Chapter 5.

Design of Blade

The design of blade of windmill depends on the operating condition of the windmill. In one condition we can design the optimum windmill to operate on that condition, but when the condition of operation changed, the optimum operation of the windmill also changes.

Consider element of blade at radius r from axis of rotation as shown in Fig.5.1, by using the momentum theory[9,10,11]

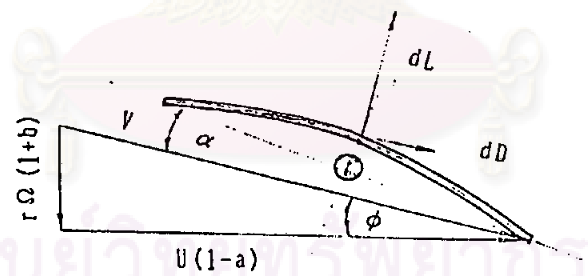

Fig.5.1 velocity vectors at blade element

Thrust(T) and torque(Q) that act on blade element are

$$dT = 4\pi \rho U^2 (1-a)\, a\, r dr \tag{5.1}$$

$$dQ = 4\pi \rho U \Omega b (1-a)\, r^3\, dr \tag{5.2}$$

and by consideration of the forces that act on this blade element, B blades.

$$dT = B \cdot 1/2\, \rho V^2 c\, (C l \sin\phi + C d \cos\phi)\, dr \tag{5.3}$$

$$dQ = B \cdot 1/2\ \rho V^2 c\ (Cl\cos\phi - Cd\sin\phi)\ rdr \tag{5.4}$$

where

$$V = U\ [(1-a)^2 + x^2(1+b)^2]^{1/2} \tag{5.5}$$

$$\phi = \tan^{-1}[x(1+b)/(1-a)] \tag{5.6}$$

$$x = r\Omega/U \tag{5.7}$$

Solving of Eqs.(5.1) to Eq.(5.4) by using the relation of Eqs.(5.5), (5.6) and (5.7).

$$a = \sigma(Cl\tan\phi + Cd)/[4\cos\phi + \sigma(Cl\tan\phi + Cd)] \tag{5.8}$$

$$b = \sigma(Cl - Cd\tan\phi)/[x[4\cos\phi + \sigma(Cl\tan\phi + Cd)]] \tag{5.9}$$

Substituting values of a, b into Eq.(5.7) yields

$$[\sigma(xCl - Cd) - 4\cos\phi]\tan\phi + 4x\cos\phi + \sigma(xCd + Cl) = 0 \tag{5.10}$$

where

$$\sigma = Bc/2\pi r$$

Generally, in design of the windmill these values can be given, σ., CL(α), CD(α).

So that we can solve for the value of ϕ then the twist angle of blade can be found from

$$\alpha_D = \alpha + \phi \tag{5.11}$$

Performance of the windmill at design condition can be calculated from

$$C_p = \frac{\text{Power from windmill}}{\text{Power from wind}} \tag{5.12}$$

The power generated by the windmill is given by

$$P = \int_{r_R}^{R} \Omega \, dQ \tag{5.13}$$

Substituting for dQ

$$P = 4 \pi \rho \Omega^2 U \int_{r_R}^{R} (1 - a) \, b \, r^3 dr \tag{5.14}$$

Power from air

$$E = \frac{1}{2} \rho U^3 (\pi R^2) \tag{5.15}$$

So that

$$C_p = P / E = \frac{8}{\lambda^2} \int_{x_R}^{\lambda} (1 - a) \, b \, x^3 dx \tag{5.16}$$

For calculation of windmill performance other than the design condition CL, CD and ϕ in Eq.(5.10) will be known as function of α instead of ϕ, and in similar manner, the value of a, b and Cp can be determined.

Figure 5.2 shows flow chart for calculation of windmill performance.

