# Control of the Vortex Breakdown on a Delta Wing by Blowing

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## Abstract

*Although a delta wing is adequate to flight in supersonic speed, it has a problem that the lift slope is smaller than a rectangular wing in low speed. So, high angle of attack is needed to acquire large lift force when it flies in low speed. However, when an angle of attack becomes very high, the vortex breakdown occurs on a delta wing. Then it reduces the aerodynamic performance of a delta wing. However, there is little study about the comparison of effects of different blowing positions. In this paper at first, the characteristics of the leading edge vortex before vortex breakdown or after vortex breakdown were studied by the low speed wind tunnel experiment. Next, in order to control the vortex breakdown, blowing of several different conditions are curried out and effects are investigated. It is shown that magnitude and position of the vortex breakdown vary according to amounts of blowing, blowing speed and blowing positions. The effective blowing position to recover the vortex breakdown is near the vortex breakdown position.*

## 1.Introduction

The leading edge vortex occurs on the delta wing and it generates vortex lift force. But the angle of attack becomes very high, the vortex breakdown occurs on a delta wing and the region where the vortex breakdown occurs cannot generate vortex lift force. So to recover the vortex breakdown is very important problems for a delta wing.

Since the aerodynamic performance of a delta wing can be improved by controlling the vortex breakdown, there are many studies of the aerodynamic performance of a delta wing and the flow control techniques. One of them is blowing.

The characteristics of the vortex breakdown were studied using the laser light sheet technique and visualization[1]. They revealed that there are two types of vortex breakdown on the 85 degrees delta wing. One is bubble mode and the other is spiral mode. The two modes were seen to transform from one to the other at random. The measurement shows that when the vortex breakdown occurred, the core flow was transformed from a jet-like to a wake-like. Reynolds number effects were investigated[2]. When angle of attack was small relatively, the vortex breakdown point was insensitive to the Reynolds number. But at high angle of attack, the vortex breakdown delays as Reynolds number increases. Moreover the blunt leading edge was seen to significantly delay the vortex breakdown compared with the sharp edge delta wing.

Many blowing techniques for the controlling the flow were studied. One of them is along-core blowing[3]. It is found that the highly sensitive character of the central region of the vortex core occurs not only in the along core direction but also in the circumferential direction. Furthermore spanwise blowing[4], [5] was studied too. These blowing were carried out by near the apex of the delta wing and lead to the substantial delay of the vortex breakdown. On the other hand, trailing edge blowing was studied and there are two blowing types. As for them, directions of blowing differ. One of them is at right angle to trailing edge[6), 7)]. The other type is parallel to trailing edge. This type is called as trailing edge lateral blowing[8)]. These blowing also delay the vortex breakdown.

However, these results cannot compares easily because experimental conditions are different. The comparisons of effects against the vortex breakdown by different blowing conditions have not studied in detail. In this paper at first, the characteristics of the leading edge vortex before the vortex breakdown or after the vortex breakdown and velocity distributions of the leading edge neighborhood were studied by the low speed wind tunnel experiments using the constant temperature two-dimensional hot-wire anemometer[9)]. Moreover, controlling the vortex breakdown by different blowing conditions, effects of the blowing against the recovery of the vortex breakdown were investigated.

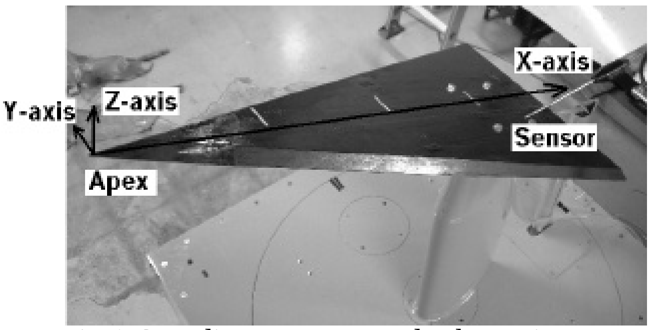



Fig.1 Coordinate system and schematics.

## 2.Experimental Method and Results

### 2.1. Experimental Method

Experiments have been carried out in the low speed wind tunnel at Tokai University. The working section size of the wind tunnel is $1.5*1.0m^2$ with a length of 2m. The wind speed can be varied from 0 to 43 (m/s).

The X-type two-dimensional hot wire probe was used to obtain velocity distributions. The two-dimensional hot wire probe is moved to any positions by the three-dimensional traverse system.

The coordinate system and schematics of experiments are shown in Fg.1. The origin of the coordinate system in this study is the apex of the delta wing. The mainstream direction is X-axis and time averaged velocity is U (m/s). The spanwise direction is Y-axis and time averaged velocity is V (m/s). The lift force direction is Z-axis and time averaged velocity is W (m/s). The speed of uniform flow for experiments is 12.5(m/s) and the turbulent intensity is below 0.2%.

