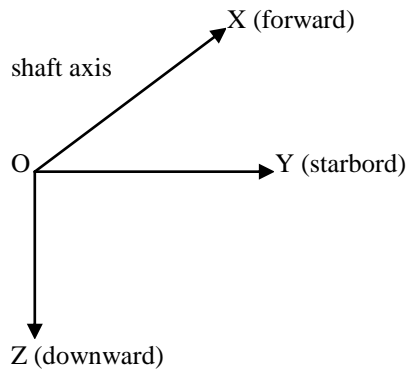


## 2. PROPELLER GEOMETRY

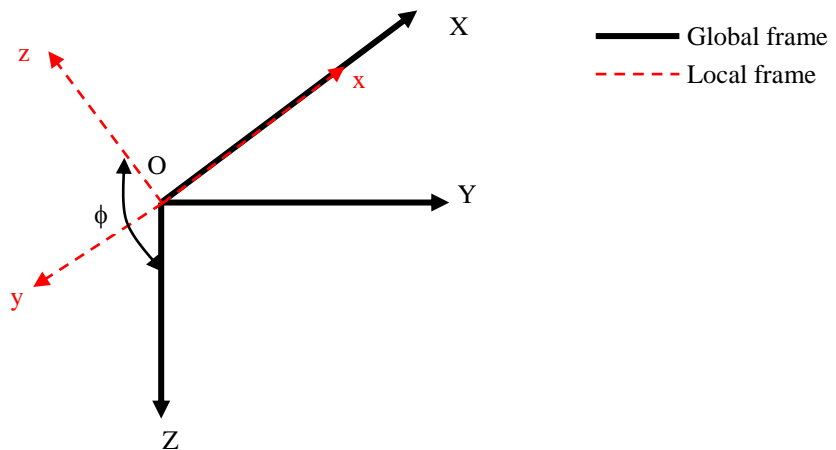
### a) Frames of Reference

10<sup>th</sup> International Towing Tank Conference (ITTC) initiated the preparation of a dictionary and nomenclature of ship hydrodynamic terms and this work was completed in 1975.

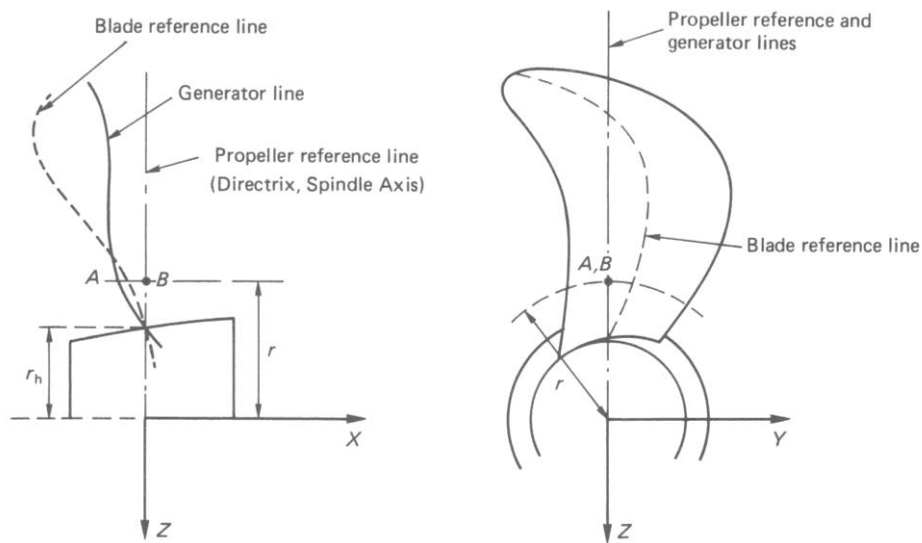


The global reference frame proposed by the ITTC is a right-handed rectangular Cartesian system.

