BVI Noise Mitigation Via Steady Flap Deflection –
An Analysis-Led Test Program

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Abstract

A simple method for reducing BVI noise generated by rotorcraft by 6-12dB has been identified through analysis and substantiated through experiment. The concept involves the deployment of lift-inducing devices along the inboard portion of the rotor to fixed positions for flight conditions (typically descent) where noise reduction is desired. An inboard deployment greatly reduces the performance penalty compared with outboard devices and in fact can improve performance in some flight conditions if the overall system is properly designed. The use of fixed flap positions without the need to oscillate during each blade revolution greatly simplifies implementation relative to other candidate active noise mitigation systems and limits possible vibratory fatigue loads. This paper describes the process by which the noise mitigation concept was identified through analysis and then substantiated through an Inboard Flap Test (IFT) conducted in the Army 7- by 10-Foot Wind Tunnel at NASA Ames Research Center.

Notation

a	sectional lift curve slope, rad^{-1} or speed of sound, fps
c	local blade chord, ft.
$\bar{c}$	mean blade chord, ft.
C_Q	torque coefficient, $Q/\rho\pi R^3(\Omega R)^2$
C_T	thrust coefficient, $T/\rho\pi R^2(\Omega R)^2$
c_ℓ	sectional lift coefficient
c_d	sectional drag coefficient
c_m	sectional pitching moment coefficient
I_b	blade flapwise moment of inertia, slug-ft^2
L	rotor blade lift force
M	Mach number
N_b	number of blades
Q	rotor torque, ft.-lbs.
R	rotor radius, ft.
r	radial distance along rotor blade or interacting vortex miss distance
r_c	vortex core size, ft.
T	rotor thrust, lbs.
U	free stream velocity, fps
x	nondimensional radial distance r/R along the blade
α_s	shaft angle of attack, deg.
Γ	vortex circulation, ft^2/sec
μ	advance ratio, $U/\Omega R$
ρ	air density, slugs/ft^3
σ	rotor solidity, $N_b\,\bar{c}\,/\,\pi R$
ψ	blade azimuth angle, deg.
Ω	rotor rotation rate, rad/sec

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Introduction

Reduction of rotor noise is one of the most pressing design challenges for helicopter manufacturers, given its importance in minimizing detectability of military rotorcraft, as well as in gaining community acceptance for both military and civil helicopter operations. One of the most intractable sources of noise is the interaction between rotor blades and the strong tip vortices trailed from preceding blades when the helicopter is in low speed forward flight. This Blade-Vortex Interaction (BVI) noise mechanism is depicted in Figure 1, which shows how vortices generated near azimuth angle 135° are convected downstream and interact with subsequent blades (e.g., at locations 3 and 4 in this figure).

Substantial effort has gone into both experimental and analytical study of BVI noise and its alleviation, (e.g., Hardin and Lamkin 1986; Brooks 1993; Hassan et al. 1993; Tung et al. 1996, 1998). A good overview can be found in Yu, 1995. Approaches for reducing BVI noise can be categorized as either passive or active. Passive devices typically involve diffusing the interacting tip vortex responsible for the BVI noise