報告番号	※甲　第10729号

主　論　文　の　要　旨

論文題目　Investigation of the Influence of Initial Condition on the Spatial Development of Plane Jets Using Direct Numerical Simulation（直接数値シミュレーションを利用した二次元噴流の空間発展に及ぼす初期条件の影響に関する研究）

氏　名　呉　楠楠

論　文　内　容　の　要　旨

Plane jets are prototypical free shear flows and statistically two-dimensional flows possessing the relatively simple geometry and easily-simulated boundary conditions, which makes them attractive for fundamental research into the turbulent flow. On the basis of the past researches on the plane jet, it is clear that, even though both the experimental data and numerical results are required to investigate the characteristics of the plane jet, the numerical simulation is quite promising accompanied by the improvement of calculation capacity of scientific computer, which can easily achieve the simultaneous parameters' acquirement and avoid the effects of external disturbances on the evolution of jet flows in the experiments.

It is considered that the transport and mixing processes of passive scalar in turbulent shear flows are of great interests due to their importance to the diffusion of contaminants in environmental flows as well as the wide range of applications involving turbulent combustion. The evolution characteristics of velocity field and scalar field should be simultaneously studied. Moreover, although some researches on the effects of initial conditions (mainly the Reynolds number and the initial velocity profile) on the evolution of plane jets have been done, only one kind of initial conditions is usually considered in one single work; the cross-impact or overlapping effects between these initial conditions have not been

discussed.

Meanwhile, the most sufficient study on the plane jet in the past was obvious about the flow characteristics in the fully developed region with quite large exit Reynolds number. The flow transition or development with moderate or small Reynolds number should be investigated more.

Based on the above analysis, in the present study, the direct numerical simulations (DNSs) of plane jets are carried out. The characteristics of turbulent plane jets are mainly investigated in view of the velocity and scalar fields, meanwhile we focus on the effects of the flow initial conditions, i.e., exit Reynolds number (Re) and exit mean velocity profile, on the spatial development of the flow on the basis of the simulation results about the instantaneous and mean flow field. Furthermore, the features and evolution of coherent structure and the interface between the plane jet and the ambient fluid are also observed in the plane jets with different initial conditions.

Moreover, the kinematics, dynamics and local structure of the planar jet in the fine-scale are studied by analyzing the evolution of the invariants of the velocity gradient tensor. Meanwhile, the effects of the initial condition on the flow evolution are also assessed, particularly the characteristic features of the planar jet in the inhomogeneous transition zone.

The content and main conclusions of this thesis are introduced as follow.

In chapter 1, the past study on the plane jet is reviewed first. Based on the introduction and analysis of the basic characteristics and initial conditions of the plane jet, the motivation and study objectives are introduced.

In chapter 2, the study on the utilization of the numerical simulation in plane jet study will be recalled. The information about the present DNS are introduced, including the governing equations, the non-dimensionalization and discretization of the governing equations, the grid system, the solution of Possion equation and others. The computational domain and the definition of the initial and boundary conditions are also presented.

In chapter 3, the influence of exit Re on the plane jet was investigated based on the instantaneous and statistical results. The streamwise and lateral profile of mean and turbulent variables about the velocity and scalar were presented. Meanwhile, the convection and turbulent transport in the transport process of the mean streamwise momentum and

mean scalar were also studied.

The main results in this chapter are summarized as follows:

1. The plane jet is the exit Re-dependent, which is especially obvious in the near field, but this dependency becomes weaker in the downstream region of the flow. As the exit Re increases, the length of the jet potential core becomes shorter and the flow transition is promoted; however, the larger turbulent variables are observed at the small exit Re in the flow development process.

2. The transition of the plane jet from the laminar state to the turbulent state is advanced by a large exit Re; however, in the near field region behind the potential core, the mean streamwise momentum and mean scalar transport are strengthened by a small exit Re.

3. The streamwise convection and the lateral turbulent transport are dominant in the transport of the mean streamwise momentum and mean scalar.

4. The plane jet shows the stronger Re dependency in the condition with a small Re.

In chapter 4, based on the data from DNS of plane jets with two kinds of mean velocity profiles at the jet exit, the influence of the exit mean velocity profile is investigated; meanwhile, the cross impact between the exit Re and the exit mean velocity profile is also discussed.

The main results in this chapter are summarized as follows:

1. The obvious influence of the exit mean velocity profile is observed in the present study. In the transition process of the plane jet, the large decay rate of mean variables and large local maxima of the turbulent variables are found, and the fluxes of streamwise momentum and scalar caused by the fluctuating velocity filed are enhanced in the cases with PA.

2. The influence of mean exit velocity profiles is also weak in the downstream region similar to the influence of exit Re.

3. The cross-impact between the exit Re and the exit profile of the mean velocity exists and cannot be ignored. In the cases with PA, the effect of the exit Re is amplified in the downstream region of the plane jet, and the length of the potential core is almost same in two cases with different exit Re, and in the downstream region the turbulent values of velocity and scalar with different exit Re do not converge like that with TH.

In chapter 5, the information on the characteristics and evolution of CS and the T/NT

interface, and the influence of exit Re and mean velocity profile on turbulence structures related to these two topics are provided. The process of occurrence, pairing and tearing of CS accompanying the flow evolution of turbulent plane jets are visualized on the basis of the instantaneous velocity and pressure data. The characteristics of CS are observed and discussed, especially in the near field region, which is barely studied in the past researches. Moreover, the interface between the plane jet and the ambient fluid is investigated using the data from the scalar field.

The main results in this chapter are summarized as follows:

1. The large-scale CSs detected by the local minimum of pressure are mainly spanwise and the small-scale CSs detected by the second invariant of velocity gradient are more three-dimensional.

2. The evolution of the interface between the plane jet and the ambient fluid corresponds to the evolution of the jet, which is initially two-dimensional and then three-dimensional.

3. The increase of exit Re advances the occurrence and merging of CS, and induces more small-scale CS in the downstream region, meanwhile, in the case with low exit Re, the CS in a larger scale can be detected.

4. In the case with large exit Re, the evolution of the interface is also accelerated, and the topology of interface is more complicated.

5. In the transition process the scale of CSs with PA is much larger than the ones with TH.

In chapter 6, with the computation of the invariants of the velocity-gradient, rate-of-strain, rate-of-rotation tensors, the investigation in this chapter provides the information on the rates of vortex stretching and compression, the topology and geometry of deformation of the fluid element, and the kinetic feature of the local straining.

The results in this chapter reveal that in the jet potential core, the flow possesses a strong predominance of dissipation over enstrophy and the equilibrium between vortex stretching and vortex compression. In the transition process of the plane jet, the evolution of vortex structure is faster than the evolution of the deformation of fluid elements; meanwhile the local straining is gradually enhanced. After the plane jet attains the fully-developed state, irrotational dissipation with small velocity gradient dominates, however, the vortex tubes

with solid body rotation and small kinetic energy dissipation still exists with the small probability density; in addition, the characteristic teardrop shape of the (R,Q) map also forms, which implies the remarkable sheet structure and vortex stretching; the geometry of the fluid elements with the most frequent occurrence should be a geometry between biaxial stretching and axisymmetric stretching.

In chapter 7, the overall conclusions of the present thesis are presented and some prospects about the future study are also introduced and discussed.