APPLICATION OF THREE-COMPONENT PIV TO A HOVERING ROTOR WAKE

Gloria K. Yamauchi
NASA Ames Research Center
Moffett Field, CA

Luiz Lourenco
Florida State University
Tallahassee, FL

James T. Heineck
NASA Ames Research Center
Moffett Field, CA

Alan J. Wadcock
Aerospace Computing, Inc.
Mountain View, CA

Anita I. Abrego
NASA Ames Research Center
Moffett Field, CA

Aerodynamics Session, 56th AHS Forum, Virginia Beach, VA, May 2-4, 2000

Introduction

The key to accurate predictions of rotorcraft aerodynamics, acoustics, and dynamics lies in the accurate representation of the rotor wake. The vortical wake computed by rotorcraft CFD analyses typically suffer from numerical dissipation before the first blade passage. With some a priori knowledge of the wake trajectory, grid points can be concentrated along the trajectory to minimize the dissipation. Comprehensive rotorcraft analyses based on lifting-line theory rely on classical vortex models and/or semi-empirical information about the tip vortex structure. Until the location, size, and strength of the trailed tip vortex can be measured over a range of wake ages, the analyses will continue to be adjusted on a trial and error basis in order to correctly predict blade airloads, acoustics, dynamics, and performance. Using the laser light sheet technique (Refs. 1-2), tip vortex location can be acquired in a straightforward manner. Measuring wake velocities and vortex core size, however, has been difficult and tedious using point-measurement techniques such as laser velocimetry. Recently, the Particle Image Velocimetry (PIV) technique has proven to be an efficient method for acquiring velocity measurements over relatively large areas and volumes of a rotor wake (Refs. 3-8). The work reported to date, however, has been restricted to 2-component velocity measurements of the rotor wake.

Three-component velocity measurements of a hovering rotor wake were acquired at NASA Ames Research Center in May 1999. This experiment represents a major step toward understanding the detailed structure of a rotor wake. This paper will focus primarily on the experimental technique used in acquiring this data. The accuracy and limitations of the current technique will also be discussed. Representative velocity field measurements will be included.

Model Description

Figure 1 shows the two-bladed rotor and test stand used in this experiment, which was conducted at NASA Ames in the U.S. Army Aeroflightdynamics Directorate Hover Test Chamber. The rotor diameter was 7.5 ft and the blades were rectangular with a chord of 7.5 inches. The outer 50 percent of each untwisted aluminum blade has a NACA 0012 profile; the profile linearly tapers to a NACA 0020 profile from 0.5R to 0.2R. The collective pitch of the blades was manually adjusted. The rotor hub was approximately 8 ft above the chamber floor. The test stand was powered by two 90-HP electric motors. The rotor was operated at a negative collective pitch to minimize recirculation in the chamber; therefore, the rotor thrust was downward and the wake convected upward. Two large roll-up doors on opposite sides of the chamber were raised slightly to allow the rotor to draw in air from the outside. The wake was exhausted through an annulus in the chamber ceiling and then to the exterior through openings near the top of the chamber. The height of the chamber ceiling is adjustable and was located approximately 6 ft above the rotor hub. A similar installation was used by Ref. 9, which provides additional details about the rotor and test stand.

Laser and Camera Installation

Figure 2a) provides a schematic of the test set-up. Since the rotor was thrusting downward, a vertical laser sheet was formed above the rotor to capture images of the wake. The sheet was projected along the trailing edge of the reference blade when the blade was placed in a reference position. Two Kodak ES 1.0 double-exposure cameras were placed in a photogrammetric stereoscopic arrangement. The time between image pairs was 30 microseconds; the acquisition rate was 15 image pairs per second. Each camera used a 55 mm focal lens. Figure 2b) shows a view of the sheet from one of the two cameras. The sheet was generated using a Spectra Physics dual Nd:YAG 380 mJ laser and cylindrical optics. The image area was approximately 12 inches high and 18 inches wide. A Corona Integrated Technologies smoke generator was used to seed the flow. The smoke generator was placed on the floor of the hover chamber and emitted seed particles with an average diameter of less than 0.5 microns.

The application of the PIV technique to the off-axis imaging configuration shown in Fig. 2 is not straightforward. In using off-axis imaging, perspective effects must first be eliminated from the camera view. The final paper will discuss in detail the perspective correction, Scheimpflug focussing condition, the image calibration technique, and the high-resolution correlation algorithm (Ref. 10) used to process the images.

