2017/Feb./

Introduction of horizontal axis wind turbine rotation mechanism (Beta Ver.xx)

Some fluid dynamics expression is barren of accuracy,
because these files aims are for beginners.

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Contents

- Variety of horizontal axis wind turbine
- Foundation of Fluid dynamics and Airfoil element theory
- Horizontal axis wind turbine rotation mechanism
- What is Reynolds Number ?

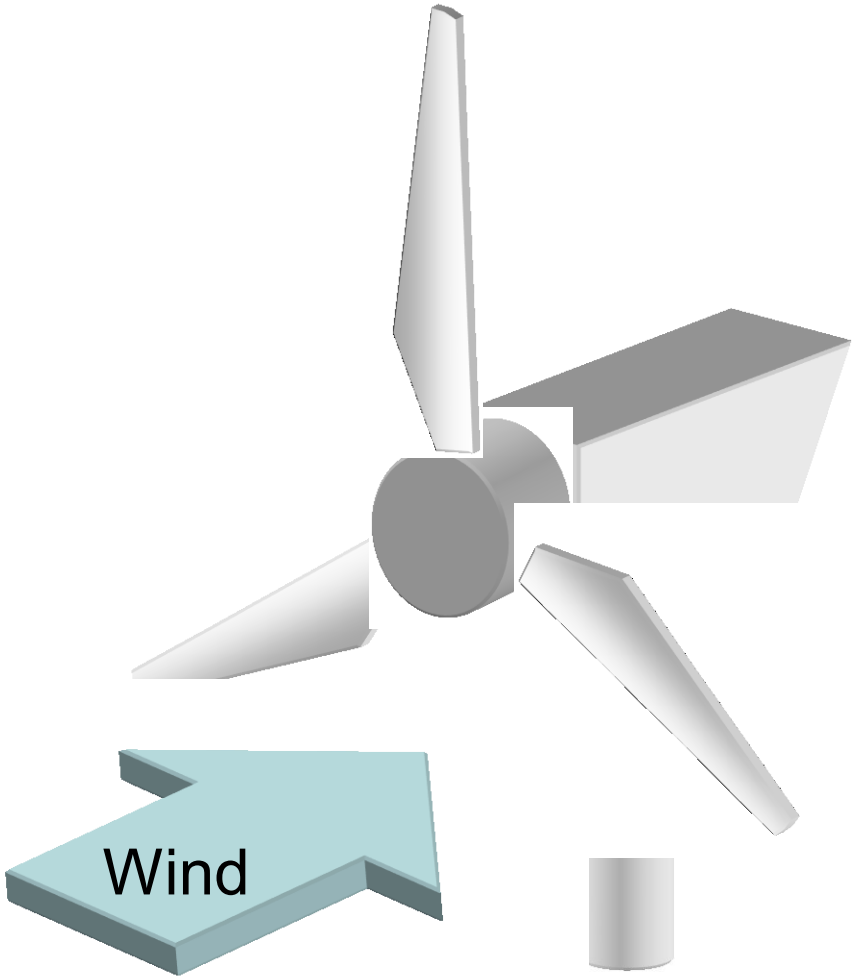
Variety of horizontal axis wind turbine

Up wind type

-

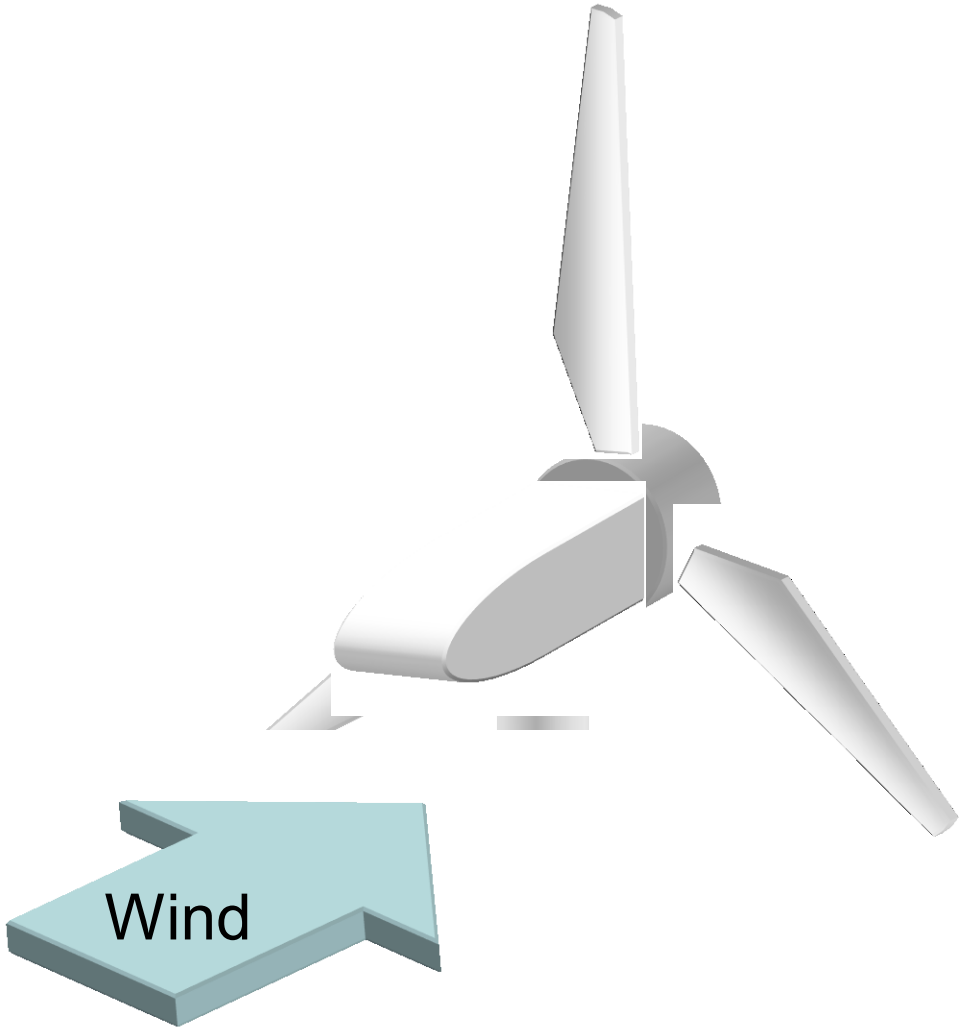
Down wind type

Up wind type



Rotor blade located at front side of the tower

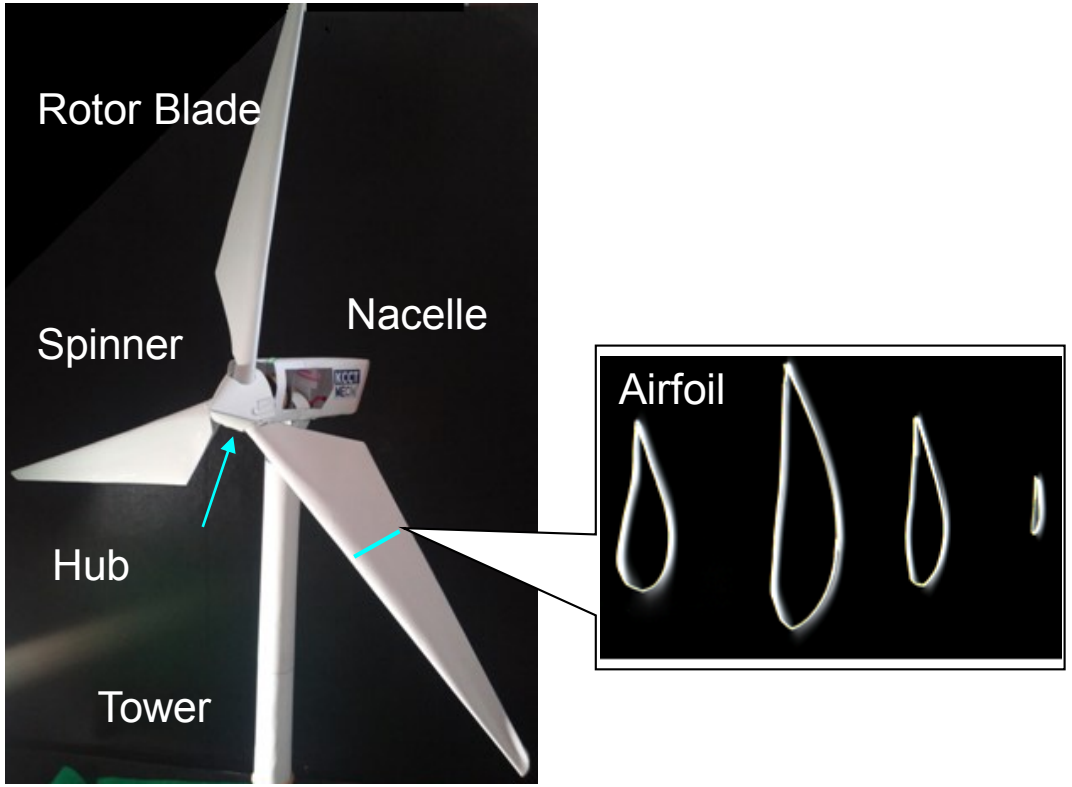
Down wind type



Rotor blade located at back side of the tower

Names of parts

- Airfoil
- Rotor Blade
- Nacelle
- Hub (root of the blade)
- Spiner
- Tower



Horizontal axis wind turbine rotation mechanism

Before the wind turbine rotation mechanism,,,

Foundation of Fluid dynamics and Airfoil element theory

See Wikipedia:

Misunderstandings about the generation of lift

http://en.wikipedia.org/wiki/Bernoulli%27s_principle#Misunderstandings_about_the_generation_of_lift

Lift (force)

http://en.wikipedia.org/wiki/Lift_%28force%29

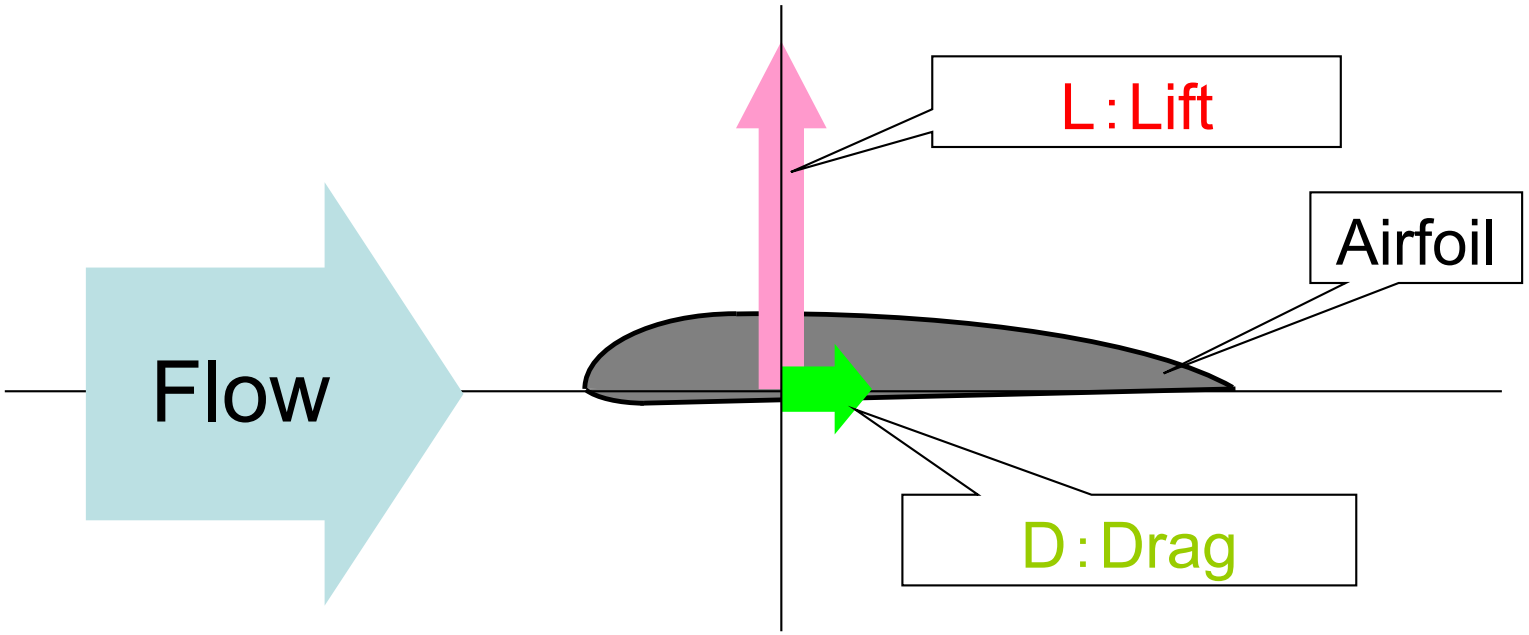
More accurate information of fluid dynamics and the blade element theory

NASA:Incorrect Lift Theory http://www.grc.nasa.gov/WWW/k-12/airplane/wrong1.html

NASA:Incorrect Lift Theory #2 http://www.grc.nasa.gov/WWW/k-12/airplane/wrong2.html

Lift and Drag

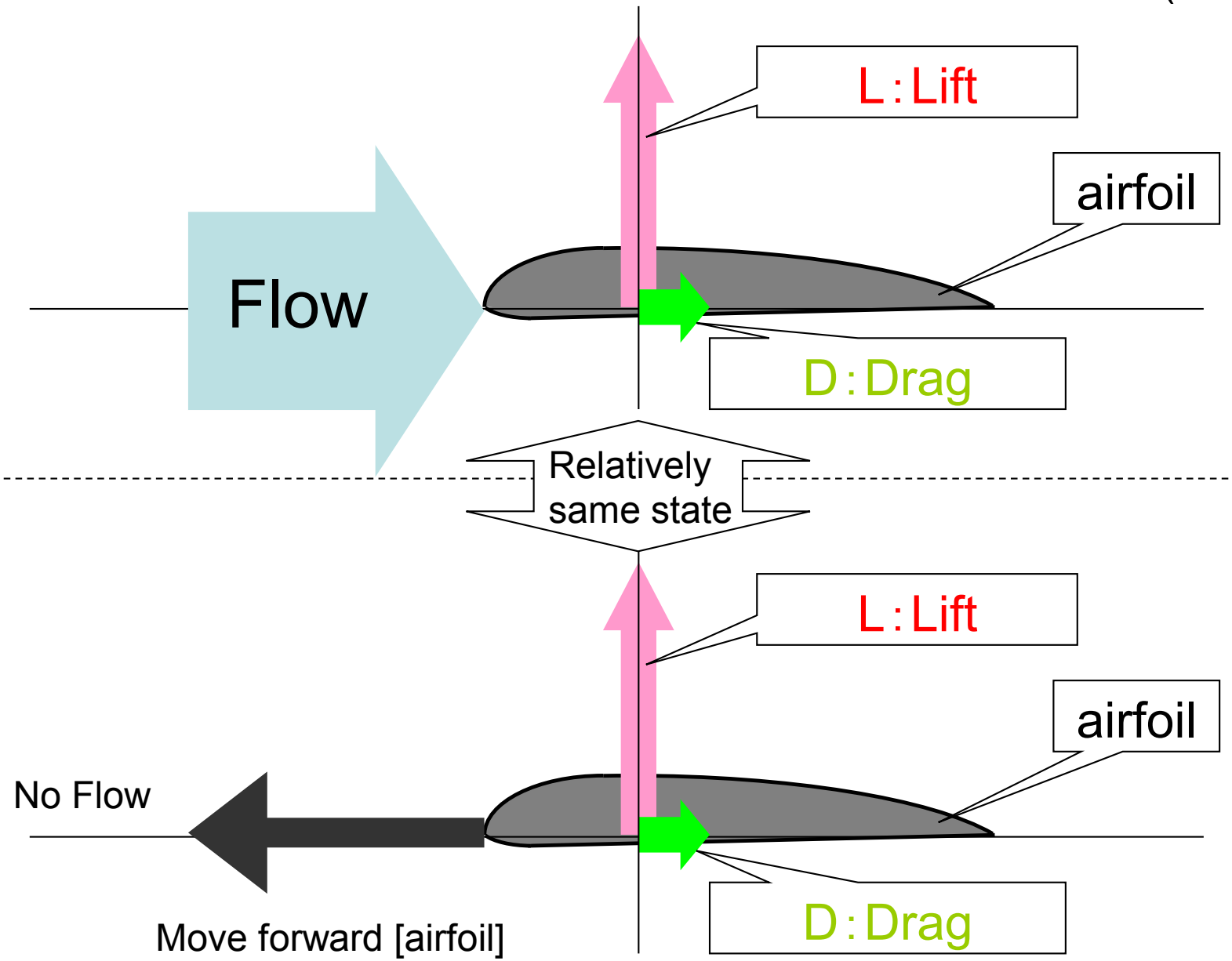
- Lift: Normal force caused by flow
- Drag: Parallel force caused by flow



Airfoil: The shape which maximize the lift and minimize the drag

It's relatively same state!

Put an airfoil into the air flow = Move forward an airfoil in the (no flow) air



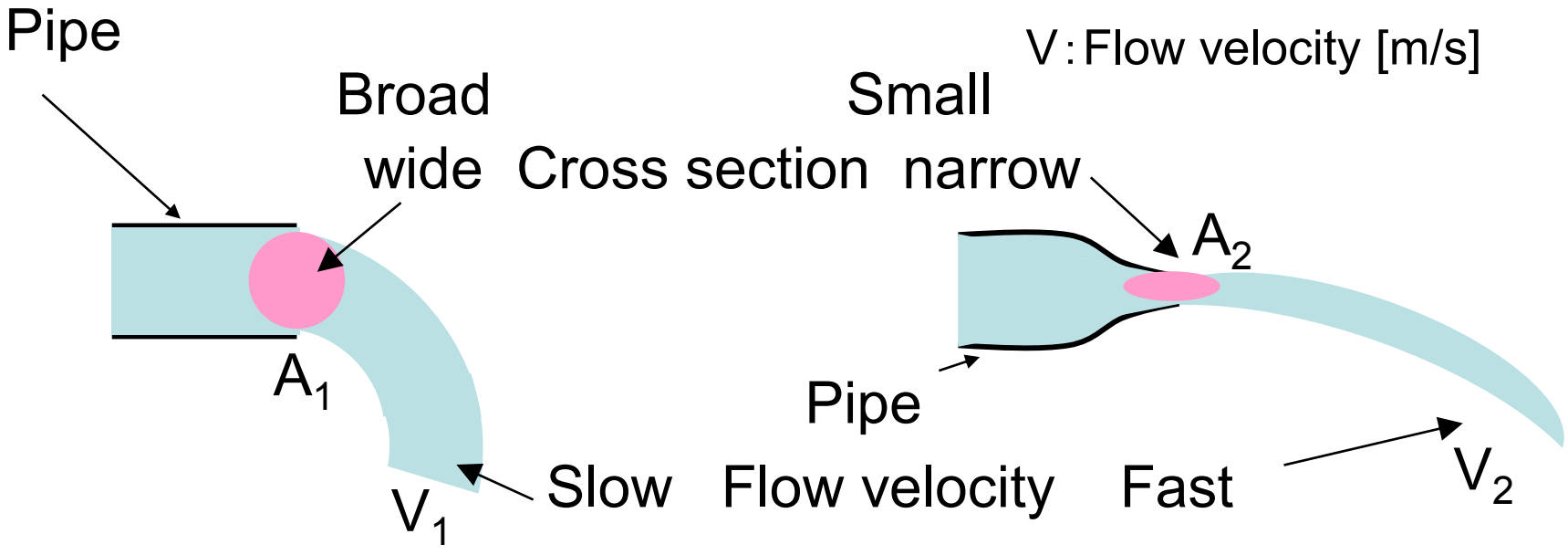
Law of continuity (Flow rate)

$$Q[m^3/s]=A[m^2]V[m/s]=\text{constant}$$

Q: flow rate[m^3/s]

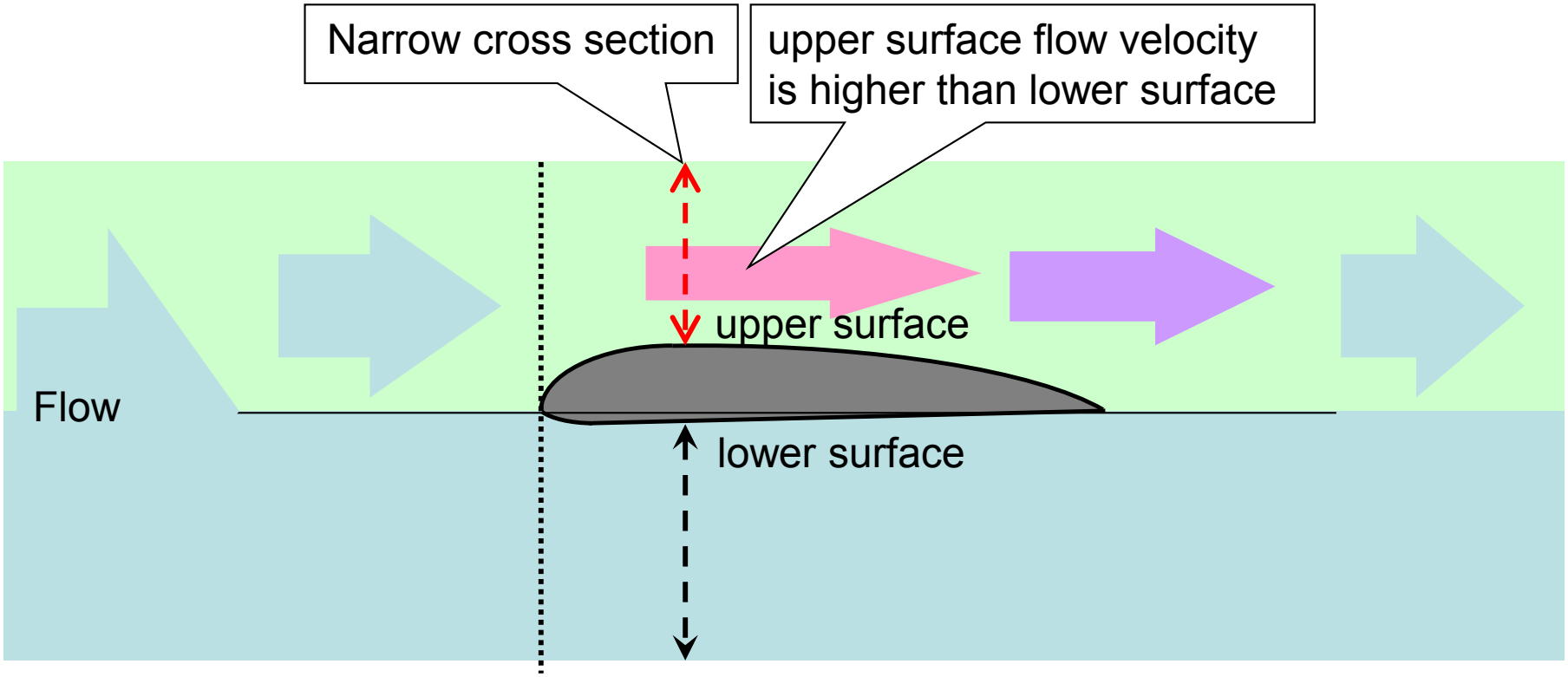
A : Cross section of flow [m^2]

