Laser Velocimetry and Doppler Global Velocimetry Measurements of Velocity Near the Empennage of a Small-Scale Helicopter Model

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Abstract

A test program was conducted in the NASA Langley 14- by 22-Foot Subsonic Tunnel to measure the flow near the empennage of a small-scale powered helicopter model with an operating tail fan configuration. Velocity profiles were measured with three-component Laser Velocimetry (LV) one chord forward of the horizontal tail for four forward speeds to evaluate the effect of the rotor wake impingement on the horizontal tail angle of attack. These velocity data indicate the horizontal tail can experience unsteady downwash angle variations of over 30° due to the rotor wake influence. The horizontal tail is most affected by the rotor wake above speeds of 23 m/s (44 knots). Three-component velocity measurements of the flow on the inlet side of the fan were made for a low-speed flight condition using both LV and a promising, non-intrusive, global, three-component velocity measurement technique called Doppler Global Velocimetry (DGV). The velocity data show an accelerated and non-uniform flow into the fan. DGV shows promise as an evolving tool for rotor flowfield diagnostics.

1. Introduction

As rotor and fuselage designs become more integrated, compact, and complex, close rotor wake-fuselage interactions and interference play an increasingly important part in the performance characteristics of rotorcraft. Sheridan and Smith (1979) attribute the importance of interactional effects for modern helicopters to increased disk loading, more compact designs, low level flight requirements, and the increased requirement for directional trim after the loss of the tail rotor which results in larger vertical tail surfaces. These effects are especially important in the design and placement of the anti-torque system and the hortizontal and vertical stabilizers as documented in Prouty and Amer (1982).

Much work has already been done experimentally and analytically to define the interaction effects between the rotor and the fuselage. More limited is the amount of experimental data available for analyzing the main rotor/anti-torque interactions. As advanced configurations such as the RAH-66 are designed and manufactured with sophisticated anti-torque devices, there is a need for high-quality experimental data to support the development of analytical models which have the flexibility to model these types of configurations. Torok and Ream (1993) specifically cite the difficulty in predicting unsteady empennage loads at speeds below 22 m/s (40 knots). While Moedersheim and Leishman (1995) provide experimental pressure data at model scale for a generic T-tail empennage, and Keys et al. (1991) discuss the tremendous amount of testing involved in the Light Helicopter (LH) design process, there does not appear to be specific information in the literature on the velocities in the flowfield near an operating tail fan.

In order to investigate the rotor wake/fuselage/empennage interactions near the empennage of a powered small-scale helicopter with an operating tail fan and a T-tail, the U. S. Army Joint Research Program Office, Aeroflightdynamics Directorate, in cooperation with the NASA Langley Measurement Sciences and Technology Branch, recently conducted a wind tunnel test program in the 14- by 22-Foot Subsonic Tunnel.

2. Model and Instrumentation

The test program was conducted in the Langley 14- by 22-Foot Subsonic Tunnel using the Army's 2-Meter Rotor Test System (2MRTS), a four-bladed, 15-percent scale rotor, a fuselage model representative of the RAH-66, and the tunnel's three-component Laser Velocimetry (LV) system. In addition, a new optical flow measurement technique, Doppler Global Velocimetry (DGV), was applied for the first time to a rotorcraft flowfield during this test program.

The 14- by 22-Foot Subsonic Tunnel is a closed-circuit, atmospheric wind tunnel designed for the low-speed testing of powered and high-lift configurations. This investigation was conducted with the tunnel in the open test section configuration to allow complete optical access to the rotor flowfield. Figure 1 shows the 2MRTS ready for testing in the tunnel. The LV system in operation is also visible in the photograph. The rotor system which was installed on the 2MRTS was a 4-bladed, articulated hub with blades that closely matched the airfoils, planform, and twist of the RAH-66 blades. The anti-torque device of the configuration was modeled by a tip-driven, 20.3-cm (8-in) diameter, 22-bladed fan mounted in the tail fan duct. The fan configuration is shown in Figure 2. As the photograph shows, the fan duct section was painted black to minimize the optical reflections from the surface.

The LV system was a three-component system operating in the backscatter mode. The downstream and vertical components of velocity are measured by the optics which are located on the side of the tunnel, out of the flow; the lateral crossflow component of velocity is measured by the optics which are located beneath the tunnel floor. As can be seen in Figure 1, the third component beams originating beneath the flow were angled at 33° to the vertical to access the inflow area of the canted tail fan.

