Wind power

energy of any particle is equal to one ha
square of its velocity, or $\frac{1}{2}mV^2$. The amount
ime, through an area A, with velocity V, is $A.V$, a
to its volume multiplied by its density ρ of air, o

$$m = \rho AV \qquad ...($$

of air transversing the area A swept by the ro
mill type generator).

ing this value of the mass in the expression fo
we obtain, kinetic energy $= \frac{1}{2}\rho AV.V^2$ watts

$$= \frac{1}{2}\rho AV^3 \text{ watts} \qquad ...($$

eter D in *horizontal axis* aeroturbines, then $A = \frac{\pi}{4} D^2$, (sq. m

when put in equation (6.2.2) gives,

$$\text{Available wind power } P_a = \frac{1}{2} \rho \frac{\pi}{4} D^2 V^3 \text{ watts}$$

$$= \frac{1}{8} \rho \pi D^2 V^3 \qquad \ldots(6.$$

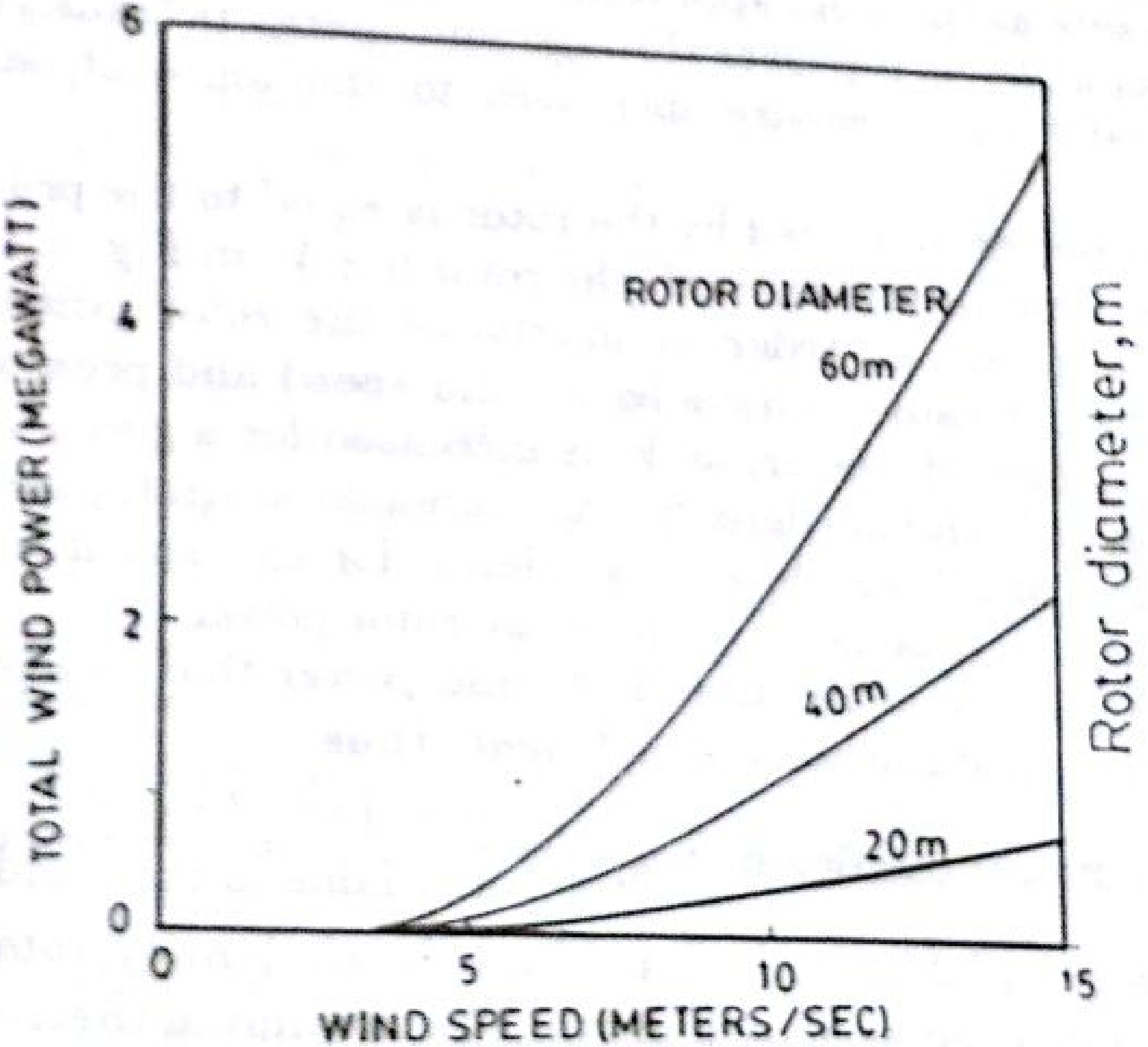

Fig. 6.2.1. Dependence of wind-rotor power on wind speed and rotor diameter.