V : Flow velocity [m/s]



Flow Rate $Q[m^3/s]=A_1V_1=A_2V_2=\text{Constant}$

What's happened at around the airfoil ? =upper surface flow velocity is higher than lower surface

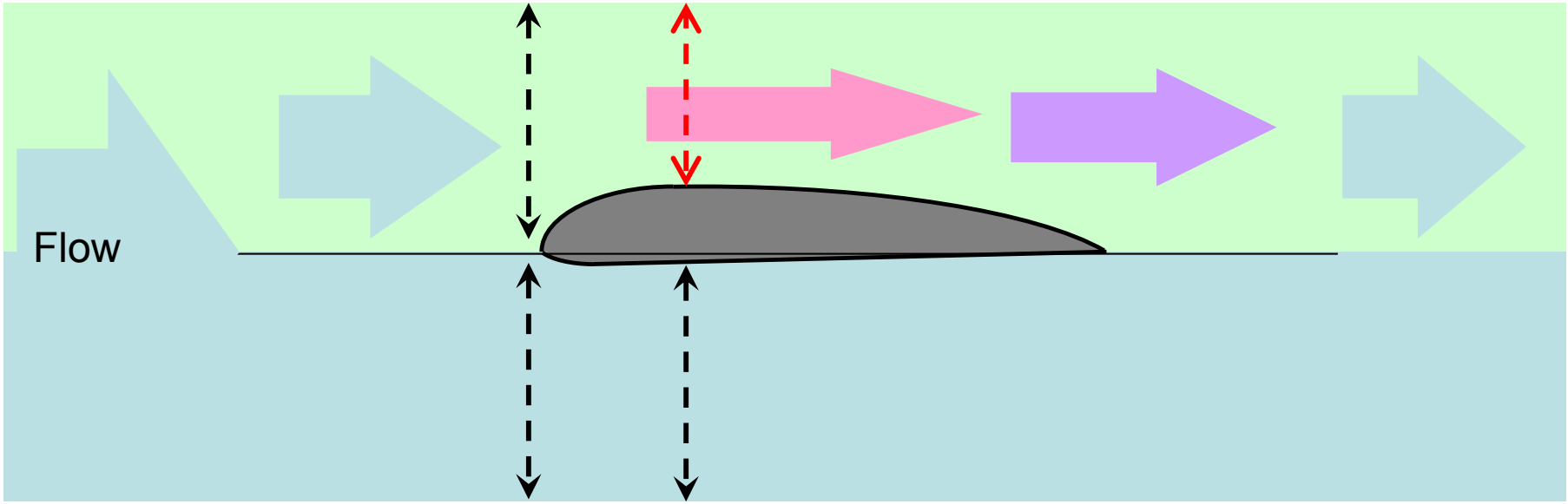


Bernoulli's principle

$$\frac{1}{2}V^2 + \frac{p}{\rho} = const.$$

V : Flow velocity [m/s]
p : Pressure[Pa]
ρ : Density of the fluid [kg/m^3]

Dynamic Pressure + Piezometric head = const.



See Wikipedia:

Misunderstandings about the generation of lift

http://en.wikipedia.org/wiki/Bernoulli%27s_principle#Misunderstandings_about_the_generation_of_lift

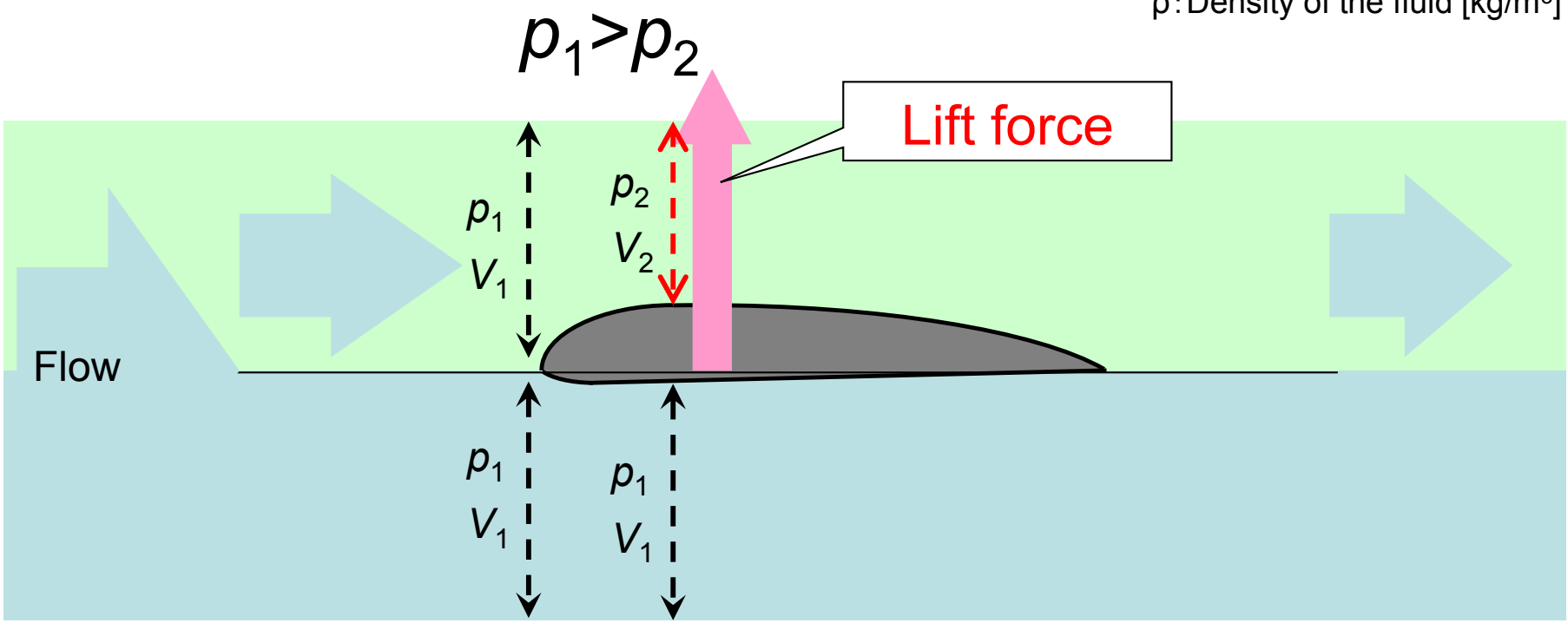
Lift (force)

http://en.wikipedia.org/wiki/Lift_%28force%29

Bernoulli's principle

$$\frac{1}{2}V_1^2 + \frac{p_1}{\rho} = \frac{1}{2}V_2^2 + \frac{p_2}{\rho} = const.$$

V_1, V_2 : Flow velocity [m/s]
p_1, p_2 : Pressure[Pa]
ρ : Density of the fluid [kg/m^3]



Airfoil upper surface shape >>> accelerate flow velocity >>> Low pressure >> Lift force

Some fluid dynamics expression is barren of accuracy,,,

In any case, an airfoil is

the shape that regarded low drag force as high lift force

It is ideal to Keep the AoA which shows Largest Lift force-Drag force rate

- What is Angle of Attack (AoA: α)
- Large AoA gives not only high lift force(L) but also high drag force(D)
- Larger AoA is trigger of the stall (separation flow)
- It is ideal to Keep the AoA which shows Largest Lift-Drag rate (L/D or C_L/C_D)

C_L: Lift Coefficient
C_D: Drag Coefficient

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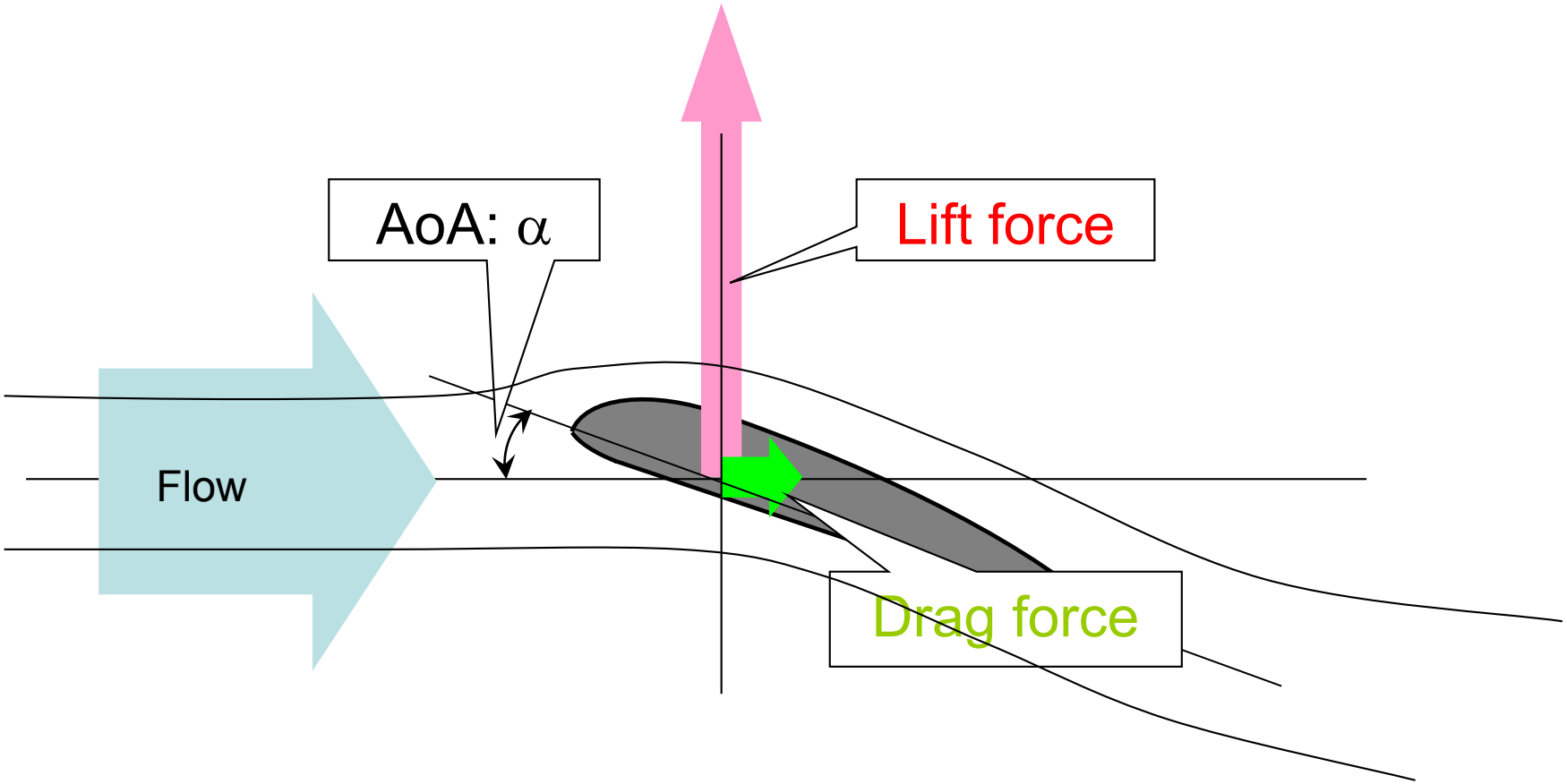
What is Angle of Attack (AoA: α)

The angle of attack is the angle between the chord line of an airfoil and the oncoming air.



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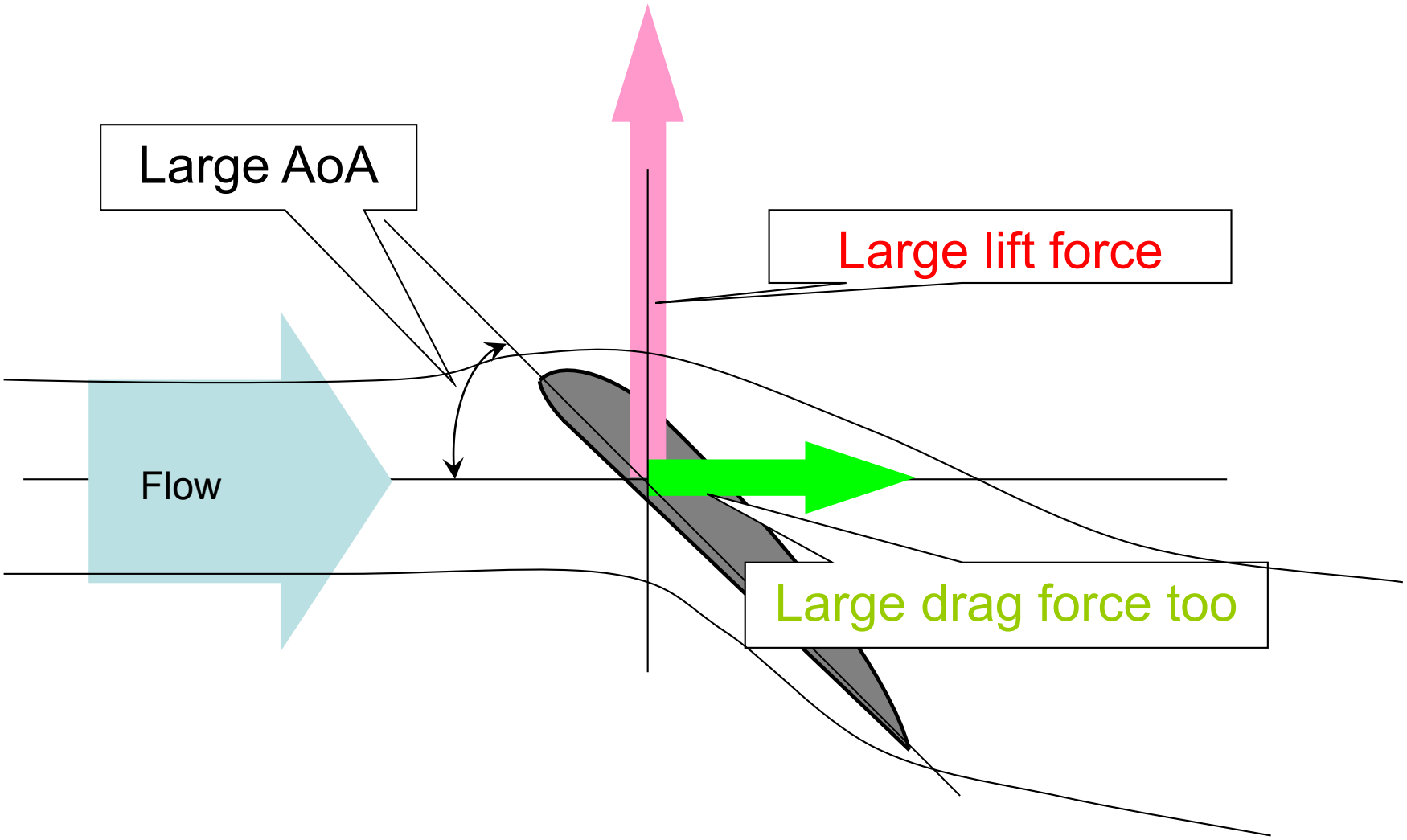

