A NEW METHODOLOGY FOR HELICOPTER FREE WAKE ANALYSES

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PRESENTED AT THE 39th ANNUAL FORUM OF THE AMERICAN HELICOPTER SOCIETY MAY 9-11, 1983

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Abstract

A method using curved vortex elements has been developed for rotor free wake calculations. The complexity of the element model is somewhat increased as compared to straight-line elements, but many fewer curved elements are needed to simulate the wake. Sample calculations show that curved elements give far better accuracy when velocities near the vortex are computed, even if less than half as many curved elements are used. Several method to connect and orient curved elements to form a wake shape are discussed and a preferred method is identified. A simplified model of a single blade rotor in hover was solved using curved elements in conjunction with a new solution technique. The flow field was analyzed in blade-fixed coordinates and the vortex motion was followed in a series of cross-flow planes located at collocation points along the wake. One advantage of this approach is that it allows a degree of independence between the time step and the element size. The new method worked well and generally yielded behavior typical of other free wake hover calculations. Nearly identical results were obtained for 45° and 22.5° element arc sizes.

Introduction

The critical issue in the field of rotor aerodynamics is the treatment of the wake. The wake is of primary importance in determining overall aerodynamic behavior and in predicting structural vibration and aerodynamic noise. These problems are particularly critical in low speed flight, precisely where the wake behavior is the most complex and the least well understood. The two approaches in use can be broadly categorized as prescribed wake and free wake analyses.

In prescribed wake models, the wake position is determined according to some relatively simple criterion. For example, the wake location can be kinematically determined from the rotor motion and the downwash field derived from momentum theory. The Biot-Savart law can then be used to find the downwash induced by this wake at the rotor plane. In some schemes, the wake location may be adjusted by empirical factors or slightly updated as the calculation progresses. However the determination of the wake shape always involves a process which does not consider in detail the various effects acting on the wake, and in particular the effect of the wake on itself. Thus, a prescribed wake configuration is not a valid free vortex flow. Prescribed wake methods are nevertheless valuable since they provide accurate results for many applications, and have the advantage of relative simplicity and low user cost.

Free wake models have been developed in an attempt to simulate in detail the actual shape and motion of the wake.[1-5] The primary emphasis has been on locating the strong tip vortex, although methods have also been developed to model the inboard shed vorticity. Typically, the tip vortex has been approximated by a series of connected straight-line segments. The velocity induced at each connection point is calculated by integrating the Biot-Savart law over the rest of the wake and over the bound vorticity on the rotor. A cut-off distance approach is used to avoid singular behavior when evaluating the velocity induced on the vortex itself. The connection points are assumed to be convected at the local velocity over a small time increment. The wake location is then updated and new convection velocities are calculated. This procedure is continued until the solution converges to a final wake configuration which is repeatable from cycle to cycle within some specified accuracy.

The current available free-wake models have been somewhat more successful than prescribed wake models in the low speed flight regime. In particular, computed wake shapes show a fair degree of qualitative agreement with the primary features seen in flow visualization experiments, namely, substantial wake contraction in very close proximity to the rotor plane, and a tendency in forward flight for the wake to begin to "roll-up" on the downstream side of the rotor. However, to obtain good quantitative agreement between predicted aerodynamic loads and experimental results often requires the judicious adjustment of model parameters. Given this fact, the