Experimental Investigation of Vortex Structure in Corner Region of a Linear Compressor Cascade

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Abstract

A detailed experimental investigation was carried out to examine the vortex structure in the corner region (between the end wall and the suction surface of blades) of a linear compressor cascade. A corner vortex was identified in the corner flow in the experiment. The corner vortex sheds from the pressure-driven boundary layer on the end wall in a process of three-dimensional separation. It dominates the corner flow by the strong interaction with the main flow and the boundary layer on the suction surface of blade. The difference between the corner vortex and the well-known passage vortex is discussed. A topology of the vortex structure is proposed. Furthermore, the dynamic effects of the vortex structure has been investigated, which leads to an explanation for the mechanism of corner stall in compressor cascades.

List of Symbols

- \( U_e \): inlet mean velocity
- \( Re = U_e \cdot c / \nu \): Reynolds Number based on chord blade chord length
- \( \delta \): thickness of inlet boundary layer
- \( T_i \): intensity of turbulence
- \( C_f = \tau_w / (\frac{1}{2} \rho U_e^2) \): coefficient of shear stress
- \( C_p = (p - p_o) / (\frac{1}{2} \rho U_e^2) \): coefficient of static pressure
- \( F_p = \int (C_{p+} - C_{p-}) dx \): coefficient of loading
- \( \omega_p = (p^+ - p^-) / (\frac{1}{2} \rho U_e^2) \): coefficient of total pressure loss

Subscripts

1. inlet plane
a. circumstance
+ pressure side
- suction side

1. Introduction

The flow in modern compressors with high blade loading and low aspect ratio is very complex. In many instances corner stall is accompanied with highly viscous and unsteady three-dimensional flow which is of a profound effect on the performance of compressor cascades. In order to improve the understanding to the complex flow a considerable amount of investigations concerning the end wall flow in axial compressors has been conducted. Joslyn et al. (1984) observed the corner stall on the hub of a stator. The low-momentum fluid extended up to 75% span at reduced flow rate. Dong et al. (1986) investigated the loss mechanism in a single stage low speed compressor. They observed flow separation at both ends of the stator. Tao et al. (1988) observed the corner stall in a linear compressor cascade. A possible vortex structure in the corner region was shown in Fig. 3 of the paper. Recently Schulz et al. (1988) carried out a detailed investigation into the end wall flow in an annular compressor cascade. They found that the separation in the corner region is the primary three dimensional feature of the flow. The significant secondary flow on the end wall is partly responsible for the corner separation. The secondary flow induces a vortex in the corner region. The corner separation and the secondary flow are responsible for the high loss found downstream. Furthermore Fottner (1989) described the flow phenomena in axial-flow turbomachines in a AGARD lecture series. In Fig.1 of his paper a corner vortex was taken as one of significant flow pattern at the hub of compressor rotor.

Although the vortical type flow has been widely found in the end wall flow of compressor cascades the knowledge about it is limited. This is because the three-dimensional and unsteady feature of vortices makes experimental investigation of the special structure of the vortices difficult, especially at the situation with high inlet speed and practical compressor rig.
The present paper is a summary of a series of experimental investigations for the vortex structure in the corner region of a linear compressor cascade with relatively low inlet velocity. At the low velocity the detailed observation and the measurement in the corner region became possible. It was helpful for understanding the development of the corner vortex structure and its effects on the performance of compressor cascades under the experimental condition. A new observation on the vortex structure is made from the following experimental results:

(i) the quantitative measurements of the three dimensional flow in the linear compressor cascade with a 'x' type hot wire and a five hole probe;
(ii) the measurements of the temperature distribution at the exit of the cascade;
(iii) the flow visualizations in wind and water tunnels;
(iv) the measurements of pressure and shear stress on the surface of blades.

Based on these results a description of the formation and the development of the corner vortex structure is given. The distinct characteristics of the corner flow in the compressor cascade is related to a vortex structure composed of the corner vortex and some secondary vortices. The difference between the corner vortex and the well-known passage vortex is discussed. The topology of the corner vortex structure under moderate incidences is proposed on the experimental observation. The development of the corner vortex structure at high incidences is investigated, which leads to a explanation to the mechanism of corner stall in the compressor cascade.