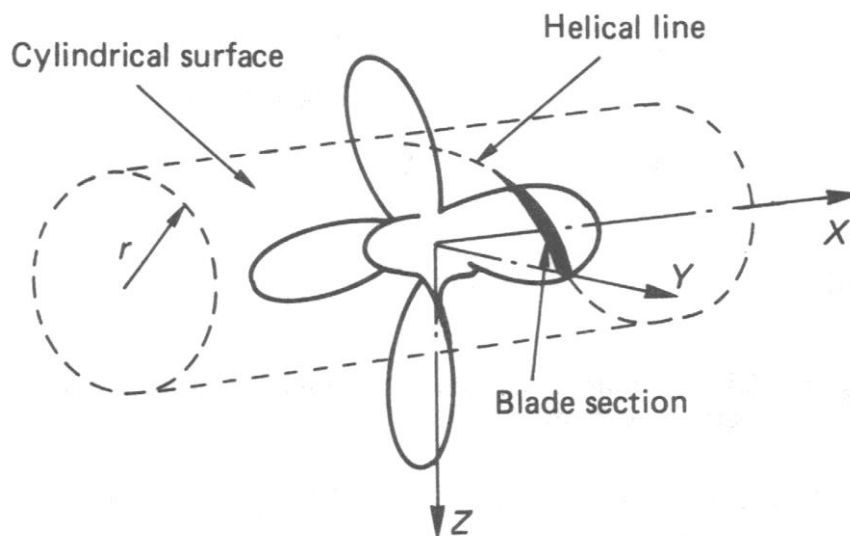
For propeller geometry it is convenient to define a local reference frame having a common axis such that OX and Ox are coincident but Oy and Oz rotate relative to the OY and OZ fixed global frame.



## b) Propeller Reference Lines



- The line normal to the shaft axis is called either propeller reference line or directrix. In the case of controllable pitch propeller the spindle axis is used as synonymous with the reference line.
- Generator line: The line formed by intersection of the pitch helices and the plane containing the shaft axis and propeller reference line.
- The aerofoil sections which together comprise the blade of a propeller are defined on the surfaces of cylinders whose axes are concentric with the shaft axis.



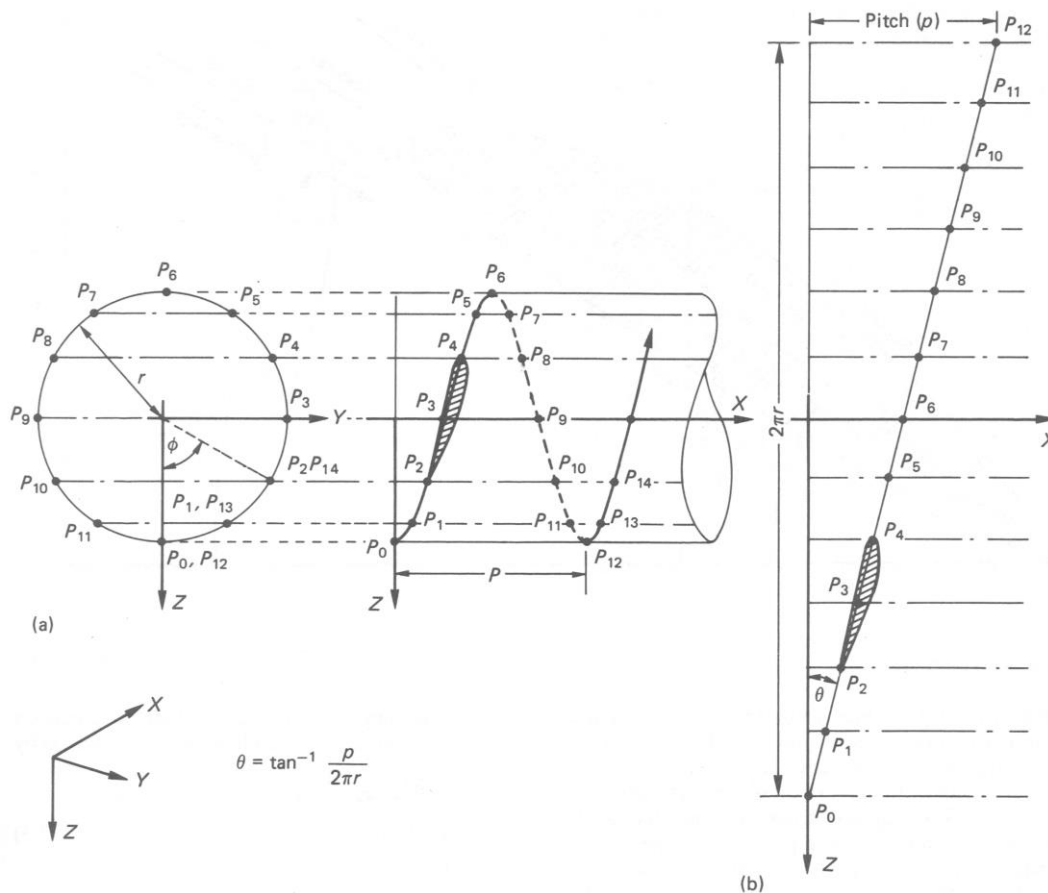
**Face:** The side of a propeller blade which faces downstream during ahead motion is called face or pressure side (when viewed from aft of a ship to the bow the seen side of a propeller blade is called face or pressure side).

