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翼型失速的非线性动力学特性及其控制

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Nonlinear Dynamics of Static Stall of Airfoil and Its Control

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摘要 以NACA0012翼型为研究对象,应用CBS(Characteristic-Based Split)有限元方法对翼型绕流流场进行数值模拟,着重对翼型失速现象的动力学机理和特征进行研究。首先给出了静止翼型在不同迎角下流场的瞬时流线图以及静态翼型的迎角-升力系数关系曲线,并且分析出此曲线具有滞后、突跳等典型的非线性动力学特性。其次,基于映射的不动点分岔理论,通过构造映射,发现和证明了静态失速是一种鞍-结分岔现象。进一步,由于鞍-结分岔对外部激励的敏感性,因此对在失速迎角附近翼型做俯仰运动(一类外部激励)的动态失速现象亦进行了研究,通过ALE(Arbitrary Lagrangian-Euler)方法处理了翼型俯仰运动中涉及到的动网格问题并求解流场。数值模拟结果表明,特定的外部激励能够明显地提高升力系数并且有效地延迟失速现象的发生,可以作为一种控制失速的有效方法。

关键词: 翼型 失速 分岔 非线性分析 漩涡脱落

Abstract: Using the CBS (Characteristic-Based Split) finite element method, this paper studies in detail the nonlinear dynamics of stall of airfoil NACA0012.First, the Instantaneous streamline patterns and the angle of attack lift coefficient curves of flows around the static airfoil are presented, and much attention is paid to the hysteresis and jumping phenomena in the angle of attack lift coefficient curve.Next, on the basis of the fixed point bifurcation theory in the map, by introducing a map into the flow field numerical simulation the static stall is proved numerically to be a kind of saddle-node bifurcation which involves the hysteresis and jumping phenomena. Additionally the dynamic stall of the airfoil is investigated by the ALE (Arbitrary Lagrangian-Euler) method, since the saddle-node bifurcation is sensitive to external excitation, which is the pitching-motion of the airfoil around the stall attack angle.The numerical results show that the specific external excitation could significantly enhance the lift coefficient and effectively delay the stall, and it may be considered a powerful control strategy of stall.

Keywords: airfoil stall bifurcation nonlinear analysis vortex shedding

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