DESIGN AND DEVELOPMENT OF STAND STILL OMNIDIRECTIONAL WIND TURBINE

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Introduction:

Urban wind energy is characterized by low wind speeds (2–4 m/s), turbulence, and multidirectional flow, making conventional Horizontal Axis Wind Turbines (HAWTs) inefficient. Vertical Axis Wind Turbines (VAWTs) are better suited but suffer from poor self-starting due to low torque at low velocities.

This work proposes a stand-still omnidirectional enclosure that:

- Captures wind from all directions.
- Accelerates flow using a converging-diverging (Venturi) profile.
- Creates a pressure gradient for suction.

This increases the effective wind velocity at the turbine location, improving performance.

Objectives:

1. To design an omnidirectional wind capture enclosure for urban wind conditions.
2. To accelerate airflow using Venturi effect and pressure gradient.
3. To develop a design suitable for rooftop applications.

Methodology:

The system uses **Venturi effect and Bernoulli's principle** to passively accelerate airflow.

- Air enters from all directions into a cylindrical enclosure
- Flow passes through a converging section → throat → diverging section
- Velocity increases as area decreases (continuity principle)
- Pressure drops at the throat, creating a suction effect
- Increased velocity improves turbine starting and energy extraction

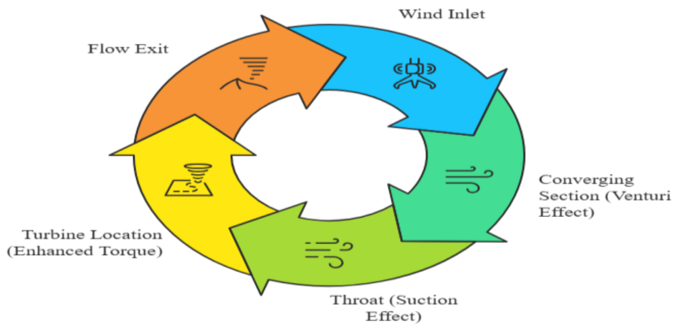


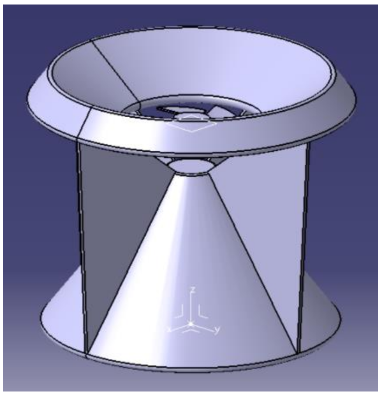
Figure 1: Wind flow cycle in the Model, from Inlet to Outlet

3D Model Generation (CATIA V5):

- Geometry: Cylindrical enclosure with internal converging-diverging passage
- Dimensions:
    - Height = 800 mm
    - Radius = 500 mm

Design Features:

- Smooth curvature to reduce flow separation
- Symmetrical geometry for omnidirectional performance
- Throat positioned at turbine location for maximum energy transfer



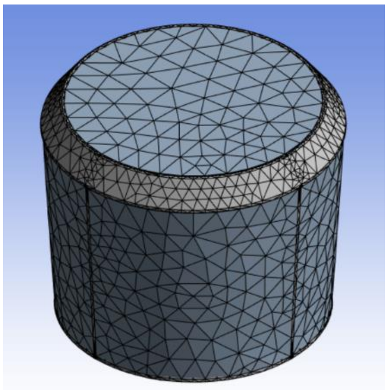


Figure 2: 3D Isometric view of the Model and Figure 3: Unstructured tetrahedral mesh of the Model

Computational Fluid Dynamics (CFD) Analysis:

Mesh

- Unstructured tetrahedral mesh
- Refinement at the Throat region (high velocity gradients) and Wall regions (boundary layer effects)
- Coarser mesh in outer regions for efficiency

Boundary Conditions

- Inlet: Velocity = 3 m/s
- Outlet: Pressure = 0 Pa
- Walls: No-slip condition

Solver Setup

- Pressure-based, steady-state solver
- Turbulence model: Realizable k–ε
- SIMPLE algorithm for pressure-velocity coupling
- Second-order upwind schemes for accuracy

Convergence

- Residuals: 10^{-4}
- 1000 iterations
- Monitoring throat velocity stabilization

Mathematical Model

The design is governed by the Continuity Equation (1) and Bernoulli's Equation (2).

$$A_1V_1 = A_2V_2 \quad (1)$$

$$P_1 + \frac{1}{2}\rho {V_1}^2 = P_2 + \frac{1}{2}\rho {V_2}^2 \quad (2)$$

The performance is quantified by the Velocity Amplification Factor (AF), defined as the ratio of the wind speed at the throat to the free-stream wind speed. Since power available in the wind is $P_w = \frac{1}{2}\rho A V^3$ even a modest AF results in substantial power gains.

Result and Conclusion:

Pressure Distribution:

- Inlet: High pressure (stagnation region)
- Throat: Low pressure zone

  Pressure difference: $\Delta P = P_{inlet} - P_{throat}$

Effects:

- Induces suction
- Increases mass flow rate
- Prevents flow separation

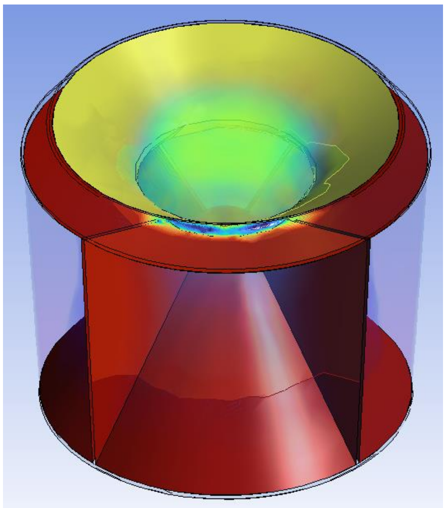
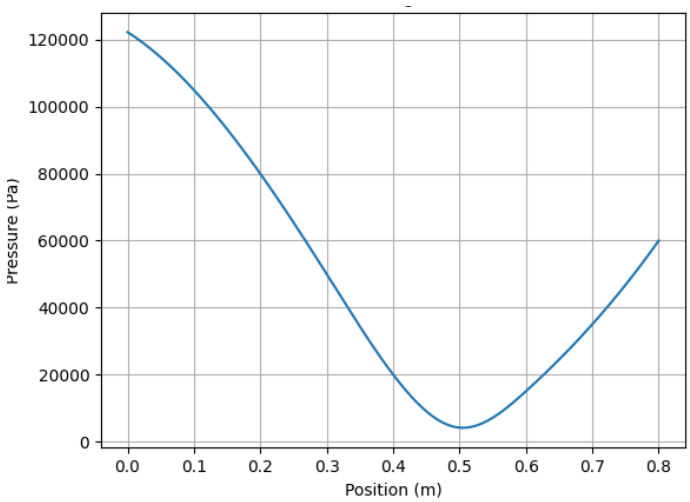



Figure 6 & 7: Pressure Contour of the Encloser and Pa variation along the central axis of the enclosure

Velocity Distribution and Flow Acceleration:

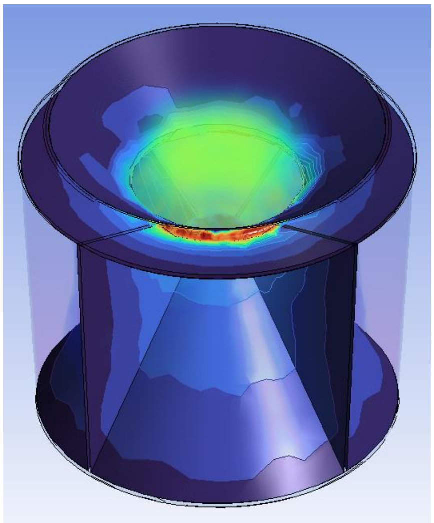
- Inlet velocity ≈ **3 m/s**
- Throat velocity ≈ **10–25 m/s**

  From continuity:

$$V_{throat} \gg V_{inlet}$$

Flow behavior:

- Smooth convergence
- Minimal recirculation
- Directed toward turbine



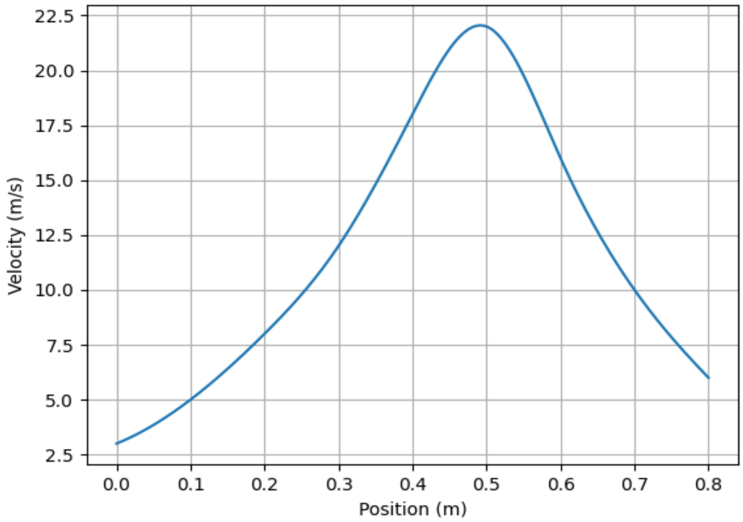


Figure 8 & 9: Velocity Contour of the Encloser and Velocity along the centerline showing amplification.

Velocity Amplification:

Using effective values => Amplification Factor = $\frac{Vthroat}{Vinlet} = \frac{15 \text{ to } 20}{3} = 5 \text{ to } 6.5$

This indicates that the enclosure significantly enhances wind energy availability.

Observations:

Table 1: Observations from Velocity and Pressure Contours

Region	Velocity(m/s)	Pressure (Pa)	From Contours
Wind Inlet	3 m/s	1.223e+05 Pa	Low-speed entry
Converging	Increasing	Decreasing	Acceleration
Throat Region	10 - 25 m/s	4.131e+03 Pa	Peak velocity
Flow Exit	Reduced	Recovering	Flow diffusion

Conclusion:

The enclosure effectively:

- Captures wind omnidirectionally
- Accelerates airflow using Venturi effect
- Creates a strong pressure gradient
- Amplifies velocity from ~3 m/s to 10–20 m/s

This significantly improves:

- Self-starting capability
- Energy extraction efficiency

Hence, the system is highly suitable for urban rooftop applications

Project Outcome & Industry Relevance:

The project results in a compact, enclosed wind energy system tailored for urban use.

Key advantages:

- Operates in low wind conditions
- Safer than open-blade turbines
- Suitable for residential and commercial rooftops
- Reduces dependency on grid power

The system has potential applications in:

- Smart cities
- Green buildings
- Decentralized energy systems
- Renewable energy startups

The unique enclosure design also presents potential for intellectual property development.

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Future Scope:

The current work can be extended in several directions:

1. Optimization of nozzle shape and vane angles.
2. Reduction of localized velocity peaks for better efficiency.
3. Experimental validation using wind tunnel testing.
4. Integration with IoT for performance monitoring.
5. Hybrid systems combining solar and wind.
6. Scaling for commercial rooftop deployment.
7. Noise and vibration reduction.