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Direct numerical simulation of passive scalar in decaying compressible turbulence

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Abstract :

In this paper, direct numerical simulation of decaying compressible turbulence with passive scalar is performed by using 7th order upwind difference scheme or 8th order group velocity control scheme. The start Reynolds number (defined by Taylor scale) is 72 and turbulent Mach numbers are 0.2-0.9. The Schmidt numbers of passive scalar are 2-10. The Batchelor k^{-1} range are found in scalar spectra, and the high wavenumber spectra decays faster with increasing turbulent Mach number. The extend self-similarity (ESS) is found in the passive scalar in compressible turbulence.

Keyword: *passive scalar, decaying compressible turbulence, direct numerical simulation*

1. Introduction

There are many papers report the DNS of passive scalar in isotropic turbulence (forcing turbulence or decaying turbulence), but all of those cases are incompressible. However, DNS for passive scalar in compressible isotropic turbulence may be more interested in aeronautics and astronautics. Some results of DNS for passive scalar in decaying compressible turbulence with much higher turbulent Mach number ($M_{t\max} = 0.9$) are performed in this paper.

2. Direct numerical simulation and data verification

The control equations are compressible Navier-Stokes equations and the transport equation for passive scalar. Flux vector splitting is adopted for the convection terms, the 7th order upwind difference scheme (UD7)[1] or 8th order group control schemes (GVC8)[2] are used to discretize it. 8th order centre difference scheme is used to discretize viscous terms, 3 stage TVD type Runge-Kutta method [1-2] is used for time advance. In order to improve the computing efficiency, the grid size in computing the scalar function is different comparing with grid size for the basic physical parameters. 8th order Langrage interpolation are used for grid size changing.

The computation cases are showed in following table, where Re_λ is Reynolds defined by Taylor scalar and M_t is turbulent Mach number, Sc is Schmidt number of passive scalar.

CASE	Flow fields ($t/\tau = 1$)	Re_λ	*Mt*	Sc	Scheme	Grids for flow	Grids for passive scalar
D1	FD1	72	0.2	5	UD7	256^3	512^3
D2	FD2	72	0.5	5	UD7	256^3	512^3
D3	FD3	72	0.7	5	UD7	256^3	512^3
D4	FD4	72	0.9	5	GVC8	256^3	512^3
E1	FE1	72	0.5	2	UD7	256^3	512^3
E2	FE2	72	0.5	10	UD7	256^3	512^3
E1T	FE1T	72	0.5	2	UD7	128^3	256^3
D2Ta	FD2Ta	72	0.5	5	UD7	128^3	256^3
D2Tb	FD2Tb	72	0.5	5	GVC8	256^3	512^3

The code for flow computing is verified in paper [1,2]. Figure 1 shows the time history of root-mean-square of passive scalar for case D2 agree well with those of case D2Ta, which verify the

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passive scalar computing of those two cases. For validation of the computed results, the number of grid points is doubled. Agreement of the computed results with different grid size confirms our results.

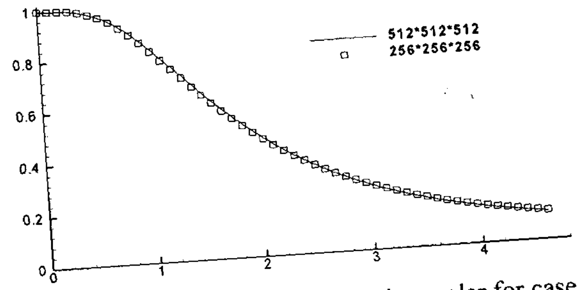

Figure 1. Time history of root-mean-square of passive scalar for case D2 and D2T

3.Results and conclusions

Figure2 shows the scalar spectra E_g [3] for scalar fields of FD1-FD4 (scalar fields at $t/\tau = 1$ of cases D1-D4). We can find that the high wavenumber spectra decays faster with increasing turbulent Mach number. Figure3 shows the normalized scalar spectra[3] for FE1 FD2 and FE2, indicated that Batchelor k^{-1} spectral is universal for all those cases.

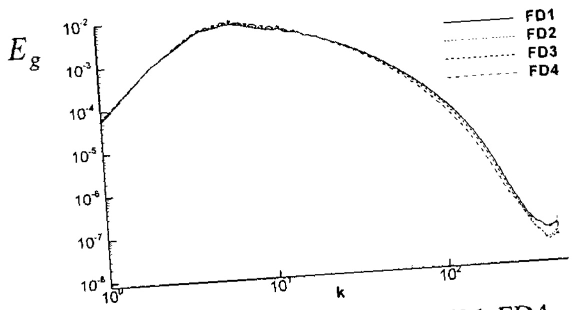

Figure 2. Scalar spectra of FD1-FD4.

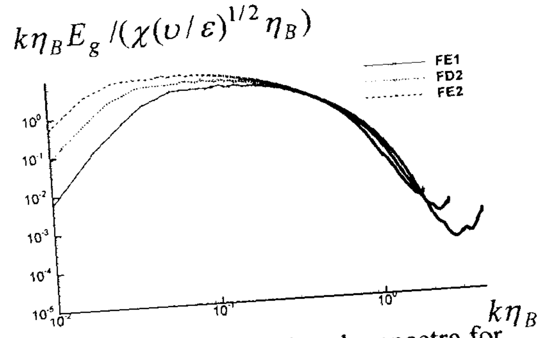

Figure 3. Normalized scalar spectra for FE1,FD1and FE2

Figure4. shows the isosurface of scalar gradient normalized by its root-mean-square of FD4, which shows the sheet structure of passive scalar in compressible turbulence.

