1.117
Reference results [1]	14.295	0.7638

Table 7: Results for the FSI1 test

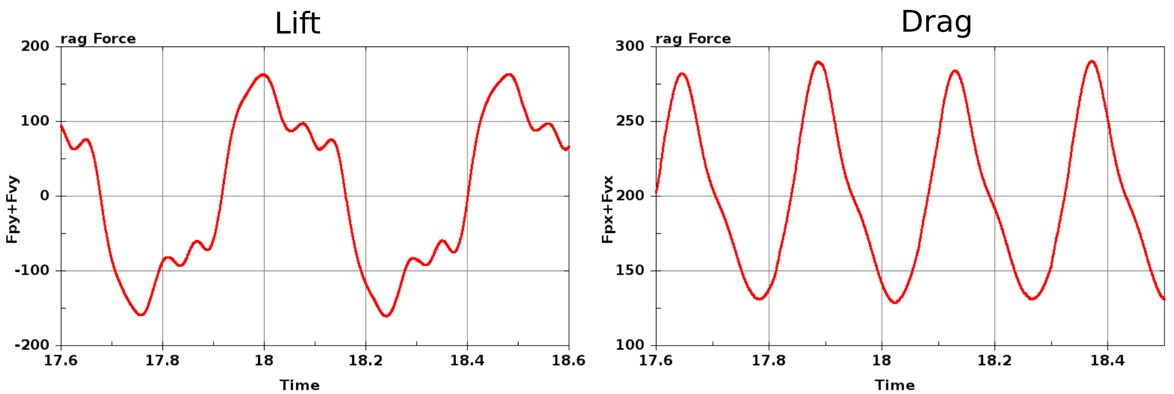

Figure 6: FSI2 Lift and Drag behavior

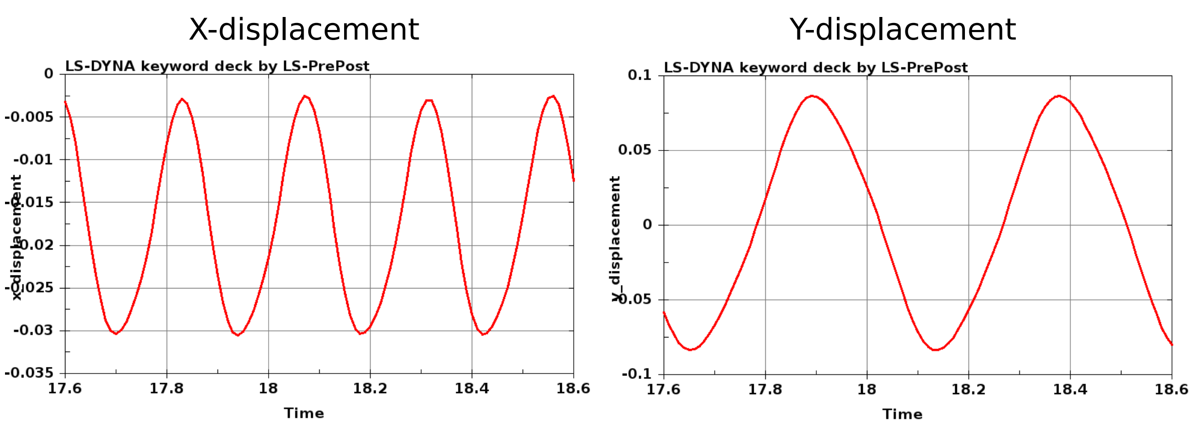

Figure 7: FSI2 Flag Tip displacement

	X-displacement (10^{-3})	Y-displacement (10^{-3})	Drag	Lift
Present Analysis	-16.54 $\pm$ 14.00	1.45 $\pm$ 85.11	209.35 $\pm$ 80.91	1.33 $\pm$ 161.9
Reference results [1]	-14.58 $\pm$ 12.44	1.23 $\pm$ 80.6	208.83 $\pm$ 73.75	0.88 $\pm$ 234.2

