RESPONSE ON THE CORNER FLOW SEPARATION TO PLASMA AERODYNAMIC ACTUATION IN A HIGHLY LOADED COMPRESSOR CASCADE

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Summary The effect of plasma aerodynamic actuation (PAA) on the corner flow structure and the total pressure loss in a highly loaded compressor cascade was investigated. Microsecond or nanosecond pulsed PAA was used on the blade surface and the endwall. Both the amount and the distribution of the singular point change dramatically with the PAA. PAA on the endwall is more effective than that on the suction surface. Due to the higher disturbance strength, nanosecond pulsed PAA is more effective than the microsecond pulsed PAA.

INTRODUCTION

Corner separation, forming over the suction surface and the endwall corner, induces flow breaking down in the stator passage and significant reduction of the stage efficiency in highly loaded compressors [1]. Plasma aerodynamic actuation (PAA), which is promising in improving aircraft aerodynamic characteristics and propulsion efficiency, was used to control the corner separation in a low speed compressor cascade [2, 3]. In this paper, the response on the corner flow separation to PAA in a highly loaded, low speed compressor cascade was investigated. A highly loaded, low speed, linear compressor cascade was used in this study. Asymmetric surface dielectric barrier discharge plasma aerodynamic actuator was used to control the corner separation. Streamwise PAA on the suction surface and pitchwise PAA on the endwall were investigated, as shown in Figure 1.

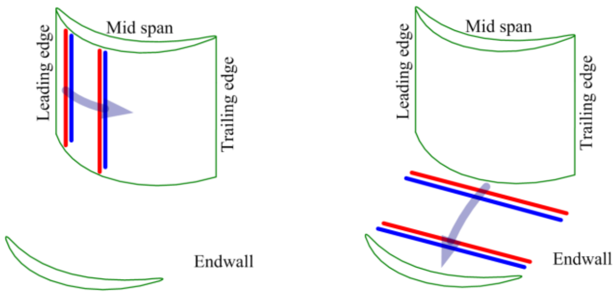

Figure 1. Streamwise PAA on the suction surface (left) and pitchwise PAA on the endwall (right).

RESULTS AND DISCUSSION

Total pressure measurement indicates that the relative reductions of the pitch averaged total pressure loss coefficient are 2.9% and 8.1% with streamwise PAA on the suction surface and pitchwise PAA on the endwall, respectively. The freestream velocity is 50 m/s, and the corresponding Reynolds numbers is 37520. The angle of attack is 2 degree. The PAA was generated by microsecond discharge. PAA on the endwall is more effective than that on the suction surface. As illustrated in Figure 2, streamwise PAA on the suction surface accelerates the boundary layer, while the pitchwise PAA on the endwall inhibits the crossflow from the neighbouring pressure side to the suction side.

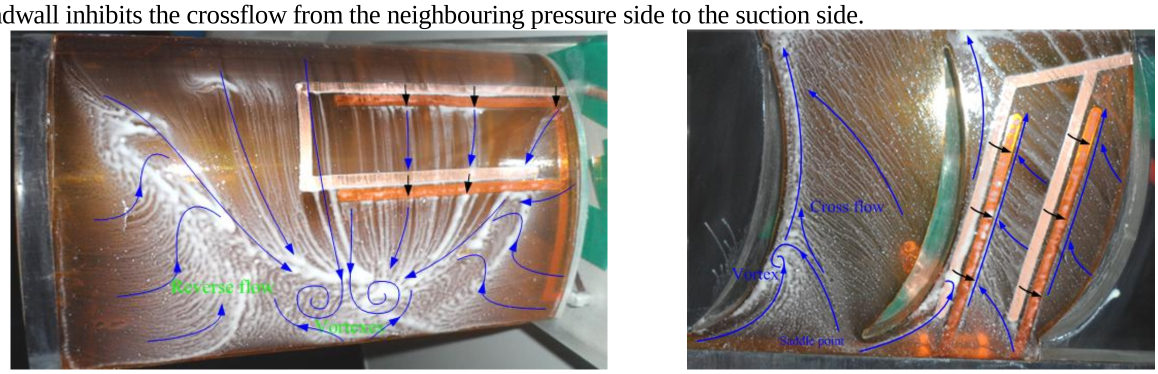

Figure 2. Surface oil visualization with streamwise PAA on the suction surface (left) and pitchwise PAA on the endwall (right).

It is found in the simulation that the topology structure on the suction surface and endwall changes dramatically with the PAA, including the locations, numbers and types of the singular points, as shown in Figure 3. With PAA on the suction

