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A PIV STUDY ON A DELTA WING(LEX) MODEL FLOW IN MODERN AIRCRAFT

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ABSTRACT

Highly swept leading edge extensions(LEX) applied to delta wings have greatly improved the subsonic maneuverability of contemporary fighters. Fundamental approach by PIV method was adopted to study the basic flow of the vortex pair formation appearing on a delta wing model with or without LEX. Three angles of attacks(16°, 24°, 28°) and four measuring section of chord length(LEX-on) and three section(LEX-off) were selected as experimental conditions. From the PIV analysis, maximum vorticity was found at a given chord length and maximum velocity was also detected at larger chord length where stronger vortex was generated. Furthermore, the effect of LEX was remarkable at the vortex pair distance indicating narrower distance at LEX-on case.

1. INTRODUCTION

The flow over a delta wing at an angle of attack is dominated by the two leading-edge vortical structures. Those consist of two vortex sheets that shed from the leading edges of the wing and roll up to form two axial vortices. The geometry is nearly conical, as long as the vortices develop over the surface of the wing[1]. Highly swept leading edge extensions(LEX) applied to delta wings have greatly improved the subsonic maneuverability of contemporary fighters. The LEX vortices generated at high angles of attack improve the maximum lift capability of the basic wing by way of induced suction over the inboard surfaces directly under the vortices and additionally through beneficial interaction with the separating flow outboard on the wing[2].

In this study, fundamental approach by PIV experimental method was adopted to study the basic flow characteristics of vortex pair formation appearing on a delta wing model with or without LEX for three angles of attacks(16°, 24°, 28°) and four measuring sections of chord length(LEX-on) and three sections(LEX-off). High resolution CCD camera and synchronizing system with an illuminating laser was featured to obtain the reliable PIV data. Distribution of time-averaged velocity vectors and vorticity upon the delta wing model was compared among the chord length sections. Quantitative vorticity and maximum velocity were also discussed to signify the magnitude of the spanwise vortex pairs

2. EXPERIMENTATION

Figure 1 show the dimension of model delta wing with or without LEX. In case of LEX-off wing, the chord length is 14.5cm and the swept angle is 65°. The measuring section is three(30%, 60%, 80% of chord length). In LEX-on delta wing, the chord length is 17.5cm and its measuring sections are four(30%, 43%, 60% and 80% of the chord length). The two models were made of acrylic plate by NC machine cutting. The surface of the model was pasted with black paper for good particle images on CCD camera. These models were fixed to the bottom plate within a closed water circulating tunnel. Its measuring cross section is 200mm x 200m. The water tunnel was transparent at all walls to secure good access of the camera and illumination laser. The laser was selective. Nd-Yag dual pulse laser(100mJ) or continuous Argon-Ion laser(5W) was adopted at initial stages. As the upstream velocity is slow, Argon-Ion

laser with 1K x1K digital CCD camera was applied with the support of an optimized pulse generator(max. resolution is 10 ns), The operating water was tapping water(7℃) and the approaching water velocity was 0.17m/sec. The corresponding Reynolds number with the 17.5cm of the LEX model was 2.12 x 10^4. The Reynolds number of LEX-off(14.5cm chord length) was 2.12 x 10^4 with the inlet velocity of 0.21m/sec. The illuminating light from the Argon-Ion laser through a cylindrical lens was directly used without any light delivery system such as fiber optic cable. Table1 is a summary of the present experimental condition.

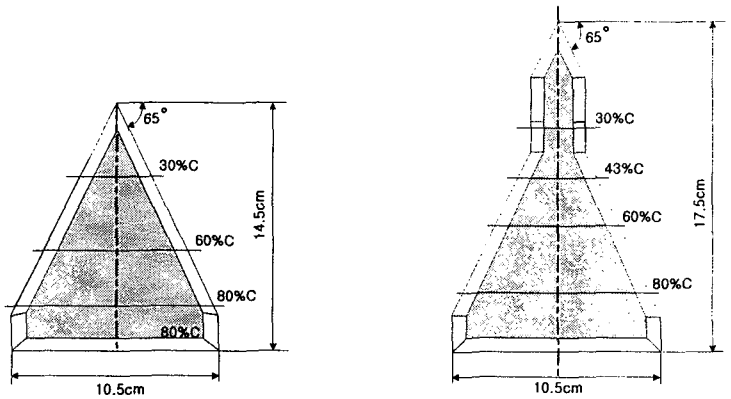


Fig.1 Dimension of Delta Wing Model(left:LEX-off, right:LEX-on)