2. Experimental Schemes

All these experiments were carried out on the low velocity wind tunnel and water tunnel in Beijing University of Aeronautics and Astronautics (BUAA). The details of these tunnels were given by Tang et al.(1988,1990). The details of measurement techniques and the estimation of measurement error of the hot wire and the five hole probe has been given by Chen et al.(1988) and Tang et al.(1988) respectively. The flow visualization techniques have been described by Tang et al.(1990).

The technique of Preston tube used in the experiment was developed by Preston (1954). A circular tube (the out-diameter is 0.8mm, the ratio of inter- and out-diameter is 0.6) is used. On the suction surface a row of static pressure tap was arranged spanwise. Static pressure was measured by surface taps and total pressure was measured by the Preston tube whose mouth was put on the surface of the blade near the spanwise position of the static pressure tap. With the curve given by Preston, the spanwise distribution of shear stress was calculated by the measurements of static and total pressure. With this technique only the shear stress induced by the gradient of the streamwise velocity could be taken. The spanwise distribution of streamwise shear stress on the suction surface of blades can be used to measure the interaction between streamwise vortices and the boundary layer on the surface of blades.

In the temperature measurement a thermo-couple is used. A bottle of ice water was used to provide a constant reference temperature. A electro- resistance wire (the diameter is 0.35mm) was put in the inlet boundary layer normal to the mean velocity and parallel to the end wall. A high temperature flow sheet at the inlet of the cascade was generated by heating the wire (the wire was heated up to 300°C). Then the downstream development of the heated flow sheet was taken by the thermo-couple at the exit. The traverse surveys of the probe was made with a programmable three-axis traversing mechanism. The details of the mechanism was introduced by Chen(1988).

In all experiments the same compressor cascade is used. The parameters of the cascade are:

- Chord (mm): 112
- Camber angle (deg): 37.3
- Stagger angle (deg): 18.6
- Solidity c/t: 1.7
- Tip clearance (mm): 0.0
- Aspect ratio h/c: 1.1

The inlet flow conditions of these experiments are listed in Table 1.

<table>
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<th>Experiment</th>
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<th>Tk</th>
<th>δ</th>
<th>Profile</th>
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<td>1.9 x 10^5</td>
<td>18mm</td>
<td>NACA-65</td>
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*a* visualization experiments in water tunnel
*b* visualization experiments in wind tunnel
*c* experiments with the "x" hot wire
*d* experiments with the five hole probe
*e* temperature distribution measurement

3. Experimental Results and Discussion

3.1 Corner Vortex Structure (moderate incidences)

Fig.1 shows the secondary velocity vector at four measurement section inside and outside the cascade. The measurement was taken by the 'x' type hot wire at 5° incidence. The secondary flow defined by the present paper is the flow in the plane normal to the main flow. The direction of the main flow was determined by the mass-averaged flow angle at the midspan of the cascade. The axial locations of every measurement section are shown in Fig.2.

At the section 1 (Fig.1a) the end wall boundary layer is driven by pitchwise pressure gradient. The secondary flow appears near the end wall and a passage vortex starts to form.

At the section 2 (Fig.1b), a clear core of passage vortex is formed near the end wall. The passage vortex occupies half of the passage. In most of the space of the passage, the passage vortex shows itself as a vortex sheet attaching on the end wall. But in the corner region between the end wall and the suction surface of the blade a spanwise bubble structure appears near the suction surface.
At the section 3 (Fig. 1c), the passage vortex is also obvious, but the core of the passage vortex is not so clear as that in section 2. In the corner region the flow pattern changes into a complex one. It means that some new flow structures emerge in this region. A possible explanation is that the original core of the passage vortex sheds from the pressure-driven boundary layer on the end wall in the corner region, so that the initial passage vortex changes into a line vortex and a vortex sheet. The line vortex in the corner region is defined as CORNER VORTEX by the present paper and the vortex sheet is called the passage vortex. In this way the different flow behaviours in the corner region and in the other space of the passage are correspondent to different vortex structures. A possible multiple vortices structure in the corner region is shown in Fig. 1c. Here the vortex pair A is composed of the corner vortex and the secondary vortex I (SVI) which is caused by a process of secondary separation. The vortex pair below the vortex pair A is composed of two other secondary vortices. This new line vortex structure dominates the flow in the corner region. The complex flow pattern in the corner region of Fig. 1c is the result of the interaction among the corner vortex, secondary vortices and the main flow.

