Oral presentation | Turbulence simulation (DNS,LES,RANS)

Turbulence simulation(DNS,LES,RANS)-IV

Thu. Jul 18, 2024 2:00 PM - 4:00 PM Room B

[11-B-01] DNS of hypersonic shockwave/turbulent boundary layer interactions: Wall temperature effects

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DNS of hypersonic shockwave/turbulent boundary layer interactions: Wall temperature effects

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Direct numerical simulation (DNS) of hypersonic shock wave/turbulent boundary layer interactions in a 34-degree compression ramp is conducted by using high-order GPU heterogeneous parallel code OpenCFD-SCU developed by the authors[1]. The free-stream Mach number is 6 and the wall-to-recovery-temperature ratio (Tw/Tr) are 0.5, 0.75 and 1.0, respectively. Each case runs on two different grids (see table 1), and the results show good grid convergence.

The numerical results show that the size of the separation bubble increases significantly as the wall temperature rises, and this is because that as the increasing of wall temperature, the decrease of near-wall density leads to the decrease of momentum of near-wall fluids. An equation based on the 0.85-power-law[2] and the free-interaction theory, $\mathrm{p_{w2}}\left(\frac{\mathrm{x}}{\delta_2}\right) = \mathrm{p_{w1}}\left(\frac{\mathrm{x}}{\delta_2}\left(\frac{\mathrm{T_{w1}}}{\mathrm{T_{w2}}}\right)^{0.85}\right)$, is proposed to predict the distributions of the wall pressure at different wall temperatures. The prediction results are generally consistent with the simulations. In addition, the low-frequency unsteadiness is studied through the weighted power spectral density of the wall pressure. The results indicate that the wall-cooling can significantly suppress the low-frequency unsteadiness, including the strength and streamwise range of the low-frequency motions. In addition, the low-frequency unsteadiness is studied through the weighted power spectral density of the wall pressure. The results indicate that the wall-cooling can significantly suppress the low-frequency unsteadiness, including the strength and streamwise range of the low-frequency motions.

Figure 1 shows the instantaneous temperature of the corner region with different wall temperatures, and it shows that the separation bubble increases significantly as rising of the wall temperature. Fig. 2 shows the wall pressures, and it shows that the value of prediction equation agrees well with the DNS data.

Table 1 Mesh number and resolution.

Case	$(L_{x1}, L_{x2}, L_{x3}), L_y, L_z$ / mm	Mesh ($N_x \times N_y \times N_z$)	$\Delta x^+, \Delta y^+, \Delta z^+$
$T_w / T_r = 0.50$	(290.0, 60.0, 49.7), 55.0, 13.5	Mesh 1-1 (4050 × 300 × 225)	4.92, 0.48, 4.80
		Mesh 1-2 (4700 × 400 × 300)	3.69, 0.36, 3.60
$T_w / T_r = 0.75$	(325.0, 75.0, 62.2), 55.0, 30.0	Mesh 2-1 (3100 × 300 × 300)	4.66, 0.47, 4.66
		Mesh 2-2 (3600 × 400 × 400)	3.49, 0.35, 3.49
$T_w / T_r = 1.0$	(325.0, 75.0, 62.2), 55.0, 32.0	Mesh 3-1 (2680 × 220 × 230)	4.68, 0.46, 4.69
		Mesh 3-2 (3040 × 290 × 310)	3.51, 0.35, 3.48

