AIR COOLED CONDENSER USERS GROUP

Howden

Air flow management – tutorial session

ACC Users Group – 8th Annual Conference

Dallas, 4 October 2016

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Revolving Around You™

Introduction

Basic definitions

Basics of fan performance

Basics of fan application

Practice of fan application

Summary

Introduction

Tutorial session

Many presentations in the past about fan performance and influencing factors:

2015

- Caithness windscreen study – Maulbetsch/DiFilippo
- Wind loads on fan blades & blade dynamics – Romano (Cofimco)
- General ACC improvement considerations - Villafuerte

2014

- Axial fan wind turning vane – Cuerdon

2013

- Considering the options to add fan modules to the Matimba ACC's – Goldschagg (Eskom)
- Wind shield solutions – Wilde/Scudamore (Galebreaker)
- How to improve the air side of the ACC – Huis in 't Veld (Howden)

Tutorial session

…. but what do we know about the basics of fan performance?

In this tutorial session:

- Fan laws
- Fan selection
- Limiting factors
- Influencing factors

Approached from the ACC user's perspective:

- operating stability
- cooling capacity
- energy usage
- (noise)

This tutorial session is not about the performance of the ACC.

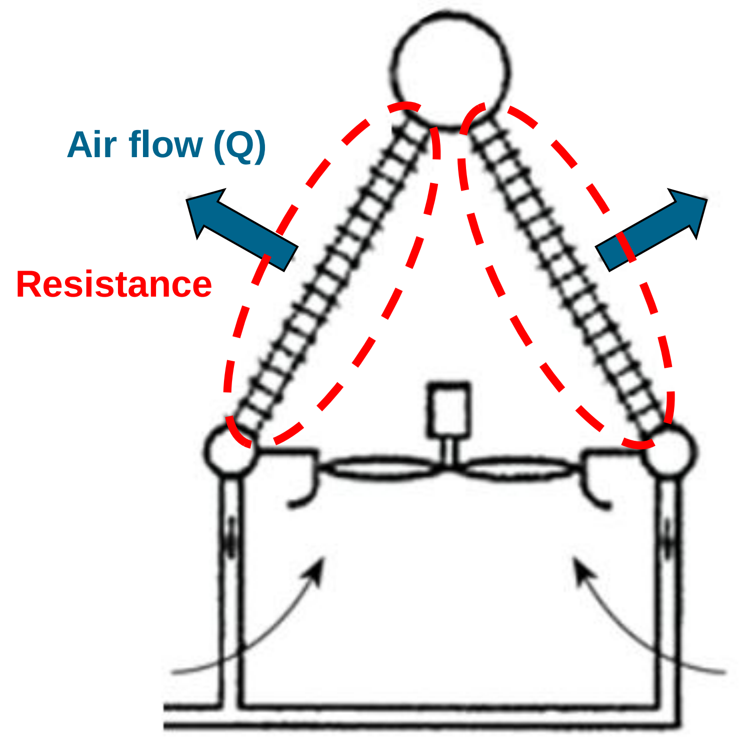
Basic definitions

System resistance

ACC user needs <u>cooling capacity</u>

→ air flow (Q in [m³/s])

Air flowing through a system experiences <u>resistance</u>



System resistance

System pressure drop Δp

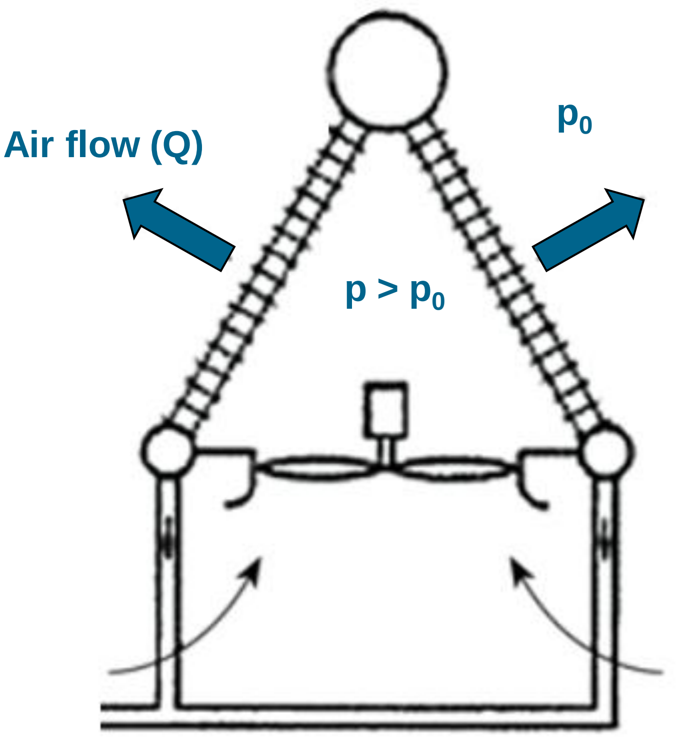
$$\boxed{\Delta p = k \rho Q^2}$$

Δp = pressure drop (Pa or N/m^2)

k = resistance coefficient (system characteristic)

