Benchmark of Femlab, Fluent and Ansys

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Contents

1 Introduction

This is a benchmark of **Femlab** 3.0a, **Ansys** 7.1 and **Fluent** 6.1.18. We also conducted some tests with the former version 2.3 of **Femlab**. This was done in order to compare the performance and reliability of these programs under two sets of problems. The first set is composed of two and three dimensional structural mechanics benchmarks which are taken from the benchmark documentation of **Ansys**. Some of them are also part of the NAFEMS benchmarks. The second set is composed of two dimensional standard fluid mechanics benchmarks to test the incompressible Navier-Stokes model in laminar mode.

All the tests were run on the same machine in order to be able to effectively compare the performances. Each case was set up with an artificially large number of degrees of freedom. This was done in order to have an idea of the behaviour of the tested programs on heavy industrial problems, while keeping the geometry simple and disposing of measured or theoretical reference quantities.

We begin with the description of the test cases, we then give some information about the experimental procedure and finally give the results of the measurements.

2 Case Descriptions

2.1 Structural Mechanics Cases

2.1.1 Elliptic Membrane

The original case is an elliptic membrane with an elliptic hole in its center (cf. figure 1). An outward pressure load is applied on the external edge. Because of the symmetry of the problem, only a quarter of the elliptic membrane is simulated. So the case is a quarter of an elliptic membrane with a slipping boundary condition on two edges (to account for the symmetry), plus a pressure load on its outer edge. Figure 2 on page 13 shows the resulting deformation of the membrane. A reference for this case is [Barlow and Davis, 1986].

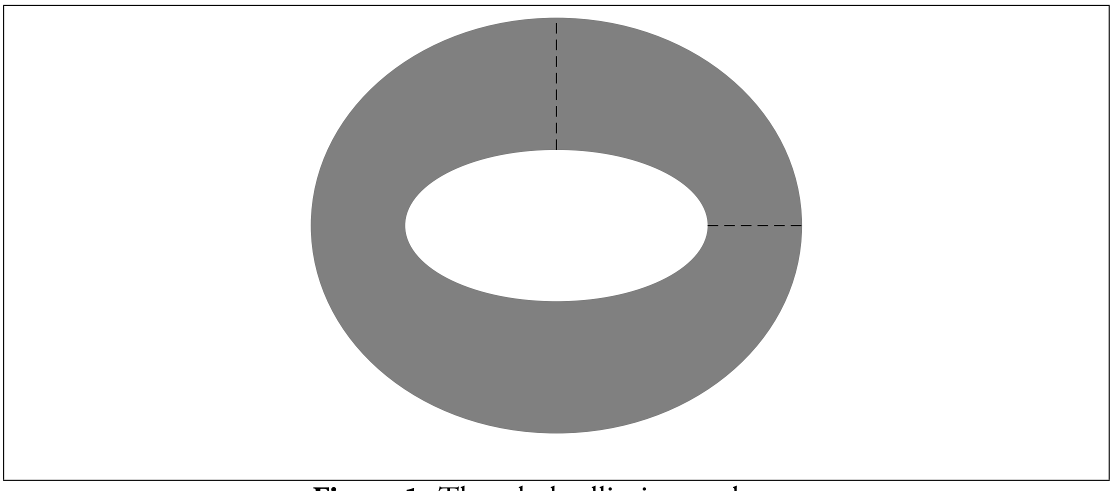
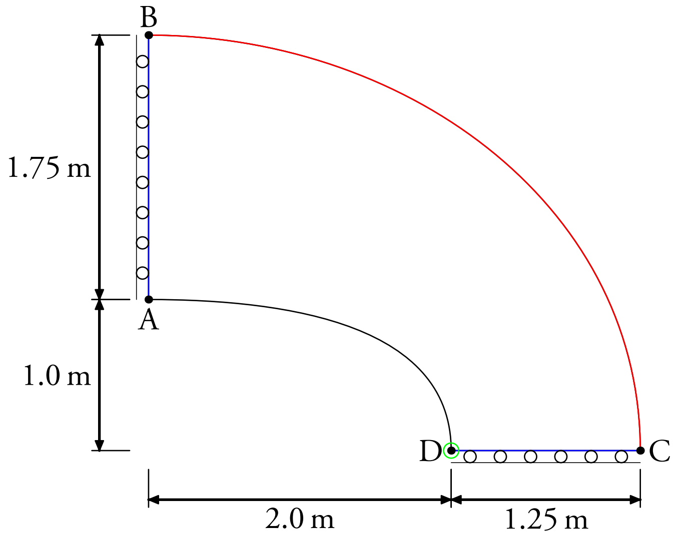


