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.

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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
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. Active flow control methods, such as boundary layer suction, flow blowing plasma flow control 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, endwall contouring etc, as well as combination of passive and active control methods, 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. 

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. 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), 

Tiedemann17 and Zhang et al. 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, 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 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 can be changed continuously. To keep the periodicity of the cascade flow passages, seven blades were utilized in the experiment.

<table>
<thead>
<tr>
<th>Geometric parameter</th>
<th>Value</th>
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<tr>
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<tr>
<td>Span h (mm)</td>
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<tr>
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<tr>
<td>Inlet flow angle βi (°)</td>
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<td>Outlet flow angle βo (°)</td>
<td>90</td>
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<tr>
<td>Stagger angle βs (°)</td>
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<tr>
<td>Inlet Mach number</td>
<td>0.7</td>
</tr>
<tr>
<td>Solidity</td>
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</tr>
</tbody>
</table>

Table 1 Main parameters of NACA-65 K48.

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...
tunnel at different inlet Mach numbers to obtain accurate experimental results.

The measurement system employed in the experiments consists of high-frequency pressure transducer, high-accuracy pressure scanning module (DAS3217) and high-accuracy thermocouple temperature measurement module (DTS3250).

3. Experimental results

3.1. Endwall boundary layer flow

Topological analysis has become a mature method in the researches of three-dimensional separations in compressor cascade and correspondingly, oil visualization on solid wall has been treated as a useful tool to study the compressor cascade topological structures. Here, with topological structures reflected by oil visualization, flow structures of endwall boundary layer in the compressor cascade flow passage are investigated qualitatively.

As shown in Fig. 3, according to oil visualization results on endwall, compressor cascade flow passage is occupied by an acceleration zone and a cross flow zone. As the incidence \( i \) increases from \(-4^\circ\) to \(0^\circ\), the acceleration zone is smaller while the cross flow zone extends forward to the leading edge, which indicates the deterioration of endwall secondary flow because of the enhancement of pressure difference between suction side and pressure side.

At the conjunction of suction surface and endwall, corner separation indicated by green solid line is aroused. From the comparison of Fig. 3(a) and (b), that corner separation is expanded with the increase of inlet flow incidence can be qualitatively concluded. At the outlet of the cascade flow passage, trailing edge separation, which is caused by the mixing of flow from suction surface and pressure surface, is observed.

As oil visualization experiment is just a quantitative method, to further increase the incidence from \(0^\circ\) to \(8^\circ\), no substantial changes are observed for flow structures on endwall. So other oil visualization results on endwall are not presented in this paper.

To conclude, flow acceleration, cross flow, corner separation and trailing edge separation coexist near endwall. The enhancement of secondary flow and corner separation is caused by higher incidences. Since the pressure gap between suction side and pressure side (blade load) is one main reason for cross flow and corner separation, flow structures changing along with the incidence is easy to understand. More favorable blade load is achieved under higher incidence.

As the information of endwall boundary flow provided by oil visualization is to some extent limited, more detailed researches of endwall boundary layer flow structures are investigated through the analysis of endwall static pressure distributions.

According to Fig. 4, static pressure distribution laws on endwall with different inlet Mach numbers obey almost the same rule. The low static pressure region caused by flow acceleration around the leading edge are located and shaped quite similarly. As the inlet flow incidence is at design point, a gradual increase of static pressure in the flow passage is observed in both Fig. 4(a) and (b), indicating a satisfying endwall boundary layer flow behavior.

Static pressure distributions on endwall in high subsonic flow with different incidences are presented in Fig. 5. Although the variance of the endwall boundary layer flow behavior under different incidences cannot be clearly captured and reflected by oil visualization, the developing procedure of endwall boundary layer flow structure is presented by the static pressure distributions, according to Fig. 4(b) and Fig. 5.

Generally speaking, from the endwall static pressure distributions, the leading edge acceleration and pressurization process in the cascade passage can be analyzed.

Local flow acceleration is marked by the low static pressure region. According to Fig. 4(b) and Fig. 5, with the increase of
incidence, the low static pressure region on suction surface side is gradually moved to the leading edge, indicating that the leading edge acceleration is aroused much earlier. Along with the upstream moving of the suction surface leading edge acceleration, the shrinking of low static pressure region is observed, indicating the faster accomplishment of leading edge acceleration. In Fig. 5(a), however, at the leading edge, low static pressure region on pressure side is observed. Apparently, flow acceleration on pressure side at the leading edge has been brought about under negative incidence. Looking back onto the oil visualization results on endwall, the development of leading edge acceleration along with different incidences is too quantitatively presented.

