Turbulence Measurements in Aircraft Wake Vortices: Comparisons between Aircraft Measurements, Laboratory Experiments, and Numerical Simulations

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Wake vortices are generated from the wingtips of aircraft in flight and trail behind the generating aircraft. Because of the rolling moment associated with these vortices, they represent a potential hazard for following aircraft. Because of this hazard, following aircraft are required to maintain fixed separation distances behind leading aircraft. These separation distances limit the number of aircraft that can land at a given airport during a given time interval, and, therefore, impact airport capacity. In order to reduce these separation distances and increase airport capacity, we must understand the evolution of wake vortices.


An unknown aspect of vortex evolution, however, is the level of turbulence inside the vortex cell as a function of vortex age. This parameter is important for determining the mixing in the vortex cell, the decay of the cell, and for validation of the numerical simulations.

Recently, we have performed measurements of turbulence levels in the laboratory, and we have made similar estimates from a 3-D numerical simulation using a code made available to us by F. Proctor at the NASA Langley Research Center (Han et al, 2000a and 2000b). We have also recently obtained data taken in the trailing vortices behind a C-130 aircraft in flight, using an instrumented OV-10 aircraft (Vicroy et al, 1998). (These data were provided by D. Vicroy at NASA Langley Research Center.) Figure 1 presents our first comparisons of these data. In this figure, T is nondimensional time, defined as T=V_o t/b_o, where V_o is the initial vortex descent rate of the vortices, t is dimensional time, and b_o is the initial horizontal separation of the vortices. The normalized turbulent velocity dissipation rate, ε*, is defined as ε*=(εb_o)^(1/3)/V_o, where ε is the dimensional turbulent velocity dissipation rate.

In Figure 1, the squares represent laboratory measurements from a hot film probe located between the two vortex cores. In these measurements, the vortices were generated by towing a small wing down a tank filled with unstratified water (N=0). The solid line through the squares represents the average of the laboratory measurements at each value of T. The triangles in Figure 1 are estimates from velocity measurements
made with the OV-10. Here, the solid triangles denote the longitudinal velocity fluctuations and the open triangles denote the lateral velocity fluctuations. To obtain the OV-10 measurements, the C-130 had smoke on its wingtips, which made the wake vortices visible. The OV-10 flew into these wake vortices and traversed the wake from one side to the other. These traverses were made at varying distances behind the C-130. Only the center sections of the velocity time series (the region between the vortex cores) were used in the analysis. This region corresponded to the region where measurements were made in the laboratory. We note that the C-130 measurements shown in Figure 1 were obtained in a stratified atmosphere, where the vortex Froude number, Fr= Vo/No, was between 1.7 and 2.6, where N is the Brunt-Vaisala frequency. Finally, the diamonds in Figure 1 are from the 3-D numerical simulation in a nonstratified flow. For these estimates, the velocity time series between the vortex cores was used to estimate the velocity dissipation rate.

We note three things in Figure 1. First, the laboratory measurements are fairly representative of the C-130 aircraft measurements, despite the large difference in chord Reynolds number, Re, where Re = Uc/v, and U is the aircraft speed or towing speed, c is the chord of the wing, and v is kinematic viscosity. For the laboratory, Re ~ 100,000, while for the C-130 in level flight, Re ~ 30,000,000. Thus, it is encouraging that the measurements overlay as well as they do. Second, we note that the laboratory measurements were obtained in a nonstratified environment while the C-130 measurements were obtained in a highly stratified environment. We do not know the effect of stratification on e*, but we are currently investigating this topic. Finally, the estimates from the numerical simulation are significantly lower than either the laboratory measurements or the aircraft data. We do not yet know the reason for this large difference. Additional simulations, currently being performed, should lead to increased insight into this issue.

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NASA wake-vortex flight tests, flow-physics database and wake-development
Figure 1. Measurements of normalized turbulent velocity dissipation rate in a region between the vortex cores. Laboratory measurements in a nonstratified fluid are shown as squares, aircraft measurements behind a C-130 with Froude number between 1.7 and 2.6 are shown as triangles, and numerical predictions in a nonstratified fluid are shown as diamonds.