**Back:** The side of a propeller blade which faces generally direction of ahead motion is called back or suction side (when viewed from aft of a ship to the bow the unseen side of a propeller blade is called back or suction side).

**Leading Edge:** When the propeller rotating the edge piercing water is called leading edge.

**Trailing Edge:** When the propeller rotating the edge trailing the leading edge is called trailing edge.

### c) Pitch



- Consider a point  $P$  lying on the surface of a cylinder of radius  $r$  which is at some initial point  $P_0$  and moves as to form a helix over the surface of a cylinder.
- The propeller moves forward as to rotate and this movement creates a helix.
- When the point  $P$  has completed one revolution of helix that means the angle of rotation:

$$\phi = 360^\circ \text{ or } 2\pi$$

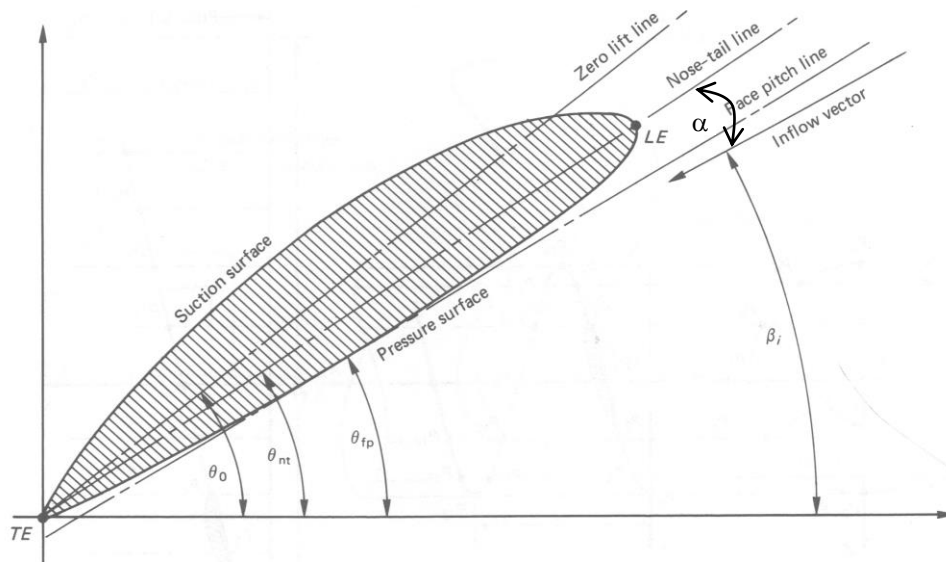
the cylinder intersects the X-Z plane and moves forward at a distance of P.

- If the cylinder is opened out the locus of the point P lies on a straight line.
- In the projection one revolution of the helix around the cylinder measured normal to the OX axis is equal to  $2\pi r$ .
- The distance moved forward by the helical line during this revolution is p and the helix angle is given by:

$$\theta = \tan^{-1}\left(\frac{p}{2\pi r}\right)$$

- The angle  $\theta$  is termed the pitch angle and the distance p is the pitch.