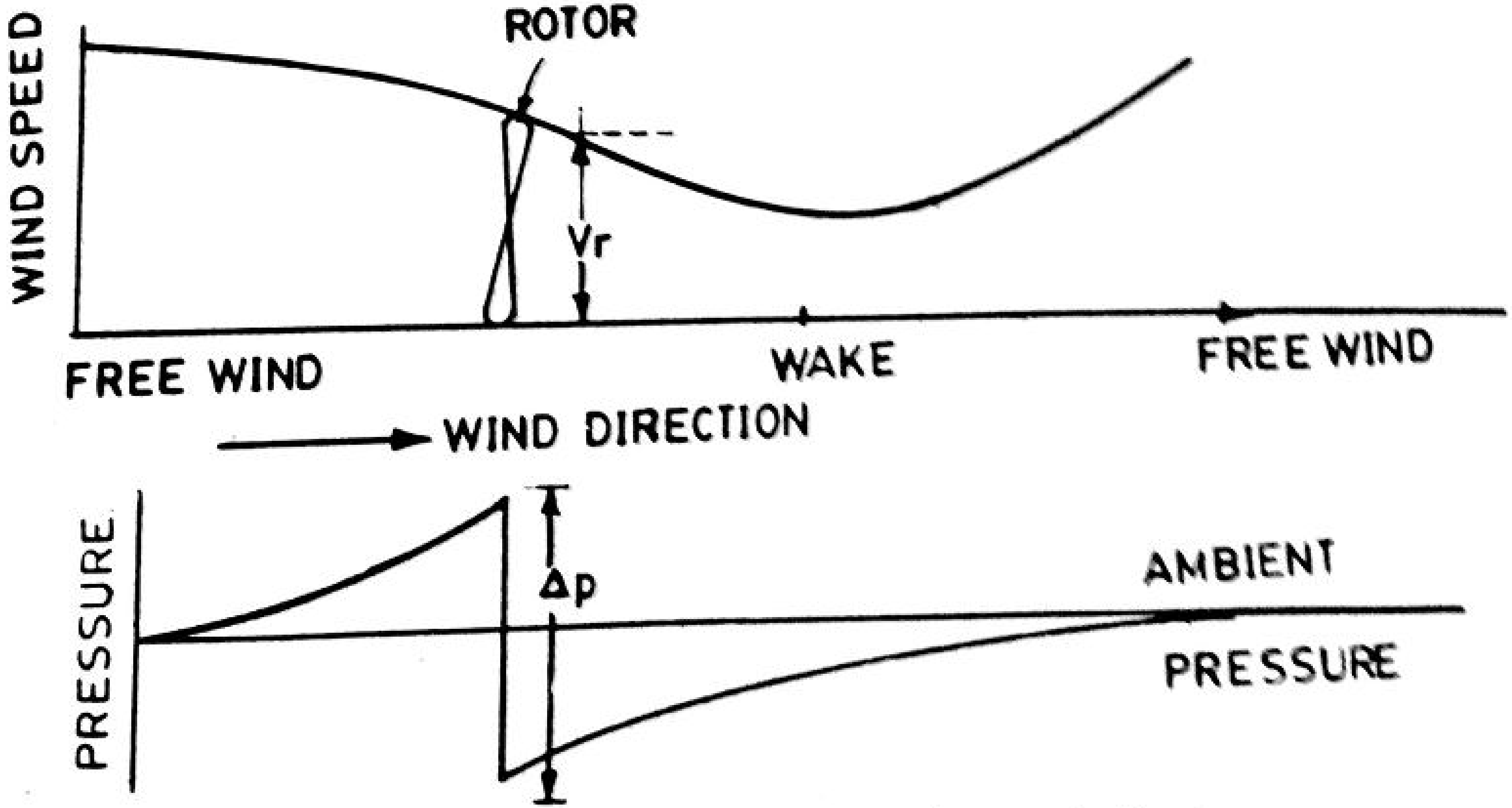

Fig. 6.2.2. Conditions in traversing a wind rotor.

The fraction of the free-flow

rotor is called the *power-coefficient*; thus

$$\text{Power coefficient} = \frac{\text{Power of wind rotor}}{\text{Power available in the wind}}$$

is calculated from the air density, rotor dia

Maximum power

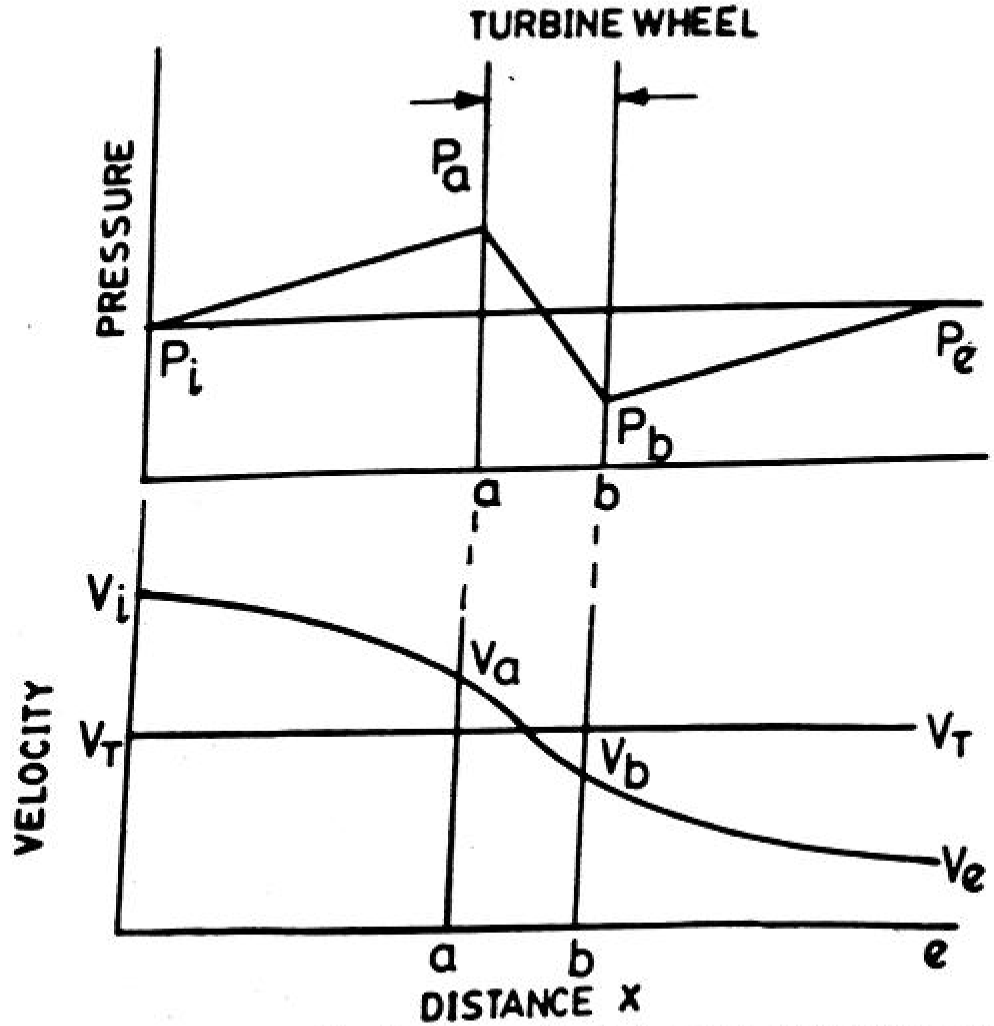

Fig. 6.2.3. Pressure and velocity profiles of wind moving through a horizontal-axis propeller-type wind turbine.

$-W_{sf}$ = net steady flow mechanical work

$$P_i + \rho \frac{V_i^2}{2g_c} = P_a + \rho \frac{V_a^2}{2g_c}$$

Similarly for the exit region *be*,

$$P_e + \rho \frac{V_e^2}{2g_c} = P_b + \rho \frac{V_b^2}{2g_c}$$

$$P_a - P_b = \left(P_i + \rho \frac{V_i^2 - V_a^2}{2g_c} \right) - \left(P_e + \rho \frac{V_e^2 - V_b^2}{2g_c} \right) \quad \text{...(6.2.9)}$$

It can be assumed that wind pressure at e can be assumed to ambient, *i.e.*,

$$P_e = P_i \quad \text{...(6.2.10)}$$

As the blade width $a . b$ is very thin as compared to total distance considered, it can be assumed that velocity within the turbine does not change much.

$$V_a \simeq V_t \simeq V_b \quad \text{...(6.2.11)}$$

Combining equation (6.2.9) to (6.2.11) yields,

$$P_a - P_b = \rho \left(\frac{V_i^2 - V_e^2}{2g_c} \right) \quad \text{...(6.2.12)}$$

The axial force F_x, in the direction of wind stream, on a turbine wheel with projected area, perpendicular to the stream A, is given by

$$F_x = (P_a - P_b)A = \rho A \left(\frac{V_i^2 - V_e^2}{2g_c} \right) \quad \text{...(6.2.13)}$$

This force is also equal to change in momentum of the wind (from Newton's second law).

$$F_x = \Delta(\dot{m}V)/g_c$$

where $\dot{m}$ = mass flow rate = ρAV_t

Thus $$F_x = \frac{1}{g_c} \rho AV_t(V_i - V_e) \quad \text{...(6.2}$$

Equating equations (6.2.13) and (6.2.14),

$$\rho A \frac{(V_i^2 - V_e^2)}{2g_c} = \frac{1}{g_c} \rho AV_t(V_i - V_e)$$

$$V_t = \frac{1}{2}(V_i + V_e)$$

from T_i to T_e, and flow energy change is there from $P_i v$ to $P_e v$. In the system no heat is added or rejected *i.e.* adiabatic flow. The general energy equation how reduces to the steady flow work W and kinetic energy terms,

$$\dot{W} = kE_i - kE_e = \frac{V_i^2 - V_e^2}{2g_c} \quad ...(6.2.16)$$

The power P is defined as the rate of work, from mass flow rate equation

$$P = m\frac{V_i^2 - V_e^2}{2g_c} = \frac{1}{2g_c}\rho A V_t (V_i^2 - V_e^2) \quad ...(6.2.17)$$

