Flow characteristics of the wandering blade tip vortex

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Abstract: The blade tip vortex moves around its mean position, and thus various vortex identification methods are applied to identify its center location. The averaged flow field around the blade tip vortex is obtained by aligning instantaneous flow fields with the identified vortex center. The instantaneous flow fields are obtained by performing a large eddy simulation of an isolated multirotor propeller at hovering condition. Mislocating vortex centers results in incorrect mean vortex parameters and evolutionary characteristics. Especially, turbulence statistics inside the vortex core exhibit very different distributions depending on the methods used. Among the methods applied, the Γ method is the most effective way to identify the vortex center.

Keywords: Tip Vortex, Wandering Motion, Turbulence Statistics, Large Eddy Simulation.

1 Introduction

The blade tip vortex is one of the major features of a rotary wing wake, and its close proximity to the blade results in various aerodynamic and aeroacoustic phenomena. It is therefore crucial to understand the underlying flow physics to predict the strength and position of the blade tip vortex. However, the tip vortices exhibit wandering motions about their mean position, which leads to large errors in obtaining the mean statistics. Previous studies investigated the flow characteristics by overlapping instantaneous flow fields with respect to their vortex centers to remove the effect of wandering motion [1, 2]. Several vortex identification methods were utilized for identifying the center location, but they did not produce same results even in a qualitative sense. In the present study, we perform a large eddy simulation of tip vortices trailing from an isolated two-bladed multirotor propeller, and apply different center identification methods to the flow fields to find their center locations, which allows us to examine the flow characteristics of wandering blade tip vortices.

2 Numerical details

The governing equations are the spatially filtered continuity and Navier-Stokes equations. The sub-grid scale stress tensor is modeled with a dynamic global model [3]. No-slip boundary condition at the propeller surface is achieved using an immersed boundary method [4]. The computation is performed in a cylindrical coordinate system rotating with the blade. A second-order semi-implicit fractional-step method with the domain decomposition method [5] is used, and the second-order central difference method is used for spatial discretization. Neumann boundary conditions are imposed on all boundaries and a sponge layer at the outlet is employed for computational stability. The Reynolds number based on the tip speed V_{tip} and chord length at 75% span c is about 73,000.

3 Results

The vortex centers are identified using the axial vorticity, helicity, axial velocity, pressure, λ_2 criterion [7], and Γ method [8]. The vortex parameters such as the peak swirl velocity and core radius significantly vary depending on the vortex identification methods. We show that the difference in the core radius is as large as 10% even in an early wake age (figure 1(a)). The rms azimuthal velocity fluctuations by different identification methods are shown in figure 1(b). It shows very different distributions of turbulence intensity within the core. This is because the vortex core is highly unsteady in nature due to the interactions of the tip vortex with multiple vortices separated from the blade tip. Note the high rms values at the vortex center. Identifying vortex centers with the Γ method [8] results in mean and turbulence characteristics of the tip vortex that are consistent with previous theoretical studies and flow visualization results.

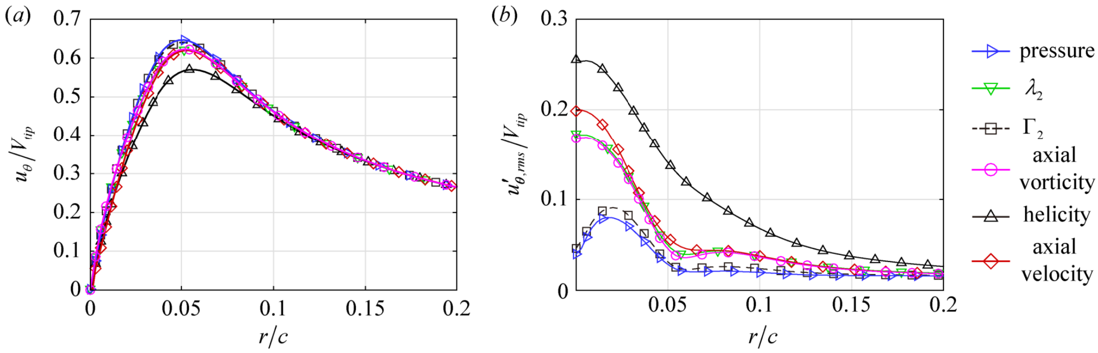

Figure 1: Flow characteristics at the wake age of 25° using various vortex identification methods: (a) swirl velocity; (b) rms azimuthal velocity fluctuations.

References

[1] K. W. McAlister. Rotor wake development during the first revolution. *J. Amer. Helicopter Soc.*, 49:371-390, 2004.

[2] M. Ramasamy, B. Johnson and J. G. Leishman. Turbulent tip vortex measurements using dual-plane stereoscopic particle image velocimetry *AIAA J.*, 47:1826-1840, 2009.

[3] J. Lee, H. Choi and N. Park. Dynamic global model for large eddy simulation of transient flow. *Phys. Fluids*, 22:075106, 2010.

[4] D. Kim and H. Choi. Immersed boundary method for flow around an arbitrarily moving body. *J. Compt. Phys.*, 212:662-680, 2006.

[5] K. Akselvoll and P. Moin. An efficient method for temporal integration of the Navier-Stokes equations in confined axisymmetric geometries. *J. Compt. Phys.*, 125:454-463, 1996.

[6] H. B. Squire. The Growth of a Vortex in Turbulent Flow. *Aeronaut. Q.*, 16:302-306, 1965.

[7] J. Jeong and F. Hussain. On the identification of a vortex. *J. Fluid Mech.*, 285:69-94, 1995.

[8] L. Graftieaux, M. Michard and N. Grosjean. Combining PIV, POD and vortex identification algorithms for the study of unsteady turbulent swirling flows. *Meas. Sci. Technol.*, 12:1422-1429, 2001.