Chapter -1-Presentation of an axial turbine

1-1-General information on supporting profiles:

During the 1930s the NACA (National Advisory Committee for Aeronautic) (predecessor of NASA) systematized the study of profile performance. The organization uses the 4 and 5 digit NACA classification (laminar profiles, supercritical profiles, etc.).

a)-Classification of a wing according to its geometry: (see fig1-1)

▸Its bearing surface S=b.l With b: span, l: chord

▸Its elongation λ: λ=b/l

▸Its geometric camber: h_{max}/l=0 to 20%

▸Its relative thickness: e_{max}/l=4 to 20%

b)-Classification of a wing according to its use and by family: (see fig1-2)

The different types of profiles are classified by families. There are 6 of these families.

c)- Flow and pressure distribution around a wing profile: (see fig1-4)

A depression on the upper surface and an excess pressure on the lower surface. We see that the greatest lift forces are located on the front third of the wing profile. It is the extrados which is mainly responsible for the lifting effect.

d) – Stall of the wing: (see fig1-4) For angles of incidence α less than approximately 15°, the flow remains attached to the wing. On the other hand, for higher angles, this flow generates an excess pressure on the extrados side and consequently a loss of lift: this is the wing stalling.

1-2- The main aerodynamic forces: (see fig1-3)

F applied at one point (aerodynamic focus).

This resulting force is classically broken down:

► into forces linked to the flow:	► In some dawn-related apps:
– A drag force **D** // at speed V1	– a normal component $F_N \perp$ to the string
– A lift force **L** ⊥ at speed V1	– a tangential component F_T // to the chord

► The different components above are linked by the following expressions:

$D = F_N \sin(\alpha) + F_T \cos(\alpha)$; $L = F_N \cos(\alpha) - F_T \sin(\alpha)$;

$F_T = D \cos(\alpha) - L \sin(\alpha)$; $F_N = D \sin(\alpha) + L \cos(\alpha)$

a)-Overall aerodynamic coefficients:

To judge the aerodynamic performance of a wing, we introduce the most used coefficients:

▸Drag coefficient: $C_D = \frac{D}{q_\infty A}$ ▸Lift coefficient: $C_L = \frac{L}{q_\infty A}$

▸Normal force coefficient: $C_N = \frac{F_N}{q_\infty A}$ ▸Axial force coefficient: $C_T = \frac{F_T}{q_\infty A}$

- With: $q_\infty = \frac{1}{2}\rho V_\infty^2$: The dynamic pressure at infinity upstream, A: The surface of the wing

b)-Local aerodynamic coefficients: ▸ pressure coef: $C_p = \frac{p - p_\infty}{q_\infty}$

▸ coefficient of friction: $C_f = \frac{\tau_p}{q_\infty}$

1-3-Finesse and loss angle: (see fig1-5)

►**The finesse** f of a profile or a wing is the ratio between the lift coefficient and the drag coefficient: $f=C_L/C_D=L/D=d/h$, The finesse is a function of the shape of the profile or the wing, but also the angle of incidence and the flow regime.

►**On the other hand the loss angle ε** defined by the relation: $tg\varepsilon=D/L=1/f$

►-**The performances** are given in graphic form C_L and C_D as a function of the angle of incidence α as shown in figure 1-5 (see fig1-5).

-**Or by a Polar of a wing:** (see fig1-6) The POLAR is the curve to determine the characteristics of a profile, of a wing. It shows how lift varies as a function of drag and as a function of angle of incidence.

►**Remarkable points of a polar: P1:** C_L zero: point of zero lift**, P2:** drag C_L minimal**, P3:** maximum finesse**, P5:** lift C_L maximum**:** minimum sink speed