Figure 1: The whole elliptic membrane



Geometry

The membrane is $0.1\,\mathrm{m}$ thin.
(We use the plane-stress model)

Material

$E = 2.10 \cdot 10^5\,\mathrm{MPa}$
$\nu = 0.3$

Constraints and Loads

The boundary conditions, as indicated on the picture, come from horizontal and vertical symmetry: no vertical displacement on the lower edge (CD) and no horizontal displacement on the left edge (AB).
A pressure

$$P = -10\,\mathrm{MPa}$$

is applied on the outer edge (BC).

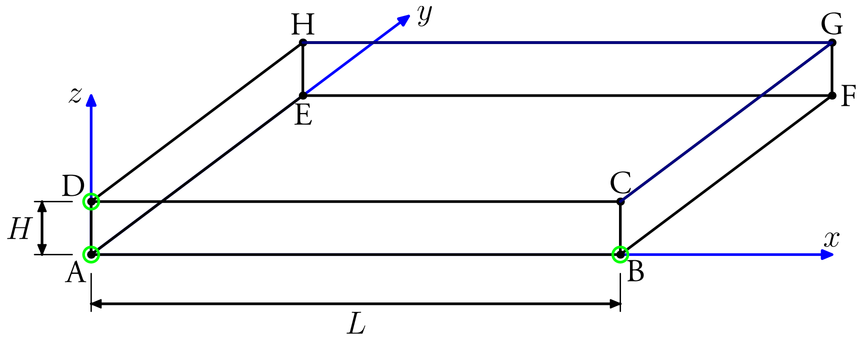
Quantities to be measured

The value of σ_y at the point D is to be measured. Its theoretical value is

$$\sigma_y = 92.7\,\mathrm{MPa}$$

2.1.2 Built-in Plate

A rectangular plate with built-in edges is subjected to a uniform pressure load on the top and bottom surfaces. Due to the symmetry of the problem only an eighth of the plate is simulated. The reference for this case is [Timoshenko and Woinowsky-Knieger, 1959].



Geometry and Material

$H = 1.27 \cdot 10^{-2}\,\mathrm{m}$
$L = 1.27 \cdot 10^{-1}\,\mathrm{m}$
$E = 6.89 \cdot 10^{4}\,\mathrm{MPa}$
$\nu = 0.3$

Face Constraints

Face Description	Constraint
$x = 0$	$u_x = 0$
$x = L$	$u_x = 0$
$y = 0$	$u_y = 0$
$y = L$	$u_y = 0$
$z = H$	$u_x = u_y = 0$
$z = 0$	$P = -3.447\,\mathrm{MPa}$

Edge Constraints

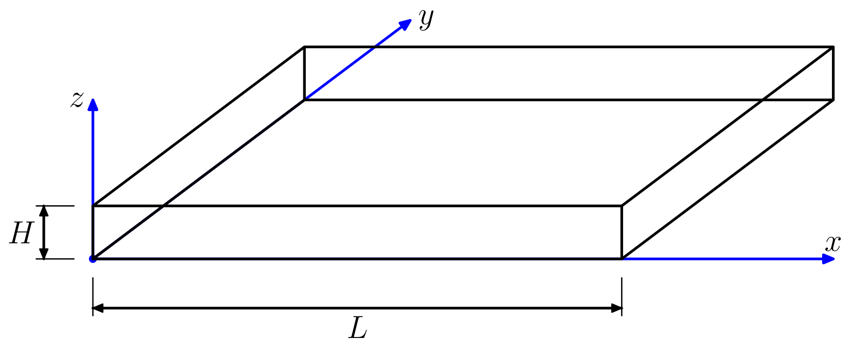
Edge	Constraint
CG	$u_z = 0$
HG	$u_z = 0$

Quantities to be measured

Quantity	Location	Theoretical
u_z-1	D	$4.190 \cdot 10^{-4}\,\mathrm{m}$
σ_y-2	B	$-2.040 \cdot 10^{2}\,\mathrm{MPa}$
σ_y-3	A	$9.862 \cdot 10^{1}\,\mathrm{MPa}$

2.1.3 Square Supported Plate

The eigenmodes of a plate supported on its lower edges are well known analytically. The test case consisted in finding the ten first eigenmodes and eigenvalues and to compare the latter to the theoretical values. The first three eigenvalues should be zero (solid mode) because the solid is free to move the horizontal plane. The last three modes (8, 9 and 10) are *plane modes* (no displacement in the vertical direction). For more details, cf. [NAFEMS, 1989].