Table 1 Experimental Conditions

	Item	Specification
Visualization Equipment	CCD camera	1K x 1K
	Light Source	Argon-Ion Laser
	Sheet Light	Cylindrical Lens
Measuring Condition	Working Fluid	Tap Water
	Temperature	7℃
	Particle	PVC
Image Processing	Host Computer	Pentium IV PC (1.7GHz)
	Calculation Time	20 sec/frame
	Number Data for Time-averaged	200 Frames
	Identification	Cross Correlation PIV *(FlowInside3.0)*
	Ratio of Error Vector	less 1%/ frame

The tracer particle was PVC and its average diameter was 120μ m. The input camera was a digital CCD camera(resolution is 1K x 1K, KODAK). 200 consecutive images were first captured and their grey levels at all pixel positions were averaged to produce a background image. This image was then used as a reference image data to reduce the grey level of any original image processed. This procedure was very effective to eliminate any noisy components found in flow images. Various pre-processing techniques adopted in PIV software were

implemented to improve the efficiency of the identification. The cross-correlation algorithm by direct calculation of the coefficients from the two consecutive images was adopted. The interrogation area was 41 x 41 pixels and the maximum displacement was 8 pixels. The sampling interval was 1/15 seconds for the 200 consecutive data in case of the single time-average processing. The pulse interval of the pulse generator was 5 ms and the pulse width was 100μ s. Table 2 shows the list of the measuring section.

Table 2 Measuring Section

LEX-off	x/c	x/c	x/c	LEX-on	x/c	x/c	x/c	x/c
α =16°	0.3	0.6	0.8	α =16°	0.3	0.43	0.6	0.8
α =24°	0.3	0.6	0.8	α =24°	0.3	0.43	0.6	0.8
α =28°	0.3	0.6	0.8	α =28°	0.3	0.43	0.6	0.8

3. RESULT AND DISCUSSION

Table 3 indicates a summary of the absolute maximum vorticity found in the experimentation of the delta wing with or without LEX. In case of LEX-off, the maximum vorticity was found at the 60% chord for 16° and 24° AOA(angle of attack). But at 28°AOA, the maximum value was found at the 30% chord. It is not yet clear whether this phenomenon is common at other flow condition. At LEX-on, different distribution of the maximum values were found.

Table 3 Absolute Maximum Vorticity

LEX-off	Vorticity	LEX-on	Vorticity
16°: 30%C	0.0224	16°: 30%C	0.0232
16°: 60%C	0.0380	16°: 43%C	0.0294
16°: 80%C	0.0311	16°: 60%C	0.0381
24°: 30%C	0.0319	16°: 80%C	0.0450
24°: 60%C	0.0366	24°: 30%C	0.0257
24°: 80%C	0.0260	24°: 43%C	0.0426
28°: 30%C	0.0411	24°: 60%C	0.0474
28°: 60%C	0.0265	24°: 80%C	0.0461
28°: 80%C	0.0238	28°: 30%C	0.0434
		28°: 43%C	0.0428
		28°: 60%C	0.0476
		28°: 80%C	0.0402

Table 4 shows the maximum velocity found in the model wing test. This data symbolize the magnitude of any momentum or kinetic energy produced by the spanwise vortex pairs shedding from the leading edge of the delta wing. For example, at LEX-off, 0.777 m/sec at 16°AOA and 80% chord is nearly 4 times larger than the inlet velocity(0.21 m/sec). And, in case of LEX-on, at 28°AOA, 0.731 m/sec is sufficiently 4 times larger than the approaching velocity(0.17 m/sec). This high rotational velocity can give a negative pressure upon the delta wing surface producing upward lift effect necessary in modern aircraft.