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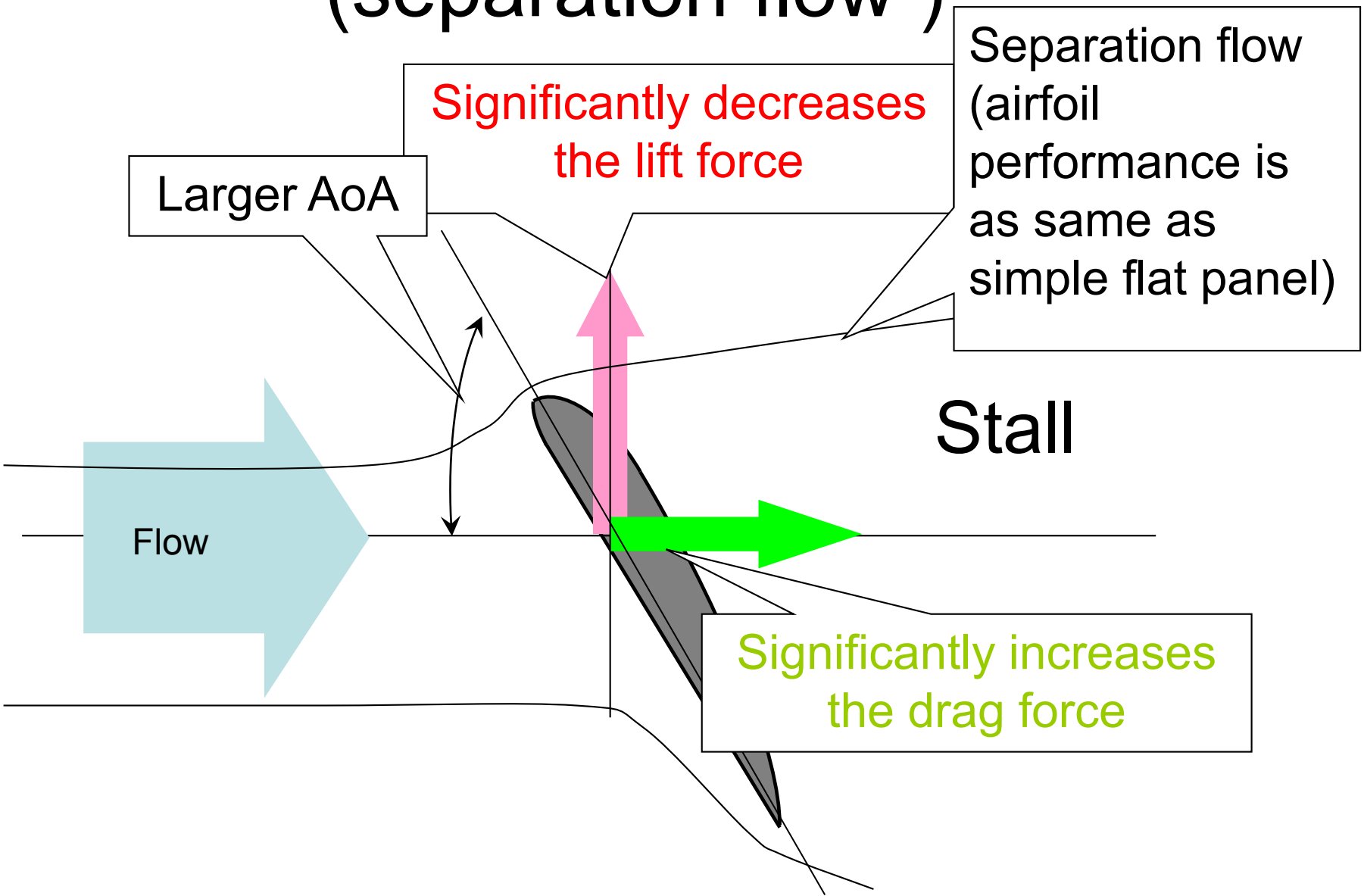
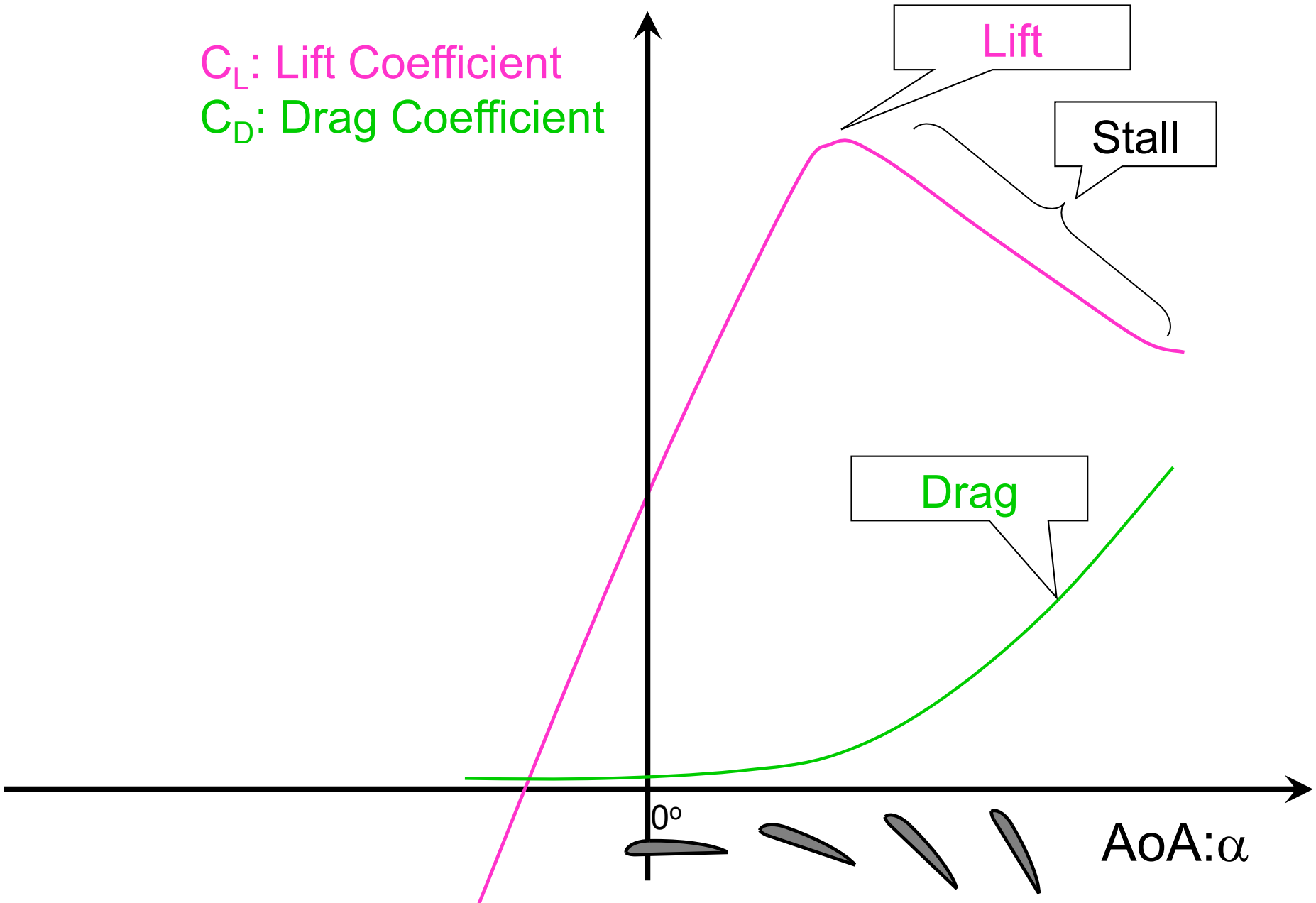
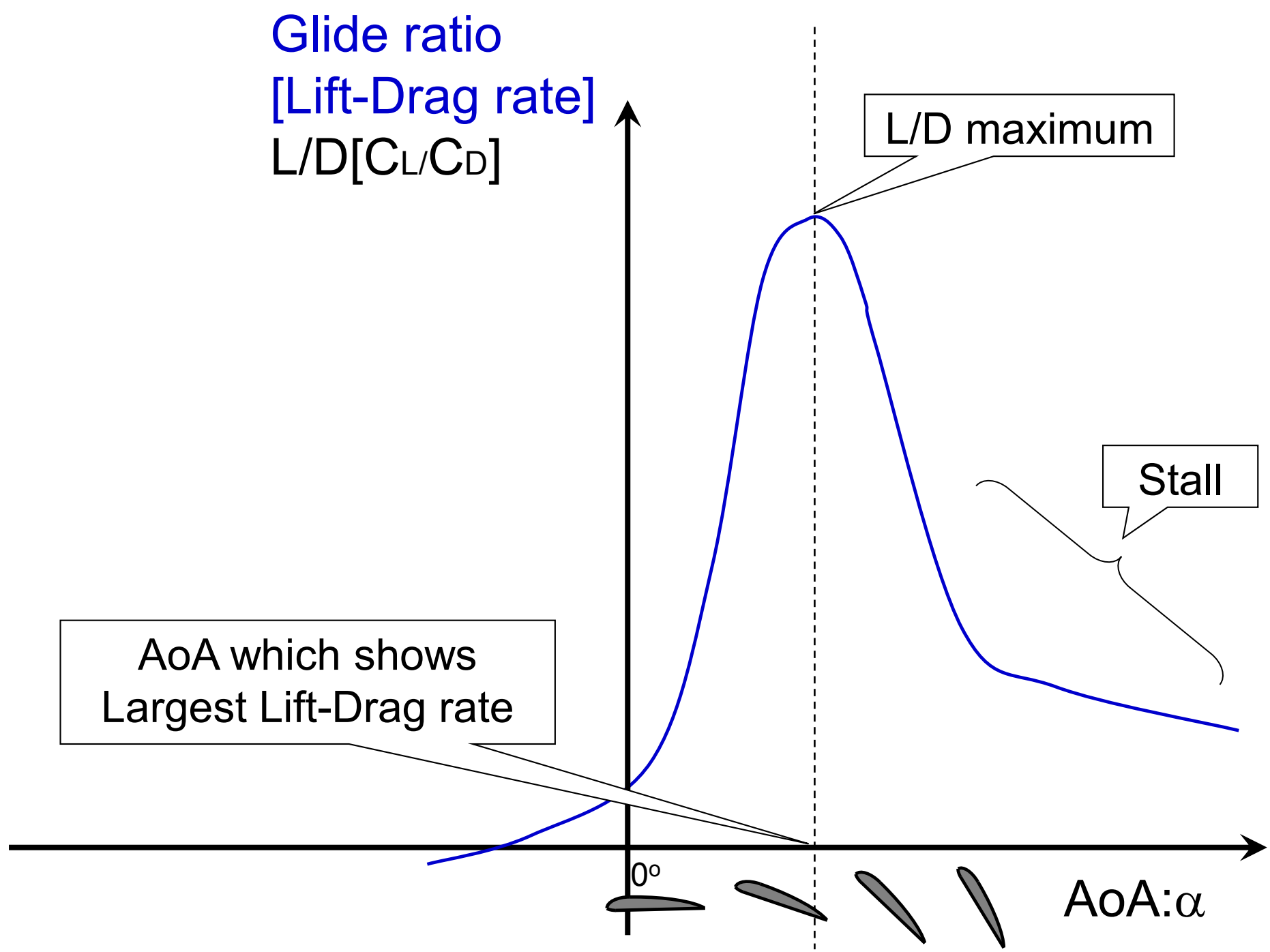


It is ideal to Keep the AoA which shows Largest Lift-Drag rate (L/D or C_L/C_D)

[Carry out the performance test of airfoil in all AoA range]

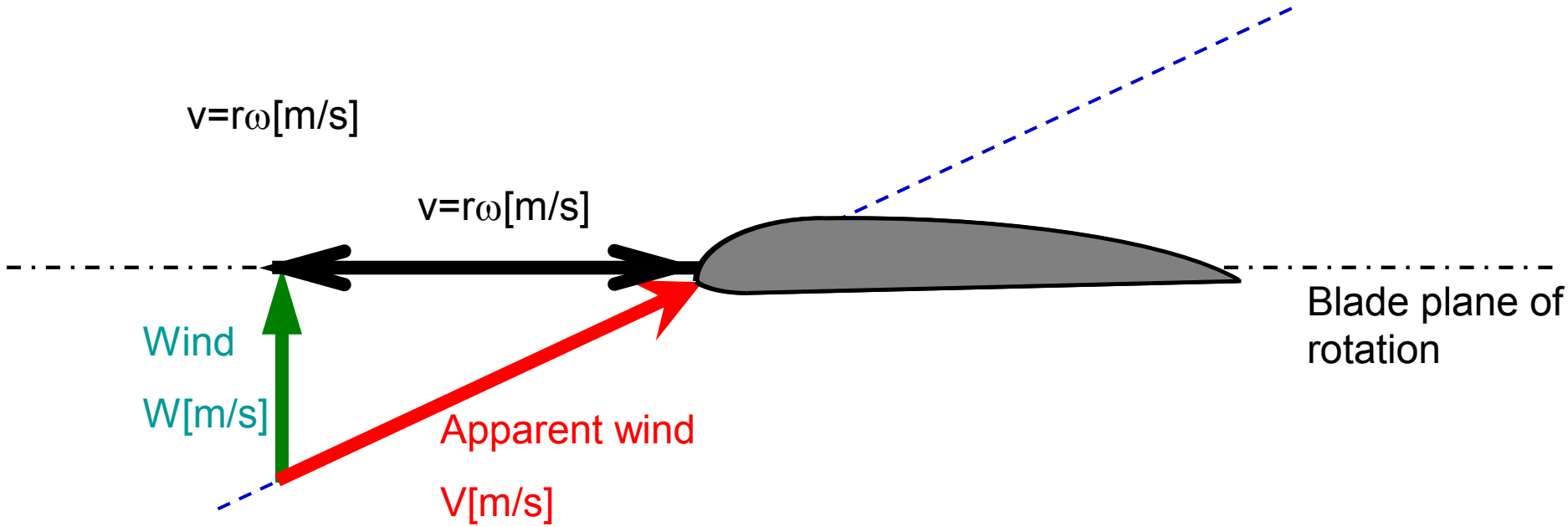
Large AoA gives not only high lift force(L) but also high drag force(D)




Glide ratio
[Lift-Drag rate]
L/D[CL/CD]
L/D maximum
Stall
AoA which shows
Largest Lift-Drag rate
0°
AoA:α

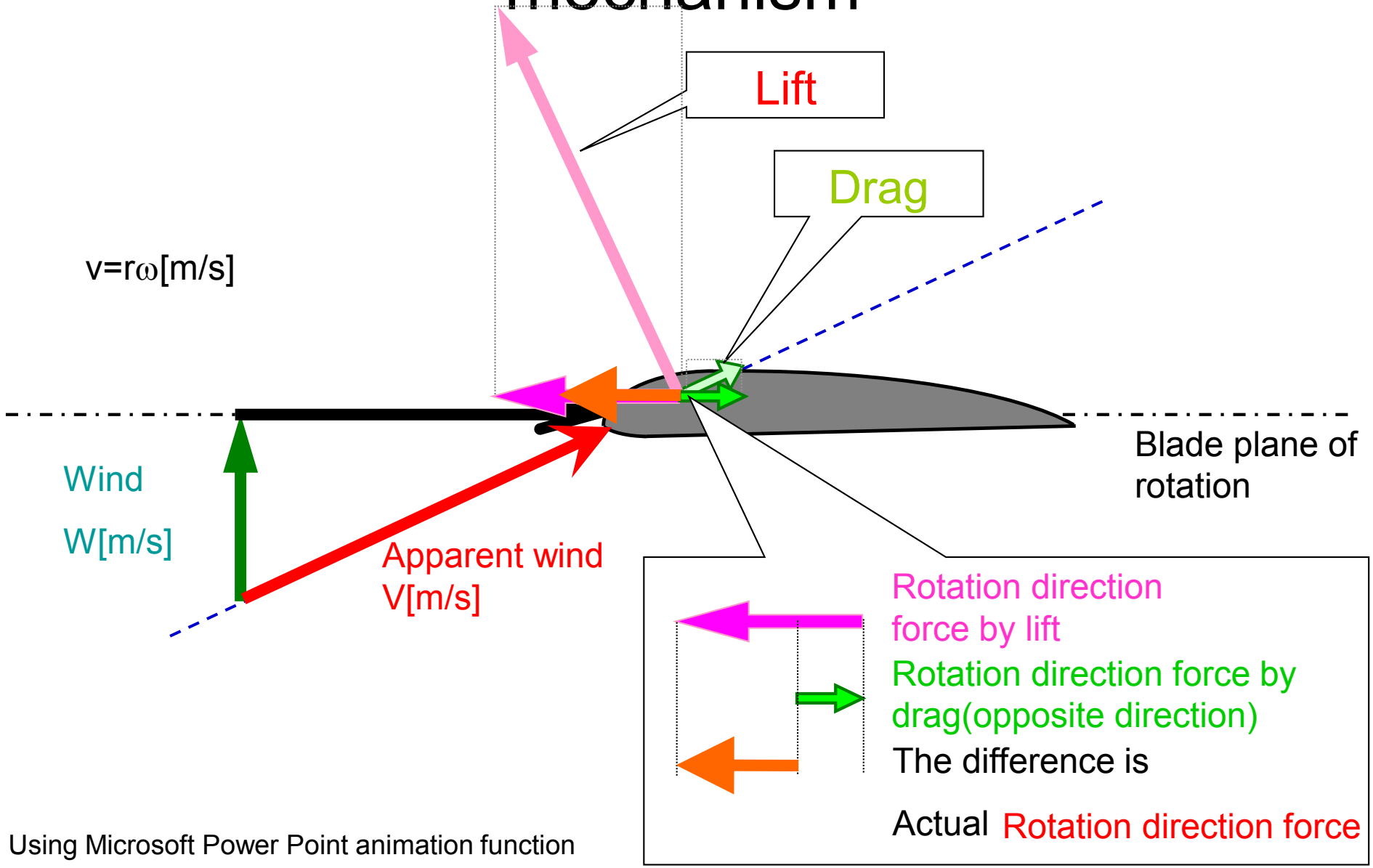
Horizontal axis wind turbine rotation mechanism

Horizontal axis wind turbine rotation mechanism



Using Microsoft Power Point animation function

Horizontal axis wind turbine rotation mechanism



Using Microsoft Power Point animation function

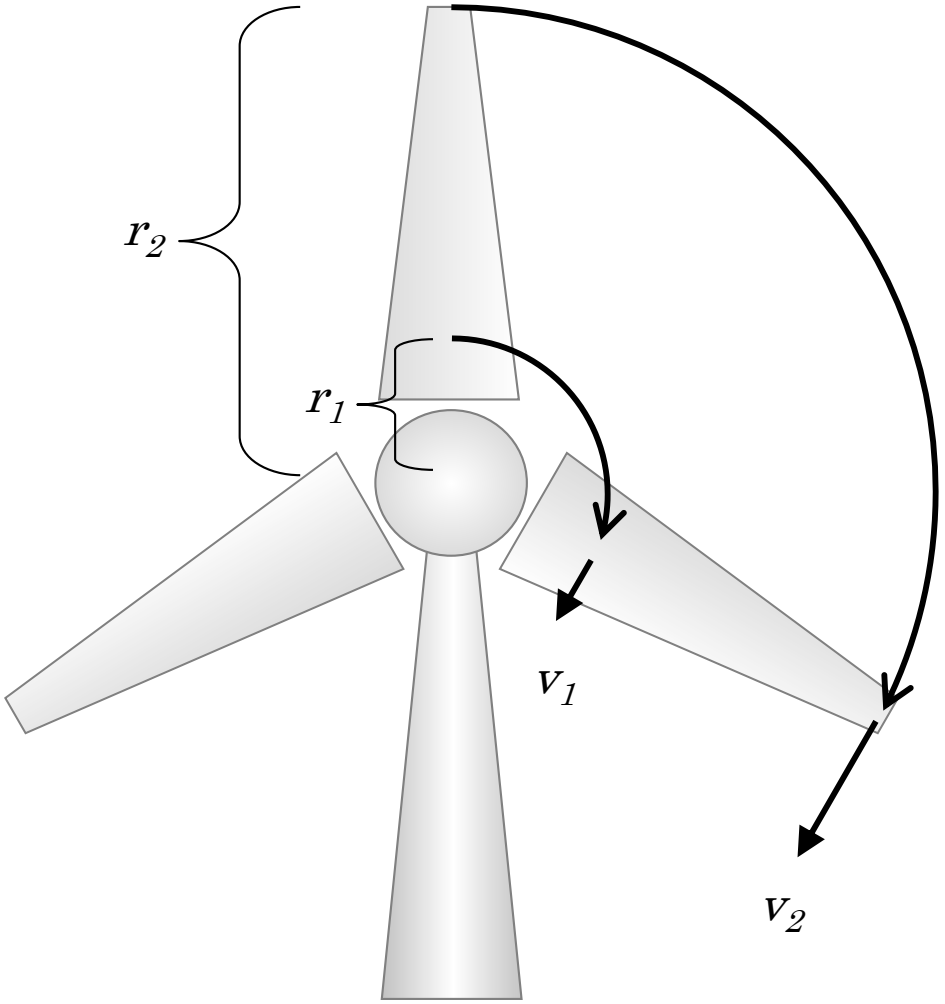
Altogether

"Large Lift-Drag rate" means "Wind turbine rotate"

Why the wind turbine blade is twisted?

Why the wind turbine blade is twisted?

There is velocity difference between at the root and the tip of the blade



$$v = r\omega = \frac{2\pi r}{T} \qquad \left(\omega = \frac{2\pi}{T} \right)$$

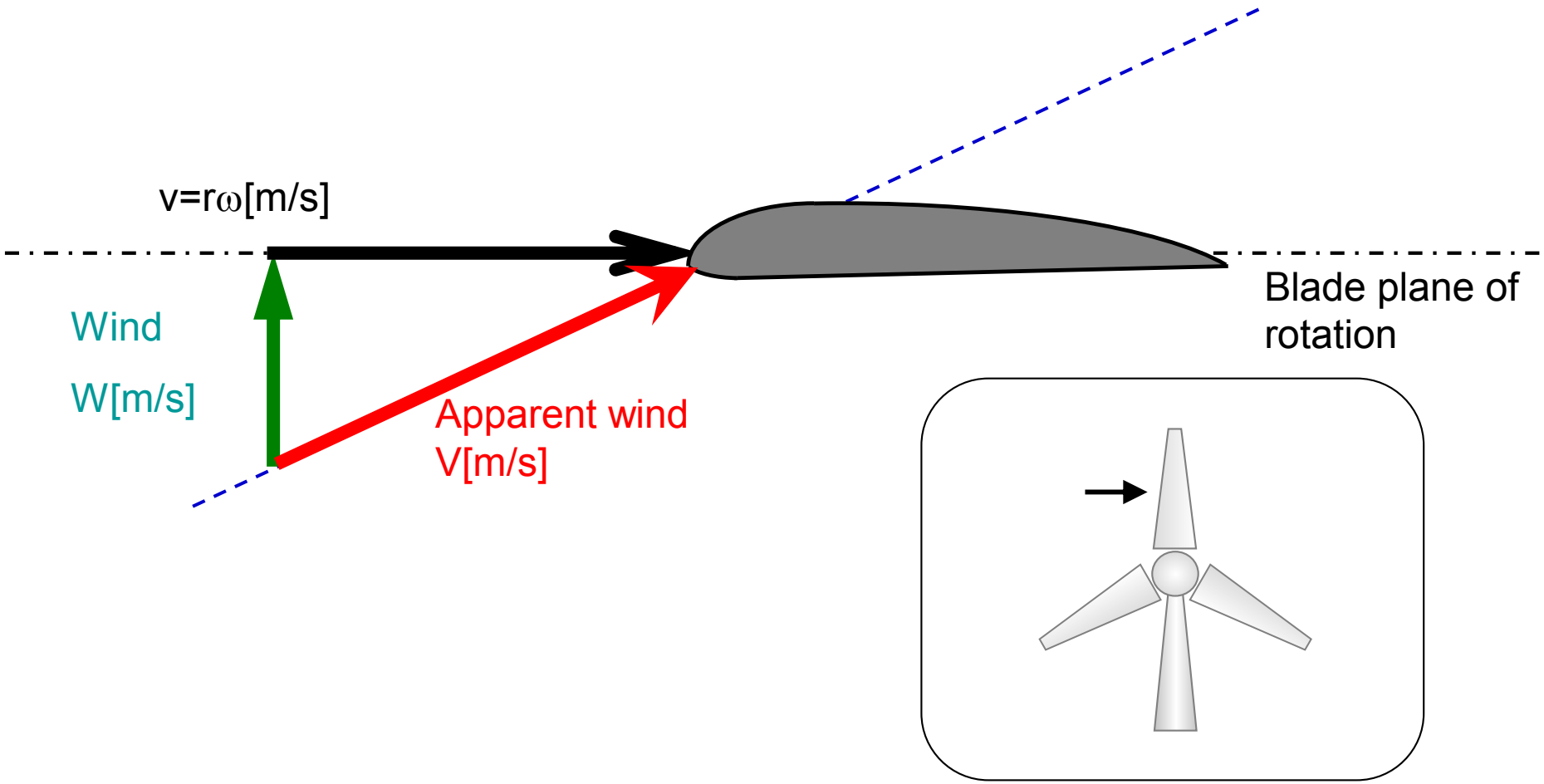
ω : angular velocity [rad/s]

