LARGE SCALE STRUCTURES IN SUPERSONIC MIXING LAYERS

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Summary The spatial evolution of large scale structures in supersonic mixing layers with the convective Mach number Mc=0.2 to Mc=0.8 is investigated with a 2d Discontinuous Galerkin code, to look into the function of large scale structures on the growth rate of mixing layers. Special attention is paid on the process of the evolution of large scale structures in mixing layers from up to down streams. It is found that the scale of structures is larger in higher Mc case, and the merge, interaction process of large scale structures in higher Mc case is slower as that of lower Mc case, which is partially answer the decreasing of growth rate of mixing layers with increasing Mc, namely the compressibility.

INTRODUCTION

In mixing layers study, the behavior of the large scale structures and the growth rate are two unfading topics, and it is believed that the structures play an important role in the mixing layer growth rate.

The existence of well organized large scale structures in subsonic mixing layer was first discovered by Brown and Roshko[1], they aimed to investigate the density ratio effect on the growth rate of mixing layer, but the conclusion is that it is the compressibility that affect the mixing layer growth rate a lot. To describe the compressibility effect on compressible mixing layer, Bogdanoff[2] proposed the concept of convective Mach number based on a theoretical analysis and the frame moving along with large scale structures in mixing layer. In 1980s, Papamoschou and Roshko[3] also found well organized large scale structure in the schlieren results of supersonic mixing layer experiment, and they backed up the using of Mc for the compressibility effect description. After that, on the one hand, extensive investigation has been conducted on the compressibility effect on the growth rate of compressible mixing layer. Up to now, it is agreed that as Mc, namely the compressibility effect, increasing, the normalized growth rate of compressible mixing layers decrease and go to a constant about 20% of that of incompressible case as the Mc near unit. However, the physical mechanism back is still not compellent. On the other hand, also lots of work are focused on the behavior of large scale structures in mixing layer, most of them are flow visualization experiments, for the reason numerical simulations for spatially developed mixing layers are too expensive. Frankly speaking, people did obtain fruitful results. But it is a pity that most of them settle for telling a story with the visualization pictures, for the reason too limit information the experiments gave.

In the present study, numerical simulation are used to investigate the spatial evolution of large scale structures. Special attention is paid on the difference of large scale structures behavior at different stream-wise position, and in different Mc case.

NUMERICAL SIMULATION

The conservation form of 2D non-dimensional Navier-stokes equation is solved with a 2D P2 polynomial Discontinuous Galerkin method, the time advance is a 3rd order Runge-Kutta method. No limiter is used for cases Mc < 0.6 and a TVB limiter is used for the rest cases to ensure the stability of DG scheme and high resolution in smooth region, the TVB constant is chosen as $M = 0.2/(\Delta x)^2$ [4].

In the current study, all physical variables are normalized with initial vorticity thickness $\delta_\omega(0)$, density and sound speed of the high speed stream ρ_1, a_1 and $\rho_1 a_1^2$. Initial momentum thickness $\delta_m(0)$ is given as $\delta_m(0) = \delta_\omega(0)/4 = 1/4$. Gas constant is γ=1.4, the Reynolds number $\mathrm{Re} = \Delta u \delta_m(0)/\nu$ is defined with the initial momentum thickness $\delta_m(0)$, speed difference of the two free streams $\Delta u = u_1 - u_2$, and kinetic viscosity ν. To investigate the compressibility effect, we keep Reynolds number *Re=500* and convective velocity $u_c = (u_1 + u_2)/2$ same for all of the four cases.

The calculation domain and grid scale are summarized in table 1.

Table 1 Simulation parameters for the two dimensional spatial mixing layers

Case	Mc	uc	u1	u2	Lx×Ly	Nx×Ny
1	0.2	2.	2.3	1.9	480×15	1600×30
2	0.4	2.	2.5	1.7	480×15	1600×30
3	0.6	2.	2.7	1.5	480×15	1600×30
4	0.8	2.	2.9	1.3	480×15	1600×30

RESULTS

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Fig.1 show us the numerical results of pressure and concentration field for the cases Mc=0.6 and Mc=0.8, from which we can see the spatial evolution of large scale structures clearly. To investigate the scale of the structures, we pick out the velocity fluctuation signals at different streamwise position for cases Mc=0.4-0.8, as shown in Fig.2.