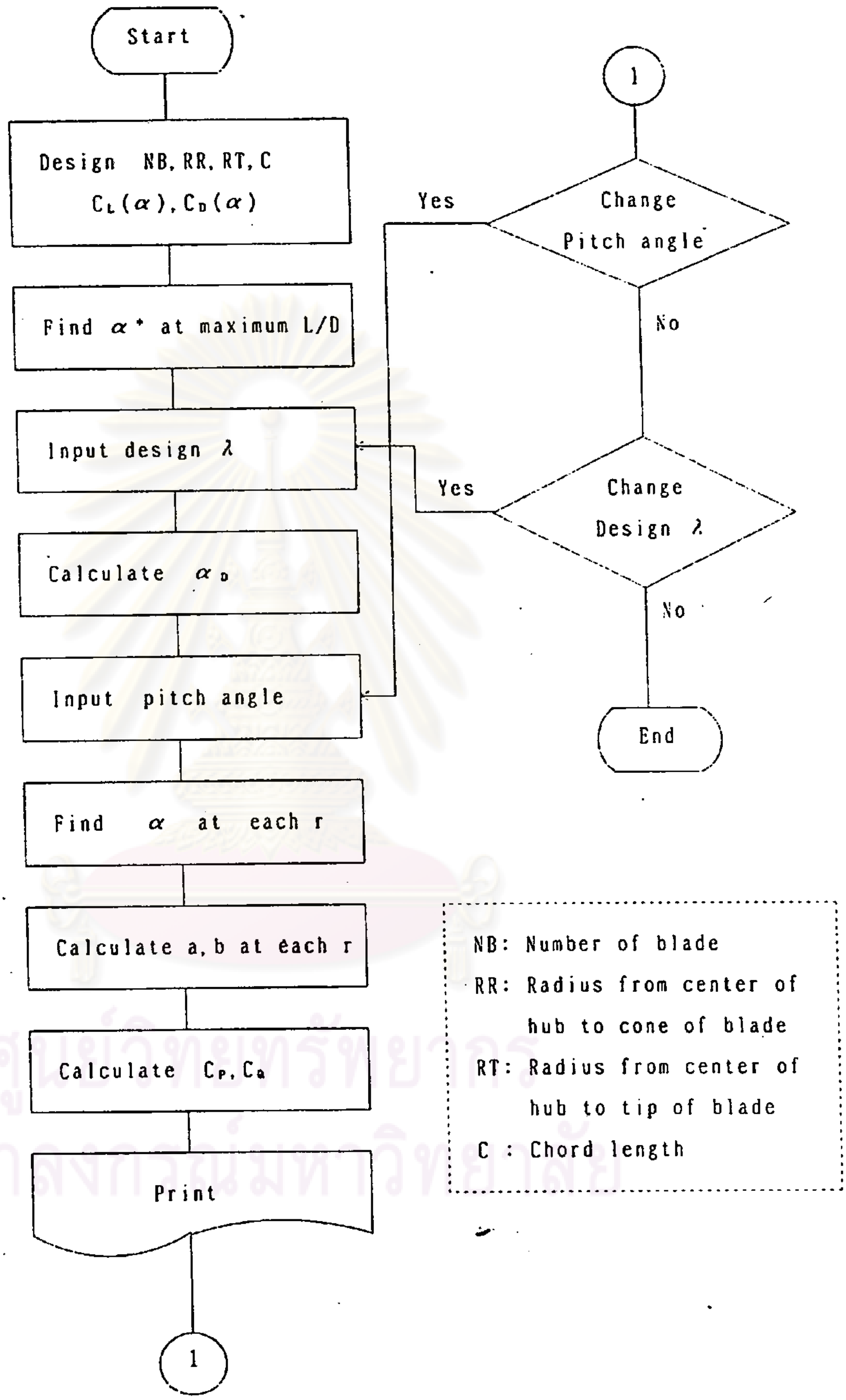

Fig. 5.2 Flowchart for calculation of C_P, C_Q

5.1 Design Conditions

Since the informations of the aerodynamic characteristics of airfoils at low Reynolds number were insufficient, the experiment to find the aerodynamic characteristics of airfoil was done in a low speed wind tunnel. From this experiment one type of airfoils was selected for windmill blades.

Number of blade was considered from the influence of blade on Cp which is large at low tip speed ratios therefore high number of blades was preferred.

Design conditions of the model are :

Arched blade type

Number of blade = 8

Diameter = 1.25 m

Attack angle = 4 degrees

(at maximum CL/Cd ratio)

Lift/Drag ratio = 25

Tip speed ratio = 2

Wind velocity = 2 m/s

Chord length at cone = 90 mm

Chord length at tip = 60 mm

Figures 5.3 and 5.4 show the design twist angle of blades and blade figure from the given design conditions.