As has been stated in the analysis of Fig. 3, higher incidence brings more favorable blade load, indicating higher pressurizing ability. Here, from the gap between static pressure at the passage inlet and outlet, the improvement of pressurizing ability in the cascade flow passage is quantitatively visualized with the increase of incidences. With separation in the flow passage, static pressure rise in the separation zone will be delayed, resulting in the unsatisfied performance of compressor cascades. From Fig. 5(c), as the incidence increases to 8°, static pressure rise near the suction side is obviously delayed, indicating unsatisfied endwall boundary layer flow behavior.

In the oil visualization experiments, no obvious separations on the endwall are presented even the incidence increases to 8°. On the one hand, oil visualization experiments being effective in quantitatively capturing corner separation structures on suction surface are unable to provide detailed information on endwall boundary layer flow behavior. On the other hand, although the endwall boundary layer flow behavior has been aggravated under high incidence, according to the oil visualization results, no obvious corner stall has been aroused which is commonly accompanied by big scale separation vortex structures on the endwall.

3.2. Transition and structure of corner separation

Compared with the oil visualization results on the endwall, more information on the flow structures in compressor cascade flow passage is provided by the oil streaks on suction surface. According to Fig. 6, transition and corner separation are two main key structures in the cascade flow passage with high subsonic inlet flow.

As shown in Fig. 6(a) and (c), the forward movement of transition zone to the leading edge and its further extension to endwall from midspan area are caused by the increase of inlet Mach number from 0.45 to 0.70. For flow structures at the corner, with the increase of inlet Mach number, corner separation is aroused earlier in the streamwise direction, say its origin is more close to the blade leading edge. However, in this process, little extension of the corner separation to the midspan from the endwall area is observed.

Fig. 6(b)–(e) are especially successful in manifesting the cascade flow structures in high subsonic environment. With negative incidence, because of the weak adverse pressure gradient, suction surface transition is not observed in the experiment (shown in Fig. 6(b)). For positive incidences, increase of incidence angle is accompanied by the upstream moving and spanwise enlargement of transition zone. With the incidence being 8°, transition zone is so close to the leading edge that the oil particles' accumulation caused by laminar
separation bubble has been greatly weakened. Here, the increase of adverse pressure gradient plays a key role in the shifting of suction surface transition. As the flow is faced with higher adverse pressure gradient, laminar boundary layer easily transits to turbulence. Under negative incidence, the adverse pressure gradient is rather weak, so in Fig. 6(b) no obvious transition zone is observed. And this must be the reason for differences between transition zones in Fig. 6(a) and (c), which is caused by the variance of inlet Mach number. In the cascade flow passage, as threedimensional separation is aroused at the corner, on the one hand more mixing of boundary layer and mainstream is followed, and on the other hand secondary flow pushes the boundary layer away from the corner region, so laminar boundary layer transition is wiped out near the endwall. With the increase of positive incidences, however, the spanwise enlargement of transition zone is observed. At higher positive incidences, corner separation aggravates and covers a much larger area in the suction surface according to the oil visualization results. But at the origin of corner separation, the transition zone extends further to the endwall because of higher adverse pressure gradient in spite of stronger corner separation vortexes.

According to Fig. 6, corner separation is made up of cross flow and reversal flow. Because of corner separation, low-speed fluid is accumulated near the endwall, resulting in the static pressure enhancement. For this reason, cross flow near the endwall on the suction surface is aroused by the pressure gap between corner region and midspan. Being the threedimensional separation, corner separation is made up of complex separation vortex structures. So apart from the cross flow, at the trailing edge, reversal flow from pressure side is caused by these vortex structures.

Under negative incidence (shown in Fig. 6(b)), the appearance of corner separation is delayed compared with the positive incidences (shown in Fig. 6(c)–(e)). However, at negative incidence, corner separation extends further to midspan compared to the work condition under design incidence shown in Fig. 6(c). So, although delay of corner separation is caused by negative incidence, no dramatic reduction of corner separation influence on the flow field is necessarily obtained.

Concentrated shedding vortex which is a common phenomenon in low-speed compressor cascade flow passage is observed in this paper. As shown in Fig. 6(e), when incidence increases to 8°/C176, the flow passage concentrated shedding vortex becomes so strong that its vortex core is observed at the blade trailing edge. In contrast, relatively weak passage concentrated shedding vortexes under smaller incidence work conditions are indicated by Fig. 6(b)–(d).