A delta wing model used for experiments is shown in Fig.2. This model is made of wood and six aluminum pipes are passed inside the model for blowing as shown in Fig.2. Chord length is 80 (cm) and the swept angle is 76 degrees. Maximum trailing edge length is 40(cm). Wing model thickness is 1.4(cm) and leading edge is sharp. Reynolds number on the basis of the chord length is about $6.4*10^5$. Blowing directions and positions are also shown in Fig.2. In CASE1, the blowing is carried out at X=16(cm) position from the apex. In CASE2, at X=45(cm) position. CASE3 is trailing edge lateral blowing. The diameter of the blowing area can be changed. The diameters are 5.9(mm), 4(mm) and 3(mm). The amounts of the blowing are 40 (L/min) and 80 (L/min) in this study. Data processing system is shown in Fig.3.

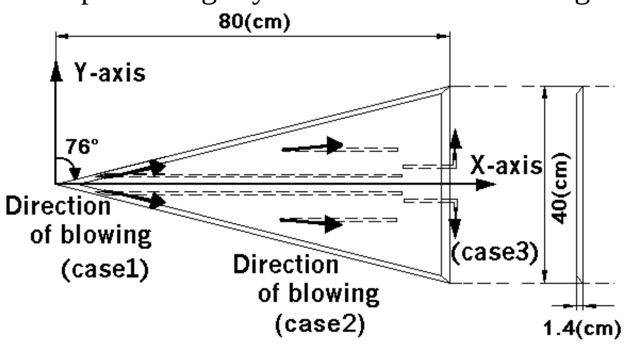



Fig.2 Wing model and directions of blowing.

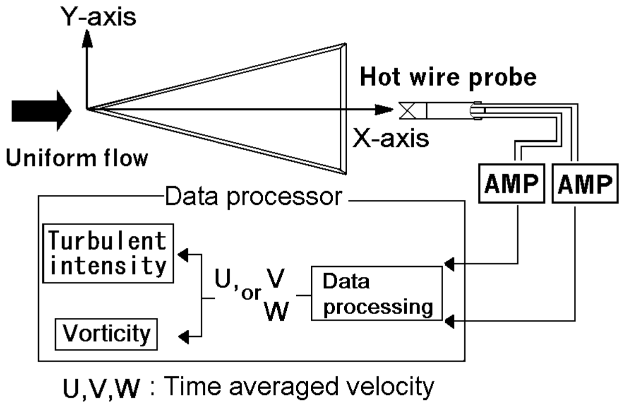
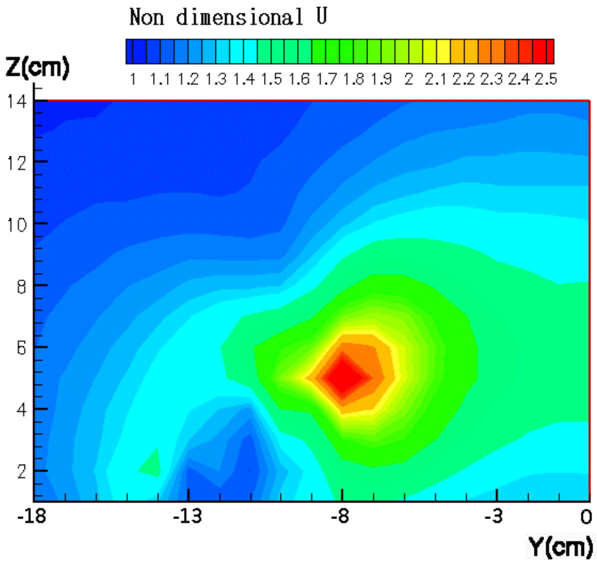


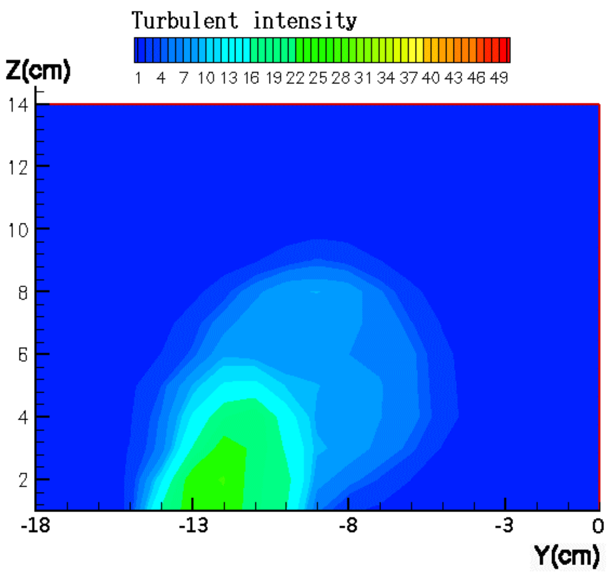

Fig.3 Data processing system.