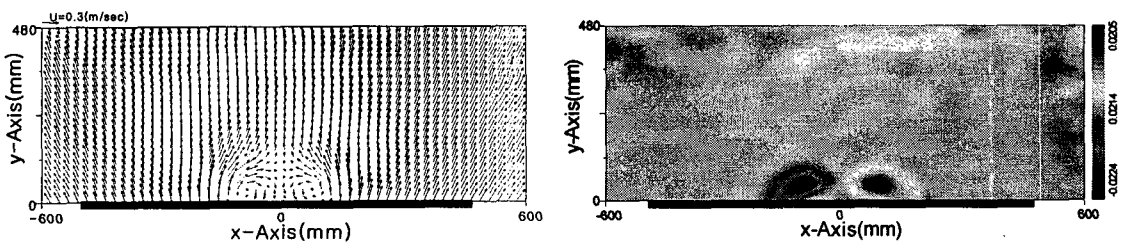
Table 4 Maximum Velocity

LEX-off	Velocity(m/s)	LEX-on	Velocity(m/s)

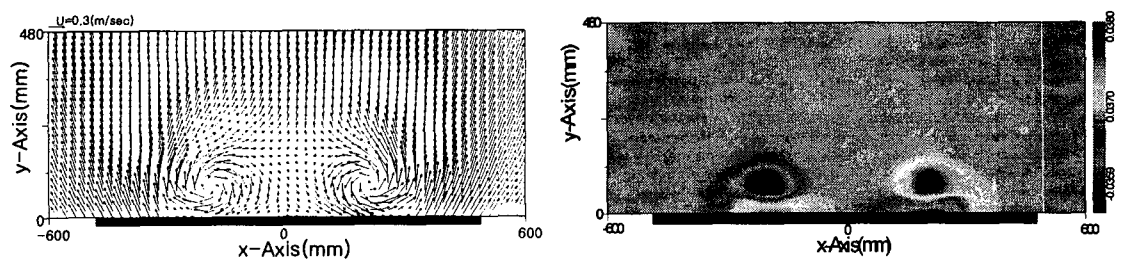
16°: 30%C	0.376	16°: 30%C	0.421
16°: 60%C	0.530	16°: 43%C	0.422
16°: 80%C	0.777	16°: 60%C	0.501
24°: 30%C	0.521	16°: 80%C	0.607
24°: 60%C	0.618	24°: 30%C	0.434
24°: 80%C	0.645	24°: 43%C	0.518
28°: 30%C	0.567	24°: 60%C	0.624
28°: 60%C	0.654	24°: 80%C	0.694
28°: 80%C	0.649	28°: 30%C	0.486
		28°: 43%C	0.591
		28°: 60%C	0.705
		28°: 80%C	0.731

Figure 2 shows the time-averaged velocity vectors and vorticity distribution of the LEX-off at 16°AOA. Symmetric pattern reveals a good experimental configuration of the model fixed within the water tunnel. Significant vortex pair formation becomes clear with the larger chord length. Figure 3 represents the velocity and vorticity distribution at 24°AOA without LEX. More remarkable vortex formation is found and this tendency continues at the 28°AOA(Fig.4).

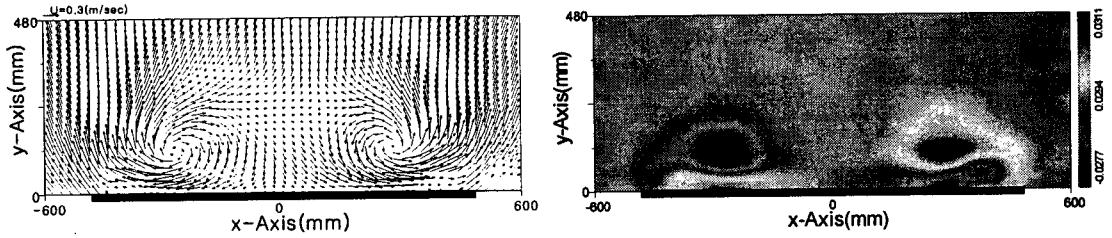
Figure 5 shows the case of LEX-on at the same corresponding AOA. What is important is the distance between two vortex centers. Compared to the LEX-off result, narrower distance was found in the LEX-on due to LEX effect. This comparison gives well the different flow characteristics between the LEX-on and LEX-off and LEX-on causing any aerodynamic property particular to the modern aircraft such as air-fighters. More detailed analysis will be necessary to give satisfactory understanding of the delta wing flow applied to any modern craft. The present work suggests just a simple representation of PIV measurement result in case of low Reynolds number.



