Abstract

Large eddy simulation (LES) of high-speed compressible flows over various geometries has been of great interest among researchers for the past few years. In this thesis, a high-order accurate finite-difference based three-dimensional Navier-Stokes equations solver has been developed to perform large eddy simulations over a number of geometries. The numerical technique is first validated with various 1D and 2D test case problems and further validation of the 3D code is carried out by performing large eddy simulation of the shock wave-boundary layer interaction (SWBLI) problem wherein a shock generated from a 6^o wedge in a free stream Mach number of $M_\infty = 2.0$ impinges at an angle of 35.36^o on a laminar boundary layer over a flat plate. Simulated streamwise mean pressure and skin friction distributions on the mid plane of the flat plate as well as velocity profiles at several stations are validated against experimental data.

The solver is further used to perform large eddy simulation of supersonic intakes. Two different intake geometries are simulated at different design Mach numbers, namely 2.2 and 3.0. Both intakes are simulated with bleed holes at open and closed conditions. The computed mean pressure distribution in the two intakes match quite well with the corresponding measurements. With the bleed holes closed intake 1 operates in started condition but with considerable amount of total pressure loss due to the shock-induced turbulent separated bubble at the throat. The hairpin vortices in the turbulent flow are well resolved. With bleed holes opened the flow is completely controlled and the separation bubble is eliminated. When the bleed holes are closed intake 2 can not start as the separation bubble on the vehicle side surface slowly moves upstream and grows in size simultaneously to block the mass flow completely. When the bleed holes are opened, the intake operates in start condition with an oblique shock at the throat and with very small total pressure loss at the diffuser exit.

Large eddy simulation of the supersonic flow at $M_\infty = 1.35$ and $Re_D = 3,103,553$ over a three-dimensional cavity with $L/D = 5$ and $W/D = 1$ is performed and analysis is carried out on the generated flow field database. The cavity is observed to experience violent shear layer oscillations with associated forward and backward oscillation of the acoustic waves and compression waves inside the cavity raising the peak sound pressure level (SPL) up to 176 dB near the aft wall of the cavity. Investigation carried out on one typical feedback cycle of oscillation inside the cavity shows the feedback compression wave reflected from the front wall of the cavity not only adds perturbations to the shear layer at the leading edge but also couples with a K-H roll-up vortex at the time of interaction with front wall and travels along with the vortex over the cavity length. This observation is further consolidated from one of the five dominant modes of pressure extracted using the dynamic mode decomposition (DMD) algorithm. The oscillation of the compression waves inside the cavity is seen to influence the stretching of the streamwise elongated vortex filaments which are visualized using the second invariant of the velocity gradient tensor. Investigation on the helicity of these stretched vortices shows that the vortices are aligned with the velocity either in the opposite or in the same sense corresponding to the direction of movement of the pressure wave and thus confirms the possibility of existence of vortices with helical behavior in an open cavity flow.

Keywords: WENO, LES, mixed time scale, SWBLI, intakes, cavity