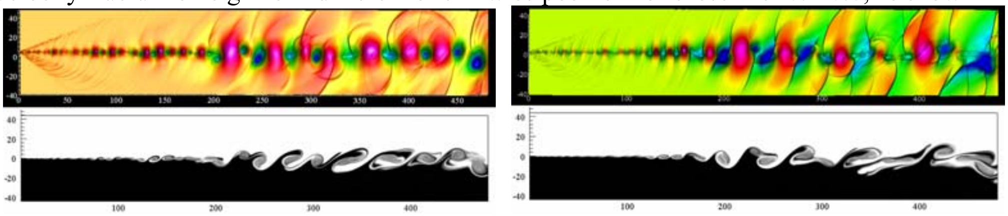

Fig.1 Typical numerical simulation results, pressure and concentration field with Mc=0.6, Left; Mc=0.8, Right.

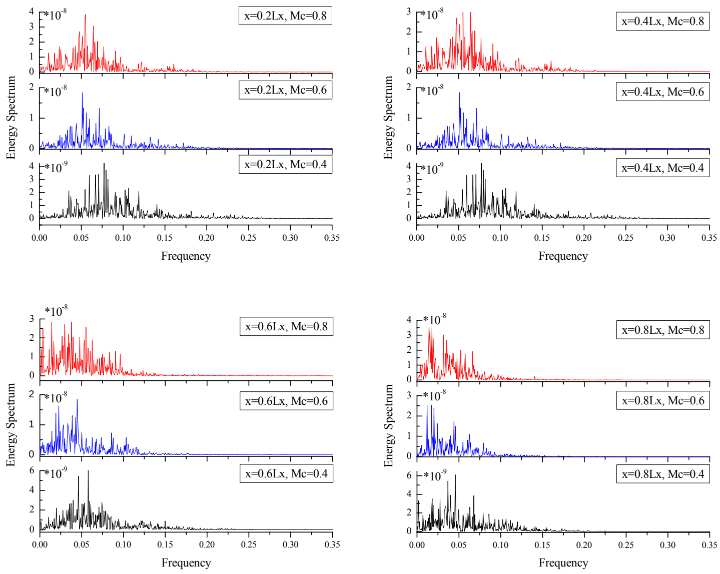

Fig.2 Energy Spectrum of stream-wise velocity fluctuation signals in mixing layers center along stream-wise for case Mc=0.4, 0.6 and 0.8

DISCUSSION

From Fig.1 we can see that vortex merging and interaction process are common in both cases, and as compressibility effect increasing, eddy shock can be seen in the case Mc=0.8. It is also found that the higher the Mc, the larger the scale of the structures. From Fig.2, we can see that from up to down streamwise direction, the frequency of velocity fluctuation deceasing, for the reason vortex merging happen. At a same streamwise position, the frequency of higher Mc case is less than that of lower Mc case, which means that as Mc increasing, the field choose a lower frequency perturbation and amplified from the most unstable frequency in incompressible case, which partly answer that the decreasing of growth rate as Mc increasing.

CONCLUSIONS

The spatial evolution of supersonic mixing layers is investigated with a 2D DG numerical simulation, with the results, vortex merging and interaction process can be observed, as Mc larger than Mc=0.6, eddy shock can be seen. From the results of concentration field and energy spectrum of velocity fluctuation, it is found that as Mc increasing, the scale of the structures become larger, and the field choose a lower frequency perturbation, which partly answer that the decreasing of growth rate as Mc increasing. Confirm the current results in deep with a linear stability analysis for compressible spatial evolution mixing layer will be the next step work.

References

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