3.3 Flow loss and secondary flow

Apart from the pressurizing ability, flow loss has drawn a lot of attention in the researches of compressor cascade performance. Meanwhile, secondary flow in compressor cascade flow passage, the typical flow structure in axial compressors, is a main factor in the production of flow losses.

In this part, flow losses and secondary flow developments in the cascade passage are researched with the five-hole probe. Generally, total pressure loss coefficient is a common variable to evaluate the flow losses on many occasions. In this paper, the total pressure loss coefficient $\omega$ is defined as
The corresponding pitch averaged total pressure loss coefficient is defined as

\[ \omega = \frac{p_1 - p_2}{p_1 - p_{1s}} \]  

where \( p_1 \) is the total pressure of the incoming flow, \( p_{1s} \) the static pressure of the incoming flow, and \( p_2 \) the local total pressure.

To better evaluate the flow loss at different blade heights, the pitch averaged total pressure loss coefficient is defined as

\[ \omega_k = \frac{\sum_j \omega(x_j \Delta t)}{\Delta t} \]  

where \( \omega_k \) is the corresponding pitch averaged total pressure loss coefficient at the blade height.

To better evaluate the overall flow loss in the cascade flow passage, the mass plane averaged total pressure loss coefficient \( \omega_{pk} \) is defined as

\[ \omega_{pk} = \frac{\int_{S} \omega \nu x \, dS}{\int_{S} \nu x \, dS} \]  

where \( S \) is the area of the plane, which is chosen as vertical to the flow direction in the experiments, and \( v_x \) is the axial velocity.

**Fig. 7** shows the measured pitch averaged total pressure loss coefficients and plane averaged total pressure loss coefficients at different incidences. The data were obtained at the locations 160% chord length away from the leading edge. With the increase of the incidence, the plane averaged total pressure loss coefficients increases as well. Based on this phenomenon, the increase of inlet flow incidences is followed by the growing of overall flow losses in the compressor cascade flow passage. In other words, higher blade load is strongly related to higher cascade passage flow loss, which has long been the research focus in the compressor cascade flow control.

Although the overall flow loss in the compressor cascade flow passage obeys a rather simple variance law with the increase of incidences, the corresponding change of the total pressure loss coefficient distributions seems quite complex. In **Fig. 7**, to clearly analyze the change of total pressure loss coefficient distributions, cascade flow passage is separated into three zones: endwall zone, intermediary zone and midspan zone.

In the intermediary zone, with the increase of the incidence, pitch averaged total pressure loss coefficients increase gradually. From the intermediary zone to the midspan zone, the pitch averaged total pressure loss coefficients for negative incidence increase steeply, while the flow losses for positive incidences continue decreasing. In **Fig. 6**, according to the suction surface oil visualization results, at negative incidence, corner separation aroused from the corner of endwall and suction surface extends a little further to midspan compared with the working condition of 0° incidence. Accordingly, higher flow loss at midspan zone is aroused by negative incidence, indicating much severer deterioration of the midspan flow induced by the corner separation. On the other hand, higher flow loss for negative incidence at the midspan zone must be associated with the deterioration of flow around the blade airfoil.

In the endwall zone, a dramatic difference of the flow loss distributions between negative incidence and positive incidences can be observed. According to the analysis in the previous parts, higher incidence brings about higher blade load and passage adverse pressure gradient, which play a key role in pushing the corner separation from endwall to midspan. So, negative incidence gets higher flow loss near endwall which is mainly caused by the stronger local corner separation vortex. Besides, according to **Fig. 7**, from 0.05 to 0.15 blade height, flow losses decrease continuously for negative incidence, while in the endwall region flow losses change quite differently for positive incidences. As flow loss in the endwall zone are closely related to corner separation, the developments and structures of corner separation for negative incidence and positive incidence must be quite different. For positive incidences, from endwall to midspan, a quite similar rule is obeyed by the variances of flow loss which must be in accordance with similar flow structures in the cascade flow passage. In the endwall zone, flow loss for higher positive incidences does not enjoy much superiority over the design incidence, which is very different from the midspan and intermediary zones. At blade heights of 0.02 and 0.15, flow loss at design incidence is even higher than the work conditions of 4° and 8° incidences. To further research the corner separation structures precisely, apart from the deduction based on the flow loss, more detailed and advanced measuring technique should be employed.