Except for its long focal length and zoom lens assembly, the system operated as a standard fringe-based LV system; polystyrene particles (1.7 μm) suspended in an alcohol and water mixture were used to seed the flow. The velocity data were acquired using Frequency Domain Processors (FDP's) to maximize the signal to noise ratio of the measurement signal. The LV data acquisition system was designed to acquire rotor azimuth position in addition to the velocity measurements so that an "azimuthal history" of the velocity could be reconstructed in the post-processing of the velocity data.

DGV is a fairly new technique to measure three-components of velocity which has been mainly applied to fixed-wing studies. To date, this technique has been used to acquire only steady-state data; however, the extension of the technique to capture the unsteady rotor flowfield is underway at Langley. This effort is a jointly funded project between the Army and NASA. As a first step in applying DGV to rotorcraft, the technique was used during this test program to measure three-component mean (or steady-state) velocity near the fan tail. This established the feasibility of using DGV in the facility for the types of low-speed and reversed flows which occur in rotor wakes.

The DGV system which was used for this test program was based on the theories described in Meyers (1994). For this test program, three sets of two cameras each were used; each camera pair measured a component of velocity. Although the camera pairs did not measure orthogonal velocity components, post-test processing transformed the velocity measurements into the standard u, v and w components.

Figure 1. Model and LV installed in tunnel.

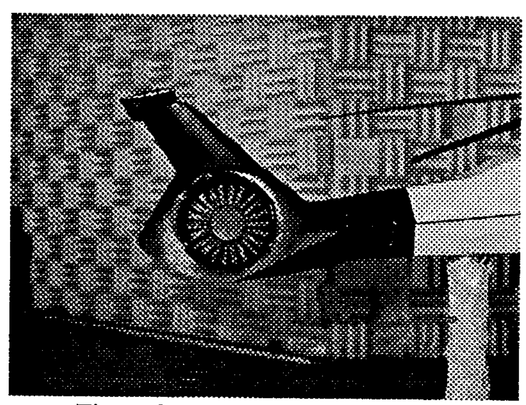

Figure 2. Tail fan configuration.

A light sheet produced by a single frequency Argon-ion laser was projected into the flow. This sheet defined the measurement plane for the three-component DGV velocity measurements. The DGV measurements were made in the same plane as the LV measurements so that detailed comparisons of the two techniques could be made. Propylene glycol smoke was injected into the flow from the settling chamber of the tunnel. As the smoke passed through the sheet, it scattered light that was Doppler-shifted in optical frequency proportional to the particle velocity.

At each camera pair location, an iodine vapor cell was placed in front of the signal video camera to attenuate the collected scattered light in proportion to the shift in the laser light optical frequency. A second camera, without an iodine cell, was used to provide a reference image of the scattered light intensity distribution emitted by the smoke passing through the light sheet. Normalization of the signal image by this reference image removed spatial variations in light intensity. The resulting image amplitude distribution was a map of the velocity flowfield in the locations illuminated by the laser light sheet.

3. Discussion of Results

Velocities were measured in two regions with both the main rotor and the tail fan operating. In the first region, forward of the horizontal tail, velocity was measured with the LV system for four forward speeds. In the second region, on the inlet side of the tail fan, velocity was measured with both LV and DGV.

3.1 Horizontal Tail

The average downwash angle at the tail is presented in Figure 3. As expected, the downwash decreases with increasing speed as the rotor wake is swept downstream. In Figure 4, the unsteady downwash angle is shown for four speeds. These data show that the tail can experience angle variations of over 30° occurring at frequencies of 4/rev. By analyzing the frequency content of the velocity time history, it is possible to determine the position of the rotor wake relative to the tail for each speed. Figure 5 shows the results of this analysis. The rotor wake impinges on the horizontal tail at speeds above 23.5 m/s (44 knots).

3.2 Tail Fan

Figure 6 presents contour plots in the fan system coordinates of the average downstream velocity, u, the lateral (perpendicular to the fan) velocity, v, and the vertical (parallel to the fan) velocity, w. These are presented for a forward speed of 18.2 m/s (33 knots) and an equivalent full-scale vehicle weight of 33,362N (7500 lbs). Note the accelerated flow at the forward section of the duct. The data indicate the flow is separated along the upstream lip of the tail fan duct.

