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Review of the PhD dissertation of Ms Thanushree Suresh, MSc, BEng., entitled "Aeroacoustic Investigation of Streamwise Vortex Generators for Flow Control" in the doctoral procedure conducted in the discipline of mechanical engineering at the Institute of Fluid-Flow Machinery of the Polish Academy of Sciences

This review was prepared following the decision of the Scientific Council of the Institute of Fluid-Flow Machinery of the Polish Academy of Sciences in Gdansk made at the Meeting of 19 December 2023 and appointing me a reviewer of the doctoral dissertation submitted by Ms Thanushree Suresh, MSc, BEng., entitled "Aeroacoustic Investigation of Streamwise Vortex Generators for Flow Control".

1. Description of the doctoral dissertation

The PhD dissertation submitted by Ms Thanushree Suresh, MSc, BEng., entitled "Aeroacoustic Investigation of Streamwise Vortex Generators for Flow Control" deals with the analysis of the physics of the phenomena related to the generation and propagation of sound generated by rotating blades of horizontal axis wind turbines (HAWTs). Noise is a kind of environmental pollution that directly determines the quality of human life. With the continuous increase in the share of renewable energy sources in the energy mix, we have recently witnessed a significant development in onshore wind power, also in Poland. In the context of wind turbines, it is not the high level of noise, but rather its nuisance that is cited as one of the reasons for public concern over the construction of wind farms. Therefore, works aimed at a reduction in noise emissions from wind turbines are important and still relevant. This means that the subject matter of the dissertation is important for the development of the scientific discipline of mechanical engineering.

The PhD dissertation submitted by Ms Thanushree Suresh is made of a list of symbols and abbreviations, 7 main chapters, a bibliography, a list of figures and tables and two appendices, which gives about 160 pages in total. The dissertation was prepared in the English language. It is logically structured, with lucid contents and clear and well-prepared figures and tables.

The PhD dissertation begins with a list of symbols and abbreviations. It was prepared with great care. The symbols and the abbreviations are cleverly grouped so there is no difficulty finding relevant items. Owing to that, it is much easier to read and understand the dissertation contents.

Chapter 1, "Introduction and research objectives" is divided into 6 sections, the last of which presents the objective and scope of the work. It informs that the objective of the research undertaken by the PhD candidate is to better understand the mechanism of the creation of aerodynamic noise generated by HAWT blades, operating by off-design condition, for which boundary layer separation occurs on the profile suction side. For this reason, the main objective assumed in the work is numerical and experimental testing of the use of a vortex generator, in this case: the rod vortex generators (RVGs) that reduce boundary layer separation. In addition to the main objective, the PhD candidate formulated one hypothesis and a number of partial tasks. One of those tasks deserves special mention: construction of an own acoustic postprocessor based on the FW–H analogy using the Tecplot 360EX software. In the next chapter, the PhD candidate offered a theoretical introduction to computational aeroacoustics (CAA) presenting the numerical methods used in aeroacoustics and the fundamental acoustic analogies useful in the numerical analyses carried out in the work. The next chapter marks the beginning of the proper part of the doctoral dissertation. In the chapters that follow, the Ph.D. candidate adopted the principle of ending each chapter with a summary, which I really like. Chapter 3 presents a description of the developed aeroacoustic code based on the FW–H equation derived by Farassat. In parallel with the description of the code prepared using the Tecplot software, the computational algorithm is presented along with validation results. The results are compared to the analytical solutions for four main configurations – stationary monopole/dipole and rotating monopole/dipole. The comparison showed a good quality of the developed code.

The code was verified further in the next chapter to identify the so-called low-frequency harmonic noise (LF-IPH). The testing was performed using the geometrical data and the

results of an experiment performed for a single-bladed model rotor at the University of Maryland. This made it possible to assess the code with regard to thickness and loading noise prediction.

Chapters 5 and 6 are closely related to the dissertation title and deal with the analysis of the rod vortex generators mounted on the HAWT blade. The analysis was conducted based on the geometry of the turbine blade tested earlier and known to the research team in which the PhD candidate realised her doctoral dissertation. The calculations were performed using the CFD + FW–H method enabling identification of the thickness and the loading noise. Interesting experimental research was also carried out which has a great value for the validation of both CFD and CAA codes.

The last chapter of the dissertation presents the reached conclusions and the plans for the future.

