

**Review of the PhD dissertation of Ms Shivangi Sachar, MSc Eng., entitled  
“Performance and Noise Sources of a Savonius Wind Turbine in an Urban Environment”  
in the doctoral procedure conducted in the discipline of mechanical engineering  
at the Institute of Fluid-Flow Machinery of the Polish Academy of Sciences in Gdańsk**

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 21 January 2026 and appointing me a reviewer of the doctoral dissertation submitted by Ms Shivangi Sachar, MSc, BEng., entitled “Performance and Noise Sources of a Savonius Wind Turbine in an Urban Environment”.

**1. Description of the doctoral dissertation**

The PhD dissertation submitted by Ms Shivangi Sachar, entitled “Performance and Noise Sources of a Savonius Wind Turbine in an Urban Environment”, concerns the analysis of the performance and acoustic emission of small-scale vertical-axis Savonius wind turbines intended for deployment in complex urban flow conditions. The work addresses both the aerodynamic efficiency and the noise impact of such turbines, with particular emphasis on their applicability and acceptability in densely populated areas. The candidate formulates a clear central hypothesis stating that the integration of wind energy into urban environments requires specific turbine characteristics that ensure both environmental and social acceptance, and that these characteristics can be identified and optimised for Savonius-type rotors.

The dissertation is written in English and comprises an abstract and Polish summary, an extensive nomenclature, six main chapters grouped into thematic parts, an appendix and a rich bibliography of over 220 items. The total length is about 177 pages. The structure is logical and transparent: after an introduction and motivation, the author presents the theoretical background, the methods used for wind potential assessment, numerical and experimental analysis of rotor performance, detailed acoustic investigations, and finally the integration of Savonius turbines into specific urban environments including rooftop and countryside installations. Contents, figures and tables are prepared in a clear and consistent manner, and the nomenclature is comprehensive and well organised, which substantially facilitates reading.

Chapter 1 provides a broad overview of wind energy development, types of wind turbines and their classification, with particular focus on vertical-axis concepts and the Savonius rotor. The candidate discusses fundamentals of wind turbine operation, including power in the wind, Betz limit, coefficient of performance and tip speed ratio, and compares performance characteristics for different turbine types. She then introduces the specific context of urban wind power, explaining the role of surface roughness, atmospheric boundary layer structure, turbulence and the need for reliable wind statistics in cities. The research hypothesis and detailed objectives are formulated at the end of the chapter, along with a concise outline of the thesis.

Chapter 2 describes the methodology adopted in the work. The author presents approaches to wind dynamics analysis and site selection, with emphasis on statistical modelling of wind speed using

Weibull and other probability distributions, as well as statistical tools for distribution evaluation. She then introduces the numerical methods used for the performance analysis of Savonius rotors, including governing equations, turbulence models and general CFD setup. Finally, she describes the acoustic measurement techniques, both single-microphone methods and beamforming with microphone arrays, including construction of the cross-spectral matrix, source power integration and post-processing of acoustic maps. This chapter provides a solid theoretical and methodological basis for the subsequent analyses.

Chapter 3 is devoted to the performance analysis of Savonius wind turbines. It begins with a literature review of Savonius rotor characteristics, including the influence of overlap ratio, segmentation, aspect ratio and other design parameters. The author then presents numerical simulations of a reference Savonius rotor, first in free-stream conditions and then in a wind-tunnel test section. Detailed descriptions of geometry, computational domains, meshes, boundary conditions, turbulence models and grid-convergence analysis are included. The obtained torque and power coefficients are compared for different rotor positions relative to the test-section outlet, and the influence of blockage and flow non-uniformity is discussed. The second part of the chapter describes experimental evaluation of rotor performance, with measurements carried out in the IMP PAN laboratory. Experimental characteristics are compared with CFD results for several rotor–test-section distances, and overall a satisfactory agreement is demonstrated. Every subchapter concludes with a brief summary of the key findings, enhancing understanding.

Chapter 4 focuses on the experimental acoustic assessment of Savonius VAWTs. In the first part, the author investigates the effect of rotor segmentation on noise and performance by comparing single-segment and five-segment rotors in the IMP PAN test section. The experimental set-up, measurement procedure and signal processing chain are described in detail. Noise spectra, overall sound pressure levels and psychoacoustic metrics are analysed and correlated with aerodynamic performance for different tip speed ratios and operating conditions. In the second part, more advanced acoustic studies are reported, based on experiments carried out in the open jet facility at TU Delft using a large microphone array. The candidate analyses the dependence of noise on loading and inflow velocity, explores scaling of power spectral densities with wind speed and provides beamforming maps identifying dominant noise sources at selected frequencies and operating conditions. The results convincingly show how specific parts of the rotor and its support structure contribute to the overall acoustic emission.

