Large-Eddy Simulation of a Three-Dimensional Shock-Wave/Turbulent Boundary Layer Interaction of a Single-Fin

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Abstract

The three-dimension (3D) shock-wave/turbulent boundary layer interaction (SWTBLI) raised from a hypersonic flow passing a single-fin at Mach 5 is investigated i by using LES. The performed LES has demonstrated very good agreements with available experimental data[1] in terms of the mean flowfield structure, the surface pressure and as well as the surface flow pattern (as shown in Fig 1 left). However, significant under-prediction in the surface skin-friction peak in the vicinity of the reattachment line is observed (as shown in Fig 1 right).

As present in Fig 2, the λ-shock system is formed in the 3D SWTBLI and the shock waves are unsteady in nature. The wrinkling of the front shock surface can be seen, and the scale of wrinkles increases with the distance to the wall, which is caused by the interaction with turbulence structures in the incoming flow. By analyzing the mean skin-friction-line in Fig. 3 (left), the flow is separated at the foot of the separation shock and reattached near the corner region. The secondary flow separation and reattachment lines can also be identified, which is consistent with the characteristic regime suggested by Zheltovodov et al.[2]. The streamlines are lifted-off at the separation line and fell-back near the fin's surface (as shown in Fig. 3 right), which transport the fluid with high energy to the near-wall region.

The flow field of the 3D single-fin can be categorized into five zones according to the characteristics of turbulent flow structures, as present in Fig. 4. Zone 1 is the undisturbed wall turbulence in the upstream boundary layer. Zone 2 is the separated free shear layer, which contains some large-scale structures with high fluctuant energy. Zone 3 is near the slip line, which is also the edge of the jet. The turbulence in this zone is also dominated by the free shear but the flow is still in the process of transition. Zone 4 is the reverse flow, which also characterized by the wall-turbulence, but only restrained in a thin layer attached to the wall. Zone 5 is the low-turbulence zone, which includes the core of the jet and the gap between the zone 2 and zone 4. The analysis of turbulent flow field supports the experimental observation that the near-wall reverse flow beneath the main separation vortex is fully turbulent and the secondary separation is essentially a turbulent separation. The transition to turbulence in the reverse flow happens in a short distance from the impinging location of the jet flow at R1, mainly due to the strong kinetic energy of contained in the jet flow.

References

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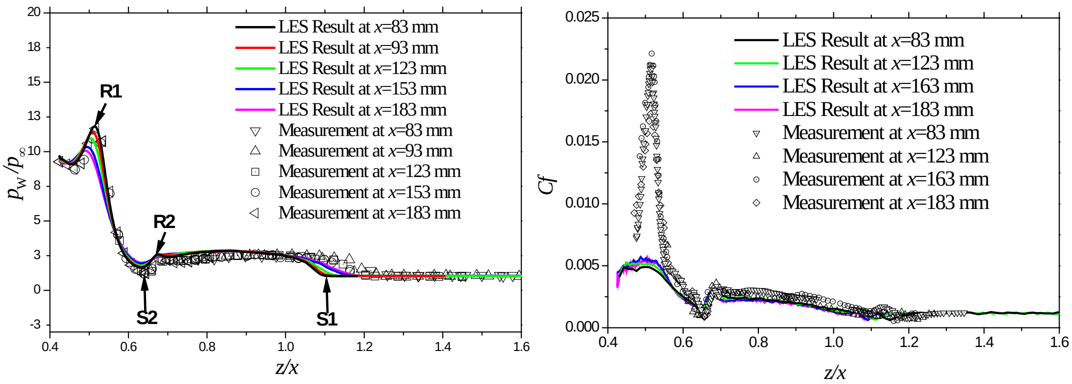

Fig. 1. Comparisons of of wall pressure (left) and skin friction coefficient (right) at several *x*-slices

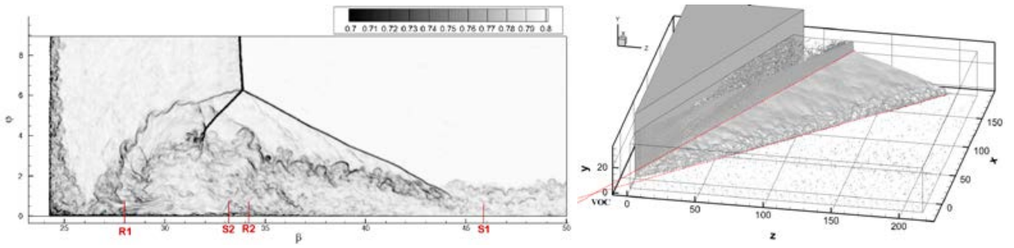

Fig. 2. Instantaneous numerical Schlieren on the 3-D spherical arc section (left) and shock surface (Right).

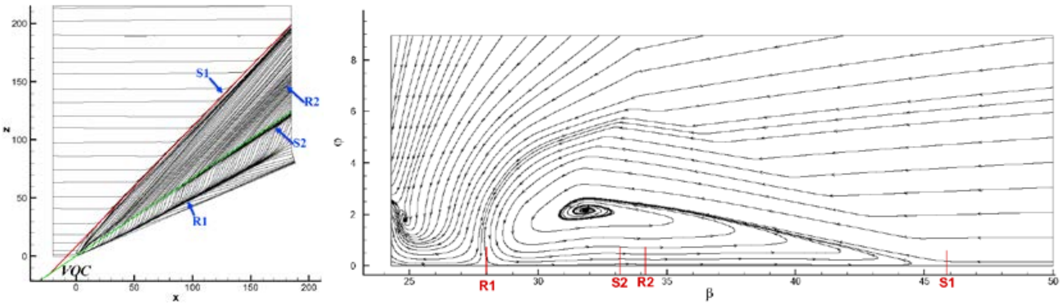

Fig. 3. mean skin-friction-line at the bottom wall (left) and mean streamlines on the 3-D spherical arc section.

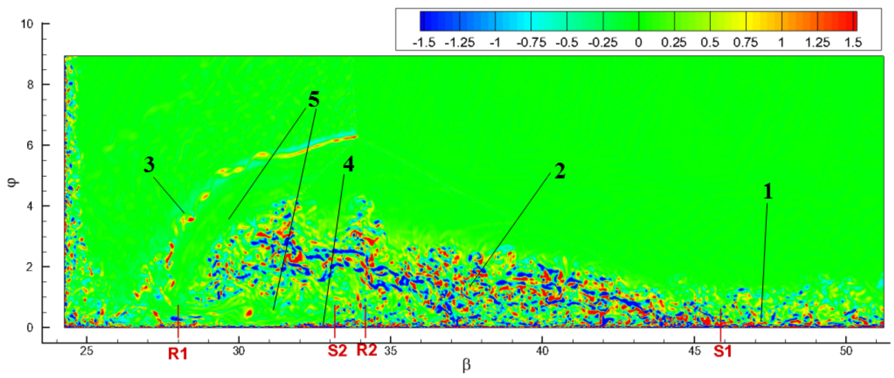

Fig. 4. T Instantaneous streamwise vorticity fluctuation on the 3-D spherical arc section