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平板边界层中展向波包型扰动引起的转捩

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Transition Induced by Spanwise Wave Packet Disturbance in a Flat Plate Boundary Layer

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摘要 过去在平板边界层转捩及湍流的研究中,主要考虑的扰动在展向是均匀分布的,这样有利于研究,但在实际问题中扰动形式是多样的,边界层可能是三维的,扰动在展向是不均匀的。对于以往研究的扰动来说,三维平板边界层中的展向非均匀扰动是比较复杂的扰动形式,更接近自然转捩,因此研究这种扰动引起的转捩和湍流具有重要的实际意义。基于此,针对平板边界层,控制方程为无量纲化的Navier-Stokes扰动方程,时间上采用三阶精度的差分格式,空间上展向采用伪谱方法,流向和法向采用高阶精度差分格式,应用数值模拟的方法研究了小振幅值和有限振幅值展向波包两种情况。通过数值模拟和线性稳定性理论分析小振幅波包的演化,得到了小振幅波包的演化符合线性稳定性理论(LST);分析了有限振幅值的展向波包型扰动引起的转捩和湍流,描述了物理空间和谱空间中波包型扰动的演化特征;同时针对不同展向位置进行分析,结果表明不同展向位置的转捩位置不同,但转捩过程和特征是类似的。

关键词: 边界层 波包 转捩 湍流 数值模拟

Abstract: In previous research, the main consideration for disturbance distribution in the transition and turbulence of a flat plate boundary layer is uniform along the spanwise direction, which is relatively easy to study. But in actual situation, the disturbance form is diverse. The boundary layer may be three-dimensional and the disturbance distribution may not be uniform along the spanwise direction. Compared with the disturbance form studied before, the non-uniform disturbance distribution along the spanwise direction in a three-dimensional flat plate boundary layer is a more complex disturbance form and it is closer to natural transition. Therefore, it is of important significance to study the transition and turbulence caused by this disturbance form. For the flat plate boundary layers, the governing equations are the non-dimensional Navier-Stokes perturbation equations. The difference scheme of three order precision is used for time discrete. For the space discrete, the pseudo-spectrum is used in spanwise direction and the high precision difference schemes are employed in streamwise and normal directions. Numerical simulation is performed to study two cases of small amplitude spanwise wave packet disturbance and finite amplitude spanwise wave packet disturbance. The evolution of small amplitude wave packets disturbance is calculated by the numerical simulation and the linear stability theory (LST). The evolution results are in close agreement with the linear stability theory results. The transition and turbulence processes caused by finite amplitude spanwise wave packets disturbance are analyzed. The evolution characteristics in physics and spectrum space are detailed described. The different positions are compared and the results are that for the different positions, the transition positions are different, but the transition processes and characteristics are similar.

Keywords: boundary layer wave packet transition turbulence numerical simulation

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