

Calculation of Rotorcraft Inflow Coefficients Using Blade Flapping Measurements

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Induced velocity gives rise to an important component of the angle of attack experienced by a blade element and, hence, the rotor loads. Finite-state induced-velocity models can be found in rotorcraft codes that require fast computation but cannot replicate real flowfield features. However, they do encapsulate in a simple and intuitive way the impact of real wakes on rotorcraft dynamics and hence are popular in codes that are used to study vehicle flight mechanics such as stability, control, and handling qualities. Explicit verification of these models is not possible, but implicit verification is possible if blade flapping is known; and this paper presents results from flight tests of a light gyroplane fitted with a two-bladed teetering rotor instrumented to measure the rotor flapping behavior. An appropriate model structure is developed to allow calculation of induced-velocity components from steady-flight flapping data recorded across the aircraft's level-flight speed range. Very good agreement is obtained between flight and theory in respect to the uniform and longitudinal components, correlating well with previous studies. However, the lateral component is very poorly correlated, and this is attributed to strong nontrapezoidal behavior in the real wake. Notwithstanding this, it is concluded that the simple finite-state, induced-velocity model is a valid tool for gyroplane flight mechanics studies and rotorcraft autorotation in general.

Nomenclature

a_0	= blade section lift coefficient at the zero angle of attack	β_{1s}	= rotor disc lateral tilt, rad
a_1	= blade section lift-curve slope, rad^{-1}	γ	= rotor Lock number
C_T	= thrust coefficient	θ	= blade pitch angle, rad
c	= blade chord, m	θ_{tw}	= blade twist distribution, rad/m
dM_{flap}	= elemental blade flap moment about the hinge, Nm	ρ	= air density, kg/m^3
dr	= elemental length, m	σ	= rotor solidity
I_β	= blade flap moment of inertia about the hinge, kgm^2	ϕ	= blade element inflow angle, rad
L_{aero}	= rotor aerodynamic rolling moment, Nm	χ	= wake skew angle, rad
M_{aero}	= rotor aerodynamic pitching moment, Nm	ψ	= blade azimuth angle, rad
R	= rotor radius, m	ψ_m	= flight-measurement blade azimuth angle, rad
r	= radial location of a location on blade from the flap hinge, m	Ω	= rotor speed, rad/s
T_{aero}	= rotor aerodynamic thrust, N		
U_T	= component of the blade element relative airflow tangential to the blade, ms^{-1}		
U_p	= component of the blade element relative airflow normal to blade, ms^{-1}		
V	= airspeed, ms^{-1}		
v_T	= total velocity at the rotor disc center, ms^{-1}		
v_i	= induced velocity, ms^{-1}		
v_{i0m}	= momentum induced velocity, ms^{-1}		
v_m	= mass flow parameter, ms^{-1}		
v_0	= uniform component of the induced velocity, ms^{-1}		
v_{1c}	= longitudinal component of induced velocity, ms^{-1}		
v_{1s}	= lateral component of induced velocity, ms^{-1}		
w_{hub}	= velocity normal to the rotor disc, ms^{-1}		
α	= blade element angle of attack, rad		
β	= blade flapping angle, rad		
β_t	= teeter angle, rad		
β_0	= rotor-coning angle, rad		
β_{1c}	= rotor disc longitudinal tilt, rad		

Introduction

THE induced-velocity distribution across the rotor disc is an integral element of a rotorcraft mathematical model because it constitutes a significant component of blade element angle of attack and hence loading. Codes are available to calculate the environment around the entire aircraft, naturally embodying real flowfield features such as blade–blade and rotor–rotor aerodynamic interactions [1]. However, most engineering models applied to stability, control, and handling quality studies use finite-state representations that mimic or emulate real-wake effects, because their computational demands are so much less than full-flowfield models [2]. Momentum-disc and actuator-disc theories underpin many of these modeling approaches. Model fidelity is normally checked by comparison with flight-test data, but either of these induced-velocity modeling approaches requires verification by implicit, rather than explicit, means due to the intrinsic complexity of the inflow distribution. This implicit approach takes advantage of the intimate relationship between rotor blade flapping and the induced velocity [3], and the relative ease with which blade flapping data can be obtained. The objective of this paper, therefore, is to validate a finite-state induced-velocity model, a novel aspect in reference to operation in autorotation. Blade flapping data measured during gyroplane flight trials is coupled with an appropriate model structure, allowing induced-velocity components to be calculated across the level-flight speed range of the aircraft.

Background

Verification of any inflow model requires an implicit, rather than explicit, approach, as the instrumentation required to measure and record induced velocity does not exist. Central to any implicit approach is the availability of blade flapping data, as inflow and

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