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Experimental investigation on a high subsonic compressor cascade flow

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Abstract With the aim of deepening the understanding of high-speed compressor cascade flow, this paper reports an experimental study on NACA-65 K48 compressor cascade with high subsonic inlet flow. With the increase of passage pressurizing ability, endwall boundary layer behavior is deteriorated, and the transition zone is extended from suction surface to the endwall as the adverse pressure gradient increases. Cross flow from endwall to midspan, mixing of corner boundary layer and the main stream, and reversal flow on the suction surface are caused by corner separation vortex structures. Passage vortex is the main corner separation vortex. During its movement downstream, the size grows bigger while the rotating direction changes, forming a limiting circle. With higher incidence, corner separation is further deteriorated, leading to higher flow loss. Meanwhile, corner separation structure, flow mixing characteristics and flow loss distribution vary a lot with the change of incidence. Compared with low aspect-ratio model, corner separation of high aspect-ratio model moves away from the endwall and is more sufficiently developed downstream the cascade. Results obtained present details of high-speed compressor cascade flow, which is rare in the relating research fields and is beneficial to mechanism analysis, aerodynamic optimization and flow control design.

1. Introduction

In axial compressor stator blade passage, at the conjunction of endwall and suction surface, corner separation is considered to be the result of endwall and suction surface boundary layer accumulation, secondary flow in the blade passage and strong streamwise adverse pressure gradient. Through the years, to improve the work performance of highly loaded axial compressor, the structure of corner separation has been studied worldly in the aeronautical research field.[1–11]

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Compressor cascade is a simplified model of real axial compressor stator blade and has been widely applied to researching the mechanism and control of corner separation, as well as the compressor tip clearance flow structures and effects of three-dimensional compressor blades.[12,13] Active flow control methods, such as boundary layer suction,[14–16] flow blowing,[17,18] plasma flow control[19,21] etc, have been applied to the control of compressor cascade corner separations over years. Meanwhile, the application of passive flow control methods, such as vortex generator,[22–24] endwall contouring[25] etc, as well as combination of passive and active control methods,[26] for corner separation control have been investigated with great efforts. To control the corner separation effectively, the design of both active and passive methods should be based on the in-depth understanding of flow structures in the compressor cascade flow passage and various efforts have been spared.[1–11,14–27]

In low speed flow, with inlet Mach number under 0.3, detailed researches on the flow structures in the compressor cascade flow passage have been launched.[3,7–10] When inlet Mach number increases to be bigger than 0.3, the flow becomes more unsteady and compressible. As found in the series research of Ref.[17], a transfer of findings of low-speed case to realistic Mach numbers of a real compressor cannot be easily done. Under the real work conditions, compressor blades are more likely to encounter high subsonic fluid, and research groups of German Aerospace Center Deutsches Zentrum für Luft-und Raumfahrt (DLR),[22–26] Tiedemann[17] and Zhang et al.[20] have carried out some trial study to control the corner separation with the inlet Mach number around 0.7. While the research on control separation in high-speed flow is under way, compressor cascade flow structure has been studied, too,[5,11,16,17,20,22–26] but is still in lack of detailed investigation compared with that under low-speed flow circumstances. So it is meaningful to provide detailed research of compressor cascade flow structure as the basis for better understanding and controlling of corner separations in high subsonic flow. And this is just what this paper mainly focuses on.

In this paper, flow structures in the compressor cascade flow passage with high subsonic inlet flow are researched in detail with some traditional measuring methods. Results obtained are aimed at deepening the knowledge of high-speed compressor cascade flow, thus providing references for the optimal design of the blade and the better understanding and flow control of the corner separations in high subsonic flow.

2. Experimental setup and methods

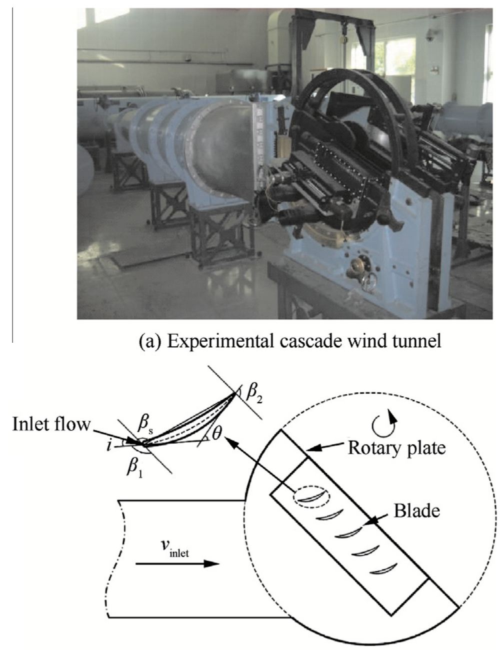
A typical high-speed compressor cascade NACA-65 K48[11,16,20,22–26] is studied. Its main geometrical and aerodynamic parameters are shown in Table 1.

The experimental results in this paper were obtained in high-speed linear cascade wind tunnel, Dalian Maritime University (shown in Fig. 1). The highest inlet Mach number reaches about 1.1, thus being qualified for high subsonic compressor cascade experiments.

During the experiment, blades were confined to a rotary plate, and through rotating the plate inlet flow incidence i can be changed continuously. To keep the periodicity of the cascade flow passages, seven blades were utilized in the experiment.

Table 1 Main parameters of NACA-65 K48.

Geometric parameter	Value
Chord c (mm)	60
Span h (mm)	100
Camber angle θ (°)	42
Inlet flow angle β_1 (°)	132
Outlet flow angle β_2 (°)	90
Stagger angle β_s (°)	112.5
Inlet Mach number	0.7
Solidity	1.82



(a) Experimental cascade wind tunnel

(b) Sketch of cascade wind tunnel

Fig. 1 High-speed cascade wind tunnel.

Inlet flow parameters were obtained with a total pressure probe located 5 m upstream the blade in the main stream and 5 static pressure probes located on the endwall 20 cm upstream the blade.

To capture the solid wall boundary layer flow structure and to study the three-dimensional flow structures through topological analysis, oil visualization experiments were implemented. During this procedure, a mixture of blue ferric oxide powder and silicone oil was used, and the corresponding proportion was varied from 1/3 to 1/4 according to the inlet flow velocity to better reflect the boundary layer flow structures.

Static pressure in the cascade passage was investigated through distributing pressure measurement holes on the endwall. As shown in Fig. 2, there are in total 96 static pressure measurement holes on the endwall, and they are distributed from locations 5 mm upstream the leading edge to 10 mm downstream the trailing edge.

The total pressure and velocities in the cascade flow passage were measured with a five-hole probe. Before the experiments, the five-hole probe was calibrated in the calibration wind