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Effect of axisymmetric endwall contouring on the high-load low-reaction transonic compressor rotor with a substantial meridian contraction

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ABSTRACT

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For a high-load low-reaction compressor transonic rotor based on an increase in outlet axial velocity, the stage reaction is decreased by a substantial meridian contraction of the endwall. The axisymmetric endwall contouring has a deep impact on the aerodynamic performance of the rotor. Therefore, nine combinations of endwall contours with three different shapes including a linear wall, a sinusoidal wall and a symmetrical wall of the sinusoidal wall about the linear wall were firstly studied through 3D steady Reynolds Average Navier-Stokes simulations. The results show that the cases with a linear hub have the highest peak pressure ratio and the largest peak efficiency, whereas the cases, featured with a sinusoidal hub, have the widest stall margin, the largest mass flow and the lowest pressure ratio. Endwall contouring not only influences the shock structure across the flow passage but also dominates the location and intensity of separation. In addition, the effect of endwall contouring on loading distribution is also presented and the case with a sinusoidal hub is characterized by aft-loading and the other two cases have a feature of fore-loading.

1. Introduction and background

In a conventional aero-engine compressor, with an increase in stage loading, the flow field within flow passage becomes more and more complicated. And in order to maintain a wide operating range, the low aspect ratio gradually turns into a significant feature for the high-performance blade. With high blade loading, the streamwise adverse pressure gradient is exacerbated and the intensity of the secondary flow is extremely enhanced due to the increased circumferential pressure gradient. A geometry characteristic of low aspect ratio will contribute to reducing adverse pressure gradient. Nonetheless, the decrease in blade height inevitably enhances secondary loss induced by thicker endwall boundary layer and increasing three-dimensional effects. Denton [1] pointed out that in a typical axial compressor, the endwall loss approximately accounted for 2/3 of the total loss. Therefore, it is essential to reduce endwall loss as much as possible to improve overall efficiency of the compressor through some active or passive control measures [2].

For the compressor stator, active and passive flow control measures are all feasible to lower endwall loss, such as boundary layer suction, vortex generator, synthetic jet, bowed blading, casing treatment [3] and so on. However, for the rotor, considering the complexity of active flow control system installation, layout and the effect of some control methods on the blade strength, passive flow control technology-endwall contouring will be better.

The endwall contouring methodology includes axisymmetric profiling along axial direction and non-axisymmetric profiling along circumferential direction. Most researches on endwall contouring start from application in the turbines. In the past two decades, numerical simulations and experiments on turbine axisymmetric contouring, namely two-dimensional endwall contouring, have been performed to decrease the intensity and size of the secondary vortices by contracting the flow area locally [4-12]. An experiment study of axisymmetric/2D endwall contouring with low aspect ratio carried out by Burd and Simon [6] demonstrated that in contrast to the case with flat wall, the size and strength of the secondary flow with contoured endwall were greatly suppressed. As for the compressor, LeJambre et al.[13] showed that the hub profile within the rotor blade flow path had a significant influence on the performance. Based on the study of LeJambre et al., Stringhan et al. [14] carried out an application of axisymmetric contouring on all of rotor hubs from a nine stage compressor to reduce losses. Hoeger et al. [15] experimentally performed a series of comparison in transonic compressor rotor flow characteristics between a linear and a concave endwall contour and revealed that the concave endwall shape can unload the profile boundary layer while changing the original shock system from an oblique shock to a normal shock. Furthermore, endwall contouring has an impact on the flow not only near the endwall but also a considerable distance from the endwall along the span. Ito et al. [16, 17] investigated the effect of casing contouring on the flow instability of NASA Rotor 37 and found that contoured endwall above the leading edge had notable improvement in stall margin and a slight decrease in efficiency and pressure ratio. For the purpose of decreasing

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