

## Investigating the Natural Frequency and Deflection of Vortex Bladeless Wind Turbines: An ANSYS and MATLAB Study



Abdalkaleg Atia Idris Hamad\*<sup>1</sup>, Adel Agila<sup>2</sup> and Abeer Abdulhamid Ali Elsherif<sup>3</sup>

<sup>1st</sup> Department of Mechanical and Energy Engineering, Libyan Academy for Postgraduate Studies- Al Jabal Al Akhtar. <sup>2nd</sup> Department of Mechanical, Omar Al Mukhtar University. <sup>3rd</sup> Department of Mechanical and Energy Engineering, Libyan Academy for Postgraduate Studies- Al Jabal Al Akhtar.

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### Abstract

Vortex bladeless wind turbines operate through oscillatory motion instead of rotating blades, offering significant reductions in cost, maintenance needs, and environmental impact. Yet, their structural behavior under wind loading—especially regarding natural frequency and deflection—remains insufficiently examined. This study investigates natural frequency, maximum deflection, and overall structural performance by analyzing the effects of mast length and material type. Model accuracy is evaluated by comparing MATLAB analytical calculations with ANSYS numerical simulations; a three-dimensional finite element model was developed in ANSYS using Bernoulli–Euler beam theory to simulate dynamic loading, supported by MATLAB computations that incorporate geometry, material properties, and wind-induced forces. Mast lengths of 2500 mm, 3000 mm, and 3500 mm were assessed with a fixed rod length of 800 mm using E-glass and S-glass materials. The results show that maximum displacement consistently occurs near the fixed rod region, with E-glass displaying greater stiffness and lower deflection compared to S-glass. Increasing mast length raises applied forces from approximately 75 N to 105 N, producing larger deformation. The strong consistency between MATLAB and ANSYS outcomes confirms the reliability of the employed model. These findings support improved material selection, optimized mast configuration, and informed structural design for future bladeless vortex wind turbine applications.

## INTRODUCTION

The search for clean and sustainable energy sources has led to increased research into wind energy, which remains one of the fastest-growing renewable sources worldwide. Traditional wind turbines, which rely on rotating blades, have been the standard solution for decades; however, they are often associated with high maintenance costs, noise pollution, and risks to wildlife. These limitations have driven the emergence of bladeless wind turbines as a pioneering and safer innovation. This technology utilizes the vortex shedding phenomenon, where airflow over a

\*Corresponding author: [a.hamad@lajak.edu.ly](mailto:a.hamad@lajak.edu.ly), Department of Mechanical and Energy Engineering, Libyan Academy for Postgraduate Studies- Al Jabal Al Akhtar

cylindrical structure induces oscillations and resonance to generate electricity. This approach is more cost-effective and environmentally friendly, representing a significant advancement in renewable energy design. This study aims to bridge the existing research gap by conducting a detailed numerical and analytical examination of the structural behavior of vortex bladeless wind turbines.

## LITERATURE REVIEW

The increasing global demand for sustainable energy has driven considerable interest in alternative wind energy technologies that can overcome the limitations of conventional horizontal-axis wind turbines (HAWTs). Among these innovations, the vortex bladeless wind turbine represents a novel design that harnesses wind energy through vortex-induced vibrations (VIV) rather than traditional rotational motion. Unlike conventional turbines with rotating blades, this technology consists of a vertical cylindrical mast that oscillates under wind excitation, converting these vibrations into electrical energy via an alternator system. Initial theoretical and experimental studies, such as those reported by Sanz-Andrés et al. (2015) [1], have demonstrated the potential advantages of bladeless designs in terms of cost reduction, reduced maintenance requirements, and minimized environmental impact.

The absence of rotating blades not only eliminates mechanical complexities but also substantially reduces the risk to birds and bats well-documented ecological concern associated with HAWTs. Furthermore, lower noise emissions and a simplified structure enhance the suitability of vortex bladeless turbines for urban and residential areas, where space limitations and noise restrictions often hinder the deployment of conventional turbines. The underlying physics of VIV has been extensively investigated within the fields of aerodynamics and civil engineering, particularly in the design of structures such as bridges and chimneys (Blevins, 1990) [2].