1-4- Geometric parameters of a blade grid (axial turbine): (see fig1-7)

l: chord, t: pitch, σ: solidity=l/t,
a: where the camber and max ≤ 0.5,
ϕ: Setting angle
-Camber angle at entry and exit: θ_1 and θ_2
-Camber angle: $\theta=\theta_1+\theta_2$
-Dawn angle at inlet and outlet:
$\beta_1=\theta_1-\phi$ and $\beta_2=\theta_2+\phi$
-Fluid angle at inlet and outlet:
$\alpha_1=\theta_1-\phi+i$ and $\alpha_2=\theta_2+\phi-\delta$
-Angle of incidence: $i=\alpha_1-\beta_1$
-Deflection angle δ: $\delta=\beta_2-\alpha_2$
-Deflection angle: $\varphi=\alpha_1+\alpha_2=\theta+i-\delta$

1-5-Components of the resultant aerodynamic forces linked to the flow speed:

(Lift and drag on a profile) (see fig1-8)

By definition the lift and drag forces are the components of $\vec{F}$, respectively perpendicular and parallel to the average speed $\vec{W}_m$ for rotor blades, or to the average speed $\vec{C}_m$ for stator blades. Average speeds are defined as follows:

$$\vec{C}_m=\frac{\vec{C}_1+\vec{C}_2}{2} \text{ et } \vec{W}_m=\frac{\vec{W}_1+\vec{W}_2}{2}\ ,\ tg\alpha_m=\frac{tg\alpha_1+tg\alpha_2}{2}\ et\ tg\beta_m=\frac{tg\beta_1+tg\beta_2}{2}$$

the lift and drag forces are: $L_R=C_{LR}A\frac{\rho W_m^2}{2}\ ,D_R=C_{DR}A\frac{\rho W_m^2}{2}$; $L_S=C_{LS}A\frac{\rho C_m^2}{2}\ ,D_S=C_{DS}A\frac{\rho C_m^2}{2}$

the axial and tangential forces are:

$$F_a=Lcos\beta_m+Dsin\beta_m=C_LA\frac{\rho W_m^2}{2}\frac{cos(\beta_m-\varepsilon)}{cos\varepsilon} \quad ; \quad F_u=Lsin\beta_m-Dcos\beta_m=C_LA\frac{\rho W_m^2}{2}\frac{sin(\beta_m-\varepsilon)}{cos\varepsilon}$$

1-6-Blade efficiency of an axial turbine grid (diffusion efficiency): (see fig1-9)

$$\eta_a=\frac{ideal\ static\ pressure\ variation}{real\ static\ pressure\ variation}=\frac{\frac{\rho}{2}(W_2^2-W_1^2)}{\frac{\rho}{2}(W_2^2-W_1^2)+\Delta P_0}=\frac{1-tg\varepsilon.tg\beta_m}{1+tg\varepsilon.cotg\beta_m}$$

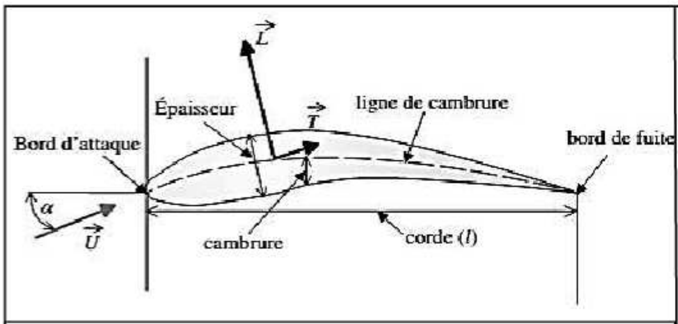


Fig-1-1. Wing profile

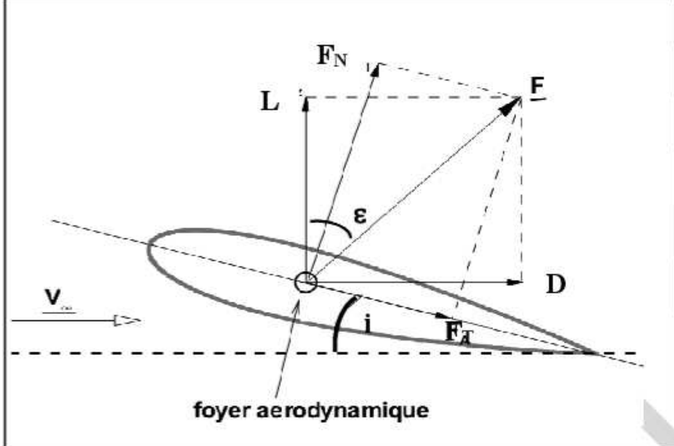


Fig.1-3- Decomposition of the resultant of the aerodynamic forces.

