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低压涡轮的气动-声学三维数值优化: 倾斜导叶策略

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Aerodynamic-acoustic Three-dimensional Numerical Optimization of Low Pressure Turbine: Lean Vane Strategy

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摘要

低压涡轮既是飞机进场着陆时发动机的重要声源,也是发动机中对效率要求很高的部件之一,为了实现低压涡轮低噪声的设计目标必须同时兼顾气动性能指标。研究给出了高效低噪声低压涡轮气动-声学三维优化的思路,即首先通过计算流体力学(CFD)定常计算评估三维设计变化对气动性能的影响;然后利用非定常CFD方法与三平面压力模态匹配(TPP)方法的结合来评估其降噪的效果与非定常气动影响;最后确定最佳的设计方案。以GE-E^3(Energy Efficient Engine)低压涡轮末级为算例,数值模拟了导叶倾斜作为低压涡轮降噪措施的潜力。计算结果表明,正倾斜导叶角度小于19° 时单级涡轮气动性能较直列叶栅要好,效率最大提高了0.3%。对单音噪声级的评估指出,正倾斜由于改变了导叶的尾迹特征,涡轮级噪声水平是增大的,因此不能作为有效的降噪策略。数值研究的结果表明CFD方法能够同时反映出叶片三维设计的细节变化对气动和噪声级的影响,可以作为三维气动-声学优化的手段。

关键词: 低压涡轮 气动 声学 倾斜 单音噪声

Abstract:

The low pressure turbine of an aircraft is an important engine noise source at approach power, and there is a high requirement on its aerodynamic efficiency. The noise level of a low pressure turbine must be considered together with its aerodynamic performance to achieve a significantly quiet low pressure turbine design. In this paper some insights are presented on three-dimensional aerodynamic-acousitc optimization for a high performance and low noise level turbine. First, a steady computational fluid dynamics (CFD) simulation is made to evaluate the aerodynamic performance with three-dimensional design variations. Then the unsteady aerodynamic effects and tonal noise level are obtained using unsteady CFD calculation combined with a triple-plane pressure (TPP) matching strategy. Finally an optimal design plan is selected. Taking as an example the calculation of the last stage of a GE-E^3 (Energy Efficient Engine) low pressure turbine, the potential of using lean vanes as a turbine tonal noise reduction strategy is numerically simulated. The results show that when the positive lean angle is smaller than 19° the single stage turbine performance is improved, with a maximum enhancement of efficiency of 0.3%. Evaluation of tonal noise shows that positive lean increases the noise level, for it changes the characteristics of vane wakes, which means this method cannot be employed for noise reduction. The numerical simulation indicates that this three-dimensional optimization method can reflect simultaneously the effects of detailed three-dimensional changes of a blade on its aerodynamic and acoustic performance, and it can be effectively used in the aerodynamic-acousitc optimization process.

Keywords: low pressure turbine aerodynamics acoustics lean tonal noise

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