Combining this with equation (6.2.15),

$$P = \frac{1}{4g_c}\rho A(V_i + V_e)(V_i^2 - V_e^2) \quad ...(6.2.18$$

Equation (6.2.17) reverts to equation (6.2.2) for P_{total} when V_t =

...ing P, and equating the derivative to zero *i.e.* ... obtained by

$$\frac{dp}{dV_e} = 0$$

r

$$\frac{dp}{dV_e} = 3V_e^2 + 2V_iV_e - V_i^2 = 0$$

This is solved for a positive V_e to give V_e opt. (The quadric has two solutions, *i.e.* $V_e = V_i$ and $V_e = \frac{1}{3}V_i$, only second solution is physically acceptable).

Thus $$V_e \text{ opt} = \frac{1}{3}V_i \quad \text{...(6.2.19)}$$

Using the equation (6.2.18), for an ideal wind machine, with horizontal axis,

$$P_{max} = \frac{8}{27g_c}\rho A V_i^3 \quad \text{...(6.2.20 a)}$$

$$= \frac{16}{27g_e}\frac{1}{2}\rho A V_i^{\ 3} = 0.593\left(\frac{1}{2}\cdot\frac{\rho V A_i^{\ 3}}{g_c}\right)$$

$$= 0.595\, P_{total} \qquad \text{...(6.2.20 } b\text{)}$$

6.2.3. Forces on the Blades and Thrust on Turbines

As stated earlier, here blades of propeller-type wind turbine is considered. There are two types of forces which are acting on the blades. One is *circumferential force* acting in the direction of wheel rotation that provides the torque and other is the *axial force* acting in the direction of the wind stream that provides an *axial thrust* that must be counteracted by proper mechanical design.

The *Circumferential force, or torque T* can be obtained from

$$T = \frac{P}{\omega} = \frac{P}{\pi D N} \qquad \text{...(6.2.21)}$$

where T = torque *kgf* or *Newton (N)*

ω = angular velocity of turbine wheel, m/s

D = diameter of turbine wheel

$$= \sqrt{\frac{4}{\pi}} . A, \ m$$

N = wheel revolutions per unit time, s^{-1}

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$\therefore$ The real efficiency $\eta = \frac{P}{P_{total}}$

or $$P = \eta \,.\, P_{total} = \eta \cdot \frac{1}{2g_c} \rho A V_i^{\,3}$$

For a turbine operating at power P, the expression for torque becomes

$$T = \eta \frac{1 \,.\, \rho}{2g_c} \frac{A V_i^{\,3}}{\pi D N}$$

$$= \eta \frac{1}{2g_c} \frac{\rho \, . \, \pi}{4} \frac{D^2 V_i^{\,3}}{\pi DN} = \eta \frac{1}{8g_c} \frac{\rho D V_i^{\,3}}{N}$$

$$= \eta \frac{1}{8g_c} \frac{\rho D V_i^{\,3}}{N} \quad \text{...(6.2.22)}$$

At maximum efficiency $\left(\eta_{max} = \frac{16}{27} \right)$, the torque has maximum value T_{max} which is equal to

$$T_{max} = \frac{2}{27g_e} \frac{\rho D V_i^{\,3}}{N} \quad \text{...(6.2.23)}$$

The axial force or thrust by equation (6.2.13)

$$F_x = \frac{1}{2g_c}\rho A(V_i^2 - V_e^2)$$

$$= \frac{\pi}{8g_c}\rho D^2(V_i^2 - V_e^2)$$

The axial force

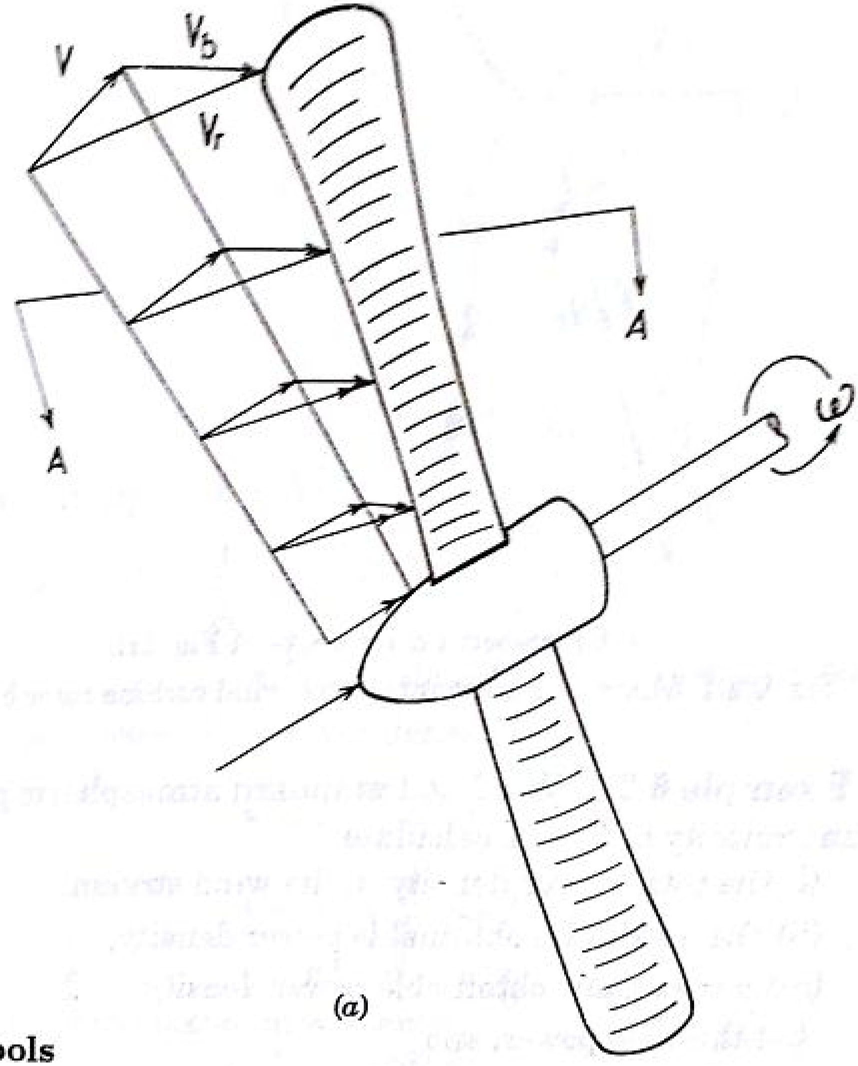
The axial force on a turbine wheel operating at maximum efficiency where $V_c = \frac{1}{3} V_i$ is given by

$$F_{x,\, max} = \frac{4}{9g_c} \rho A V_i^2 = \frac{\pi}{9g_c} \rho A V_i^{\,2}$$