However, the application of vortex bladeless turbines in energy harvesting is relatively recent. Vortex Bladeless Ltd., a Spanish startup, has led the development of prototypes and conducted tests to evaluate their performance under varying wind conditions. Early models have demonstrated power coefficients ( $C_p$ ) lower than those of conventional turbines; yet, proponents argue that overall system efficiency—considering installation, maintenance, and operational lifespan—may favor bladeless technologies in specific contexts, particularly in low-wind-speed environments. Despite these promising features, critical evaluations have identified several limitations. The energy output per unit area remains comparatively low, posing challenges for large-scale adoption. Furthermore, long-term data regarding durability, fatigue behavior under continuous oscillation, and scalability remain limited, as highlighted by Araya et al. (2019) [3].

Optimizing the resonant frequency of the structure in response to local wind profiles is crucial for maximizing energy harvesting potential. In recent years, interdisciplinary studies integrating materials science and structural dynamics have focused on enhancing performance. Innovations such as magnetostrictive and piezoelectric materials have been proposed as alternatives to conventional generators, potentially improving conversion efficiency.

While vortex bladeless turbines are in the early stages of technological maturity, their unique design positions them as a promising complementary solution. Recent studies have further explored geometric and material optimizations: Tripathi et al. [4] found that sinusoidal shapes achieve higher deflection than circular ones. Similarly, Seyed et al. [5] and Badri et al. [6]

demonstrated that linear tapering of the mast significantly improves oscillation amplitude. Regarding material selection, Francis et al. [7] and Onkar & Amol [10] identified fiberglass as a superior material compared to carbon fiber due to its higher displacement values, cost-effectiveness, and ability to achieve natural frequency vibrations at lower wind speeds.

## METHODOLOGY

### Analytical Analysis and Mathematical Modeling:

The study follows a structured multi-stage approach to evaluate the performance and structural integrity of vortex bladeless wind turbines:

**Mathematical Modeling:** Analytical models will be developed to describe the aerodynamic and structural dynamic behavior of the turbine. These models will be implemented in MATLAB to calculate natural frequencies and deflections based on Bernoulli–Euler beam theory.

**Numerical Simulation:** A three-dimensional finite element model (FEM) will be developed in ANSYS. This simulation will account for dynamic wind loading, material properties (E-glass and S-glass), and varying mast lengths to observe structural responses.

**Validation and Comparison:** The results obtained from ANSYS numerical simulations will be rigorously compared with the MATLAB analytical predictions. This step is crucial to validate the accuracy, reliability, and consistency of the proposed models.

**Comparative Analysis:** A detailed investigation will be conducted to identify any discrepancies between the numerical and analytical findings. This analysis aims to provide insights into the limitations of each approach and suggest potential modeling improvements.

**Performance Evaluation:** The suitability of the vortex bladeless design will be assessed based on energy harvesting potential, structural durability, and vibration efficiency. Finally, design recommendations will be proposed to optimize mast configurations for future applications.

## MATERIALS AND METHODS

The material required for the vortex bladeless wind turbine is fiber glass (S-glass) (E-glass) As shown in the table [1].

**Table 1:** Properties of materials

Material	Density (kg/m <sup>3</sup> )	Young's (Elastic) modulus (pa)
S-glass	2500	$9 \times 10^{10}$
E-glass	2600	$7.3 \times 10^{10}$

The structural analysis was performed using the Finite Element Method (FEM). The Euler–Bernoulli beam theory was applied to each element for calculating stiffness and mass matrices. The geometric parameters of the turbine components are shown in Table 2. The mast length is kept constant at 2 m, while the rod length varies under three conditions. As shown in the table [2].

**Table 2:** Showing different dimensions of various vortex bladeless wind turbine

Parameters	Dimension for various conditions (mm)		
	1	2	3
(Mast) $D_{out}$	137.5	137.5	137.5
(Mast) $D_{in}$	131.5	131.5	131.5
(Rod) $d$	40	40	40
(Thickness)	3	3	3
(Rod) $L_1$	225	500	800
(Mast) $L_2$	2000	2000	2000
Total L	2225	2500	2800

### Mathematical Formulation

The bladeless vortex wind turbine consists of two main components: the rod and the mast. The cross-sectional area of each component is calculated according to its diameter, assuming a circular cylindrical shape. The bending moment is then evaluated, followed by the formulation of the stiffness and mass matrices for each individual component. Subsequently, the global stiffness and mass matrices of the turbine system are assembled, based on the analytical model, the natural frequency of the structure can be determined. Furthermore, by applying the aerodynamic loading on the mast, the lateral deflection of the turbine under various wind speeds can be calculated. Cross-sectional and bending properties:

$$A_1 = \frac{\pi}{4} D_1^2 \tag{1}$$

$$I_1 = \frac{\pi}{64} D_1^4 \tag{2}$$

$$A_2 = \frac{\pi}{4} (D_{out}^2 - D_{in}^2) \tag{3}$$

$$I_2 = \frac{\pi}{64} (D_{out}^4 - D_{in}^4) \tag{4}$$

### Element Stiffness Matrix

*Stiffness Matrix K*

$$= \frac{EI}{L^3} \begin{bmatrix} 12 & 6L & -12 & 6L \\ 6L & 4L^2 & 6L & 2L^2 \\ -12 & -6L & 12 & -6L \\ 6L & 2L^2 & -6L & 4L^2 \end{bmatrix} \tag{5}$$