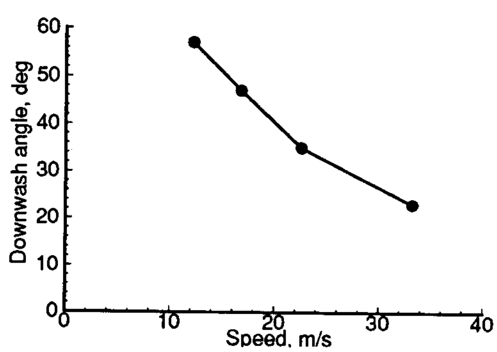

Figure 3. Average downwash angle.

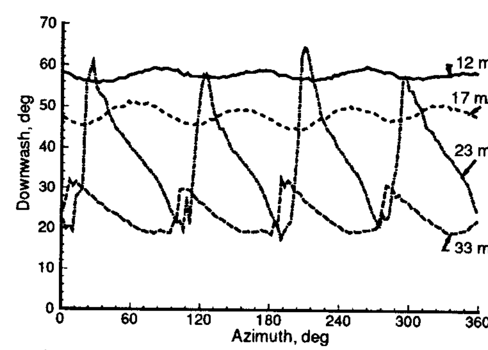

Figure 4. Unsteady downwash angle, one chord forward, one chord to the right, and 0.13 chord below horizontal tail centerline.

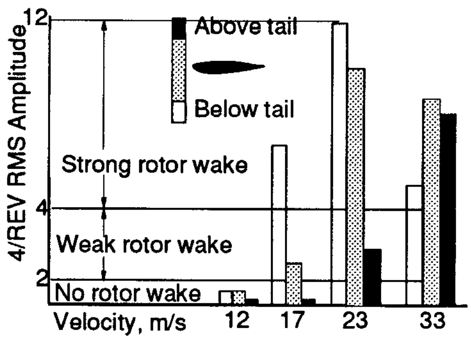

Figure 5. Wake impingement on horizontal tail.

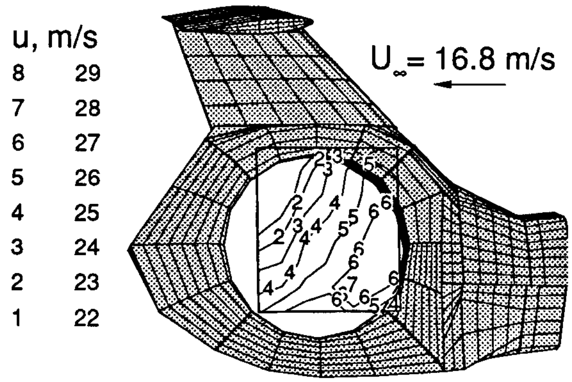

Figure 6a. Streamwise velocity, u.

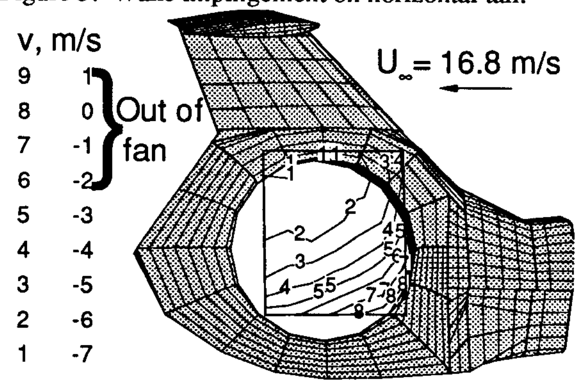

Figure 6b. Normal (inflow) velocity, v. (Corrected)

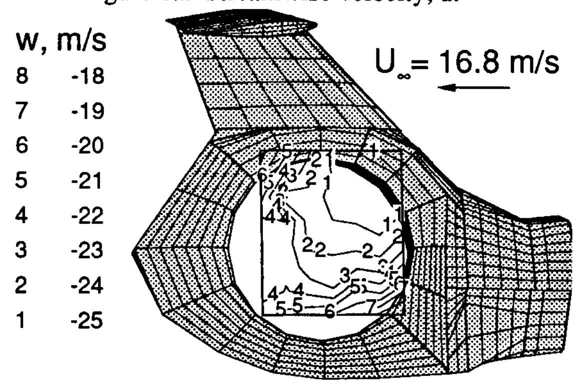

Figure 6c. Vertical velocity, w.

Figure 6. Contour plots of LV average velocity data near the tail fan.

