LES of the turbulent channel flow at Re_τ=590

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Introduction

This test case concerns the LES of the channel flow at Re_τ=590. This well-known benchmark has been intensively studied by the turbulence community. DNS and LES of the flow have been performed by numerous authors [1,2]. Therefore, various quantities are available to assess the accuracy of the LES approach, such as averaged velocity and velocity fluctuations profiles and kinetic energy spectra. An instantaneous flow field is presented on Figure 1.

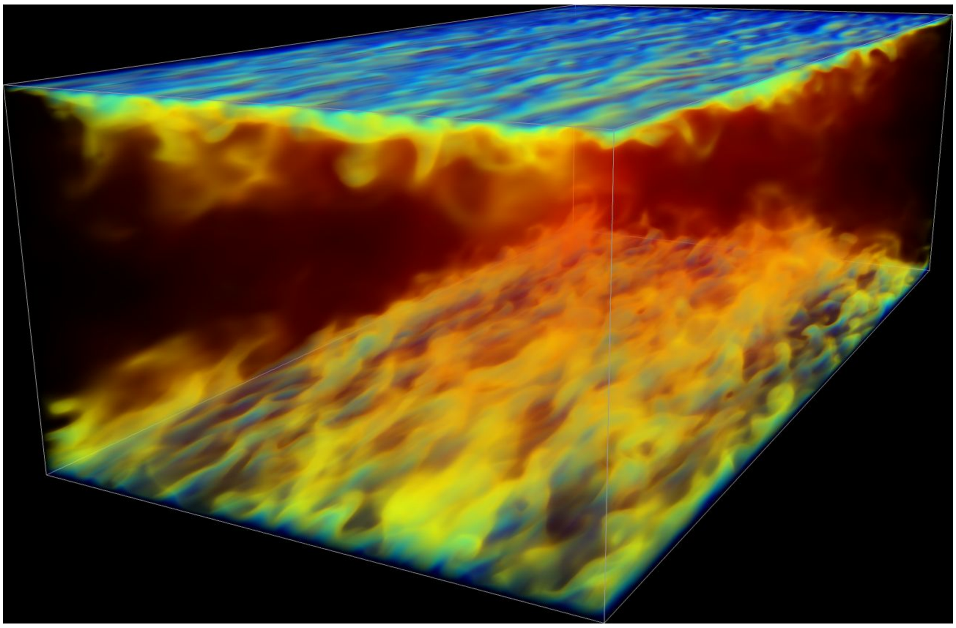

Figure 1. Volume rendering of the velocity.

The benchmark allows to compare the accuracy and the efficiency of the LES approach for near wall turbulence. The case is very sensitive to the dissipation of the model/discretisation and the correct velocity distribution can be tricky to obtain if the correct amount of dissipation is not applied on the right range of turbulent scales.

Required simulations/data

Two computational campaigns are proposed: one (mandatory) on structured grids and one (optional) on unstructured grids. The participants will provide the following statistics:

- Temporal and spatial (wall-parallel directions) averaged profiles:
    - Averaged velocity profiles
    - Averaged velocity fluctuations profiles
    - Averaged velocity correlations profiles
- Monitors:
    - Temporal evolution of the friction at the (top and bottom) walls
    - Temporal evolution of the mass flux through the inlet plane
- Spectra
    - Averaged 1D spectra in the x- and z- directions at constant y-location (y^+=10,59,249,501). Those 1D-spectra can also be averaged in time and space.

Mandatory campaign - Structured grids

Participants must provide grid convergence on structured grids. Only the number of *dof* in the wall-normal direction will be kept constant. Grids will be provided to the participants to ensure that they use the same mesh distribution in the wall normal direction.

Optional campaign - Unstructured grids

For the solvers that can handle unstructured grids, participants are greatly encouraged to perform studies on unstructured grid. A similar campaign than that on the structured will be performed: three mesh resolutions will be provided to the participants with a fixed number of *dof* in the wall-normal direction.