The global stiffness matrix is obtained by :

$$[K]_{Global} = K_1 + K_2 \tag{6}$$

### Element Mass Matrix

*Mass Matrix M*

$$= \frac{\rho AL_2}{420} \begin{bmatrix} 156 & 22L_1 & 54 & -13L \\ 22L & 4L^2 & 13L & -3L^2 \\ 54 & 13L & 156 & -22L \\ -13L_2 & -3L^2 & -22L & -4L^2 \end{bmatrix} \tag{7}$$

Global mass matrix :

$$[M] \text{ Global} = M_1 + M_2 \quad (8)$$

Modal Analysis

$$|[K]-\lambda [M]|=0 \quad (9)$$

Natural Frequency

$$\text{Natural Frequencies} = \frac{\sqrt{\lambda}}{2\pi} \quad (10)$$

$$F \text{ vector} = \frac{qL_2}{2} \begin{bmatrix} 1 \\ \frac{L_2}{6} \\ 1 \\ -\frac{L_2}{6} \end{bmatrix} \quad (11)$$

Static Deflection Under Wind Load

Force vector:

$$w = K^{-1} \text{reduce } F \text{ vector} \quad (12)$$

Distributed load:

$$q = \frac{F}{L_2} \quad (13)$$

Wind force applied to mast

$$F = 0.5 C_L \rho U^3 D_{out} L_2 \quad (14)$$

$C_L$ : Coefficient of lift force (0.6)

$D_1$ : Diameter of rod (mm)

$D_2$ : Diameter of mast (mm)

$D_{out}$ : outer diameter of the mast (mm)

E: Elastic modal (GPa)

F: the force (N)

k: Stiffness matrix

$L_1$ : Length of rod (mm)

$L_2$ : Length of mast (mm)

M: Mass matrix

w: Deflection (mm)

$\rho$ : density of air ( $Kg/m^3$ )

$\sigma$ : Equivalent (von Mises) stress (MPa)

$\epsilon$ : Elastic strain (Dimensionless)

## RESULTS

The natural frequency and maximum deflection were evaluated for three distinct models of the bladeless wind turbine using both ANSYS numerical simulations and MATLAB analytical computations. For this analysis, the material was fixed as S-Glass, with a constant mast length of 2000 mm, while the rod length was varied across the models.

The loading conditions were set at a wind speed of 8.4046 m/s, corresponding to an applied force of 60 N. The results indicate a strong correlation between the two modeling approaches, confirming the reliability of the structural analysis. As detailed in Table [3], the third model—characterized by a rod length of 800 mm—achieved the lowest natural frequency and the maximum lateral deflection.

This behavior suggests that increasing the rod length reduces the overall structural stiffness, thereby lowering the natural frequency and allowing for a greater oscillation amplitude, which is a critical factor for optimizing energy harvesting in vortex-induced vibration (VIV) systems.

**Table 3:** Natural Frequencies and Max Deflection for three models [S-glass]

Material S-glass	Model (1) L-rod=225mm		Model (2) Lrod=500mm	Model (3) Lrod=800mm
Natural Frequencies	Ansys	2.6741	1.61189	1.1717
	Matlab	2.8173	1.7167	1.2272
Max Deflection (m)	Ansys	0.048071	0.126	0.24605
	Matlab	0.0452	0.1205	0.2320

Calculating the natural frequency and maximum deflection (At 8.4046m/s 60N) for three models of bladeless wind turbines using ANSYS and MATLAB and comparing the results using E-Glass material. We find that the E-glass material exhibits a greater deflection than the S-glass material as shown in the table [4].