ρ = air density (kg/m^3)

Q = air flow (m^3/s)

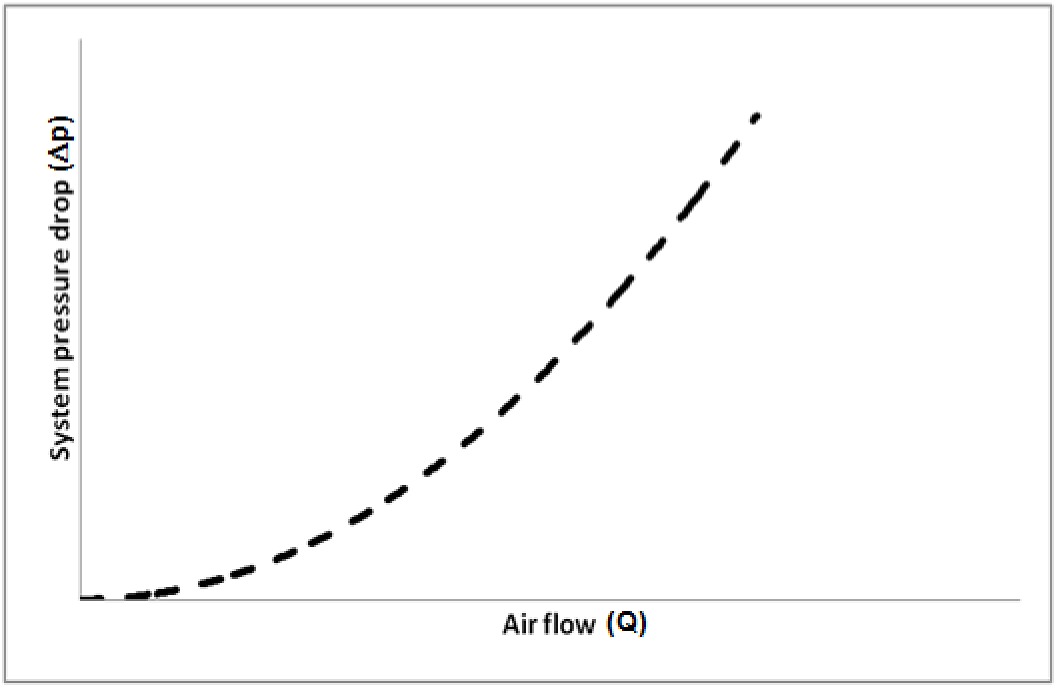


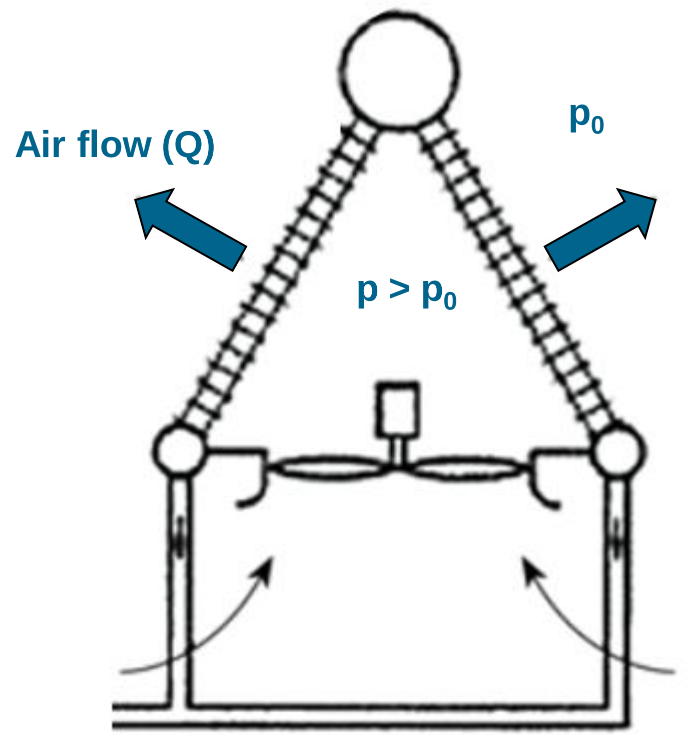
System resistance

System pressure drop Δp

$$\Delta p = k \rho Q^2$$

System resistance curve (*Short: system curve*)



