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Influence of length ratio on trailing edge cutback wake

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Abstract

The length ratio of the shorter lip plate to the longer lower plate, and the ratio of slot height to plate thickness are key geometric parameters to the aerodynamic performance of the trailing edge cutback wake. The unsteady flow past the trailing edge cutback model was experimentally studied by using particle image velocimetry (PIV) to examine the influence of length ratio. The length ratio and the ratio of slot height to plate thickness in present study are found to exert little influence on the wake.

1 Introduction

Advanced high-performance gas turbines are operated at peak temperatures that are well beyond the maximum allowable melting temperature of the blade material, and turbine inlet temperatures even in excess of 2000K have been reported in recent developments (Horbach et al. (2011)). The heat loads are extremely high at both the leading and trailing edges of a turbine blade. The implementation of trailing edge cooling is particularly difficult due to structural and aerodynamic constraints. Advanced trailing edge cooling designs feature a cutback on the pressure side of the blade trailing edge and cooling air extracted from earlier compressor stages is continuously ejected through a breakout slot onto the exterior cutback surface, forming an insulating film to prevent hot mainstream gas from impinging onto the wall of the suction side, as shown schematically in Fig.1. It has been well established that the blowing ratio and the normalized distance downstream of slot breakout are key parameters to the cooling effectiveness (Taslim et al. (1992)). Other parameters, such as the thickness to height ratio, slot width to height ratio, slot angle of injection relative to mainstream flow are recognized as having effect of various magnitudes on cooling performance but are not well established.

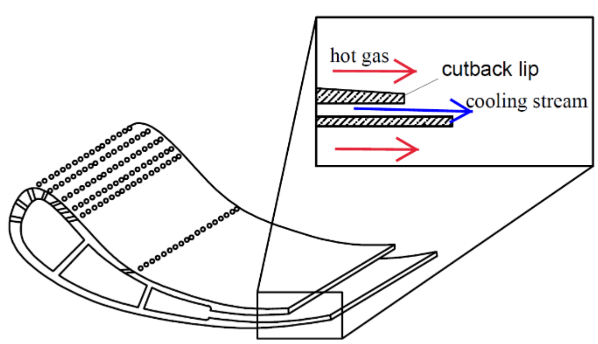

Fig. 1. Schematic of the high pressure turbine blade with trailing edge cutback cooling

In the present study, the asymmetric trailing edge cutback was simplified as a combination of two parallel plates with different lengths. The length ratio of the shorter lip plate to the longer lower plate, and the ratio of slot height to plate thickness are key geometric parameters to the aerodynamic performance of the trailing edge cutback wake. Both may significantly alter the wake flow patterns. However, the ratio of slot height to plate was fixed at unity to reduce the factors of influence. The main concern of the present study is to shed light on the influence of length ratio on trailing edge cutback wake and coherent structures from an aerodynamic view. Toward this end, Particle Image Velocimetry (PIV) measurements of the wake behind the trailing edge cutback were conducted and time-averaged flowfileds and turbulent statistics were detailedly examined. A simplified trailing edge cutback model without interior ribs or pin-pins was adopted to eliminate other impact factors except length ratio.

2 Experimental Apparatus

2.1 Overview of the Wind Tunnel

The experiments were carried out in the wind tunnel (Fig. 2) located at the Department of Power Engineering, University of Shanghai for Science and Technology. The test section was 300 mm (width) × 400 mm (height) in the cross section and 2000 mm in length. The turbulent intensity at the inlet of the test section was found to be less than 0.6% measured by hotwire anemometry. Mainstream flow was driven by a centrifugal blower and a 1.5 kW motor. The free-stream velocity was maintained at U_0 = 3 m s-1, resulting in a Reynolds number based on the slot height $\mathrm{Re}_h = 3300$.

2.2 Test Model

The trailing edge cutback model used in the present study was designed to replicate only the trailing edge portion of a typical high pressure turbine blade with trailing edge cooling. As shown in Fig. 3, the trailing edge cutback model was simplified as a combination of two parallel plates with different lengths. The thicknesses of the lip and lower plates were equal to the height of the slot between the two parallel plates. The head of the lip and lower plates were machined to be semielliptical in order to avoid flow separation. The incoming flow past the center of the two plates was served as the coolant flow, and velocity ratio was found to be little higher than unity. The length of the lip plate was fixed at 4*h*, while the length of the lower plate varies from 4*h*, 6*h* to 8*h*, resulting in a ratio of *l/t* = 0, 2 and 4, respectively.

