Experimental Investigation on Aircraft Wake Vortex Control by Spoilers

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Abstract. The experimental investigation is mainly to seek an effective method to reduce the strength of aircraft wake vortex which would introduce great hazard to the following flight and threaten the flight safety. The research was carried out in a water-towing tank which equipped with a 2-D Particle Image Velocimetry (PIV) system. By using spoilers attached on the airfoil, the Rayleigh-Ludwieg instability of the wake vortex is activated, leading to the dissipation of the wake vortex in advance. The analysis results given by the PIV system showed that the circulation of the wake vortex was reduced to nearly 40%, as early as in 30 wingspans downstream with suitable settings, instead of more than 100 wingspans for that of a “clean model”. The result could provide reference for designing the low wake vortex airfoils.

Introduction

Every aircraft creates a trailing vortex which is inevitable for the generation of lift, showed in Fig.1. Those vortices have a very powerful circulation rector and can linger for miles behind the aircraft. The following aircraft may experience a sudden decrease of climb rate or even rapid descent, a rolling motion or an overload of the aircraft's structure. This is especially dangerous when the aircraft are taking off or landing [1]. Therefore, the alleviation of the wake vortex becomes extremely important and meaningful to the flight safety.

In order to avoid a dangerous impact of these vortices, the Federal Aviation Administration (FAA) of the USA and the International Civil Aviation Organization (ICAO) has attached great importance to the wake vortex. [2, 3, 4] They established safe separations between two airplanes so that the follower aircraft must maintain a safe distance from a landing aircraft up ahead of them. [5]But these standard separations have strongly limited the capacity of many airports and cause the congestion of air traffic, showed in Fig.1.

Some European organizations, DLR and ONERA, also have done a lot of research about the control of wake vortex, mainly from the aspect of improving the shape structure of a airplane. In these projects, “Airbus Program”, ”Bilateral Program”, “Eurowake”, “Wavenc”, “C-Wake”, “S-Wake”, “I-Wake”, “ATC-Wake” and “Awiator”, numerous data were accumulated. [6, 7, 8] Even though, so far no practical ways have successfully applied in the commercial airplanes.

Fig.1 Airplanes waiting in line to take off in Beijing Airport in China

Particle Image Velocimetry (PIV)

Particle Image Velocimetry (PIV) is an optical technique for measurement of whole and instantaneous fields of velocity, which is totally different from the conventional flow measurement technology. As for its advantages of efficiency, accuracy, non-intervention, it has been applied in many fields. The principle of a PIV system is demonstrated in Fig.2.

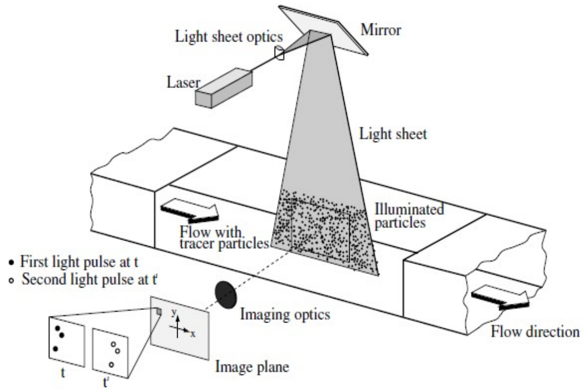

Fig.2 The principle of a PIV system [9]

Tracer particles that can be illuminated by the laser system are uniformly distributed in the flow field so that the fluid characteristics will be directly indicated by the tracer particles. When these particles flow pass by a digital high speed camera, the camera will immediately record the particles into two images in a very short time. Then the two-dimensional velocity vector distribution of the flow field is obtained by cross-correlation analysis [10] of the two images.

Rayleigh-Ludwieg Instability

The wake vortex will gradually dissipate in a long time due to the Crow instability [11]. The Crow instability describes the interaction of a pair of counter-rotating vortexes whose circulations are the same. Even though it can destroy the wake system ultimately, it takes a long time which has little practical value.

Despite the generation of wake vortex is inevitable, there are two ways to reduce the hazard of the vortex.

