Passive control of shock wave-boundary layer interaction developing on helicopter rotor blade

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1 Introduction

Impulsive noise, described as a series of intense, low-frequency impulses, is believed to be the most annoying and loud sound that can be generated by a helicopter rotor. The HSI noise phenomenon develops when the advancing tip Mach number is sufficiently high to give rise to strong compressibility effects in high-speed forward flight. Additionally, the shock wave delocalization may arise emitting intense thumping, harsh sounds heard for many kilometers compromising the detection distance of an approaching helicopter and increasing community annoyance. Delaying appearance of the HSI noise and shock wave delocalization is still one of the fundamental considerations in the early design and development process of rotor systems. The target is often met by a passive tip shape alteration relying on combined sweep, taper and thinning. Such a major modification of the blade's most important part effectively damps the HSI noise. Unfortunately, the achieved benefits in the acoustic signature may be outbalanced by a decreased aerodynamic performance. On the contrary, the proposed type of a passive control device does not require any alteration of the outer shape (section) of the blade, assuring a beneficial effect on the radiated HSI noise without degradation of the retreating side performance [1].

Two exemplary implementations of model helicopter rotors tested at NASA Ames facility in transonic conditions: Caradonna-Tung (lifting hover) and Caradonna-Laub (non-lifting, high-speed forward flight) demonstrate the possible gains in terms of the reduction of acoustic pressure fluctuations in the near-field of the blade tip. The CFD results are validated against the experimental data obtained for the reference configurations, while the analysis of the passive control arrangement is based on a purely numerical research.

2 Mechanism of passive control of shock wave by wall perforation

At the beginning of the 90's W. Braun (University of Karlsruhe, Germany) investigated experimentally passive control of the shock wave terminating a local supersonic area – a flow configuration commonly found on airfoils or helicopter rotor blades in transonic conditions [2]. It was shown for the first time that when the cavity covered by a perforated plate is sufficiently prolonged (called here "extended" passive control) a strong, normal shock wave may be interchanged with a system of oblique waves reflecting between the wall and the edge of the supersonic region (see the experimental interferograms in Figure 1). In contrast to the fixed wing applications, the "extended" passive control may constitute a basis of a new method designed for the HSI rotorcraft noise reduction.

3 Exemplary results of transonic hover of the Caradonna-Tung rotor

The exemplary numerical results are presented for a well-known case of a transonic hover of the Caradonna-Tung 2-bladed rotor ($Ma_T = 0.877$, $Re_T = 3.93 \cdot 10^6$ and $\theta = 8°$) – see Figure 2. The acoustic pressure fluctuations p' are averaged at the plane that is intersected with the moving blades. The resulting $\Delta OASPL$ (drop of the Overall Sound Pressure Level due to passive venting) is presented together with the signals recorded at point p_1 (amplitude spectra are A-weighted). The negative peak of p' is reduced by 27%, while the rms of p' is damped by 21%. The duration time is increased limiting the impulsive character as well. The $\Delta OASPL$ of 2 dB was identified, while the A-weighted value was found to be 4 dBA. At certain bands the difference was even more pronounced (> 10 dBA).

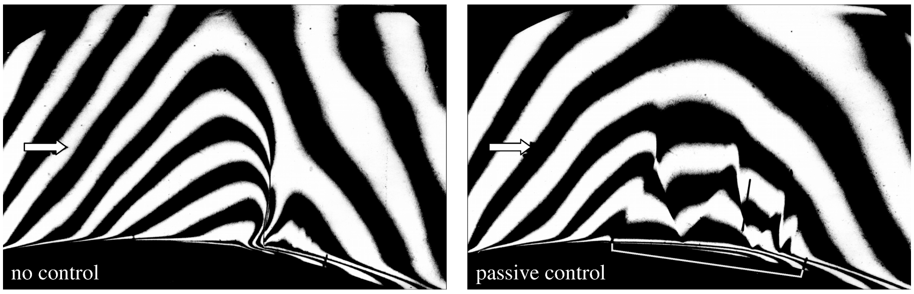

Figure 1: "Extended" passive control of shock wave at the convex wall ($Ma = 1.32$) [2].

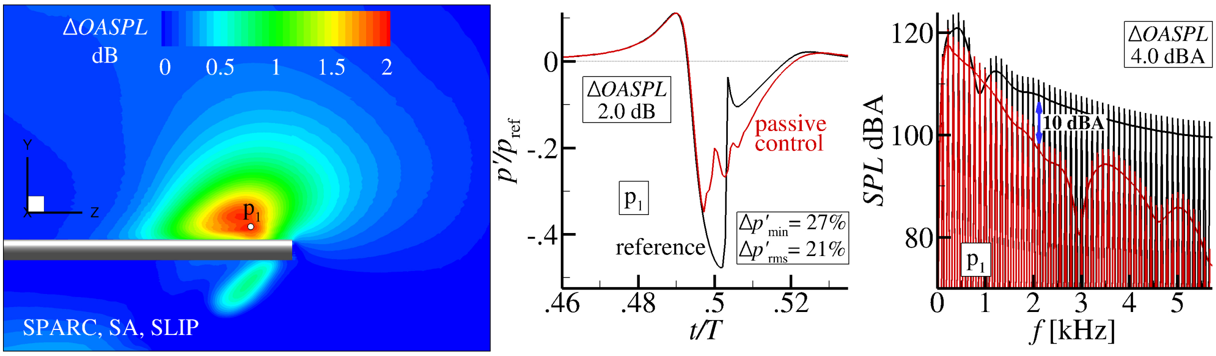

Figure 2: Effect of "extended" passive control on acoustic pressure fluctuations.

References

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[2] Braun W. *Experimentelle Untersuchung der turbulenten Stoß-Grenzschicht-Wechselwirkung mit passiver Beeinflussung*, PhD Dissertation, University of Karlsruhe, 1990.