At the section 4 (Fig. 1d), the distribution of secondary velocity supports the analysis mentioned above. The effects of the corner vortex structure are strengthened. The larger scale of vortex pair A and B can be observed in this section. The vortices transfer the low-momentum fluid along the spanwise direction and make the strong mixing between high and low momentum fluid. This process expands the flow region which is affected by the corner vortex structure.

It is necessary to provide more experimental evidences to certify the corner vortex structure mentioned above. Flow visualization techniques provide the possibility to get sight into the spatial structure of vortical type flow. A group of pictures from the smoke visualization experiments is shown in Fig. 3. The locations of different sections, in which these pictures were taken, are shown in Fig. 2. The smoke sheet was from a heated wire (the diameter of the wire is 0.14mm) which is put in the inlet boundary layer. The distance of the wire from the end wall is 3mm. In Fig. 3a, the flow sheet is distorted in the corner region obviously, which means a three dimensional separation happens in the corner region. In Fig. 3b, a beautiful vortex pair is formed in the corner region. This vortex pair should be the development of the vortex structure which is caused by the three dimensional separation of pressure-driven boundary layer upstream. but not by the inducement of Reynolds stresses. The scale and location of the vortex pair in Fig. 3b are in good agreement with the vortex pair A in Fig. 1c.

In Fig. 3c, at the axial location near the exit of the cascade, the vortex structure is formed completely. The vortex pair near the end wall is very clear and it rotates clockwise comparing with that in Fig. 3b. Below this vortex pair, there is a bulk of fluid which is from the end wall. The vortex structure in this region is more clear in the Fig. 3d which is taken outside the cascade. In Fig. 3d the vortex pair near the end wall continues to rotate clockwise and below it a clear vortex structure appears. Comparing the Fig. 1d and Fig. 3d the scales and locations of
both vortex pair are consistent with each other.

This group of pictures shows the process of the formation and streamwise development of the corner vortex structure. These results qualitatively correspond to the results from the hot wire and support the concept about the corner vortex structure proposed above.

The interaction between the corner vortex and the boundary layer on the suction surface of blades is an important mechanism of the corner vortex structure.

Fig.4, obtained at 48% axial chord by means of a Preston tube, shows the spanwise distribution of the streamwise shear stress at 5° incidence. There are two skewing points A and B. In Fig.9 given by Cutler et al. (1986) (study on the interaction between a streamwise vortex and the boundary layer of flat plate), a concave point appears in the distribution of streamwise shear stress. It means that a streamwise vortex is imbedded in the boundary layer. The flow in the boundary layer is distorted by the lateral flow induced by the streamwise vortex. This is highly possible reason of the distribution in Fig.4.

The interaction process can be clearly observed in visualization experiments. Fig.5, taken in the water tunnel at 5° incidence, shows the shedding process of SVI. Fig.5a shows a lot of material above the corner vortex (35% axial chord from leading edge). Fig.5b (42% axial chord from leading edge) shows SVI shedding from the boundary layer. These pictures show a vivid process in which the vortex pair A is formed.

![Diagram of A and B](image)

**Fig.4** spanwise distribution of the streamwise shearing stress coefficient \((1=5°, Re=1.9\times10^6)\)

\((48\%\) axial chord\)

The corner vortex structure has distinct effects on the mean and turbulent behaviour of the flow in the corner region. The effects of the vortex structure on the mean flow is measured by tracing the deformation of flow sheet which past the cascade near the end wall. **Fig.6** shows the temperature contour taken at the exit of the cascade. As mentioned before a wire was put in the inlet boundary layer. The distances of the wire from the end wall were 8mm in **Fig.4a** and 3mm in **Fig.4b**. The distances of the wires from the leading edge were the same (3mm). **Fig.4a** shows that the inlet high temperature flow sheet forms a thickened high temperature sheet at the exit of the cascade. In this process there is only pitchwise shift and no large scale spanwise disturbance on the high temperature flow sheet. **Fig.4b** shows a different sense. The inlet high temperature flow sheet encounters the big spanwise disturbance in the passage of the cascade. At the exit of the cascade no special flow sheet exists. The high temperature fluid is heaped up in the corner region.