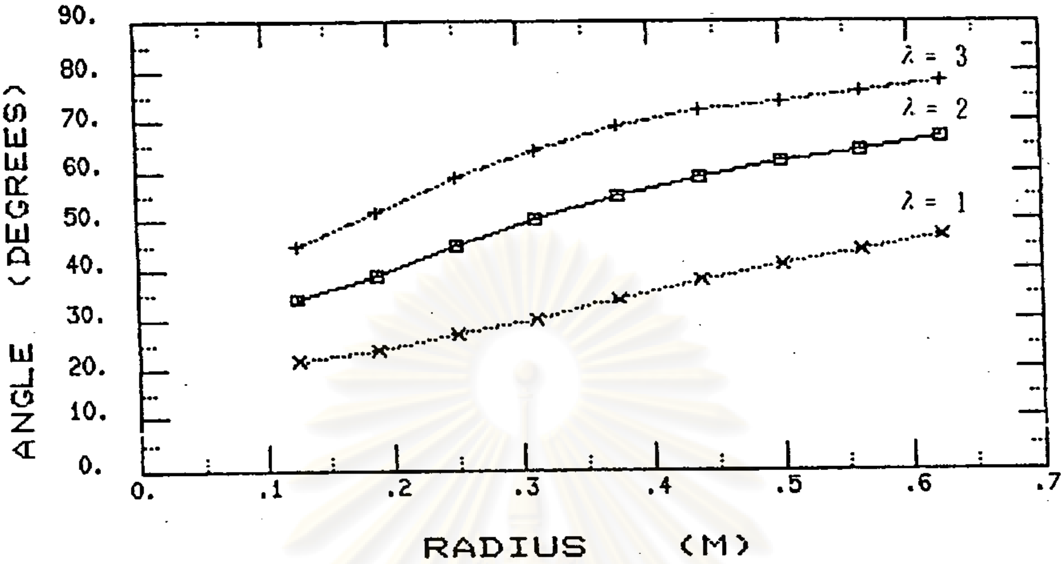

Fig.5.3 Twist angle of blade

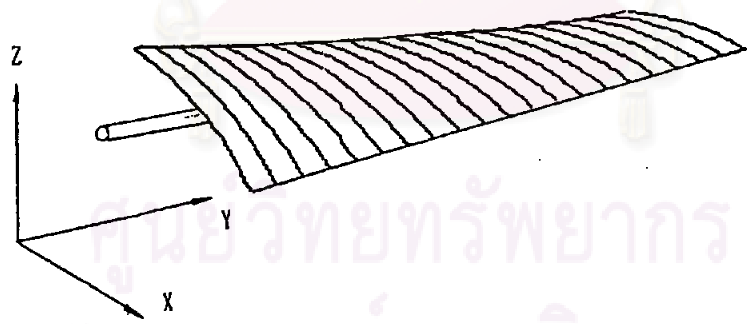

Fig.5.4 Blade figure

5.2 Model Constructions

Blades of thewindmill model were made of 6 mm in diameter of steel rod, 1 mm thick of aluminum plate. The twist angle of blades was fixed by curved pieces set at the design angle with the rod as shown in Fig.5.5. The shaft of the windmill was connected with a torque meter by coupling as shown in Fig.5.6. Figures 5.7 to 5.10 show the windmill model, components, dimensions of the windmill model and blades.