T:time

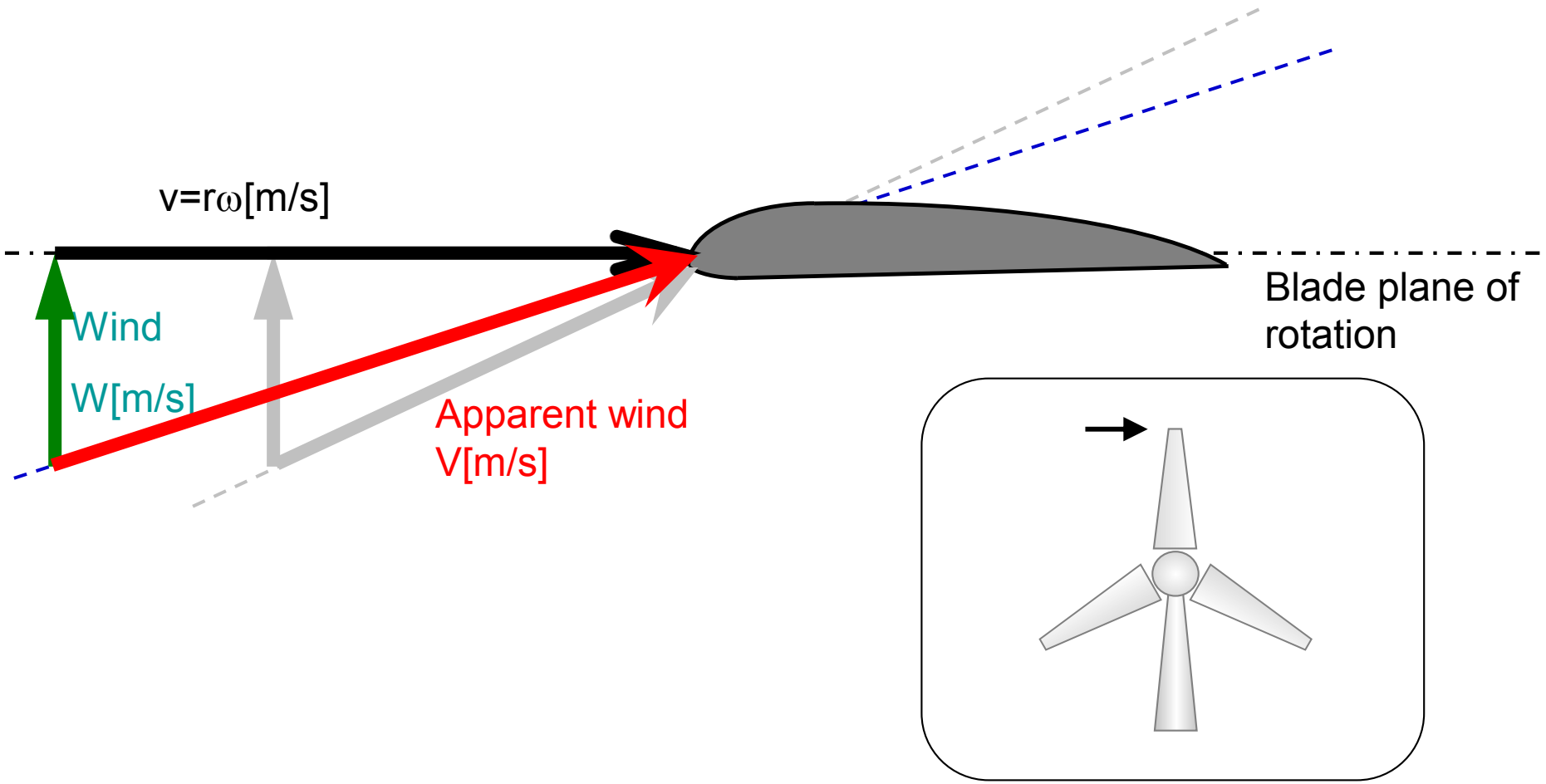
$$v_1 = r_1\omega = \frac{2\pi r_1}{T} < v_2 = r_2\omega = \frac{2\pi r_2}{T}$$

The tip of the blade is higher in rotational speed than the root

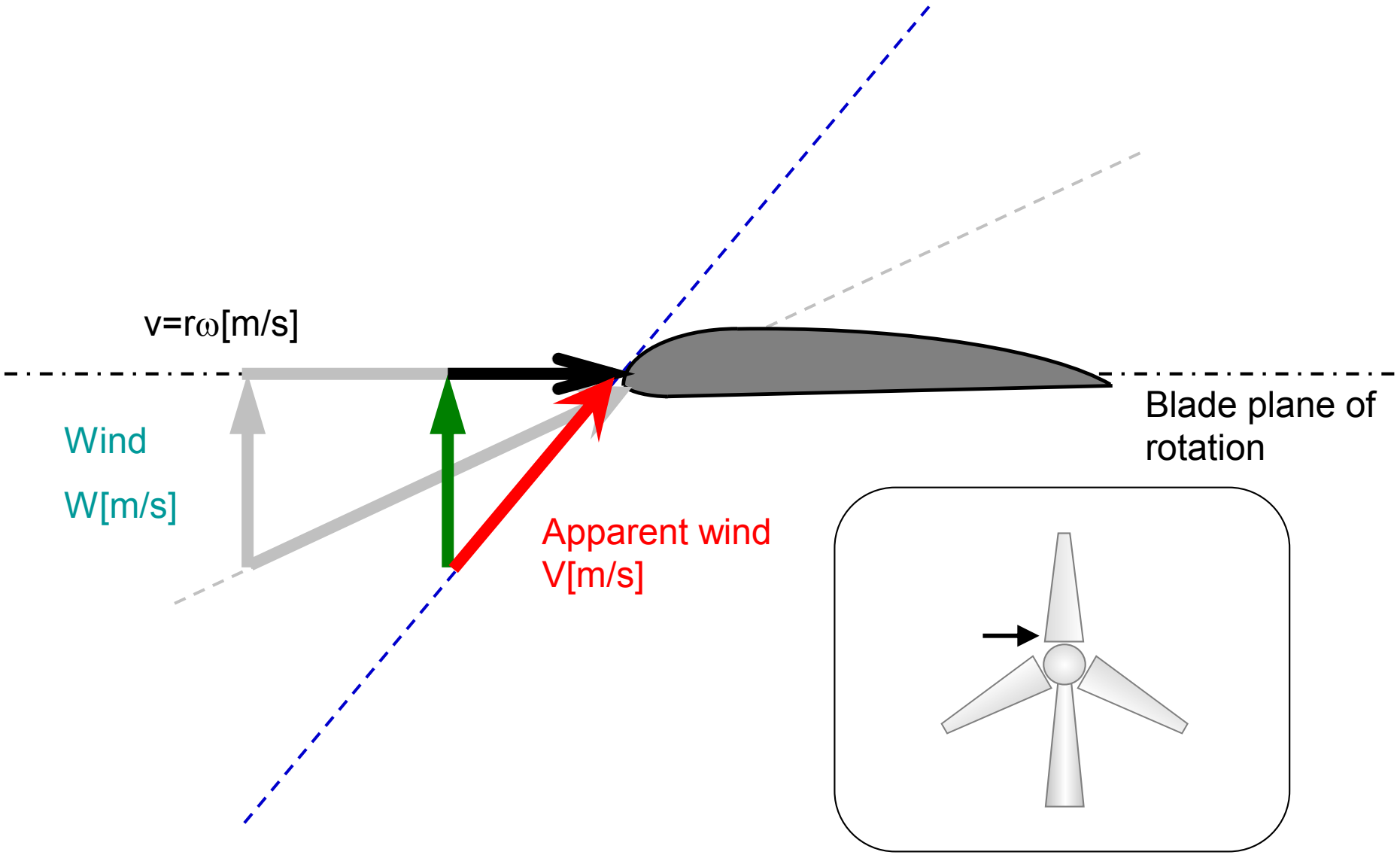
When it suppose to be the central position of the blade



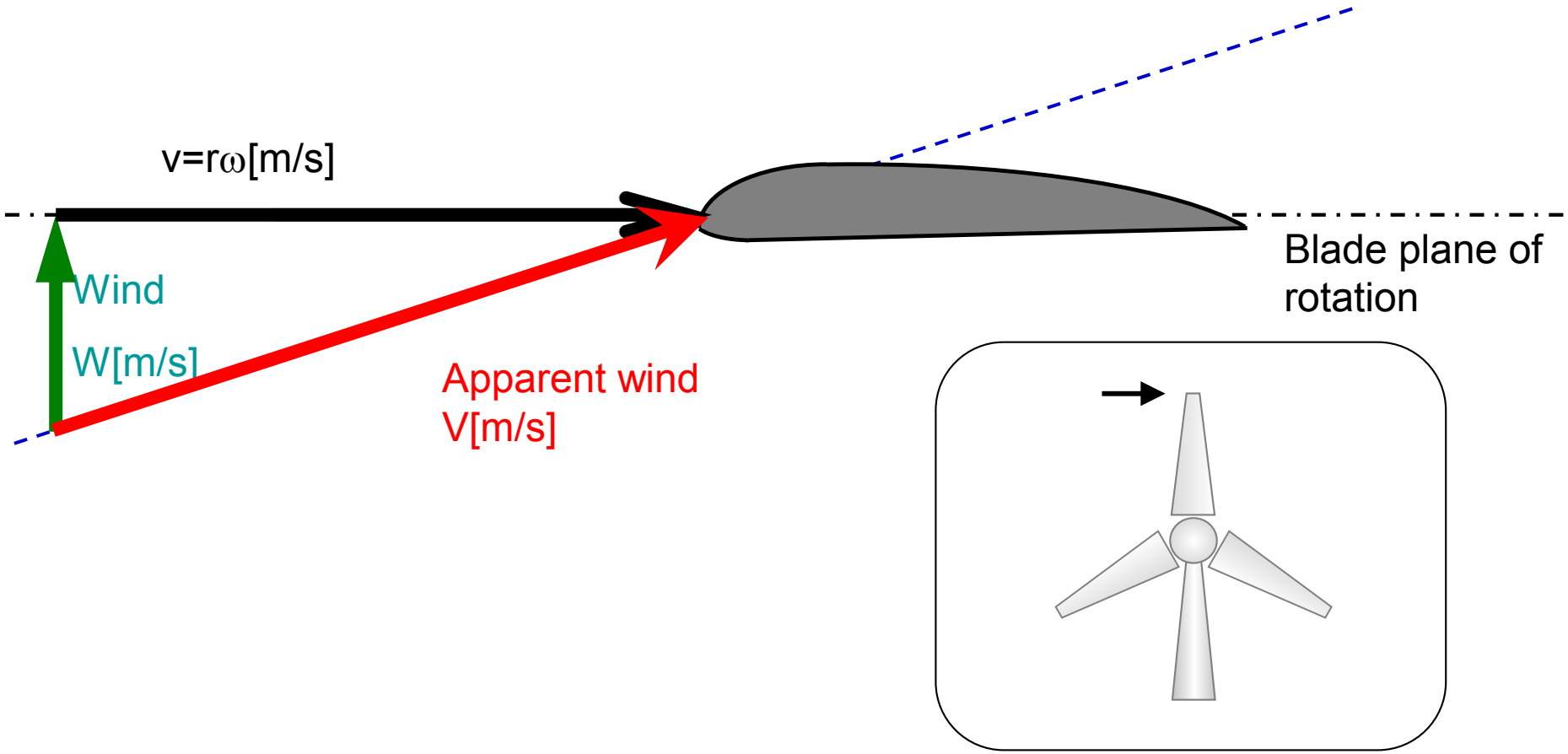
When it suppose to be the tip of the blade

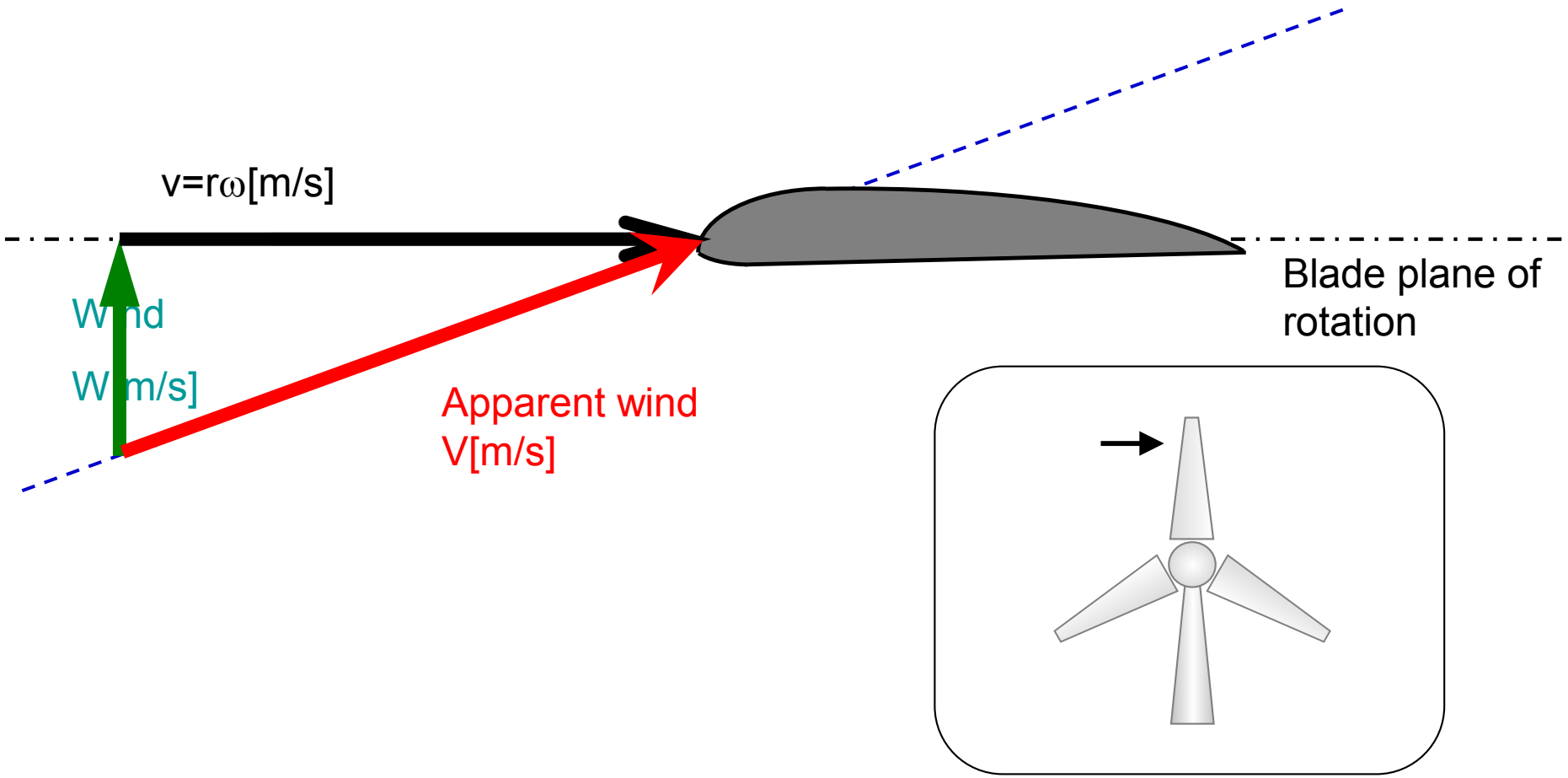


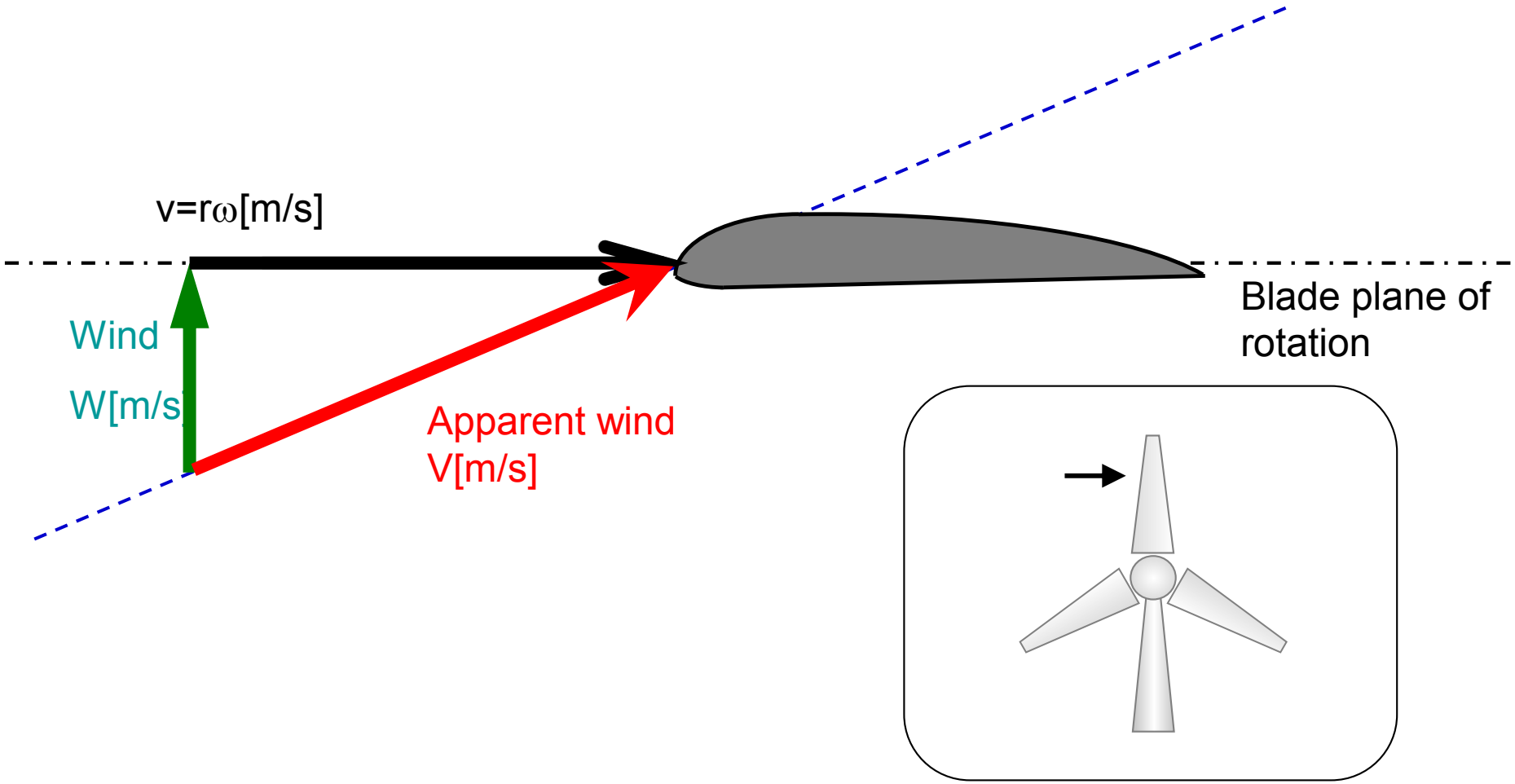
When it suppose to be the root of the blade