Geometry and Material

$L = 10\,\mathrm{m}$
$H = 1\,\mathrm{m}$
$E = 200 \cdot 10^3\,\mathrm{MPa}$
$\nu = 0.3$
$\rho = 8000\,\mathrm{kg/m^3}$

Constraints

No vertical displacement is allowed ($u_z = 0$) on the four lower edges

Quantities to be measured

The three first eigenmodes are plane modes with eigenvalue zero. The next seven eigenvalues should be measured. Here are their theoretical values:

Eigenvalue nb	4	5	6	7	8	9	10
Frequency (Hz)	45.897	109.44	109.44	167.89	193.59	206.19	206.19

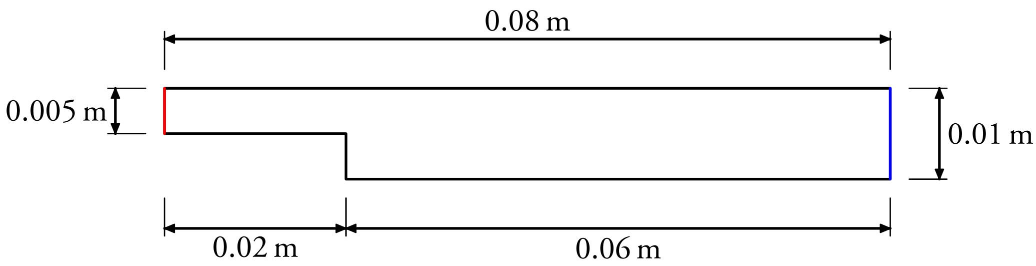
The last three eigenmodes are plane modes.

2.2 Fluid Mechanics Test Cases

The following test cases were used to compare **Fluent** and **Femlab**. All the flows are modelled by the incompressible Navier-Stokes equations and they are under laminar regime.

2.2.1 Backward Facing Step

The backstep problem is a classic test in fluid mechanics. It consists of an inflow of fluid that passes a step. Below that step a loop should be observed (see fig. 5 on page 15). More details can be found in [Rose and Simpson, 2000].



Geometry

Height of the step:

$$H = 0.005\,\mathrm{m}$$

Properties of the fluid

$\eta = 1.79 \cdot 10^{-5}\,\mathrm{m}^2/\mathrm{s}$
$\rho = 1.23\,\mathrm{kg}/\mathrm{m}^2$

Boundary Conditions

The boundary condition on the inflow (leftmost boundary, in red) is:

$$\overrightarrow{v} = 6s(1-s)\overrightarrow{v_0}$$

where $\|v_0\| = 0.544\,\mathrm{m}/\mathrm{s}$ and $\overrightarrow{v_0}$ is horizontal.
The outflow condition is a zero pressure (rightmost boundary, in blue)

$$p = 0$$

The other boundary condition are set to *no-slip*. This means $\overrightarrow{v} = 0$ on the boundary.

Reynolds Number

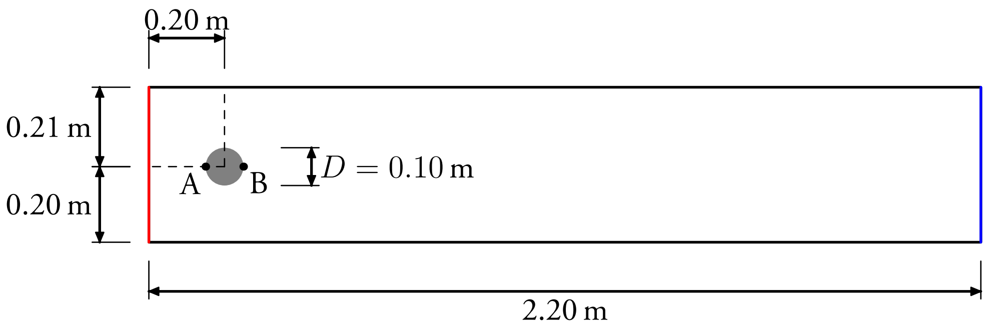
$$Re = 150$$

Quantities to be measured

The length of the loop is to be measured (cf. fig. 5 on page 15). In nondimensional form, the ratio of the length of the loop divided by the height of the step (H) is approximatively 7.93 according to experimental data.