Chapter 5 deals with the integration of wind turbines into the urban environment. First, the candidate performs wind potential assessment for several locations in Nottingham (UK) and in Poland (Gdańsk and Przywidz), using multi-year measurement data. She compares different methods of parameter estimation for the Weibull distribution and evaluates their accuracy using error metrics such as RMSE, MAPE and coefficient of determination. Based on the derived distributions she computes wind power densities, expected energy yields and assesses the suitability of various commercially available turbines for urban deployment. In the second part of the chapter, the author analyses an innovative twin-rotor Savonius-type wind turbine. She describes its rooftop installation at the IMP PAN building and a countryside installation in Przywidz, including prototype geometry, measurement system and data processing. Time histories and distributions of tip-speed ratio and power are presented, and the effectiveness of the system in different configurations is evaluated. The analysis demonstrates how the twin-rotor concept can enhance energy production while smoothing transient wind fluctuations.

The final Chapter 6 contains a concise synthesis of the main findings and an outline of future work. The candidate summarises the performance potential of Savonius turbines in urban applications, highlights

the relationship between acoustic emission and operating parameters, and suggests directions for further optimisation of rotor geometry and urban siting. The thesis is complemented by three appendices presenting, respectively, definitions of acoustic quantities and sound-quality metrics, a detailed description of the IMP PAN test section and flow-uniformity tests, and supplementary material for the wind potential analysis.

## **2. Assessment of the doctoral dissertation**

The dissertation of Ms Shivangi Sachar addresses an important and timely problem related to the deployment of small wind turbines in urban environments, where both performance and noise issues are critical for social acceptance. The focus on Savonius-type vertical-axis turbines is well justified by their low rotational speed, omnidirectional operation and relatively low mechanical complexity, which make them promising candidates for building-integrated and distributed generation systems. By combining aerodynamic, aeroacoustic and wind-resource analyses within a single work, the candidate presents an integrated perspective which is valuable for the development of urban wind energy.

From a scientific point of view, the originality of the thesis lies in several aspects. First, the candidate performs a consistent comparison of numerical and experimental performance characteristics of a Savonius rotor, including the influence of test-section confinement and rotor placement. Second, she provides a detailed experimental investigation of the acoustic emission of segmented Savonius rotors, including psychoacoustic evaluation, which is rarely addressed in the literature. Third, she carries out advanced noise-source localisation studies with a microphone array for a Savonius turbine, analysing the impact of loading and flow velocity on the spatial distribution of acoustic sources. Finally, she proposes and evaluates an innovative twin-rotor Savonius configuration installed on a building and in a countryside site, using long-term monitoring data to quantify its effectiveness under real atmospheric conditions. These contributions are, in my opinion, original and relevant to the discipline. The methodological level of the work is high. The candidate uses accepted CFD approaches for unsteady simulations of rotating machines, documents grid-convergence tests and discusses the limitations of the adopted turbulence models. She carefully designs and calibrates experimental set-ups for both performance and acoustic measurements, and applies appropriate statistical tools for wind potential assessment. The description of the measurement systems, signal processing and error estimation is sufficiently detailed to allow reproduction of the experiments. The use of psychoacoustic metrics and beamforming methods demonstrates a broad and mature approach to noise assessment, going beyond simple overall level evaluation.

In my opinion, the work is written in clear and fluent English. The presentation is generally clear, with informative figures and tables. The chapters are closed with summaries, which helps the reader to follow the logical flow of the argument. The bibliography is extensive and up to date, covering both classical references on wind energy, Savonius rotor research and recent work on urban wind and wind turbine noise.

As the main scientific achievements of Ms Sachar I would indicate:

- Development and validation of numerical models for Savonius rotor performance in free-stream and wind-tunnel conditions, including analysis of blockage effects and rotor positioning.
- Experimental characterisation of the influence of rotor segmentation on both performance and acoustic emission, supported by psychoacoustic analysis of sound quality.