Table 8: Results for the FSI2 test

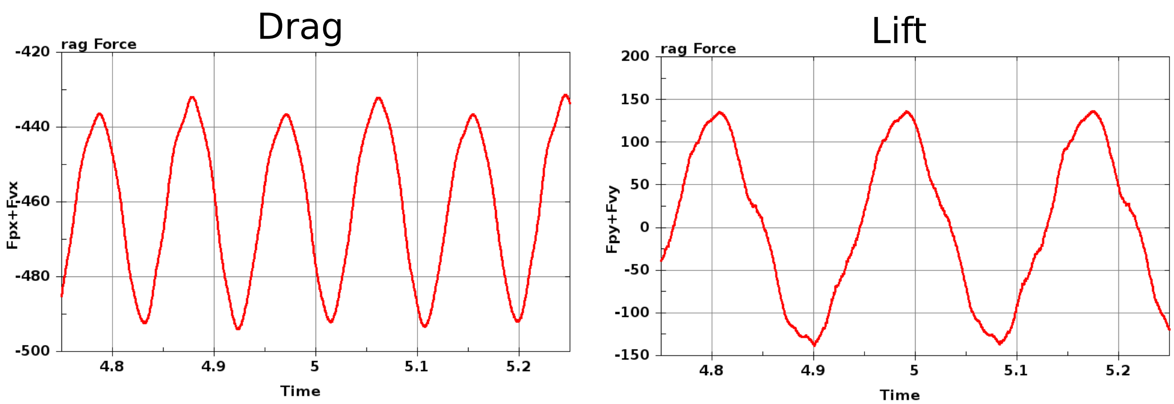

Figure 8: FSI3 Lift and Drag behavior

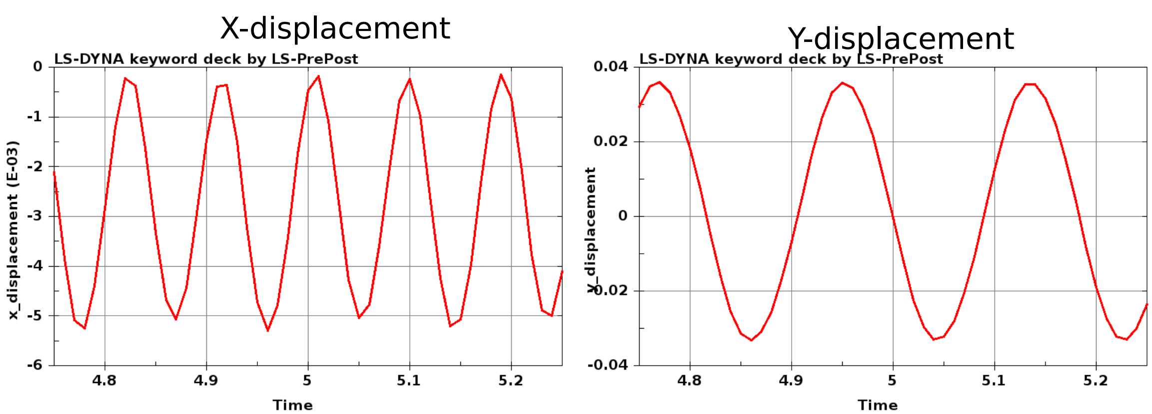

Figure 9: FSI3 Flag Tip displacement

	X-displacement (10^{-3})	Y-displacement (10^{-3})	Drag	Lift
Present Analysis	-2.76 $\pm$ 2.64	1.44 $\pm$ 34.9	464.0 $\pm$ 33.0	3.45 $\pm$ 143.5
Reference results [1]	-2.69 $\pm$ 2.53	1.48 $\pm$ 34.38	457.3 $\pm$ 22.66	2.22 $\pm$ 149.78

Table 9: Results for the FSI3 test

References

[1] S. Turek and J. Hron, *Propoposal for Numerical Benchmarking of Fluid-Structure Interaction between an Elastic Object and a Laminar Incompressible Flow*, vol. 53, h.-j. bungartz & m. schaefer. springer ed., 2006.

[2] S. Turek and M. Schafer, *Benchmark computations of laminar flow around cylinder.*, Notes on Numerical Fluid Mechanics., 52 (1996).