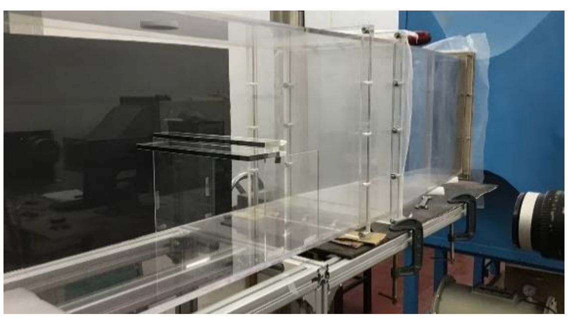

Fig. 2 The wind tunnel

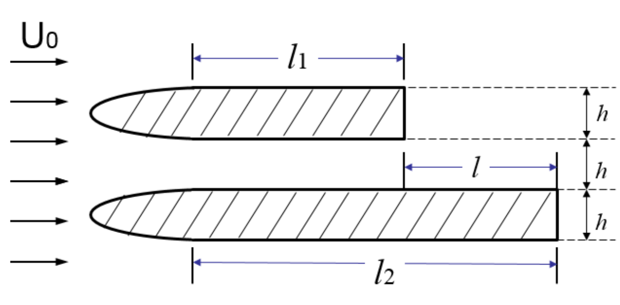

Fig. 3 The test model

3 Results and Discussion

3.1 Time-averaged flowfileds

There have been extensive investigations on the wake of two side-by-side bluff bodies (e.g. circular and square cylinders, blunt plates), and three typical flow regimes have been identified at different spacing ratios (Ishigai et al. (1972), Zdravkovich (1977)), e.g. 'single-bluff-body regime' at small spacing ratio, 'asymmetric wake regime' at moderate spacing ratio, and 'couple-street regime' at large spacing ratio. However, the influence of spacing ratio on side-by-side finite plates has never been studied. In the present study, the spacing ratio (i.e., the ratio of slot height to plate thickness) is within the scope of ''asymmetric wake regime'. The contours of mean streamwise velocity disclose that the wake behind both plates are nearly symmetric, and the biased gap flow is not observed in present study. With the increase of length ratio, the wake regions behind the two plates keep constant, indicating that the gap flap exerts little influence on the mean flowfileds.

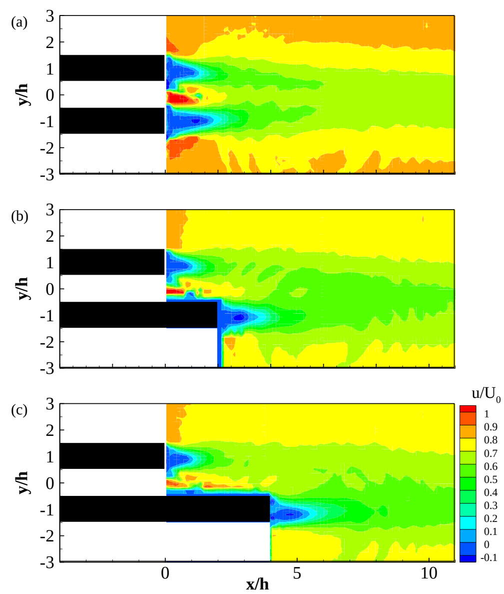

Fig.4 contours of mean streamwise velocity

POD analysis was applied to the velocity fields to examine the vortex shedding characteristics. By using POD, the large scale coherent structures in the trailing edge cutback wake can be clearly identified from the eigenmodes. The first six eigenmodes with large eigenvalues are shown in Fig.5-7.

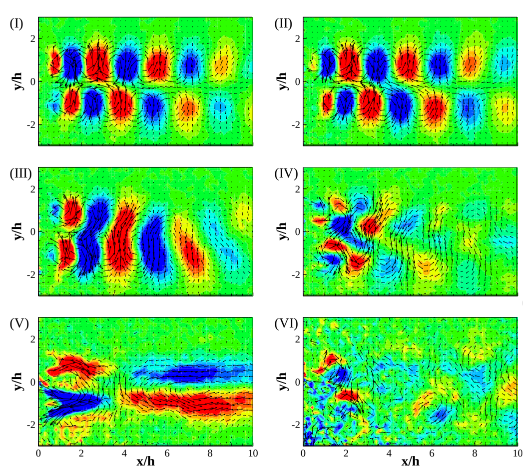

Fig.5 First 6 eigenmodes (l/t = 0)

As shown in Fig.5, the first two eigemodes indicate the vortices shed from the lip and lower plate. As the length ratio *l/t* equals to 0, i.e., the two plates have equivalent length, symmetric vortex street are found behind the two plates. The eigenvalues of the first two modes are almost equal, which also confirm that the wakes behind the plates are symmetric and no biased flow is observed.

As the length ratio *l/t* increases (Fig.6 and 7), the vortices shed from the lip plate become the dominate coherent structures in the wake as can be inferred from the contours of eigenmodes. The first two eigenmodes disclose that the vortices shed from the lip plate have more energy than that of the lower plate. It seems that there wake flow patterns behind the two plates are similar except the strength of vortices.

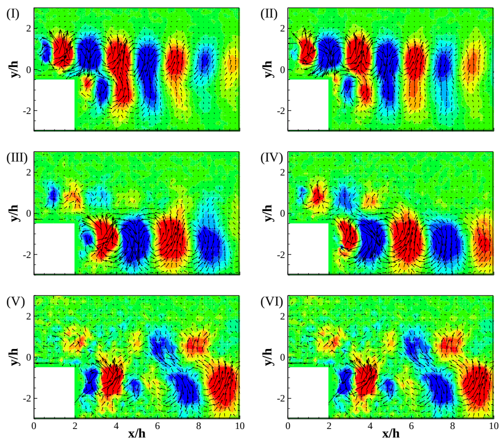

Fig.6 First 6 eigenmodes (*l/t* = 2)

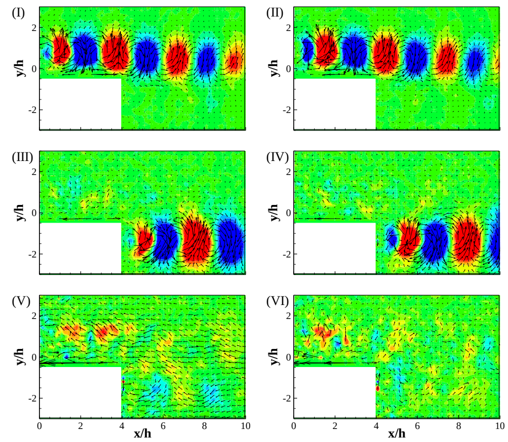

Fig.7 First 6 eigenmodes (*l/t* = 4)

4 Conclusion

In the present study, the biased gap flow is not observed for two side-by-side finite plates. The wakes behind the lip and lower plates behave independently, while with the increase of length ratio, the strength of the vortices shed from the lip plate increases.

Acknowledgements

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