Initial conditions for large-eddy simulations of decaying isotropic turbulence

H. Jane Bae & W. Rozema

1 Test case: decaying isotropic turbulence

The matlab script generates flow fields corresponding to the experimental measurements of decaying grid turbulencey by Comte-Bellot & Corrsin (1971). The setup of the simulation is discussed in Rozema *et al.* (2015) and uses the method to generate a diveregence-free field proposed in Kwak *et al.* (1975) and the rescaling technique proposed in Kang *et al.* (2003). The measurements have been made dimensionless so taht the computational domain is the unit box. The following section further explain the dimensionalization of the simulation.

2 Non-dimensionalization for simulation of decaying isotropic turbulence

The dimensionless momentum and continuity equations are given by

$$\frac{\partial u_i}{\partial t} + \frac{\partial u_i \partial u_j}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{1}{Re}\frac{\partial^2 u_i}{\partial x_j \partial x_j}, \ \frac{\partial u_i}{\partial x_i} = 0,$$

where Re is the Reynolds number. The Reynolds number is defined as

$$Re = \frac{u^* l^*}{\nu^*},$$

which in the case of the experiments of decaying isotropic turbulence by Comte-Bellot & Corrsin (1971) is given as

$$u^* = 27.19\text{cm/s}, \quad l^* = 11M = 55.88\text{cm}, \quad \nu^* = 1.5 \times 10\text{cm}^2/\text{s},$$

where $M = 5.08$cm is the size of the turbulence generating mesh.

The corresponding measurement stations in the experiment given at dimensional time of $\bar{t} = 42M/U_0$, $\bar{t} = 98M/U_0$, and $\bar{t} = 171M/U_0$. When nondimensionalized using $t^* = l^*/u^*$, this corresponds to $t = 0.103816$, $t = 0.242238$, and $t = 0.42268$.

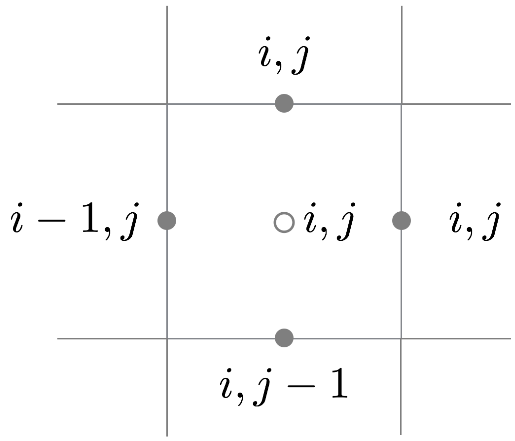

Figure 1: Default numbering of flow field.

3 Numbering of the numerical grid

The matlab script, by default, reads and writes flow fields for use in staggered simulation method. The current script assumes the numbering given in Figure 1. Sample Fortran code to read and write the generated binary flow files are provided in `readwrite.f90`.

By setting the variable `jnumb` to 1, an alternate numering given by Figure 2 is used.

4 Higher-order accurate and collocated methods

By default, the matlab script generates flow fields for use in a second-order accurate staggered method. However, by making small adjustments, the script can also be used to generate flow fields for use in collocated and higher-order accurate methods. The most important adjustment is the modified wavenumber for making the field divergence-free with respect to the used numerical discretization. This can be done by changing `kmod` in `fourier_tools/makefiled.m`.

For a collocated methods, calls to `fourier_tools/stagtocol.m` and `fourier_tools/coltostag.m` should be removed.

5 Overall use of the code

1) In order to generate a 512^3 initial condition:

- run `gen_ic_512.m` to generate a 512^3 initial condition (you can run `gen_filt_exp.m` to generate spectra of the box-filtered experimental data as reference data for a simulation with the dynamic Smagornisky model)

2) In order to generate a 64^3 initial condition filtered by the spectral cut-off filter for the QR model:

- run `gen_ic_64_qr.m` to generate a filtered 64^3 initial condition for the QR model

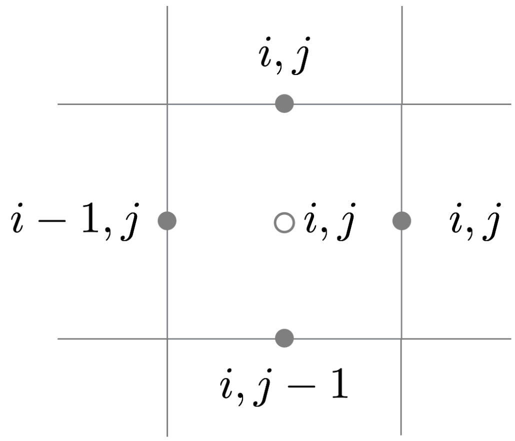

Figure 2: Numbering of flow field using `jnumb` $= 1$.

- run simulaitons with the QR model from $\bar{t} = 0$ to $\bar{t} = 42M/U_0$ with the initial conditions
- run `kang_ic_64_qr.m` to Kang-rescale the solution at $\bar{t} = 42M/U_0$ to a new initial condition for the QR model
- run simulations with the both models from $\bar{t} = 42M/U_0$ to $\bar{t} = 191M/U_0$ with the given initial condition.

3) The above procedure generates a filtered initial condition assuming a spectra cut-off LES filter. Replace `_qr.m` by `_dms.m` to generate a box-filtered initial condition.

References

Comte-Bellot, G. & Corrsin, S. 1971 Simple Eulerian time correlation of full and narrow-band velocity signals in grid-generated, isotropic turbulence. *J. Fluid Mech.*, **48**, 273–337.

Rozema, W., Bae, H. J., Moin, P. & Verstappen, R. 2015 Minimum-dissipation models for large-eddy simulation. *Phys Fluids*, **27**, 085107.

Kwak, D., Reynolds, W. C. & Ferziger, J. H. 1975 Three-dimensional time dependent computation of turbulent flow. *Technical Report*, Stanford University.

Kang, H. S., Chester, S. & Meneveau, C. 2003 Decaying turbulence in an active-grid-generated flow and comparisons with large-eddy simulation. *J. Fluid Mech.*, **480**, 129–160.