(a) 30% Chord

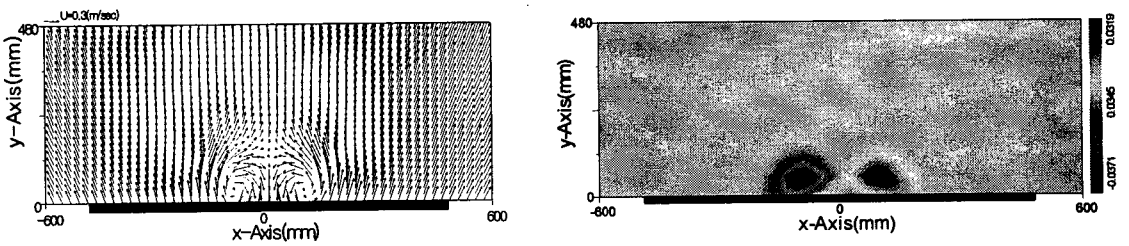


(b) 60% Chord

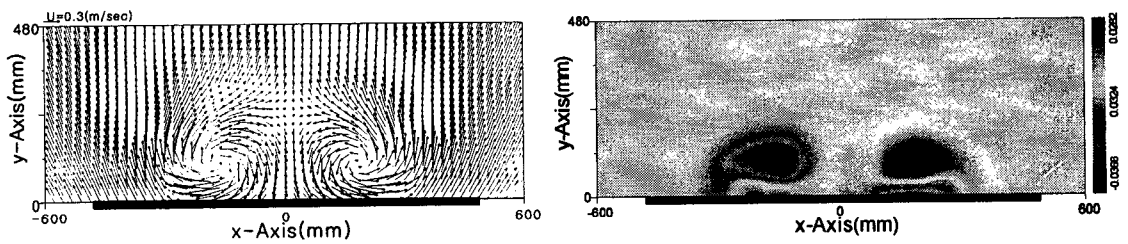


(c) 80% Chord

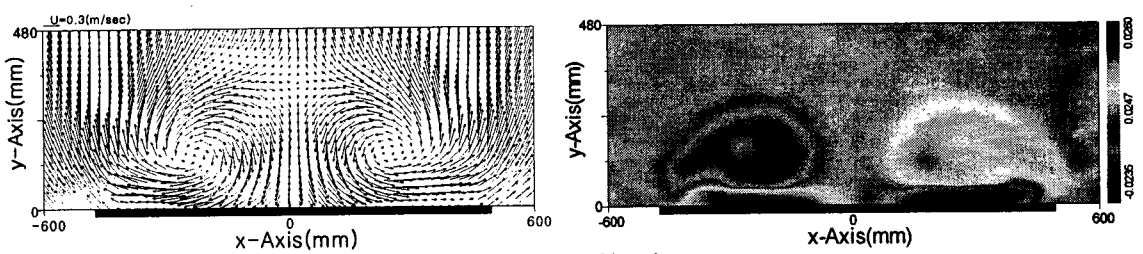
Fig.2 Velocity(left) and Vorticity(right) of LEX-off(AOA:16°)



