IDENTIFICATION OF FLOW CONDITIONS IN LINEAR COMPRESSOR CASCADE EXPERIMENT VIA BLADE LOADING MATCHING

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ABSTRACT

A computational tool for the identification of aerodynamic inlet boundary conditions in linear compressor cascade experiments based on measured blade loading and downstream mass flux is introduced. Accurate determination of the inlet Mach number, inlet flow angle, and Axial Velocity Density Ratio (AVDR) is often difficult in compressor cascade testing, but essential for reliable interpretation of experimental results. The proposed approach combines parametric CFD simulations with an inverse problem solution. Cascade geometry and typical operating ranges of the inlet parameters are prescribed, and a database of quasi-three-dimensional simulations is generated. The effect of AVDR is incorporated through a dedicated numerical boundary condition formulation without explicitly resolving the spanwise direction. Blade loadings resulting from simulations are interpolated in the parameter space and matched to experimental data using local optimization constrained by downstream mass-flux to enforce the consistency of the results with the experiment. The method can be applied to stationary compressor cascades operating in both subsonic and transonic flow regimes. The method supports experimental research by providing reliable estimates of flow conditions, enhancing the interpretability of the results of the blade cascade measurement.

INTRODUCTION

Accurate determination of aerodynamic boundary conditions (ABCs), inlet Mach number M_1, inlet flow angle α_1, and Axial Velocity Density Ratio (AVDR), is essential for interpretation of linear compressor cascade experiments. These quantities are subject to considerable measurement uncertainty, as the inlet flow field is only rarely traversed. The value of AVDR is highly affected by precision of measurements of both inlet ABCs, M_1 and α_1. Any inaccuracy in these parameters can substantially alter the understanding of the cascade behavior. This is particularly critical for transonic cascades, which typically operate within an incidence range of only a few degrees. This work presents a computational tool that identifies the aerodynamic boundary conditions of a compressor cascade experiment by solving an inverse problem. The input of the tool is the experimentally measured blade loading and the mass flux through the downstream traversing plane. The identified quantities are M_1, α_1, and AVDR.

METHOD

The tool combines parametric quasi-3D RANS simulations with radial basis functions (RBF) interpolation and local constrained optimization. A database of steady-state OpenFOAM simulations is generated by sampling the parametric space (M_1 or p_2, α_1, and AVDR). The simulations employing SST k- ω turbulence model and HLLC Riemann solver for shock capturing, solved using the implicit coupled compressible solver hisa [1], are considered converged, when all relative residua fall below 10^{-5}.

The effect of AVDR is incorporated through a dedicated quasi-3D boundary condition applied to artificial side walls, which prescribes normal velocity field that redistributes mass flux according to a linear effective contraction between the blade leading and trailing edge planes. This approach preserves the order of the 2D computational cost without modifying the mesh while in a simplified way accounting for spanwise effects.

The simulated blade loadings are interpolated across the parametric space using RBF with a linear kernel, which proved most robust given the relatively sparse sampling and the presence of shock waves in the distributions. The identification procedure minimizes the difference between the interpolated and experimental blade M_{is} distributions, while imposing a constraint on the downstream mass flux.

RESULTS AND DISCUSSION

The tool was applied to two transonic compressor cascade datasets. For the in-house Kobra cascade ([2], $M_{1experim.} = 0.8$, $\alpha_{1experim.} \in [57.7, 63.0]$), the inlet Mach number was treated as known and the two-dimensional parametric space (α_1, AVDR), illustrated in Fig. 1, was generated covering 5 experimentally measured operating points. For the DFVLR transonic research cascade ([3], $M_{1experim.} \in [0.8, 1.1]$, $\alpha_{1experim.} \in [55.2, 58.5]$), the three-dimensional identification of M_1, α_1 and AVDR was performed over the range of operating conditions.

Fig. 1 illustrates results for the Kobra cascade. The left panel shows the parametric space with the computed sample database; experimentally reported operating points and their identified counterparts are overlaid with arrows indicating the correction determined by the tool. The right panel shows the distribution measured experimentally and its identified counterpart for an under-loaded regime ($\alpha_{1experim.} = 57.7$, $AVDR_{experim.} = 1.01$). Corrections of similar characters were obtained across all five Kobra operating points and across the DFVLR dataset. For the DFVLR, the inlet angle in the experiment is stated based on the geometry of the rig. Its corrections in an order of tenths of degree, proposed by the tool, significantly shift the blade loadings.

The validation on the TCTA cascade [4] with an inlet angle measured by LDA is to be performed. One of the limitations of the tool roots in the nature of the RBF interpolation: near the choking line, the interpolation kernel is not filled, and the ability of the tool to reliably work in this region can be limited.

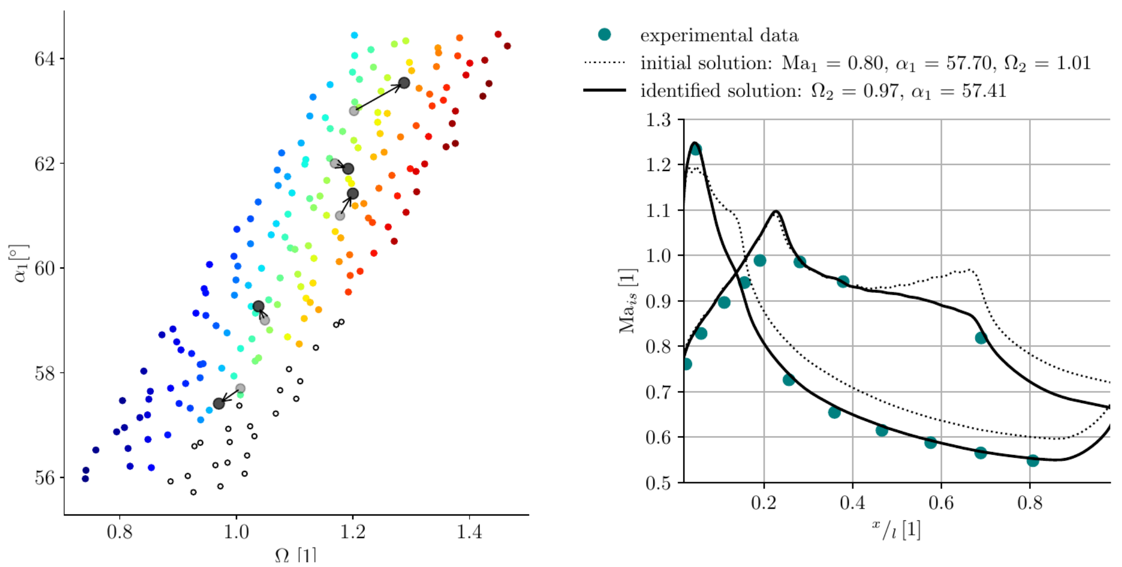

Figure 1. Results on Kobra cascade. In the left part, the parametric space is illustrated. In the right part, initial, identified and experimental isentropic Mach distributions are shown

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