Improvement of the Brooks–Pope–Marcolini Method for Estimating Wind Turbine Blade Acoustic Parameters

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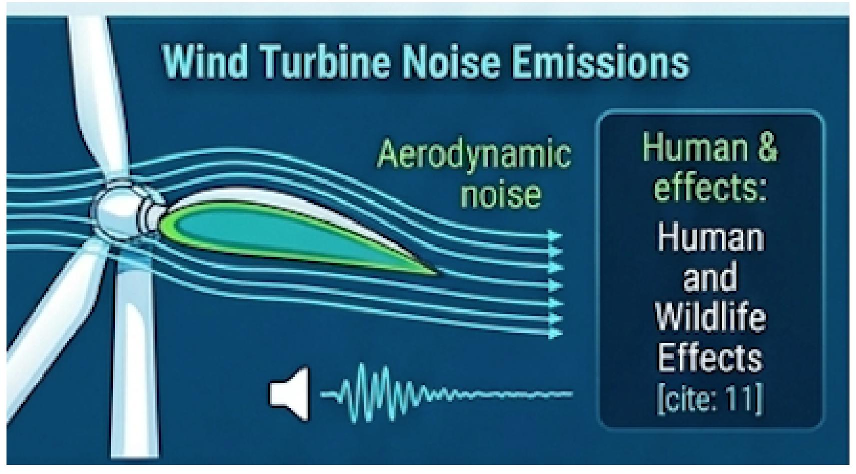
Introduction & Problem Statement

TAs wind energy capacity grows, aerodynamic noise from turbine blades has become a dominant environmental concern.Currently, the Brooks-Pope-Marcolini (BPM) model is the industry standard for predicting this noise. However, the classical BPM model was developed under controlled, stable conditions and fails to account for the chaotic nature of atmospheric turbulence. In real-world operation, this leads to a significant underestimation of sound pressure levels,making it difficult to design truly "quiet" turbines.



METHODOLOGY

A parametric study was conducted to quantify the impact of turbulence on a wind turbine blade's acoustic performance using the improved model.

- Parametric Range: Calculations were performed varying the Turbulence Intensity (TI) from a baseline of 0.05 up to 0.25.
- Workflow: First, the standard sound pressure level was calculated using the classical BPM approach. Second, the turbulence correction term (K·TI) was added to generate the corrected noise estimation.

Model	Empirical Coefficients	Turbulence Intensity
Modified BPM	0.56	0.58
Classical BPM	0.22	0.39
Nanjiing University of	0.23	0.89

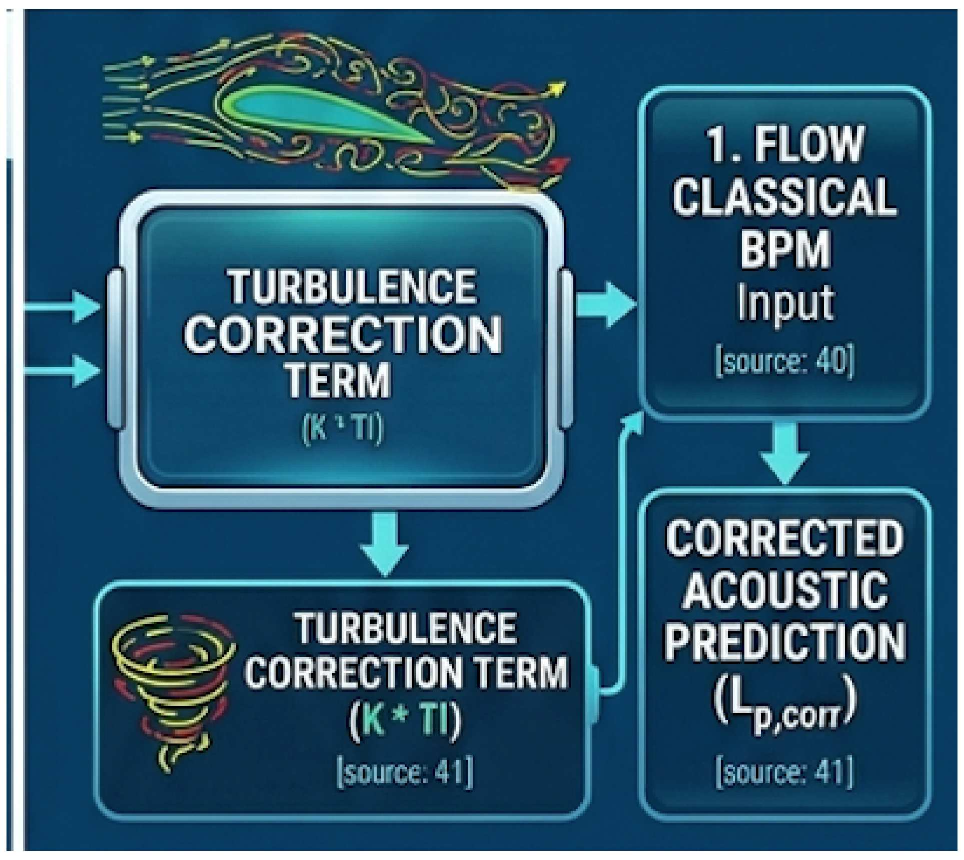
This table highlights the fundamental differences between the industry-standard approach and the proposed enhancement developed in this study.