(a) 30% Chord

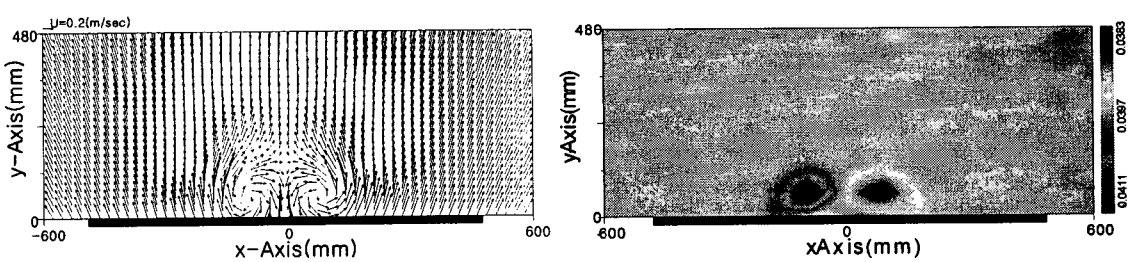


(b) 60% Chord

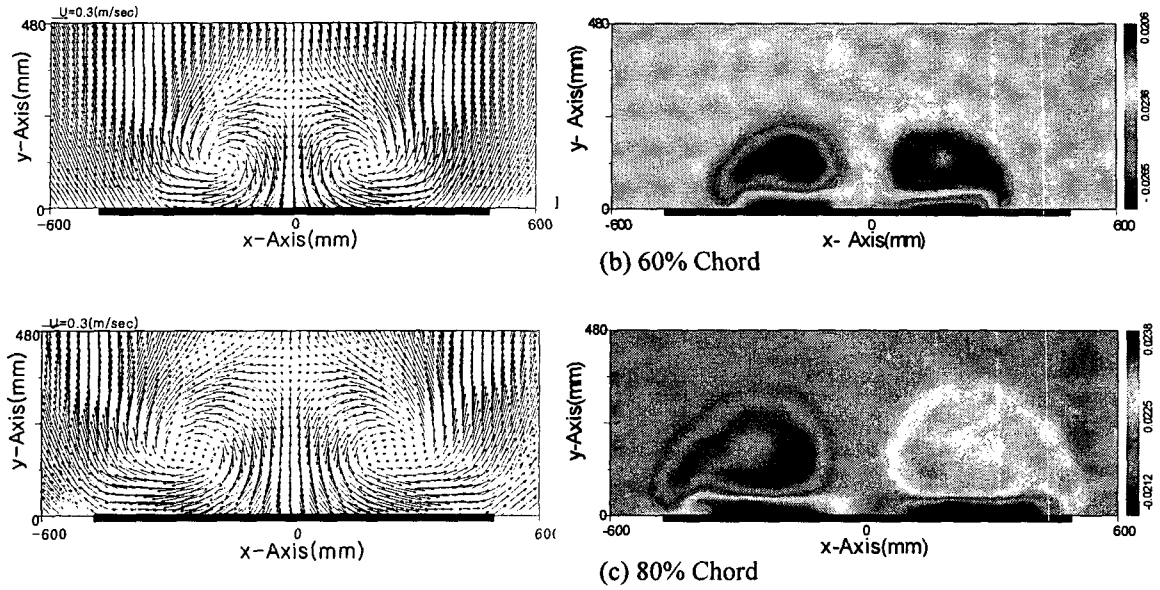


(c) 80% Chord

Fig.3 Velocity(left) and Vorticity(right) of LEX-off(AOA:24°)



