

## Reference for wind turbine blade flow angles

The purpose of this document is to provide a reference for the flow angles of a wind turbine blade.

### tip speed ratio $\lambda$

An interesting parameter to consider is the tip speed ratio ( $\lambda$ ), which is the ratio of the tip speed to the wind speed. It is used to describe the aerodynamic performance of the wind turbine blades.

$$\lambda = \frac{\omega r}{V}$$

### Blade angles

In the aerodynamics of wind turbine blades, several key angles are defined to describe the interaction between the airflow and the blade geometry. The following image shows the flow angles of a wind turbine blade.

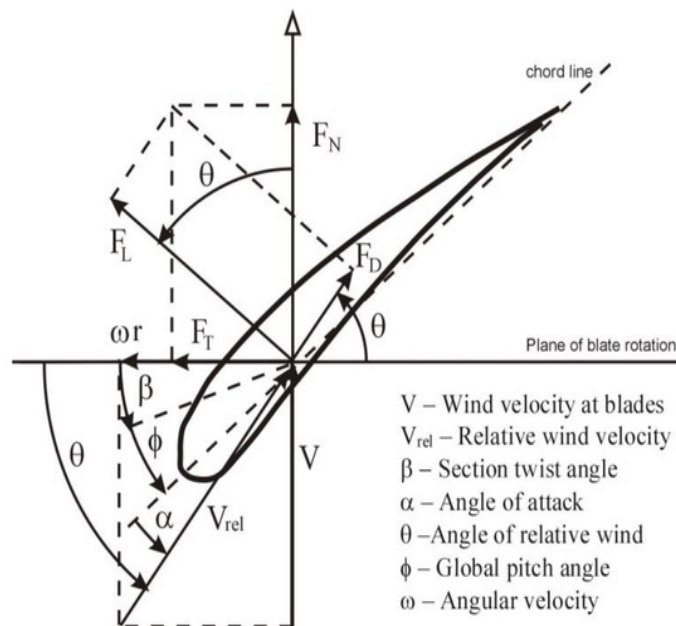


Figure 1: Chudzik-flowangles <sup>1</sup>

- **Flow (Relative Wind) Angle ( $\theta$ ):** The angle between the relative wind velocity vector ( $V_{rel}$ ) and the plane of rotation. It results from the vector

<sup>1</sup>Chudzik, S. (2023). Wind Microturbine with Adjustable Blade Pitch Angle. *Energies*, 16(2), 945. <https://doi.org/10.3390/en16020945>

combination of the free-stream wind velocity  $V$  and the rotational velocity  $\omega r$ :

$$V_{\text{rel}} = \sqrt{V^2 + (\omega r)^2}$$

$$\tan \theta = \frac{V}{\omega r} \rightarrow \boxed{\theta = \arctan\left(\frac{V}{\omega r}\right) = \arctan\left(\frac{1}{\lambda}\right)}$$

- **Pitch Angle ( $\phi$ ):** The global blade setting angle, measured between the chord line at the root and the plane of rotation.
- **Twist Angle ( $\beta$ ):** The local variation of the blade angle along the span to maintain optimal aerodynamic performance.
- **Angle of Attack ( $\alpha$ ):** The angle between the chord line of the blade profile and the relative wind velocity.

$$\alpha = \theta - \phi - \beta$$

### Relation Between Angles

The **angle of attack** is determined from the difference between the flow angle and the geometric blade settings (pitch and twist):

$$\alpha = \theta - (\phi + \beta)$$

Thus:

- $\theta$  defines the aerodynamic orientation of the relative wind.
- $\phi$  and  $\beta$  define the blade geometry.
- $\alpha$  represents the effective aerodynamic incidence of the blade section.

This formulation links the aerodynamic environment (flow) to the geometric configuration (pitch, twist), governing the lift and drag forces acting on the blade.