2.2.2 Cylinder Flow in 2D

The cylinder flow test case is similar to the backstep one, except for the geometry. The Reynolds number has to be sufficiently low (below 200) to get a physically meaningful stationary solution. If the Reynolds number is too high, Femlab finds a solution although the regime is clearly unstable. This instability can be observed using the time dependent solver in Femlab.



Geometry

The cylinder has a diameter

$$D = 0.10\,\mathrm{m}$$

Fluid Properties

$\eta = 10^{-3}\,\mathrm{m}^2/\mathrm{s}$
$\rho = 1\,\mathrm{kg}/\mathrm{m}^2$

Boundary Conditions

$\|v_0\| = 0.3\ \mathrm{m/s}$ and $\overrightarrow{v_0}$ is horizontal.
The boundary condition on the inflow (leftmost boundary, in red) is:

$$\overrightarrow{v} = 4s(1-s)\overrightarrow{v_0}$$

where s parametrises the left boundary.
The outflow condition is a zero pressure (rightmost boundary, in blue)

$$p = 0$$

The other boundary condition are set to *no-slip*. This means $\overrightarrow{v} = 0$ on the boundary.

Quantities to be measured

We define the mean velocity by

$$\bar{v} = \frac{2}{3}\|v_0\|$$

We then define the non-dimensional force of the fluid on the cylinder:

$$\vec{c} = \frac{2\vec{F}}{\varrho \bar{v}^2 D}$$

We can then define the **drag coefficient** c_D and the **lift coefficient** c_L to be the x and y coordinates of the non-dimensional force $\vec{c}$:

$$c_D = c_x$$
$$c_L = c_y$$

We also define the **recirculation length** L_a which is the distance on the line $\{y = 0.2\}$ between the right border of the cylinder and the first point where the horizontal velocity is positive (cf. figure 7 on page 16). The **pressure drop** ΔP is defined as the difference of the pressures on the left and right border of the cylinder:

$$\Delta P = P_A - P_B$$

All these quantities are taken from [Turek and Schäfer, 1996]. The values that we will choose as "theoreticals" for the precision measurements are the followings:

c_D	c_L	L_a/D	ΔP (N/m)
5.58	$1.07 \cdot 10^{-2}$	$8.46 \cdot 10^{-1}$	$1.174 \cdot 10^{-1}$

Reynolds Number

$$Re = \frac{\bar{v}D}{\eta} = 20$$

3 Measurements : Computational Results

3.1 Experimental Procedure

All the computations were carried out on the same computer which caracteristics can be found on table 2 on the next page.

Mesh Settings The generated meshes were always *isotropic* and *homogeneous* in the four tested programs for the performance tests except for some of the measures in the cylinder 2d and 3d cases.

Mesh Convergence The mesh convergence investigations were carried out using the "Mesh Parameters..." option in Femlab 3, using the whole range from "Extremely coarse" to "Extremely fine" and sometimes even more. The only exception is the graph labelled "Dense Mesh" on figure 8 on page 17, on which the mesh is denser around the cylinder.

It should be emphasised that there are is no way to modify a mesh in Fluent without losing all the boundary conditions and other settings. As a result it is very difficult to investigate the mesh convergence in Fluent.

Table 1 Versions of the tested programs

Program	Version
Fluent	6.1.18
Ansys	7.1
Femlab 2.3	2.3
Femlab 3.0a	3.0-207

Table 2 Computer Characteristics

Manufacturer	Fujitsu-Siemens
Processor	Intel P4 2.4GHz
RAM	1GB
OS	MS Windows XP

3.2 How to Read the Results

Precision The precision for a given quantity Q and its corresponding theoretical value Q_{theor} is computed according to the following formula:

$$\text{precision} = -\log\left(\left|1 - \frac{Q}{Q_{\text{theor}}}\right|\right)$$

The measured quantity in the measurement tables are **always** given in this form. Note that a precision above the theoretical precision (which is usually 2 or 3) does not mean that the precision is really better than the theoretical precision.

Mesh Convergence On the mesh convergence graphs the precision is represented against the log of the number of degrees of freedom.