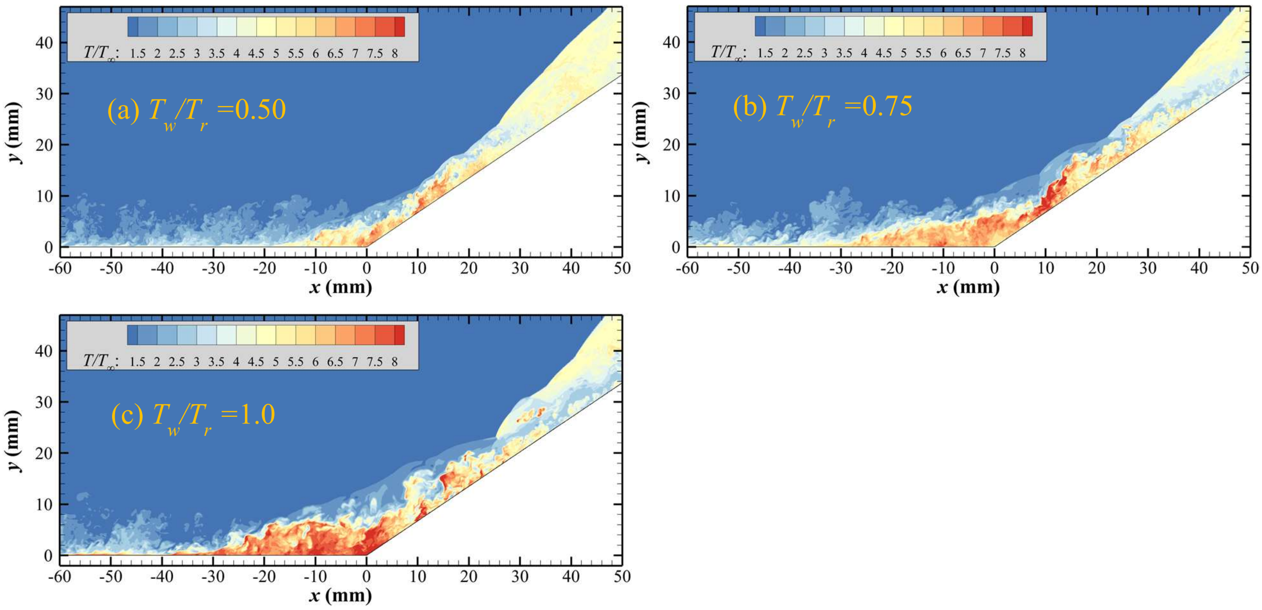

Fig. 1 Instantaneous contour of temperature in the corner region.
(a) Tw/Tr =0.50, (b) Tw/Tr =0.75, (c) Tw/Tr =1.0

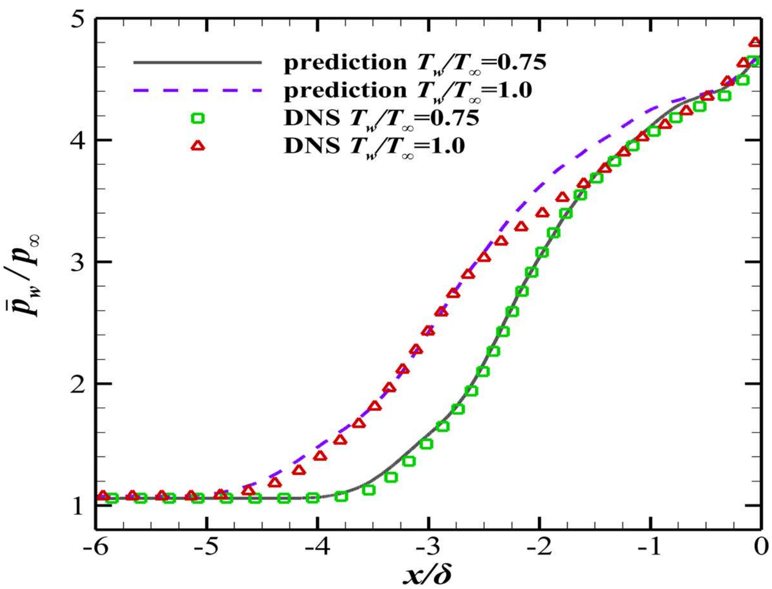

Fig. 2 Plot of wall pressure. Symbols: DNS, lines: prediction of $p_{w2}\left(\frac{x}{\delta_2}\right) = p_{w1}\left(\frac{x}{\delta_2}\left(\frac{T_{w1}}{T_{w2}}\right)^{0.85}\right)$.

References

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[2] Zhu XK, Yu CP, Tong FL, Li XL. "Numerical Study on Wall Temperature Effects on Shock Wave/Turbulent Boundary-Layer Interaction". AIAA J. 55(1):131–40, 2017.