Experimental Study of Aircraft Wake Vortices in Ground Effect

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1. Introduction

Aircraft wake consists of rotating air masses called vortices. Smaller aircraft flying into these wakes are at the risk of sudden changes in bank angle and altitude. These changes are most dangerous when flying low and slow, during takeoffs and landings. It is important to allow specified distances between aircraft for the wake to have time to dissipate. Away from the ground, the vortex motion and the required separation distance for adequate safety are well defined. However, the vortex motion at very low altitudes becomes unpredictable due to its interactions with the ground. A better understanding of the motion near the ground is needed in order to reduce the hazard posed by the vortices.

2. Experimental Method

Test Facility: The test facility was described in full in Ref. 1. Briefly, tests were conducted in a water tunnel. This was a horizontal, closed-loop tunnel containing about 3500 gallons of water. The clear test section, which was visible from five different directions, measured 6 ft. long, 3 ft. high, and 2 ft. wide.

Vortex Generators and Ground Plane: The vortices were generated using flat aluminum blades. These blades, mounted on a reflection plane, were positioned horizontally in the flow. The reflection plane was mounted 4 inches from, and parallel to, the tunnel sidewall. A splitter plate modeled the ground plane. This plate was placed 6.5 inches from, and parallel to, the opposite tunnel sidewall. The leading edge of the ground plane was 10 inches downstream of the trailing edge of the vortex generators. This position matches to $x/b_0 = 3.7$ in Fig. 2-3 and $x/b_0 = 4.3$ in Fig. 4, where b_0 was the initial vortex span. At the leading edge of the vortex generators, a vertical distance of 2.5 inches separated the vortices and the ground plane. A schematic of the experimental setup, as viewed from the top of the test section, is shown in Fig. 1. This setup is identical to that described in Ref. 2.

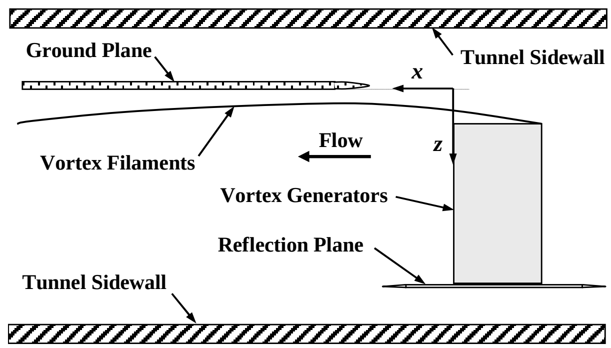


Figure 1: Schematic top view of the test setup

Flow Visualization: Details of this method were described in Ref. 1-4. Visualization was accomplished by injecting a diluted milk/alcohol mixture near the leading edge of each vortex generators where the filament separated from the blade. A high-intensity light beam, positioned perpendicular to the test section, illuminated the filament cross sections at predetermined distances downstream of the vortex generators. When viewed from downstream looking upstream towards the blades, each vortex core appeared as a bright point where the flow was intersected by the light sheet. The motion of the core was recorded at 30 frames per second for a set length of time using a digital camcorder. The vortex position and time information were extracted from the video and were used to quantify the characteristics of the flow.

3. Discussion of Results

Investigations were made of:

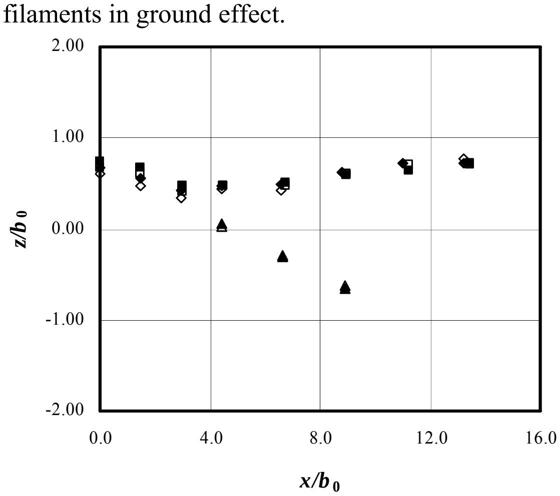
- Two counter-rotating vortex filaments, to model the wing-tip vortices of an aircraft, as in Ref. 2, and
- Two, co-rotating vortices, to model the wing- and flap-tip vortices of one side of an aircraft.

