Combustion in low Mach number isotropic turbulence

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Turbulent reacting flows are often met in industrial applications where many simulations have been performed, mostly concerning problems in practical devices.
In turbulent combustion, fluid dynamics is strongly coupled with chemical kinetics. Actually turbulent stirring may enhance chemical reaction or may lead to local quenching. A better knowledge of these interactions is required both for a better theoretical understanding and for improvements of turbulent models used for the simulation in real application, i.e. combustor chambers.
As a matter of fact when practical configurations are considered the interaction between turbulence and chemical kinetics take place in highly non homogeneous and non isotropic conditions. This represents a further difficulty when the focus is on the analysis of basic physical mechanism on turbulent combustion.

In order to avoid such complications we consider a periodic box where the complete interaction between turbulence and chemical kinetics can be analysed in the simplest geometrical configuration, where homogeneous and isotropic conditions are restored [1][2].

In order to perform a statistical analysis of the reacting flow, both turbulence and chemical kinetics need to reach a statistically steady state. Actually turbulence is stirred at the largest scales by a random forcing acting on the solenoidal component of velocity field. On the other hand chemical kinetics is forced by a source of mass acting on largest scales of the computational domain. Such source is positive for reactants and negative for product [2].

Furthermore due to the heat release the local Mach number of the flow is rather small although strong variation of density with temperature observed. A low Mach number asymptotic expansion is performed on the complete set of the compressible Navier-Stokes equations for reacting flow. Here the essential feature of turbulent combustion, i.e. the variation of density with temperature, is fully described avoiding the numerical stiffness related to the time-step limitation of the complete formulation. As far as chemical kinetics are concerned, a single step Arrhenius type reaction has been used; this involves three chemical species namely: fuel, oxidiser and products.
A direct numerical simulation is used to solve the low-Mach number equations set. Spatial discretization uses a pseudo-spectral method where non-linear terms are fully dealiased. Time advancement is performed by a four steps, low-storage, Runge-Kutta method with third order

time accuracy. An iterative method to solve the elliptic problem for the pressure has been used. It allows to compute the appropriate pressure correction also when large variations of density occur in the flow, which is the actual case.

In figure 1 (left panel) we show an iso-surface of reaction rate that describe the position of flame front corrugated by turbulent velocity fluctuations.
In same figure (right panel) the spectra of the rotational and dilatational component of velocity field, normalised with their respective energy, are plotted. The rotational spectra shows the typical behaviour associated with the energy cascade from the largest to the smallest scales. On the contrary in the dilatational spectra it is evident a relative maximum at intermediate scales due to the heat release associated to the chemical reactions. Here the classical picture of energy cascade along the inertial range typical of incompressible turbulence is not fully recovered.

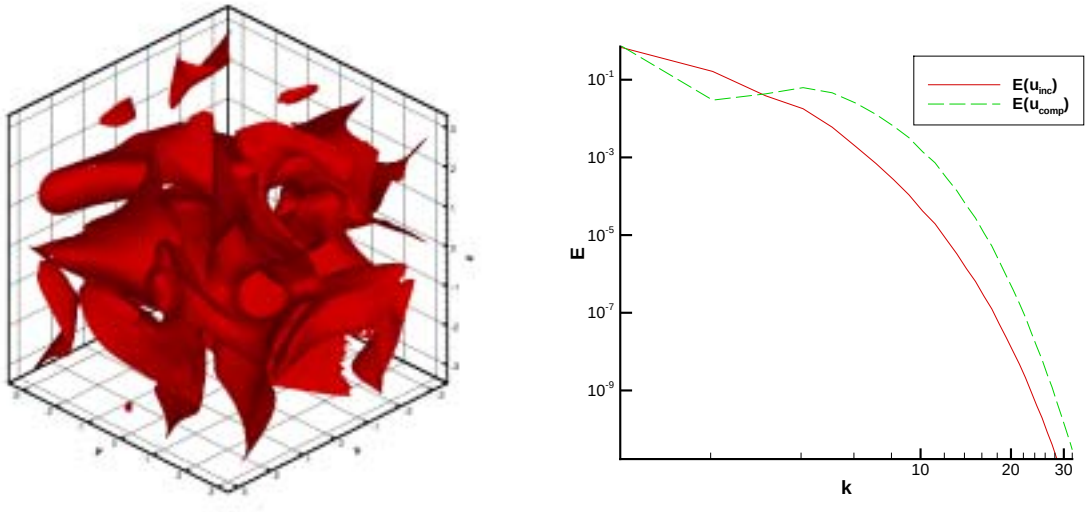

Figure 1: Left: iso-surface of reaction rate during a steady state. Right: spectra of rotational component (continue,red) and of dilatational part of velocity field (dashed,green).

References

[1] Jaberi, F.A., Livescu, D., Madnia, C.K., *Characteristics of chemically reacting compressible homogeneous turbulence*, Phys. Fluids, **12**(5), 1189-1209, 2000.

[2] P. Gualtieri, B. Favini, R. Piva, *Statistically steady combustion in forced isotropic turbulence* Procedings ETC10, Trondheim, Jun 2004.