Units If not explicitly mentioned, the units are always SI units. The units of the performance tables are the following:

Denomination	Units
DOF (Degrees of Freedom)	Thousands
Mem (Peak Memory)	MegaByte
Time (CPU Time)	Second

The peak memory is the maximum memory used by the process during the computation.

Out of Memory When the peak memory measurement is preceded by ">", it means that the computation process could not be completed because of an out of memory error.

Missing Measures Missing measure are indicated by a "**?**" sign. It means that the quantity could not be measured with a sufficient accuracy.

Measure Accuracy All the measures were taken with 4 significant digits.

3.3 Structural Mechanics

Ansys and Femlab are comparable in CPU time and memory usage on the structural mechanics cases, except in the Supported Plate case where Ansys turns out to be much more efficient in time and memory for the same accuracy as Femlab. Note also that the results vary very much according to the numerical solver used. The sovers on Femlab 3 have been carefully tuned in order to obtain the best perfomances. Such a possibility does not seem to be available in Ansys.

3.3.1 Elliptic Membrane

Program	DOF	Mem	Time	σ_y
Ansys	74	180	10	2.67
Femlab 3.0a	76	135	9	3.12
Femlab 2.3	85	380	33	2.97
Femlab 3.0a	89	152	13	3.19

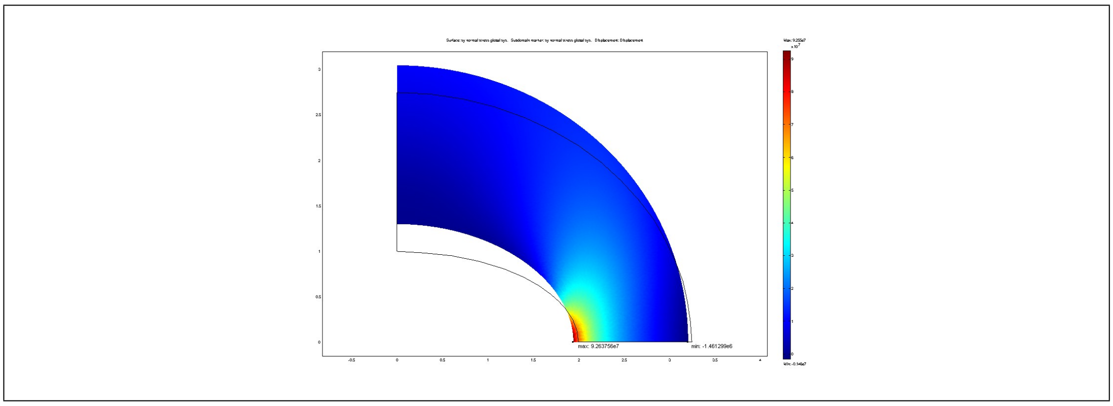


Figure 2: Deformation of the Elliptic Membrane

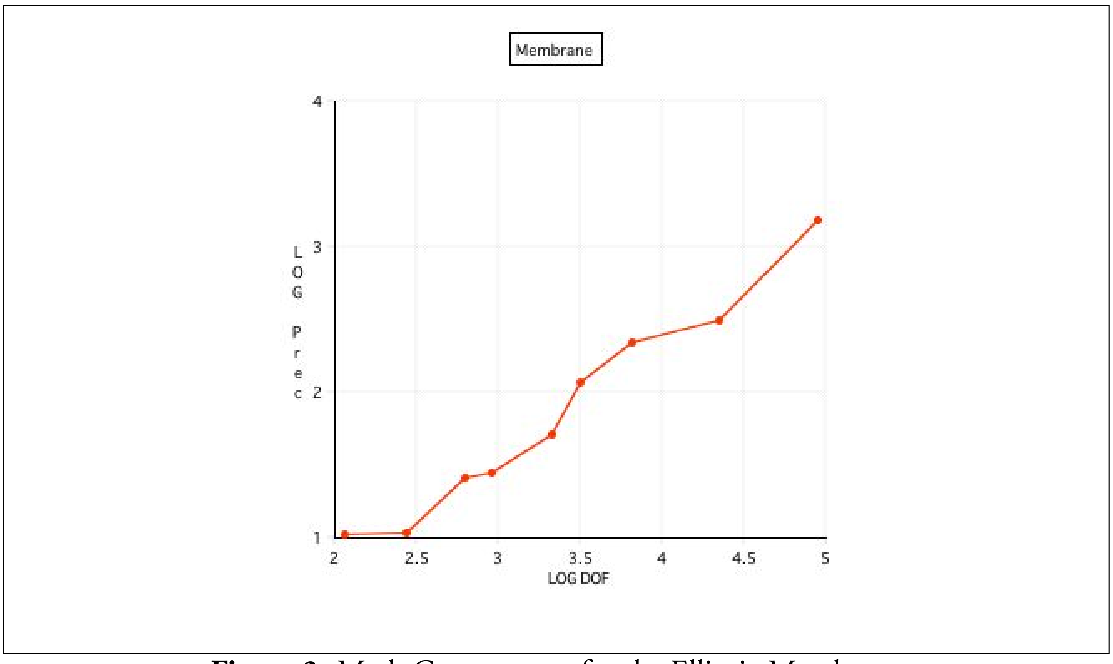


Figure 3: Mesh Convergence for the Elliptic Membrane

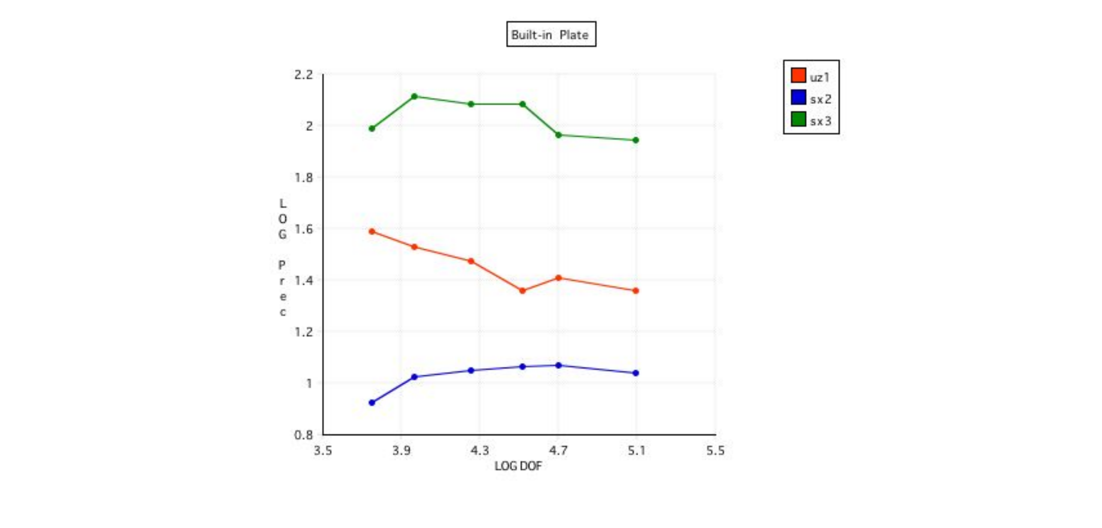