In both cases, the behavior of the vortex pairs was recorded both in and out of ground effect. Preliminary results are included in Fig. 2-4. In these figures, the trailing edges of the vortex generators were located at x/b_0 = 0 and the location of the ground plane, when it First, counter-rotating vortices were formed and the side view of the wake is shown in Fig. 2. The vortices sank at a constant rate outside of the ground effect. This was identical to the behavior described in Ref. 1. When the vortices entered ground effect, the wake sank to a minimum height above the ground and then rebounded. Fig. 3 shows the top view of the same data. When the vortices were outside of ground effect, the span remained constant, which agreed with the results shown in Ref. 1. The two cases which include the effects of the ground showed a constant vortex span up to the point where they reached a minimum height above the ground, and an increasing span after that point, during the rebound phase. The experimental flow features shown compared favorably with results obtained with a numerical scheme.[2, 5, 6]

The side view for the case of co-rotating vortices is shown in Fig. 4. The behavior of the vortices outside of ground effect agreed well with that shown in Ref. 4. The rate of spiraling was similar, regardless of the presence of the ground. In addition, the vortex span remained nearly constant in both cases. However, the vertical heights differed, showing that the co-rotating filaments were also rebounding in ground effect.

4. Conclusion

These preliminary investigations have shown that the current experimental method is viable for studying the effects of the ground on vortex motion. Flow features observed experimentally with counter-rotating vortices have been consistent with LIDAR data and numerical methods. There is no data in the current literature on the behavior of co-rotating vortices in ground effect. Further investigations will lead to the better understanding of the time-dependent motion of vortex filaments in ground effect.



was in the test section, was z/b_0 = 0.

Figure 2: Vertical position versus downstream distance, counter-rotating filaments*

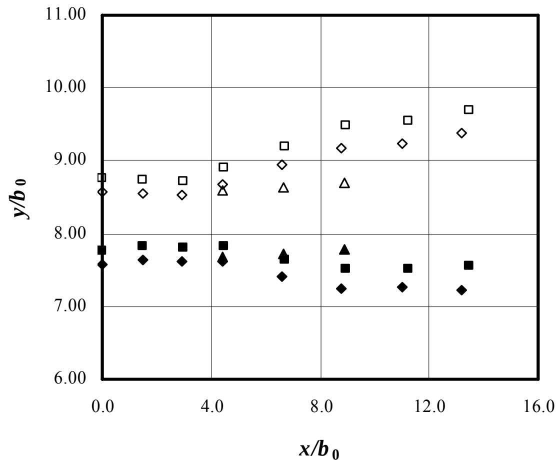


Figure 3: Lateral position versus downstream distance, counter-rotating filaments*

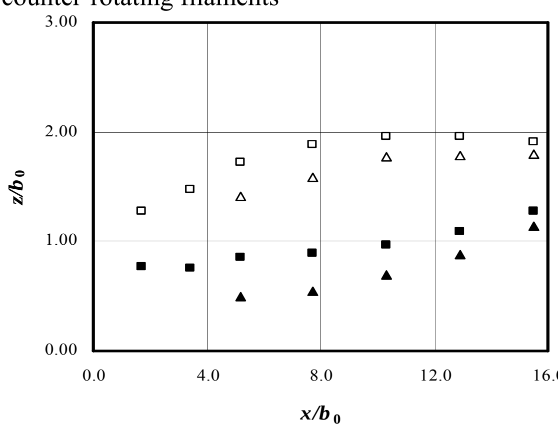


Figure 4: Vertical position versus downstream distance, co-rotating filaments*

5. References

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[6] Robins, R.E. and Delisi, D.P., "NWRA AVOSS Wake Vortex Prediction Algorithm Version 3.1.1," NASA CR-2002-211746, June 2002.

* The triangles show the data for the cases without ground effect, while the squares and diamonds show the cases with ground effect. The solid and the hollow symbols depict right and left filaments, respectively.