The image of AoA from tip to root is…


v=rω[m/s]
Wind
W[m/s]
Apparent wind
V[m/s]
Blade plane of
rotation


v=rω[m/s]
Wind
W[m/s]
Apparent wind
V[m/s]
Blade plane of
rotation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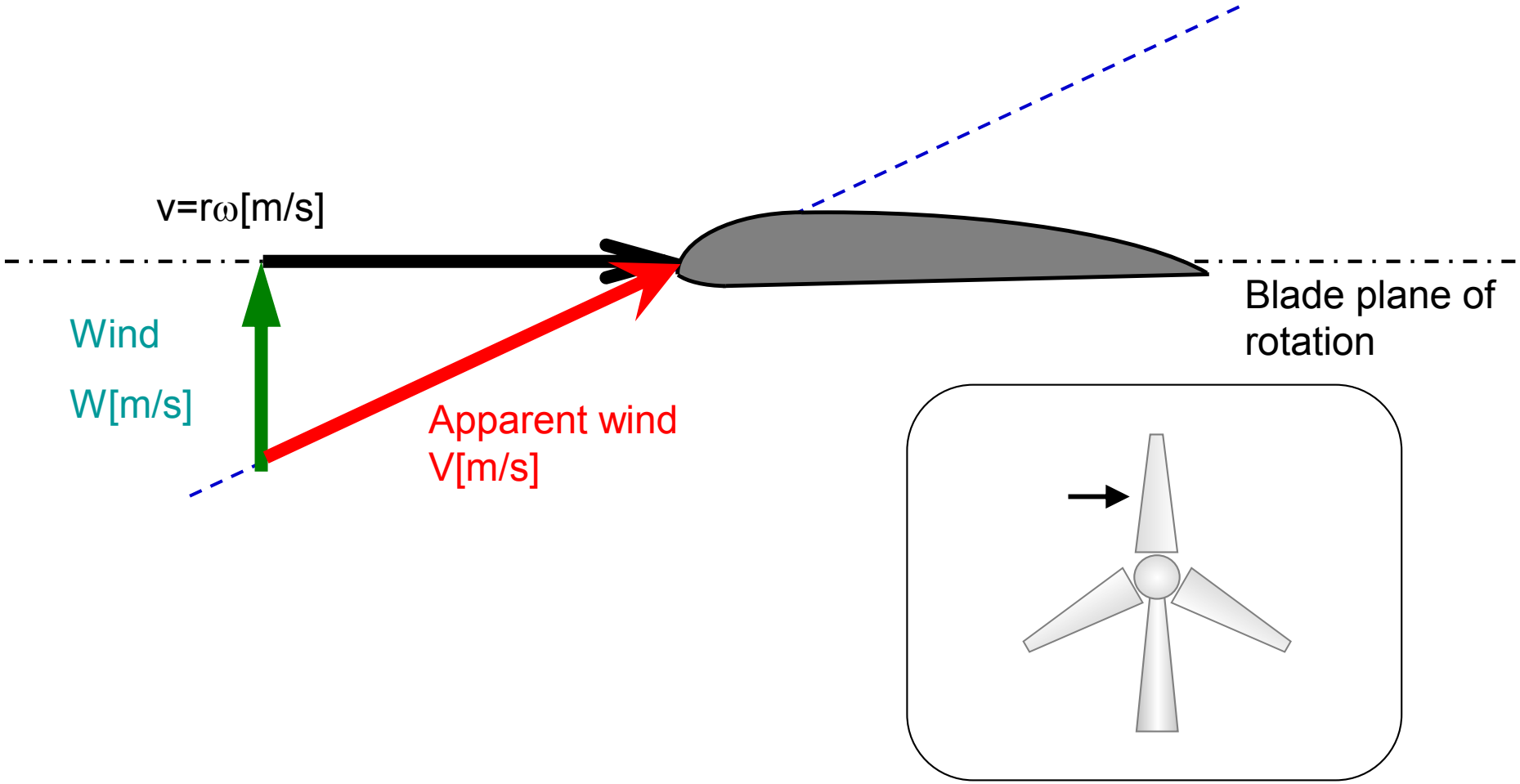
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Wind
W[m/s]
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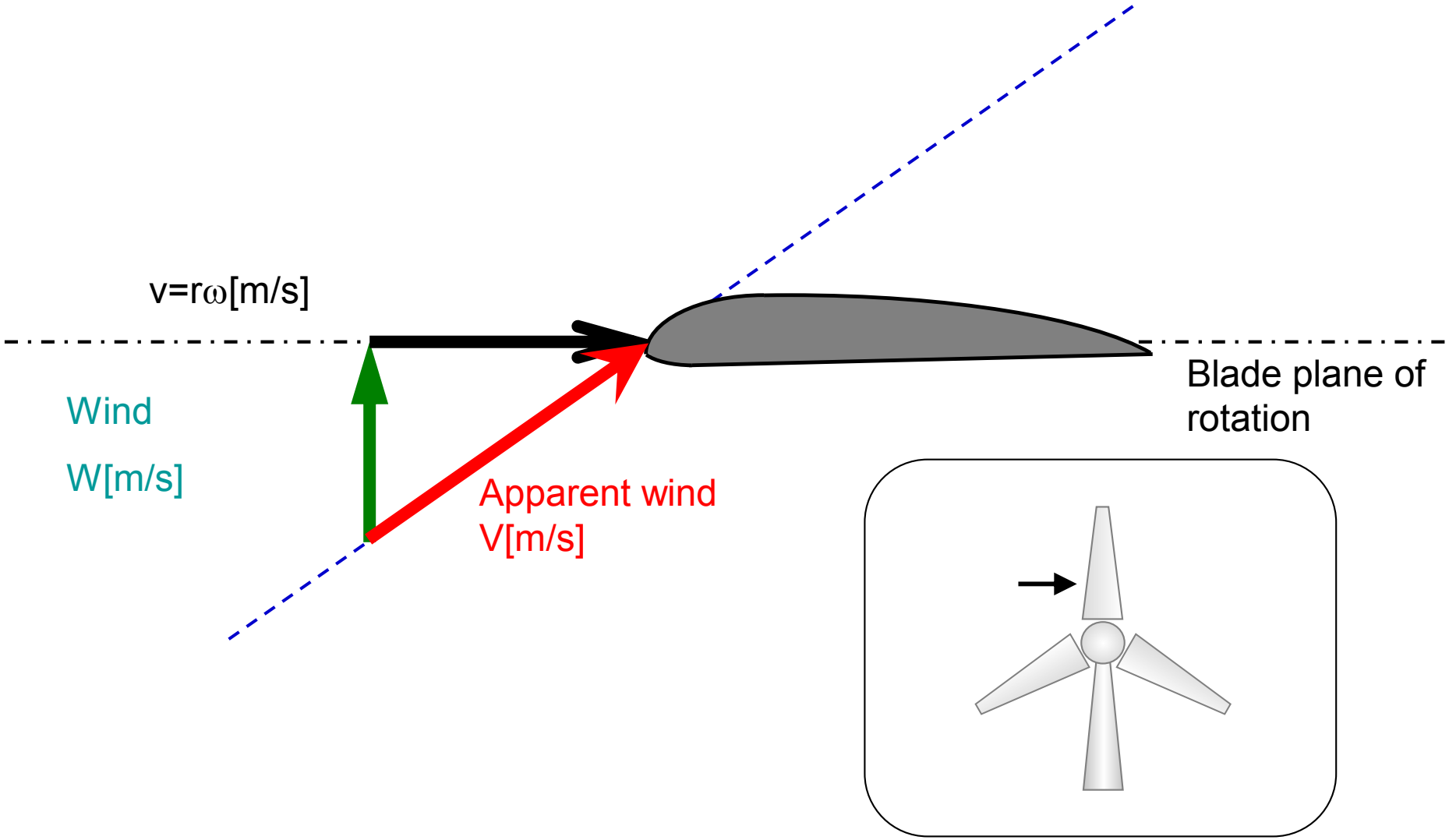
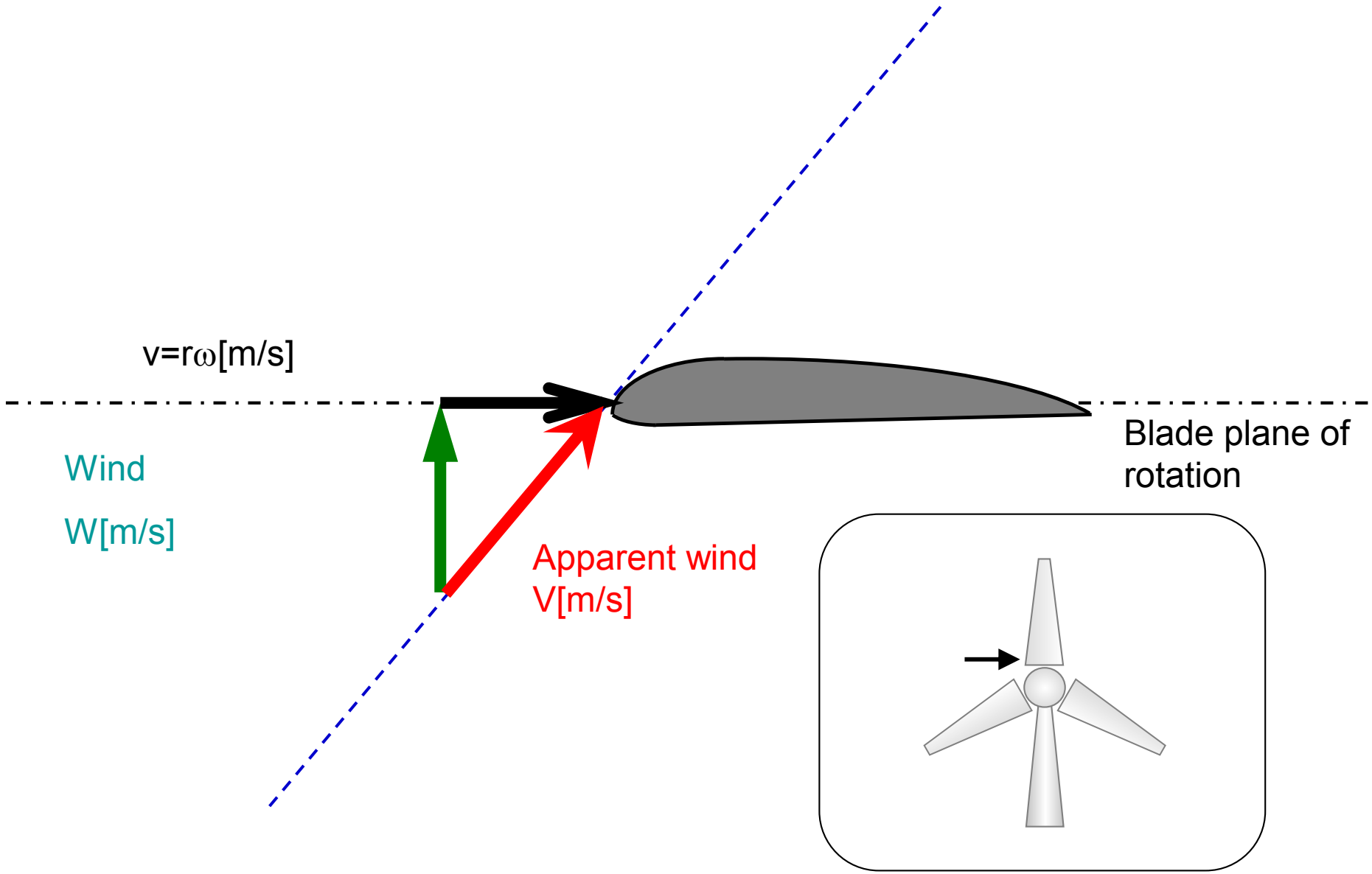
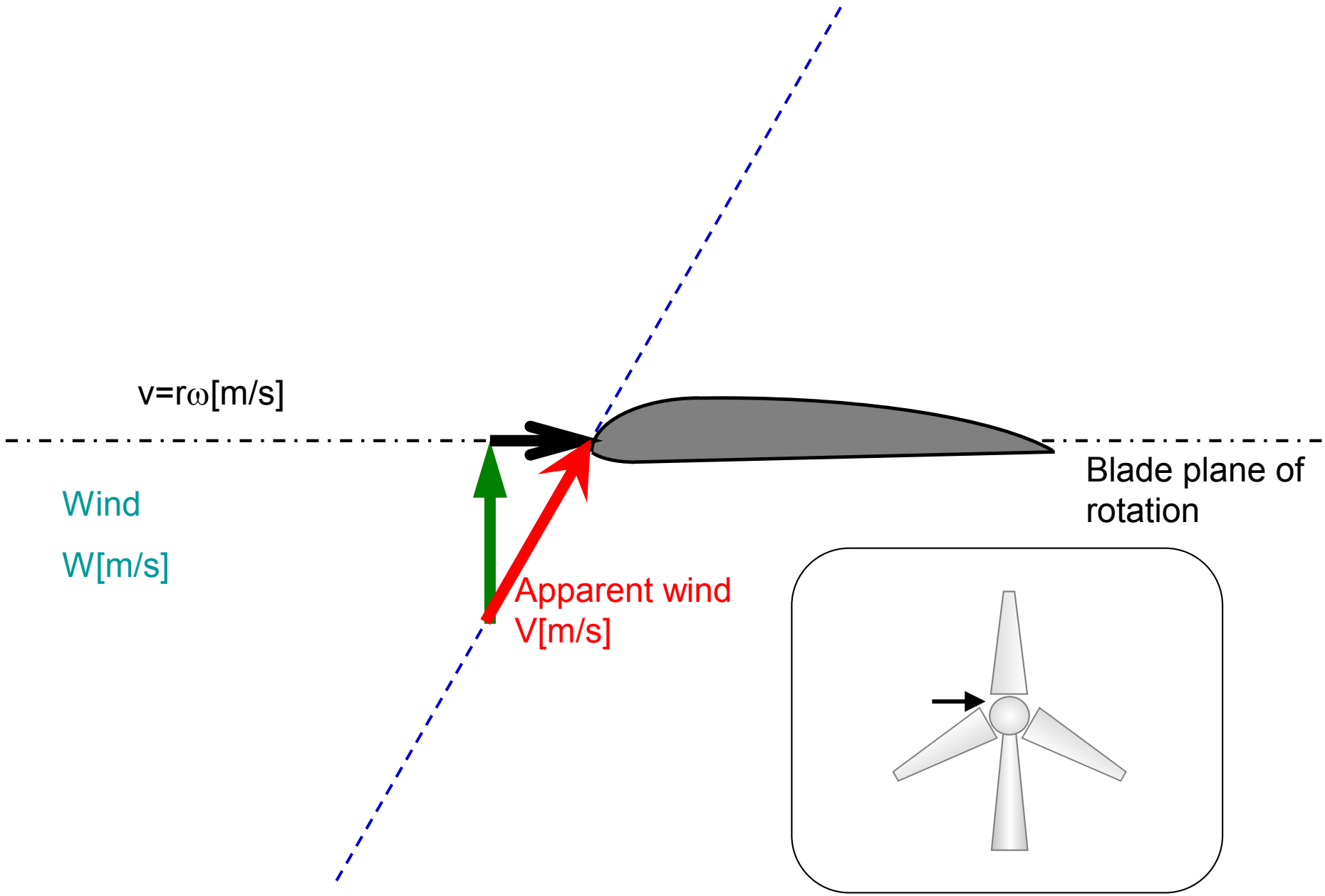
V[m/s]
Blade plane of
rotation


v=rω[m/s]
Wind
W[m/s]
Apparent wind
V[m/s]
Blade plane of
rotation

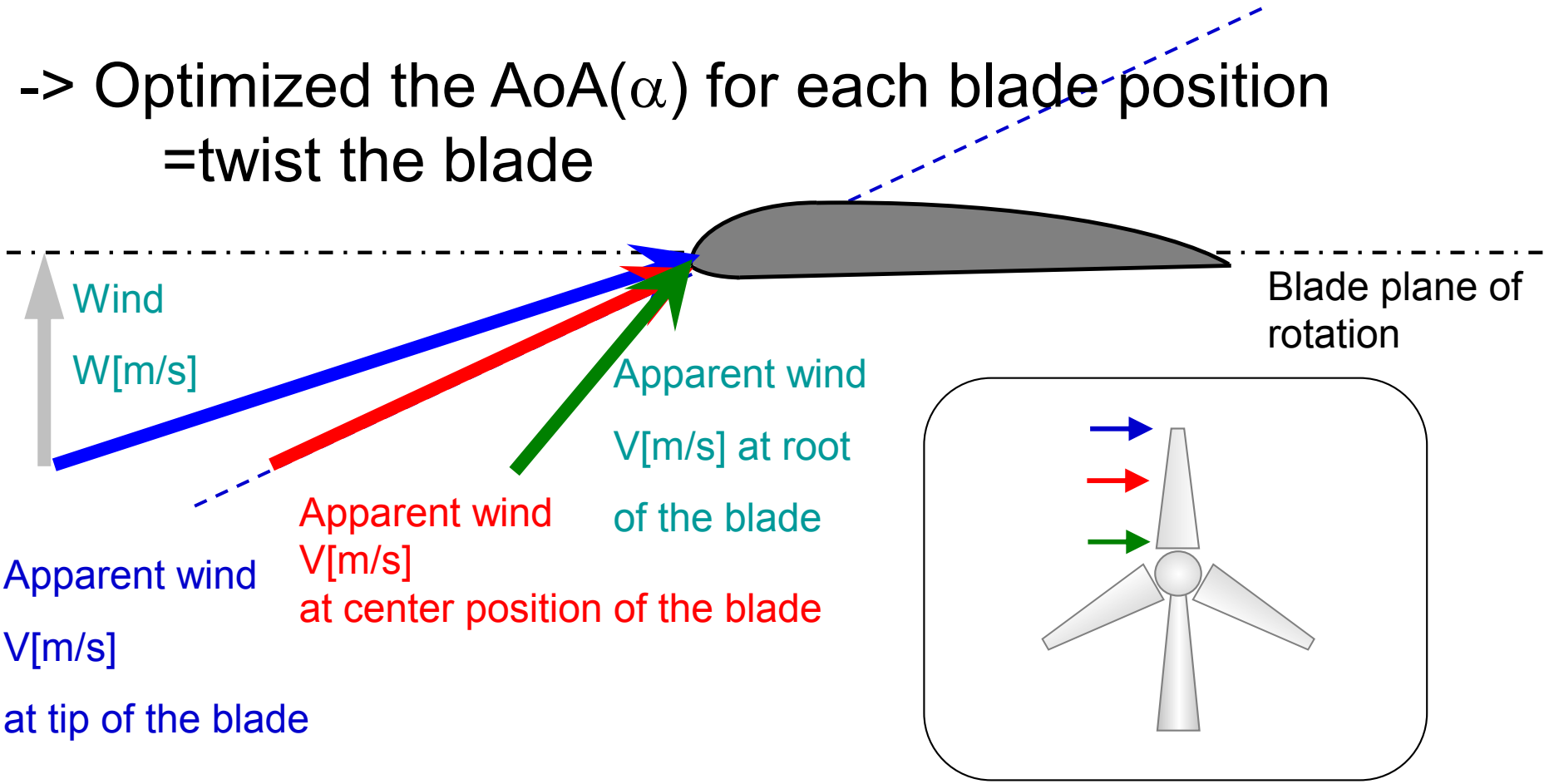

v=rω[m/s]
Wind
W[m/s]
Apparent wind
V[m/s]
Blade plane of
rotation


v=rω[m/s]
Wind
W[m/s]
Apparent wind
V[m/s]
Blade plane of
rotation

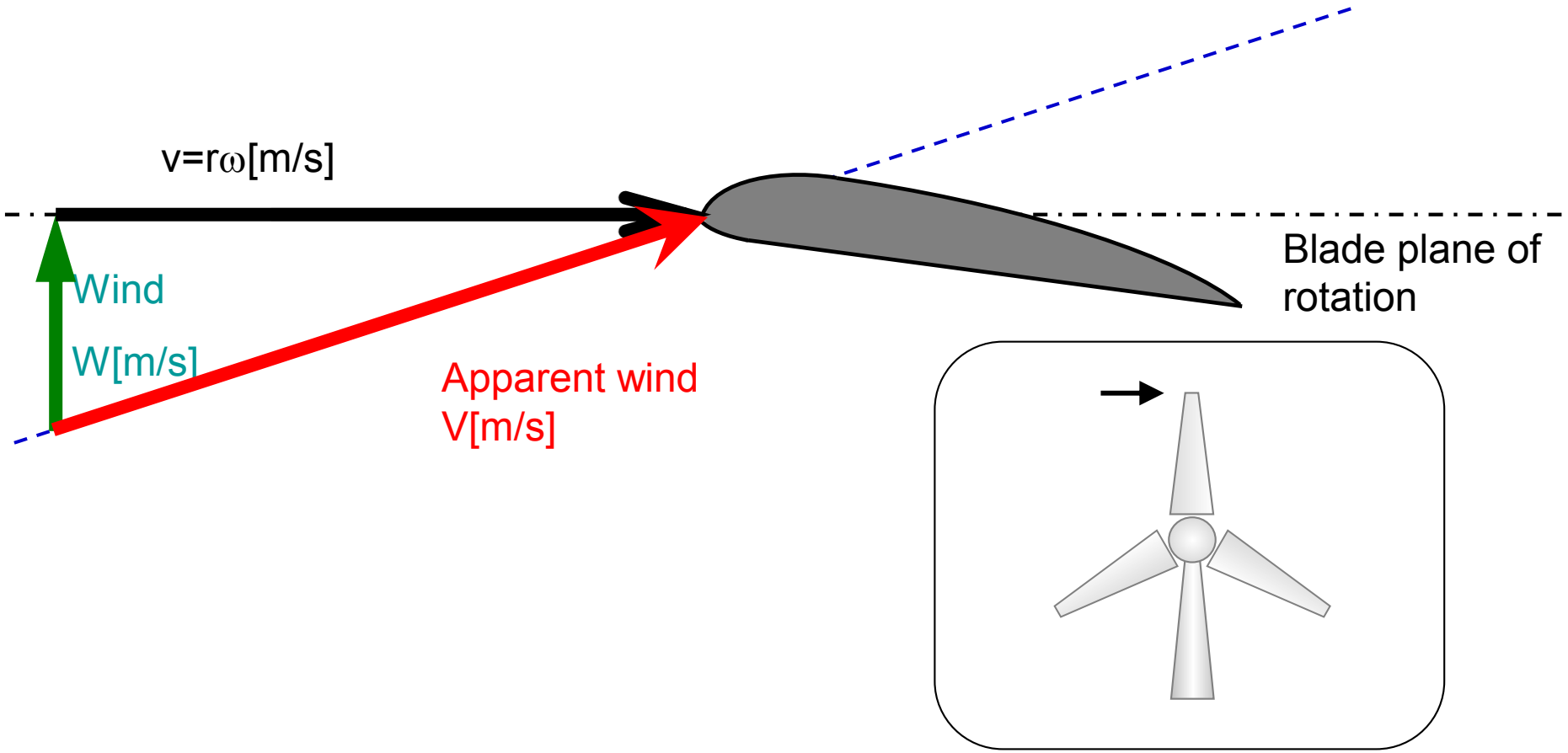
If Blade is not twisted(straight),

AoA is not optimized

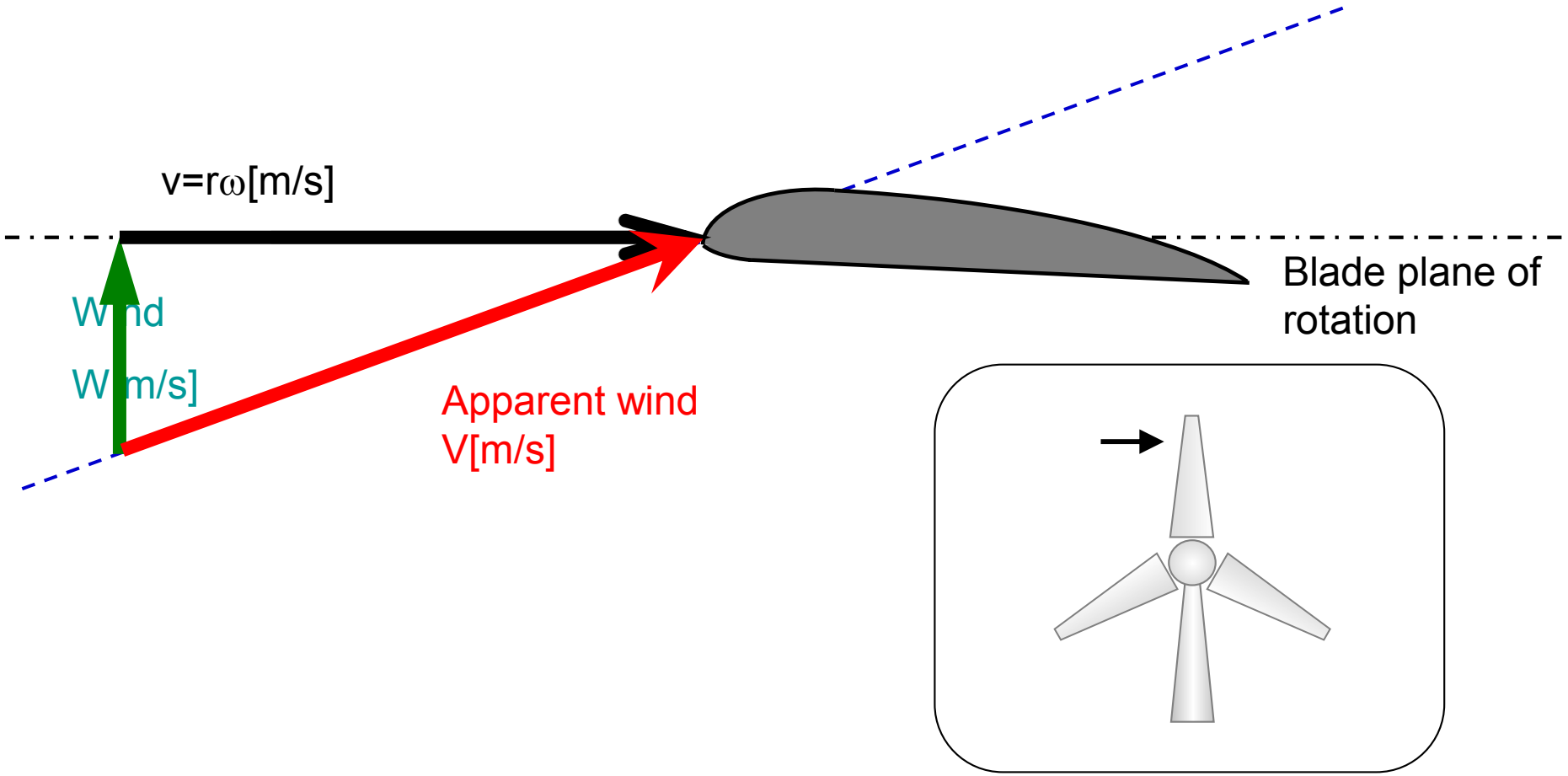
-> Optimized the AoA(α) for each blade position
=twist the blade



