

Computer-aided rehabilitation supported by zygomatic implants: A cohort study comparing atrophic with oncologic patients after five years of follow-up

*Original*

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# Step onset from an initial uniform distribution of turbulent kinetic energy.

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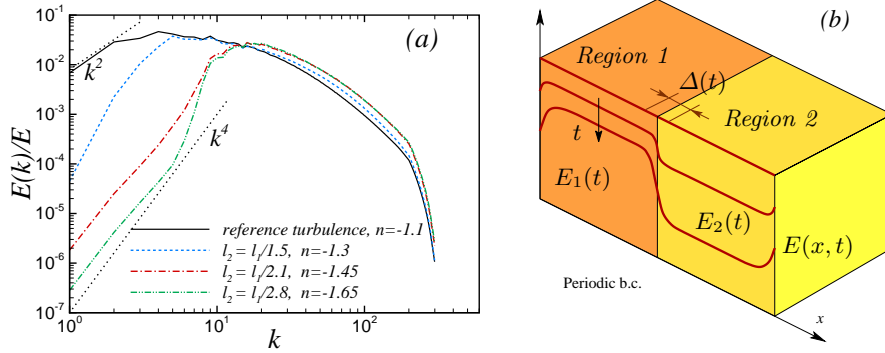
## 1 Introduction

We consider the time decay of a field with an initially uniform turbulent energy distribution where the macroscale has been slightly varied in two adjacent regions. The flow is studied by means of Direct Numerical Simulation carried out in a parallelepiped, see fig. 1 b. The interesting observation is that the time evolution of the field shows the onset of a step of turbulent energy. It is sufficient to introduce a slight dishomogeneity associated to the integral scale that the nonlinear interaction is able to induce a dishomogeneity also in the kinetic energy. We present here a set of results from experiments where we actually follow the temporal decay of two isotropic turbulences (of initial equal turbulent kinetic energy, but of different integral scales) that match over a thin region  $\Delta(t)$ . The two isotropic regions are characterized by a different shape of the spectrum in the low wavenumber range, as shown in figure 1, see , a thing which was obtained by means of a high-pass filter (see [5]).

## 2 Results and discussion

The present simulations are performed on a parallelepiped domain with periodic boundary conditions in all directions, see the scheme in figure 1. The Navier-Stokes equations are solved by means of a fully dealiased Fourier-Galerkin pseudospectral method with explicit fourth order time integration [7]. The initial conditions are obtained by matching two fields, coming from simulations of homogeneous and isotropic turbulence, over a thin region by means of a smoothing function [5]. The two fields are characterized by a different shape of the spectrum in the low wavenumber range, as shown in figure 1. The fields with a steeper spectrum in the low wave number range, and thus a smaller integral scale, have been obtained by the application of a high-pass filter to a same reference field, which produces a  $k^\alpha$  slope with  $\alpha$  between 2 and 4. As a consequence, the integral scales of the two interacting

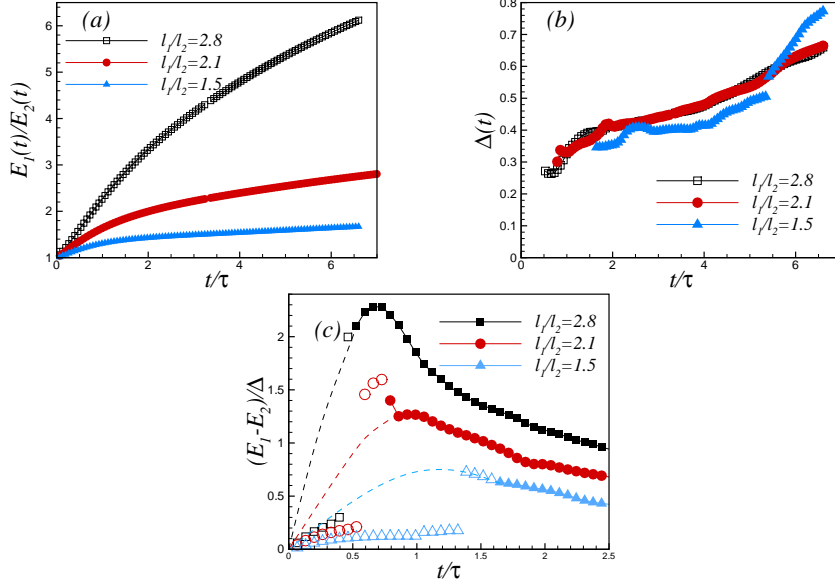
isotropic turbulences are different and a scale gradient is present across the initial matching layer. The Taylor microscale Reynolds number  $Re_\lambda$  is 150. The simulations show that the flows with a smaller integral scale decay faster and have higher decay exponents, that range from 1.1 up to 1.65. The smaller the macroscale, the higher is the exponent value. These different decay rates are in agreement with previous literature [1, 2, 3, 4] which suggests that the shape of the spectrum at low wavenumbers determines the decay rate at least for low to moderate Reynolds numbers.