There are several pitch definitions.



where

- $\theta_0$  is the effective pitch angle of the propeller
- $\theta_{nt}$  or  $\theta$  is the geometric pitch angle of the propeller
- $\beta_i$  is the hydrodynamic pitch angle
- $\alpha$  is the angle of attack of section

**1- Nose-tail pitch:** The straight line connecting the extremities of the mean line or nose and tail of a propeller blade is called nose-tail pitch line. The section angles of attack are defined to the nose-tail line.

- 2- **Face pitch:** The face pitch line is basically a tangent to section's pressure side surface and you can draw so many lines to the pressure side. Therefore its definition is not clear. It is rarely used but it can be seen in older drawings like Wageningen B series.
- 3- **Effective or no-lift pitch:** It is the pitch line of the section corresponding to aerodynamic no-lift line which results zero lift.
- 4- **Hydrodynamic pitch:** The hydrodynamic pitch angle ( $\beta_i$ ) is the pitch angle at which the incident flow encounters the blade section.

Effective pitch angle ( $\theta_0$ ) = Noise-tail pitch angle ( $\theta, \theta_{nt}$ ) + 3-D zero-lift angle

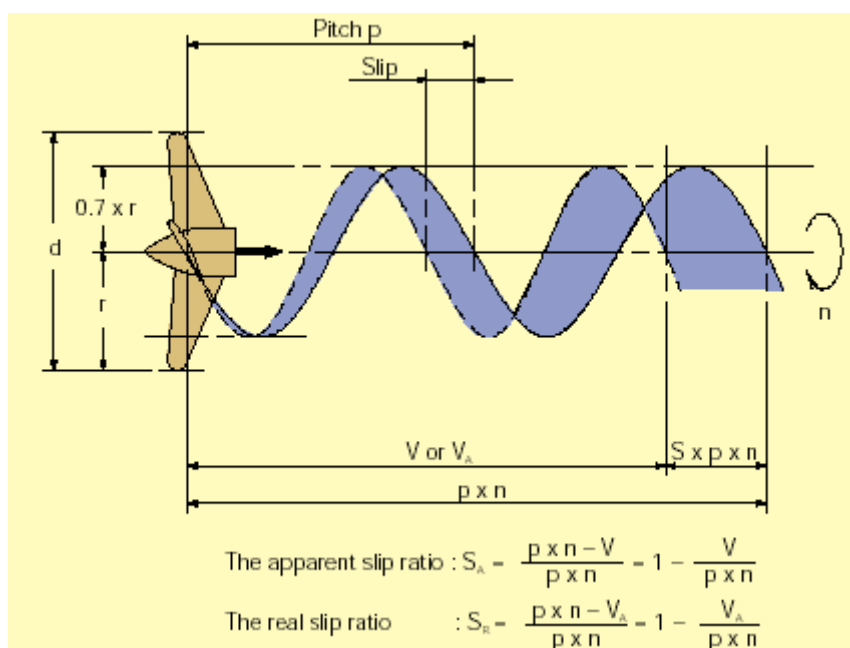
where 3-D zero lift angle is the difference between  $\theta_0$  and  $\theta$ .