Figure 4: Mesh Convergence for the Built-in Plate

3.3.2 Built-in Plate

Program	DOF	Mem	Time	u_z-1	σ_y-2	σ_y-3	min	max
Ansys	101	547	72	1.22	1.05	1.98	1.05	1.98
Femlab 3.0a	101	309	85	1.38	1.07	1.99	1.07	1.99
Femlab 2.3	98	669	133	1.36	1.10	?		

3.3.3 Supported Plate

Neither Ansys nor Femlab seem to be able to compute the eigenfrequencies with a satisfactory precision. The plane modes vary very much according to the mesh, and we never got the last three plane modes together. It appears therefore that a much clever mesh or a larger mesh would be necessary to obtain a better accuracy.

Program	DOF	Mem	Time	4	5	6	7	8	9	10	min	max
Ansys	84	164	252	1.21	1.25	1.25	1.06	1.94	1.17	1.21	1.06	1.94
Femlab 3.0a	84	695	360	1.30	1.32	1.33	1.11	1.99	1.19	1.22	1.11	1.99
Femlab 2.3	84	>592	∞									

3.4 Fluid Mechanics

These test cases were compared with Fluent. Fluent turns out to have no stationary solver[1]. This implies that the convergence for the chosen cases can be very slow, since it

[1]This is a mistake. It is an iterative solver that we mistook for a time-dependent one.

endeavours to find an asymptotic solution from a nonstationary solver. This implies that the performances of Fluent are very sensitive to the given precision which was 10^{-5} on all the cases. We will also see in both 2D cases that Femlab is more accurate even used with a non-stationary solver and also that Fluent does not converge, no matter how long we let it iterate. At last we tested Fluent with very large numbers of elements but the precision is not improved.

