Experimental Study of the Aircraft Wake Vortex Systems

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1. Introduction

The problem of aircraft wake vortex hazard became important with the introduction of heavy transport aircraft. These aircraft operate within the terminal areas along with much lighter aircraft, which can be dangerously upset by the wake vortex system of the heavier vehicles. The issue is exacerbated by the fact that vortex strength is not only linearly proportional to the aircraft weight, but also inversely proportional to flight speed, meaning that the vortex strength is greatest for heavy aircraft traveling at slow speeds. Therefore, the vortices posing the greatest threat are concentrated in a high-traffic area, near the airports.

The capacity of air traffic handled at existing airports is limited by the wake turbulence separation criteria. The current FAA guideline requires separation distances between aircraft as shown in Figure 1. Various aviation regulatory establishments throughout the world have adopted these separation distances. However, these distances, while maintaining acceptable levels of safety, are an obstacle to increasing airport traffic. Reducing the required aircraft separation would result in a significant increase in the air traffic capacity of the present airports. This would not only have an economic effect, as more aircraft could be accommodated, but it would also reduce delays, leading to higher customer satisfaction. It is important, though, that safety is not compromised.

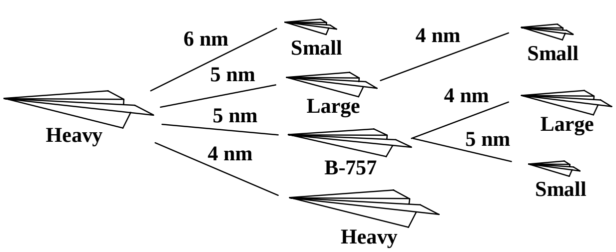

Fig. 1. Current wake turbulence separation criteria.

The current approach of avoiding the wake vortices becomes increasingly difficult as traffic congestion is increasing. An alternative approach to dealing with the hazard is to eliminate the vortex wake, or at least reduce the danger posed by it. However, before this is possible, the dynamics of the wake must be understood. The purpose of this research is to investigate experimentally the time-dependent behavior of aircraft wake vortex systems.

2. Experimental Method

The experimental apparatus that is used for this research is identical to that described in Reference 1. A brief description of the facility and equipment follows.

Test Facility

The experiments are performed in the water tunnel located in the National Institute for Aviation Research (NIAR) on the campus of Wichita State University. This is a horizontal, closed-loop tunnel containing 3500 gallons of water. It has a clear test section measuring 6 ft. long, 3 ft. high, and 2 ft. wide that can be viewed from five different directions. A schematic of the water tunnel is shown in Figure 2.

Vortex Generators

Vortices are generated using aluminum blades positioned vertically in the flow. The blades are mounted on a reflection plane that is located 3 inches below the free surface of the water. The blade assembly is shown in Figure 3.

Flow Visualization

The vortices are visualized by injecting a diluted milk and alcohol mixture near the leading edge of the vortex generators. The injection of the dye is placed as

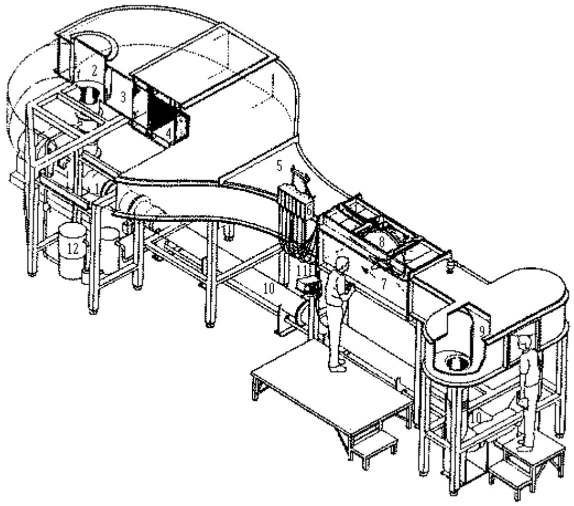

Fig. 2. Schematic view of the water tunnel.

close as possible to the point where the vortex filament separates from the blade. The filament cross sections are illuminated with a high-intensity white parallel beam that is positioned perpendicular to the test section. When viewed through the downstream window, a bright spot for each vortex is observed against a black background. A typical video frame showing a two-vortex case is presented in Figure 4. The motion of these cores is recorded on a tape in Digital 8 format, at a rate of 30 frames per second, using a camcorder. The time history of the core locations is then extracted from the video and the information is used to determine the characteristics of the flow. The details of the flow visualization and the data acquisition are outlined in References 2 and 3.

