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论文

超声速平板边界层斜波失稳转捩过程研究

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摘要 以5阶迎风和6阶对称紧致格式混合差分求解三维可压缩滤波Navier-Stokes方程，对Mach 数为4.5, Reynolds数为10000的空间发展平板边界层湍流进行了大涡模拟. 时间推进采用紧致存储3阶Runge-Kutta方法，亚格子尺度模型为修正Smagorinsky涡黏性模型. 通过在入口边界叠加一对线性最不稳定第一模态斜波扰动，数值模拟得到了平板层流边界层失稳转捩直至湍流的演化过程. 对流场转捩过程中瞬时量及统计平均量的分析表明，数值模拟结果与理论吻合，得到的Y型剪切层、交替\Lambda涡结构以及转捩后期的发卡涡结构的发展变化与相关文献结果一致，湍流流谱定性合理.

关键词 转捩 湍流 超声速边界层 大涡模拟

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The study of flow transition process induced by oblique wave instability in a supersonic flat-plate boundary layer

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Abstract

The spatial large eddy simulations of the transition process and the full turbulence in a supersonic flat-plate boundary layer at a free-stream Mach number M_\infty = 4.5 and a Reynolds number Re = 10000 are carried out by solving the three-dimensional compressible Favre-filtered Navier-Stokes equations with a hybrid method of a fifth-order upwind compact difference and a sixth-order symmetric compact difference. The compact storage third-order explicit Runge-Kutta method is applied for the time-integration. The sub-grid scales are formulated according to the modified Smagorinsky eddy-viscosity model. Based on the linear stability theory, a pair of the most unstable oblique first mode disturbances is imposed on the inflow boundary and the evolution of flow from laminar, transition to full turbulence, is simulated successfully. The instant and statistical parameters are obtained, and numerical results show a good agreement with the relevant flat-plate boundary layer theory. Especially the linear and weakly nonlinear growth of disturbance, the appearance of staggered $\Lambda $-vortex pattern, and the evolution of $\Lambda $-vortex into hairpin vortex are consistent with related findings in literature.

Key words transition turbulence supersonic boundary layer large eddy simulation

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