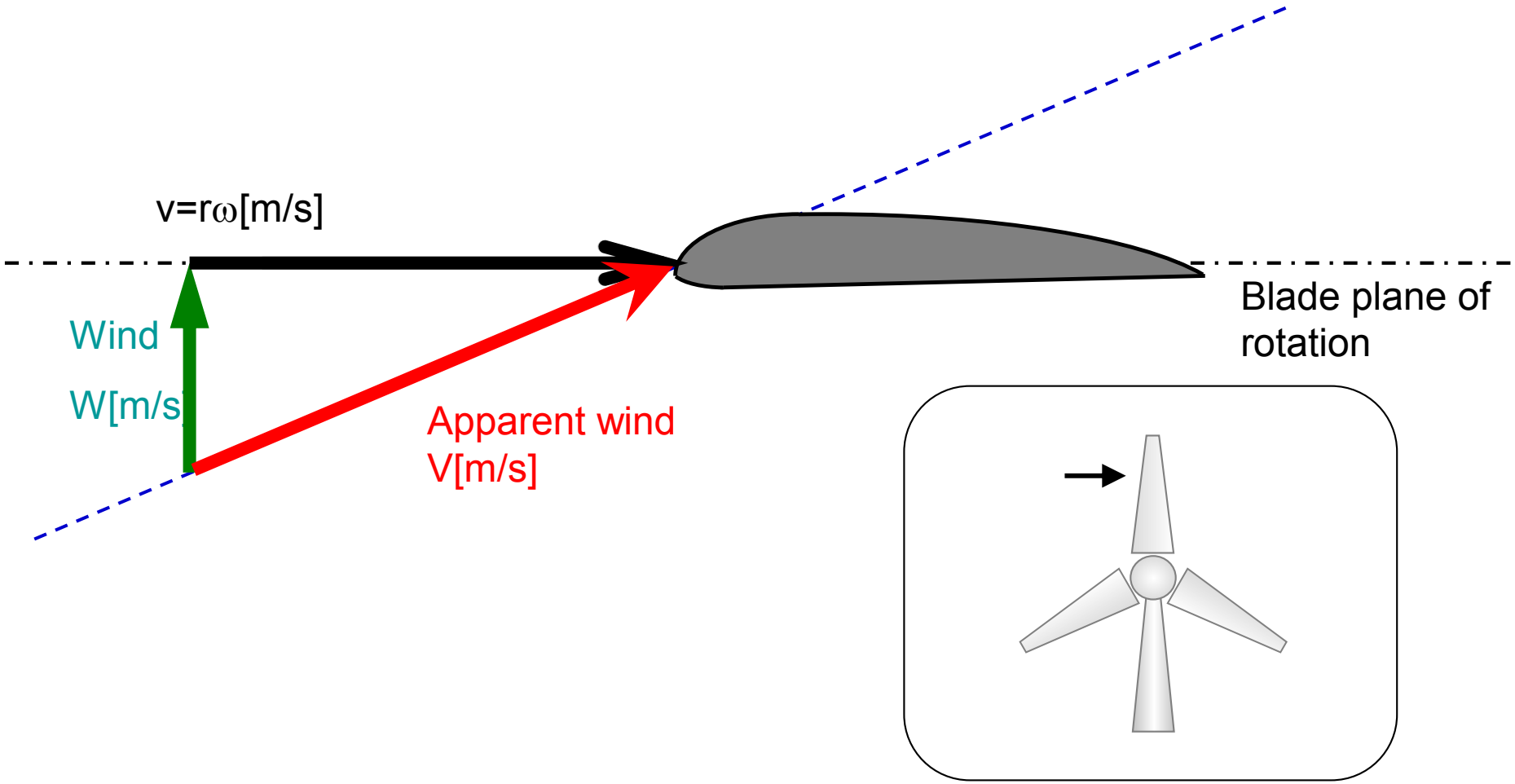
Optimized the AoA(α) for each blade position



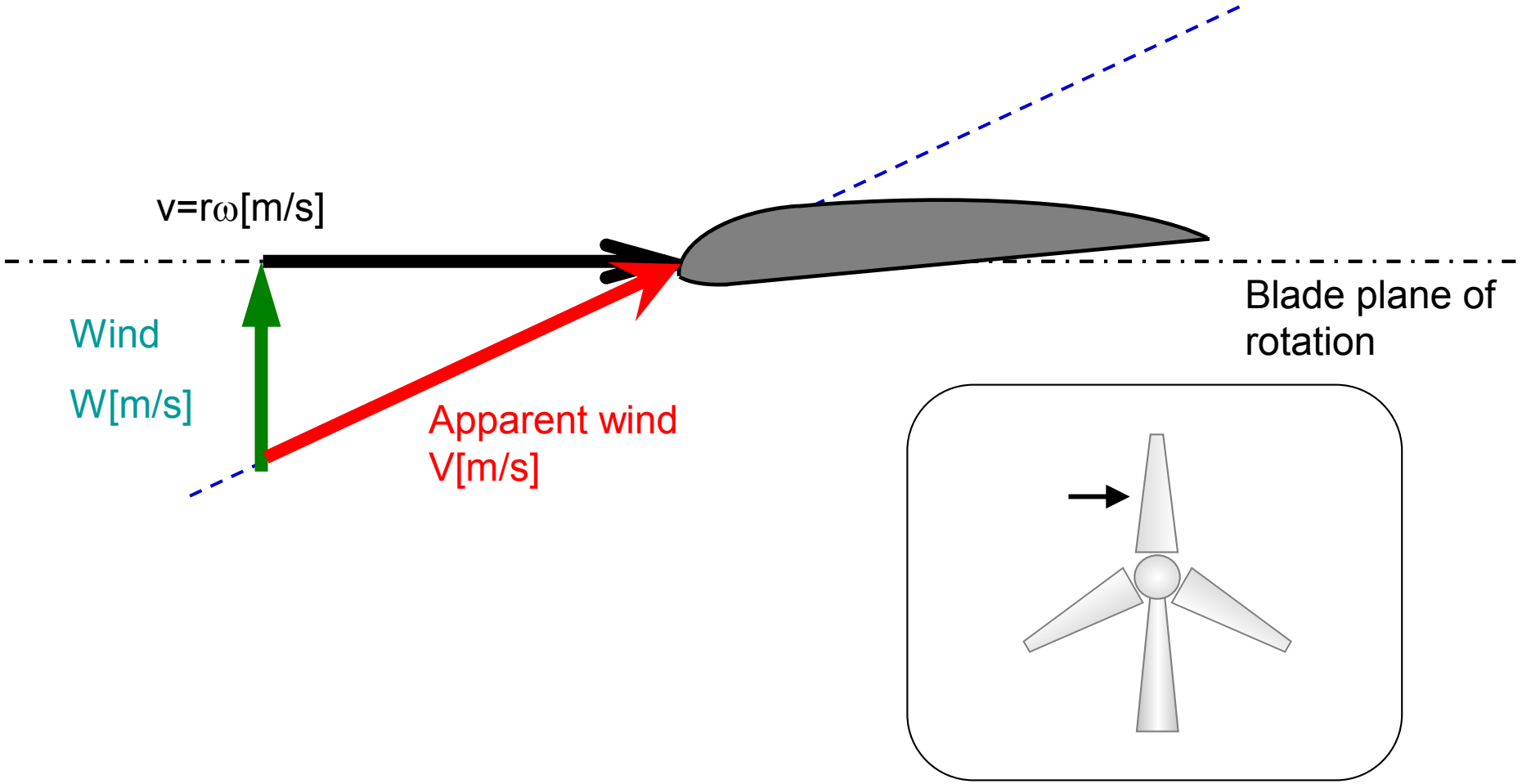
Optimized the AoA(α) for each blade position



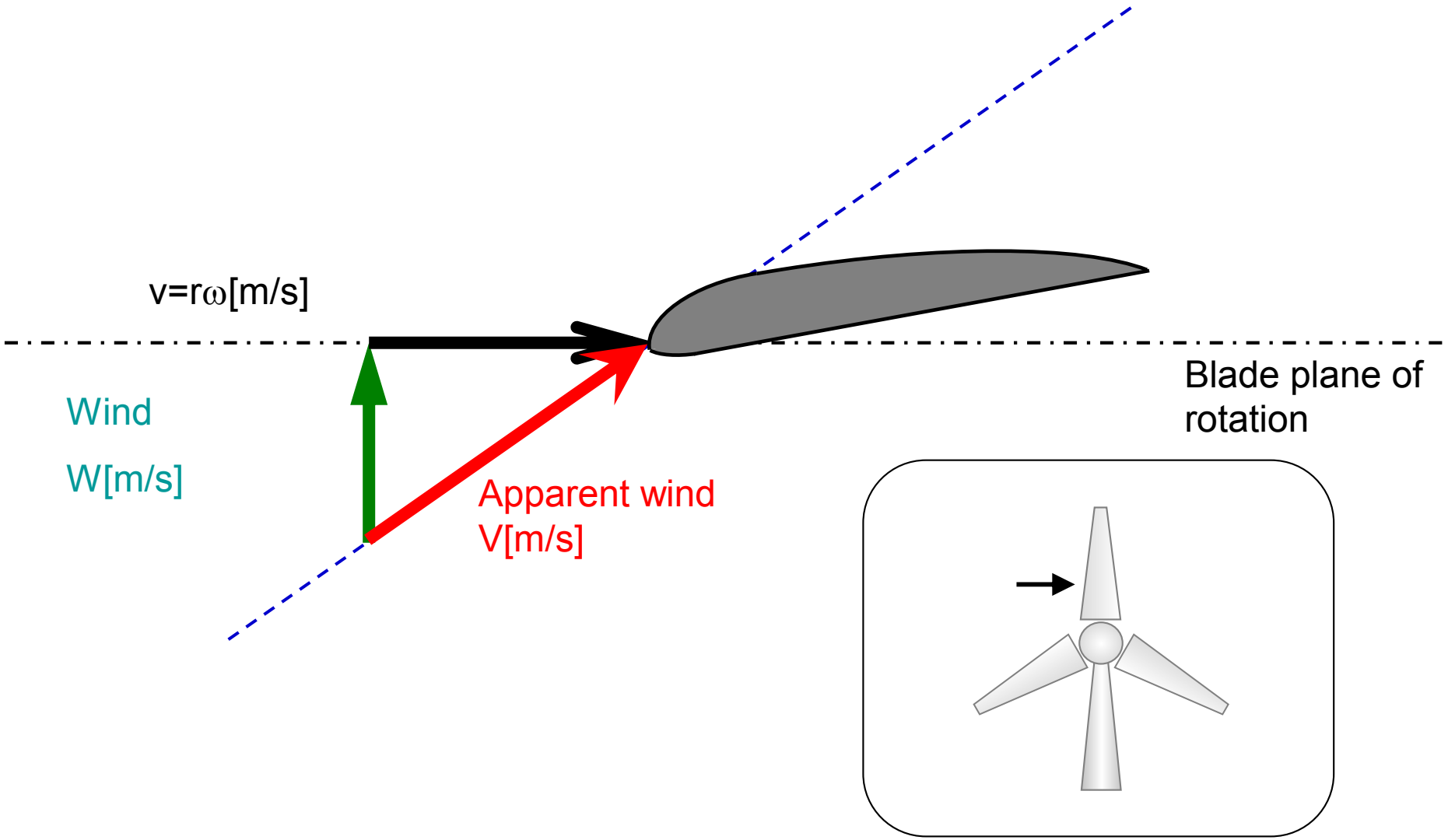
Optimized the AoA(α) for each blade position



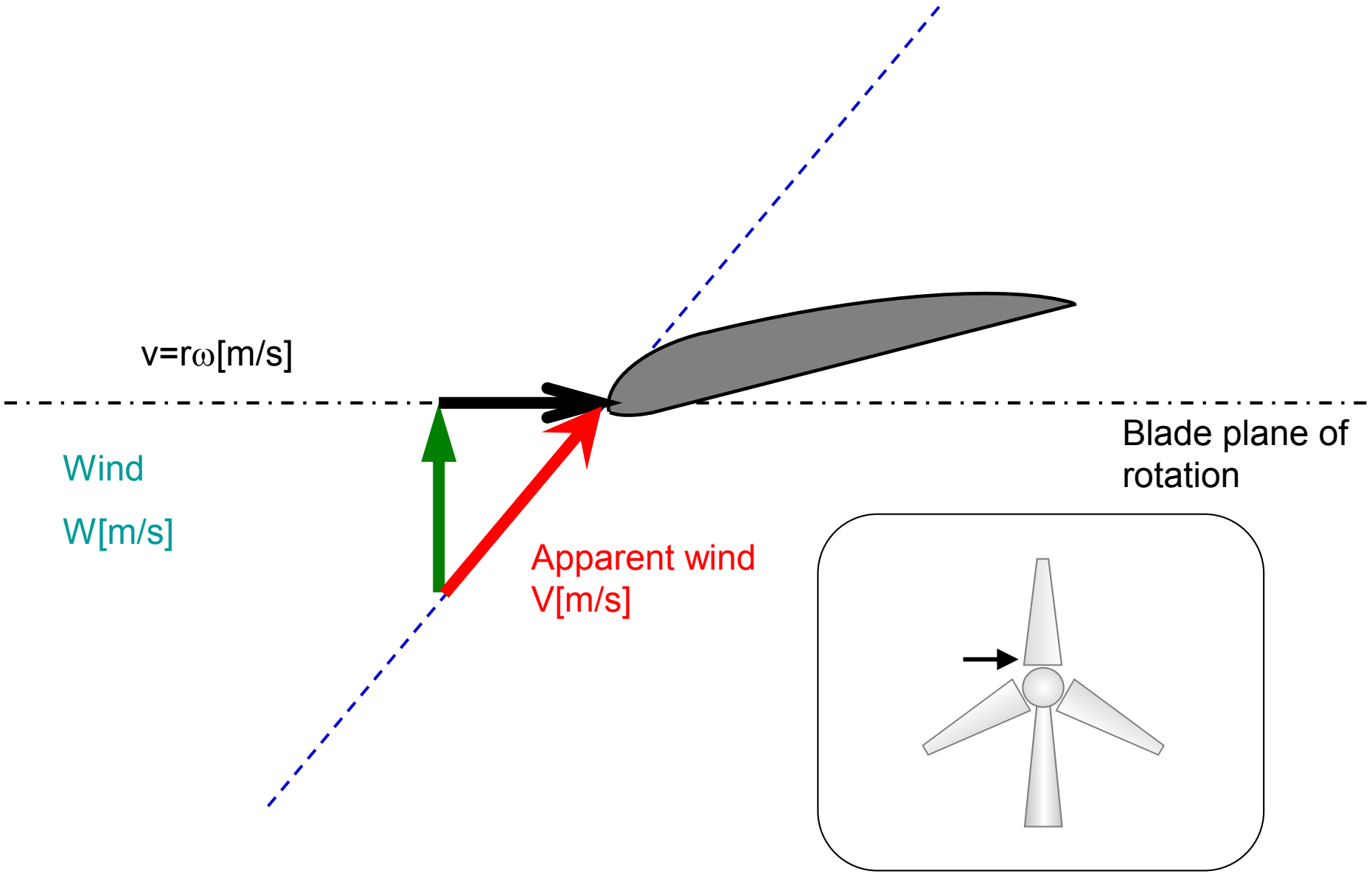
Optimized the AoA(α) for each blade position



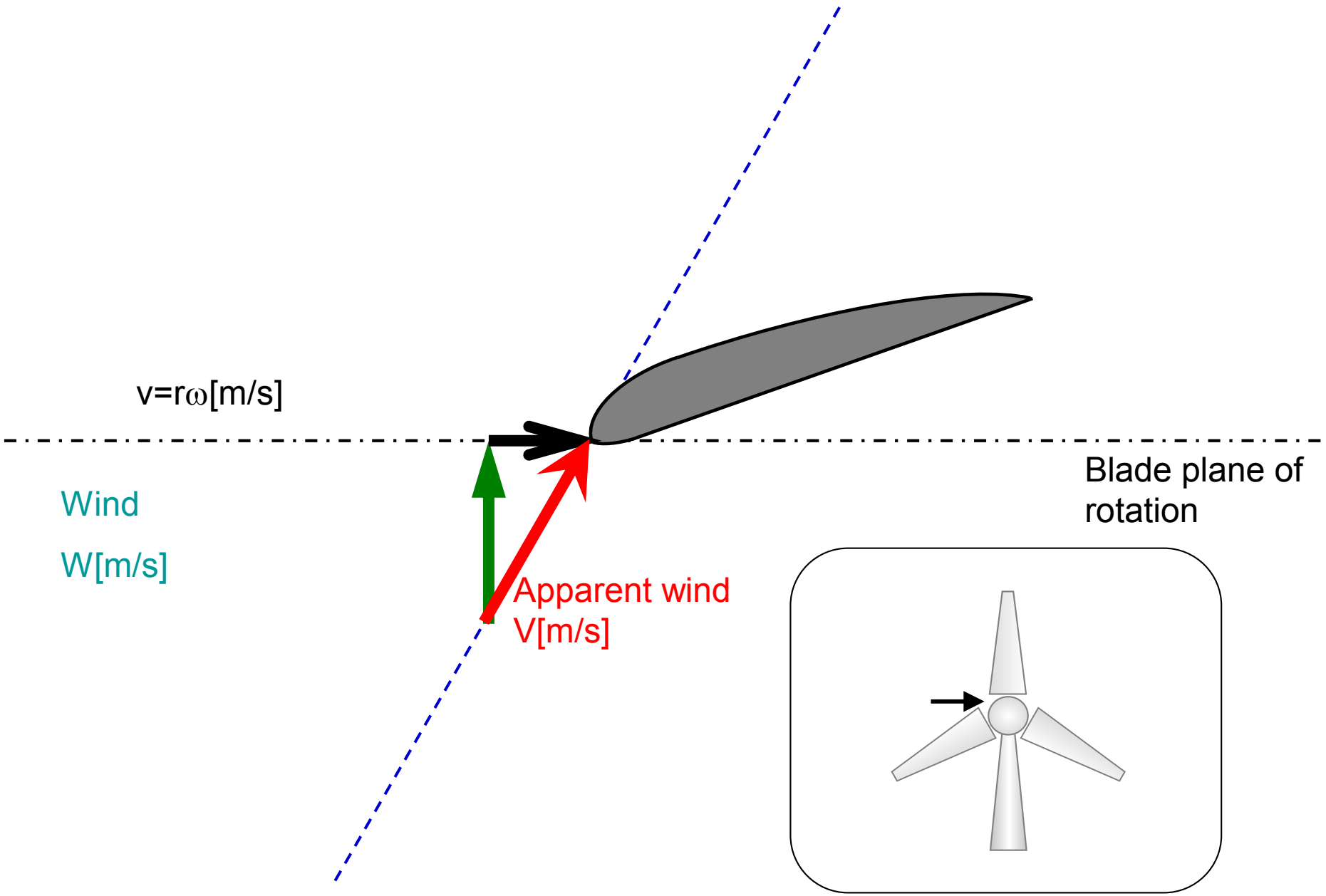
Optimized the AoA(α) for each blade position



