COMPUTATIONAL STUDIES IN LOW SPEED ROTOR AERODYNAMICS

Todd R. Quackenbush*
Graduate Student,
Princeton University
Princeton, New Jersey

Abstract

Recently, curved vortex elements have been developed for use in helicopter free wake calculations. As previously documented, these elements allow more efficient and accurate calculation of the wake-on-wake interactions than do traditional straight vortex elements. Curved elements have been applied here to the prediction of the rotor wake geometry and its associated inflow distribution in low speed forward flight. By coupling the wake model to a blade dynamic analysis, a simulation capable of predicting blade motion and hub moments in forward flight has been developed. The resulting code has been validated by successful predictions of the lateral flapping of articulated rotors in low speed level flight, and additional simulations of climb and descent have been undertaken. Successful correlation of other experimental data, including moments due to cyclic on hingeless rotors and transient thrust response in hover, has given encouraging evidence of the capabilities of this code as a tool for analysis of the low speed regime.

Introduction

The construction of aerodynamic analyses of helicopter rotors based on free wake simulations has been undertaken by several previous researchers (Refs. 1-3, for example). Such analyses are well suited to (and often necessary for) the successful prediction of aerodynamic loads on rotors at low forward speed. However, the application of free wake codes to such problems has been infrequent, with the exception of Ref. 4.

Several important issues arise in the low speed regime that are inadequately modelled by traditional momentum theory (Ref. 5) or prescribed (or "rigid") wake (Refs. 6-8) treatments. First, a general ability to accurately predict inflow velocities at the rotor in low speed is a requirement of continuing importance for advanced rotorcraft. Prediction of aerodynamic moments is of particular importance for vehicles such as the X-Wing, which combines exceptionally stiff blades with a lift control system utterly unlike that of traditional rotors. Establishing control requirements of such aircraft at low speed will require a solid understanding of the inflow generated by the highly distorted wakes characteristic of that regime. Other particular issues of importance for more conventional rotorcraft are: lateral flapping response or articulated rotors in level flight (as noted in Ref. 4) or in descent; the closely related issue of the control power of both hingeless and articulated rotors; and the dynamic response of rotors to time-varying inputs in collective or cyclic pitch. There are, of course, a host of other issues of interest related to interactional aerodynamics (e.g., main rotor/tail rotor, main rotor/empennage interactions), but the topics noted above are examples of significant isolated-rotor phenomena.

It is the object of this paper to examine the applicability of a recently developed free wake simulation to the analysis and prediction of phenomena of importance in low speed flight, like the issues cited above. This simulation takes advantage of the recent development of curved vortex elements for use in rotor wake models, as will be briefly discussed below. These elements permit more efficient execution of free wake simulations, while affording a more accurate representation of the velocity field in the vicinity of the filament than is possible using larger numbers of straight segments.

The discussion below will describe the steps that were taken to couple the free vortex motion to a rotor blade model for the prediction of blade motion and the resultant rotor loads. The final section of the paper will illustrate results of calculations undertaken with this code. As will be shown, the free wake analysis described herein has substantial potential for useful application to the prediction of rotor steady and low frequency loads at low forward speed.

Curved Vortex Elements for Free Wake Models

As indicated in the discussion above, it is highly desirable to use free wake aerodynamic models for the analysis of rotor loads at low forward speed. Several difficulties have impeded the development of useful free wake models in the past. Among these are:

- long computation times;
- locally high errors in predicted induced velocity; and
- convergence problems at low forward speed.

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* Currently Associate, Continuum Dynamics, Inc., P.O. Box 3073, Princeton, New Jersey 08543.
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