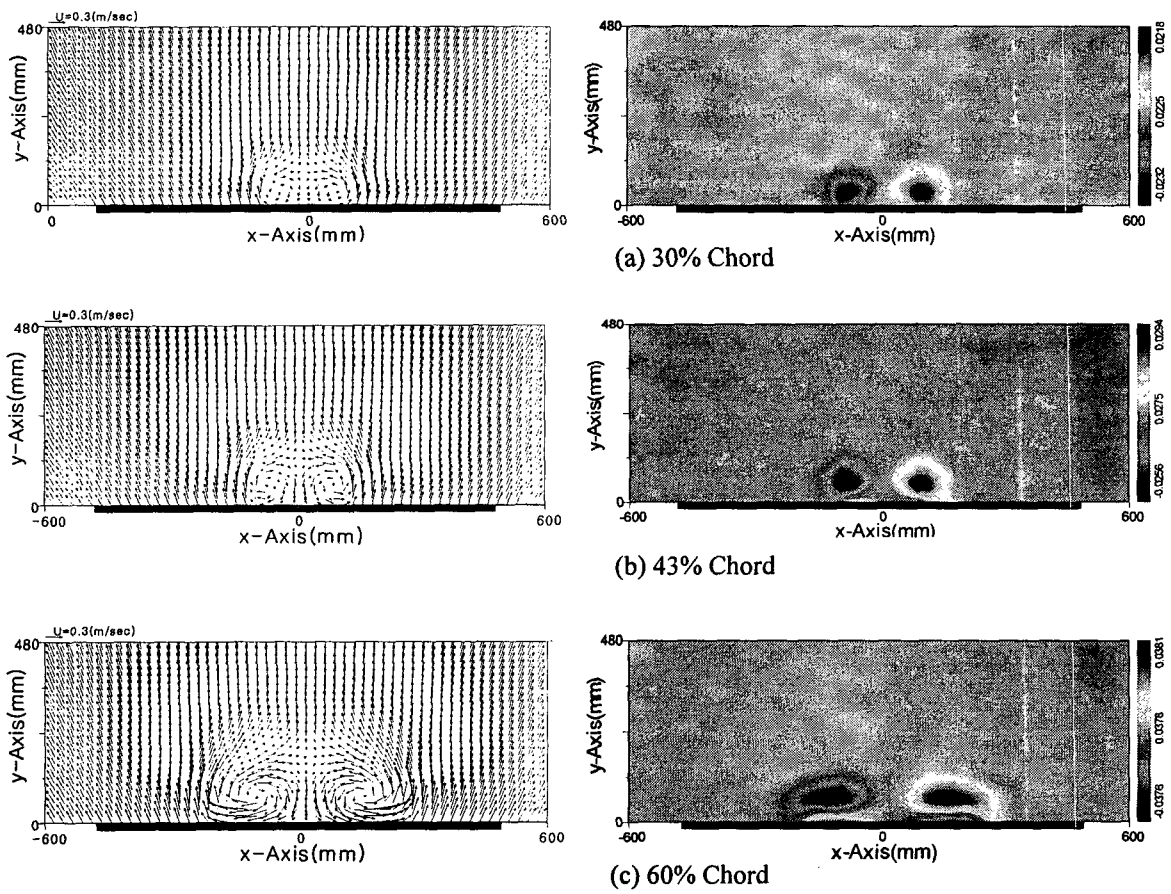
(a) 30% Chord



(b) 60% Chord

(c) 80% Chord

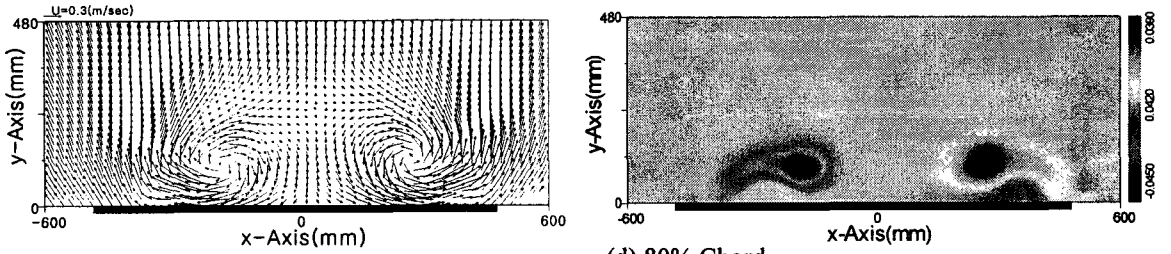
Fig.4 Velocity(left) and Vorticity(right) of LEX-off(AOA:28°)