## 2.2 The leading edge vortex without blowing

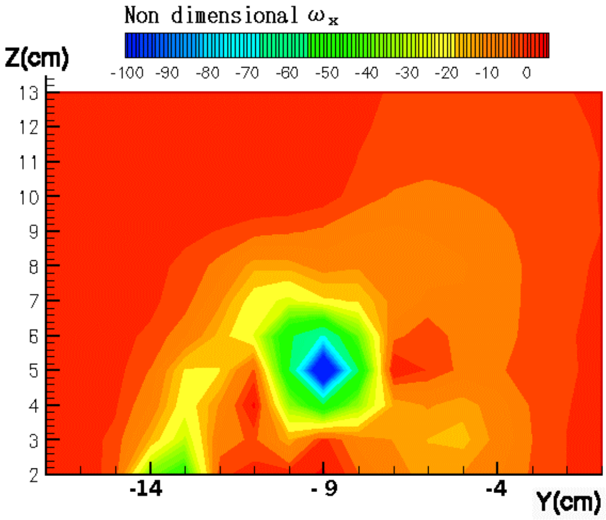
Distributions of the X-component velocity U normalized by the speed of uniform flow and the turbulent intensity of the mainstream direction (%) at positions of X=50(cm), Y=-18(cm)~0(cm), Z=1(cm)~14(cm) for 28 degrees of angle of attack are shown in Fig.4 (a) and (b), respectively. Fig.4 (c) shows X - vorticity normalized by maximum chord length and the speed of uniform flow. The turbulent intensity and X-vorticity is given by




(a) X-component velocity U normalized by the speed of uniform flow.




(b) Distribution of turbulent intensity.



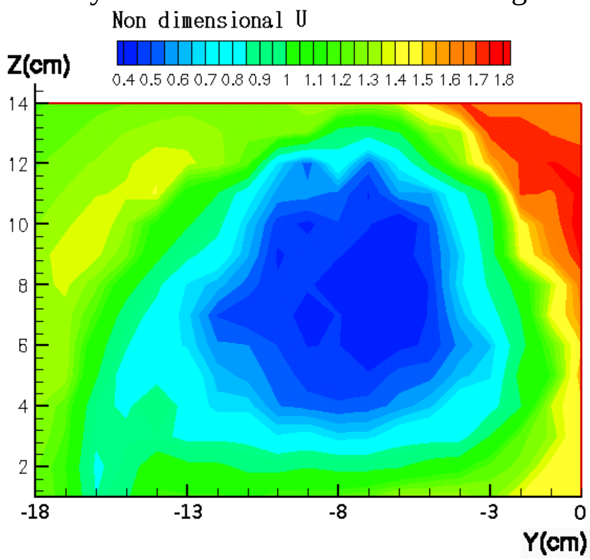

(c) Distribution of X-vorticity.

Fig.4 Distributions of leading edge vortex.
(Angle of attack is 28 degrees)

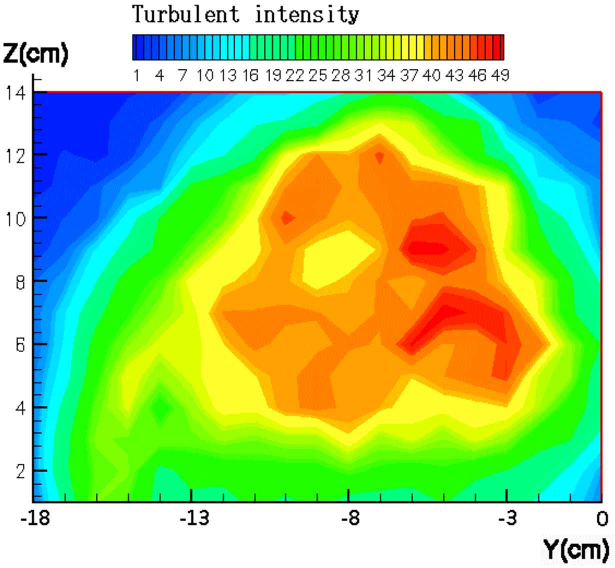
$$TI = \frac{\left[\frac{1}{n}\sum (u)^2\right]^{1/2}}{U} \times 100(\%) \qquad ,(1)$$

$$w_x = \frac{\partial W}{\partial Y} - \frac{\partial V}{\partial Z} \qquad ,(2)$$