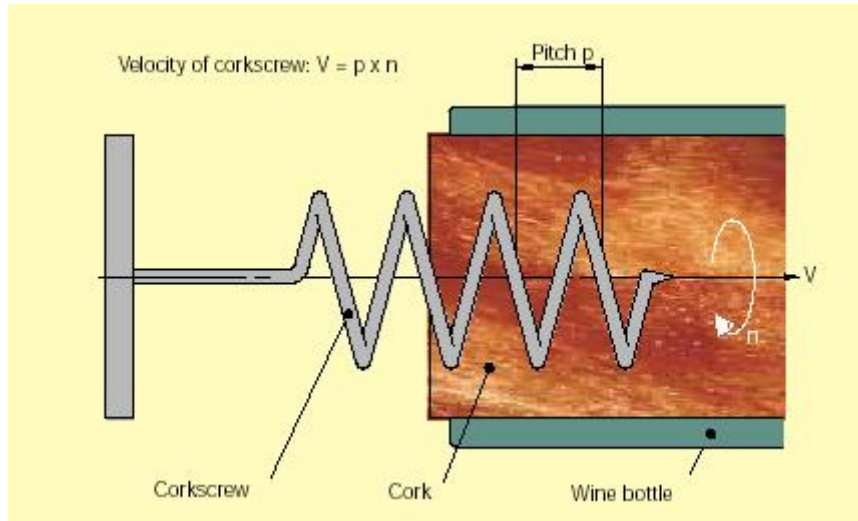
$$\theta_0 = \text{Hydrodynamic pitch angle } (\beta_i) + \text{Angle of attack of section } (\alpha) + \text{3-D zero lift angle}$$

- Pitch values at different radii are called radial pitch distribution.

## Slip Ratio

If the propeller works in a solid medium (has no slip), i.e. if the water which the propeller “screws” itself through does not yield (i.e. if the water did not accelerate aft), the propeller will move forward at a speed of  $V = p \times n$ , where  $n$  is the propeller's rate of revolution, as seen in the below figure. The similar situation is shown for a corkscrew, and because the cork is a solid material, the slip is zero and, therefore, the cork screw always moves forward at a speed of  $V = p \times n$ . However, as the water is a fluid and does yield (i.e. accelerate aft), the propeller's apparent speed forward decreases with its slip and becomes equal to the ship's speed  $V$ , and its apparent slip can thus be expressed as  $p \times n - V$ .





The apparent slip ratio  $S_A$ , which is non-dimensional, is defined as:

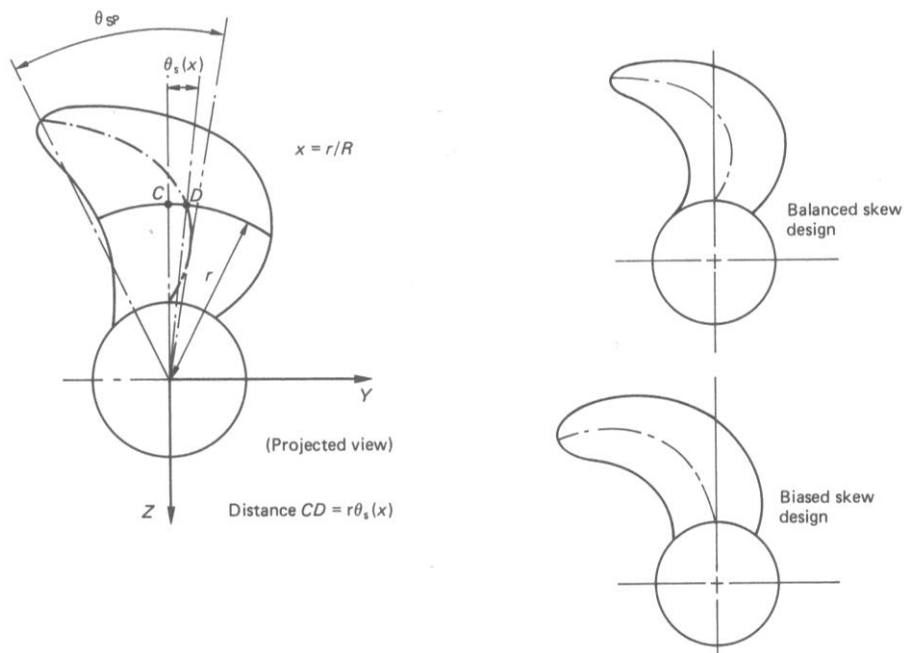
$$S_A = \frac{pn - V}{pn} = 1 - \frac{V}{pn}$$