(a) 30% Chord

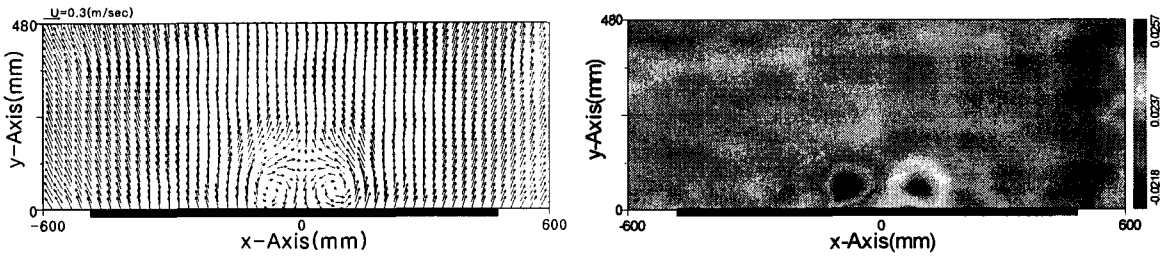
(b) 43% Chord

(c) 60% Chord

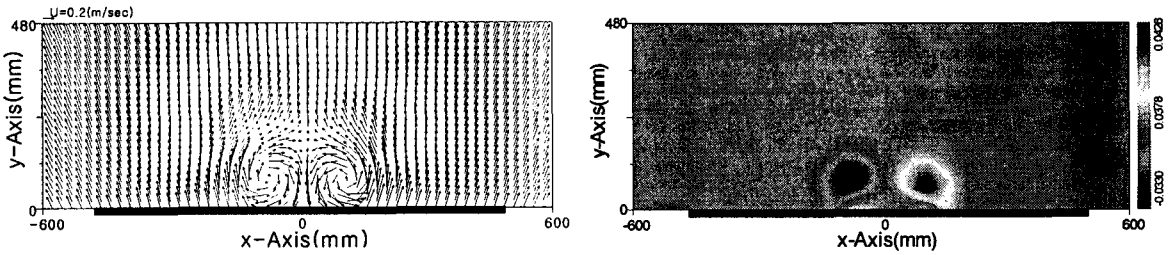


(d) 80% Chord

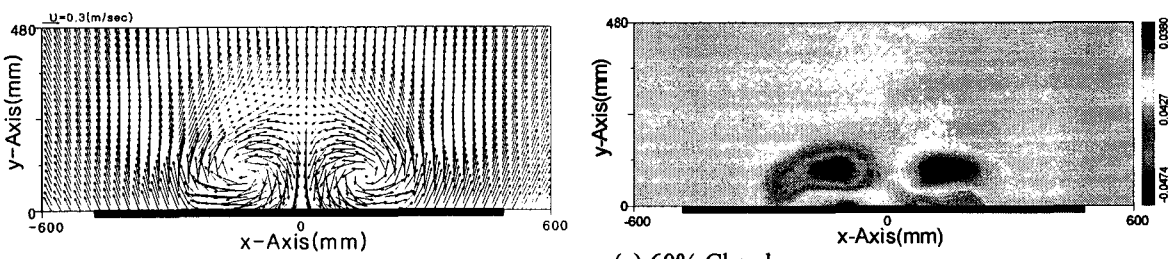
Fig.5 Velocity(left) and Vorticity(right) of LEX-on(AOA:16°)