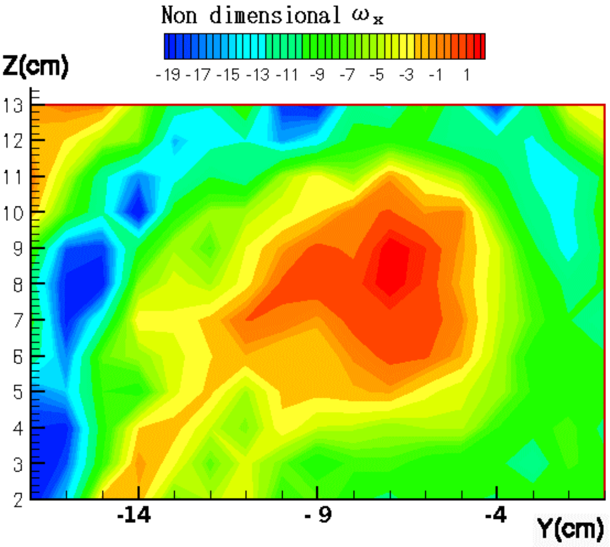
where u is the fluctuation velocity of the mainstream direction. In this case, the leading edge vortex does not breakdown. The velocity of near the vortex core becomes about 2.5 times the uniform velocity. If the X-component velocity near the vortex core is larger than




(a) X-component velocity U normalized by the speed of uniform flow.




(b) Distribution of turbulent intensity.




(c) Distribution of X-vorticity.

Fig.5 Distributions of leading edge vortex after vortex breakdown.

(Angle of attack is 36 degrees)

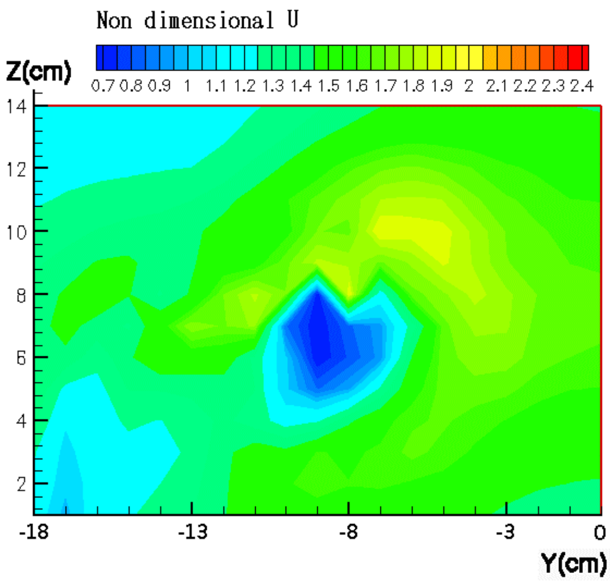
the near field one, the vortex breakdown does not occurred. Moreover the turbulent intensity is small and X-vorticity near the vortex core is very large.

However, if the X-component velocity near the vortex core is smaller than the near field one, the vortex breakdown occurred. Fig. 5(a), (b) and (c) show distributions of normalized U, turbulent intensity of the mainstream direction (%) and X-vorticity at X=60(cm) for 36 degrees of angle of attack. In this case, the vortex breakdown occurred on the delta wing. The turbulent intensity near the vortex core becomes very large and X-vorticity near the vortex core becomes small compare with the near field one.

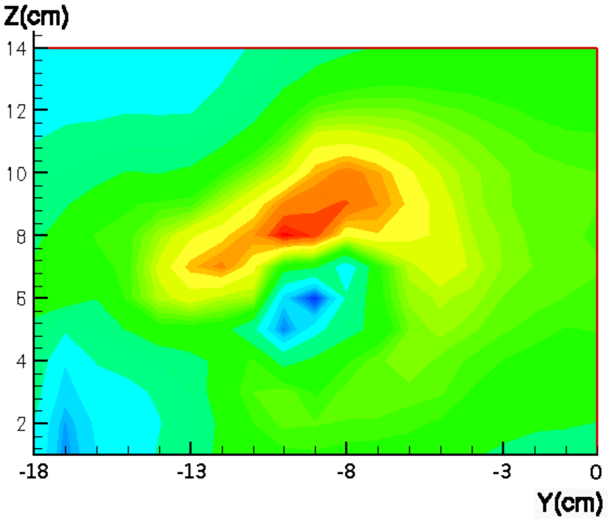
## 2.3. The leading edge vortex with blowing