3.4.1 Backstep

Fluent gets the loop with a remarkably poor accuracy. Femlab yields better results even when used with a non stationary solver. Only a few hundreds of elements is needed to Femlab to achieve a better accuracy than that of Fluent.

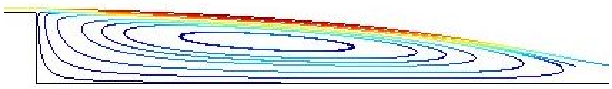


Figure 5: The loop behind the step

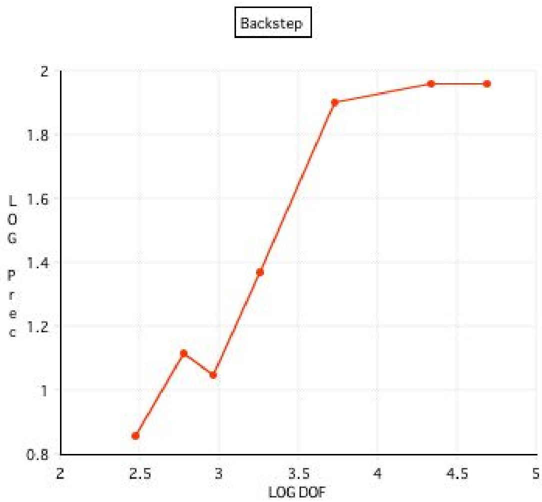


Figure 6: Mesh Convergence for the Backstep

Program	DOF	Mem	Time	Loop
Fluent	83	55	146	0.79
Femlab 2.3	100	>602	∞	
Femlab 3.0a	96	445	630	2.02
Femlab 2.3	25	322	77	1.85
Femlab 3.0a	25	136	77	1.90

3.4.2 Cylinder 2D

The first computations are carried out using a *homogeneous* mesh. The last two line, however, are results of computations with refined mesh around the cylinder. One should be careful about these last two results, though, since the refinement methods are not the same.

We tried to let Fluent iterate for a very long time (about 20000 iterations) and still the residual remains above 10^{-5}. The subsequent results for Fluent are not better than those presented here.

We also used Femlab 3 for a non-stationary simulation of this case and the precision is the same as in the stationary one. Moreover the solution converges fairly quickly to the stationary one (whereas Fluent does not converges at all if the residual tolerance is chosen below 10^{-5}).

