Abstract

In this thesis, DNS and LES have been used to study compressible flow in planar nozzles without shocks and also flow in a channel with shocks.

Large-eddy simulations of supersonic, turbulent flow in asymmetric and symmetric planar nozzles are carried out using high-order compact finite difference schemes and an LES-approach based on explicit filtering. The inflow to the nozzles are from supersonic, fully developed turbulent channel flows at $Re_\tau = 180$ and 360 with centerline Mach number 1.2. The combined effects of expansion and acceleration of the flow in this geometry result in reductions of mean pressure, density and temperature as well as a reduction of Reynolds stresses. The asymmetry of the nozzle leads to notable differences in the abovementioned effects near the straight and the curved walls. It is shown that the decay in Reynolds stresses is more near the curved wall than near the straight wall of the asymmetric nozzle and it is nearly the same near both walls of the symmetric nozzle. Effects of longitudinal streamline curvature are found to be localised near the curved wall of the asymmetric nozzle and are quantified. The abovementioned effects of acceleration, expansion and streamline curvature are found to be similar in the flow cases with two different Reynolds numbers, although with increasing Reynolds number subtle differences in these effects are found.

Direct numerical simulations of supersonic, turbulent flow in asymmetric and symmetric planar nozzles with incoming Mach number around 1.45 and friction Reynolds number 245 are carried out using high order compact finite difference schemes. The asymmetric and symmetric planar nozzles with the same area ratio, and symmetric planar nozzles with different area ratios are compared. Also, a comparison of the symmetric planar nozzle with the axisymmetric (circular cross-section) nozzle results existing in the literature with the same area ratio for incoming Mach number around 1.5 and friction Reynolds number 245 is done.

High-order bandwidth-optimized Weighted Essentially Non-Oscillatory (WENO) schemes with limiters are applied in this thesis to a wide variety

of problems including DNS of shock train in a channel flow with isothermal walls. A comparison of the performance of these schemes with 3-point and 4-point stencils is shown for one-dimensional and two-dimensional test problems. For the one-dimensional and two-dimensional test cases, these schemes show their advantage over the standard 5^{th}-order and 7^{th}-order WENO schemes proposed in the literature in capturing the small-scale structures appearing in these flows. Effects of the limiter threshold values are discussed for the bandwidth-optimized WENO schemes. Further, the bandwidth-optimized WENO schemes with limiters are compared with other variants of the WENO scheme found in the literature. Direct numerical simulation (DNS) of supersonic channel flow is also performed with the bandwidth-optimized WENO scheme (with 3-point stencil) with limiter, and the results are found to be in good agreement with the literature. This scheme is then used for performing DNS of shock train in a turbulent channel flow. LES results using 6th order compact central scheme along with explicit filtering based ADM approach is compared with the results of DNS using WENO3P-LIM-5 scheme for shock-turbulence interaction in channel flow with isothermal walls.