Modelling a helicopter rotor’s response to wake encounters

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ABSTRACT
In recent years, various strategies for the concurrent operation of fixed- and rotary-wing aircraft have been proposed as a means of increasing airport capacity. Some of these strategies will increase the likelihood of encounters with the wakes of aircraft operating nearby. Several studies now exist where numerical simulations have been used to assess the impact of encounters with the wakes of large transport aircraft on the safety of helicopter operations under such conditions. This paper contrasts the predictions of several commonly-used numerical simulation techniques when each is used to model the dynamics of a helicopter rotor during the same idealised wake encounter. In most previous studies the mutually-induced distortion of the wakes of the rotor and the interacting aircraft has been neglected, yielding the so-called ‘frozen vortex’ assumption. This assumption is shown to be valid only when the helicopter encounters the aircraft wake at high forward speed. At the low forward speeds most relevant to near-airfield operations, however, injudicious use of the frozen vortex assumption may lead to significant errors in predicting the severity of a helicopter’s response to a wake encounter.

NOMENCLATURE

\begin{align*}
a & \text{ aerofoil lift-curve slope} \\
A & \text{ rotor disc area } \pi R^2 \\
c & \text{ blade chord scaled by } R \\
C_l & \text{ blade section lift coefficient} \\
C_T & \text{ rotor thrust, scaled by } p A (\Omega R)^2 \\
I_\beta & \text{ blade flapping inertia, scaled by } p A R^3 \\
L & \text{ distance from the vortex core to the rotor hub} \\
N & \text{ number of rotor blades} \\
r & \text{ radial coordinate, scaled by } R \\
r_c & \text{ vortex core radius, scaled by } R \\
R & \text{ rotor radius} \\
S & \text{ vorticity source, scaled by } \Omega^2 R^2 \\
t & \text{ time, scaled by } 1/\Omega \\
v & \text{ velocity of flow surrounding rotor, scaled by } \Omega R \\
v_c & \text{ velocity at periphery of vortex core, scaled by } \Omega R \\
v_f & \text{ velocity normal to rotor disc, scaled by } \Omega R \\
v_P & \text{ velocity parallel to blade section, scaled by } \Omega R \\
v_T & \text{ velocity normal to blade section, scaled by } \Omega R \\
v_{\text{vortex}} & \text{ vortex-induced velocity field, scaled by } \Omega R \\
v_{\text{wake}} & \text{ wake-induced velocity field, scaled by } \Omega R \\
\alpha & \text{ blade section angle-of-attack} \\
\beta & \text{ blade flapping angle} \\
\beta_0 & \text{ rotor coning angle} \\
\beta_{ls} & \text{ rotor lateral tilt angle} \\
\beta_{lc} & \text{ rotor longitudinal tilt angle} \\
\gamma_\beta & \text{ rotor Lock number } ac/\pi I_\beta \\
\theta & \text{ blade feathering angle} \\
\theta_0 & \text{ collective pitch control angle} \\
\theta_{ls} & \text{ longitudinal cyclic pitch control angle} \\
\theta_{lc} & \text{ lateral cyclic pitch control angle} \\
\mu & \text{ motor forward speed, scaled by } \Omega R \\
\sigma & \text{ rotor solidity } Nc/\pi \\
\psi & \text{ blade azimuth} \\
\omega & \text{ vorticity of flow surrounding rotor, scaled by } \Omega R^2 \\
\omega_f & \text{ blade flapping frequency, scaled by } \Omega \\
\Omega & \text{ rotor rotational speed} \\
\end{align*}

1.0 INTRODUCTION
Innovative exploitation of the runway-independent nature of helicopter operations has been proposed as a means of maximizing the use of ground- and air-space at airfields\textsuperscript{1} and thus of increasing...