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Report on the PhD manuscript submitted by

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entitled

Aeroacoustic investigation of streamwise vortex generators for flow control

The research work proposed by the candidate is focused on the noise generated by Rod Vortex Generators (RVGs), a flow control technology that was previously shown by the IMP-PAN research group to offer interesting potential for the mitigation of flow separation on wind turbine blades operated off-design. The research work has combined numerical developments for the prediction of the noise emitted by rotating blades fitted with RVGs, with advanced experimental diagnostics aimed at elucidating the associated noise mechanisms. The manuscript conciseness and writing style are efficient, the work is quite interesting and includes several original contributions to the field, detailed hereafter chapter by chapter.

The Chapter 1 introduces the basic physical concepts and quantities related to acoustics, hydrodynamic pressure fluctuations, and flow-induced noise. A review of the various types of vortex generators (VGs) is provided, a distinctive advantage of RVGs being that they can be activated (inserted in the flow by sliding them through perforations of the blade surface) only at off-design conditions. It would have been interesting in this chapter to discuss the relative performance of the RVGs compared with their fixed (non-retractable) variants in terms of aerodynamic performance characteristics such as separation delay, added drag, etc. The motivation of this PhD is then introduced, which constitutes its first originality: to investigate the additional noise that results of the insertion of the RVGs in the flow, with a specific focus on the low-frequency range, more susceptible to propagate unattenuated from the wind turbine to the nearby communities. The importance of the study is justified by the large impact that a 1dB noise reduction – or increase – can have on the annual energy production of a wind turbine, due to curtailment necessities. The chapter proceeds with a review of the noise generation mechanisms in wind turbines, which are the primary application targeted by this research, but also in helicopter rotors as the codes developed by the candidate had a preliminary validation on helicopter rotor noise data from the literature. The chapter concludes with a presentation of the various codes developed during the PhD, pointing at the respective subsequent subsections of the manuscript.

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In Chapter 2, the candidate provides a review of the theoretical background underlying the codes developed in this work. After a short review of the different numerical approach, the candidate reminds the fundamental developments of Lighthill's analogy, its integral solution by Curle, Kirchhoff's equation valid in the linear acoustic region, the more general Ffowcs Williams and Hawkings' analogy, and the Farassat formulations. The candidate discusses the conditions related to acoustic compactness, acoustic and geometrical far-field permitting to derive simplified solutions of these integral solutions of the analogy, but sometimes in an intricate way making it difficult to precisely understand which assumption leads to which simplification. Some misconceptions are also found in this chapter, such as relating the position of the aerodynamic center of an airfoil at the quarter-chord (which comes from linearized incompressible airfoil theory) with the chord compactness (an acoustic concept). It would also have been interesting to discuss more in depth the extent to which the different assumptions impose important restrictions for the specific case of wind turbines. Still in Chapter 2, the candidate discusses the integral solution of the wave propagation for the case of moving point canonical sources (monopole, dipole, quadrupole), which is relatively classical material, but will serve for the validation of the code developed by the candidate and presented in Chapter 3. The last section of the chapter provides detailed information from the literature about conventional beamforming techniques and deconvolution techniques, which don't appear crucial to understand the beamforming results that will be presented later.

The Chapter 3 presents the main numerical contribution of the candidate, i.e. the implementation of the FW-H solution derived by Farassat using the Tecplot environment and macro language. The choice of this programming environment is certainly original, and justified by the candidate by the availability of advanced data processing tools already present and optimized in this commercial software, and the possibility to import source data from numerous CFD solvers. While those arguments would be debatable considering the numerous tools and interfaces that are openly available nowadays, I must reckon that I would not have thought possible to program a Farassat formulation using the Tecplot scripting language. The successful validation of this implementation with the analytical solutions given in Chapter 2 does undoubtedly represent a significant achievement in that respect. My only regret is that the spatial and temporal convergence studies could have been made considering non-dimensional parameters, precisely to better understand and illustrate the compactness, acoustic and geometrical far-field effects. It would have yielded more generally applicable guidelines as well.

The validated tools are then applied in Chapter 4 for the prediction of the noise radiated by a hovering helicopter rotor. The source data are successively provided by a BEMT method and a RANS solver. The noise prediction, accounting for the thickness and steady loading source components, are in good agreement with the literature, requiring only small adjustments of the environmental conditions with respect to the experimental ones.

The Chapters 5 and 6 are eventually addressing, numerically and experimentally respectively, the main question defined in the introduction, i.e. what is the effect of RVGs on the noise emitted by wind turbines. The Chapter 5 is focused on the noise mechanisms associated with the steady loads and thickness of the blade. It turns out that the RVGs don't show any significant impact on any of the two mechanisms. This could have been expected for the thickness noise, mainly associated with the displacement of the fluid by the blade passage, given the extremely small volume occupied by the RVGs. This result was perhaps less expected considering the loading noise, since the RVGs were supposed to delay separation and thus

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influence the sectional blade loading. One wonders if the RVGs lead to any significant modification of the flow simulated by the RANS solver. The chapter 5 lacks evidence to ascertain this effect. The experimental tests carried out at TUD, reported in Chapter 6, could have been processed to produce Cp-distributions, which could have shed some light on this question, but then it would be also interesting to comment on the complementarity/consistency between the experimental campaign carried out at TUD in the LTT wind tunnel (Chapter 6), and the simulations reported in Chapter 5.

The Chapter 6 provides a wealth of information about the aerodynamic and acoustic effects of the RVGs, and provides a detailed picture of how the vortical structures shed by the RVGs are affecting the flow statistics, in both natural and tripped transition cases. In the latter case – presumably the closest to a realistic operation of the wind turbine, the RVGs a shown to reduce the low frequency noise and re-generate some high-frequency content. The argumentation about the fact that the low-frequency part of the spectrum is dominating the OASPL is certainly correct, but I would be curious to discuss with the candidate about how this interpretation of the results might change when the spectrum is expressed in dB(A), accounting as well for Strouhal-Helmholtz scaling towards the full-sized application.

The Chapter 7 provides a summary of the main outcomes of the work and suggests some future paths for a continuation of this research. The latter might have been a little more elaborated.

In summary, the work presented in this PhD manuscript is substantial and constitutes undoubtedly an original contribution to the field. The results provide new insight about the scientific problem addressed by the candidate, and confirm that she possesses the key abilities to conduct scientific research independently. She has also demonstrated being able to collaborate very successfully with highly ranked academic institutions in her field.

For all these reasons, I am respectfully requesting the Scientific Council to admit the candidate to the next stages of the proceedings for the award of the doctoral degree, in accordance with the Polish Act of 20 July 2018, *Law on Higher Education and Science*. I confirm that I don't have any conflict of interest to declare in relation with this PhD thesis.

Sincerely,

C. Schram, Professor.

Perwez, 15 May 2024.

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