The difference of **Fig.6a** and **Fig.6b** gives a clue to analyse the different characteristics of the passage vortex and the corner vortex. In **Fig.6a** the high temperature flow sheet is far from the end wall at inlet, so that it enters the flow region dominated by passage vortex. The behaviour of the flow sheet at the exit shows that in this region, fluid does not encounter the significant spanwise transfer. It is a obvious evidence that there is no a concentrated vortex core in this region, so that the passage vortex is a vortical sheet, but not a line vortex. In **Fig.6b**, the high temperature fluid is near the end wall at inlet. Because of the secondary flow this fluid is transferred to corner region in which the corner vortex dominates the flow. The high temperature fluid is transferred spanwise at a large scale. This is the distinct behaviour of a line vortex structure with a concentrated vortex core. The high temperature fluid is transferred by both the direct inducement of line vortices and the local pressure distribution determined by the vortex structure.

**Fig.7** shows the distribution of turbulent kinetic energy (Fig.7a and turbulent shear stress \(\overline{w''w''}\) (Fig.7b) measured by a hot wire. It provides a sense of the effect of the corner vortex structure on the turbulence. In **Fig.7a** there are four high energy regions. These regions correspond to the high shearing regions caused by the interaction of vortex-vortex and vortex-boundary layer. The wandering of the core of vortices also makes important contribution to the production of turbulent kinetic energy. **Fig.7b** shows a regular distribution of \(\overline{w''w''}\), in which the positive regions pair up with the negative regions. In the transport equation of streamwise mean vorticity, the \(-\overline{w''w''}\) term can actually produce streamwise vorticity, although strictly speaking, this is transport rather than some terms in \(yz\) plane. However this term is equal to zero at the exit and has high values at the inlet. It shows the spatial development of a streamwise vortex structure.

A topology of the corner vortex structure at moderate incidences was deduced on the experimental observation mentioned above. **Fig.8** shows the flow topology. A is a separation saddle point in the inlet boundary layer and at this point the inlet horseshoe vortex is generated. B is another saddle point on the end wall. Point B, together with the separation node C, shows the position where the corner vortex, as the core of the passage vortex, is generated. D is a separation-spiral point on the suction surface of blades, which is produced by the interaction between the corner vortex and the boundary layer on that...
surface. From D a secondary vortex SVI sheds with a rotating direction opposite to that of the corner vortex. G is a spiral point on the end wall near the exit, which is formed by the secondary flow and a strong streamwise adverse pressure gradient. The reversed flow regions F, G, and G' are caused by the adverse pressure gradient and the low momentum fluid in the boundary layers. They exist even at the moderate incidence under the experimental condition of this paper.

From Fig. 8 it can be seen that there is a closed region near the solid walls in the cascade corner. Fluid cannot pass through this region along the solid walls. According to the principle of mass conservation, the fluid must be lifted up from the solid walls by a spatial flow structure, and then it can move out the cascade. Therefore there should be a spatial vortex structure that corresponds to the flow topology in Fig. 8.

Fig. 9 shows the vortex system mentioned above. The horseshoe vortex has two “legs”. One is leg A which develops along the pressure side of the blade, and the other is leg B which develops along the suction side. The corner vortex C gets the initial vorticity from A, then interacts with the boundary layer on the suction surface. The secondary vortex I (SVI) sheds from the spiral point D by the interaction. The C' and D' are the development of C and SVI at the exit of the cascade. At the spiral point G a spanwise vortex sheds, then bends to the streamwise direction and twins together with the corner vortex C. As mentioned above, low momentum fluid cannot pass through the cascade along the solid walls. It is the vortices the corner vortex C, SVI and the vortex from point G that induce fluid into some spatial regions in which the fluid gets kinetic energy from the main flow. A vortex pair E, E' is formed from the flow induced by the corner vortex and SVI.

Fig. 9 and Fig. 8 are the description for flow at moderate loading in a steady flow. At high loading some important changes in the flow structure take place.

3.2 Characteristics of Corner vortex structure at High Loading
Fig. 10 shows the secondary velocity vector outside the cascade. The measurement was taken by the five hole probe at different incidences. The definition of secondary flow is the same as that in Fig. 1. The axial locations of the measurement sections are shown in Fig. 2.

At the section 1 (Fig. 10a), at 0° incidence, a passage vortex occupies half of the passage. Low momentum fluid migrates along the suction surface because of the inducement of the passage vortex. There is not any obvious vortex structure in the corner region.

