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1 Introduction

The noise mitigation strategies will be designed based on the outcomes of the experimental campaigns of WP3 completed by the numerical simulations of WP4, using the modelling approaches developed in Tasks 2.7 and 2.8. Where needed, the optimization platforms consolidated in Task 2.5 and applied in WP5 will be used to derive the optimal geometrical parameters of the noise control devices. The mitigation techniques will then be tested in WP3, and simulated in WP4 where applicable. A successful cross-validation between the predicted and measured noise attenuation will be a significant step towards the design of those technologies for full-scale applications.

2 Task 6.1

2.1 Context and objectives

The objective of Task 6.1 is to investigate potential methods to mitigate noise emissions for boundary layer ingestion configurations. Configuration A1 is the zero-pressure gradient boundary layer ingestion scenario while A2 is the adverse pressure gradient scenario. Representing both propeller adjacent and fuselage-buried arrangements. The A1 configuration mitigation techniques include surface treatments such as porous media and acoustic liners. Propeller blades with serrated trailing edges will be evaluated for their noise mitigation capabilities for Configuration A2 as well as the use of surface-mounted vortex generators. Selected datasets are to be published.

2.2 Involved partners and work distribution

The partners involved in Task 6.1 were UBRI, UTWE, and ECL in a supporting role. UBRI will carried out experimental noise mitigation tests regarding the adverse pressure gradient configuration (A2) and UTWE will carried out the noise mitigation experiments on the zero pressure gradient configuration (A1). If needed, ECL provided guidelines for noise mitigation strategies and geometry, based on previous observations on rotors with serrated blades.

2.3 Main achievements

2.3.1 UBRI

UBRI carried out the A2 adverse pressure gradient boundary layer ingestion acoustic mitigation tests at its Aeroacoustic Facility. Vortex generators were placed at several locations along the curvature of the plate (see D3.6 for plate geometry) to assess their effectiveness in increasing flow mixing and reducing flow non-uniformity. Two geometries of serrated trailing edges were 3D printed and tested in the A2 BLI scenario. The trailing edge serrations on the blade noticeably reduced high-frequency noise at medium thrust conditions, at higher speeds the presence of additional tonal peaks caused the acoustic benefits to reduce. OASPL results showed a clear reduction in noise at upstream angles only. The use of vortex generators to increase flow mixing and reduce turbulence interaction noise was found to be minimally effective, with any degree of noise reduction occurring at only a specific rotational speed corresponding to a medium thrust case. It was found that placing the vortex generator device after the 'separation' point and inside the low-velocity bubble provided a degree of reduction in tonal noise. Upstream locations caused a significant increase in noise output. Overall, the reduction in noise is minor, and alternative mitigation techniques should be considered.

2.3.2 UTWE

UTWE performed the experiments on the noise mitigation of configuration A using serrations and advanced liners. The experiments' main idea was to use noise absorbers, flush mounted with the flat plate in a slot underneath the mounted propeller (Configuration A1, See D3.6) to reduce the noise incoming from the propeller immersed in a non-uniform inflow. Two different noise absorption elements were tested: a

set of quarter-wavelength resonator arrays (QWR), carefully designed to suppress a band frequency, in which the distribution of those arrays could be changed — in a way that there were regions with QWR and other areas with flat-plates—; and a high porosity metal foam. The noise mitigation mechanisms underneath the propeller absorb the noise reflected by the surface before it spreads to the far field. The choice of QWRs was made due to their efficiency in planar wave noise absorption. Moreover, there have been many developments in using the same technique but in more compact ways (folded, labyrinth, etc.). The SPL results revealed a significant hydrodynamic interaction between the propeller blade tips and the holes of the QWRs, leading to substantial peaks in the harmonics of the blade passing frequency. The key solution was the strategic removal of the QWRs from the areas the propeller blades were immediately passing through. This action directly led to a reduction in those peaks. Additionally, it was discovered that the most effective configuration for noise reduction in the case of Configuration A1 was to use those mitigators everywhere in the area beneath the propeller, except immediately underneath the propeller's wetted area, referred to as flat-plate-blade. The overall sound pressure levels (OSPL) were processed for each microphone in the array, in a way that made it possible to assess directivity. The results showed that the flat-plate-blade configuration was superior in noise reduction (about 1.5 dB) and performed better than the porous metal fully applied. For the directivity manipulation, the QWRs were applied only upstream or downstream, and the results showed a minor difference in directivity, so no firm conclusions about this manipulation can be made. Indeed, using the QWRs only upstream showed a lower noise level for the upstream microphones compared to the downstream-only configuration. The side array of microphones also showed some increase in upstream levels for the downstream-only configuration, while for the porous material and the optimal QWR distribution, the noise was virtually not affected.