### 2.3.1. Effects of blowing positions

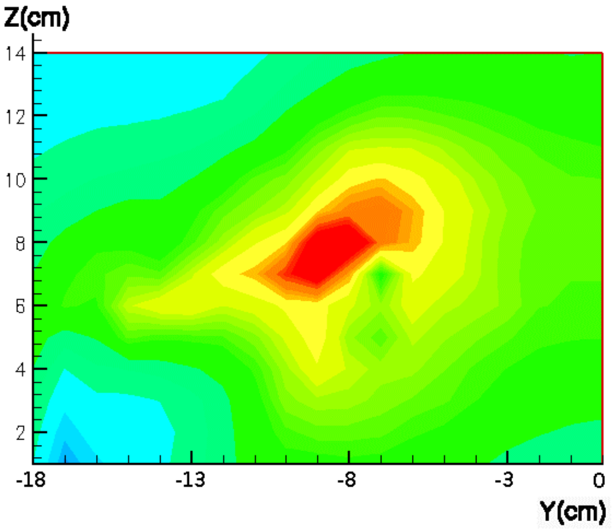
Blowings are carried out at X=16(cm) (CASE1) and X=45(cm) (CASE2) for 32degrees of angle of attack. The vortex breakdown occurred near X=50(cm) position. Fig.6 (a) shows distributions of normalized U without blowing at X=60(cm) position from apex. Then Fig.6 (b) and (c) show distributions of normalized U with blowing for CASE1 and CASE2, respectively. Amounts of blowing are 80(L/min) and diameter of blowing area is 5.9(mm). Comparing with these results, low velocity region near the vortex core becomes small by blowing regardless of the blowing positions. But normalized U near the vortex core in CASE1 still has small value. In CASE2, normalized U near the vortex core is larger than the near field one and the velocity of near the vortex core becomes about 2.5 times the uniform velocity. In other wards, vortex breakdown does not occur in CASE2. Blowing near the place where the vortex breakdown occurs can give higher energy to the vortex. So, CASE2 is more effective to recover the vortex breakdown than CASE1.




(a) Distribution of U with zero blowing.




(b) Distribution of U with CASE1 blowing.

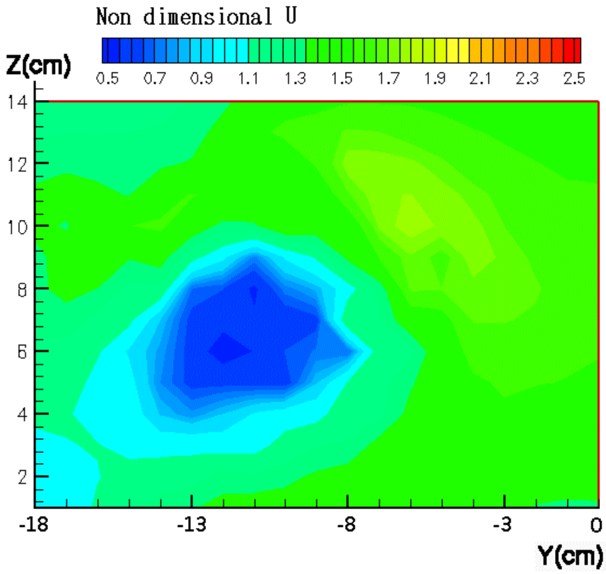



(c) Distribution of U with CASE2 blowing.

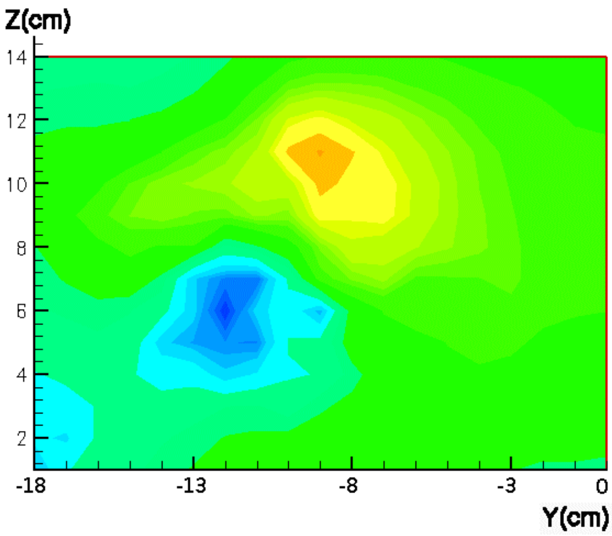
Fig.6 Distributions of U at X=60(cm) position.