One is to increase the characteristic radius of the wake vortex by import some turbulence into the wake vortex. In this way, the rolling torque that an airplan

The presence of wake vortices with opposite signs ($\Gamma 1 > 0, \Gamma 2 < 0$) and different strengths are the preconditions of triggering out this so called Rayleigh-Ludwieg instability, [9-12] showed in Fig.2. As early as in 1916, Rayleigh explained a spiral type of vortex breakdown being a hydrodynamic instability. Ludwieg (1960) explained it as a centrifugal instability including the presence of axial flow, which is a promising approach to apply to the design of tailoring of aircraft wake systems (Stuff, 2002).bears when it goes into the vortex will decrease. But the circulation of the vortex is still very strong and the manipulation of adding in turbulence into the vortex is not that easy in reality.

Another way is to trigger the instability of the wake vortex by introducing two different vortexes who have a smaller circulation to formulate a four-vortex system, as sketched in Fig.3.

The vortex pairs may be co-rotating ($\Gamma 1 > 0, \Gamma 2 > 0$) or counter-rotating ($\Gamma 1 > 0, \Gamma 2 < 0$). The stability of these configurations can be studied provided that the core radii of the vortices are small with respect to their separations. [12]

$$a1, a2 \ll b1, b2, (b1-b2)/2$$

This method is particularly efficient in the presence of inner vortices with counter-rotating vorticity. [12] In the light of the study of professor Bao [5, 13-14], it seems to be a promising way to control the wake vortex.

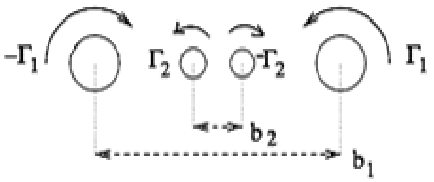

Fig.3 Four-vortex wake model

By using this instability, according to the early studies, the wake vortex has been minimized efficiently. Of all the methods inducing the instabilities, Rayleigh-Ludwieg instability is one of the promising approaches which would reduce the wake strength to certain extend. So in this paper, we will also utilize this instability to study the development of the wake system.

Experimental Facilities and test Model

The research was carried out in a water towing tank of Fluid Mechanics and PIV Laboratory in Xiamen University (XMU). Meanwhile, the PIV system undertook the measurements and presented the whole experimental data.

The test section of the water towing tank used in this experiment has a dimension of 0.5m×0. 58m×2m. The water towing tank consists of a water tank and a trolley supporting the towing system and the controlling instruments, showed in Fig.4. The towing speed can reach the maximum velocity of 0.5m/s.

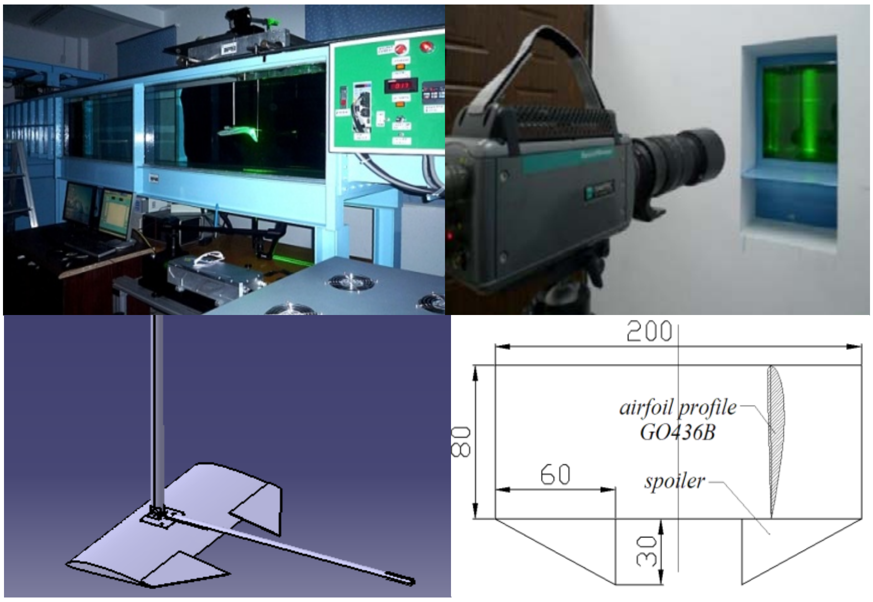

Fig.4 Experiment facility and the test model

In this research we selected GO436B as our airfoil whose stall angle is 12 degree. So the attack angle of the model varied from 6 degree to 10, and towing speed is 0.5m/s, which in Table 1. See in Fig.3. Since the four-vortex system is totally symmetrical, we focus on the study of the two vortexes on the left.