At the section 2 (Fig. 10b), at 5° incidence, the flow in the corner region changes into a complex one. Beside the passage vortex a multiple vortex structure, which is similar to that in Fig. 1c, appears in the corner region. The interesting phenomenon happens at the section 3 which was taken at 11.5° incidence. The passage vortex is also clear in Fig. 1c, but there is not any obvious vortex structure in the corner region. A lot of low momentum fluid migration happens in the region C. In region L reversed flow happens because unreasonable measurements of pressure (the value of static pressure was higher than that of total pressure) were found in the experiment. Normal two-dimensional separation takes place in the region S. These results mean that the corner vortex structure broke down in the passage of the cascade at a high incidence.

On these experimental results, the passage vortex exists at the exit of the cascade from low to high incidences. The characteristics of the corner vortex structure depend on the change of incidence. The corner vortex emerges within the passage at both moderate and high incidences, but it develops into a complete vortex system at the exit of the cascade only at the moderate incidence. At a high incidence the corner vortex breaks down in the passage of the cascade.

At a high incidence obvious reversed flow appears in the corner region of the cascade. Fig. 11 taken in water tunnel, shows the reversed flow near the end wall at 8.5° incidence. The red fluid, which is from the holes on end wall at the inlet, branches into two streams. One of them flows down to the trailing edge, and the other turns back to the leading edge. This phenomena was not observed at moderate incidences.

In Fig. 12a the red fluid is from the hole row near the leading edge on the suction surface of the blade. It shows the reversed flow on the suction surface of a blade both at leading and trailing edges at 11.5° incidence. However, there is no reversed flow observed in the leading edge region at 5° incidence (Fig. 12b).

Fig. 13a was taken in water tunnel at 11.5° incidence. The blue fluid is from the hole row on the end wall at inlet. It forms a smoothing streamline in the region of 25% axial chord, then twines together with red fluid forming the core of the corner vortex. At the location of 45% axial chord the vortex core is disturbed at a large scale. In the experiment the severe shaking of the vortex core was observed at this location, then the diameter of the vortex core was expanded suddenly downstream as that shown in Fig. 13a.

Fig. 13b shows the end wall flow of the cascade in the wind tunnel at 10° incidence. Here the smoke sheet was generated by the electrically heated wire near the end wall at the inlet of the cascade. The smoke sheet twines together at first in the corner region, indicating the formation of the corner vortex. Then a sudden expansion of the vortex core happens. This process is similar to that in Fig. 13a.

Vortex breakdown is a large scale disturbance on a vortex structure. One of the important features of vortex breakdown is a sudden expansion of the diameter of the vortex core, and the other is the appearance of reversed flow in the vortex core region. The first character of vortex breakdown has been observed in Fig. 13 from the flow visualization experiment at low Reynolds number. The measurement at high Reynolds number by five
hole probe provides the second character of vortex breakdown (Fig.10c). From these results it is reasonable to consider that the breakdown of the corner vortex structure is a important feature of the corner flow at a high incidence and that it should be related to the obvious reversed flow in the corner region at high loading.

3.3 Dynamic Effects of Corner Vortex Structure

Fig.14 shows the distribution of static pressure coefficient \( C_p \) at 11.5° incidence with different distances \( y \), between the measurement sections and the end wall.

The distribution of a loading coefficient \( F_p \) (Fig.15) is helpful for understanding the behaviour of the loading structure in Fig.14. The characteristics of the distribution of the loading coefficient \( F_p \) (Fig.15) are as follows:

(i) With the increase of incidence an obvious change of loading coefficient happens only in the front part, about 40% axial chord from the leading edge, while the change in the rear part is quite small. It implies that at high incidences the increase of loading is undertaken mainly by the front part of blades.

(ii) At an incidence, 5° or 11.5°, the loading in the region near the leading edge (20% from the leading edge) at the sections near the end wall is higher than that at midspan. With the increase of incidence, the increase of leading edge loading at the sections near the end wall is much higher than that at midspan.

The point (i) seems to be the general behaviour of subsonic compressor cascade. In Fig.7 given by Schulz et al. (1988) the low-pressure region shifts to the leading edge on the suction surface with the increase of incidence. It means the rapid loading increase near the leading edge as that described in the point (i), although the experiment (Schulz et al. 1988) was carried out in an annular compressor cascade with high inlet velocity.