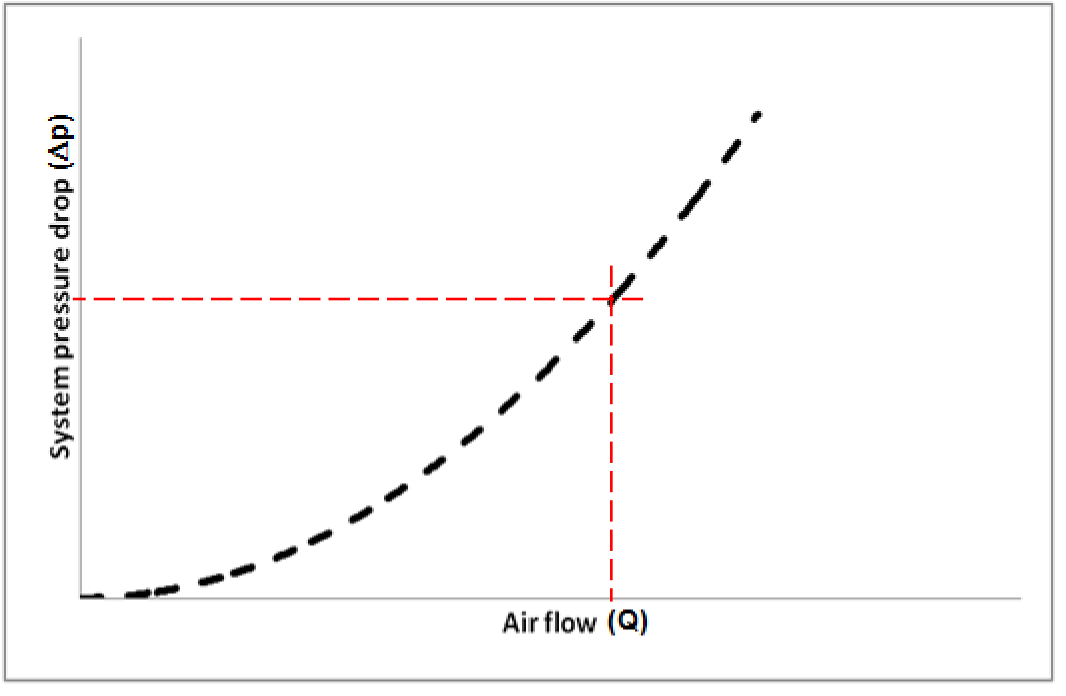


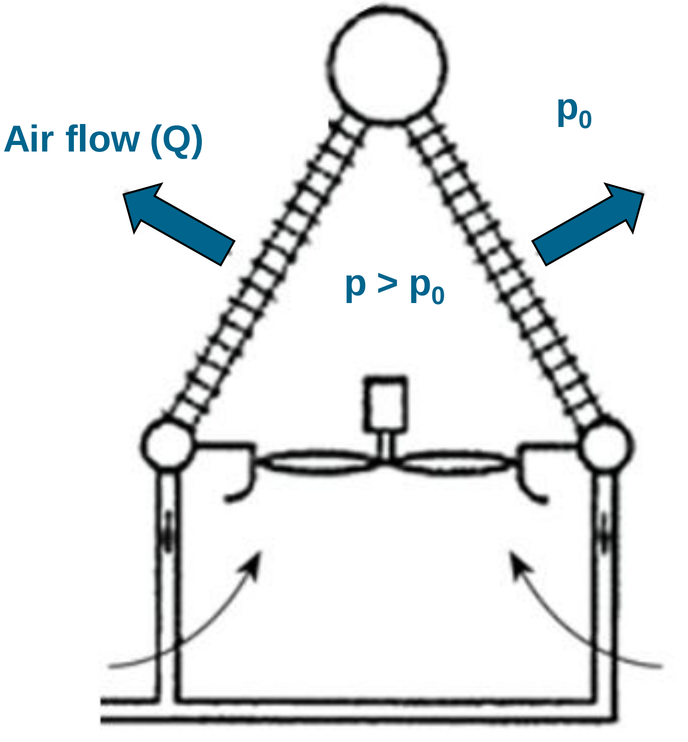
System resistance

ACC user needs <u>cooling</u>

→ air flow (Q in [m³/s])

for a given design, pressure Δp (Pa) follows from the required flow Q (m³/s) → duty point [Q, Δp]

