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趋于临界马赫数的圆柱跨声速绕流特性分析

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Characteristics Analysis of the Transonic Flow past a Circular Cylinder Towards the Critical Mach Number

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摘要 通过深化认识趋于临界马赫数Ma_{cr}的圆柱跨声速绕流特性,明确新型飞行器增升减阻设计的空气动力学理论依据。采用大涡模拟方法数值研究了来流马赫数Ma_∞为0.75和0.85、雷诺数Re为2×10^5的圆柱跨声速绕流。结果表明:当Ma_∞趋于临界马赫数($Ma_{cr}\approx0.9$)时,圆柱的阻力下降且升力系数振荡被抑制;通过力的分解,得知圆柱的阻力减小来自旋涡力的影响,而非可压缩性;圆柱的阻力减小与其背压上升有关;剪切层初始阶段的对流马赫数Ma_c随Ma_∞的增加而增大,而增长率相反,这使得剪切层更为稳定、柱体背压更高。此外,由于$Ma_\infty=0.85$时边界层分离点处的激波和尾迹处的激波向下游推移,使得近尾迹处的湍流脉动减弱,进而导致柱体的表面压力振荡和升力系数振荡被抑制。

关键词: 激波 圆柱 可压缩湍流 大涡模拟 亚格子模型

Abstract: Detailed knowledge about flow characteristics of the transonic flow past a circular cylinder towards the critical Mach number Ma_{cr} can provide an aerodynamics theory basis for increased lift and drag reduction of the new aircraft. Numerical investigation of the transonic flow past a circular cylinder is carried out by means of an large eddy simulation technique for two free-stream Mach numbers Ma_∞=0.75and 0.85, and Reynolds number based on the cylinder diameter $Re=2\times10^5$. Results show that towards the critical Mach number ($Ma_{cr}\approx0.9$), drag of the cylinder is reduced and lift coefficient fluctuation is suppressed. Based on the force decomposition, it is found that the drag reduction is attributed to the vortex force rather than the compressing process. Usually, drag reduction of a bluff body is closely associated with the higher base pressure distribution. Analysis of the convective Mach number Ma_c indicates that Ma_c in the initial stage of the shear layers increases with Ma_∞, while its growth rate decreases, which results in a more stable shear layer and higher pressure distribution. Furthermore, less turbulent fluctuation in the near wake of the circular cylinder at Ma_∞=0.85 corresponds to the eliminated shock wave at the separation point and delayed shock wave in the near wake. Finally, the wall pressure fluctuation and fluctuating lift coefficient are suppressed.

Keywords: shock waves circular cylinder compressible turbulence large eddy simulation subgrid-scale model

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