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基于PSE的单股剪切混合流稳定性分析

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Stability Analysis of Single-stream Shear Mixing Layer Based on Parabolized Stability Equations

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摘要 将抛物化稳定性方程(PSE)方法应用到可压缩单股剪切混合流的稳定性研究中。采用并发展了适用于自由剪切流的高精度数值方法,包括六阶紧致格式、坐标变换以及渐近边界条件等,对PSE进行有效求解。通过求解相似边界层方程得到更准确的剪切层内基本流;求解线性稳定性理论(LST)控制方程得到扰动的初始条件,并通过流向空间推进方法对扰动的空间不稳定性进行求解。计算并分析了在不同马赫数和温度比情况下,不同频率、波数等参数的扰动波线性发展过程。计算结果表明:在弱压缩性情况下,二维扰动最不稳定,随着压缩性增强三维扰动变得比二维扰动更不稳定,对流动不稳定性起主导作用;在流动的上游,温度比的增加对流动起稳定作用,而在下游,温度比的增加起不稳定作用;当频率增加或波角增大时,扰动的流向不稳定区减小;PSE方法是单股剪切混合流稳定性快速有效的分析方法。

关键词: 单股剪切混合流 可压缩 线性稳定性理论 抛物化稳定性方程 紧致格式

Abstract: A study of the stability of the compressible single-stream shear mixing layers is performed by using parabolized stability equations (PSE). Associated high accuracy numerical methods are adopted and developed for the free shear layer to solve the parabolized stability equations effectively, including a sixth order compact scheme, algebraic transformation, gradual boundary conditions, etc. Similar boundary layer equations are solved to obtain more accurate basic flow in the shear layers; initial conditions of disturbances are achieved by solving equations of linear stability theory (LST); the spatial stability of disturbances are resolved through streamwise marching methods. The linear evolutions of disturbances with different frequencies and wave numbers at different Mach numbers and temperature ratios are computed and analyzed. The results demonstrate that, 2D disturbances are most unstable under weak compressibility conditions; 3D disturbances become more unstable than 2D ones with the increase of compressibility and dominate the flow instability; temperature ratio has a stabilizing effect at the upstream area, but destabilizing effect downstream; the streamwise instable area becomes smaller when the frequency becomes higher or when the wave angle becomes larger. The study proves that the PSE methods are effective for the stability analysis of single-stream shear mixing layers.

Keywords: single-stream shear mixing layer compressibility linear stability theory parabolized stability equation compact scheme

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