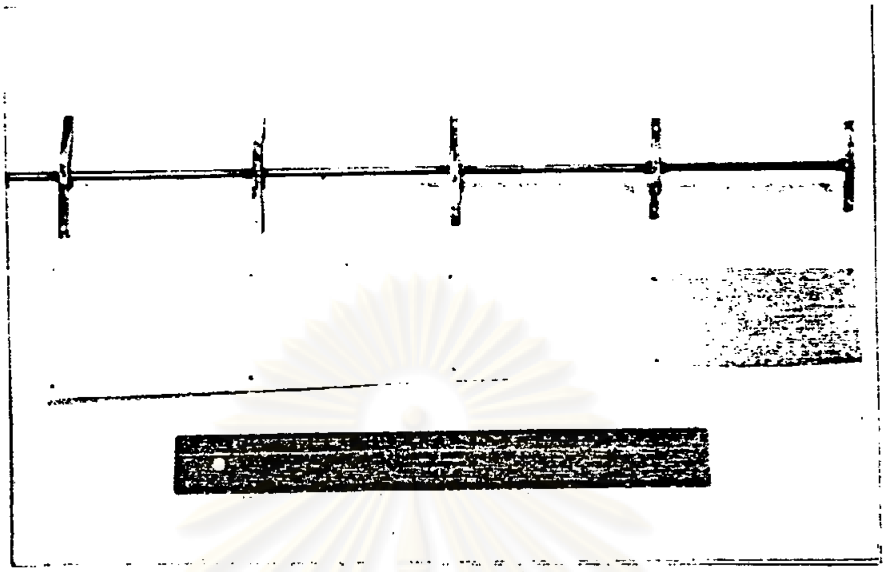

Fig. 5.5 Structure of blade

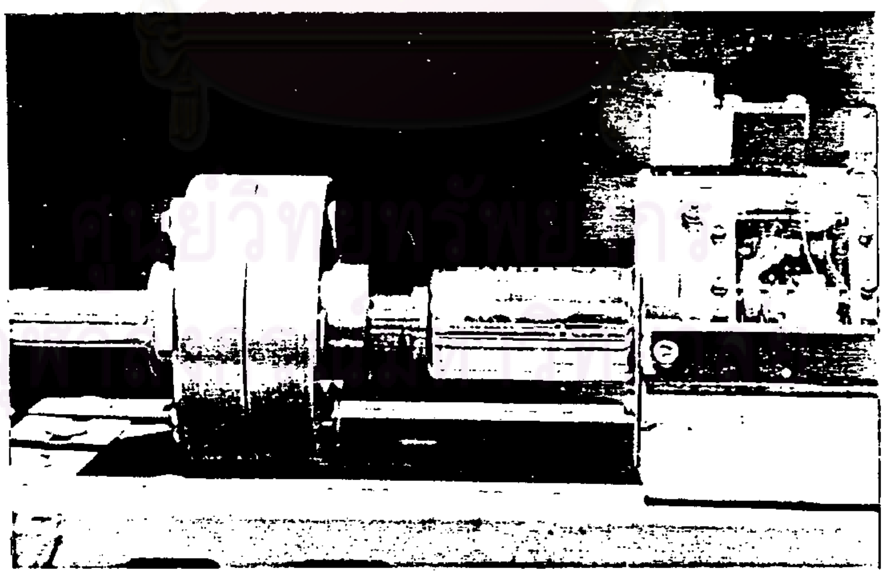

Fig. 5.6 Connection between windmill & torque meter