To research the development of flow loss and secondary flow in the compressor cascade flow passage, several measurement planes were chosen. Then total pressure loss coefficient \( \omega \) and secondary flow were measured on the planes at design incidence. The planes are located 160%, 140%, 120%, 100%, 90%, 80% and 70% chord length downstream the leading edge, vertical to the design outlet flow. In **Fig. 8**, saddle and nodal points are marked with letters S and N respectively; PV represents the passage vortex; AL and SL represent attachment and separation lines. In **Fig. 8(e)**, LC represents limiting circle, which is a common topological structure that appears as the passage vortex rotating direction changes. Obviously, the developments of passage flow loss and secondary flow are described clearly.

From **Fig. 8(a)**, as a result of corner vortex structures, high flow loss region is aroused from the suction surface and endwall corner and is constrained to a rather small area from the start. In **Fig. 8(b)**, the high loss region leaves the corner...
and moves to the midspan while more fluid has been drawn into the high loss region. In Fig. 8(e) the further transferring and expansion of high loss region are observed. In Fig. 8(d), more flow loss at the midspan region is induced by the mixing of suction and pressure side flow. Out of the compressor cascade flow passage, according to Fig. 8(e)–(g), flow loss caused by corner separation, mixing and two dimensional airfoil separation are gradually dissipated although more fluid is absorbed into the loss region because of the action of sheering force caused by viscosity.

Encouragingly, from the secondary flow on the measurement planes, more information can be obtained on the flow structures in the compressor cascade flow passage. In the cascade flow passage, from Fig. 8(a)–(c), passage vortex PV stems from the corner and moved to the midspan along with the high loss region. Meanwhile, the size of PV increases in accordance with the expansion of the high loss region. In Fig. 8(b), an attachment line AL and in Fig. 8(c), a saddle point S0 are observed, indicating the complex flow structures in the corner separation zone, which cannot be fully captured with the five hole probe measurement method. In Fig. 8(d), because of the influence of flow mixing, more flow loss is observed in the region out of the reach of PV. To research the stability of PV, the rotating direction should be taken into consideration. Inside the cascade flow passage, rotation of PV is observed in the direction from vortex core to external flow field, which is an unstable structure according to the topological theory. In Fig. 8(e), a limiting circle LC is observed at the PV vortex core. As illustrated by Zhang and Deng, appearance of LC is a phenomenon of Hopf bifurcation and signifies the change of vortex rotating direction on cross sections vertical to its axial direction. Reasonably, in Fig. 8(f) and (g), rotation of PV is observed in the direction from external flow field to vortex core, which is a stable structure according to the topological theory. Based on the stability analysis of PV, the unstable nature of the corner vortex structures can be witnessed and this is mainly caused by the adverse and accelerating pressure gradient in and out of the cascade flow passage.

Although PV plays a main role in the development of flow structures, the influences imposed by mixing outside the cascade flow passage cannot be ignored. In Fig. 8(e), because of the flow mixing influences, a separation line SL, a saddle point S1 and a nodal point N are observed. The interaction between complex topological structures induced by flow mixing and PV results in more complicated flow structures. In Fig. 8(f), with the vanishing of S1 and N, the nodal point N1, attachment line AL and saddle point S1 are observed. Compared with Fig. 8(e), in Fig. 8(f), more influences on PV have been imposed by the flow mixing induced topological structures, because of which the scale of PV further decreases. In Fig. 8(g), however, the influence of flow mixing is greatly weakened and only the separation line SL is still observable. After all, the corner separation vortex is a more crucial factor.

Fig. 8  Flow losses and secondary flow developments in compressor cascade flow passage with $Ma = 0.7, \frac{i}{C_p} = 0°$.
to the cascade passage flow structure than the trailing edge flow mixing.

4. Impact of aspect-ratio on compressor cascade flow structure

For the experiments in this paper, as illustrated previously, the compressor cascade aspect ratio is chosen as 1.67 to make the value of solidity being 1.82, which is the same as the compressor cascade model investigated by DLR research group.22–26 In Refs.,22–26 aspect ratio of compressor cascade is set as unity and experimental results corresponding to this aerodynamic parameter are available there. As corner separation is aroused from endwall, more influence of corner separation is expected to be imposed on the compressor cascade flow structure when the cascade aspect ratio is smaller. To briefly research the impact of aspect ratio on the flow structure of high-speed compressor cascade, characteristics of high-speed compressor cascade with different aspect ratios are compared in this part.

