Effect of Ground Roughness on Aircraft Trailing Vortices

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Abstract. The work presented here is aimed at investigating the effect of the terrain roughness on the behavior of aircraft wake vortices. The tests are conducted in the water tunnel with a smooth ground plane first. Then, streamwise ridges are added to the ground in order to simulate terrain roughness. In addition, a case is presented without the ground plane. This latter data, showing the behavior of the vortices in the absence of any ground, provides a basis for comparison as well as allowing calculation of the wake vortex strengths.

The experimental data shows temporal and spatial behavior of the vortices. In the cases without a ground plane and with a smooth ground plane, the water tunnel measurements are consistent with information in the literature. With the information garnered from these tests, the authors are able to quantify the effect of ground roughness on wake vortex behavior.

1. Introduction

The vortical wake of an airplane poses a great threat to following aircraft when flying near the ground. The changes in altitude and bank angle, resulting from a wake encounter, are most dangerous to an aircraft when it is flying close to the ground. Previously, the authors focused on understanding and predicting vortex motion in ground effect (Refs. 1-3). Knowing this motion allows pilots to avoid the wake of other aircraft. Here, the authors examine possible ways of accelerating the decay of these flow structures using terrain roughness. There is anecdotal evidence that suggests that manipulating the shape of the terrain can affect the dynamic instabilities of the vortices.

2. Experimental Method

The data was collected in the water tunnel located in the National Institute for Aviation Research (NIAR) on the campus of WSU. A detailed description of the test facility can be found in Ref. 4. Flat, aluminum blades were used to generate the vortices. These blades were mounted on a reflection plane which was positioned 1.63 inches from and parallel to the tunnel side wall. For these experiments, the blades were angled so that counter-rotating vortices of nearly equal strength were generated. The strengths were 5.98 in^2/s for the left vortex and 7.12 in^2/s for the right. At the quarter-chords, the blades were separated by 3 inches, which resulted in a vortex separation distance at the trailing edge of the blades, b_0, of 3.89 inches.

A splitter plate was used to model the ground plane. This was positioned 8 inches from and parallel to the opposite side wall. The leading edge of the ground plane was located 17.25 inches downstream of the trailing edge of the vortex generators. This setup was nearly identical to that described in Refs. 1-3. However, for part of these results, surface roughness was simulated by attaching 0.085 inch diameter wires to the ground surface with adhesive tape. These ridges ran in the streamwise direction. The spacing between the ridges was 1 inch, while the distance between the two center wires was 2 inches. A picture of the vortices passing over the ridges is shown in Fig. 1.

3. Results, Discussion, and Significance

Three sets of results are presented here. In all three cases, the position of the blades and the ground plane, if present, remained the same. Data was first recorded
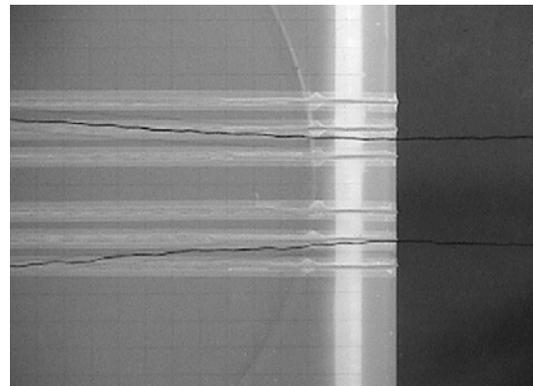

Figure 1. Top view of the wake passing over the ridges. The flow is from right to left.

with the smooth ground plane present in the tunnel. The vortices were then recorded after removing the ground plane. Then the ground plane was re-introduced to the test setup, this time with the streamwise ridges added, and the third set of results was recorded.

The vortex positions are shown in Figs. 2 and 3. In these figures, the x-axis is positive in the flow direction with the origin at the trailing edge of the vortex generators, mid-way between the quarter-chords. The y-axis is positive towards the right vortex. The z-axis measures the height above the ground where $z/b_0 = 0$ is the ground plane's surface. In these figures, $x/b_0 = 4.43$ is the location of the leading edge of the ground plane.

The vertical positions of the vortices as a function of the distance downstream are shown in Fig. 2. Outside the ground effect, the vortices descended at a constant rate. In the presence of the smooth ground plane, there was a very weak vortex rebound. Both of these results were consistent with those seen in Refs. 1 and 2. In addition, the vertical trajectory of the wake in ground effect was not affected by the ridges.