**Table 4:** Natural Frequencies and Max Deflection for three models [E-glass]

Material E-glass	Model (1) Lrod=225mm		Model (2) Lrod=500mm	Model (3) Lrod=800mm
Natural Frequencies	Ansys	2.3605	1.4297	1.0347
	Matlab	2.4880	1.5160	1.0837
Max Deflection	Ansys	0.052266	0.15534	0.30334
	Matlab	0.0557	0.1485	0.2850

The structural response of the composite mast was evaluated under incremental loading conditions to determine its operational limits. Tables 5 through 10 summarize the numerical results obtained from the finite element analysis (FEA), specifically focusing on Total Deformation and Equivalent (von Mises) Stress. These parameters were recorded as the mast was subjected to applied forces of 74.9 N, 89.9 N, and 104.9 N, respectively.

This consolidated presentation facilitates a clear comparative analysis of the material performance across different force magnitudes. By examining the relationship between increased loading and the resulting stress distribution, the study identifies the mechanical behavior of E-glass and S-glass composites under varying wind-induced pressures.

**Table 5:** Natural Frequencies and Max Deflection by Matlab and Ansys

	Matlab	Ansys mesh-coarse	Ansys mesh-medium	Ansys mesh-fine
Natural Frequencies HZ	0.8177	0.7829	0.78126	0.68101
Deflection (m)	0.5070	0.5244	0.53645	0.62749

**Table 6:** Natural Frequencies and Max Deflection by Matlab and Ansys

	Matlab	Ansys mesh-coarse	Ansys mesh-medium	Ansys mesh-fine
Natural Frequencies HZ	0.6450	0.61173	0.61675	0.52429
Deflection (m)	0.8194	0.8572	0.85398	1.041

**Table 7:** Natural Frequencies and Max Deflection by Matlab and Ansys

	Matlab	Ansys mesh-coarse	Ansys mesh-medium	Ansys mesh-fine
Natural Frequencies HZ	0.5254	0.4906	0.4911	0.45275
Deflection (m)	1.2390	1.3068	1.3121	1.44

**Table 8:** Natural Frequencies and Max Deflection by Matlab and Ansys

	Matlab	Ansys mesh-coarse	Ansys mesh-medium	Ansys mesh-fine
Natural Frequencies HZ	0.9259	0.88651	0.88465	0.77113
Deflection (m)	0.4112	0.42619	0.43513	0.50896

**Table 9:** Natural Frequencies and Max Deflection by Matlab and Ansys

	Matlab	Ansys mesh-coarse	Ansys mesh-medium	Ansys mesh-fine
Natural Frequencies HZ	0.7303	0.69269	0.69837	0.59367
Deflection (m)	0.6646	0.69578	0.69268	0.84436

**Table 10:** Natural Frequencies and Max Deflection by Matlab and Ansys

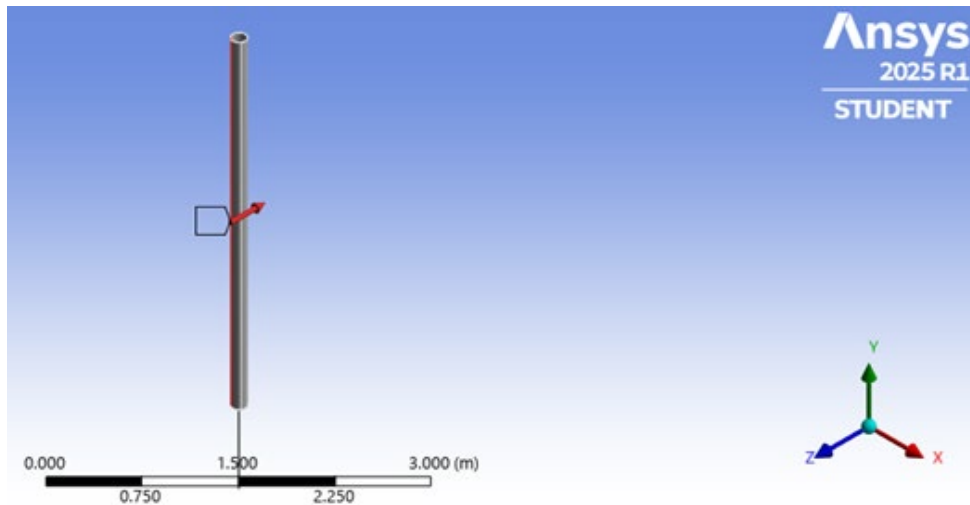
	Matlab	Ansys mesh-coarse	Ansys mesh-medium	Ansys mesh-fine
Natural Frequencies HZ	0.5950	0.55553	0.55231	0.51267
Deflection (m)	1.0049	1.0599	1.0329	1.168

From the previous tables, we find that the maximum deflection occurs when the mast height is 3500 mm. As the height increases, the deflection also increases. Moreover, by comparing the results of ANSYS with those of MATLAB, it is observed that the ANSYS Mesh-Coarse results are closer to the MATLAB results.

