Testcase 3.6
DNS and LES of the flow over a 2D periodic hill

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1 Overview

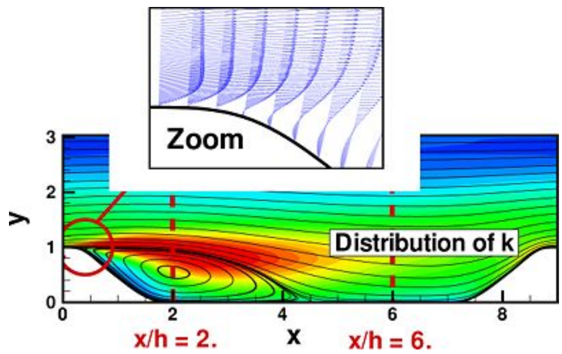

Figure 1: Streamtraces computed on the time- and spanwise averaged velocity field (source: ERCOFTAC QNET-CFD wiki)

This testcase has been taken up as a standard benchmark in ERCOFTAC, and hence a thorough description, including references, can be found at:

- testcase 9.2 of the ERCOFTAC SIG 15 http://www.ercoftac.org/fileadmin/user_upload/bigfiles/sig15/database/9.2/index.html
- Underlying flow regime case 3-30 of the ERCOFTAC QNET-CFD database. http://qnet-ercoftac.cfms.org.uk/w/index.php/UFR_3-30

2 Governing Equations and models

The incompressible or compressible Navier-Stokes equations should be used. The compressible fluid should have a behaviour comparable to air, *i.e.* it should have a heat capacity ratio $\gamma = \frac{C_p}{C_v} = 1.4$ and Prandtl number $Pr = \frac{\mu C_p}{\kappa} =$

0.71. Here C_p and C_v are the specific heats at constant pressure and volume respectively, μ the dynamic viscosity and κ the heat conductivity.

The testcase is foreseen to be run with large eddy simulation (LES) approach, up to direct numerical simulations (DNS). Participants are obviously free concerning the choice of models, but are expected to provide details on the model itself as well as the specificities of the implementation in relation to the discretisation method. In addition, the participants are encouraged to investigate LES with wall modelling (WMLES).

3 Flow Conditions

The flow conditions are determined by the Reynolds number based upon the bulk velocity at the crest

$$Re_b = \frac{u_b h}{\nu} \tag{1}$$

with

$$u_b = \frac{1}{2.035h} \int_h^{3.035h} u(y) dy \tag{2}$$

and ν the kinematic viscosity. Thereby the flow is assumed to be periodic in both the streamwise and spanwise direction. Two flow regimes have been chosen, namely $Re = 2800$ and $Re = 10595$, corresponding to conditions amenable for resolution with DNS and LES respectively.

The mass flow rate is assured by the addition of a body force, following from the decomposition of the pressure in a linearly varying mean component and a fluctuation p':

$$p = p_0 + \frac{dp}{dx}(x - x_0) + p' \tag{3}$$

In case of incompressible flows, one solves for the fluctuation pressure p', whilst for compressible flows, one solves for $p_0 + p'$. In both cases the linearly varying mean translates in the addition of a body force dp/dx.

This body force is calibrated continuously to provide the correct mass flow rate, using a procedure proposed by Benocci and Pinelli (1990), as mentioned in the testcase description on QNET-CFD. This reference could not be found though, and therefore reference [1] is used, in which the procedure is described once again. The imposed pressure gradient then follows from a simplified global momentum equation

$$\left(\frac{dp}{dx}\right)^{n+1} = \left(\frac{dp}{dx}\right)^{n+1} - \frac{1}{A_c \Delta t}\left(\dot{m}^* - 2\dot{m}^n + \dot{m}^{n-1}\right) \tag{4}$$

where $\dot{m}^*$ is the imposed mass flow rate (in agreeemnt with Re_b), $\dot{m}^n$ is the mass flow rate through the area above the hill crest measured at time t^n, and A_c the throughflow area above the hill crest.

For compressible flows, flow conditions have to be chosen such that the Mach number $M = 0.1$. To this end, the global temperature is fixed by imposing its value at the solid walls T_w to be constant, and given by

$$T_w = \frac{(u_b/M)^2}{\gamma R} \tag{5}$$

4 Geometry and grids

The description of the geometry can be found on the QNET CFD wiki pages. The 2D geometry (parasolid format) is also available on the HOW website.