### 2.3.2. Effects of amount of blowing and blowing area

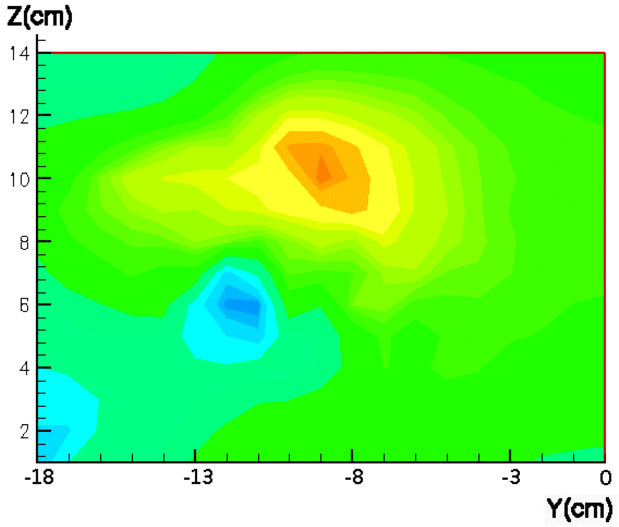
Blowing is carried out at X=45(cm) (CASE2) for 31 degrees of angle of attack. In this case, the vortex breakdown occurs near X=50(cm) position from apex. Fig.7 (a) shows distributions of normalized U at X=70(cm) without blowing. Fig.7 (b) and (c) show distributions of normalized U with blowing. Amounts of blowing are 40(L/min) and diameters of blowing area are 4(mm) and 3(mm), respectively. Fig.7 (d) and (e) show normalized U with blowing. Amounts of blowing are 80(L/min) and diameters of blowing area are 5.9(mm) and 4(mm), respectively. Comparing with Fig.7 (a), (b), and (c), low velocity region near the vortex core becomes small for 3(mm) diameter blowing rather than 4(mm) diameter blowing even if the same amounts of blowing. Because blowing area becomes small, blowing speed becomes faster. As a result, higher energy was generated. Comparing with Fig.7 (d) and (e), amount of blowing is one of the important factors to recover the vortex breakdown. Two maximum points of normalized U are shown in Fig.7 (e). The point at Y=-15(cm) and Z=10(cm) is the maximum velocity point because of the blowing.



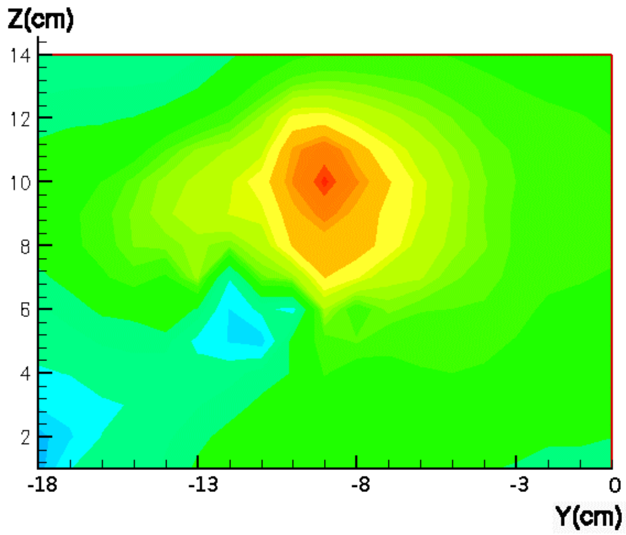

(a) Distribution of U with zero blowing.



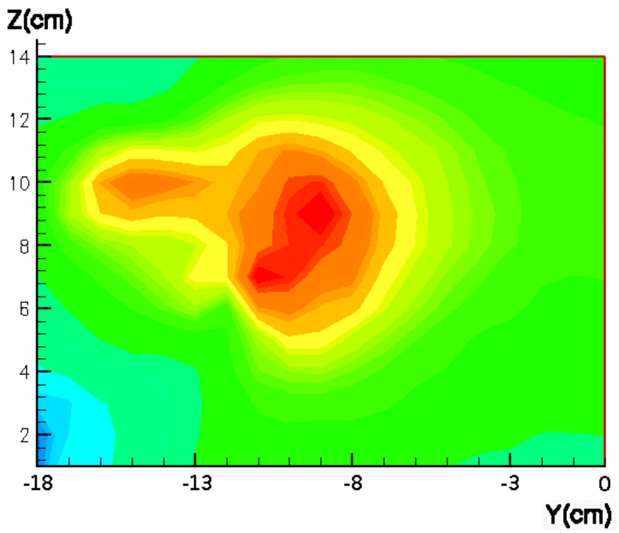

(b) U for 4(mm) diameter and 40(L/min).



