11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
July 20 - 25, 2014, Barcelona, Spain

Numerical Investigation of Turbulence Drag Reduction with Streamwise Riblets in High-Speed Channel Flow

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Key Words: *Turbulence, streamwise riblets, high-speed flow, drag reduction*

High-speed (supersonic and hypersonic) turbulence drag reduction with streamwise riblets is studied by using direct numerical simulation (DNS). The numerical model is a fully developed turbulent channel flow with riblet wall in one-side, and the mean Mach number (based on the mean velocity and sound speed at the wall temperature) is 3 and 6. The mesh that contains about 138 millions of grid points to resolve all essential turbulence scales and the independence of the mesh resolution is tested. The DNS results of Mach 6 show that drag reduction of approximately 10% is achieved for riblets with the height is 20 wall units and the spacing is 125 wall units.

1 Introduction

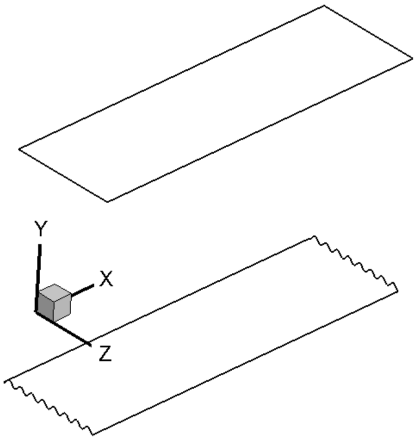
Drag reduction of turbulent flow is a hot topic in the study of turbulence for its potential applications in engineering. Thereafter, there are many theoretical, experiential and numerical studies on the drag reduction by using riblets. Choi et al.[1] performed direct numerical simulations of turbulent flows over riblet surfaces to study the mechanism of drag reduction by riblets. However, most reported studies on drag reduction are for incompressible or low-speed flows, and studies for high-speed (supersonic or hypersonic) flows are very few. The study of turbulent drag and heat reduction for high-speed flow is also needed for its potential applications in supersonic/hypersonic vehicles. In this paper, we conduct investigation of drag reduction of the streamwise riblets for supersonic/hypersonic channel flows, and the numerical results show that the riblets can reduce the drag significantly.

2 DNS and numerical results

We perform the DNS fully developed turbulent flow in a channel with one-side streamwise riblet wall, and the mean Mach number is 3 and 6. A schematic of the wall with streamwise riblets is shown in figure 1. The surface is defined as

$$h(x,z) = h_w \cos(2\pi z / \lambda_w)$$

Where h_w is the height of streamwise riblets, λ_w is the spanwise space of streamwise riblets. In this DNS, the compressible Navier-Stokes equations are solved numerically by using the 7th-order upwind scheme for convection terms together with a eighth-order accurate central different for the viscous terms. A three-step TVD type Runge-Kutta method is used for time march.



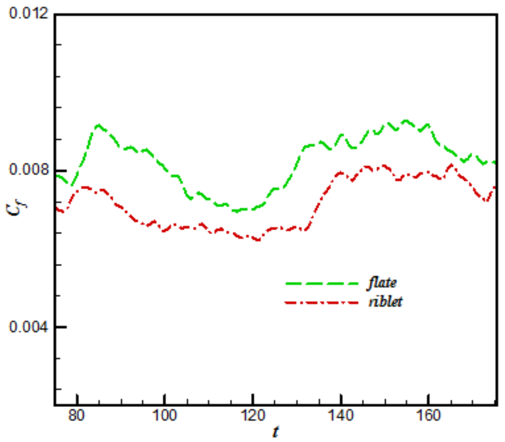


Fig. 1: Schematic of the computational domain   Fig. 2: Time history of skin-friction coefficient

Table 1: Simulation parameters for the direct numerical simulations of turbulent channel flows over riblets. In the last column denote the drag reduction for each riblet configuration.

Case	*Mach*	*Re*	$Lx \times Ly \times Lz$	$Nx \times Ny \times Nz$	h_w^+	λ^+	*DR*
M3-1	3	8000	Pi*2*1.25	128*161*320	20	100	7.12%
M6-1	6	8000	Pi*2*1.25	128*161*640	34	169	7.2%
M6-2	6	8000	Pi*2*1.25	128*161*320	20	125	10.3%

Table 1 shows the simulation parameters for the direct numerical simulations of turbulent channel flows over riblets. The last column shows the drag increase or decrease for each riblet configuration studied. Fig. 2 shows the time history of the spatial mean skin-friction coefficient of Mach 6 case with $h_w^+ = 20$, $\lambda_w^+ = 125$, and this figure shows approximately 10% drag reduction of the riblet wall.

REFERENCES

[1] Choi, Moin, Kim, Direct numerical simulation of turbulent flow over riblets. *J.Fluid Mech* 255, 503-539, 1992 .

[2] Lian Duan, Effects of riblets on Skin Friction and Heat Transfer in High-speed Turbulent Boundary Layers . *AIAA* 2012-1108..