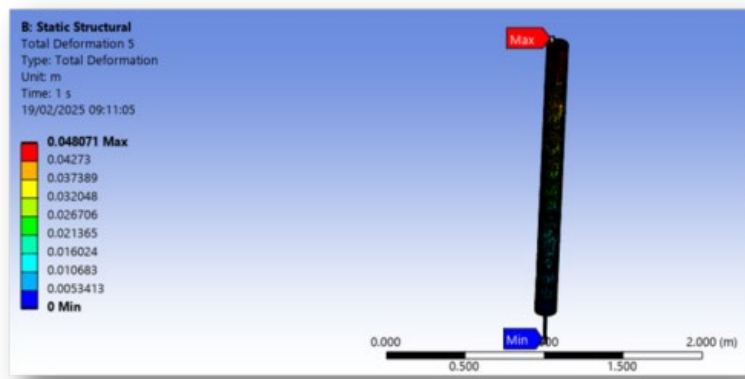
The force acting on the mast length is directly proportional to the wind speed; as the wind speed increases, the mast deflection also increases due to the applied force. The following table presents the maximum deflection at different wind speeds ranging from 2.8 m/s to 11 m/s, along with a comparison of deflection results between MATLAB and ANSYS as shown in the table [11].

**Table 11:** Max deflection by Ansys and Matlab for different air speeds

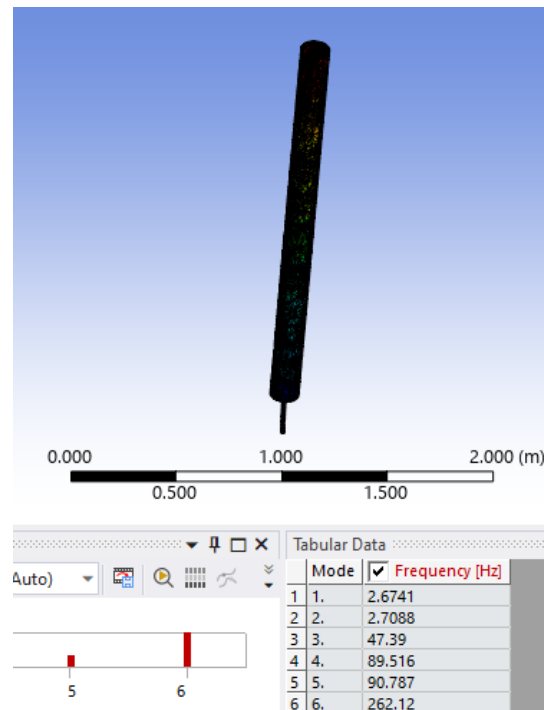
Air speeds m/s	The force (N)	Mesh Coarse	Deflection Mesh fine	Deflection Matlab
2.8 (10 km/h)	3.8824 N	0.039192	0.43189	<b>0.0372</b>
4.2 (15 km/h)	13.1032 N	0.13228	0.14576	<b>0.1254</b>
5.6 (20 km/h)	31.0593 N	0.31354	0.34551	<b>0.2973</b>
7.5 (27 km/h)	74.6125 N	0.75321	0.83	<b>0.7141</b>
9.2 (33 km/h)	137.7183 N	1.39003	1.532	<b>1.3181</b>
11 (40 km/h)	235.3998 N	2.3763	2.6186	<b>2.2530</b>



**Figure 1:** Applied the force on the mast by Ansys program



**Figure 2:** Max deflection



**Figure 3:** Natural Frequency

## CONCLUSION

This study developed a three-dimensional model of bladeless wind turbines and compared the analytical and numerical results obtained from ANSYS and MATLAB. The results demonstrated a strong convergence between the analytical and numerical values of natural frequency and turbine deflection when varying the mesh in ANSYS, confirming the accuracy and reliability of the model for design purposes. These findings provide a solid foundation for more detailed analyses in future research. The study also highlights the need for further investigations into fluid dynamics and the variables affecting turbine efficiency and performance in different locations. Despite certain limitations such as focusing on static forces rather than dynamic forces, assuming a constant cylindrical mast diameter instead of a more realistic variable conical shape, and neglecting damping—these simplifications were necessary to streamline the mathematical and numerical model. Overall, the study and its results represent a significant step toward practical, efficient, and sustainable solutions in energy systems.

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