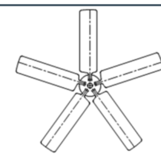




Fan performance definitions

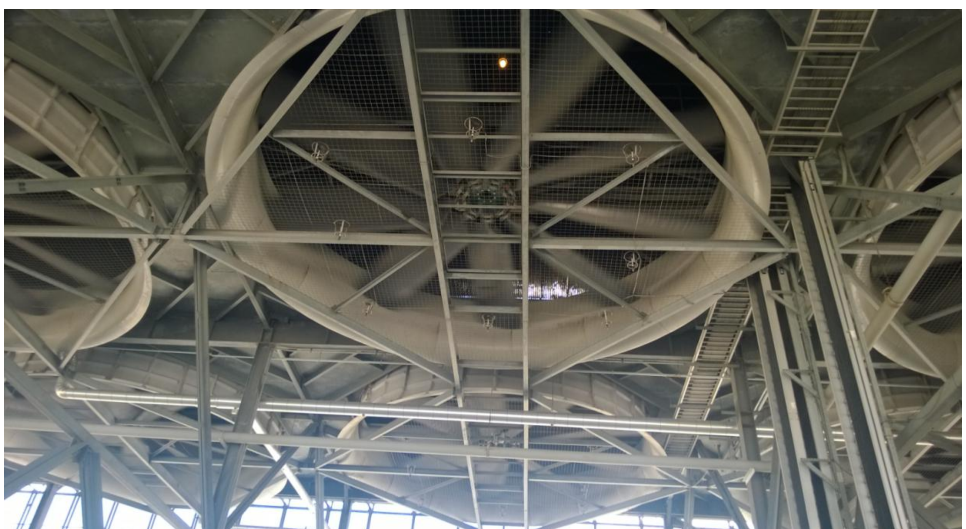
A fan is a mechanical device that converts mechanical input power into aerodynamic power (air flow against a pressure difference)

