New Free-Wake Analysis of Rotorcraft Hover Performance Using Influence Coefficients

Todd R. Quackenbush*
Continuum Dynamics, Inc., Princeton, New Jersey
Donald B. Bliss†
Duke University, Durham, North Carolina
and
Daniel A. Wachspress‡
Continuum Dynamics, Inc., Princeton, New Jersey

Free-wake analyses of helicopter rotor wakes in hover using time stepping have been shown to encounter instabilities which preclude convergence to valid free-vortex solutions for rotor-wake geometries. Previous work has demonstrated that these convergence difficulties can he overcome by implementing a new free-wake analysis method based on the use of influence coefficients. The present paper reviews this approach and documents its incorporation into a hover performance analysis called Evaluation of Hover Performance using Influence Coefficients (EHPIC). The technical principles underlying the EHPIC code are described with emphasis on steps taken to develop the single-filament wake models used in previous work into a multifilament wake valid for realistic hover performance predictions. The coupling of the wake model to a lifting surface loads analysis is described, and sample problems are solved that illustrate the robustness of the method. Performance calculations are also undertaken for hover to illustrate the utility of EHPIC in the analysis of rotorcraft performance.

Nomenclature

$\boldsymbol{b}$ = binormal unit vector at a collocation point
$\boldsymbol{n}$ = normal unit vector at a collocation point
$\boldsymbol{q}$ = vector of cross-flow velocities at each collocation point
Δq_b = perturbation in binormal component of $\boldsymbol{q}$
Δq_n = perturbation in normal component of $\boldsymbol{q}$
$Q_{(\ )(\ )}$ = influence coefficient submatrices
r = radial distance from rotor hub
r_f = radius of far wake
t = tangent unit vector at a collocation point
w = velocity normal to rotor blade surface at a control point
w_f = downwash velocity in the far wake
$\boldsymbol{x}$ = vector of collocation point position
Δx_b = perturbation of collocation point position in binormal direction
Δx_n = perturbation of collocation point position in normal direction
γ = vector of bound circulation of each vortex quadrilateral
Γ = filament circulation
Ω = rotor blade rotation rate (rad/s)

Introduction and Basic Principles

New Approach to the Hover Problem

THE determination of the wake of a hovering rotor poses a particularly challenging computational problem. Previous numerical solutions for the free wake of a hovering rotor[1-4] have experienced stability and convergence problems. The instability encountered causes the wake to depart from an idealized, smoothly contracting helical form. This behavior is described in Ref. 1 and was also encountered using the significantly different computational method in Ref. 4. The instability causes residual unsteadiness in the downwash velocity at the rotor blade and, if left unchecked, it may lead to uncontrollable divergence of the solution.

This fundamental difficulty arises because the wake of a hovering rotor actually is unstable, as has been confirmed by experiment. The instability can be viewed as the first step in the evolution from an orderly flow structure near the rotor to a turbulent jet far below. The unstable behavior observed computationally for rotor wakes is also closely related to the instability observed in analytical treatments of vortex helices,[5,6] which revealed a wide range of unstable modes of motion in both single and interdigitated helices. A linearized analyses of these solutions indicated that any perturbation of the self-preserving helical solution would produce divergent oscillations in time domain computations.[7]

The common feature of the preceding free-wake hover analyses is that they seek to find the solution through just such time marching schemes. Starting with an incorrect initial wake configuration, the subsequent wake motion is computed in the hope that it will progress to the desired hover solution. However, because of the wake instability, it is not possible to obtain an equilibrium solution for the wake structure using a time marching approach. Researchers have tried to circumvent this stability problem by artificial suppression of the instability. Methods of suppression include periodically smoothing and imposing symmetry on the wake and the introduction of substantial amounts of numerical damping. Unfortunately, such approaches may effectively impose forces on the wake leaving open the question of whether equilibrium-free motion conditions are really being satisfied. Depending on the type of suppression used, long computer run times may still be required to obtain convergence or to compute time-averaged results if some residual instability remains.

In order to circumvent the limitations of the traditional approach, a new method for finding solutions to the hover problem was proposed several years ago.[1] This new approach is based on the proposition that the free-wake hover problem possesses a self-preserving steady solution when viewed in

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*Senior Associate. Senior Member AIAA.
†Associate Professor, College of Engineering, Department of Mechanical Engineering and Materals Science. Member AIAA.
‡Associate.