Main Findings

- Significance of Turbulence: Atmospheric turbulence intensity is a critical driver of aerodynamic noise, and its exclusion leads to inaccurate environmental assessments.
- Addressing Underestimation: The classical BPM model was found to systematically underestimate sound pressure levels (SPL) because it ignores the energy increase caused by flow fluctuations.
- Quantifiable Impact: The results show that at a TI of 0.15, noise levels increase by approximately 3 dB, representing a doubling of sound energy that traditional models fail to capture.

Theoretical Background

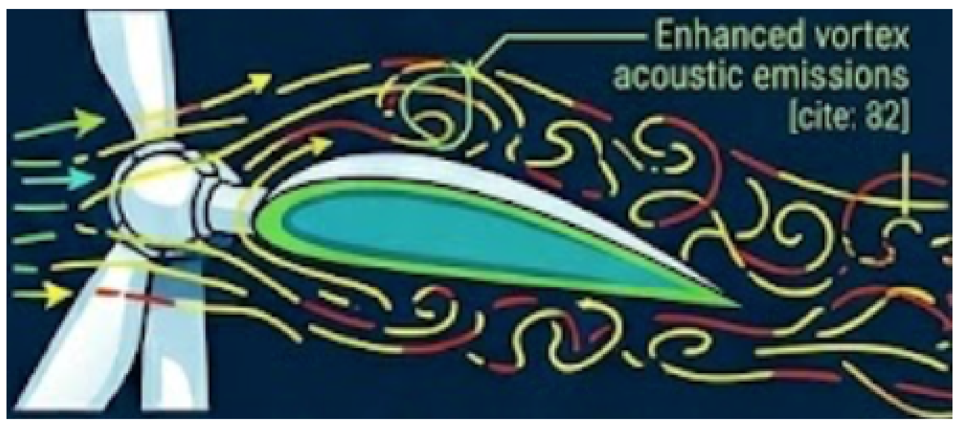
The primary noise mechanisms involve the interaction between the turbulent boundary layer and the blade's trailing edge,as well as vortex shedding. We define Turbulence Intensity (TI) as the ratio of the root-mean-square of velocity fluctuations to the mean flow velocity. Our research shows that as TI increases, the energy of these velocity fluctuations also increases, leading to more pronounced pressure fluctuations and stronger acoustic emissions from the blade surface.



Our study proposes an enhancement to the BPM framework by introducing a turbulence-dependent correction term.The modified formula is:

Lp,corr=Lp,BPM+K·TI

In this equation, we add a product of an empirical coefficient (K) and the turbulence intensity (TI) to the baseline BPM prediction. This allows the model to scale acoustic output based on actual atmospheric variability rather than assuming a static environment.



Conclusion

The findings of this study provide a significant step toward bridging the gap between theoretical acoustic modeling and real-world wind turbine operations.

