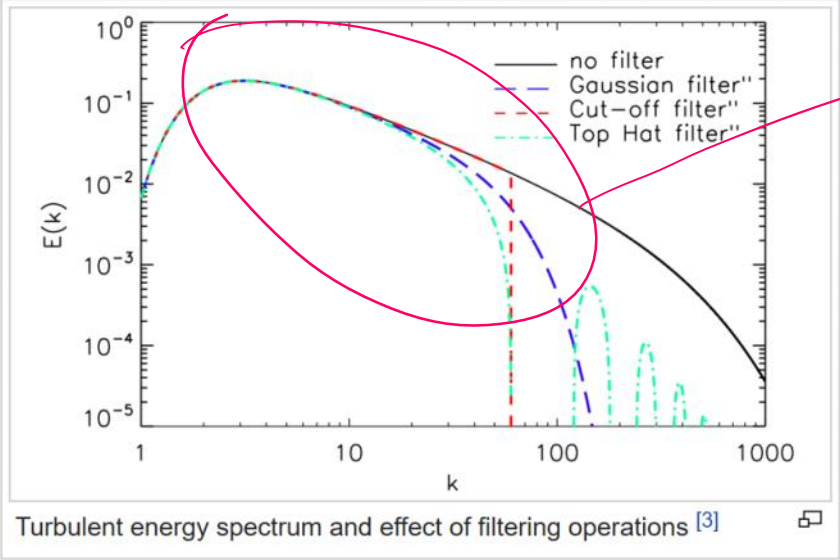
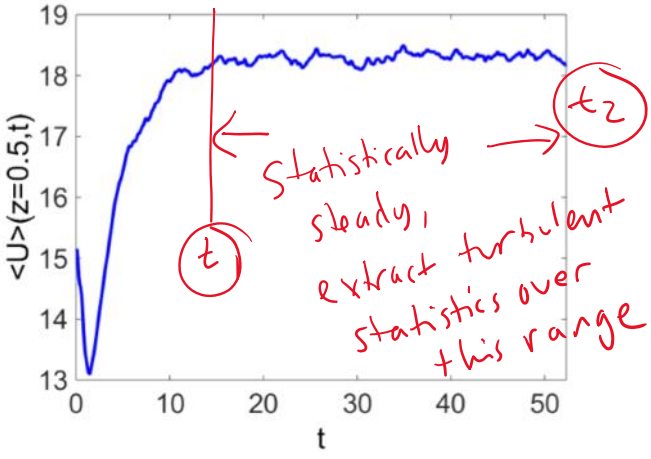
Figure 1. Effect of different filters on the energy spectrum of turbulence.



A properly-implemented LES leaves the inertial range intact.

https://en.wikipedia.org/wiki/Filter_(large_eddy_simulation)

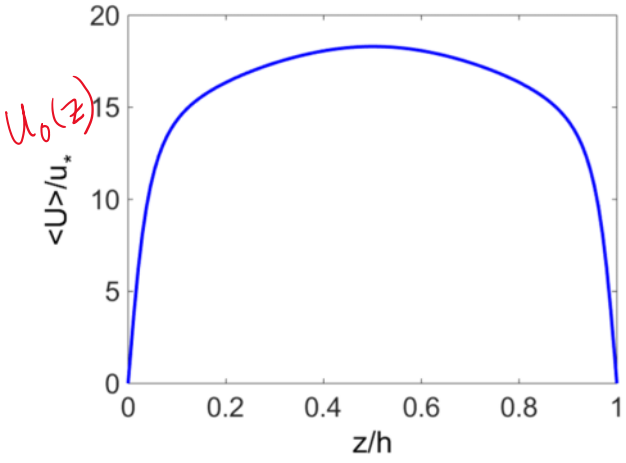
Figure 2. Relaxation of the centreline velocity to a statistically steady state



$$\langle U \rangle(z,t) = \frac{1}{L_x}\frac{1}{L_y}\int_0^{L_x} dx \int_0^{L_y} dy\, \bar{U}(x,y,z,t)$$

Instantaneous "raw" velocity from the LES.

Figure 3. Mean streamwise velocity, showing "law of the wall"

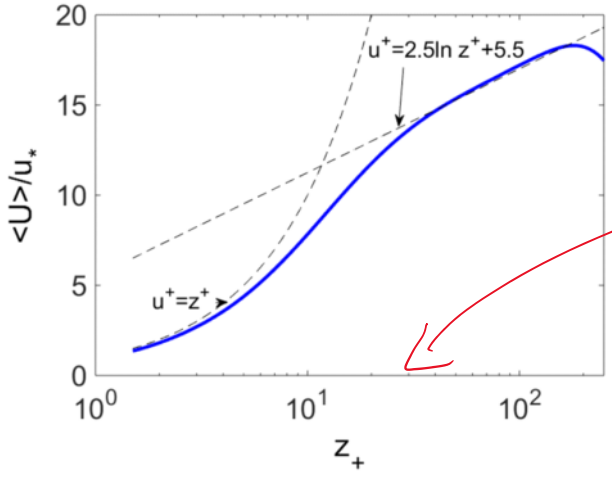


$U_0(z)$

After extracting the statistically steady range in ①, the time-average mean streamwise velocity is computed as follows:

$$U_0(z) = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} dt \int_0^{L_x} dx \int_0^{L_y} dy \; \underbrace{U(x,y,z,t)}_{\text{the "raw" velocity again from the LES}} \times \frac{1}{L_x L_y}$$

Figure 4. The same as Figure 3, only on a semilogarithmic scale



$$z_+ = \frac{z}{d_*} = \frac{z}{H}\frac{H}{d_*} = \tilde{z}\,\frac{\rho H u_*}{\nu} = \tilde{z}\,Re_*$$

Figure 5. Scaling behaviour of the mean velocity

Define $U_{mean} = \frac{1}{H}\int_0^H U_0(z)\,dz$

Check: $\frac{\max U_0(z)}{U_{mean}} \simeq 1.16$ (value from full DNS)

$C_f = 2u_*^2 / U_{mean}^2 \simeq 8.18 \times 10^{-3}$ from DNS

$C_f = 2u_*^2 / u_{mean}^2 \simeq 8.18 \times 10^{-3}$ from DNS

C_f is the drag coefficient or more precisely, the skin friction coefficient.

Figure 6. Parameters of simulation

$Re_* = \rho u_* H / \nu = 360$

$N_x = 288$ $\quad \Delta x \simeq L_x / N_x = 1/36$

$N_y = 120$ $\quad \Delta y \simeq L_y / N_y = 1/36$

$N_z = 120$ $\quad \Delta z \simeq L_z / N_z = 1/120$

$\Delta t = 5 \times 10^{-5}$

Figure 7. Reference

European Journal of Physics

PAPER

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Published 20 April 2016 • © 2016 IOP Publishing Ltd

European Journal of Physics, Volume 37, Number 4

Citation James Fannon *et al* 2016 *Eur. J. Phys.* **37** 045001

DOI 10.1088/0143-0807/37/4/045001