Investigation on a High-Frequency Controller for Rotor BVI Noise Alleviation

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Among the several sources of acoustic annoyance produced by rotorcraft in operating conditions, blade-vortex interactions (BVIs) capture the interest of much of the current research. This paper deals with the reduction of BVI noise from helicopter main rotors by application of the active twist rotor concept (ATR), exploiting smart materials for twisting blades through higher-harmonic torque loads. An optimal, multi-cyclic, control approach is applied to identify the control law driving the ATR actuation during the occurrence of severe BVI events. Numerical predictions are obtained through a computational tool that is able to predict the aeroelastic response of the rotor blades and the emitted noise in arbitrary steady flight conditions. The approach for the control law identification is described and numerical results concerning aeroelastic and aeroacoustic performance of the controlled rotor are presented to assess the proposed methodology.

NOMENCLATURE

$\mathbf{f}_{aer}, \mathbf{f}_{str}^{nl}$	Forcing terms of linear structural dynamics
$\mathbf{m}$	Generalized ATR torque moments
p'_T, p'_L	Thickness and loading noise
$\mathbf{q}$	Vector of the Lagrangian coordinates
$\mathbf{r}$	Distance between source and observer positions
$\mathbf{u}, \mathbf{z}$	Vectors of control and output variables
$\mathbf{v}$	Flow velocity
$\mathbf{x}, \mathbf{y}$	Observer and source position
G	Unit-source solution of the Laplace equation
$\mathbf{G}_u, \mathbf{G}_z$	Gain matrices
J	Cost function
$\mathbf{M}, \mathbf{C}, \mathbf{K}$	Mass, damping and stiffness matrices
S_B, S_W^N, S_W^F	Body, near wake and far wake surfaces
$\mathbf{T}$	Input-output control transfer matrix
$\mathbf{W}_u, \mathbf{W}_z$	Optimal control weighting matrices
c_0, p_0, ρ_0	Speed of sound, pressure and density of undisturbed medium
τ	Emission time
φ_S, φ_I	Scattered and incident velocity potential
u_n, v_n	Flow and body normal velocity components

1. INTRODUCTION

The acoustic annoyance is one of the critical issues concerning the flight of helicopters. The main rotor plays a crucial role in noise generation, through several aerodynamic phenomena that affect its performance. Among these, blade-vortex interactions (BVIs) are relevant sources of noise. Indeed, BVI noise has an impulsive nature, which is particularly annoying for the human ear and typically occurs when the helicopter is in descent or in slow advancing flight[1,2] (i.e., when it operates near the ground and the community). As a consequence, prediction and control of BVI noise (in terms of magnitude and directivity pattern) are important issues for rotorcraft designers both for civil applications and for improving stealthiness in military missions.

Identification of optimal rotor blade shapes and active controls, as well as a definition of optimal minimum noise descent trajectories are strategies extensively investigated by researchers to reduce the acoustic impact of helicopters on communities. Active control systems are particularly suitable for BVI alleviation, in that severe BVIs occur during low speed flight when more power is available to actuators, as compared to high speed forward flight. Approaches based on higher harmonic blade control have been investigated in detail, both numerically and experimentally in the past literature.[2–5] Specifically, the attention has focused mainly on two types of control systems: the individual blade control (IBC), for which each blade is controlled in the rotating frame through pitch links or flaps, and the so-called higher harmonic control (HHC), which acts on all the blades simultaneously by driving the non-rotating component of the swashplate. The benefits of HHC and IBC in reducing both vibrations and acoustic annoyance have been widely discussed, although some drawbacks emerged. Besides problems related to the increase of weight and complexity of the actuation devices, the way these controllers act for BVI noise reduction often corresponds to an increase in low-frequency noise content and in rotor vibration levels.[2,6] Furthermore, the actuators that are typically used for the conventional active control are characterized by limited frequency bandwidth and high vulnerability of the hydraulic systems. Active materials help to overcome most of these limitations, since they operate through the direct conversion from the electrical signal to the mechanical deformation of the material. This allows low-mass and high-bandwidth actuators thus increasing the ability to control the aeroelastic behavior of the individual blades for cancelling the unsteady high-frequency aerodynamic loads, which are the main cause of rotor noise and vibrations. Indeed, in recent years increasing attention to the application of the smart materials to rotorcraft systems has been paid by the research community.[7–12]

This paper presents an IBC controller relying on active twist rotor (ATR) actuation that is aimed at reducing high-frequency rotor noise aerodynamically generated by BVIs. It is an extended version of the work recently presented by the authors,[13] where the conceptual idea of this active twist BVI-controller has been introduced.

The proposed control strategy relies on high-frequency actuation to generate loads aimed at direct suppression/alleviation of those due to BVI. This approach is different from the more