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Modeling the Mutual Distortions of Interacting Helicopter and Aircraft Wakes

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Flight procedures that will decrease the following distance between successive aircraft have been considered as a means of alleviating pressures on airport capacity while still conforming to conventional air traffic management rules. A major limitation to the implementation of such procedures is perceived to be an associated increase in the possible severity of encounters with the wakes of nearby aircraft. Modeling efforts have focused on quantifying such interactions in terms of structural loading or degradation in handling and have established that helicopters respond in a fundamentally different way than fixed-wing aircraft to encounters with wake vortices. This paper suggests that, particularly at the low forward speeds typical of terminal phase operations, the mutually induced distortion of the helicopter's own wake and the wake of the interacting aircraft strongly influences the aerodynamics of the helicopter rotor. Results from numerical simulations suggest that neglecting this aspect of the interaction, as has commonly been done in the past, can indeed be valid at high helicopter forward speeds, but can lead to significant misrepresentation of the severity of wake encounters under terminal flight conditions.

Nomenclature

A = rotor disc area πR^2
a = aerofoil lift-curve slope
C_L = blade local lift coefficient
C_T = rotor thrust, scaled by $\rho A\,(\Omega R)^2$
C_T^* = rotor thrust under trimmed conditions
c = blade chord length, scaled by R
I_β = blade flapping inertia, scaled by $\rho A R^3$
M = disc-weighted moment of vortex velocity
N = number of rotor blades
R = rotor radius
r = vortex or rotor radial coordinate, scaled by R
r_c = vortex core radius, scaled by R
S = vorticity source, scaled by $\Omega^2 R^2$
v = flow velocity, scaled by ΩR
v_c = tangential velocity at outer edge of vortex core, scaled by ΩR
v_i = induced velocity normal to rotor disc, scaled by ΩR
α = blade local angle of attack
β = blade flapping angle
β_0 = rotor coning angle
β_{1c} = rotor longitudinal tilt angle
β_{1s} = rotor lateral tilt angle
γ_β = rotor Lock number $ac/\pi I_\beta$
θ = blade local feathering angle
μ = rotor advance ratio (forward speed scaled by ΩR)
σ = rotor solidity Nc/π
ψ = blade azimuth
Ω = rotor rotational speed $d\psi/dt$
ω = natural frequency of blade flapping, scaled by Ω
ω = flow vorticity, scaled by ΩR^2

Introduction

AN issue of current concern to transport planners is the positioning of helicopter final approach and takeoff areas for the simultaneous operation of rotary and fixed-wing aircraft from airfields. Pressures exist to decrease the separation between successive fixed-wing arrivals or departures, to make maximal use of available ground at airfields, and indeed to promote the use of helicopters in increasing airport capacity.[1]

In the fixed-wing community a major and legitimate practical concern is that an encounter with a concentrated wake vortex, left lying parallel to the aircraft's flight path on the approach to, or departure from, a runway by the earlier passage of another aircraft might be sufficiently strong to induce a roll rate on the airframe, which is larger than can be overcome by full aileron deflection.

Concerns in the helicopter world mirror those of the fixed-wing community because helicopters are presently required to fit into established fixed-wing flight patterns during joint operations from airfields. Helicopters have a fundamentally different response to vortex encounters compared to fixed-wing aircraft, however, and a long-standing debate has been whether their behavior is more or less severe, as gauged by some appropriate measure, than in the fixed-wing case.[2] The response of a helicopter is complicated by aerodynamic cross coupling between the pitch and roll response of the rotor and the filtering of aerodynamic loads that is provided by the various possible methods of attaching the rotor blades to their hubs. On a conventionally configured helicopter at least, these effects tend to dominate the fixed-wing aircraft-like behavior of the fuselage.[2]

Our understanding of the aeromechanical behaviour of helicopters during wake encounters is based almost exclusively upon a series of papers detailing various numerical simulations of idealized helicopters interacting with representative model wake structures. These simulations have been used to quantify the loading changes, rotor flapping response or flight-path deviations that might arise during typical wake encounters. More recent approaches[3,4] have attempted to evaluate the outputs of simulations in terms of quantitative measures of helicopter handling qualities such as those laid out in the ADS-33 airworthiness standard. Validation of these numerical studies has always been hampered, however, by the relatively small and somewhat dated body of supporting experimental data. In the absence of suitable validation data, the issue of modelling fidelity remains largely unresolved.

In this paper we explore one aspect of this issue by examining the validity of the so-called "frozen-vortex" assumption adopted in most previous numerical studies of wake interactions. This assumption holds that the mutually induced distortion of the helicopter's own wake and the wake of the interacting aircraft contributes insignificantly to the aerodynamic loading on the helicopter's rotor and hence to the subsequent dynamics of the helicopter. Although this

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