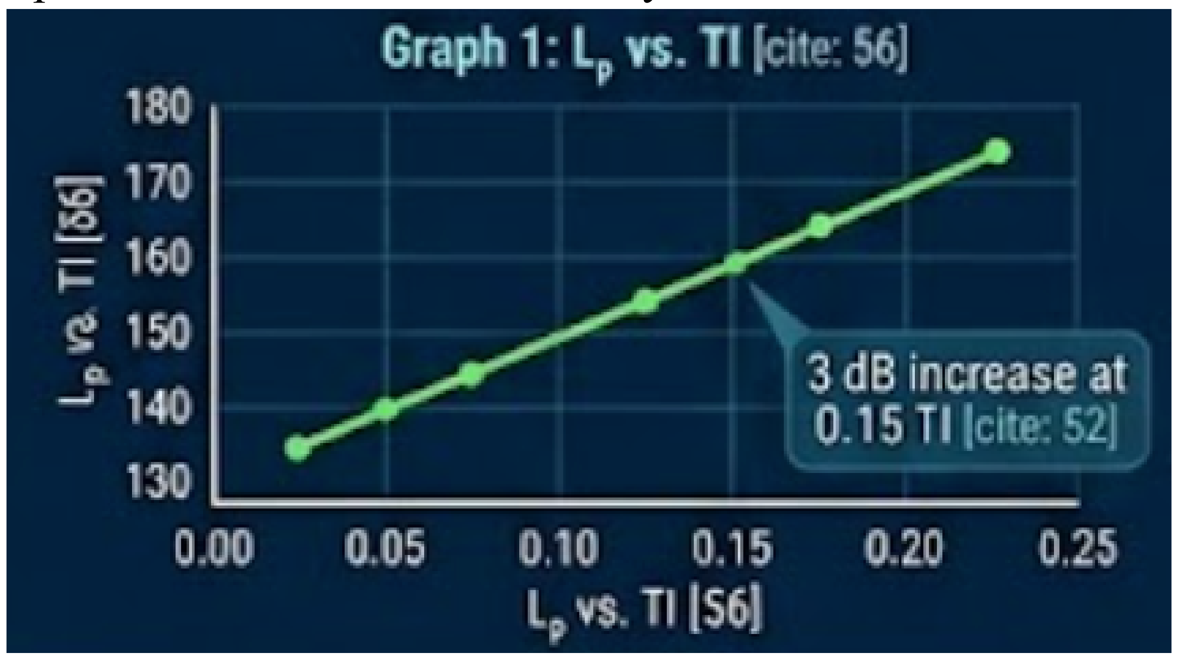
Results & Discussion

The results confirm a nearly linear relationship between turbulence intensity and noise. Key findings include:

- Significant Noise Jump: At a TI of 0.15, the modified model predicts an increase of approximately 3 dB over the classical model.
- Sensitivity: The model is highly sensitive to small changes in turbulence, highlighting that TI is a dominant factor in noise generation.
- Realism: By comparing the models, we find that the modified approach provides a much more realistic estimation for environmental noise assessments in complex terrains.

Influence Intensity [S3]	TI on Sound Pressure Level [S3]				
	0.05	0.10	0.15	0.20	0.25
0.05	30.1	32.4	32.6	30.4	31.1
0.1	31.7	32.1	33.3	31.4	33.5
0.15	33.7	33.5	34.3	35.6	35.7
0.2	37.3	37.2	35.3	36.6	37.8
0.25	30.4	36.6	39.8	37.9	35.5

- The comparison, detailed in Table 1, shows the corrected model (Lp,corr) providing consistently higher (and more realistic) noise predictions compared to the classical approach.
- At a moderate Turbulence Intensity of 0.15, the model predicts a significant increase of approximately 3 dB over the classical BPM prediction , which is crucial for practical noise and environmental assessment.
- The corresponding graph confirms the physically expected nearly linear dependence between sound pressure and turbulence intensity.



A specialized analysis confirmed the high sensitivity of the acoustic response to changes in TI.

- Even minor increments in turbulence intensity lead to noticeable and measurable changes in the predicted sound pressure level.
- This high sensitivity validates that atmospheric turbulence is a dominant factor in aerodynamic noise generation and cannot be ignored.

REFERENCES

1. Brooks, T.F., Pope, D.S., & Marcolini, M.A. (1989). Airfoil self-noise and prediction. NASA Reference Publication 1218.
2. Oerlemans, S., Sijtsma, P., & Méndez López, B. (2007). Location and quantification of noise sources on a wind turbine. Journal of Sound and Vibration.
3. Amiet, R.K. (1976). Noise due to turbulent flow past a trailing edge. Journal of Sound and Vibration.
4. Blake, W.K. (1986). Mechanics of Flow-Induced Sound and Vibration. Academic Press.
5. Zhu, W.J., Heilskov, N., Shen, W.Z., & Sørensen, J.N. (2005). Modeling of aerodynamically generated noise from wind turbines. Journal of Solar Energy Engineering. Full reference list available in the published manuscript.