$$= \frac{\pi}{9g_c} \rho D^2 V_i^{\,2} \qquad \text{...(6.2.25)}$$

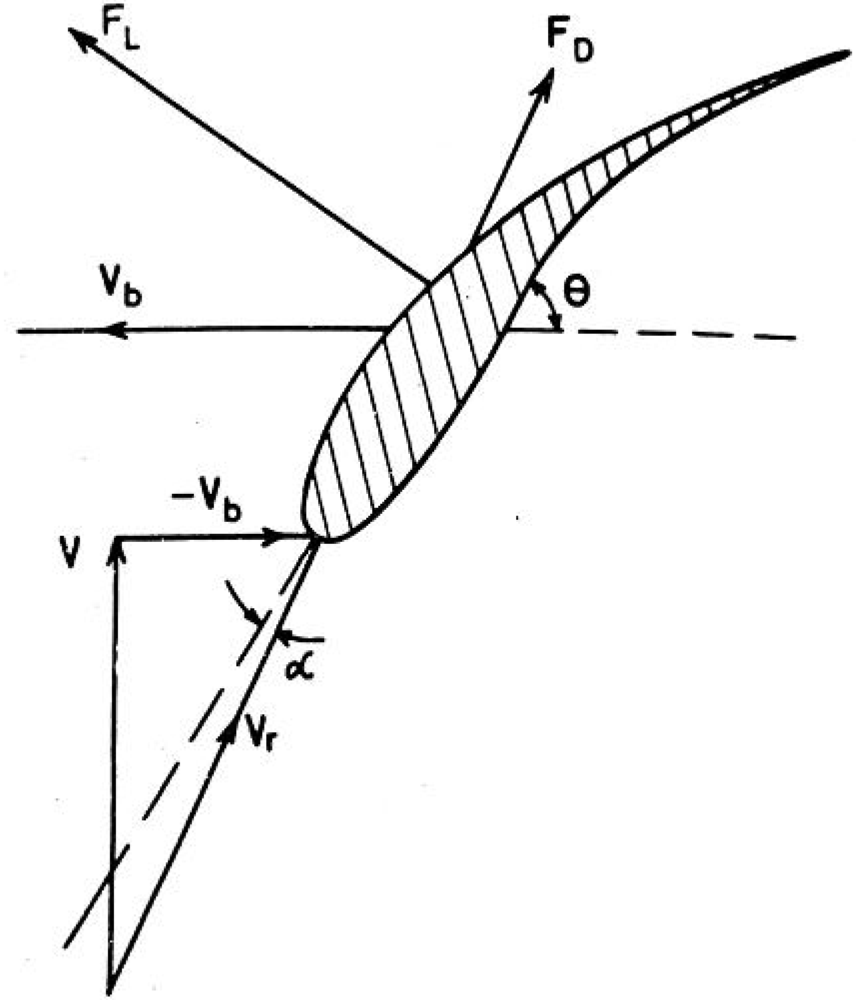
We see that axial forces are proportional to the square of the diameter of the turbine wheel, this limits turbine wheel diameter of large size.

ues probably have little practical potential



(a)

Symbols



(*b*) Cross-section across *A*—*A* Fig. (*a*)

Symbols

V	Free wind velocity
V_b	velocity of airfoil element $(\lvert V_b \rvert = \omega_r)$
V_r	resultant wind as 'seen' by airfoil element
F_L	lift force (perpendicular to V_r)
F_D	drag force
θ	angle of twist
α	angle of incidence
ω	angular speed of rotor
r	distance of airfoil element from its axis of rotation.

The windmill blade 'sees' the resultant vector V_r. The blades
…ortion to radius.

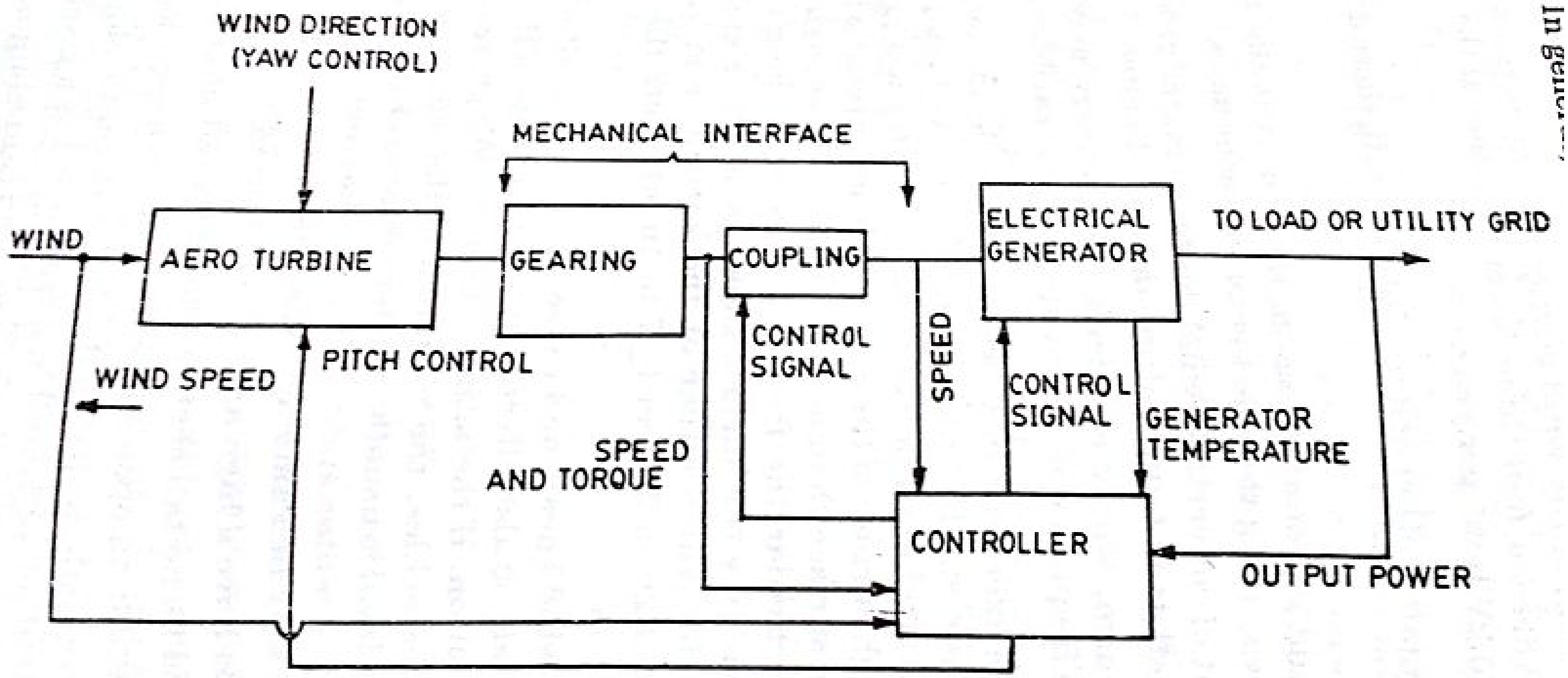
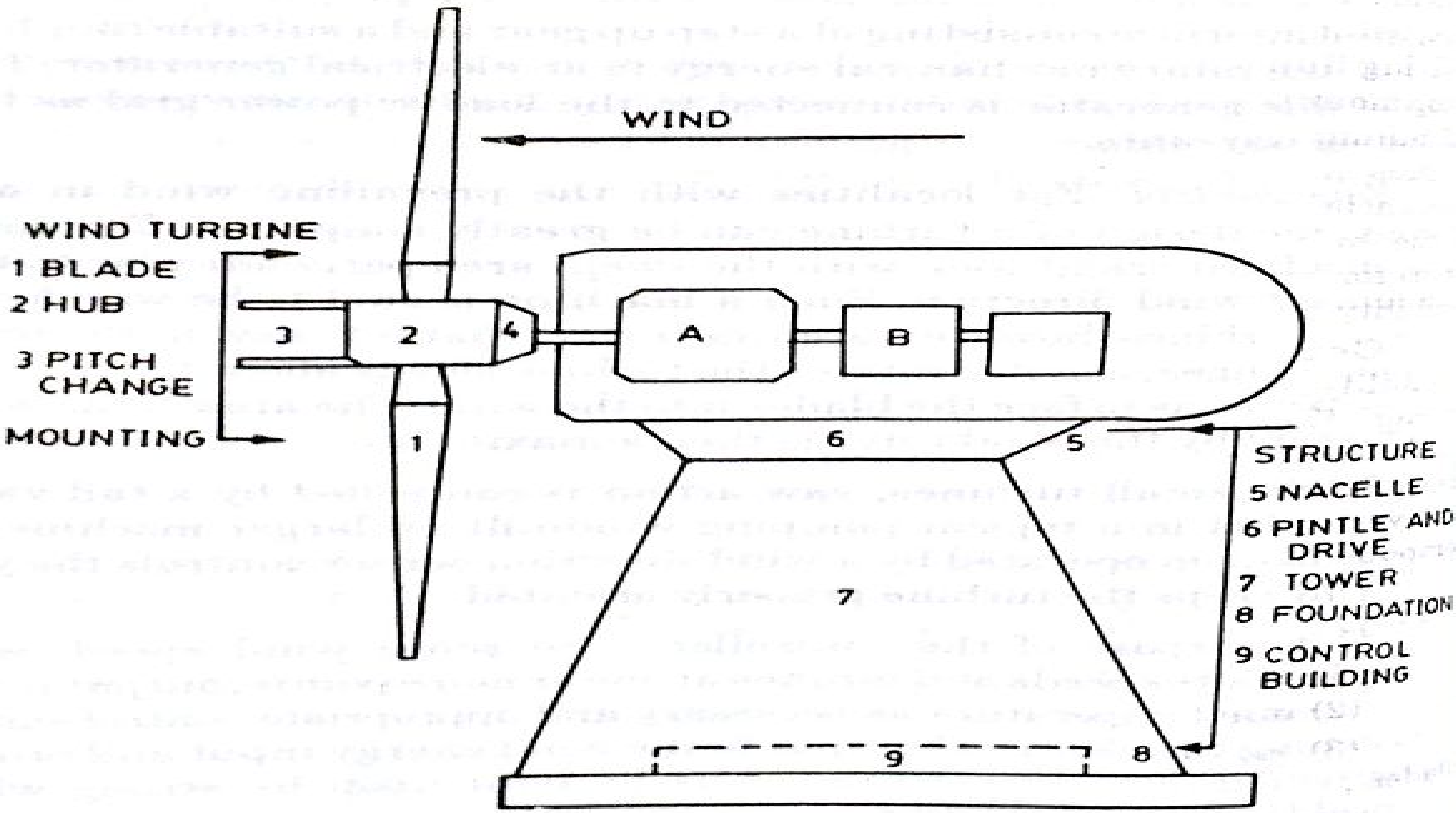


