§17. Enstrophy and Vorticity Generation in a Shock-Dominated Turbulence

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Mechanism of enstrophy and vorticity generation in a shock-dominated, isotropic and homogeneous turbulence was investigated by means of direct numerical simulation of a system of equations of motion for an ideal gas. In this simulation, a random external force was imposed only on the compressive component of the flow and the initial condition was set irrotational to make the enstrophy be generated only through shock-curvature and/or shock-shock collisions. The Reynolds, Prandtl and Mach numbers were set at 200, 0.7, 2.0, respectively.

Time-evolution of the dilatation and the enstrophy are plotted in Fig.1. Thick and thin solid lines denote the mean square of the dilatation and the enstrophy, respectively, while two dashed lines represent local maximum and minimum of the dilatation. Sharp peaks of the dilatation, designated by arrows, synchronize with the generation of the enstrophy. These peaks originate from shock-shock collisions, a typical picture of which is drawn in Fig.2. A detailed observation of the vorticity vector and the enstrophy density revealed that vortex generated behind shocks takes form of a vortex pair, in spite of complicated flow geometry due to collisions of many shocks.

Generation of vorticity by shocks is usually attributed to the baroclinic term, $\nabla\rho \times \nabla p$ (ρ and p are the density and the pressure of the fluid, respectively) in the vorticity equation. However, in this simulation, it was shown that the baroclinic effect is not the primary source of the enstrophy though it still has significant contribution to the enstrophy generation. The most dominant contribution to the enstrophy generation comes from the outer product of the density gradient and the viscous term of the equation of motion.

The vorticity generation by these two terms comes not only from their strong magnitude but also from strong alignment between the vorticity and them. Since the equation of the enstrophy density consists of the inner product of the vorticity and each term in the r.h.s. of the vorticity equation, these two terms mentioned above generate the enstrophy quite effectively when the vorticity is aligned strongly to these terms. This alignment is lost when shocks (or the dilatational component of the flow) become weak or vanish, to cause slow decay of the enstrophy in Fig.1.

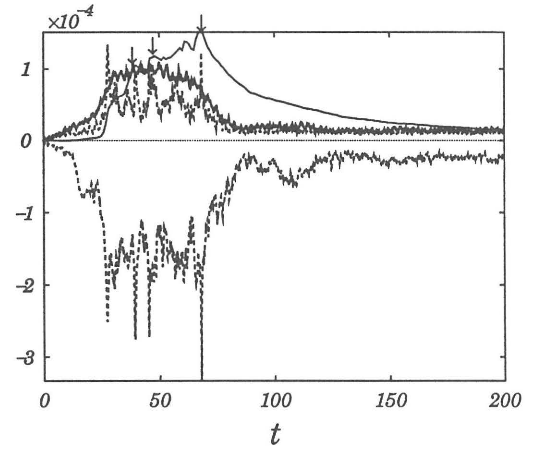

Fig. 1: Time-evolution of dilatation and enstrophy

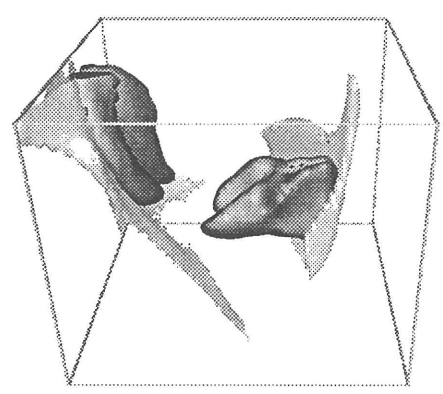

Fig. 2: After a head-on collision of two shocks(light gray), strong vorticity (enstrophy density) are generated behind them as pairs.