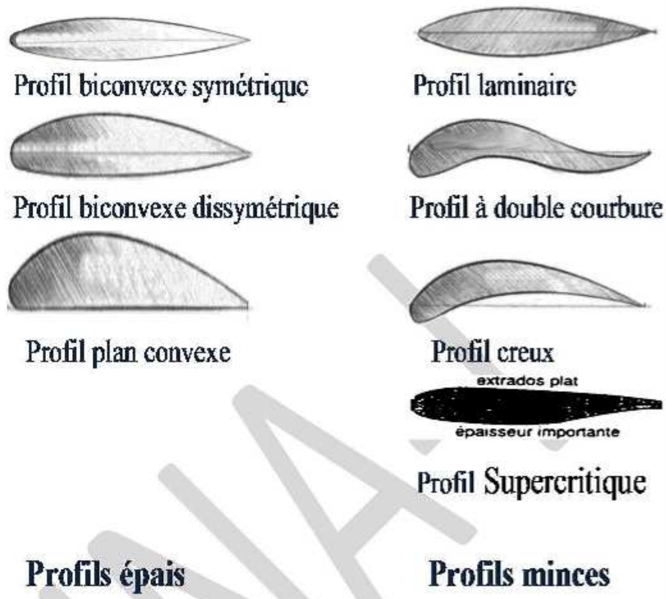
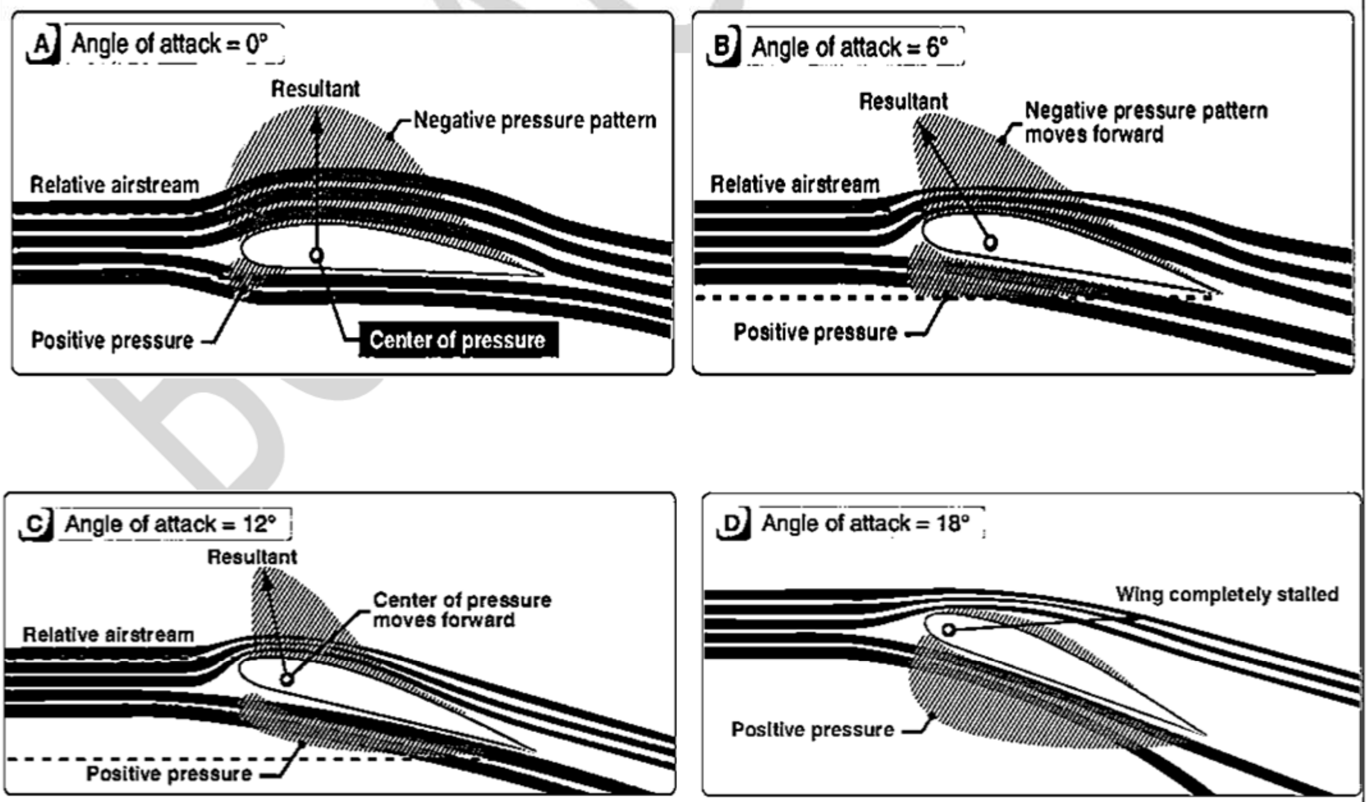