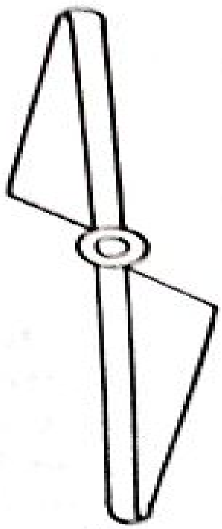
Fig. 6.5.1. Basic components of a Wind Electric System.



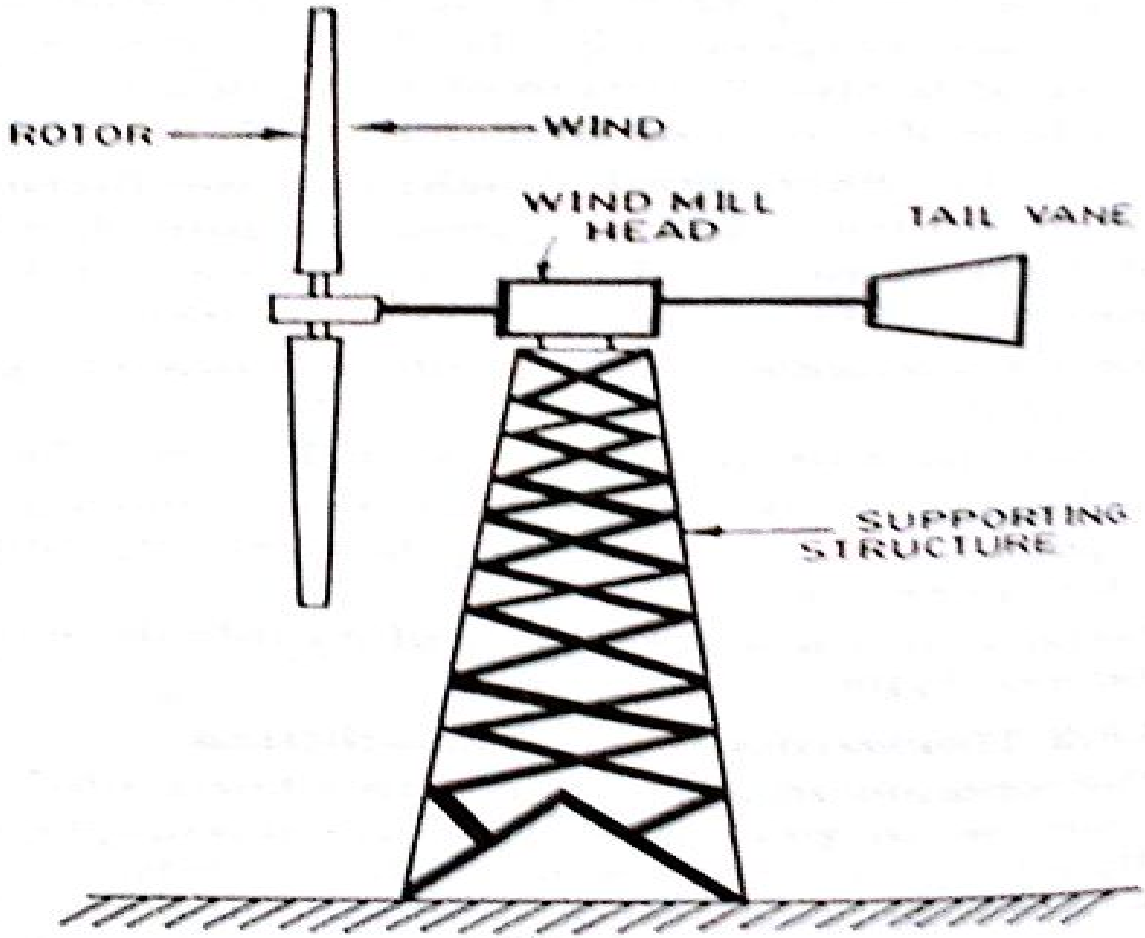
A—*Transmission*
Speed Increaser
Driver Shaft add Bearing Brake
Clutch and Coulping.