Test Conditions

The rotor speed was limited by the frequency range of the laser (14.5-15 Hz), therefore, all data were acquired at a rotor speed of 870 rpm. Since a rotor balance was not installed for this test, a thrust condition matching the condition tested in Ref. 9 was selected. Therefore, all data were acquired for –8 deg collective pitch which corresponds to a rotor thrust coefficient of 0.005.

Five hundred image pairs were acquired in increments of 50 image pairs at each wake age. Image pairs were acquired from 0 to 270 deg of wake age in increments of 15 degrees. A limited amount of data were also acquired for smaller increments of wake age. Figure 3 shows an instantaneous image of a 3-component velocity vector field. The contours represent the vorticity. In Fig. 3, the tip vortex from each blade is clearly seen. In addition, the shed sheet associated with the lower vortex (aged 30 deg) is visible.

The complete paper will present additional details of the experimental technique and image processing algorithm. Instantaneous and ensemble averaged velocity fields will also be shown.

References

1. Mercker, E., Pengel, K., "Flow Visualization of Helicopter Blade Tip Vortices: A quantitative technique to determine the trajectory and the position of the tip vortex pattern of a model rotor," Eighteenth European Rotorcraft Forum, Avignon, France, September 1992.
2. Lau, B. L., Wadcock, A. J., Heineck, J. T., "Wake Visualization of a Full-Scale Tilt Rotor in Hover," AHS Technical Specialists' Meeting for Rotorcraft Aerodynamics and Acoustics, Williamsburg, VA, October 1997.
3. Raffel M., Seelhorst, U., Willert, C., "Vortical Flow Structures At a Helicopter Rotor Model Measured by LDV and PIV," *Aeronautical Journal,* Vol. 102, (1014), April 1998.
4. Raffel M., Willert C., Kompenhans J., Ehrenfried K., Lehmann G., Pengel K., "Feasibility and Capabilities of Particle Image Velocimetry (PIV) for Large Scale Model Rotor Testing," Heli Japan 98, Proceedings of the AHS International Meeting on Advanced Rotorcraft Technology and Disaster Relief, Gifu, Japan, April 1998.
5. Horner, M.B., Stewart, J.N., Galbraith, R.A.McD., Grant, I., Coton, F.N., "An Examination of Vortex Deformation During Blade-Vortex Interaction Utilising Particle Image Velocimetry," 19th Congress of the International Council of the Aeronautical Sciences, Vol. 2, 1994.
6. Saripalli, K.R., "Application of Particle Imaging Velocimetry Techniques to Helicopter Rotor Flowfields at McDonnell Douglas Aerospace," 33rd AIAA Aerospace Sciences Meeting and Exhibit, Reno, January 1995.
7. Murashige, A., Kobiki, N., Tsuchihashi, A., Nakamura, H., Inagaki, K., Yamakawa, E., "ATIC Aeroacoustic Model Rotor Test at DNW," AHS International Meeting on Advanced Rotorcraft Technology and Disaster Relief, Gifu, Japan, April 1998.
8. Yamauchi, G. K., Burley, C. L., Mercker, E., Pengel, K., and JanakiRam, R. D., "Flow Measurements of an Isolated Model Tilt Rotor," AHS 55th Annual Forum, Montreal, Canada, May 1999.
9. McAlister, K. W., Schuler, C. A., Branum, L., and Wu, J. C., "3-D Wake Measurements Near a Hovering Rotor for Determining Profile and Induced Drag," NASA TP 3577, ATCOM TR 95-A006, August 1995.
10. Lourenco, L., "Mesh-Free Second-Order Accurate Algorithm for PIV Processing," proceedings of VSJ-SPIE98, Paper AB079, Yokohama, Japan, December 1998.