2.3.3 ECL

Previous tests performed at ECL on small-size drones, and a literature survey, confirmed the ability of leading-edge (LE) and/or trailing-edge (TE) serrations to reduce rotor broadband noise. Guidelines can be proposed, in particular the serration angle must be large enough for optimal performance, typically about 60°-70°. LE serrations reduce the noise from ingestion of turbulence, only if the size of the serrations is tuned on the turbulent scale. For low-Reynolds number airfoils, they also can reduce or suppress laminar separation bubbles on the blades, thus reducing broadband noise. They have not been tested in the present project. But ECL tests with blade tips equipped with serrations and crossing the shear-layer of a jet were shown to evidence only a weak benefit. TE serrations reduce trailing-edge noise for attached flows on moderately loaded blades. Regeneration of sound at high frequencies is a known fact. It could be avoided by designing flexible serrations but such a technology is sensitive. It has not been applied as such either. Limitations in serration design are the acceptable size of the serrations, which must be kept small enough compared to blade chords, and possible mechanical issues.

2.4 Lessons learnt

2.4.1 UBRI

The use of leading edge serrations might be more promising since it was found to be the one of the major sources of BLI noise. When 3D printing blades, ensure the printing technique/material employed has minimal flex otherwise higher thrust analyses will not be viable.

2.4.2 UTWE

Using liners and porous materials to treat the surface close to the propeller was shown to be a promising technique to reduce the reflected noise. However, the noise reduction (or increase) is highly dependent on the position of those mitigators on the surface. Additionally, commonly used materials such as foams or porous media will not always be the best solution, and a custom-made solution is necessary for each different case.

2.5 Deliverables

The three deliverables that this Task 6.1 contributed towards are:

- D6.1
- D6.4
- D6.5

2.6 Dissemination

Castelucci, Leandro A., Cornelis H. Venner, and Ysbrand H. Wijnant. *Experimental study of surface noise mitigation for propeller in boundary layer ingestion configuration.*, *Forum Acusticum 2023.* DOI:10.61782/fa.2023.0814

Castelucci, Leandro A., Martinus P.J. Sanders, Ysbrand H. Wijnant, Cornelis H. Venner, and Lionel Hirschberg. *Comparing band-stop and broadband noise absorbers for non-uniform inflow propellers.*, *AIAA/CEAS Aeroacoustics Conference 2024*

3 Task 6.2

Pylon- and control surface-mounted distributed propulsion systems

3.1 Context and objectives

The objective of Task 6.2 was to reduce the sources of noise associated with the interaction between a propeller and the airframe. The focus has been placed on configuration B1, for which the potential and viscous interactions between the propeller and the downstream airfoil are the strongest and hence the most likely to benefit from a mitigation technology. Porous materials applied to the leading edge of the wing have been explored as a potential strategy to reduce the intensity and radiation efficiency of the unsteady pressure fluctuations induced by viscous wake interactions.

3.2 Involved partners and work distribution

RWTH, VKI, TUD, ECL

3.3 Main achievements

3.3.1 RWTH

In Task 6.2, RWTH was responsible for investigating noise mitigation approaches for the wing-mounted distributed propulsion systems using high-fidelity LES-CAA simulations. A preliminary numerical work has been conducted by comparing the acoustic signature of (a) free/uninstalled distributed propellers and (b) wing-mounted distributed propellers, to evaluate the significance of the leading-edge impingement noise. The predicted far-field noise shows similar directivity patterns for the uninstalled and installed configuration, and the propeller-airfoil interaction leads to an overall increase of 1 to 3 dB noise levels, supporting the experimental findings from TUD. The results suggest that the propeller noise is the dominant noise source in the distributed propulsion system, and the noise mitigation benefits of leading-edge porous treatments could be marginal, compared to the aerodynamic penalties it brings.

3.3.2 TUD

The primary goal of this task was to examine the effects of noise reduction strategies on a distributed propeller system akin to configuration B1. The initial proposal of applying porous materials to the wing's leading edge, with the anticipation of reducing noise generated by combined slipstreams impinging on the wing's leading edge, was examined. However, during the ENODISE project, it became clear that the propeller's tonal noise was the dominant noise source for such configurations. Consequently, mitigation techniques applied to the wing noise would not significantly affect the overall system's noise, a conclusion reinforced by earlier TUD research performed by Sinnige *et al.* [1]. This earlier study indicated that porous materials on a single-propeller setup had a minimal impact on noise reduction. Therefore, it was concluded that applying porous materials to the wing's leading edge in a setup similar to B1 would not significantly decrease the noise. The raw data, results and conclusion of the work of Sinnige *et al.* were shared in deliverables 6.2, 6.4, and 6.5.

3.3.3 ECL

In configurations B, LE serrations could be used to mitigate flow-separation issues, and TE serrations to reduce the trailing-edge noise of the blades. This has not been extensively applied, because of the small-size blades of tested propellers, which makes the manufacturing challenging. Furthermore, the role of serrations on the blades in installed configurations B is not likely to significantly differ from what it is for isolated propellers.

3.4 Lessons learnt

3.4.1 RWTH

The propeller-airfoil interaction could lead to an overall increase of 1 to 3 dB noise levels, therefore the noise mitigation benefits of leading-edge porous treatments should be within this order of magnitude. The propeller noise is the dominant noise source in the distributed propulsion system. Addressing the unsteady loading noise due to propeller-propeller interactions could yield more significant effects on the overall noise reduction of the aircraft.

