Asociación Argentina de Mecánica Computacional

Mecánica Computacional Vol XXXII, págs. 9-9 (resumen)
Carlos G. García Garino, Aníbal E. Mirasso, Mario A. Storti, Miguel E. Tornello (Eds.)
Mendoza, Argentina, 19-22 Noviembre 2013

COMPACT HIGH-SPEED TURBOMACHINERY DESIGN AND ANALYSIS

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Keywords: Computational fluid dynamics, fluid machinery, turbines, shock waves

Abstract. The quest for compact aircraft engines and power generation systems, based on thermal cycles, offers attractive aerodynamic opportunities for innovative research. Compact turbomachinery can be achieved through counter-rotating concepts and highly loaded designs. However, the aero-thermal performance of highly loaded turbines is abated by the unsteady impact of the vane shocks on the rotor. This lecture presents the physical analysis of the stator–rotor interactions in transonic turbine stages based on experimental and numerical research. The experimental assessment of the turbine was performed in unique short-duration wind-tunnels, that required ad-hoc instrumentation.

The detailed comparison of computational fluid dynamic results and experiments led to the understanding of the complex unsteady flow physics in highly loaded turbines. The vane shock impingement on the rotor originates a separation bubble that is responsible for the generation of high losses. Furthermore, in high-pressure turbines, a small amount of cold flow is ejected at the hub from the cavity that exists between the stator and the rotor disk, to prevent the ingestion of hot gases into the wheel-space cavity. Despite the small amount of gas ejected, the hub-endwall cavity flow has a significant influence on the mainstream flow. The Navier-Stokes predictions show how the ejected cold flow is entrained by the rotor hub vortex. When the cavity flow rate is increased, the unsteady forces on the rotor airfoil are reduced, causing additionally a net increase in turbine efficiency. The turbine overtip flow was also investigated at engine representative conditions, with focus on very tight rotor tip gaps, revealing unconventional flow topologies.

Based on the presented research, passive and active control techniques were investigated. A differential evolution algorithm was applied to optimize the transonic vane using a cost-effective Reynolds-averaged Navier–Stokes solver, computing the downstream pressure distortion and aerodynamic efficiency. Attenuation above 60% of the unsteady forcing on the rotor (downstream of the optimal vane) was observed, with no stage-efficiency abatement. On the other hand a novel proposal to control the resulting fish tail shock waves was developed based on pulsating coolant blowing through the trailing edge of the airfoils. A linear cascade representative of modern turbine bladings was specifically designed and constructed. Minimum shock intensities were achieved using pulsating cooling. The impact of cooling on wake unsteadiness for various Mach and Reynolds numbers are quantified in terms of the Strouhal number. The potential implementation of the proposed cooling scheme in turbine applications might lead to improvements on turbine efficiency and life-span.