The top view of the wake as a function of downstream distance is shown in Fig. 3. Outside ground effect, the vortex span remained nearly constant. In the presence of the smooth ground, the span increased. Again, this behavior was consistent with that shown in Refs. 1 and 2. The vortex positions did not change when the ridges were added to the ground plane.

While surface roughness did not change the spatial behavior of the vortices, it was thought that the dynamic instability would be affected by the ridges. A growth in the amplitude of motion with downstream distance could be used as a measure of increased instability. The maximum moment of inertia can be used to represent the amplitude of motion. This quantity is shown in Fig. 4 as a function of downstream distance. For all three cases, the maximum moment of inertia grew with downstream distance. However, all three cases showed comparable rates of growth of amplitude of motion. This suggested that the dynamic instability of the vortices was not influenced by the terrain.

4. Conclusions

Experiments were performed in a water tunnel to study the effect of terrain roughness on the spatial and temporal behavior of trailing vortices. Without ground roughness, the spatial behavior was consistent with data in the current literature. The ground roughness had negligible effect on the position of the vortices and their temporal behavior. These results were based on one combination of vortex span and ground roughness. Other combinations may lead to different results.
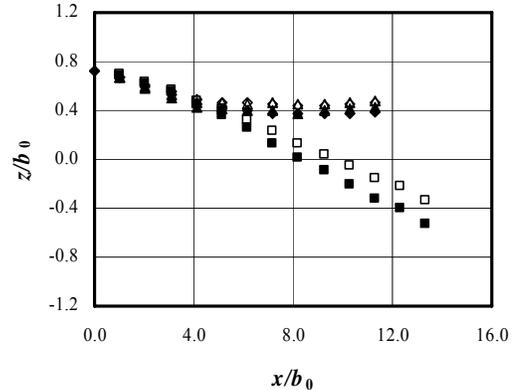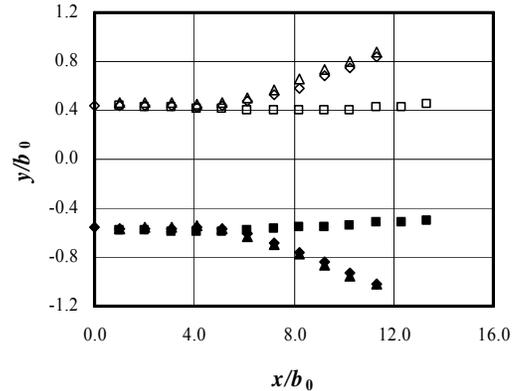

Figure 2. Side view of the wake.*

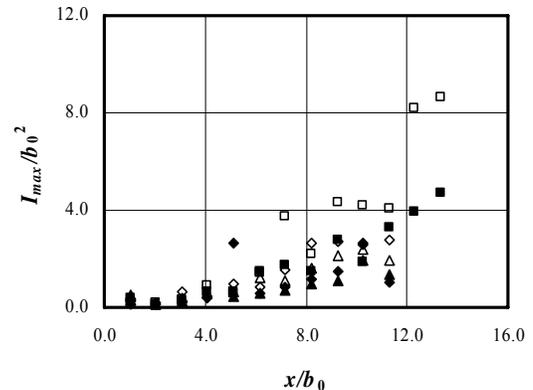Figure 3. Top view of the wake.*

Figure 4. Growth of the amplitude of motion.*

[1] Rokhsaz, K. and Kliment, L.K., "Feasibility of Modeling Wake Vortices in Ground Effect in a Water Tunnel," SAE-2005-01-3360, 2005 World Aerospace Congress, Dallas, TX, Oct. 2005.

[2] Kliment, L.K. and Rokhsaz, K., "Experimental Study of Aircraft Wake Vortices in Ground Effect," *Proceedings of the Graduate Research and Scholarly Projects 2nd Annual Symposium*, Wichita State University, Wichita, KS, April 2006.

[3] Kliment, L.K. and Rokhsaz, K., "Experimental Investigation of Pairs of Vortex Filaments in Ground Effect," AIAA-2006-3751, *36th AIAA Fluid Dynamics Conference and Exhibit*, San Francisco, CA, June 2006.

[4] Rebours, R., Kliment, L.K., and Rokhsaz, K., "Forced Response of a Vortex Filament Pair Measured in a Water Tunnel," *J. of Aircraft*, V. 41, N. 5, Sept.-Oct. 2004, pp. 1163-1168
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