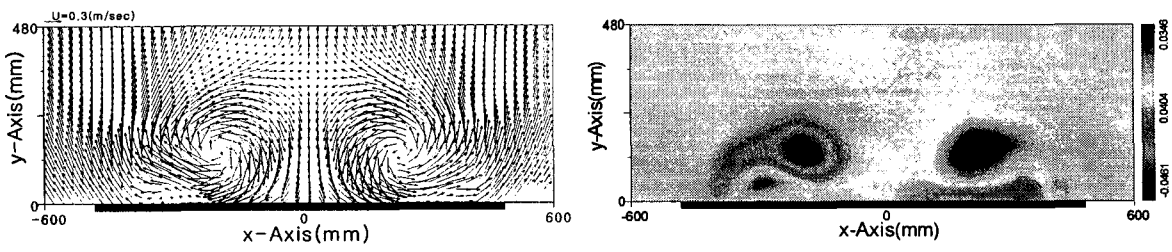
(a) 30% Chord



(b) 43% Chord

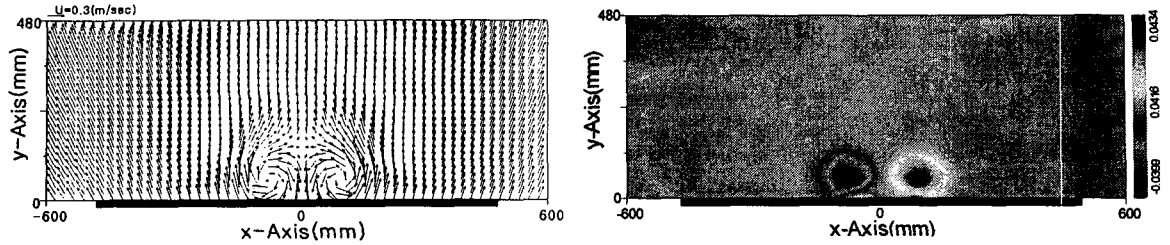


(c) 60% Chord

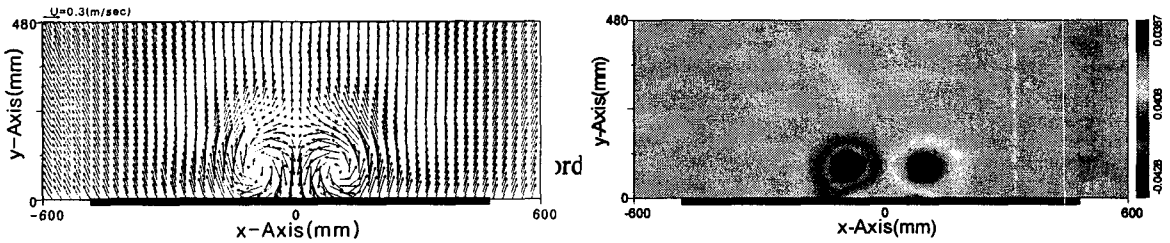


(d) 80% Chord

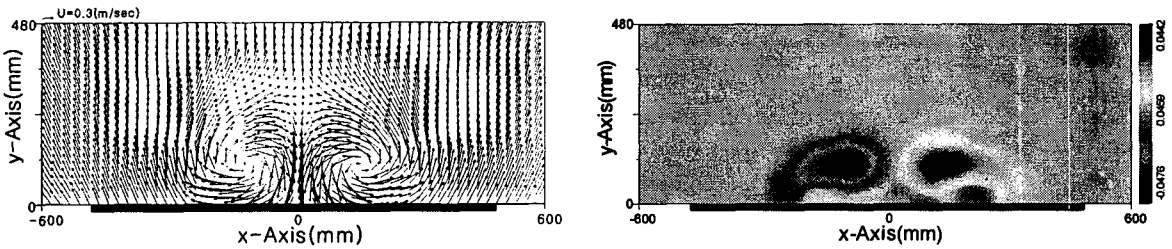
Fig.6 Velocity(left) and Vorticity(right) of LEX-on(AOA:24°)



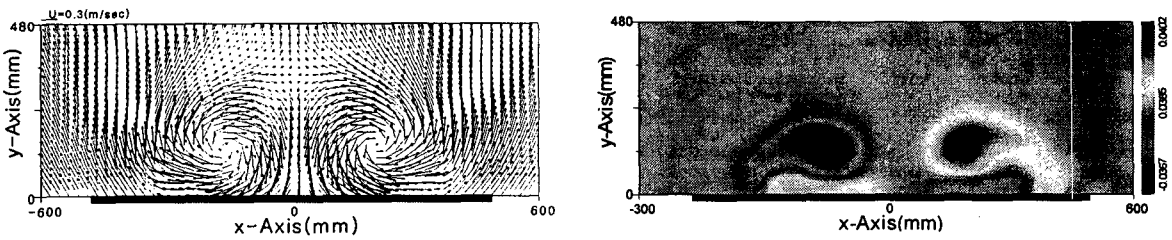
(a) 30% Chord



(b) 43% Chord



(c) 60% Chord



(d) 80% Chord

Fig.7 Velocity(left) and Vorticity(right) of LEX-on(AOA:28°)

4. CONCLUSION

The present study is focused on the fundamental PIV experimental analysis of the vortex pair formation appearing on a delta wing model with or without LEX for three angles of attack(16°, 24°, 28°) and four measuring sections of chord length(LEX-on) and three sections(LEX-off). Time-averaged velocity vectors and vorticity upon the delta wing model was compared among the chord length sections. Maximum vorticity was found at a given chord length and maximum velocity was also detected at larger chord length where more remarkable vortex was found. Furthermore, LEX effect was found at the vortex pair distance indicating narrower distance at LEX-on experimentation.

REFERENCE

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2. Brandon, J. M., "Dynamic Stall Effects and Applications to High Performance Aircraft", AGARD-R-776, NASA Langley Research Center, Hampton, VA, 1991.