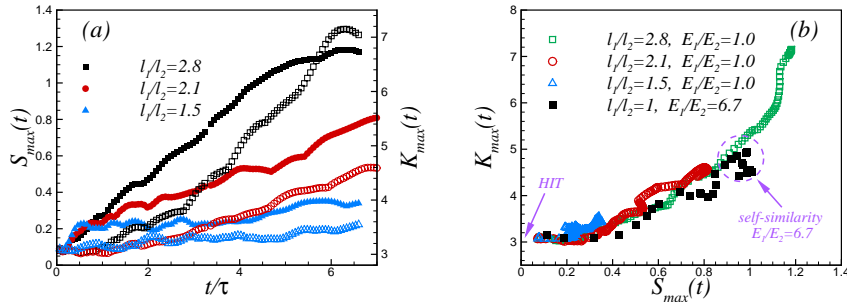
**Fig. 1.** (a) Initial three-dimensional spectra  $E(k)$  normalized with the initial energy  $E$ . Continuous line: homogeneous region ( $Re_\lambda = 150$ ) with the larger scale  $\ell_1$ ; other lines: spectra of the other fields to be mixed, with integral scale  $\ell_2 < \ell_1$ ;  $n$  is the decay exponent found in the simulation. Reference  $k^2$  and  $k^4$  slopes are also shown. (b) Scheme of the flow and of the kinetic energy distribution during the decay.

Another interesting point is that, due to the different decay, an energy gradient, always concurrent to the integral scale gradient, soon emerges during the decay. It is maximum after about one eddy-turnover time  $\ell/E^{1/2}$ , then it is gradually reduced while the ratio of kinetic energy between the two regions still increases, see fig. 2 (a, c). The thickness of the induced kinetic energy layer increases while the two flow interact, see fig. 2 (b). The scale and energy mixing layer becomes immediately intermittent and the intermittency level is close to the that found in the shearless mixings with imposed gradients discussed in ref. [5, 6]. The instantaneous level of velocity skewness and kurtosis is comparable with the one which can be seen in the shearless mixings with higher energy ratios but uniform scale, see fig. 3 (a). The departure from the almost gaussian initial conditions always follows the same path, see figure 3(b), which is shared not only by the present mixings but also by the mixings with an imposed energy gradient. Another common aspect is the anisotropy of the velocity moments in the mixing layer: for the second order moments deviations of about a 10% of the isotropic value of  $1/3$  are visible, while for the third order moments about half of the total kinetic energy flow was contributed by the velocity fluctuations in the direction of the mixing. This

property seems related to the behaviour of the pressure-velocity correlations in absence of shear [6].



**Fig. 2.** (a) Time evolution of energy ratio  $E_1/E_2$ , where  $E_1$  and  $E_2$  are the energy of the homogeneous regions with the largest and smallest macroscale;  $\tau$  is the initial eddy turnover time. (b) Mixing layer thickness, conventionally defined as the distance between the points with normalized energy  $(E(x, t) - E_2(t))/(E_1(t) - E_2(t))$  equal to 0.75 and 0.25 [5, 6]. (c) Time evolution of the energy gradient.



**Fig. 3.** (a) Maximum of the velocity skewness (filled symbols) and kurtosis (empty symbols) in the mixing layer. (b) Comparison of the intermittency level with a mixing with an initially uniform integral scale, each point corresponds to one time instant.

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