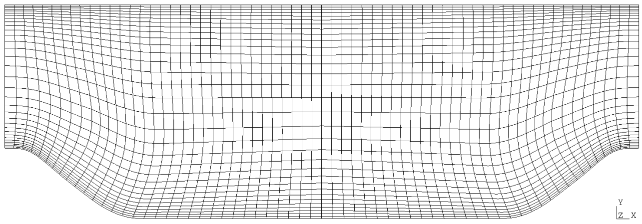

Figure 2: Second order curved mesh constructed by coarsening the $128 \times 64 \times 64$ mesh.

The base resolution found in literature corresponds to $512 \times 256 \times 256$. A suite of linear (CGNS) and quadratic/curved hexahedral meshes (Gmsh) have been constructed by successive coarsening this baseline mesh as shown in figure 2. Those grids are available on the HOW website. Curved hybrid meshes corresponding to the same size specifications and consisting of hexahedral elements near the walls and prisms elsewhere will also be constructed. Grid dependency studies, both refinement and coarsening can be performed. The meshes can be obtained at request at different resolutions, again in Gmsh format (see http://www.geuz.org/gmsh for more information).

5 Results

All data (including space and time) should be non-dimensionalised using the values from the Reynolds Re_b, Mach M_b and Prandtl Pr numbers. The convective time t_c is defined as $t_c = t\ u_b/(9h)$.

The header of each data file should contain the name of the participant and his affiliation, the name of the case and the Reynolds number, the numerical scheme with its order of accuracy and the total number of degrees of freedom (dof). For example:

George Abitbol, Cenaero
2D Periodic hill, Re_b = 2800
4th order energy conserving finite difference scheme
256x128x128 dof

5.1 Mandatory results

5.1.1 Transient results

In order to show that the flow has reached a statistically developed state and the correct regime, participants should provide the time evolution of the mass flow $\dot{m}$ through the periodic plane at the hill crest (time data from initialisation).

Provided data should obey the following format (CPU time in work units):

$$\# \quad t_c \quad \dot{m} \quad \text{CPU}$$

5.1.2 Average results

Next to the averaged velocity field and streamlines, the requested results consist of the vertical variation of

- the non-dimensionalised averaged velocity components $\overline{u}/u_b$ and $\overline{v}/u_b$
- the velocity correlations $\overline{u'u'}$, $\overline{v'v'}/u_b^2/u_b^2$, $\overline{w'w'}/u_b^2$ and $\overline{u'v'}/u_b^2$

as a function of the non-dimensional height y/h at streamwise positions $x/h = 0.05, 0.5, 1, 2, 3, 4, 5, 6, 7, 8$ from the hill crest. To guarantee statistical convergence, data should not only be time but also spanwise averaged. Participants should demonstrate statistical convergence by comparing the results at two different sampling periods. Results are expected for both Re=2800 and Re=10595. The results should be contained in one file per sampling period and/or x-position and obey the following format:

$$\# \quad y/h \quad \overline{u}/u_b \quad \overline{v}/u_b \quad \overline{u'u'}/u_b^2 \quad \overline{v'v'}/u_b^2 \quad \overline{w'w'}/u_b^2 \quad \overline{u'v'}/u_b^2$$

Furthermore the obtained global flow conditions should be detailed, *i.e.* both the obtained mass flow, Reynolds number as well as imposed dp/dx (averaged from the values computed with the mass flow equation 4).

6 Suggested additional results

Participants are encouraged to also provide the mean profile of pressure C_p and skin friction coefficients C_f in the x-direction. The coefficients are defined as:

$$C_p = \frac{p - p_\infty}{\frac{1}{2}\rho u_b^2}, \; C_f = \frac{\tau_w}{\frac{1}{2}\rho u_b^2} \tag{6}$$

The provided data should obey the following format:

$$\# \quad x/h \quad C_p \quad C_f$$

7 Reference data

Experimental data as well as reference results can be found at the QNET CFD wiki pages.

References

[1] Wen Wang, *A non-body conformal grid method for simulations of laminar and turbulent flows with a compressible large eddy simulation solver*, PhD dissertation, Iowa State University, 2009, pp. 114-115.