Optimized the AoA(α) for each blade position

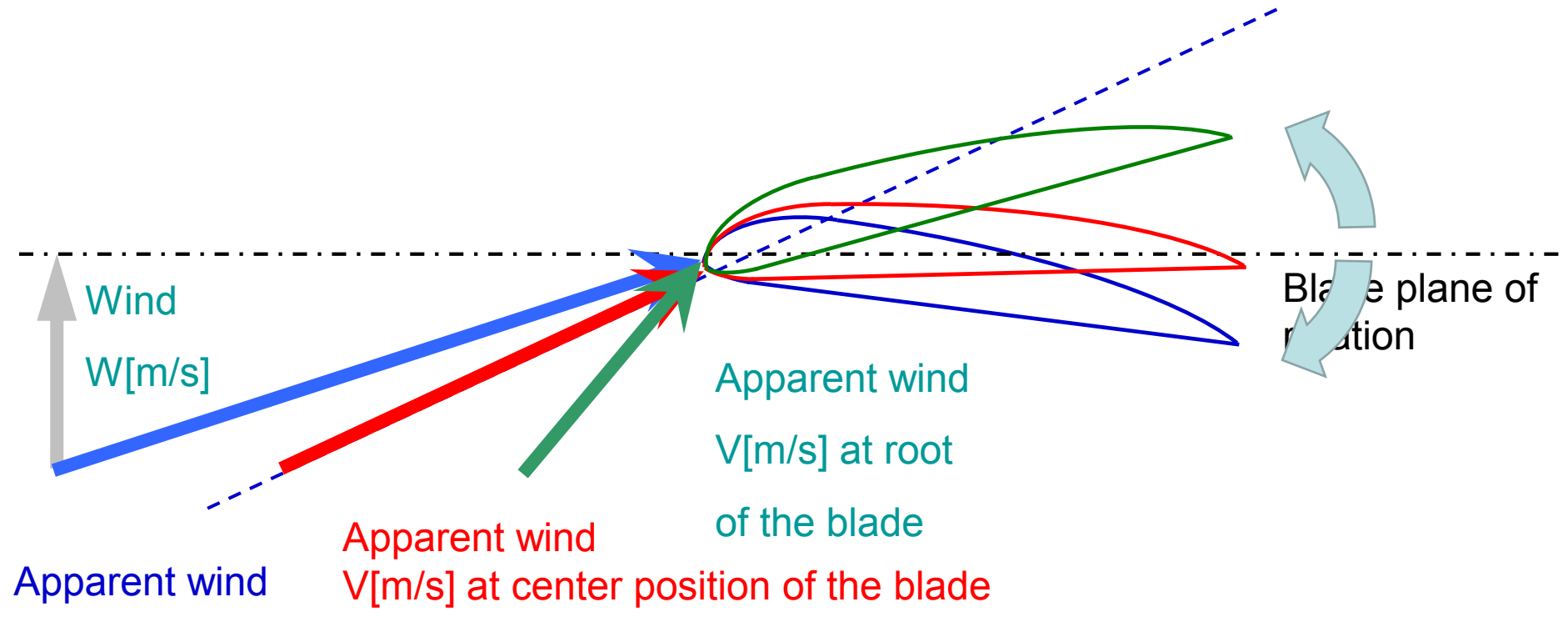


Optimized the AoA(α) for each blade position



Optimized the AoA(α) for each blade position

=the wind turbine blade is twisted

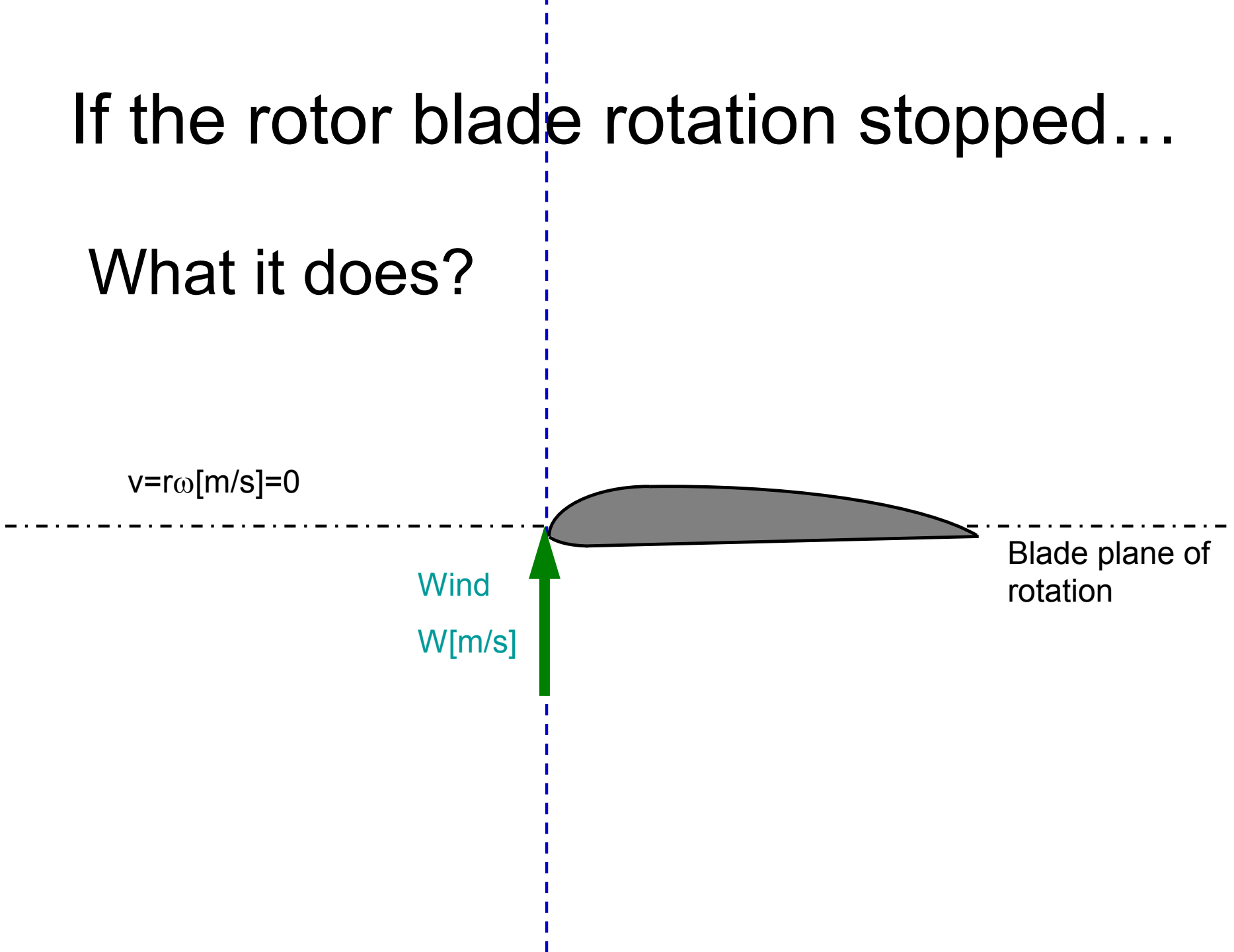


Actually, airfoil shape is different for each position of the blade, because of apparent wind velocity difference.

If the rotor blade rotation stopped…

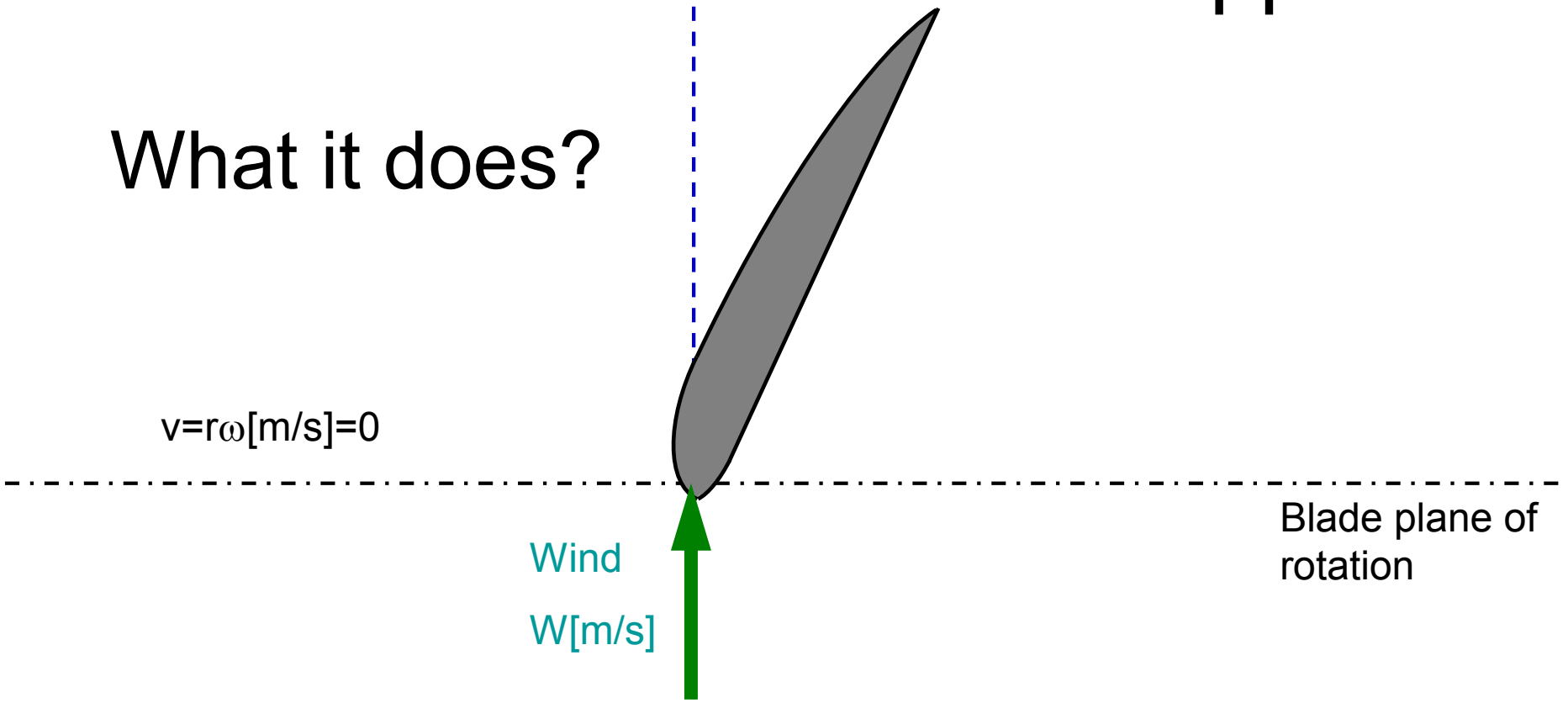
If the rotor blade rotation stopped…

What it does?



If the rotor blade rotation stopped…

What it does?

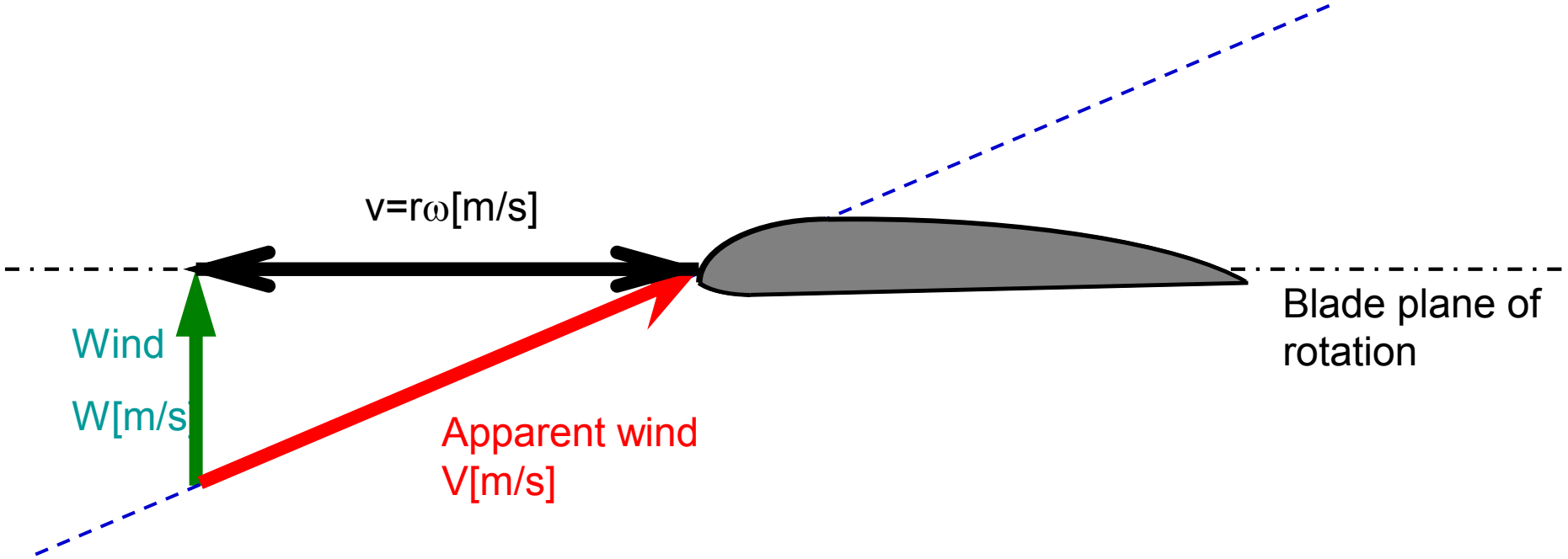


① Change the pitch angle

or…

If the rotor blade rotation stopped…

What it does?



② give more peripheral velocity[starting torque]

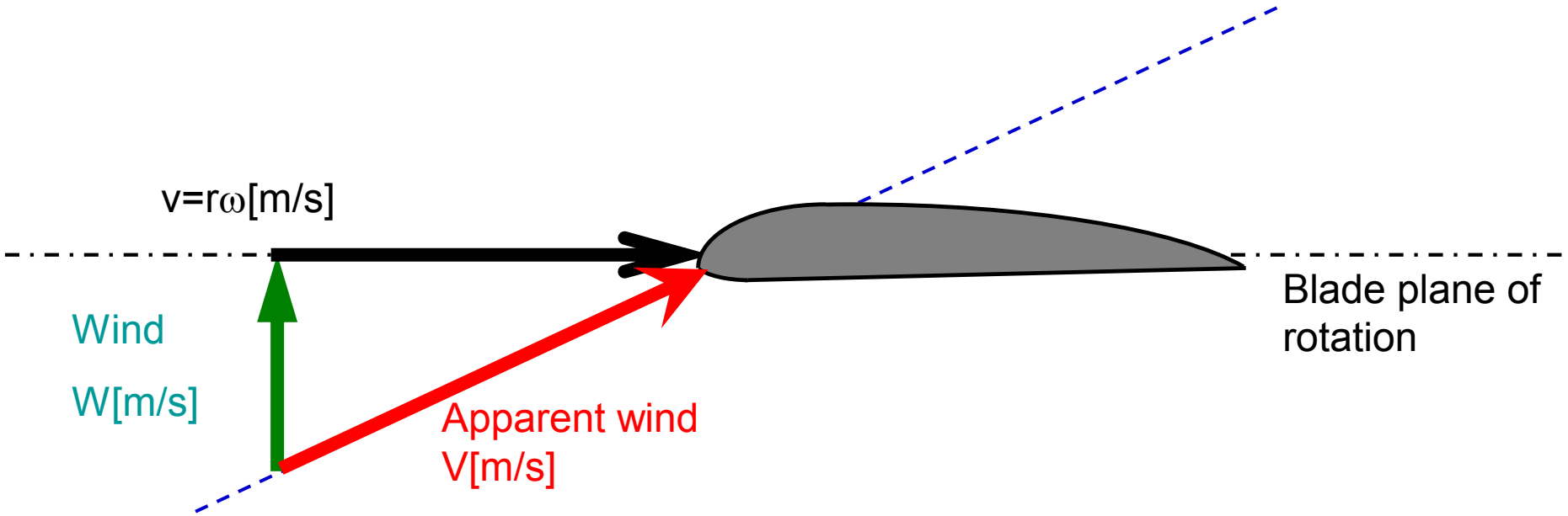
This slide is using Microsoft PowerPoint animation

If the wind speed change?

Wind stops or gust of wind blew!

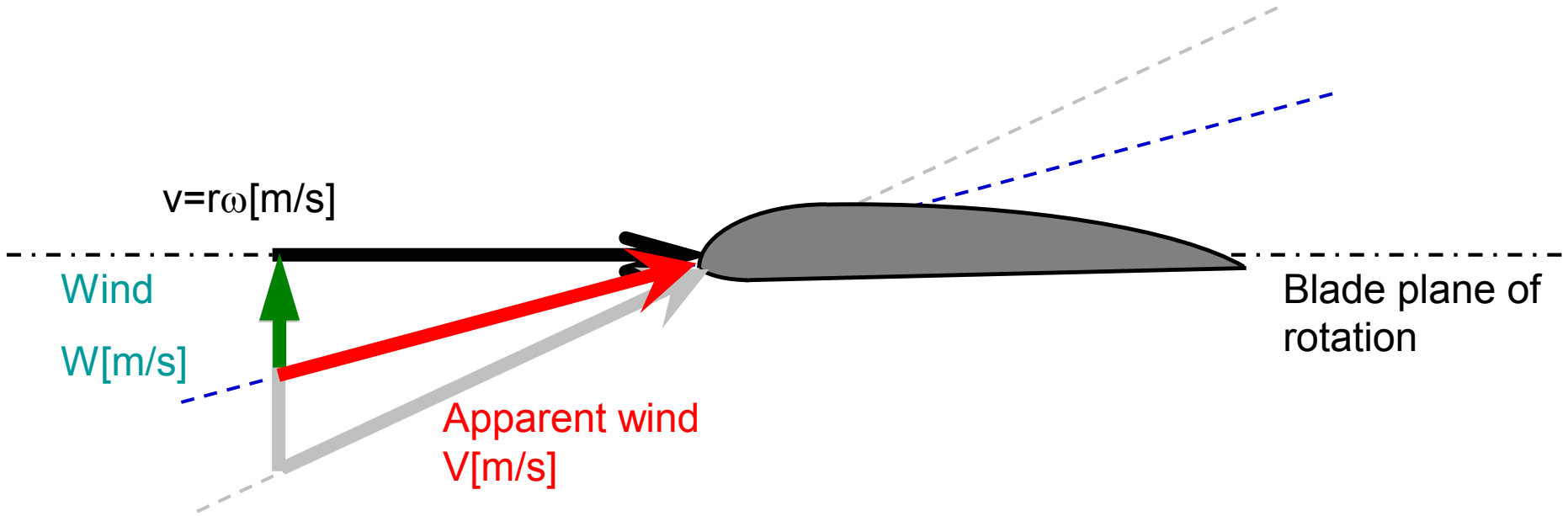
If the wind speed change?

If wind stops



If the wind speed change?

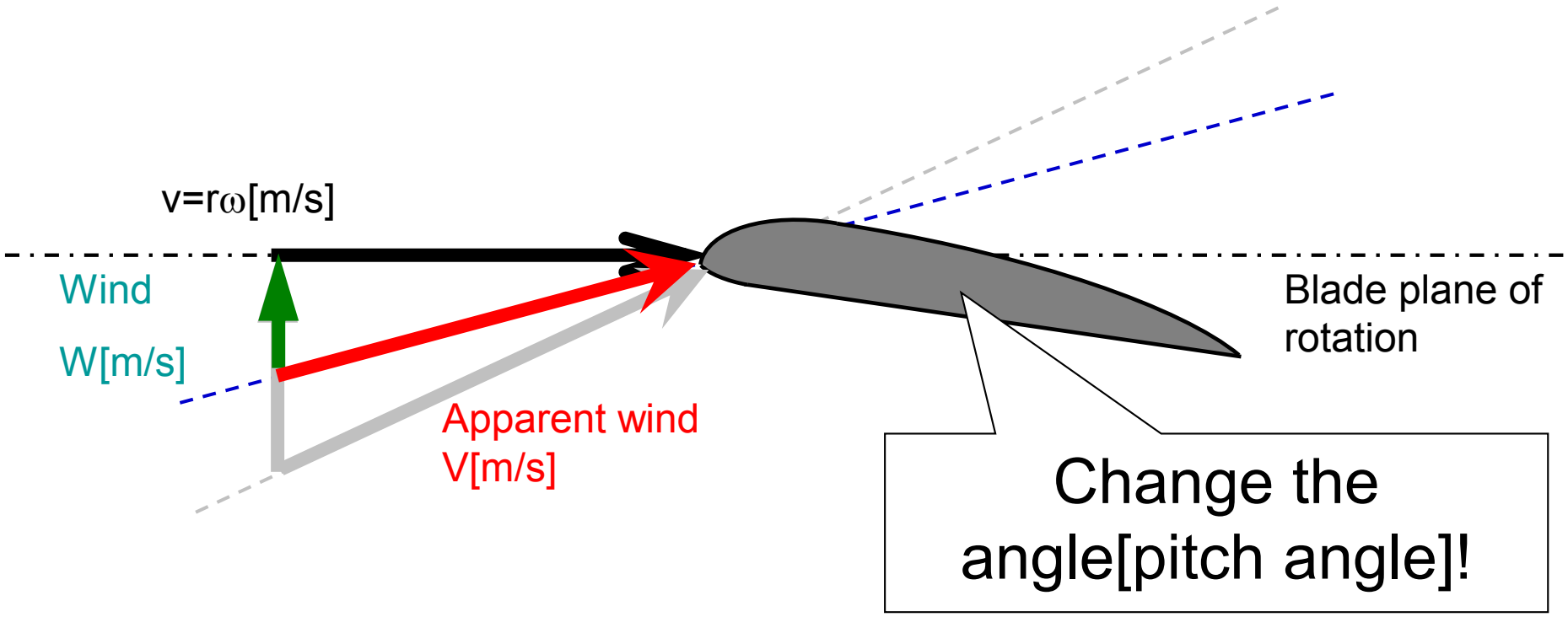
If wind stops



AoA(a) get small => Lift will reduce

If the wind speed change?