- Detailed beamforming-based noise source localisation for a Savonius VAWT in an open jet facility, revealing frequency- and condition-dependent source regions and scaling of noise levels with inflow velocity.
- Comprehensive wind resource assessment at several urban and semi-urban locations in the UK and Poland using different statistical distributions and parameter-estimation methods, leading to recommendations for turbine selection.
- Long-term field evaluation of an innovative twin-rotor Savonius turbine in rooftop and countryside installations, demonstrating its potential for smoothing wind fluctuations and delivering useful energy in realistic conditions.

In my view, these achievements demonstrate the candidate's ability to conduct independent research, to design and execute complex experiments, and to interpret results in a broader engineering context.

### 3. Remarks and comments

Although the dissertation is prepared in a careful and comprehensive manner, some aspects could, in my opinion, be elaborated or clarified. I present below several remarks and questions which may be considered during the public defence:

- The CFD part of the work would benefit from a more detailed discussion of numerical uncertainty. While a grid convergence analysis for rotor torque is presented, additional information on time-step sensitivity and the influence of turbulence model choice on both mean and unsteady loading would strengthen confidence in the simulations. Were alternative turbulence models (e.g. different RANS or hybrid approaches) tested for the Savonius rotor, and if so, how did the results differ?
- In the performance comparison between numerical simulations and wind-tunnel experiments, the agreement is generally good. Nonetheless, some discrepancies are visible at particular tip speed ratios and rotor positions. Could the candidate comment more explicitly on the possible sources of these differences (e.g. support-structure interference, inflow non-uniformity, measurement uncertainty) and on how they might affect extrapolation of the results to full-scale urban installations?
- The effect of rotor segmentation on noise and performance is one of the interesting topics of the thesis. However, the physical mechanisms responsible for the observed changes in sound spectra and psychoacoustic metrics could be interpreted in more depth. For instance, can the candidate relate specific spectral components to flow structures observed in previous studies or simulations, and explain why the segmented rotor exhibits the reported sound-quality differences compared to the single-segment configuration?
- In the beamforming analysis, several illustrative acoustic maps are presented for selected frequencies and operating points. It would be valuable to discuss more quantitatively how the localisation accuracy and dynamic range of the array influence the interpretation of the maps, particularly at low frequencies where spatial resolution is limited. Are there indications that some distributed noise sources may be smeared or underestimated by the applied method?
- The wind potential assessment in Nottingham and Poland uses several parameter-estimation methods for the Weibull distribution, and their errors are compared. While the analysis is thorough, the practical implications for turbine selection could be emphasised more strongly. For example, how sensitive are the predicted annual energy yields of the considered turbines to the choice of Weibull-parameter method, and does this influence the ranking of candidate machines?

- The innovative twin-rotor Savonius configuration is an important and practical outcome of the work. However, its acoustic behaviour in real installations is only briefly touched upon. Are there preliminary measurements or qualitative observations regarding noise produced by the rooftop and countryside prototypes, and how do they compare with the single-rotor configurations studied earlier? Given the importance of noise in urban applications, further comments in this direction would be welcome.

Can the estimated overall drag (including the frame and housing), the calculated load limits, or the results of the fatigue assessment limit the range of its possible applications?

These remarks do not diminish the overall value of the dissertation; rather, they indicate directions in which the already rich material could be extended or clarified.

#### **4. Final conclusions**

Summing up, I state that the doctoral dissertation of Ms Shivangi Sachar, MSc Eng., entitled “Performance and Noise Sources of a Savonius Wind Turbine in an Urban Environment” meets the conditions specified in Article 187 of the Act of July 20, 2018, Law on Higher Education and Science (Dz.U. 2018, item 1688). The work proves the candidate’s broad theoretical knowledge in the field of mechanical and energy engineering and her ability to carry out independent scientific research. The results obtained are original and valuable, and the applied research methods – encompassing advanced numerical simulations, carefully designed laboratory experiments, sophisticated acoustic analyses and long-term field measurements – are modern and appropriate to the research objectives. Therefore, I request the Scientific Council of the Discipline Mechanical Engineering of the Institute of Fluid-Flow Machinery of the Polish Academy of Sciences in Gdańsk to admit Ms Shivangi Sachar, MSc Eng., to the further stages of the doctoral proceedings.

Moreover, taking into account the high scientific level of the research, the comprehensive treatment of both performance and noise aspects of Savonius turbines, the successful integration of laboratory, numerical and field studies, and the practical significance of the innovative twin-rotor concept for urban wind energy, I also request that the dissertation of Ms Shivangi Sachar, MSc Eng., be awarded a distinction.