Experimental results of compressor cascade flow structure with aspect ratio being 1.67 are obtained by this research while experimental results of compressors cascade flow structure with aspect ratio being unity are provided by Ref.22. In Ref.22, the inlet Mach number is 0.67, which is slightly lower that the inlet Mach number researched in this paper. For the ease of illustration, compressor cascade with aspect ratio 1.67 is named as B-model while compressor cascade with unity aspect ratio is named as S-model.

Fig. 9 provides a comparison of outlet pitch averaged total pressure loss distributions along blade height between high-speed compressor cascades with different aspect ratios at design incidence. According to Fig. 9, flow loss near midspan is quite similar between these two compressor cascade models while obvious deviations are observed in the region close to the endwall. Firstly, flow loss of B-model is much bigger than that of S-model near the endwall. On the other hand, the biggest flow loss of S-model is observed at the location closest to endwall while the biggest flow loss of B-model is observed a little far away from endwall. To conclude, compared with S-model, corner separation of B-model moves away from the endwall and is more sufficiently developed downstream the cascade.

Fig. 10 provides a comparison of outlet mass plane averaged total pressure loss between high-speed compressor cascades with different aspect ratios at different incidences. Generally, flow loss of B-model is much bigger than S-model. For S-model, flow loss at negative incidences is much bigger than positive and design incidences, and on the contrary, flow loss of B-model at negative incidence is slightly smaller than that of design incidence. As analyzed previously, flow loss inside the compressor cascade flow passage is mainly caused by corner separation. So differences between the experimental results of B-model and S-model must be mainly associated with different corner separation structures of these two compressor cascades.

Fig. 11 provides a comparison of midspan flow characteristics between high-speed compressor cascades with different
aspect ratios at different incidences. From Fig. 11, variance trends of midspan flow characteristics with incidences of B-model and S-model fit well. In Fig. 11(a), turning angle of B-model is bigger than that of S-model. From Fig. 11(b), axial velocity density ratio (AVDR) of B-model remains almost constant as the incidence increases from negative to design angle, while AVDR of S-model experiences an apparent increase. As the incidence increases to be positive, AVDR of B-model increase much more sharply with the incidence compared to that of S-model. Although for both the two compressor cascade, corner separation has not been extended to midspan, the blocking aroused by corner separation must be directly linked to midspan flow characteristics. So differences between the midspan flow characteristics of the two compressor cascade must be mostly caused by different structures of corner separation. In Fig. 11(c), static pressure coefficient of B-model is much smaller than that of S-model which indicates stronger flow blocking.

All in all, as has been discussed, dramatic influence of aspect ratio on the high-speed compressor cascade flow structure is observed. However, experimental results are obtained in two different wind tunnels and other geometrical and aerodynamic parameters of these two compressor cascades are not the same, so the influence of aspect ratio on high-speed compressor cascade flow still needs further and detailed investigation.

5. Conclusions

(1) On the endwall, the leading edge acceleration zone, passage cross flow zone, corner separation at the conjunction of suction surface and endwall and trailing edge separation coexist. With the increase of incidences, the aggravation of endwall boundary layer flow behavior, as well as the blade pressurizing ability, is clearly presented by static pressure distributions. With the increase of incidences, the passage pressurizing ability is enhanced while the endwall boundary layer behavior is further aggravated, but no corner separation stall is observed.

(2) On the suction surface, the transition zone and corner separation structures in the cascade passage are observed. Cross flow from the endwall to midspan is caused by corner separation, and mixing of corner boundary layer and main stream, as well as reversal flow, is caused by the corner separation vortex structures. At the corner of suction surface and endwall, boundary layer transition is wiped out by corner separation and secondary flow, and as the adverse pressure gradient increases, transition zone on suction surface extends further to the endwall.

(3) Flow loss in the cascade flow passage is mainly caused by the corner separation and the flow mixing at the passage outlet. With the increase of incidence, the overall compressor cascade passage flow loss increases. Under different incidences, apparent differences of flow loss distributions in the cascade passage are observed.

(4) As PV is scaled to bigger size while moving downstream, its rotating direction changes simultaneously, and in this process, a limiting circle is observed. Outside the cascade passage, flow mixing interacts with corner separation structures and the influence of flow mixing dissipates much faster while moving downstream.

(5) For high-speed compressor cascade, compared with low aspect-ratio model, corner separation of high aspect-ratio moves away from endwall and is more sufficiently developed downstream the cascade. Higher overall flow loss and smaller pressure rise at midspan should be related to this phenomenon.

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References


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