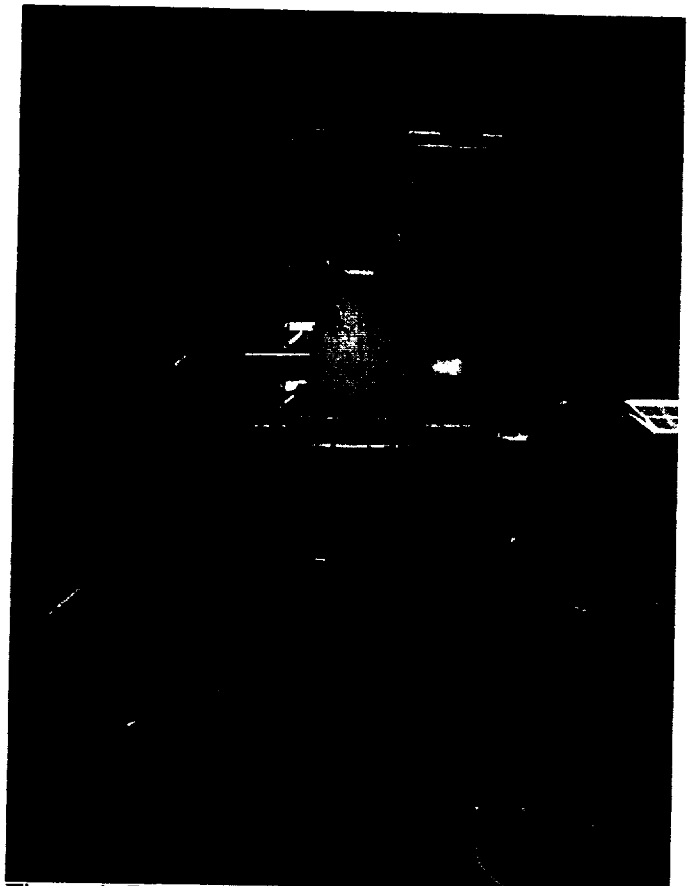
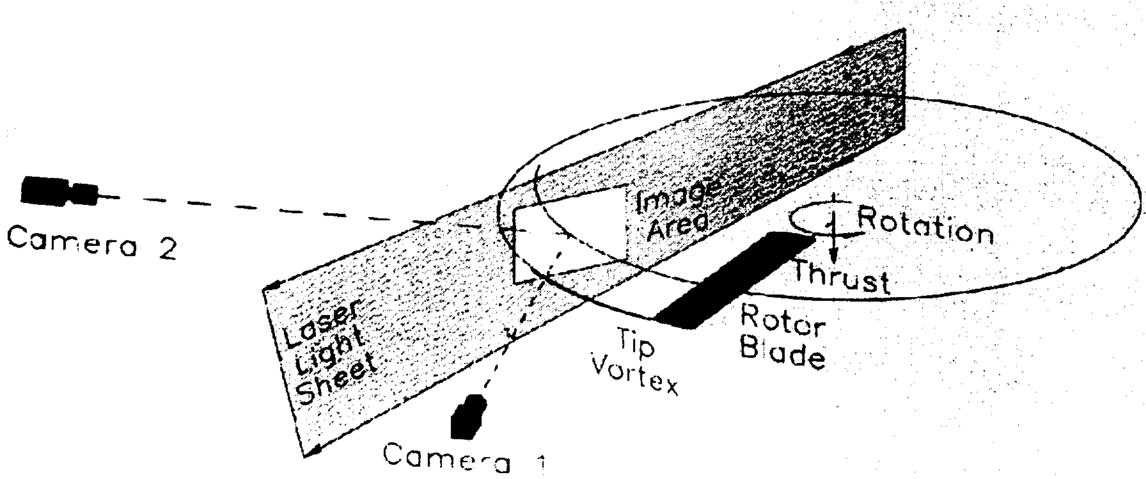


Figure 1. Rotor installation in hover chamber.



a)

Figure 2. Camera and laser installation. a) schematic of overall test set-up

b)

Figure 2. Camera and laser installation. b) view from Camera 2

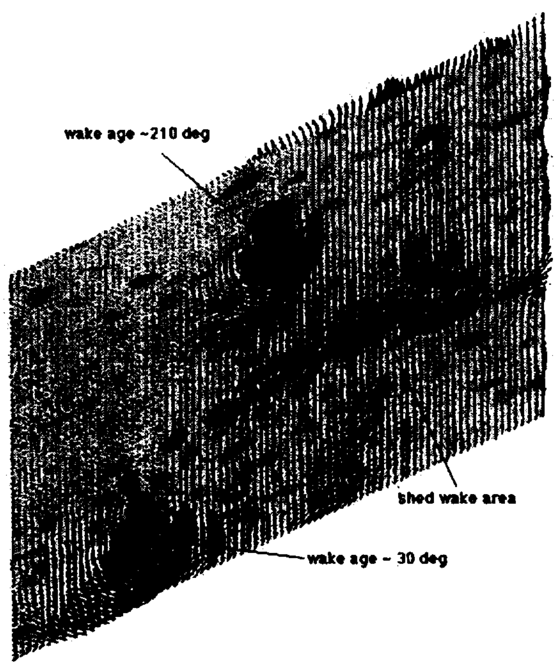


Figure 3. Instantaneous 3-component velocity field with vorticity contours (CT=0.005, RPM=870).