Table 1 Configuration of attack angle and towing speed

	without spoilers			with spoilers		
Set Number	1#	2#	3#	4#	5#	6#
Attack Angle (°)	6	8	10	6	8	10
Towing Speed (m/s)		0.5			0.5	

Experimental Results

Study the perdurability of the wake vortex by scientific data given by the PIV system. We can achieve the velocity vector field of the test section by cross-correlation analysis. Just take set 3# and 6# into discussion. The process result of sets sketched in Fig.4.

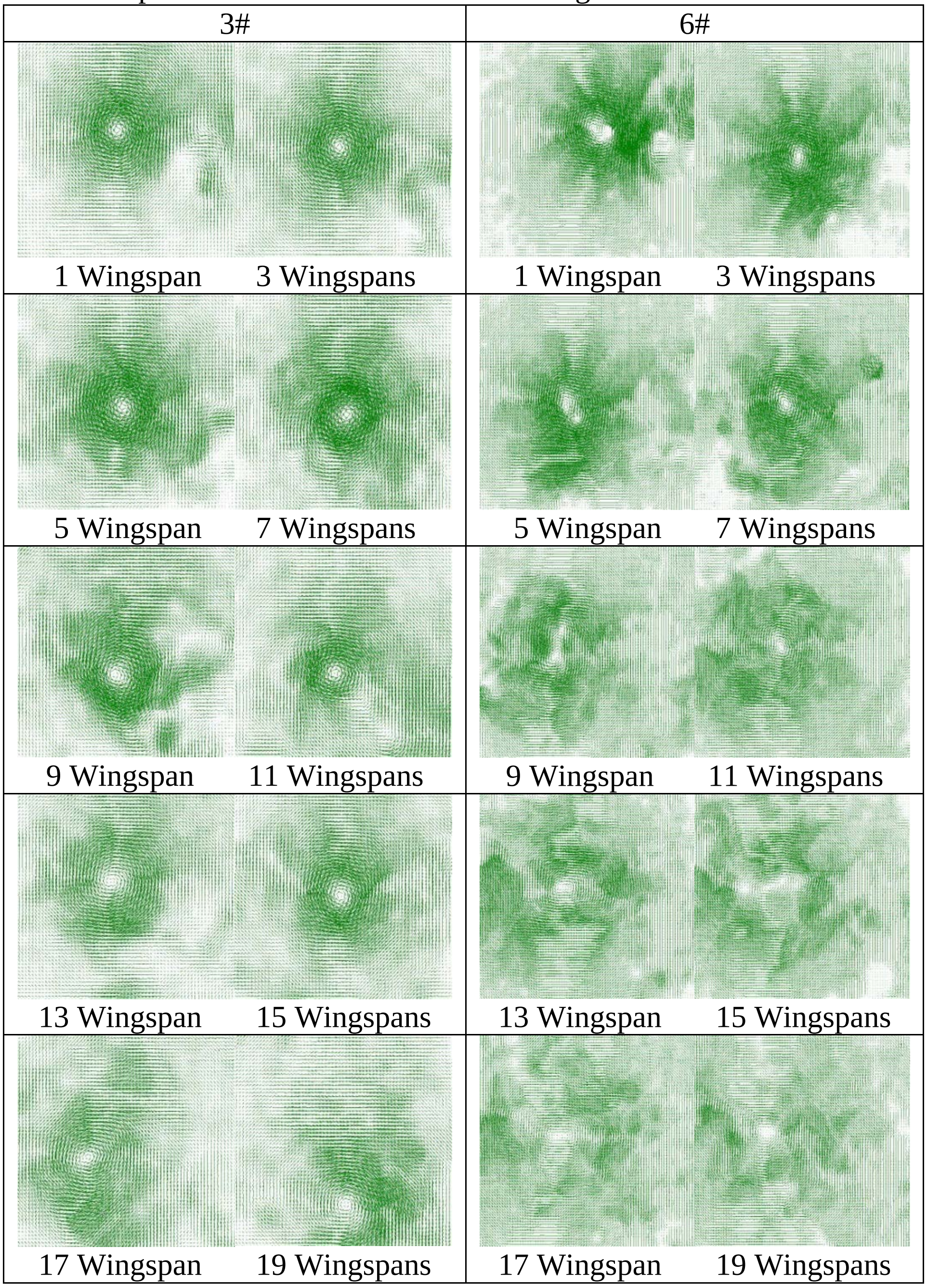

Fig.5 PIV analysis of set 3# and 6#

The vortex core of set 3# is very clear even at the position of 19 Wingspans. This describes that the wake vortex will last for a long time [13]. The first three pictures in the right side of the Fig.4demonstrated the secondary vortex rotated around the primary vortex anticlockwise. When the wake vortex moved to 6 wingspans, the secondary vortex was absorbed by the primary vortex, leading to a deformation of the vortex, accelerating the dissipation of the wake vortex.

If we regard the circulation at 0 wingspan as the reference value Γ0, the circulation at other different wingspan divide Γi, so we can obtain the relative circulation curve of the wake vortex at different wingspan, depicted in Fig.6.

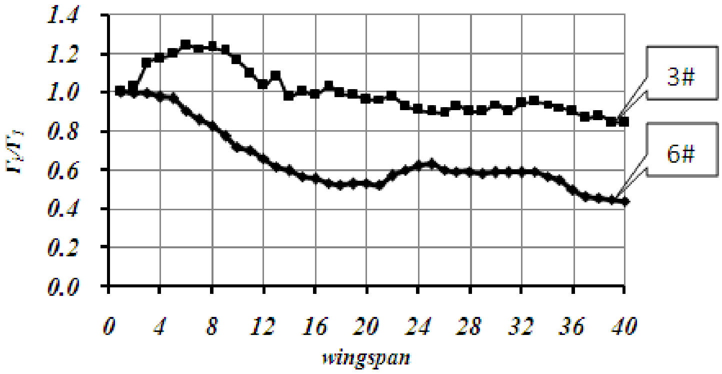

Fig.6 Relative circulation of different wingspan of set 3# and 6#

Fig.6 above showed that in the first 20 wingspans the circulation of the set 6# declined rapidly. After that the dissipation speed of the vortex became slow. However, contracted to the circulation change of the main wing vortex, the circulation dropped to nearly 60% in the 40 wingspans which powerfully proved the effectiveness of Rayleigh-Ludwieg instability in weakening of wake vortex. But it changed little in the set 3#.

Conclusions