3. Discussion of Results

In the course of this research, investigations have been made of:

- Self-induced motion of single vortex filaments,

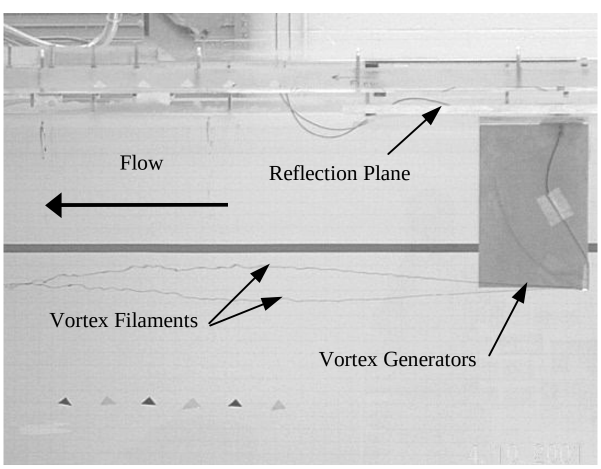

Fig. 3. Blade assembly as seen from the side window.

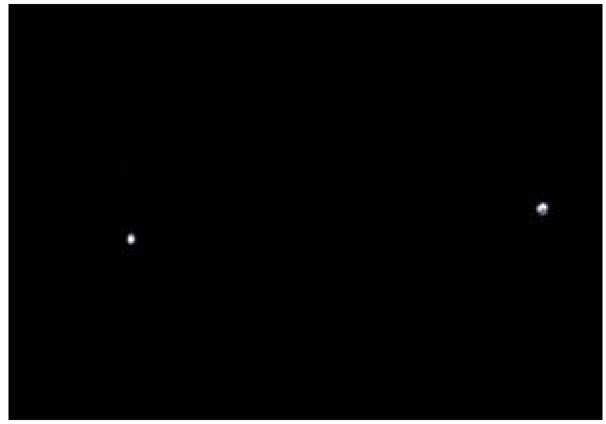

Fig. 4. Typical view of the illuminated vortex cores.

published in Reference 4,
- Self- and mutually-induced motion of co-rotating vortices to model those of the wing- and flap-tip on one side of an aircraft in their natural states, presented in Reference 4,
- Motion of co-rotating vortices forced to oscillate over a range of frequencies, given in Reference 5,
- Interactions among four filaments consisting of two sets of co-rotating vortices to model the complete wake of the aircraft, Reference 6.

4. Conclusion

These investigations have led to the better understanding of the time-dependent motion of such vortex filaments. Prior to this effort, the technical literature was void of such information. Several of the flow features that have been observed have also been shown to be consistent with previous analytical models.

5. References

[1] R. Rebours, “Quantitative Measurement of Wake Vortex Motion in a Water Tunnel,” MS Thesis, Wichita State University, Wichita, KS, May 2001.

[2] R. Rebours, L.K. Kliment, and K. Rokhsaz, “Forced Response of a Vortex Filament Pair Measured in a Water Tunnel,” AIAA-2001-2448, 19th Applied Aerodynamics Conference, Anaheim, CA, June 2001.

[3] K. Rokhsaz, R. Rebours, and S.R. Foster, “Quantitative Measurements of Wake Vortex Motion in a Water Tunnel,” AIAA-2001-0111, 39th AIAA Aerospace Sciences Meeting and Exhibit, Reno, NV, January 2001.

[4] K. Rokhsaz and L.K. Kliment, “Experimental Investigation of Co-Rotating Vortex Filaments in a Water Tunnel,” AIAA-2002-3303, 32nd AIAA Fluid Dynamics Conference and Exhibit, St. Louis, MO, June 2002.

[5] L.K. Kliment and K. Rokhsaz, “Experimental Investigation of the Forced Response of a Pair of Co-Rotating Vortex Filaments,” AIAA-2004-2434, 34th AIAA Fluid Dynamics Conference and Exhibit, Portland, OR, June 2004.

[6] L.K. Kliment and K. Rokhsaz, “Preliminary Investigation of a Complex Aircraft Wake Vortex Configuration,” AIAA-2003-3600, 33rd AIAA Fluid Dynamics Conference and Exhibit, Orlando, FL, June 2003.