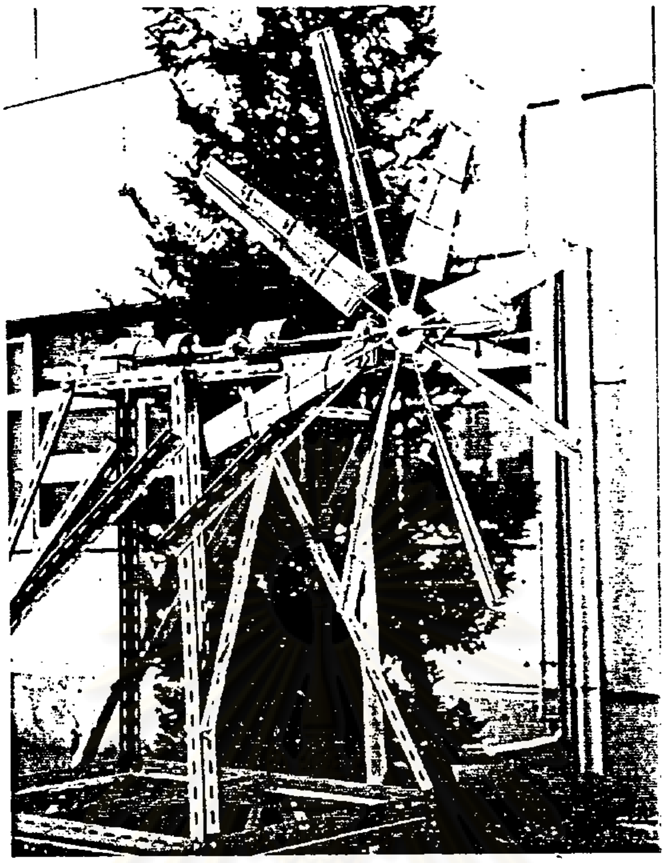

Fig. 5.7 Windmill model

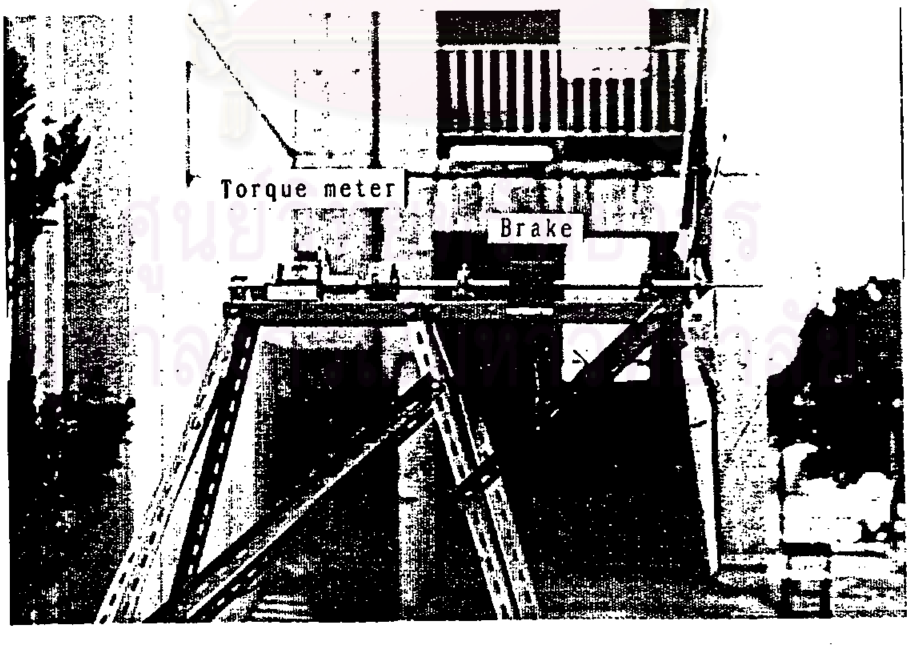

Fig.5.8 Components of model