Detailed description

Governing Equations, flow conditions and models

Compressible or incompressible Navier-Stokes equations can be used for this benchmark. For compressible code, the Mach number, based on the bulk velocity u_b is set to M_b=0.1. The flow is assumed periodic in the streamwise and the spanwise directions. The friction Reynolds number is imposed through a constant forcing in the x-momentum equation. This forcing is given by a pressure gradient, linked to the friction Reynolds number by the following relations:

$$Re_\tau = \frac{\delta u_\tau}{\nu}, \quad u_\tau = \sqrt{\frac{\tau_w}{\rho}}, \quad \frac{dp}{dx} = \frac{\tau_w}{\delta}$$

with δ the half height of the channel. Finally the Prandtl number is fixed to Pr=0.71.

Geometry and grids

The computational domain is 2πδ * 2δ * πδ. A set of structured and unstructured grids are provided on this computational domain. Structured grids are mandatory and the participants are greatly encouraged to run their codes on the unstructured grids.
Two GMSH files are provided to generate the meshes:

- channel_structured.geo
- channel_unstructured.geo

These two files can generate (linear) meshes suitable for high-order solution polynomial. To do so, users must provide the order N=p+1 of the solution together with the mesh resolution (coarse, baseline or fine, see below).

The following mesh resolutions are provided:

Type	Resolution	ID	Number of *dof*	$\Delta x^+ \times \Delta y^+ \times \Delta z^+$
Structured	Fine	MS1	256 * 96 * 128	14.5 × ~0.7 × 14.5
	Baseline	MS2	192 * 96 * 96	19.3 × ~0.7 × 19.3
	Coarse	MS3	128 * 96 * 64	29.0 × ~0.7 × 29.0
Unstructured	Fine	MU1	-	~14.5 × ~0.7 × ~14.5
	Baseline	MU2	-	~19.3 × ~0.7 × ~19.3
	Coarse	MU3	-	~29.0 × ~0.7 × ~29.0

Meshes are designed to give a y+=h0/N<1 at the wall, with h0 the first element height and N=p+1, the solution order.
For each mesh resolution/type, a set of hexahedral meshes compatible with different orders of accuracy (following the p+1 rule) will be provided the participants. For the unstructured meshes, the number of dof are close to those of the structured meshes and the distribution in the y-direction identical.

Initial condition and simulation time

The choice of the initiation solution is crucial to avoid long transient times and to ensure the thermodynamics properties (for the compressible solvers) to remain at a correct level. To this end, we propose to use an initial condition based on the Reichardt function:

$$u^+ = \frac{1}{\kappa} ln\left(1 + \kappa y^+\right) + \left(C - \frac{1}{\kappa} ln\left(\kappa\right)\right)\left(1 - e^{-\frac{y^+}{11}} - \frac{y^+}{11} e^{-\frac{y^+}{3}}\right)$$

This initial solution can be perturbed using sine and cosine functions of various wave lenghts.

To get rid of the transient region, at least 20t+ must be computed before the accumulation of the statistics. At least 20t+ additional time must be computed to obtain statistical convergence. To summarise, **the computation should run for at least 40t+!**

Output format

For the averaged profiles, the format should be the following:
 # y+ u_mean+ u_rms+ v_rms+ w_rms+ -uv+
with the following definitions:

$$y^+ = \frac{\Delta y}{y_\tau} = \frac{\rho u_\tau y}{\mu} \qquad \overline{u^+} = \frac{\overline{u}}{u_\tau}$$

$$(u')^+_{RMS} = \frac{\sqrt{\overline{u'_i u'_i}}}{u_\tau} \qquad -\overline{(u'v')^+} = \frac{\overline{u'v'}}{u_\tau^2}$$

For the monitor files, the format is:
t+ tau_w' m_flux'
using non-dimensional values.

And finally, the velocity spectra:
k UU VV WW
The spectra must be in separated files (one per y+ station and per direction).

Bibilography

[1] R. D. Moser, J. Kim & N. N. Mansour, "DNS of Turbulent Channel Flow up to Re_tau=590", 1999, Phys. Fluids, vol 11, pg 943-945.
[2] Sergio Hoyas and Javier Jimenez, "Reynolds number effects on the Reynolds-stress budgets in turbulent channels", 2008, Phys. Fluids, Vol. 20, 101511.