The literature includes 184 items, three of which are co-authored by the PhD candidate. Additional information obtained during the validation of the developed acoustic postprocessor is presented by the PhD candidate in two appendices.

2. Assessment of the doctoral dissertation

The title of the reviewed PhD dissertation indicates that the acoustic analyses presented therein focus on streamwise vortex generators. The investigated approach is a solid-type vortex generator solution in the form of inclined rods, and the wake generated by the obstacle in the form of the rods is treated as a stream. The geometry of the generators is adopted based on earlier studies. It is not analysed in detail in the dissertation, e.g. the dimensions or different configurations.

It can clearly be noticed that the reviewed doctoral dissertation presents results obtained from a bigger project, where the PhD candidate was responsible for a separate task. For this reason perhaps, a large portion of information which I find important is presented in a rather superficial manner.

As the PhD candidate's main and original achievement, I would name the development of an in-house aeroacoustic tool for investigating sound predictions of rotating bodies in subsonic motion. The code developed using the Tecplot software is based on the integral solution of the exact FW–H acoustic analogy derived by Farassat in the time domain.

Very valuable are also the experimental studies carried out at Delft University of Technology of the impact of the application of vortex generators on the broadband noise emission by the wind turbine blade. The effect of rod vortex generators on the boundary layer was examined by means of three measuring techniques: static pressure measurement on the blade sucking surface, oil visualisation and the PIV method. In addition, since the laboratory was equipped with an anechoic chamber, acoustic analyses were also carried out using the acoustic beaming technique.

The set basic objectives of the work and its scope were realised. The hypothesis formulated in the dissertation, marked in bold, was confirmed, although it was not a difficult task as it seemed obvious.

3. Remarks and comments

The doctoral dissertation was prepared in a careful and clear manner. In my opinion, though, the obtained valuable calculation results are presented too modestly. In many cases, two-dimensional maps of distributions of flow and acoustic parameters would have enriched the interpretation of the obtained data or results.

The remarks related to the contents and scope of the work, as well as some debatable issues arising after the doctoral dissertation reading, are presented below:

- Apart from spatial discretisation, was the impact of the time step investigated for the developed acoustic postprocessor? This is mainly about the CFD + FW-H method, not about the comparison with the analytical solution.
- The validation calculation results for the single-bladed model rotor simulating the helicopter rotor operation while hovering for the BEMT + FW–H and the CFD + FW–H method may suggest that the Blade Element Momentum Theory is sufficient and no CFD calculations are needed to identify aeroacoustic noise. Have I interpreted the contents of the chapter correctly?
- Was the application of rod vortex generators analysed in strength terms for the wind turbine blade under consideration?
- Can the application of rod vortex generators affect the machine life and service life? If so, in my opinion, at a relatively low gain in the rise in torque and at scarce elimination of acoustic noise, this approach can be disputable.

- During the analyses related to calculations by means of the BEMT + FW–H and the CFD + FW–H method, there should be a little more information both on the BEMT and the CFD method. Among others, what CFD solvers were used, how were the calculations carried out, and were more viscous turbulence models analysed at the RANS method?
- The valuable experimental results presented in Chapter 6, apart from the information on acoustic measurements, provide a large amount of measuring data concerning the flow itself. Can the data be used to validate CFD methods? If so, to what extent?
- Would it be possible to reduce the sound level in the area of low frequencies by changing the geometry and configuration of the rod vortex generators?

4. Final conclusions

Summing up, I hereby state that the doctoral dissertation of Ms Thanushree Suresh, MSc BEng., entitled "Aeroacoustic Investigation of Streamwise Vortex Generators for Flow Control" meets the conditions specified in Article 187 of the Act of July 20, 2018: Law on Higher Education and Science (Dz. U. [Journal of Laws] of 2018, item 1688). The work presents the PhD candidate's general theoretical knowledge in the discipline and the ability to conduct independent scientific work. The obtained results are original and valuable, and the applied research technique is correct and modern. Having said that, I request the Scientific Council of the Discipline: Mechanical Engineering of the Institute of Flow Machinery of the Polish Academy of Sciences in Gdansk to admit Ms Thanushree Suresh to further stages in the doctoral proceedings.

In addition, taking into account the high scientific level of the conducted research, the use of advanced measuring techniques, the development of an in-house acoustic postprocessor and the valuable results of the experimental research mentioned earlier, I request that the dissertation of Ms Thanushree Suresh, MSc BEng., be awarded a distinction.