The real slip ratio  $S_R$ , which gives a truer function of the propeller function, is:

$$S_R = \frac{pn - V_A}{pn} = 1 - \frac{V_A}{pn}$$

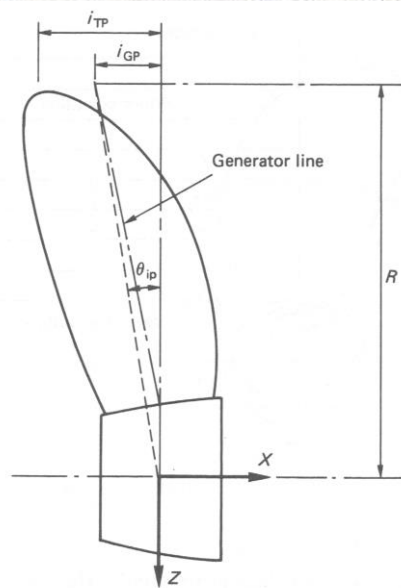
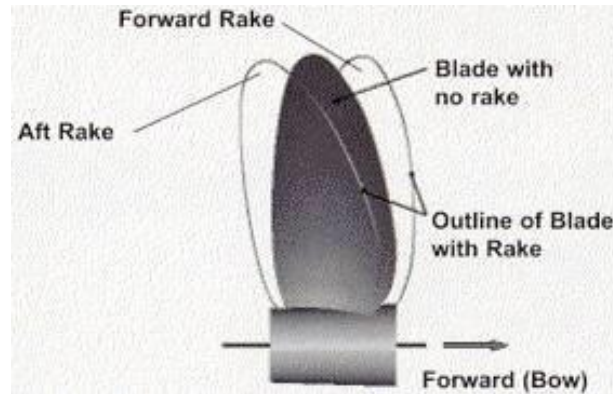
Where  $V_A$  is the velocity at the propeller plane.

## d) Skew



- It is the angle between the mid-chord position of a section and the directrix ( $\theta_s$ ).
- The propeller skew angle ( $\theta_{sp}$ ) is defined as the greatest angle measured at the shaft centre line which can be drawn between lines passing from the shaft centreline through the mid chord position of any two sections.
- The skew can be classified into two types:
  - i- **Balanced skew:** Directrix intersects with the mid-chord line at least twice.
  - ii- **Biased skew:** Mid-chord locus crosses the directrix not more than once normally in the inner sections.

### e) Rake



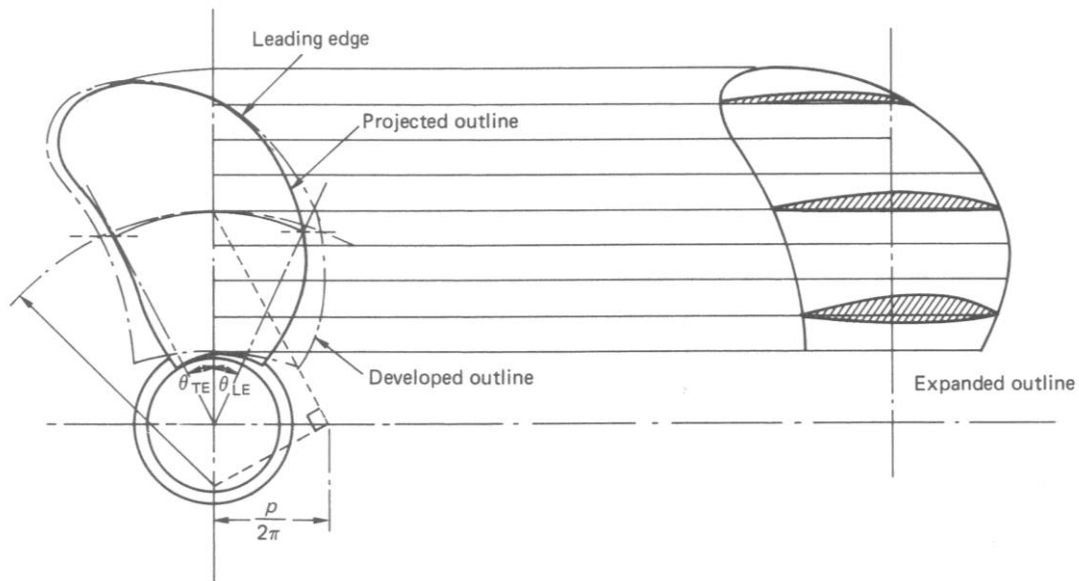
The displacement from the propeller plane to the generator line in the direction of the shaft axis is called rake. The propeller rake is divided into two components: generator line rake ( $i_G$ ) and skew induced rake ( $i_s$ ) which are defined as:

$$i_T(r) = i_G(r) + i_s(r)$$

$$i_s(r) = r\theta_s \tan(\theta_{nt})$$



## f) Propeller Outlines and Areas



There are five different outlines and associated areas of propeller in use. These are:

