§25. Development of Heat and Flow Analysis Codes for Reactor Systems

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Turbulence models are mostly constructed on the basis of the concept of energy cascade (i.e., energy transfer from large scale eddies to small ones). In reactor systems, however, a reverse energy cascade might occur with sudden flow changes under high heat flux conditions. Such a behavior is never predicted with the existing turbulence models. Therefore, some turbulence model adequately expressing the reverse energy cascade is needed for the development of heat and flow analysis codes indispensable to design reactor systems. In the present study, we aimed to construct a turbulence model which can faithfully reproduce the reverse energy cascade, noticing the energy transfer between eddies of various scales.

First, we conducted a direct numerical simulation (DNS) for isotropic turbulence. The reverse energy cascade was intentionally produced by providing pulsed energy spectra to the initial turbulence field, and various turbulence statistics obtained from the DNS are accumulated as a database[1]. Figure 1 shows the 3-D energy spectrum, the dissipation spectrum and the energy transfer function. The energy transfer function, i.e., the energy exchange function among various wavenumber components, takes positive values in the regions of low and high wavenumbers, which indicates the energy cascade to the high wavenumber and the reverse energy cascade to the low wavenumber.

In the physical space, the modelling of turbulence is generally made with a representative scale in the flow field. However, characteristics of complex turbulence cannot be predicted by using the unique scale. Therefore, we took note of energy transfer function model involving the information of various eddy scales. Although several energy transfer function models have been proposed, it is hard to say that those are strict because models are constructed on the basis of available experimental data for simple turbulence. When we evaluated these models with the DNS database, there were no models providing the reverse energy transfer. So that, we developed a new model valid for the reverse energy transfer. This model is expressed as the sum of eddy-viscous energy cascade and reverse energy cascade terms. The integral energy transfer function obtained with this model is presented in Fig. 2, which excellently reproduces the reverse energy cascade to the low wavenumber region. Figure 3 shows the comparison between the time dependent turbulent energy obtained by using the model and the DNS data. Also included is the calculated result with the standard K-ε model. The present model expresses the behavior of the DNS data more quantitatively than the K-ε model. Consequently, it is considered that turbulent quantities such as energy spectra, turbulent energy and dissipation field under the severe operative condition in reactor systems can be predicted with introducing the present model.

Though the above-mentioned study was performed to develop a new model for isotropic turbulence, the complete codes of heat and flow analysis for reactor systems require the further consideration of energy production due to mean shear and the modelling of pressure-strain correlation. Concerning these items, we have obtained important information[2] associated with the construction of new turbulence models, through evaluating the existing models with the DNS database for uniformly sheared turbulence and scrutinizing the problem. By unifying these studies, we intend to complete the heat and flow analysis codes for reactor systems.

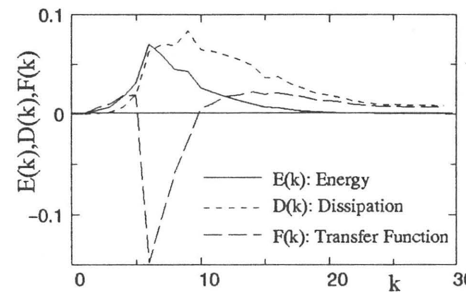

Fig. 1. Energy spectrum, dissipation spectrum and energy transfer function.

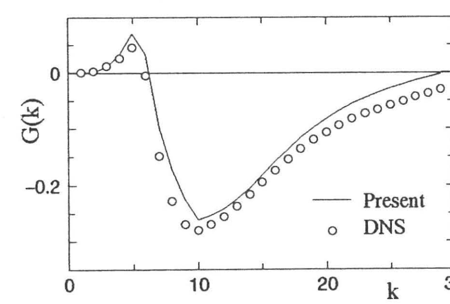

Fig. 2. Integral energy transfer function model.

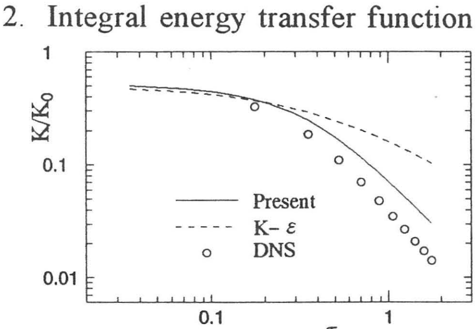

Fig.3. Decaying behavior of turbulent energy.

References

1) Matsunaga, K. and Nagano, Y., Proc. 6th Comp. Mech. Conf., Sendai (1993) 261.

2) Matsumoto, A., Nagano, Y. and Tsuji, T., Trans. JSME, Ser. B, 60-573 (1994) 1653.