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基于时间谱方法的振荡翼型和机翼非定常黏性绕流数值模拟

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Time Spectral Method for Numerical Simulation of Unsteady Viscous Flow over Oscillating Airfoil and Wing

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摘要

传统的双时间方法在非定常计算中长时间的过渡迭代推进求解导致其计算效率相对较低,针对周期性非定常流动问题的流动特征,发展了一种基于离散傅里叶变换的高效时间谱方法,用于求解振荡翼型和机翼的非定常黏性绕流。在时空耦合的雷诺平均Navier-Stokes(RANS)方程的求解中,对流项的离散应用了Roe的通量差分格式,物理时间项的离散方法为时间谱方法,伪时间推进采用了隐式LU-SGS(Lower-Upper Symmetric Gauss-Seidel)格式。考虑到湍流的时空耦合效应,时空耦合的Spalart-Allmaras一方程湍流模型的物理时间项同样采用时间谱方法进行离散。为了进一步提高计算效率,当地时间步长和多重网格技术等加速收敛的措施均被采用。算例对俯仰振荡NACA0012翼型和Lann机翼的周期性非定常流场进行了数值计算。结果表明:对于周期性非定常流场的数值模拟,相比于传统的双时间方法,用时间谱方法近似物理时间项,不仅能够提高流场的计算精度,而且更能够大幅度提高计算效率。

关键词: 周期性非定常流动 时间谱方法 双时间方法 俯仰振荡翼型/机翼 多重网格 数值模拟

Abstract:

The traditional dual time stepping formula is comparatively inefficient in solving unsteady problems due to its repeated transitional iteration stepping. In view of the characteristics of periodical unsteady flow, a high efficiency time spectral method based on discrete fourier transformation is hereby developed for such type of flow over an oscillating airfoil and wing. Roe's flux difference splitter scheme is utilized to discretize the convective terms of the time-space coupled Reynolds-averaged Navier-Stokes (RANS) equations. Time spectral method is used to treat the physical time derivative terms while the implicit LU-SGS (Lower-Upper Symmetric Gauss-Seidel) scheme deals with pseudo time stepping. Meanwhile, the physi-cal time terms of Spalart-Allmaras's one equation turbulence model, which acts as our turbulence model, is also discretized by the time spectral method in consideration of the turbulence's time-space coupling effect. In order to further improve efficiency, methods like local time step and multigrid algorithm are used to accelerate the convergence of RANS equation's solution. In the numerical examples section, the periodical unsteady flow field over an oscillating NACA0012 airfoil and Lann wing is simulated numerically. Results show that the time spectral method possesses obvious advantages in reducing computational cost and improving calculation accuracy as compared with the conventional dual time stepping formula.

Keywords: time-periodic unsteady flow time spectral method dual time stepping method oscillating airfoil/wing multigrid numerical simulation

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