Fig-1-2. Different types of profiles depending on the use.



-A-B-C- : Attached flow: lifting wing **-D- : Detached flow: wing stall**

Figure 1-4 : Attached and detached discharge

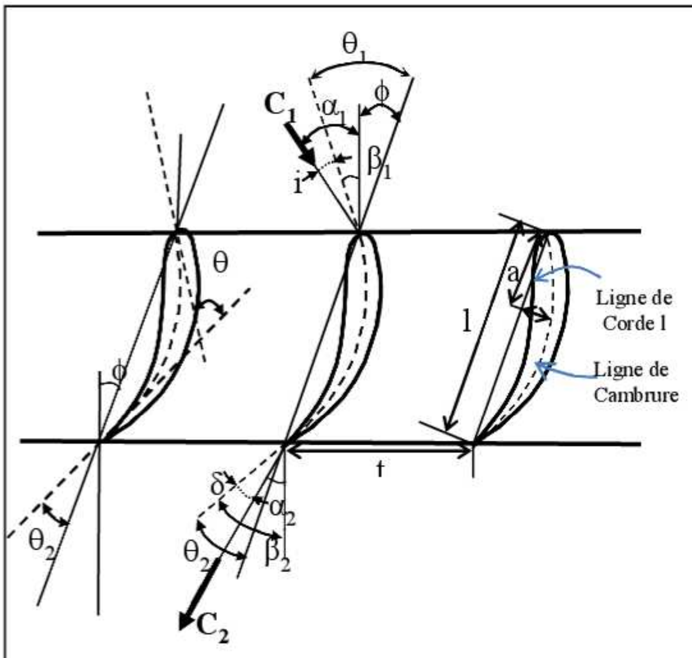


Fig-1-7- Geometric parameters of a blade grid

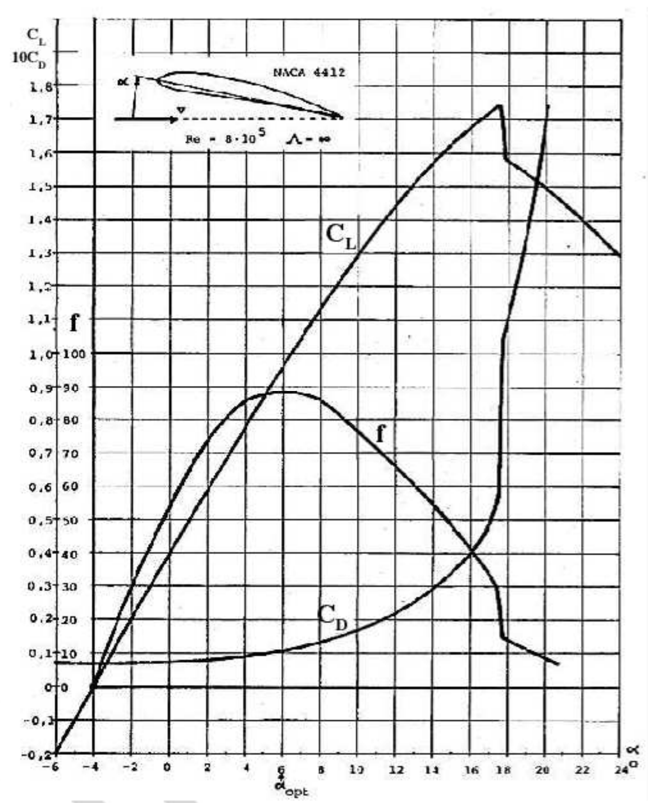