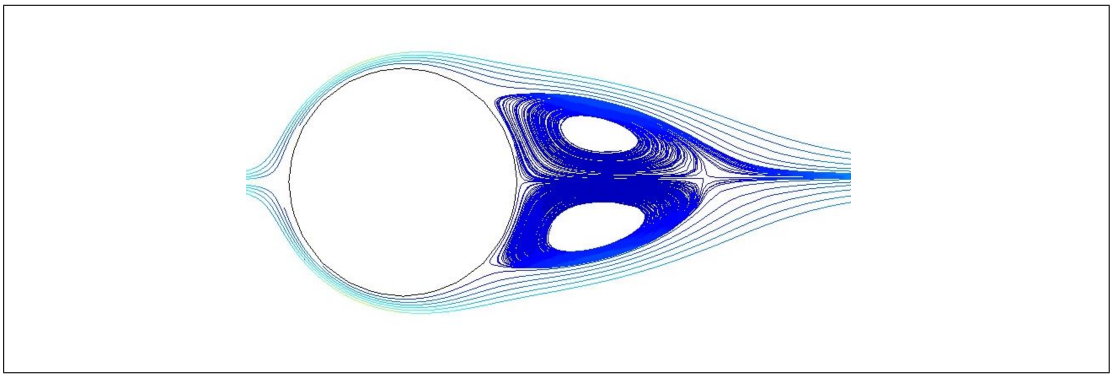


Figure 7: The recirculation area at the back of the cylinder

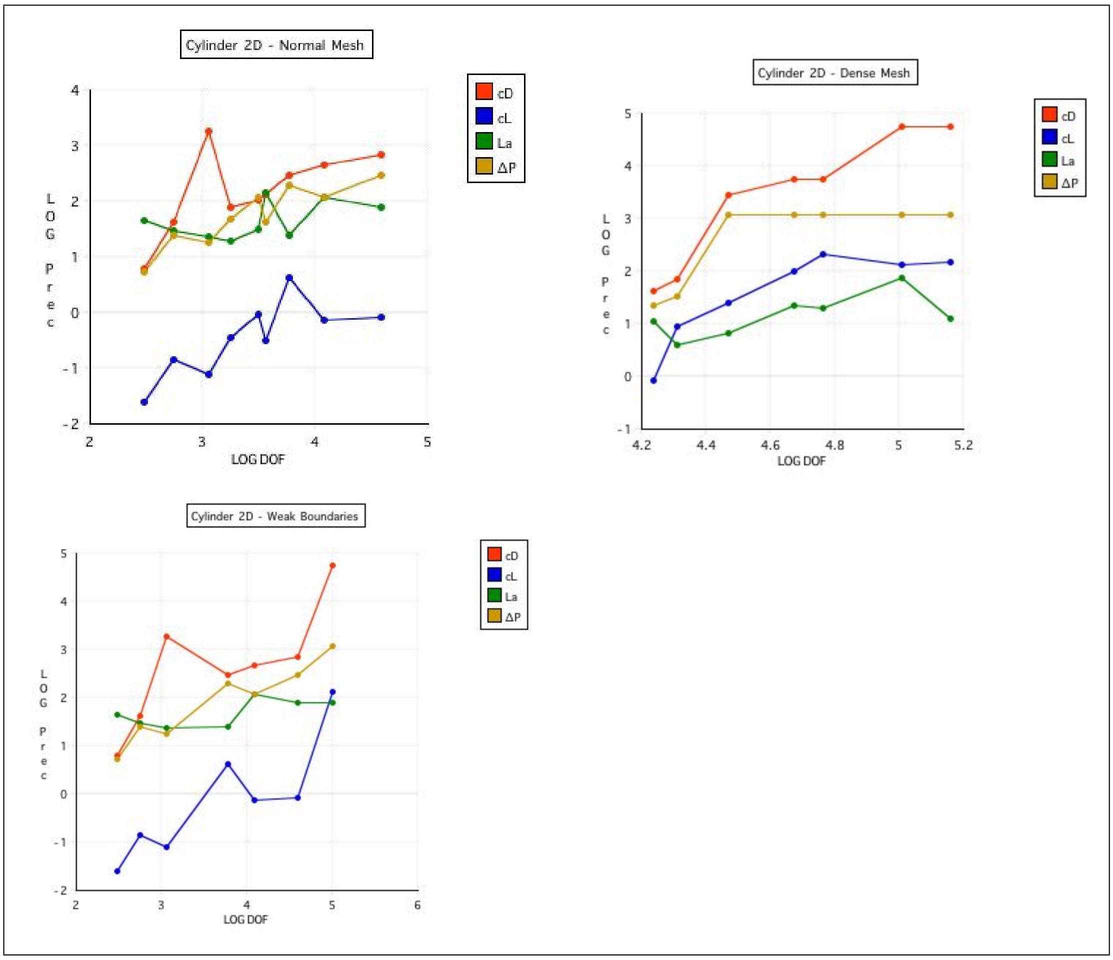


Figure 8: Mesh convergence for the Cylinder 2D Case

Program	DOF	Mem	Time	c_D	c_L	L_a	ΔP
Fluent	50	62	140	1.42	0.48	?	?
Femlab 3.0a	50	213	62	2.71	0.48	1.81	1.59
Femlab 2.3	101	>623	∞				
Femlab 3.0a	101	414	142	2.49	0.00	1.68	2.12
Fluent	109	67	450	1.97	0.00	?	?
Femlab 3.0a	101	371	108	4.75	2.13	1.91	3.07

4 Conclusions

Femlab 3 represents a very significant stride compared to the previous version 2.3. In most cases, the old version could not even carry out the computations without an "Out of memory" error message.

Femlab 3 performances are comparable, both from the precision, CPU time and memory usage, to those of Ansys, except for the eigenfrequency analysis, where Ansys is more efficient.

Surprisingly enough, and despite all our endeavours, Fluent does not yield any accurate results. For the backstep case, for instance, the precision of Femlab with a few hundreds degrees of freedom is better than that of Fluent with eighty thousands. Moreover for difficult problems like that of computing the force exerted on the cylinder, in the 2D case, a very good accuracy is needed to capture the right lift coefficient which is, in non-dimensional form, approximately one percent of the drag coefficient. There is apparently no hope for Fluent to get even a rough idea of this coefficient, no matter how long we wait or how refined the mesh is.

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