The point (ii) means that the overloading happens near the leading edge with the increase of incidence. It is interesting that the same tendency can be identified in Fig.7 of [4] at the hub of the cascade. The overloading causes large pressure gradient in both streamwise and spanwise directions around the leading edge of the corner region. A explanation for this loading structure is given in Fig.16. Fig.16 shows the flow at the leading edge of the corner region schematically. Here the mean streamline A is stretched by the interaction between the horseshoe vortex B.
and the corner vortex C. At high incidence the corner vortex is strengthened and is shifted close to the leading edge. These make stronger the stretch of the inlet mean streamline, which makes significant contribution to the low pressure at the leading edge. This flow mechanism has got further experimental evidences. Tang et al. (1988,1990) introduced a control vortex at the leading edge of the corner region. The control vortex relaxed the stretch of the inlet mean streamline, then the obvious decrease of the loading around the leading edge of the corner region was observed. The significant loss reduction was got by this method.

Fig. 17 shows the contour of total pressure loss coefficient $\omega_{p}$ at 0° incidence (Fig.17a), 5° incidence (Fig.17b), and 11.5° incidence (Fig.17c) taken by the five hole probe. The high loss region located near the corner region is a common feature of the contour from moderate to high incidences. Quantitatively, the mass-averaged total pressure loss increases 7% from 0° to 5° incidence, and 44% from 5° to 11.5° incidence. More than half of the loss increase happens in the corner high loss region. It is reasonable to relate the change of the loss structure to the change of the flow structure at different incidences.

At 0° incidence the loss distribution (Fig.17a) corresponds to an attached boundary layer flow on the end wall and the blade surface.

At 5° incidence a high loss region appears in the corner, indicating the formation of the corner vortex system. The mechanism causing the new losses in this process is:
(i) the 3D separation process in which the corner vortex and SVI are generated;
(ii) the fluid migration along the blade surface induced by the vortex system;
(iii) mixing between low and high moment fluid in the corner vortex structure.

At 11.5° incidence the corner vortex structure breaks down in the passage of the cascade. Obvious reversed flow takes place in the corner region. These processes make important contribution to the loss increase at high incidence.

4. Summary

(i) Characteristics of the corner vortex

The corner vortex is generated in a process of three dimensional separation as the core of the passage vortex under moderate loading. Except the region of the vortex core the passage vortex shows itself as a vortex sheet which occupies half of the passage. With the interaction between the vortex and the boundary layer on the surface of blades, the corner vortex sheds from the boundary layer on the end wall and forms a vortex pair with the SVI which sheds from the boundary layer on the suction surface of blades. The passage vortex also maintain the character of vortex sheet. The corner vortex pair rotates in the same direction as that of the passage vortex, although the corner vortex and SVI rotate in different directions respectively in the vortex pair. At high loading the corner vortex breaks down in the passage of the cascade. This large-scale disturbance destroys the vortex structure in the corner flow, but the passage vortex continues to exist as a vortex sheet at the exit of cascade. Therefore, unlike the passage vortex, the flow pattern of the corner vortex depends on the change of incidence.

The corner vortex dominates the corner flow in compressor cascades at moderate-high incidences. The effects of the passage vortex on the corner flow is relative small. In the region dominated by the passage vortex there are not the large-scale deformation of mean flow sheet and the obvious generation of turbulence. Oppositely, mean flow sheet encounters a tremendous deformation and a lot of generation of turbulence takes place in the corner region.

(ii) The topology of corner vortex structure

The topology of the corner vortex structure provides the basic concepts of the corner flow at moderate incidences. It
qualitatively describes the shedding process of the corner vortex, the relations of different vortices in the corner region and the interaction between the corner vortex and the boundary layer.

At high incidences flow pattern changes into a complex one. Some unsteady process, such as the intermittent reversed flow and the breakdown of the vortex structure, may happen. The topology at moderate incidence provides the clue for understanding the complex flow at high incidence.

(iii) The dynamic effects of the corner vortex structure

The corner vortex structure has a direct effect on the loss-load mechanism. One of important disadvantage of the vortex structure in the compressor cascade dealt with by this paper is that near the end wall, the loading around the leading edge in the corner region increase too fast with the increase of incidence because of the interaction between the corner vortex and the horseshoe vortex. The overloading on the flow at the leading edge destroys the flow structure, induces the reversed flow at the leading edge of the blades and makes the corner vortex breakdown in the passage of the cascade. These give rise of a rapid increase of loss and blockage in the corner region. In other words the overloading around the leading edge in the corner region is an important reason of corner stall.

References

[10] A.D. Cutler et al. 1986 The interaction between a strong longitudinal vortex and a turbulent boundary layer. AIAA 86-1071