The experiment was carried out in a water-towing tank of the Fluid Mechanics and PIV Laboratory in Xiamen University. Flow visualization and PIV measurement were employed. Eleven sets of data are analyzed with respect to the velocity vector, streamlines and circulation, as well as the development of the Rayleigh-Ludwieg instability. Based on these analyses, following conclusions could be derived:

1. The main wing wake vortex is very strong and could last for a long time if there is no disturbance put in.
2. The intensity of the wake vortex is determined by the combination of model type, model dimensions, attack angle, towing speed, etc. The bigger the attack angle is and the faster it tows, the stronger the vortex will be.
3. The spoiler on the main wing can generate a small vortex called secondary vortex which rotates in an opposite direction with respect to the main wing vortex called primary vortex. At the same time, the secondary vortex will rotate around the primary vortex during its existence.
4. The Rayleigh-Ludwieg instability could be trigged with proper settings of experimental parameters such as attack angle and towing speed.

5. The Rayleigh-Ludwieg instability plays an essential part in weakening the whole field circulation, The dissipation of wake vortex only can be accelerate instead of reducing the intensity of the vortex to zero immediately by this instability.
6. At the beginning of the interaction of the four-vortex system, the circulation in the flow field varied in a small range. But when the vortex developed to 30 wingspans, the circulation of the flow field dropped to nearly 40% which powerfully proved the effectiveness of the study in weakening the wake vortex.
7. In further experiment, different type of spoilers will be used, as well as the distance between two vortices to find the most efficient parameters to minimize the wake vortex.

Acknowledgements

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