Model for Investigation of Helicopter Fuselage Influence on Rotor Flowfields

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Abstract

THE paper presents an efficient analytical model for analyzing helicopter fuselage effects on main rotor flowfields in various flight conditions. The fuselage shapes are obtained by a discrete distribution of point and line sources/sinks along their axes which, together with the freestream velocity, create bodies with two planes of symmetry. It is shown that the method enables the description of a large family of helicopter-like shapes with very few sources. Small fuselage yaw angles are introduced by slender body theory. The paper also includes an explicit slender-body approximation for taking into account an arbitrary distribution of main rotor downwash over the fuselage surface. The model is used for parametric investigation of the fuselage influence for a variety of shapes, flight conditions, and rotor/fuselage relative positions.

Contents

Rotor/fuselage interaction effects have been shown in various studies to be significant.[4] Most of the analytical approaches to investigating the problem have involved the use of panel methods to represent the fuselage. Unlike similar calculations for fixed-wing fuselages, the prediction of helicopter fuselage influence on the main rotor usually involves the use of iterative procedures that yield consistent values of the fuselage-induced velocity over the rotor disk, and of the rotor-induced velocity over the fuselage surface (both are significantly time dependent in most of the flight conditions). Although panel methods are an effective approach, their combination with unsteady rotor downwash is normally complex and involves lengthy numerics. Thus, it appears that, as a result of computational restraints, the literature contains only limited parametric investigations of fuselage effects.[3-4] A simpler approach to the problem was taken in the paper that summarized the development of analytical modeling of the helicopter fuselage influence along with an extensive parametric investigation.[5]

Fuselage Shape Definition

The fuselage shape is determined by the case of an isolated fuselage at zero yaw angle. The stream function ψ due to a uniform freestream velocity U in the $-x$ direction (see Fig. 1) and the distribution of n discrete sources M_i at points x_i along the fuselage axis can be formulated in the $x-z$ plane as:

$$\psi = -\tilde{z}^2 + \frac{1}{2}\sum_{i=1}^{n} \bar{M}_i \frac{\tilde{x}-\tilde{x}_i}{\sqrt{(\tilde{x}-\tilde{x}_i)^2+\tilde{z}^2}} \tag{1}$$

where ($\tilde{\ }$) and ($\bar{\ }$) represent nondimensionalizations by the disk radius R and $\pi U R^2$, respectively. Note that the sources sum is assumed to vanish as required by the closed-body condition. The most common way for approximating a given shape using this formulation is to substitute pairs of data points ($x = x_j$, $z = z_j$) in Eq. (1) and to construct a system of algebraic equations for the source strengths by setting ψ equal to zero and prescribing the source locations. In cases where the number of data points is larger than h, the equations are solved by the least-square method.[6] In the present paper, the fuselage shape is obtained in a slightly different way, where for a given number of sources, their optimal locations are obtained by an iterative scheme, yielding the possibility to use an extremely small number of sources. During the process, the source strengths are obtained for each set of locations x_i by a least-square procedure (usually there are more data points than sources), resulting in some residual value of the stream function at each data point, the sum of which is minimized by the procedure. In addition, it was found that, based upon a few empirical rules, it is relatively easy to precribe the source strengths and locations in order to create a large family of simple helicopter-like shapes.

The full paper also contains similar derivations for bodies with two planes of symmetry. However, the following summary concentrates on the case of bodies of revolution only.

Fuselage Upwash

In the case of isolated fuselage at yaw angle, the flowfield around the fuselage is obtained by a superposition of influence of the axial and cross flows. The axial-flow influence is treated in a similar way to the previous case. Concerning the cross-flow components, the derivation is restricted to the case of slender fuselages at small yaw angles. The expressions are based on slender-body theory for bodies of revolution where the fuselage cross-sectional radius distribution $R_F(x)$, which was obtained by the previously mentioned procedure, is used.

So far, the influence of the rotor on the fuselage was neglected. It is well known that the rotor downwash distribution over the fuselage is of an unsteady nature. Thus, a need for an efficient method for calculating the time-dependent fuselage reaction in terms of its upwash distribution over the rotor disk is evident. Based on slender-body approximations, and similar to the calculation of the cross-flow influence, the derivation is based on satisfying the boundary condition for each cross section separately. This is done by distributing m equally spaced two-dimensional sources along the fuselage cross-sectional circumference. Denoting the rotor downwash at each source location V_i (normal to the surface and positive when directed outward), it is possible to show that the nonpenetration condition is satisfied if the sources strengths (C_i) is given by (see Ref. 5):

$$C_i/\Omega R^2 = \frac{2\pi \tilde{R}_F(\tilde{x})}{m^2}\left[\sum_{k=1}^{m} V_k/\Omega R - 2m\ V_i/\Omega R\right] \tag{2}$$

Note that the values of V_i include also three-dimensional effects. Since the above formulation does not contain a solution of an algebraic system of equations, there is no limitation to the number of sources m as long as it is possible to evaluate

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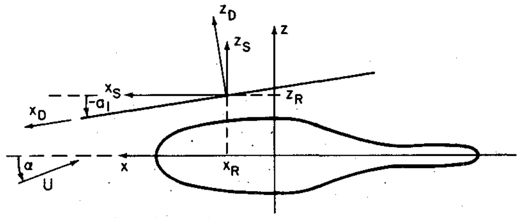

Fig. 1 Notation for reference axes and freestream velocity.