1. Disc outline (area) ( $A_0$ )
2. Projected outline ( $A_p$ )
3. Developed outline ( $A_D$ )
4. Expanded outline ( $A_E$ )
5. Swept outline ( $A_S$ )

1. **Disc area:** The area of the circle swept out by the tips of the blades of a propeller diameter ( $A_0 = \frac{\pi D^2}{4}$ ).
2. **Projected outline:** It is the view of the propeller blade that is actually seen when the propeller is viewed along the shaft centreline normal to y-z plane (when viewed forward).

$$A_p = Z \int_{r_h}^R (\theta_{TE} - \theta_{LE}) r dr$$

where  $Z$  is the number of blades.

$r_h$  is the hub radius of the propeller.

$R$  is the tip radius of the propeller.

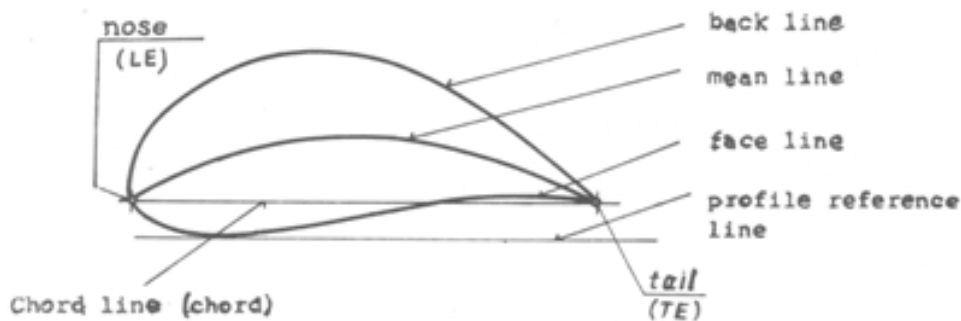
3. **Developed outline:** It is a helically based view, but the pitch of each section has been reduced to zero. The intersection of the blade with the axial cylinder is rotated along the blade reference line into a plane parallel to the propeller. The amount of rotation is equal to the pitch angle at every radius.
4. **Expanded blade outline:** It is really not an outline in any true geometric sense at all. It is a plotting of the chord lengths at their correct radial stations about the directrix. Such that the outline is constructed by laying off at each

radius  $r$ , the chord length along a straight line. The outline is formed by the locus of the end points of the chord lines laid out in the above manner.

- 5. Swept Outline:** This outline is swept by the leading and trailing edges when the propeller is rotating.

In general, the developed area is greater than the projected area and slightly less than the expanded area.

### g) Blade Sections-NACA Definitions



**Mean line or camber line:** is the location of mid-points between upper and lower surfaces when measured perpendicular to the camber line.

**Chord length (c):** The distance between the leading edge and trailing edges when measured along the chord line is termed as chord length of the section

**Camber:** is the maximum distance between the camber line and chord line.

**Thickness:** of a section is the distance between upper and lower surfaces of the section also measured perpendicular to the mean line.

- Leading edges are usually circular having a leading edge radius defined about a point on the camber line.
- Typical section used for ship propeller is NACA66 series with the mean line  $a=0.8$
- The upper and lower coordinates of the profile are given as:

$$x_U = x_C \qquad y_U = y_C + y_t$$

$$x_L = x_C \qquad y_L = y_C - y_t$$

where  $y_C$  is the camber ordinate obtained from the table,  $y_t$  is the ordinate of the chosen symmetrical thickness distribution.