TIP VORTEX GEOMETRY OF A HOVERING HELICOPTER ROTOR IN GROUND EFFECT

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SUMMARY

The wide-field shadowgraph method has been used to photograph the tip vortices of a hovering helicopter rotor in ground effect. The shadowgraphs were used to obtain quantitative measurements of the rotor tip vortex geometry both in and out of ground effect. Many important phenomena are visible in the rotor wake using this method. These include the variation in descent and contraction rates of the tip vortices in ground effect, and the interaction between tip vortices in the far wake. The tip vortex geometry from the shadowgraphs is compared with the tip vortex geometry predicted using a free wake hover performance analysis. The free wake analysis accurately predicts the tip vortex geometry both in and out of ground effect. Performance data from the test is compared with the performance predicted using several methods, including the free wake analysis. All methods provided reasonable predictions for the helicopter performance in ground effect.

NOMENCLATURE

A	= rotor disk area, πR^2, m^2
c	= rotor blade chord, m
C_Q	= rotor torque coefficient, $Q/\rho A R V_{tip}^2$
C_{Q_0}	= profile torque coefficient
C_T	= rotor thrust coefficient, $T/\rho A V_{tip}^2$
FM	= rotor figure of merit, $C_T^{3/2}/\sqrt{2}C_Q$
h	= rotor distance from ground plane, m
K	= $dC_Q/dC_T^{3/2}$
P	= rotor power, N-m/s
Q	= rotor torque, N-m
r	= radial distance, m
R	= rotor radius, m
T	= rotor thrust, N
V_{tip}	= rotor tip speed, ΩR, m/s
z	= axial distance, m
Ω	= rotor rotation speed, rad/s
ρ	= air density, kg/m^3
σ	= rotor solidity, 4cR/A
∞	= subscript denoting out of ground effect condition

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INTRODUCTION

The hover performance of a helicopter is a very important design consideration since it directly affects the maximum payload of the helicopter. One method that can be used to increase the effective lifting capabilities of a helicopter is to hover close to the ground (in ground effect). Analytical and empirical methods have been developed to predict helicopter performance in ground effect (IGE) with reasonable accuracy.[1-6] Knight and Hefner[2] developed an analytical method to predict rotor performance in ground effect, and verified it with experimental studies. They treated ground effect as a modification to the induced power of the rotor. The work of Zbrozek[3] examined experimental results from many tests and developed an empirical method that was based on rotor height and thrust coefficient. Cheeseman and Bennett[4] developed a simple analysis using the method of images that modeled the rotor as a source. Hayden[6] developed a simplified empirical model from a large set of flight test data. This method was also based on a correction to the induced power. These methods all provide reasonable results, but each has certain limitations. The simple analytical methods don't account for rotor design parameters such as blade twist, chord, and sweep that may influence the hover performance in ground effect. The empirical methods are generally limited to rotor systems that are similar to those used to develop the database. Also, none of these analyses will provide information on the blade loading characteristics in ground effect.

A greater understanding of the physics of the flow is required to develop more rigorous analytical methods capable of accurately predicting the performance in ground effect for advanced rotor designs. Flow visualization can be a very important tool in understanding the physics of the flow field. Taylor[7] examined the flow field of a hovering rotor in ground effect using balsa dust particles. This technique showed the overall shape of the wake, especially the radial expansion of the wake as the rotor/ground plane separation distance was decreased.

This paper describes an experimental and theoretical study of the wake geometry and performance of a helicopter rotor in ground effect. For the experimental portion of the study, a Lynx tail rotor was used to model a simple helicopter rotor in ground effect. The rotor performance was measured at many rotor/ground plane separation distances for a range of collective pitch settings. The wide-field shadowgraph method was used to obtain quantitative and qualitative information on the tip vortex geometry of the hovering rotor. The wide-field shadowgraph method is a photographic technique that detects the density variations of the tip vortices in the rotor wake,[8] allowing precise visualization of the tip vortices.