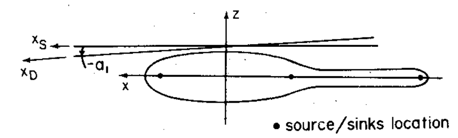

Fig. 2a The rotor/fuselage configuration.

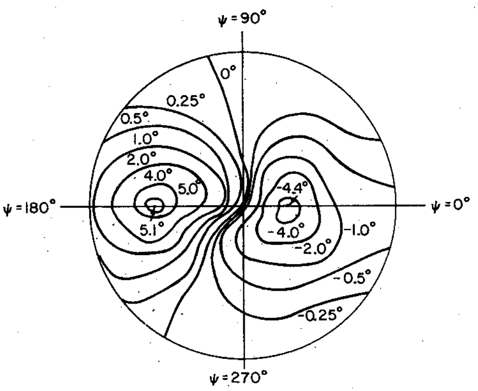

Fig. 2b The upwash distribution over the disk plane for angle of attack of −3 deg and sideslip angle of 3.5 deg.

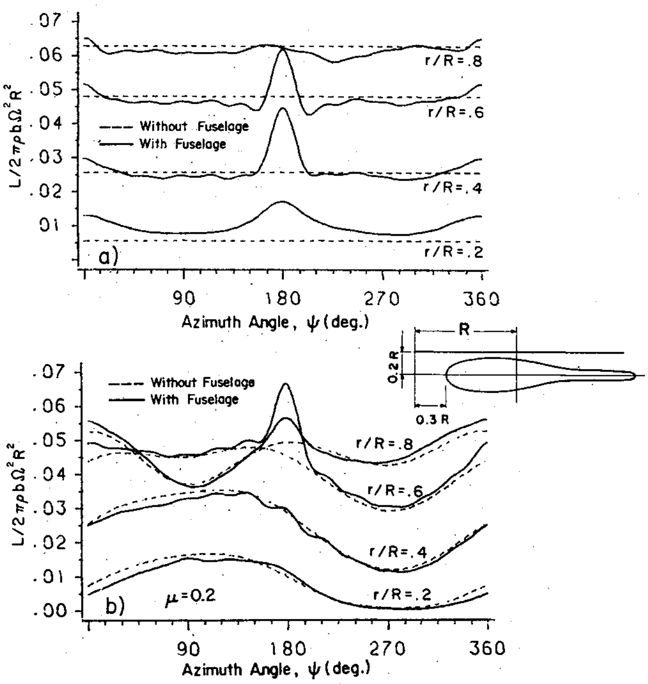

Fig. 3 Cross-sectional aerodynamic lift: a) hover, and b) forward flight.

the rotor downwash at any source location along the fuselage. In addition, the influence of different fuselage cross-section shapes can be easily investigated by this method using their conformal transformation to a circle.

It should be emphasized that the calculation of the fuselage-induced velocity over the rotor disk is, in fact, only one step in an iterative procedure in which one should check what influence these velocities have on the rotor loads and consequently on the rotor downwash.

Typical Results

The analytical model was used to investigate the fuselage influence on the rotor flowfield for different shapes, flight conditions, and rotor/fuselage relative positions. Typical examples are given in Fig. 2. In this figure, the simplest possible fuselage that was created by the present method by two sources and a sink is shown along with the isolated fuselage upwash distribution having nonzero yaw angles. Comparisons of this distribution with a similar one that was calculated by the panel method (Ref. 5) have shown good agreement. The fuselage influence appears as relatively high upwash at the front of the disk and low values of downwash at the rear of the disk. The main contribution of the fuselage angle of attack is an additional upwash over the forward disk sector, while that of the sideslip angle is a kind of rotation in the symmetric upwash distribution because of the additional upwash over the advancing side and downwash over the retreating side.

In order to demonstrate the fuselage influence on loads, including the rotor downwash effect, the fuselage model was combined with rotor and wake models. The rotor model was based on rigid flapping blades while load calculations were obtained using unsteady strip theory. The wake model is made up of tip trailing vortices. The cross-sectional aerodynamic lift with and without the fuselage in hover is shown in Fig. 3a for five different spanwase locations. The fuselage influence appears as an "impulse" disturbance at the azimuth angles 0 and 180 deg. This phenomenon is important and has significant influence on vibrations.[7] The fuselage influence in forward flight is shown in Fig. 3b. In this case, the rotor wake is well above the fuselage, and the latter upwash is mainly due to the freestream velocity bypassing the fuselage.

Concluding Remarks

An efficient analytical model for estimating the helicopter fuselage influence on the main rotor flowfields is presented. The model yields results that are in good agreement with the far more complex panel method. The efficiency of the method enables an extensive parametric investigation to be made of the influence of the fuselage in different flight conditions and rotor/fuselage relative positions. Thus, it is a suitable tool for predetermination of interference effects.

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