In Figures 7-8, the DGV data are presented. The data in Figure 7 are for the individual components of velocity in the wind tunnel coordinate system; the dark areas on the right of the figures are the absence of smoke in the image. These plots illustrate how DGV maps the entire velocity field illuminated by the smoke in the light sheet. As these velocity maps are difficult to assess, especially in gray scale, Figure 8 presents the DGV data for a single slice horizontally through the measurements for each velocity component. The location for this slice of a single row of pixels is shown on Figure 7 by arrows on each of the velocity maps. The LV data for the same configuration are also presented on the plots in Figure 8. Note that the DGV data provides a tremendous increase in the resolution of the velocity measurement locations; there are over 400 DGV measurements to compare to 7 LV measurements in the same horizontal line.

Although the DGV data do not match exactly with the LV data, there is enough similarity to encourage the continued development of the global velocity technique. The DGV technique requires some additional refinement and improvements before it is established as a reliable, accurate tool for rotorcraft; however, the immense potential payoff of increased efficiency in flowfield measurement capability is worth the investment.

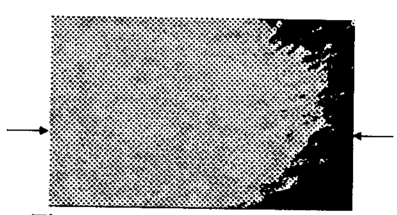
Figure 7a. u-component.


Figure 7b. v-component.

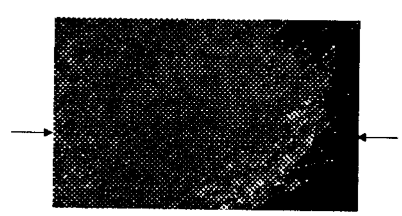
Figure 7c. w-component.

Figure 7. DGV velocity maps.

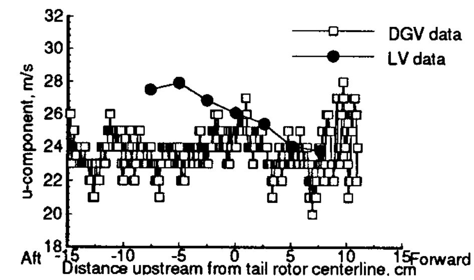

Figure 8a. Streamwise velocity, u.

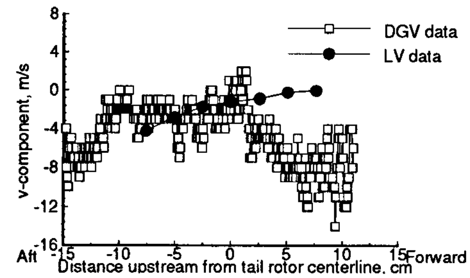

Figure 8b. Normal (inflow) velocity, v.

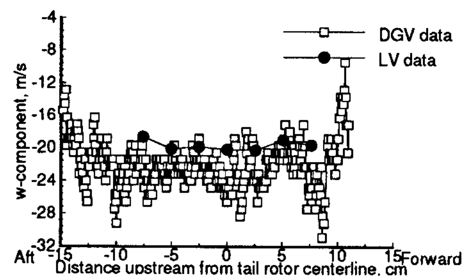

Figure 8c. Vertical velocity, w.

Figure 8. Comparison of DGV and LV data.

4. Conclusions

In order to investigate the rotor wake/fuselage/empennage interactions near the empennage of a powered small-scale helicopter with an operating tail fan and a T-tail, the U. S. Army Joint Research Program Office, Aeroflightdynamics Directorate, in cooperation with the NASA Langley Measurement Sciences and Technology Branch, recently conducted a wind tunnel test program in the 14- by 22-Foot Subsonic Tunnel. Velocity data were acquired forward of the horizontal tail for four flight conditions, documenting the unsteady downwash near the horizontal tail. Velocity data were also obtained on the inlet side of the fan for one flight condition, providing information about the inflow into the tail fan. The major conclusions from this study are: 1) There is an accelerated flow pattern near the fan tail. 2) The horizontal tail surface experiences large changes (over 30°) in the unsteady sidewash and downwash angles due to the influence of the rotor wake. The horizontal tail is most affected by the rotor wake above speeds of 23.7 m/s (44 knots). 3) A new flow measurement technique, Doppler Global Velocimetry, shows promise for improving non-intrusive global velocity measurement productivity.

References

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