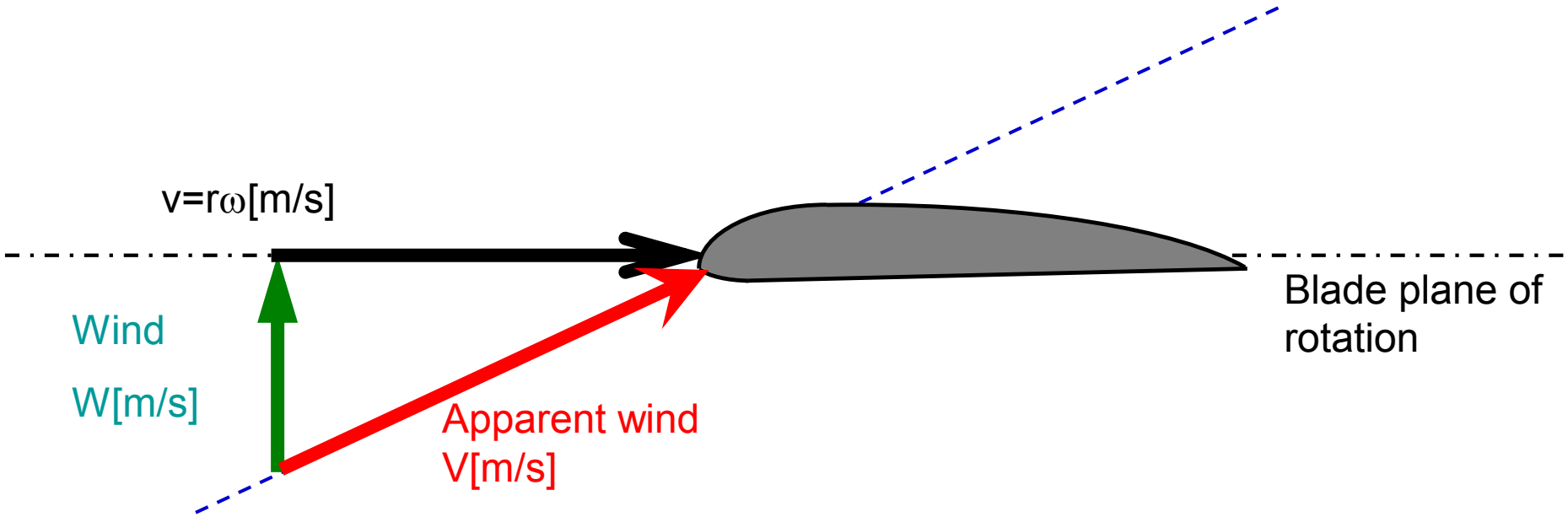
If wind stops



AoA(a) get small => Lift will reduce

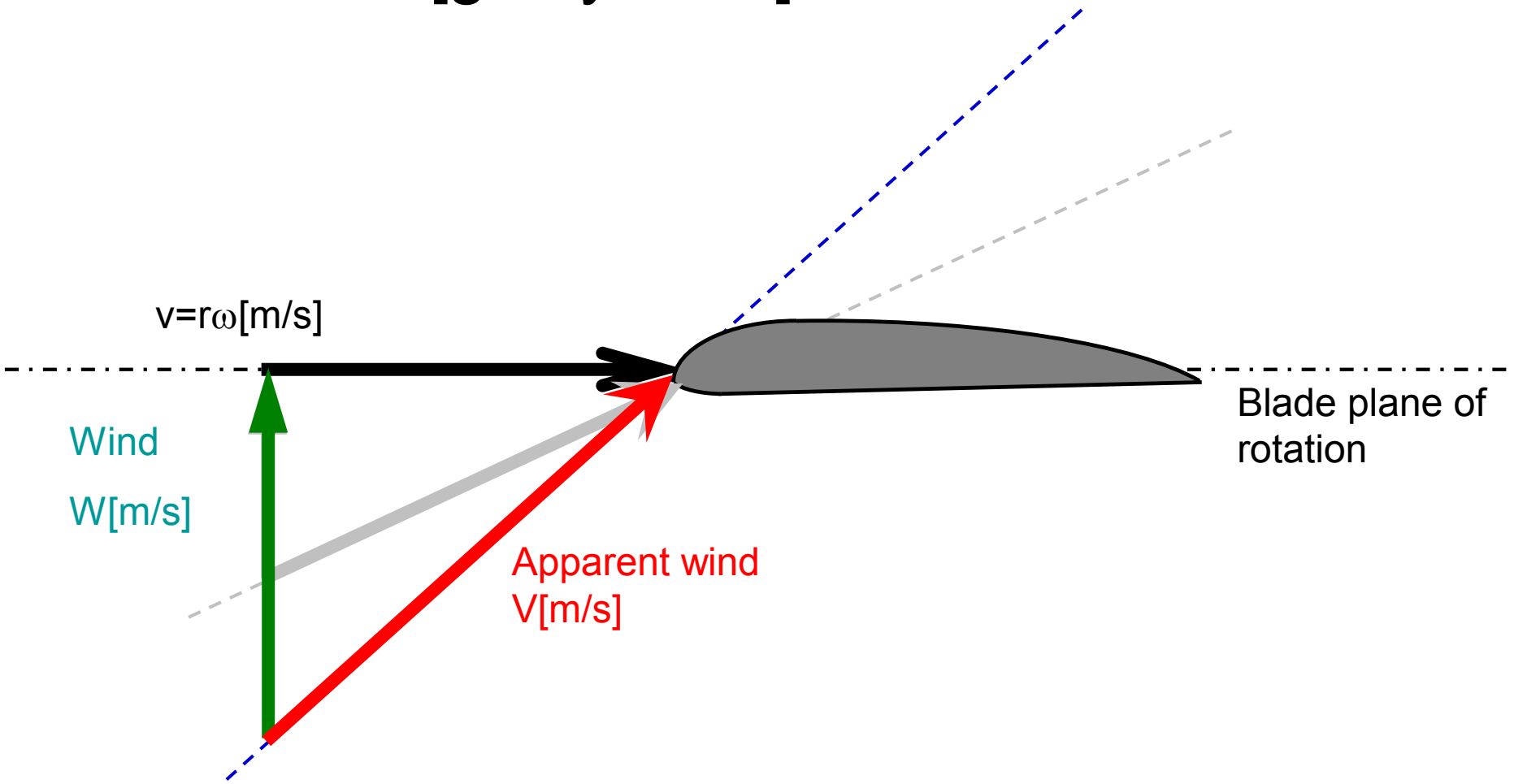
If the wind speed change?

Windblast [gusty wind]



If the wind speed change?

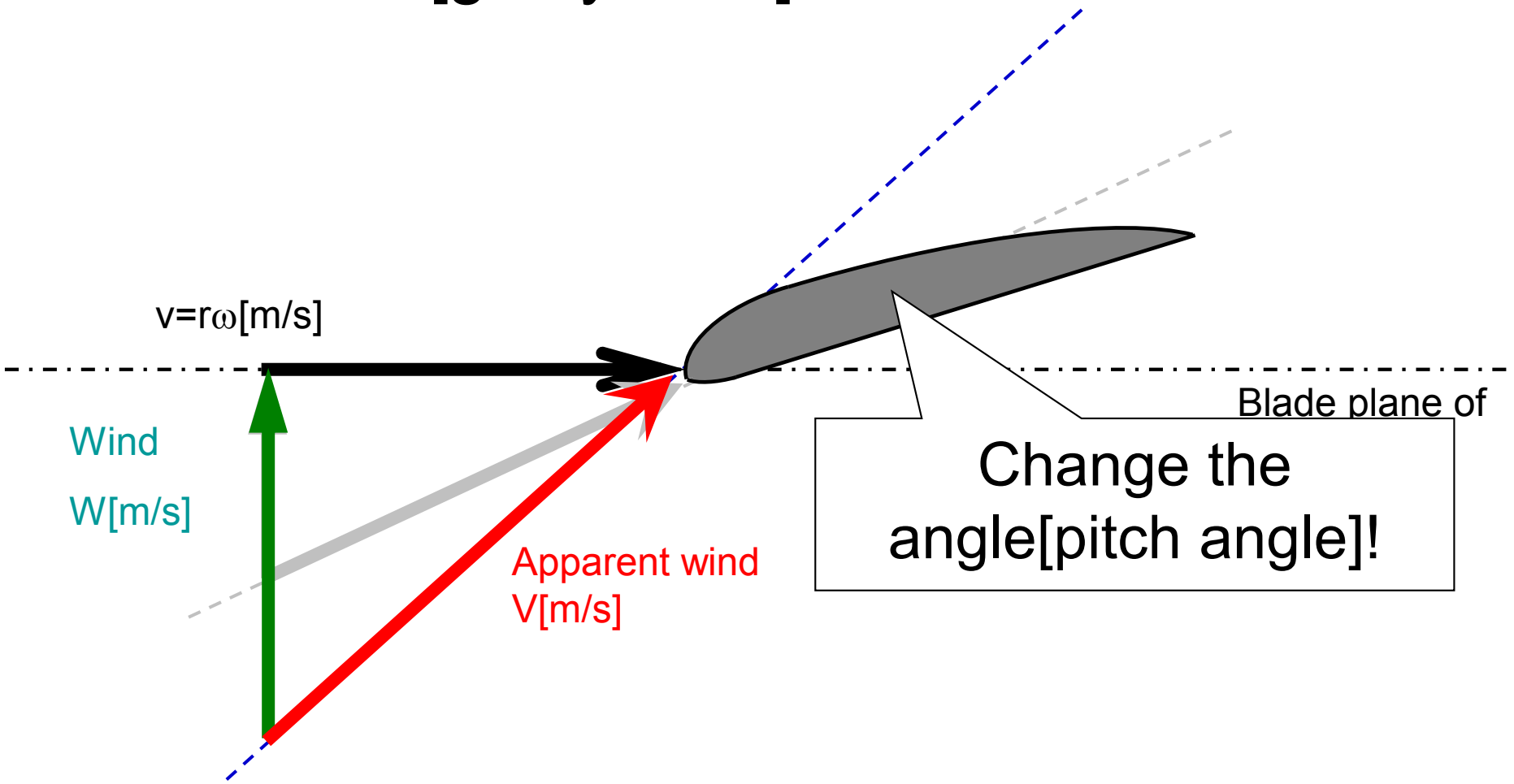
Windblast [gusty wind]



AoA(a) get big => Lift will reduce [stall]

If the wind speed change?

Windblast [gusty wind]



AoA(a) get big => Lift will reduce [stall]

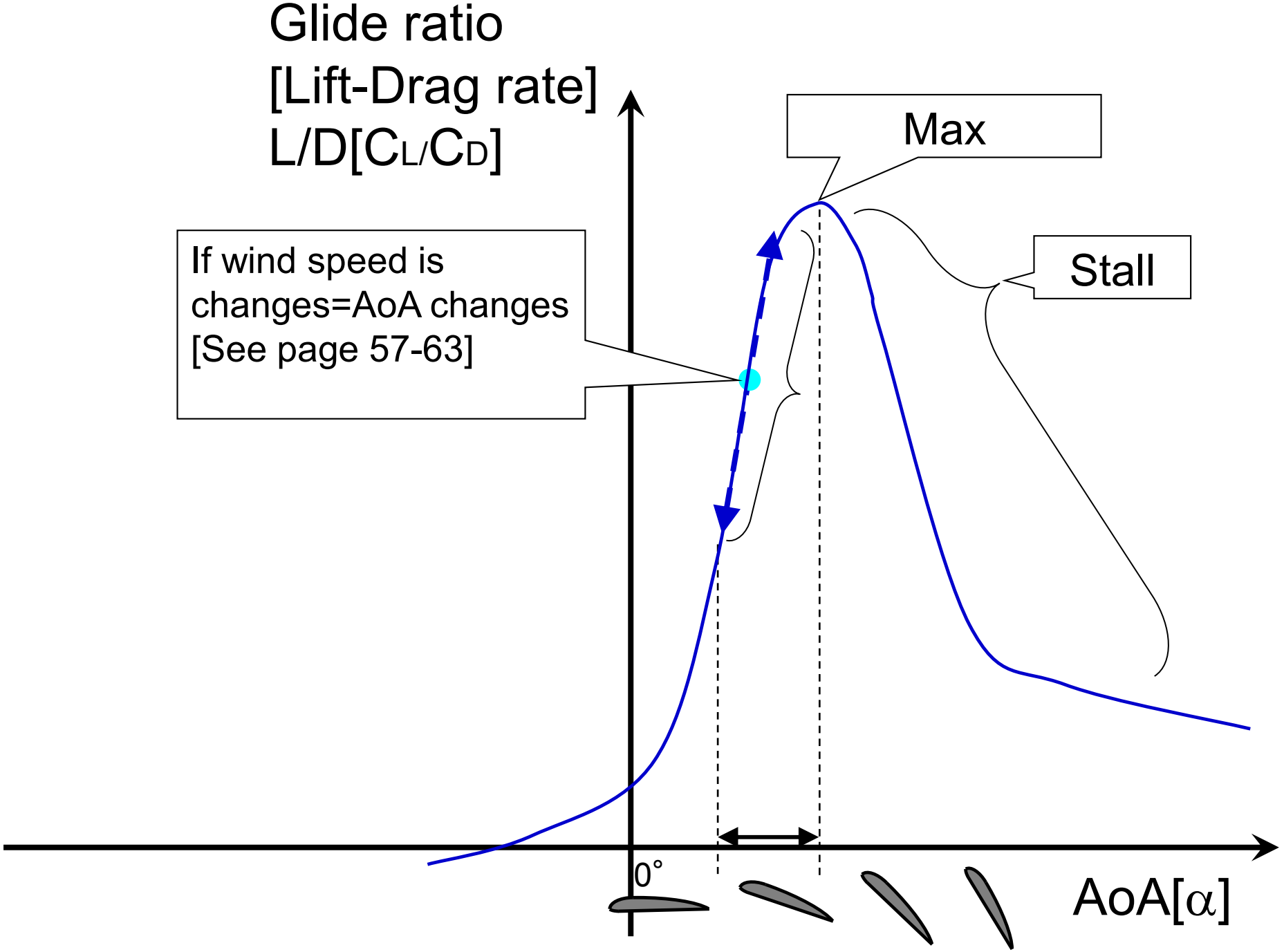
If the wind speed change?

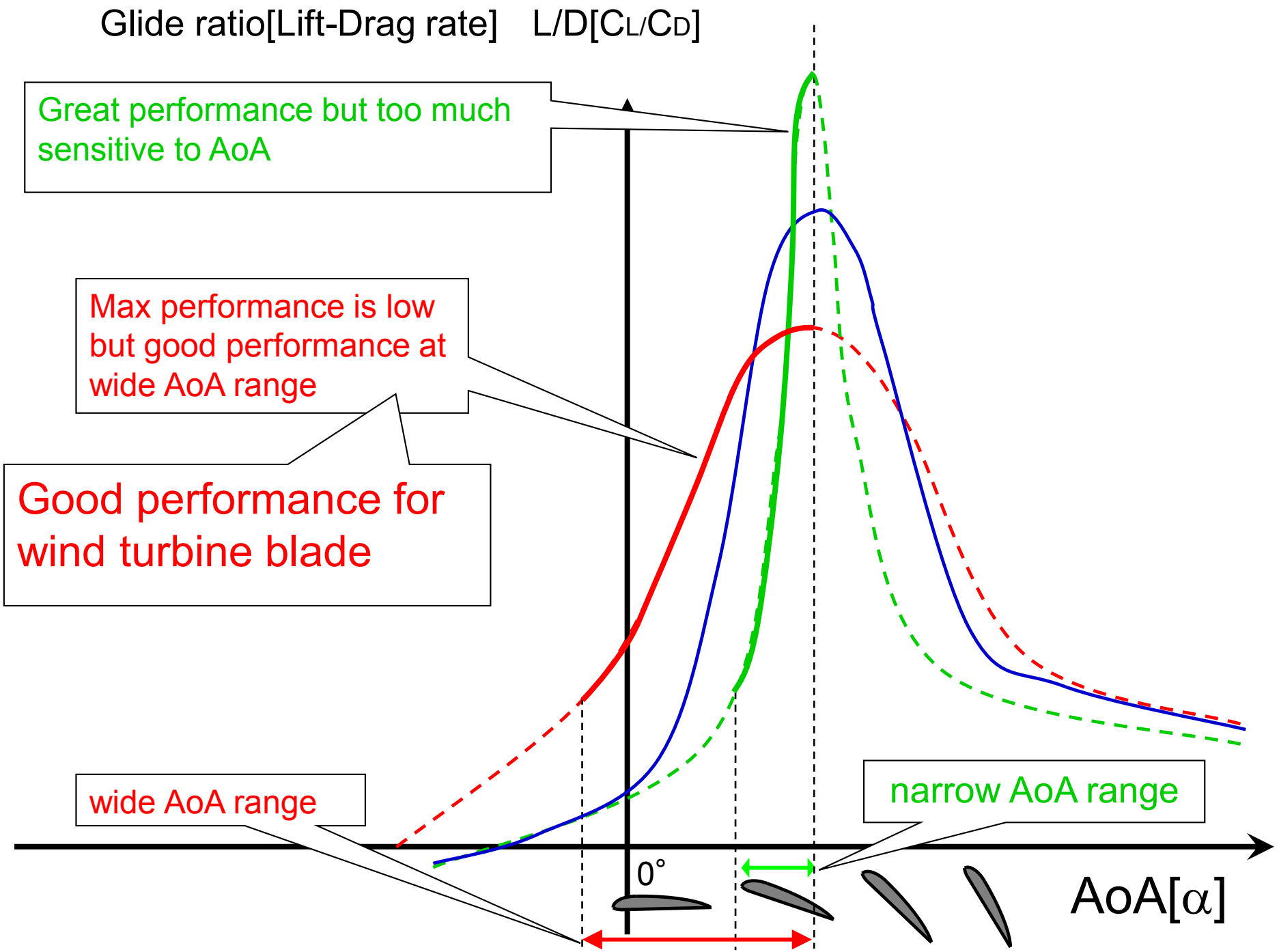
Always control the pitch angle

but

Wind turbine blade is heavy and pitch angle control is slower pace

Performance of wind turbine blade is not good for sensitive to AoA


Glide ratio
[Lift-Drag rate]
L/D[CL/CD]
Max
Stall
If wind speed is changes=AoA changes
[See page 57-63]
0°
AoA[α]

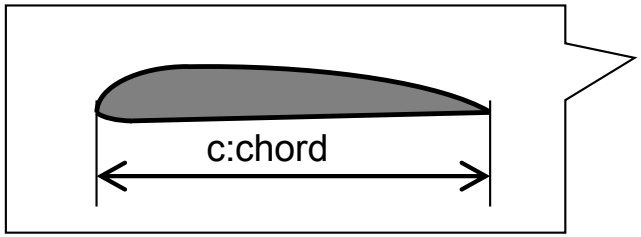

Glide ratio[Lift-Drag rate] L/D[CL/CD]
Great performance but too much sensitive to AoA
Max performance is low but good performance at wide AoA range
Good performance for wind turbine blade
wide AoA range
narrow AoA range
0°
AoA[α]

What is Reynolds number?
What is Re?

$$\mathrm{Re} = \frac{Vc}{\nu}$$

← Inertial forces

← Viscous forces



V : Apparent (wind) velocity [m/s]

c:chord [m]

ν : The dynamic viscosity of the fluid ($\nu=\mu/\rho$ 1.502×10^{-5}) [m²/s]

μ : The kinematic viscosity of the fluid ([Pa·s], [N·s/m²] , [kg/(m·s)])

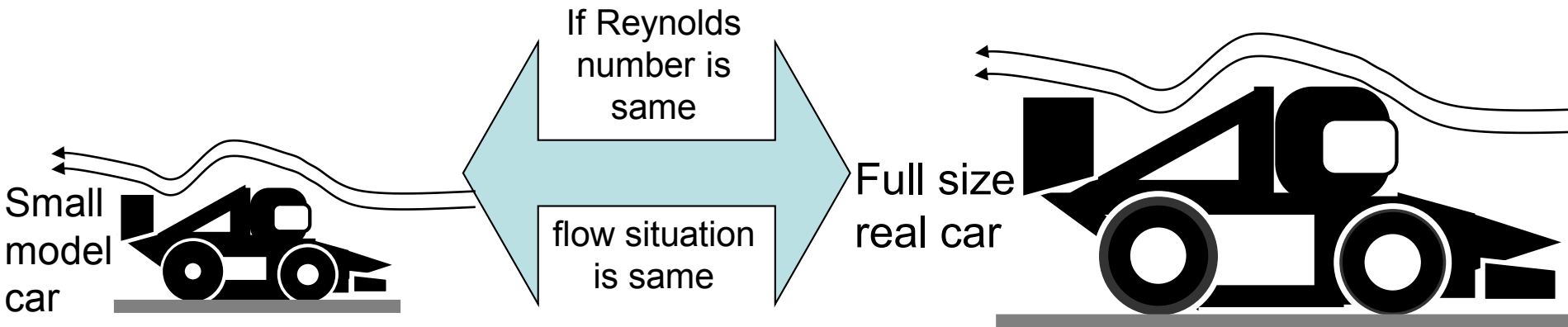
ρ: The density of the fluid [kg/m³] (1.203 kg/m³)

The Reynolds number is,,,

-> Dimensionless quantity

-> The ratio of inertial forces to viscous forces within a fluid.

-> Used in the scaling of similar but different-sized flow situations, such as between an aircraft model in a wind tunnel and the full size version.



In the case of wind turbine

Small scale model wind turbine

High velocity

small size chord

$$\mathrm{Re} = \frac{Vc}{\nu}$$

The dynamic viscosity of the air [same}

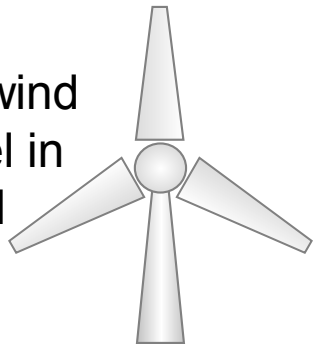
Real wind turbine

Low velocity

big size chord

$$\mathrm{Re} = \frac{Vc}{\nu}$$

Small scale wind turbine model in a wind tunnel



If Reynolds number is same

flow situation is same

Real wind turbine