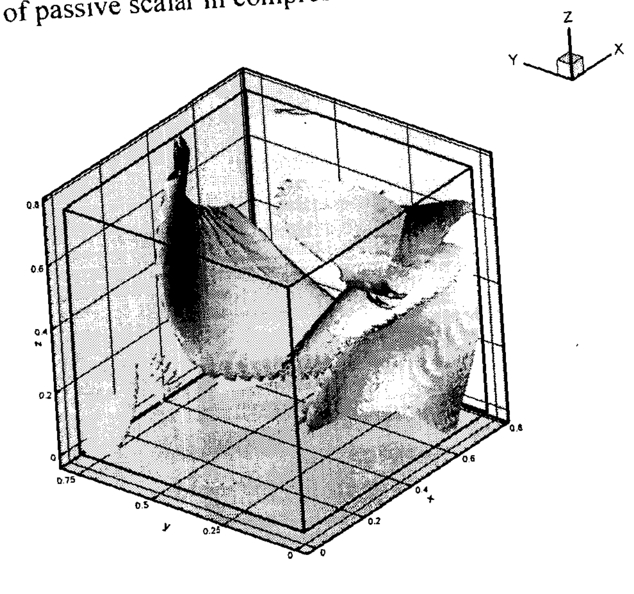

Figure 4. Isosurface of normalized scalar gradient of FD4

Figure 5 plots p-th order passive scalar structure function as a function of 3rd order passive scalar structure function in FD2, which means ESS (Extend Self-Similarity) holds in passive scalar turbulence. Figure 6 shows the relevant scaling exponents for FD1-FD4. This figure indicates that the compressibility has little effect on passive scalar's scaling exponent. Figure 7 shows the relevant scaling exponents for FE1, FD1 and FE2, where the Schmidt numbers are 2, 5 or 10 respectively. This figure shows scaling exponent become smaller with increasing Schmidt number, which means passive scalar become more intermittent when Schmidt number increase.

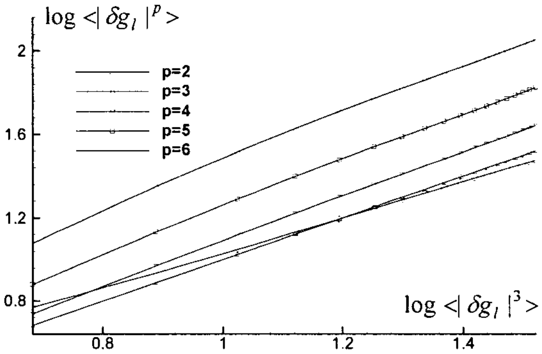

Figure 5. p-th scalar structure function as a function of 3rd scalar structure function for FD2

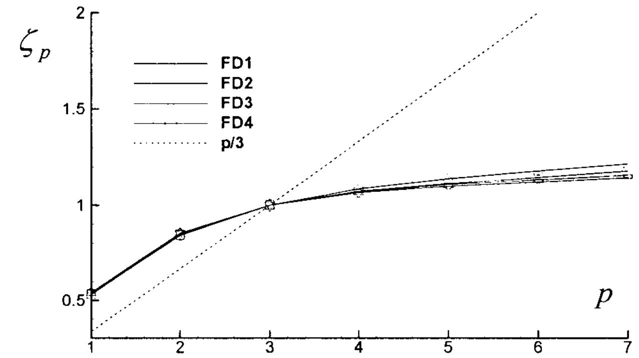

Figure 6. passive scalar scaling exponents for FD1-FD4

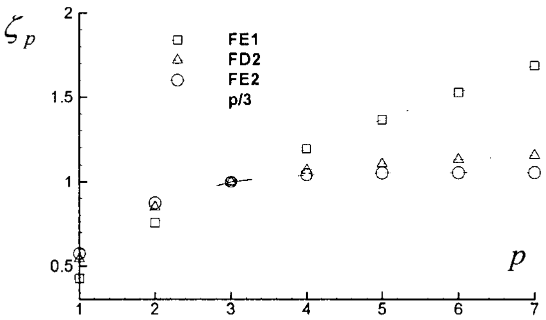

Figure 7. passive scalar scaling exponents for FE1,FD2 and FE2

References

[1] Li Xinliang, Fu Dexun, Ma Yanwen. Direct numerical simulation of compressible isotropic turbulence. Science in China A, 45(11), 2002, 1452-1460.

[2] Xinliang Li, Dexun Fu, Yanwen Ma, Optimized Group Velocity Control Scheme and DNS of Decaying Compressible Turbulence of Relative High Turbulent Mach Number, Submitted to Journal of Computational Physics

[3] P. K Yeung, Michelle C. Sykes, Prakash Vedula. Direct numerical simulation of differential diffusion with Schmidt number up to 0.4. Physics of Fluids. 12(6),2000,1601-1604.