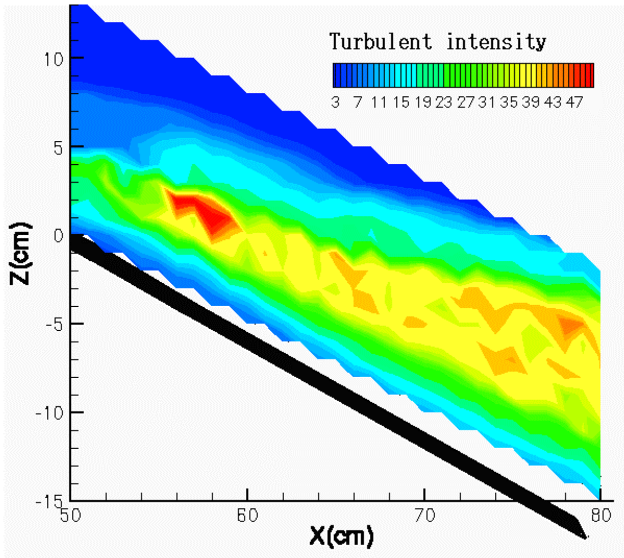

(c) U for 3(mm) diameter and 40(L/min).



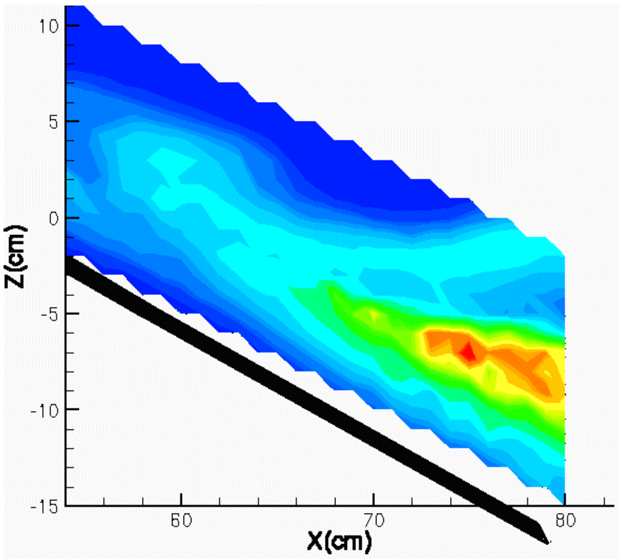

(d) U for 5.9(mm) diameter and 80(L/min).




(e) U for 4(mm) diameter and 80(L/min).
Fig.7 Distributions of U at X=70(cm) position.

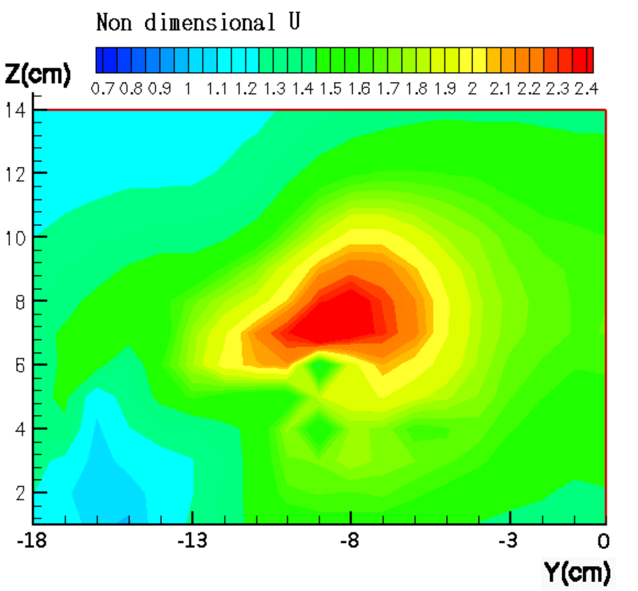



(a) Turbulent intensity of zero blowing.

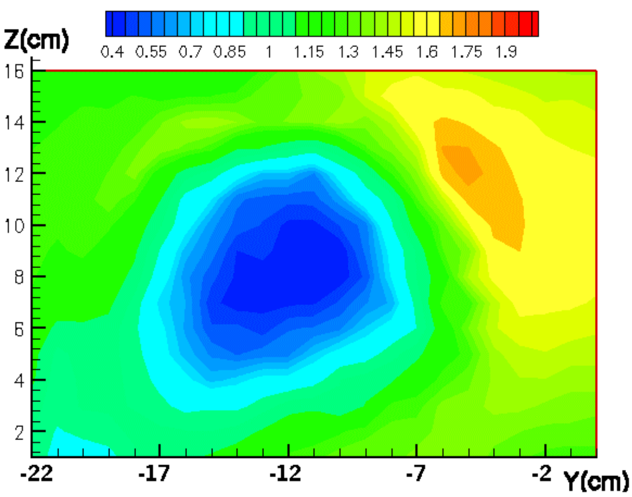



(b) Turbulent intensity of 80(L/min) blowing.
Fig.8 Distributions of turbulent intensity.

