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[Extended Abstract]

Acoustic Feedback Loop Sensitivity to Trailing-Edge Boundary Conditions in High-pressure Turbine Flows

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Introduction

High-pressure turbines (HPT) typically are subject to the highest temperatures, pressures, and velocities found in a gas turbine. The combination of transonic Mach and high Reynolds numbers results in highly complex flow physics that include laminar-turbulent transition, relaminarization, shock waves, separation bubbles and vortex shedding, to name a few. A detailed understanding of the physics is essential for predicting blade performance and aero-thermal loads and thus ensure durability. However, measurements at engine-representative conditions are expensive and often unable to provide sufficient insight into the underlying physics. Wheeler *et al.* [1] performed direct numerical simulations (DNS) of an HPT vane at engine-representative conditions, $Re = 570,000$ and $M = 0.9$, with blade loads and kinetic loss showing good agreement with laboratory measurements [2]. The DNS data revealed pressure waves originating from the trailing-edge vortex shedding and travelling upstream the throat, interacting with the suction side boundary layers. In previous DNS of airfoil flows at lower Reynolds and Mach numbers, acoustic waves generated at the trailing edge have been shown to trigger boundary layer instabilities and lead to an acoustic feedback loop [3].

In the current study, it is investigated whether the same scenario occurs in an HPT environment. To that end global stability analyses are conducted following the approach previously used to study acoustic feedback loops on NACA-0012 airfoils [4], i.e. using forced Navier–Stokes simulations to perform temporal pulse response calculations. In particular the role of the trailing-edge vortex shedding on the generation of upstream traveling pressure waves and their potential for perturbing the suction side boundary layers is studied. This is achieved by conducting additional DNS with trailing-edge blowing in order to provide a base flow resulting from a case without a near-wake recirculation region. The main focus is on elucidating the effect of the trailing-edge boundary conditions on the acoustic feedback loop mechanism.

1. Methods

Both DNS and the temporal pulse response calculations were performed with the in-house multi-block and curvilinear flow solver HiPSTAR. The compressible Navier–Stokes equations for conservative variables were solved using a 4^{th}-order central difference scheme for the spatial discretization in the axial and pitchwise directions. An ultra-low-storage 4^{th}-order Runge–Kutta scheme was used for time-integration and stability of the code was enhanced by a skew-symmetric splitting of the nonlinear terms. In addition, an 11 point wave-number optimized filter was used after each full

Runge–Kutta cycle with a weighting of 0.2 to remove possible grid-to-grid-point oscillations. More details about the code and its validation can be found in Sandberg *et al.* [5].

For the multidimensional stability analysis, at the start of each simulation the right-hand-side of the Navier–Stokes equations, containing all spatial derivatives of the base flow, was computed and stored. The simulation was then progressed, subtracting the stored forcing term for the entire blade-to-blade plane at each Runge–Kutta substep so that the initial condition could be maintained and the behaviour of small perturbations could be investigated. For three-dimensional stability analysis, a Fourier representation of the spanwise direction was used and all higher Fourier modes were perturbed at the same in-plane location. Note that in 3D cases, the stored forcing term is only subtracted from the zeroth spanwise Fourier mode.

A linear HPT cascade configuration was considered, and the DNS with trailing edge blowing and the forced Navier–Stokes simulations used the 'fine mesh' from the original DNS study by Wheeler *et al.* [1], containing a total of 2.5 million points in the blade-to-blade plane. The average near wall grid spacings were $y_1^+ = 0.8$, $\Delta z^+ = 5$, $\Delta x^+ = 15$. Figure 1 shows the two-dimensional DNS conducted with and without trailing-edge blowing and reveals pressure waves travelling upstream from the trailing edge on the suction side. However, a key difference between the two cases is that with trailing-edge blowing the waves emanating from the trailing edge do not seem to impinge onto the suction side of the adjacent blade. How this affects the acoustic feedback loop will be investigated.

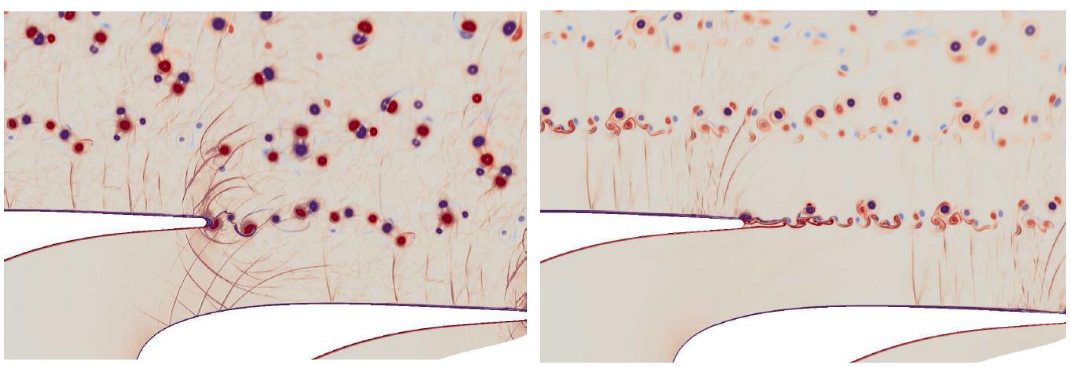

Figure 1. Instantaneous contours of spanwise vorticity (color) and dilatation field (grey scale) for DNS of an HPT at $Re = 570,000$ and $M = 0.9$ without (left) and with trailing edge blowing (right).

References

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