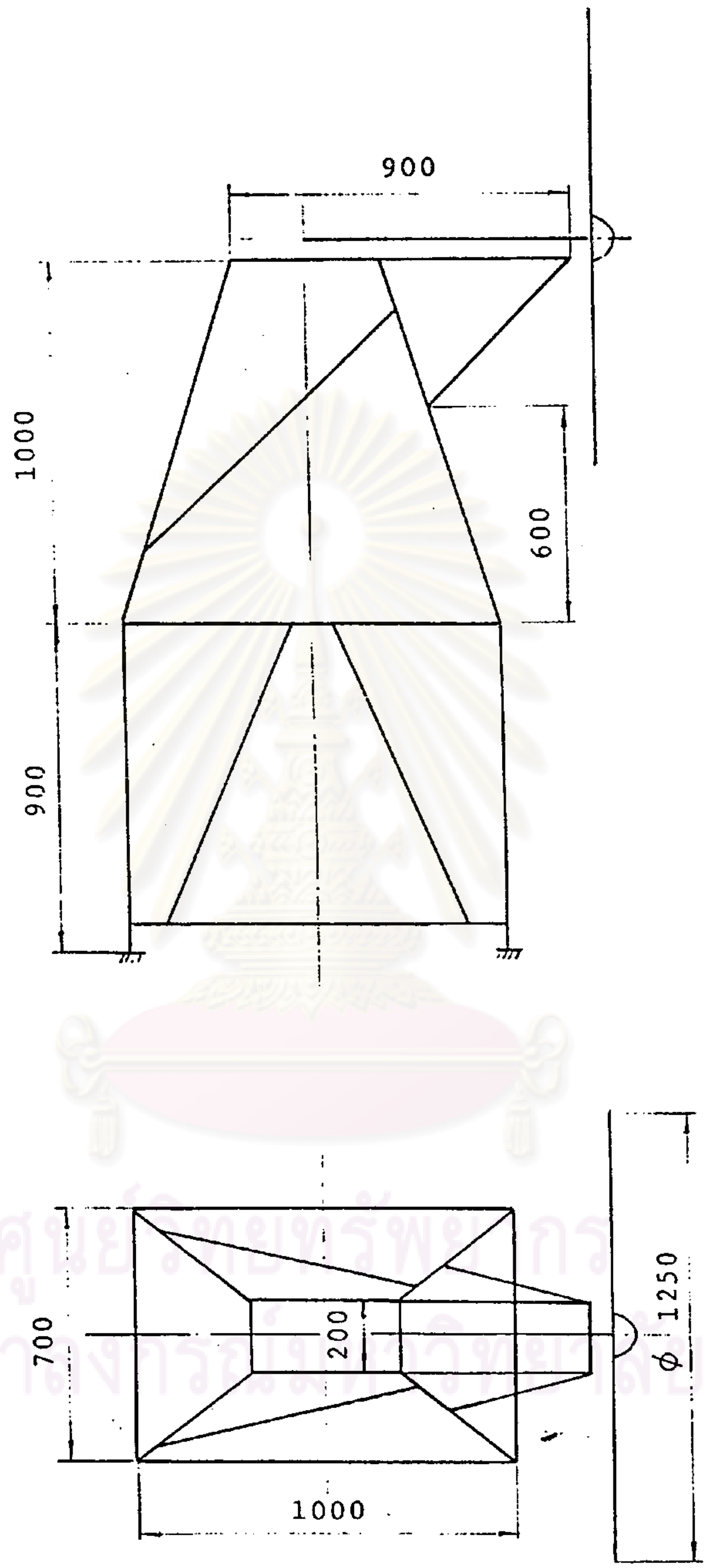

Fig.5.9 Dimensions of model with tower

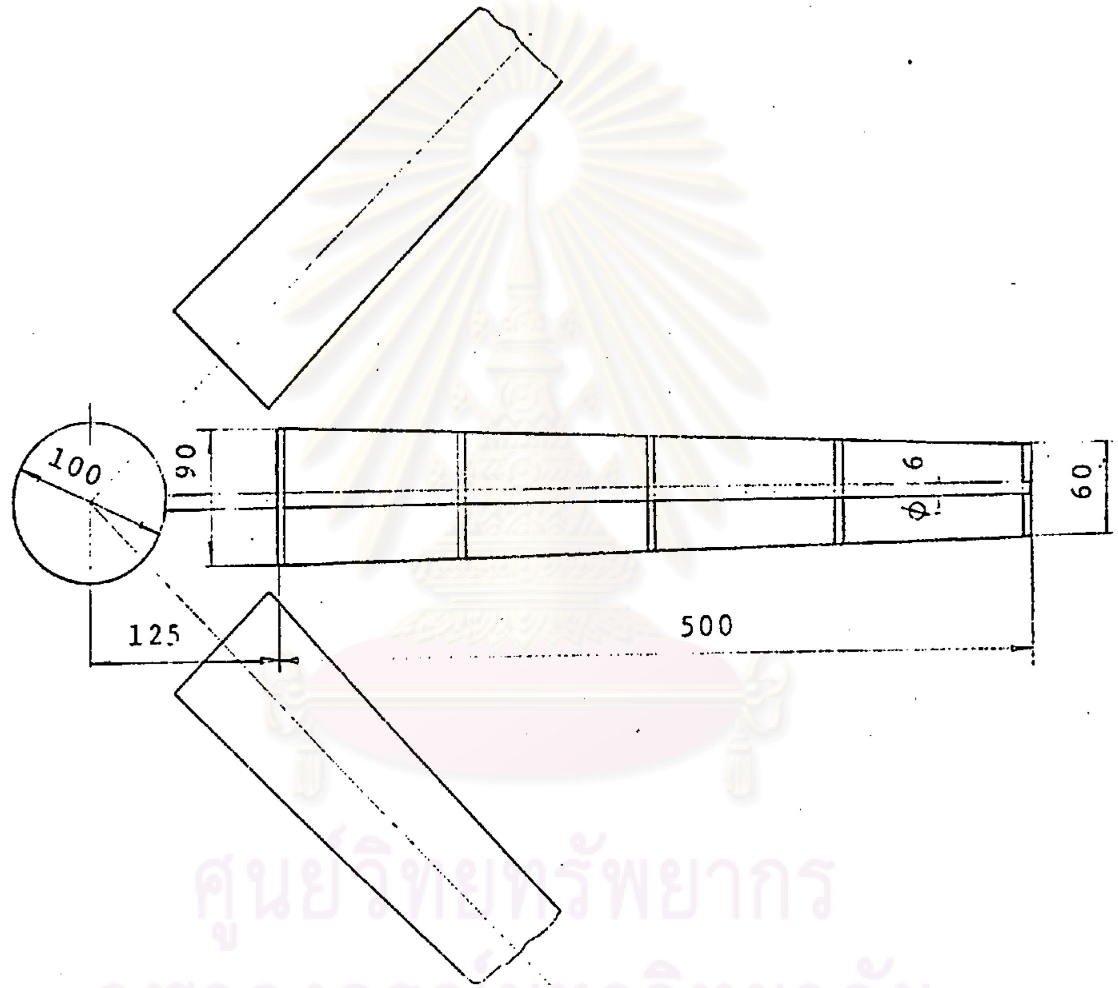

Fig.5.10 Dimensions of blade