B—*Electrical*
Generator
Control and indicators (at ground level)

Fig. 6.6.2. Physical embodiment of wind-electric generating station.



(a)
TWO BLADE PRUFILE



(b)
SCHEMATIC OF A HORIZANTAL AXIS TYPE WIND MILLS

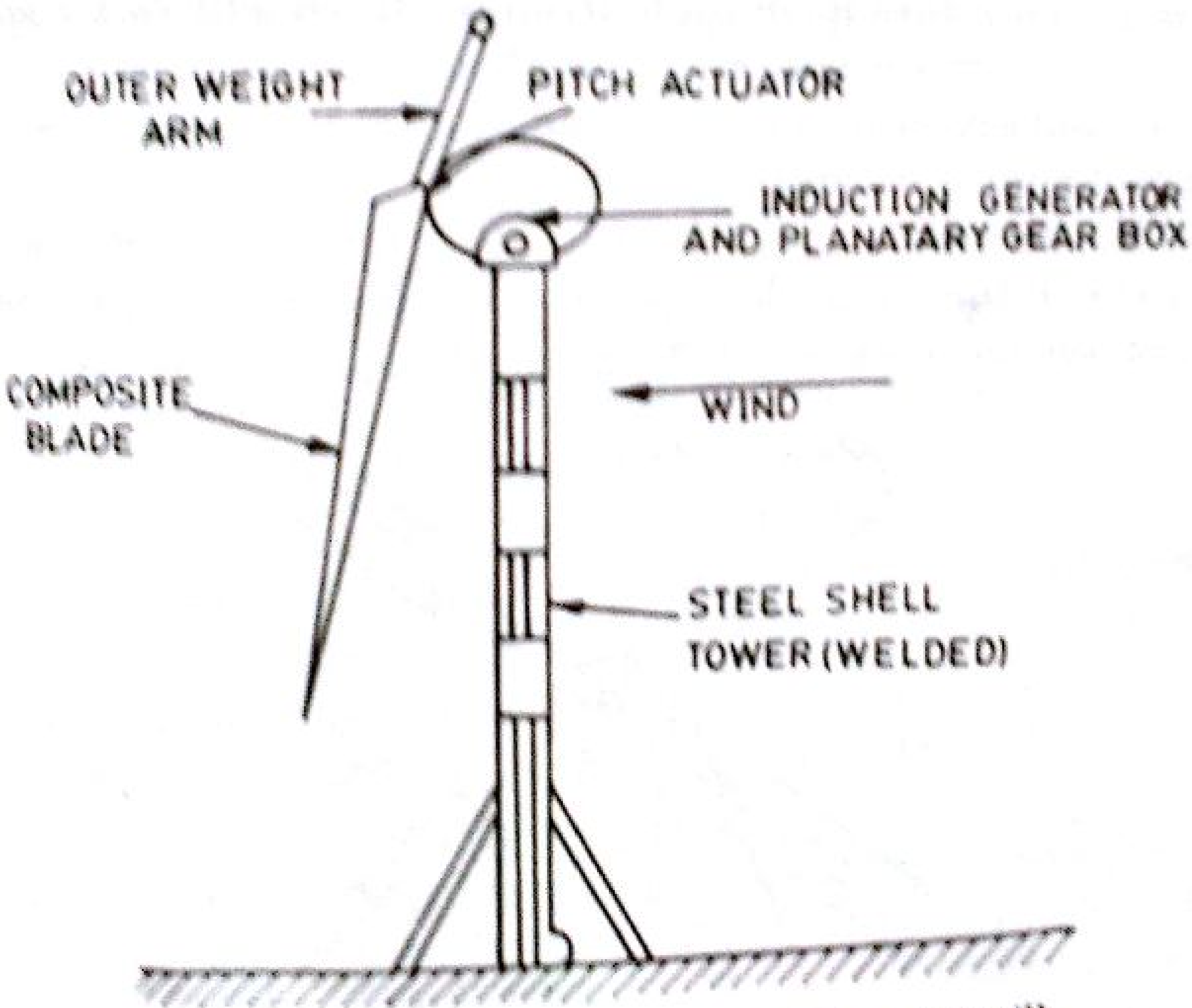


Fig. 6.8.2. Horizontal axis single blade wind mill.

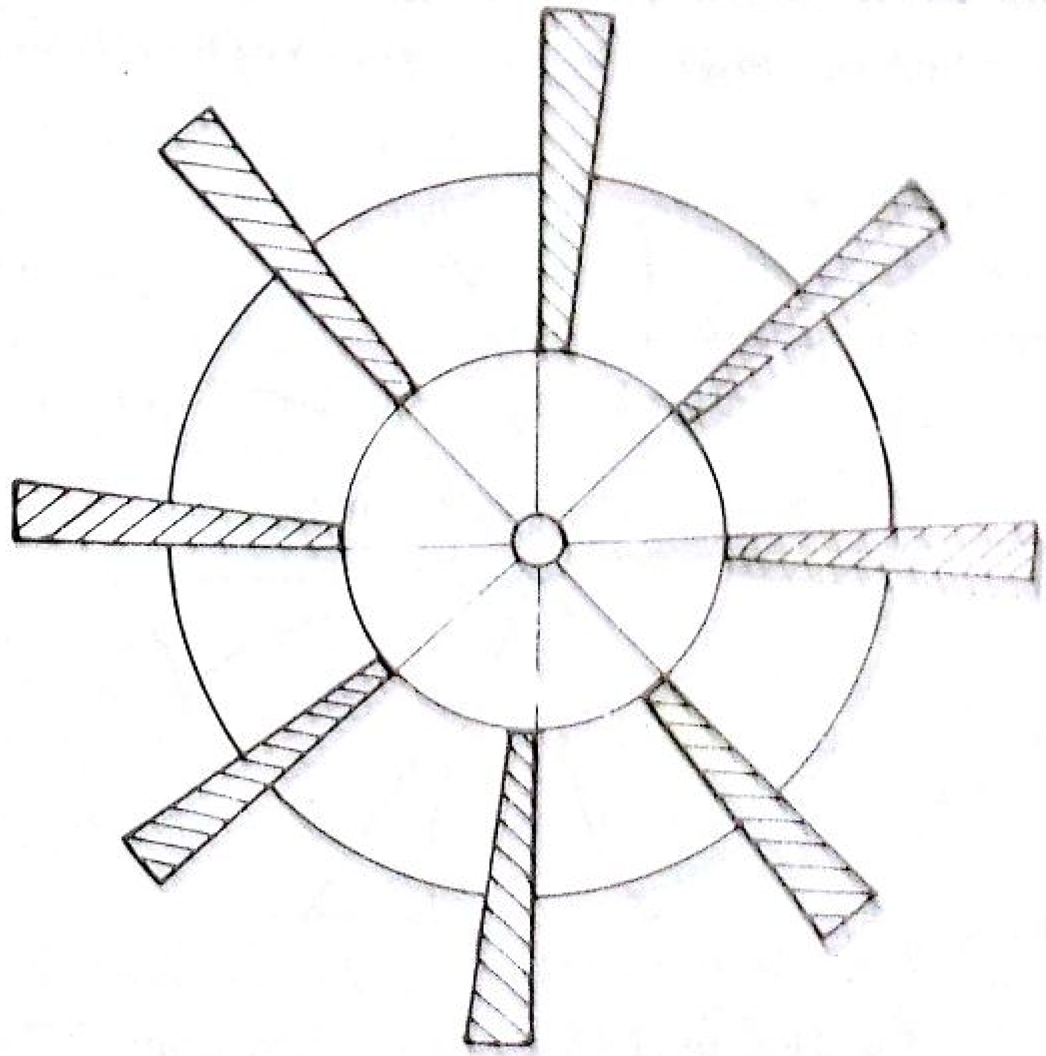


Fig. 6.8.3. Multiblade propeller.

