DNS STUDY OF SUPersonic MIXING LAYERS

A. Kourta and R. Sauvage

IMFT, Av. du Prof. Camille Soula, F-31400 Toulouse, France

kourta@imft.fr, rsauvage@cr2a-di.fr

Abstract  Direct numerical simulation is used to investigate three-dimensional temporal supersonic mixing layers at two convective Mach numbers 1.2 and 1.6. At Mach number of 1.2, the compressibility effects, characterized by the shear layer growth rate reduction, are more pronounced than at high subsonic convective Mach numbers. In this case, the structure of flow becomes three-dimensional, and $A$ structures are clearly observed which accelerate the occurrence of turbulence. For the $M_c = 1.2$ case, the absence of symmetry leads to a strong interaction between a $A$ structures. At $M_c = 1.6$, the use of a computational box the size of one fundamental wavelength maintains the symmetry of the flow. The $A$ structures, strongly inclined, are distorted by the shear layer and split into two symmetrical parts. Finally, shocklets occur in the flow for both convective Mach numbers. These viscous shocks are developed in three-dimensions and are stronger for the 1.6 case. In this paper transition mechanisms are analyzed and the existence of shocklets and their influences are studied.

Keywords: DNS, compressibility effects, shear layer, Unsteady, shocklet

1. Introduction

An important compressibility effect is the reduction of the mixing layer growth rate (Papamoschou & Roshko(1988); Papamoschou(1989); Elliott & Samimy(1990); Vreman et al(1996); Pantano & Sarkar(1999)). Nowadays, this effect is not completely explained. Another effect consists in the changes in typical eddy structures which become strongly 3D for convective Mach number equal or higher than 0.6 (Clemens & Mungal(1992)). The roll-up and the pairing mechanisms exhibit similar features to the incompressible case if the Mach number is low whereas the scenario is quite different at higher Mach numbers ($M_c > 0.6$).

It is also evidenced that the turbulence structure changes as the Mach number increases. The low Mach number organized structure is lost as
the compressibility effect becomes important. Clemens & Mungal (1995) revealed changes in turbulence statistics. Turbulence fluctuations and Reynolds stresses decrease as the Mach number is increased. It is well known that an increasing Mach number has a stabilizing effect. The amplification of the fluctuations is reduced, which is consistent with reduced mixing and a smaller spreading rate.

At supersonic Mach numbers, the local shocklets are generated by vortices and increase the compressibility effects (Papamoschou (1995) and Dimotakis (1991)). Vreman et al (1995) have found shocks for a convective Mach number equal to 1.2 in a confined case. Freund et al (2000) observed shocklets in a turbulent annular mixing layer ($M_c = 1.54, 1.80$).

In the present paper, 3D supersonic temporal mixing layer is investigated at convective Mach numbers of 1.2 and 1.6. The goal is to analyze different steps of transition and to characterize the effects of 3D features and of shocklets on the flow behaviour.

2. Numerical methodology

The full Navier-Stokes equations have been solved by a finite volume version of MacCormack explicit scheme (Kourta (1996a); Kourta (1996b)). Non-reflecting characteristic boundary conditions (Poinsot & Lele (1992)) are imposed at the normal boundaries (y). Streamwise (x) and spanwise (z) boundary conditions are treated as periodic. The temporally evolving shear layer simulations are initialized with an hyperbolic tangent mean streamwise velocity profile and zero mean transverse and spanwise velocities. The temperature profile follows the Busemann-Crocco law assuming equality of the mean temperature in the two streams. All thermodynamic properties are initialized to uniform values. The mesh size used are $385 \times 257 \times 193$ for the $M_c = 1.2$ case and $253 \times 513 \times 193$ for the 1.6 one. Two fundamental wavelengths are used as length of the computational box for the 1.2 case and only one for the 1.6 (Sauvage (2000)). Such small boxes may influence the flow.

3. Computational results

In comparison with a subsonic Mach number, for the 1.2 and the 1.6 cases, no pairing of mixing layer structures occurs. As was observed for $M_c = 0.8$ (Sauvage (2000)), a transition for $M_c = 1.2$ is dominated by 3D $\Lambda$ vortices. The flow presents the same mechanisms. The trellis topology coming from the initial forcing mode is more stretched as can be seen in figure (1). In this figure the view from the top of the iso-low-pressure is presented at different times. The difference between lozenges is more explicit here. The asymmetry of shapes contributes to create