3.4.2 TUD

The main takeaway from this task is that noise mitigation techniques should primarily target the propellers rather than the wing's leading edge noise for configurations such as B1. It was also found that applying porous materials to the wing's leading edge does not significantly reduce noise, a conclusion reinforced by previous research. This understanding should guide future noise mitigation strategies for configurations like B1, helping to concentrate efforts on more effective solutions.

3.5 Deliverables

D6.2 D6.4 D6.5

3.6 Dissemination

4 Task 6.3

4.1 Context and objectives

For this last configuration C, two noise mitigation strategies have been considered, similar to the work planned in Task 6.1 for configuration A: noise reduction at the source, and attenuation using liners. Regarding the first strategy, the efforts focused on co-rotating propellers with varying the clocking angle ϕ, as illustrated in Fig. 1. Both numerical and experimental works have been carried out. The second strategy focused on contra-rotating shrouded propellers and the noise reduction achieved with a liner. This second strategy has exclusively been studied experimentally.



(a) (b)

Figure 1: Views of (a) propeller configuration at 0° clocking angle and (b) propeller configuration at 30° clocking angle.

4.2 Involved partners and work distribution

VKI, SISW, ECL

4.3 Main achievements

4.3.1 VKI

In the context of Task 6.3, VKI developed and commissioned a test rig for multi-rotor coaxial systems. The rig features *i*) a dual-axis system, achieving an independent rotation of the two shafts; *ii*) loadcell, and torque meters for aerodynamic performance analysis; *iii*) a shroud designed to improve aerodynamic performances and to contain an acoustic liner for tip clearance noise reduction. Using this facility, force and acoustic measurements have been performed for co- and contra-rotating open rotors and shrouded contra-rotating rotors.

4.3.2 SISW

In Task 6.3, SISW focused on the simulation of the co-rotating propellers with and without clocking angles. A numerical approach, based on incompressible Unsteady Reynolds-Averaged Navier-Stokes (URANS) simulation combined with a high-order finite element method, has been selected for its relatively fast turn-around compared to higher fidelity CFD techniques like large-eddy simulation. Its performance and its applicability to noise mitigation study have been examined by comparing numerical results with available experimental data of VKI.

4.3.3 ECL

Apart from the general guidelines related to their effectiveness on isolated rotors or propellers, serrations could have additional beneficial effects on a contra-rotating system. TE serrations not only reduce trailing-edge noise, but they also accelerate mixing in the wake if implemented on the front rotor. The secondary effect is a possible reduction of the wake-impingement noise generated by the rear rotor. In view of other priorities and technical difficulties, this technology has not been applied in configuration C.

4.4 Lessons learnt

The first noise mitigation strategy involved a numerical and experimental analysis of co-rotating propellers operating at two different clocking angles, $\phi = 0$ and $\phi = 30°$, as illustrated in Fig. 1. The measurements showed that the propellers operating at 30° clocking angle emit significantly lower noise levels from the second Blade Passing Frequency (BPF) onwards. This noise reduction has been explained by a less pronounced aerodynamic interaction between the propellers at $\phi = 30°$. This interaction generates

unsteady loading responsible for higher noise levels from the second BPF for $\phi = 0$. Future perspectives, includes *i*) investigate other clocking angles and axial distances to confirm the trends observed in this study; *ii*) investigate the source of unsteadiness that is causing higher noise levels at the second BPF; a possible cause being the tip vortex shed by the front propeller that interacts with the back propellers; *iii*) use fast numerical methods, such as analytical models or panel methods, to find the optimal configuration that minimizes this interaction. In the numerical analysis, the noise reduction at $\phi = 30°$ was also confirmed, despite different noise levels computed by the simulations. Further work will be needed to understand the origin of the discrepancies between the simulated and measured predictions. Potential reasons include *i*) difficulty of the URANS approach to capture the aerodynamics of low-Reynolds number propeller configurations, or *ii*) experimental conditions not faithfully reproduced in the simulations.

The second strategy focused on shrouded contra-rotating propellers with and without the Over-The-Rotor liner designed to reduce tip clearance noise. Experimental evidence showed that using a Over-The-Rotor liner reduces broadband noise up to 7 dB between 2 kHz and 7 kHz. This suggests that, if a shroud has to be included in the design, a Over-The-Rotor liner can efficiently mitigate tip clearance noise.

4.5 Deliverables

D6.3

4.6 Dissemination

References [2, 3].

References

[1] Tomas Sinnige, Biagio Della Corte, Reynard De Vries, Francesco Avallone, Roberto Merino-Martínez, Daniele Ragni, Georg Eitelberg, and Leo L.M. Veldhuis. Alleviation of Propeller-slipstream-induced unsteady pylon loading by a flow-permeable leading edge. *Journal of Aircraft*, 56(3):1214–1230, 2019.

[2] Erica Gallo, Julien de Decker, Pauline Haezebrouck, Alessandro Zarri, and Christophe Schram. H2020 Enodise: Experimental dataset of configuration C VKI, September 2023.

[3] Andrea P. C. Bresciani, Julien de Decker, and Christophe Schram. H2020 Enodise: Experimental dataset of configuration C with mitigation VKI -, March 2024.