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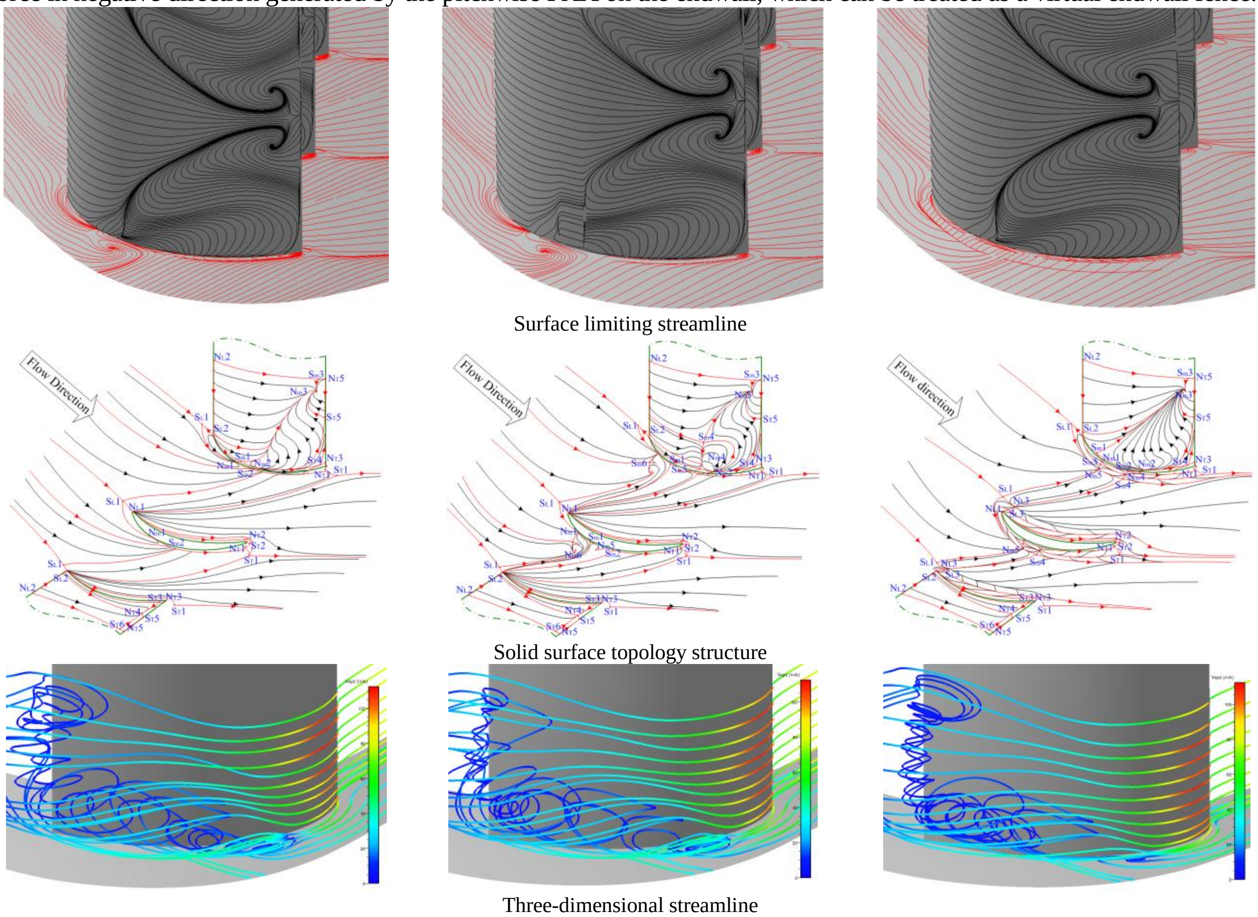
surface, only the topology structure on the suction surface changes slightly. The separation line $S_m1 \rightarrow N_m3$ breaks with a new node-saddle point N_m4-S_m4. However, one new reattachment line $N_m2 \rightarrow S_m4$ appears with PAA, leading to more complex corner separation structure. With PAA on the endwall, locations and arrangement order of singular points on the endwall change obviously and the node-saddle point S_m6-N_m6 disappears, which leads to a better control effect than the PAA on the suction surface. Corner separation is caused by the interaction between the separated boundary layer on the suction side and the crossflow from neighbouring pressure side on the endwall. With streamwise PAA on the suction surface, the corner flow structure remains almost unchanged. While less crossflow can reach the suction surface due to the body force in negative direction generated by the pitchwise PAA on the endwall, which can be treated as a virtual endwall fence.



(a) Baseline (b) Streamwise PAA on the suction surface (c) Pitchwise PAA on the endwall

Figure 3. Surface limiting streamline, solid surface topology structure and three-dimensional streamline.

In order to optimize the PAA, nanosecond pulsed discharge PAA on the endwall was also investigated. As shown in Figure 6, the total pressure loss coefficient reduces by 8.1% with nanosecond discharge PAA and 0.9% with microsecond discharge PAA. The freestream velocity is 75 m/s, and the corresponding Reynolds numbers is 56280. The angle of attack is 2 degree. Nanosecond discharge PAA is much more effective than microsecond discharge PAA. The main reason is that the nanosecond discharge PAA can induce a strong compression wave upward due to the fast heating effect, while the microsecond discharge PAA can only accelerate boundary layer to 3 m/s. Thus, the virtual endwall fence effect of nanosecond discharge PAA is stronger than that of microsecond discharge PAA.

CONCLUSIONS

Both the amount and the distribution of the singular point change dramatically with the PAA. Pitchwise PAA on the endwall, used to inhibit the crossflow in the blade passage, is more effective than the streamwise PAA on the suction surface which controls the boundary layer accumulation. Due to the higher disturbance strength, nanosecond pulsed PAA is much more effective than the microsecond pulsed PAA.

References

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