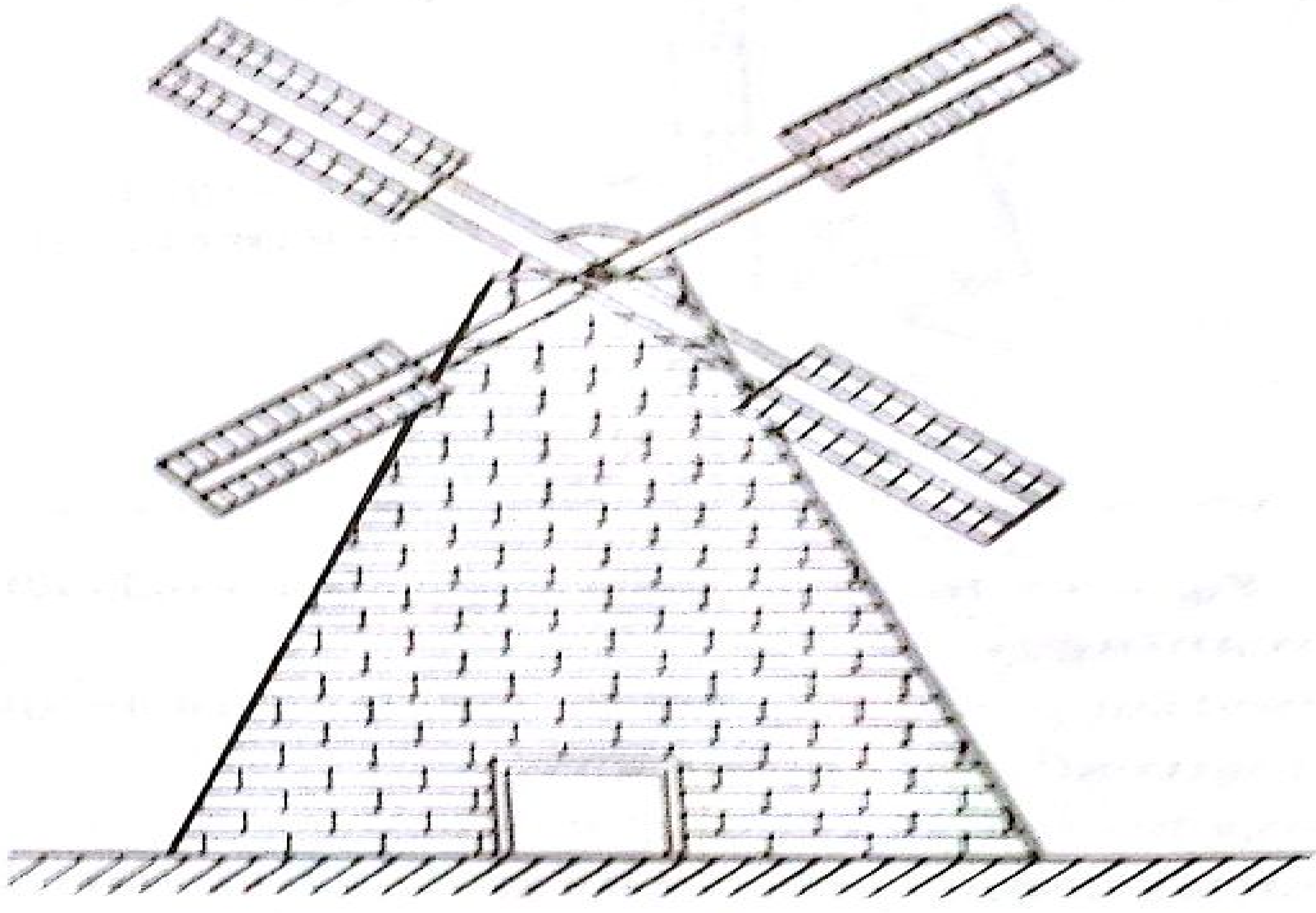


Fig. 6.8.4. Horizontal axis, Dutch type wind mill.

and pole of sailwings. There is also variation in the
d.

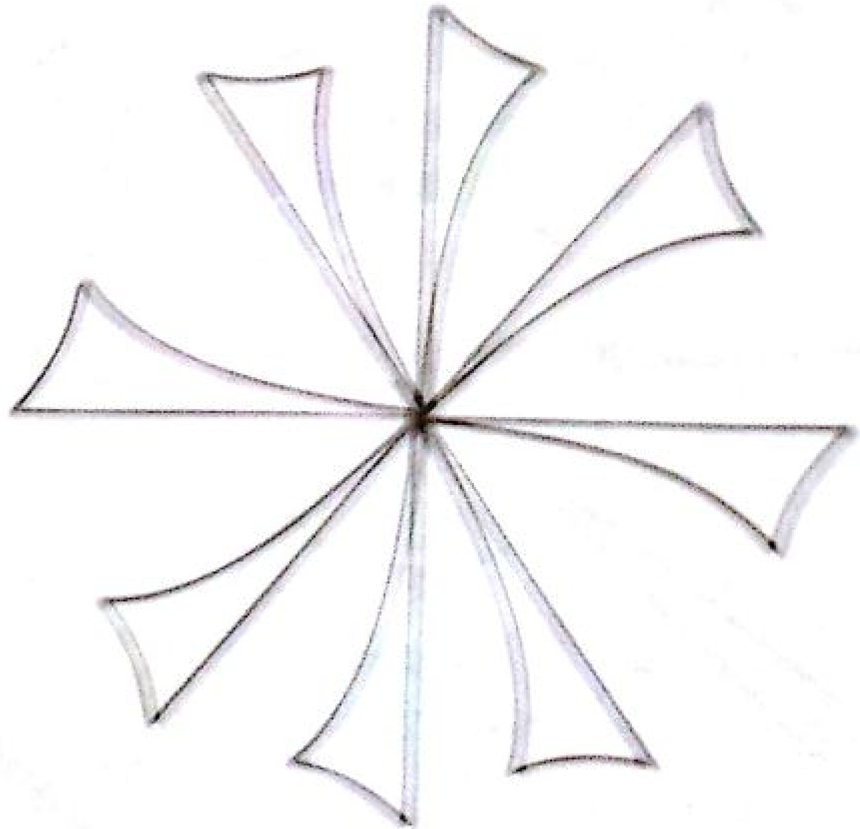


Fig. 6.8.6. Blades of sail type wind mill.