Fig-1-5- Lift and drag coefficients as a function of the angle of attack for a NACA 44112 airfoil

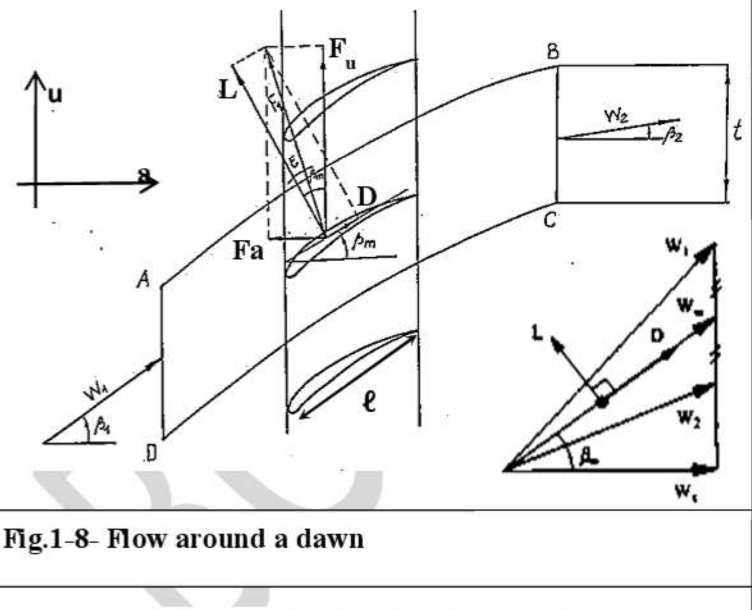


Fig.1-8- Flow around a dawn

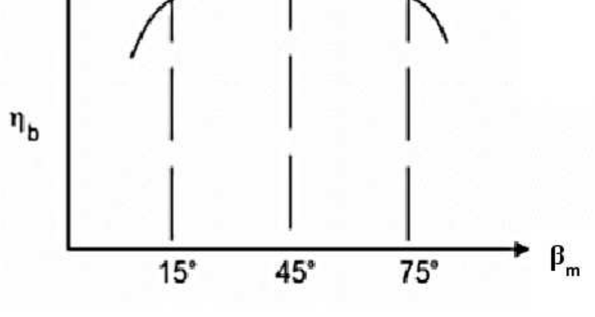


Fig.1-9- Efficiency η_a as a function of the mean angle β_m

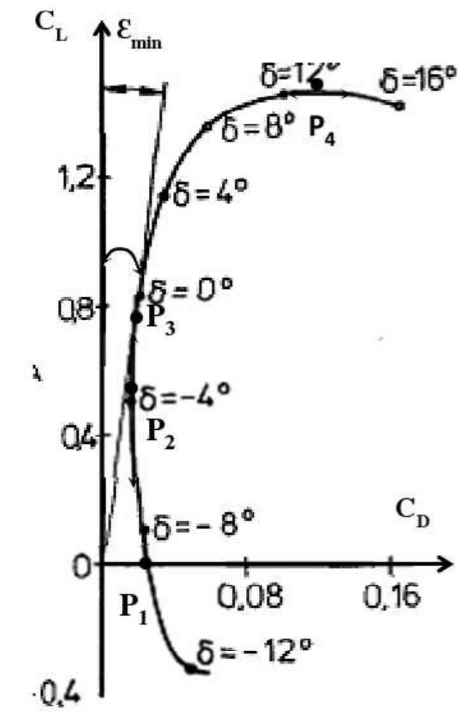


Fig-1-6. - Polar of a lifting wing