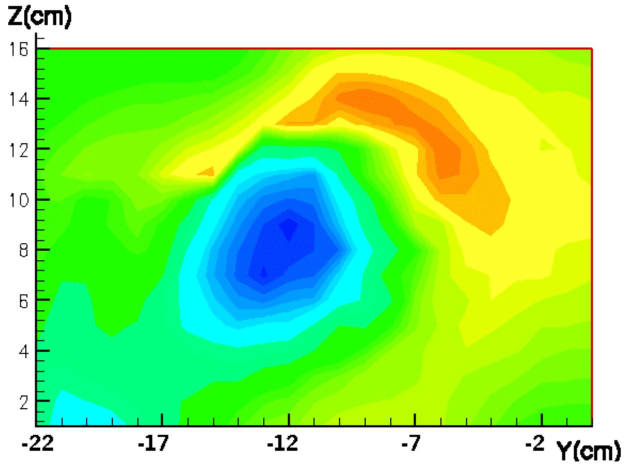
Fig.8 (a) shows distributions of turbulent intensity of the mainstream direction (%) across the vortex core at positions of X=50(cm) ~ 80(cm) without blowing. The black broad line  shows the delta wing. In this case, the vortex breakdown occurs at all X-positions so that turbulent intensity is very high at all over the X - positions. High turbulent intensity area expands to +Z direction rather than –Z direction and becomes large as it flows downstream. Fig.8 (b) shows distributions of turbulent intensity of the mainstream direction (%) across the vortex core at positions of X=54(cm) ~ 80(cm) with blowing. Amount of blowing is 80(L/min) and diameters of blowing area is 4(mm). Comparing with these results, high turbulent intensity area becomes small by blowing until about X=74(cm). After this position, the vortex breakdown begins and turbulent intensity becomes larger. Thus, it is shown that blowing not only recovers the vortex breakdown but also reduces turbulent intensity.



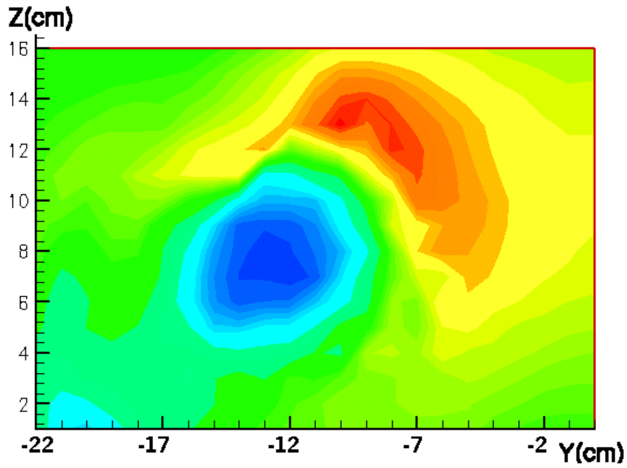

(a) U with lateral blowing at X=60(cm) position.




(b) U with zero blowing at X=80(cm) position.




(c) U with lateral blowing at X=80(cm) position.




(d) CASE2 blowing at X=80(cm) position.

Fig.9 Distributions of lateral blowing.

### 2.3.3. Effects of trailing edge lateral blowing

Lateral blowing was carried out for 31 degrees of angle of attack. Amount of blowing is 80(L/min) and diameter of blowing area is 5.9(mm). Fig.9 (a) shows distribution of normalized U at X= 60(cm) position. It is shown that the vortex breakdown does not occur at this point by lateral blowing. Fig.9 (b), (c) and (d) show normalized U at X=80(cm) position. Comparing with these results, lateral blowing can recover the vortex breakdown. But the effect of lateral blowing is a little weaker than the effect of CASE2 blowing.

## 3.Conclusion

We studied experimentally the effects of blowing against the vortex breakdown. As the result, we conclude followings:

1. Characteristics of the leading edge vortex before or after the vortex breakdown.

The characteristics of the leading edge vortex are studied by wind tunnel experiments using hot wire anemometer. The velocity of near the vortex core of the leading edge vortex before the vortex breakdown becomes about 2.6 times the uniform velocity. After the vortex breakdown, X-component velocity near the vortex core is smaller than the near field one. All over measurement points before the vortex breakdown, turbulent intensity is small and X-vorticity near the vortex core is very large. Turbulent intensity near the vortex core becomes very large and X-vorticity near the vortex core becomes small compare with the near field one.

2. Effects of several blowing conditions.

To recover the vortex breakdown, blowing was carried out and comparisons of effects of blowing against the vortex breakdown by different blowing conditions were studied. It is shown that onset of the vortex breakdown is moved to downstream according to amounts of blowing, blowing speed and blowing positions. The most effective blowing case to recover the vortex breakdown in this study was CASE2.

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