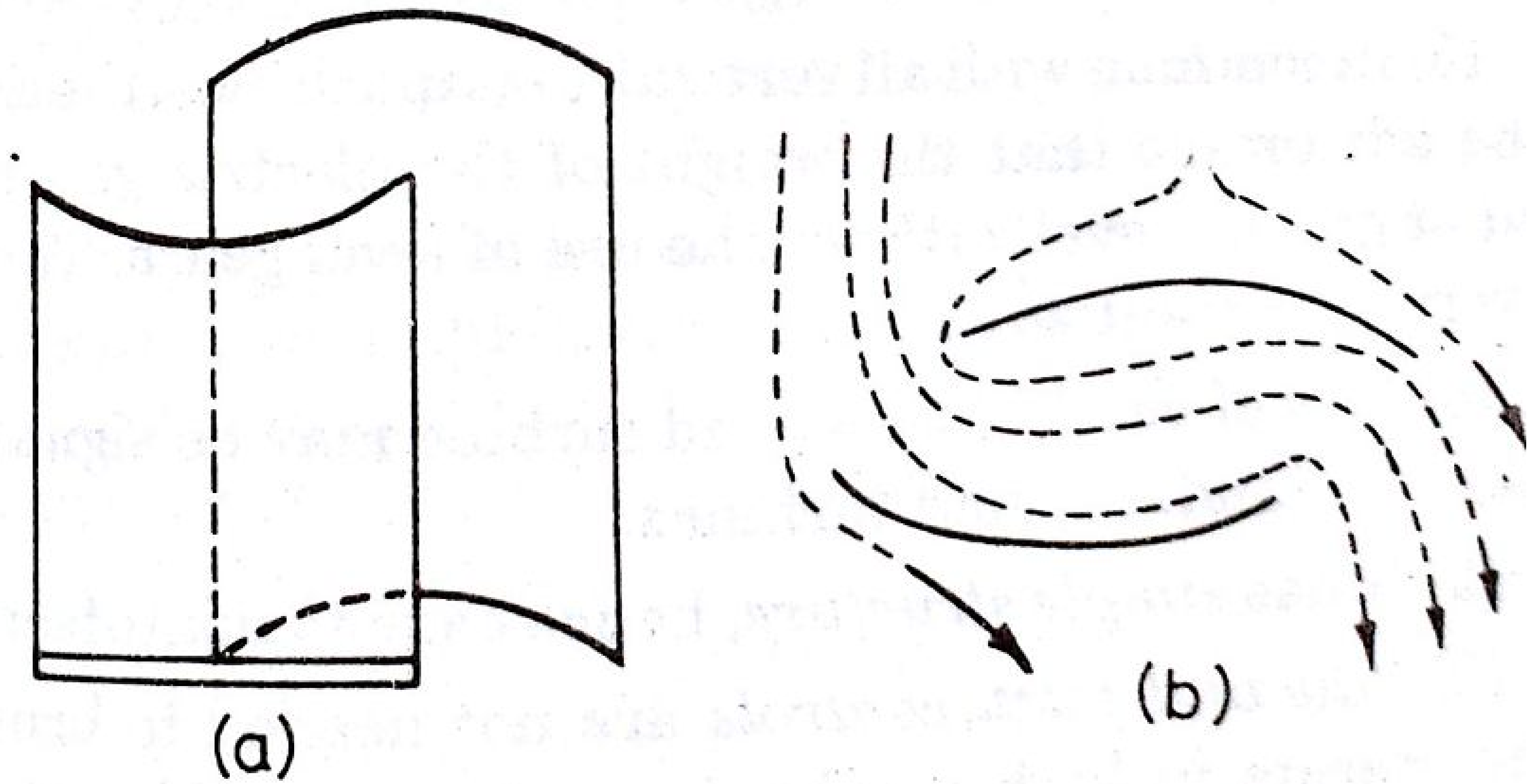


Fig. 6.8.8. The Savonius rotor and its stream flow.

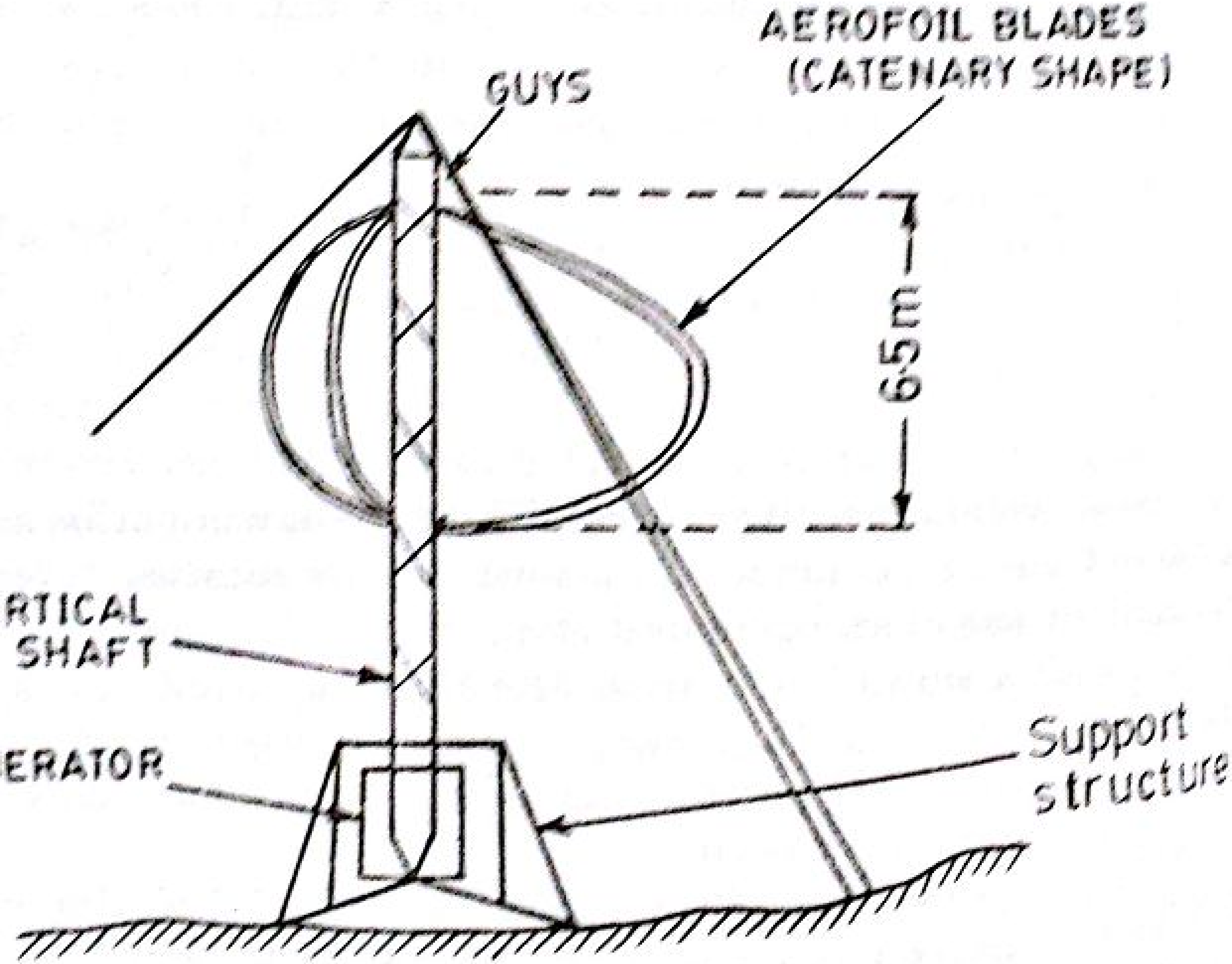


Fig. 6.8.9. Vertical axis wind mill.