TWO-WAVELENGTH INTERFEROMETRY INVESTIGATION OF A TRANSONIC TIP-SECTION TURBINE BLADE CASCADE

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ABSTRACT

The objective of the contribution is to investigate the transonic flow field and the shock-wave/boundary-layer interaction in a turbine rotor tip-section blade cascade using two-wavelength interferometry. The cascade consists of nearly flat profiles with shaped leading and trailing edges, forming short, low-turning convergent-divergent passages representative of the tip region of long low-pressure steam-turbine rotor blades. Earlier work on this cascade combined optical, pneumatic and CTA measurements with two-dimensional simulations; the present study focuses on quantitative full-field optical measurements and their comparison with three-dimensional numerical simulations. The two-wavelength method provides a single-shot reconstruction of density and isentropic Mach-number fields in regions with large density gradients. The resulting data are used to locate the sonic line, exit-shock branch and suction-side interaction region, and to assess how side-wall and passage-flow three-dimensionality affect the measured shock structure and boundary-layer response.

INTRODUCTION

In the tip section of long last-stage turbine blades, the high circumferential velocity produces transonic or supersonic relative flow. Even for cascades with very small flow turning, the passage flow is governed by strong acceleration, recompression waves, shock waves and their interaction with blade and side-wall boundary layers. In the investigated cascade, previous measurements showed a rapid suction-side acceleration downstream of the leading edge and an interaction of the inner branch of the exit shock wave with the boundary layer on the neighbouring suction side. Such shock-wave/boundary-layer interaction can induce separation, modify the transition process and increase losses in the near-wake region. Reliable experimental data are therefore required both for physical interpretation and for CFD validation. Conventional schlieren gives excellent qualitative information, while classical interferometry provides quantitative density data but is sensitive to phase ambiguity and optical imperfections in transonic flows. The present work applies a robust two-wavelength interferometric approach to obtain quantitative Mach-number maps of the turbine tip-section cascade.

RESULTS AND DISCUSSION

Two coherent wavelengths are recorded simultaneously with different carrier frequencies. After Fourier filtering, the phase maps are combined through the synthetic wavelength to unwrap the measurement phase, which is then converted to density by the Gladstone-Dale relation and to the isentropic Mach number using inlet total conditions. The new evaluation concentrates on the complete passage flow topology rather than on pointwise boundary-layer indicators. Particular attention is paid to the strongly accelerated suction-side region, the shape and streamwise position of the sonic line, the recompression pattern upstream of the geometrical throat and the exit-shock branch impinging on the suction-side boundary layer. These quantities are extracted from the reconstructed Mach-number fields and compared with corresponding planes from three-dimensional numerical simulations of the same cascade. A key issue is the distinction between genuine blade-passage effects and line-of-sight or side-wall effects. The earlier two-dimensional comparison indicated an upstream shift of the experimentally inferred sonic line, most likely caused by local three-dimensional changes of the side-wall boundary layer in the region of strong expansion. The present 3D comparison is therefore expected to clarify the origin of this discrepancy and to determine whether the observed shock position and interaction footprint can be reproduced without ad hoc corrections. The final discussion will address the ability of the simulations to predict the measured shock location, Mach-number level and interaction region, and will identify the limits of the optical interpretation in regions with strong three-dimensional gradients.

REFERENCES

[1] Psota, P.; Çubreli, G.; Šimurda, D.; Šidlof, P.; Kredba, J.; Stašík, M.; Lédl, V. Noise-resistant two-wavelength interferometry for single-shot measurement of high-gradient flows. Optics and Lasers in Engineering 2023, 164, 107505.