IMPACT OF ROTOR DESIGN ON COAXIAL ROTOR PERFORMANCE, WAKE GEOMETRY AND NOISE

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ABSTRACT

Extensive research and development is currently underway to design next generation coaxial main rotor systems for heavy lift, high speed and small-scale applications. A variety of platforms are under investigation, including small scale Unmanned Air Vehicles (UAVs), mid-scale concepts like Baldwin Technology's mono-tiltrotor, and full-scale rotorcraft such as Sikorsky Aircraft Corporation's X2 concept. In order to facilitate both the design and evaluation of such new coaxial configurations, it is necessary to develop and validate appropriate analysis tools. This paper describes work performed enhancing the CHARM comprehensive rotorcraft analysis to facilitate its use for aerodynamic/aeroacoustic design of coaxial rotor systems. Correlations of predictions with test data are presented followed by a study of how variations in key rotor design parameters impact coaxial rotor performance, wake geometry and noise.

NOMENCLATURE

b	number of blades
c	blade chord
d	rotor diameter
c_d	2D drag coefficient, $D/½\rho U^2 c$
c_l	2D lift coefficient, $L/½\rho U^2 c$
c_{l_i}	design 2D lift coefficient
c_{lmax}	maximum 2D lift coefficient
C_Q	torque coefficient, $Q/\rho\pi R^3(\Omega R)^2$
C_T	thrust coefficient, $T/\rho\pi R^2(\Omega R)^2$
D	2D airfoil profile drag
F_M	Figure of Merit, F_M=.7071$C_T^{3/2}/C_Q$
h	separation between rotors
L	2D airfoil lift
Q	rotor shaft torque
R	rotor radius
Re	Reynolds number Uc/ν
T	rotor thrust
U	free stream velocity, fps
α_s	shaft angle of attack
Γ	circulation
η^*	taper ratio c_{root}/c_{tip}
μ	advance ratio, $U\cos\alpha_s/\Omega R$
ν	kinematic viscosity
ρ	air density
τ	thrust sharing ratio between rotors, T_{lower}/T_{upper}
σ	rotor solidity, $bc/\pi R$
Ω	rotor rotation rate, rad/sec

INTRODUCTION

Coaxial rotor systems consist of two axially aligned rotors in close proximity rotating in opposite directions. A significant advantage of coaxial main rotor systems is the elimination of the need for a tail rotor for anti-torque control. Disadvantages include increased mechanical complexity and increased parasite drag which can impede high speed performance. However, coaxial rotor systems also have the potential for greater lifting efficiency in high speed flight by shifting the lift to the dual advancing sides and away from the less efficient retreating sides. The potential advantages of coaxial rotor systems in high speed flight, heavy lift applications and compact UAVs has led to a renewed interest in these systems. Ref. [1] provides an excellent compilation of experimental and analytical studies of coaxial rotors to date. Since the bulk of these are over twenty years old, it is timely to revisit and extend the understanding of these systems using the latest analytical tools and experimental methods.

The U.S. Army has an interest in developing and evaluating analytical tools suitable for the design and evaluation of new coaxial rotor systems under consideration. To this end, Continuum Dynamics Inc. (CDI) was commissioned to enhance, validate and demonstrate the use of our CHARM rotorcraft analysis in this role. CHARM has the validated capability to accurately predict performance and blade loading for conventional rotorcraft and tiltrotors [2]. An automated interface with NASA/Langley's WOPWOP computer code allows accurate prediction of thickness and loading noise, including BVI noise [3]. CHARM also possesses a capability to accurately model ducted rotors through a coupled rotor/wake/body solution utilizing unique fast vortex/panel methods.

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