Fan shaft power



Aerodynamic power
- Air flow
- Fan pressure rise

A cooling fan is designed to move a large air volume against a low pressure

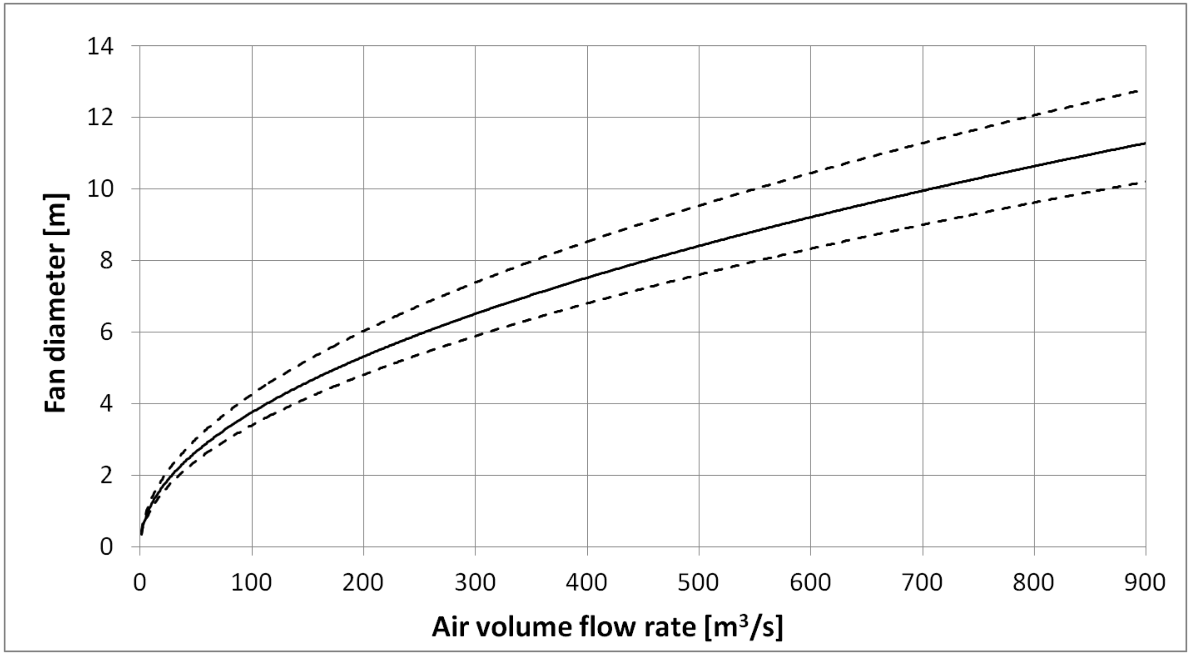


Fan performance definitions – air volume rate Q

The volume of air that passes a reference area during a given time interval

Units:	Cubic meter per second	m^3/s
	Cubic feet per minute	CFM

Typical air velocity through a cooling fan 7-11 m/s



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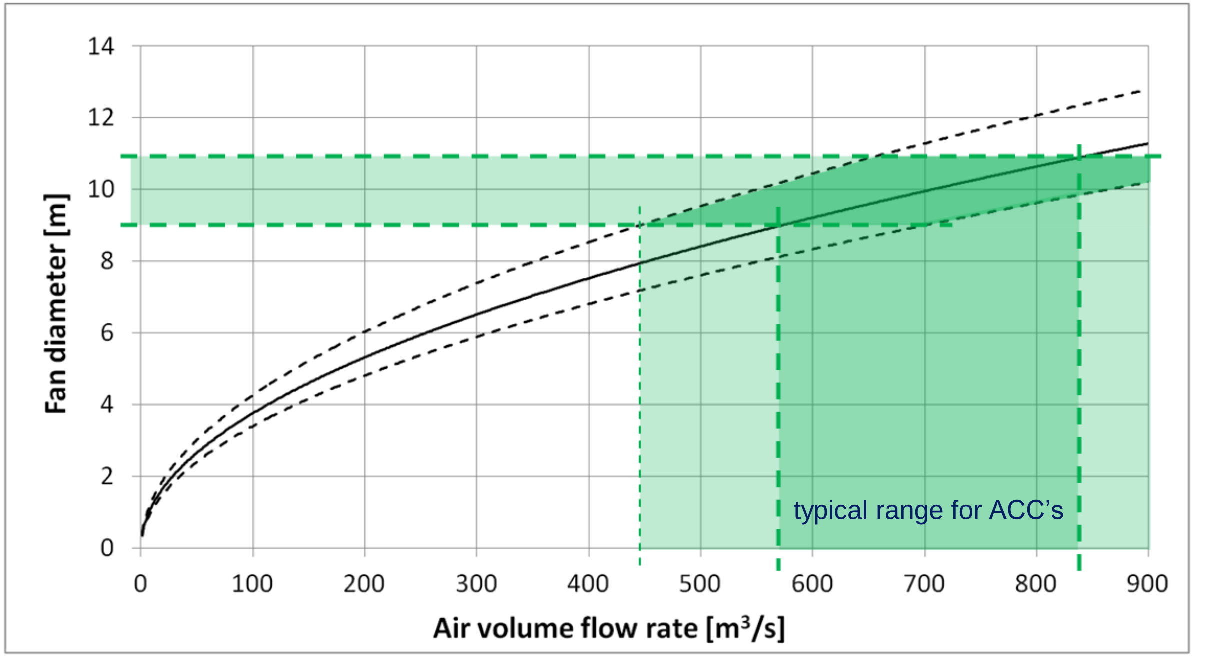


Fan performance definitions – fan pressure rise

Pressure (p) is the ratio of a force to the area over which that force is distributed

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

Units: Pascal — Pa (1 Pa = 1 N/m^2)
Pounds per square inch — Psi (1 Psi = 1 lbf/inch^2)
Many other units: mm WC, inch WC, mm Hg, etc., etc.

Absolute pressure
Pressure relative to absolute vacuum
Example: Atmospheric pressure 1013 mbar (101300 Pa)
Absolute pressure is always positive.

Relative (gauge) pressure
Pressure relative to ambient atmospheric pressure.

Fan pressure rise is always defined in term of relative pressure

Fan static pressure of a cooling fan is typically in the order of 80-200 Pa

Fan pressure rise is 1/1000th of the ambient pressure

Suction pressure in a straw ± 1000 Pa

Fan performance definitions – fan efficiency

A fan is a mechanical device that converts mechanical input power into aerodynamic power

- Mechanical input power = fan shaft power (output of the E-motor at the fan shaft) [kW]
- Aerodynamic power = air flow x pressure rise (Q x Δp)

- Fan efficiency = aerodynamic power / mechanical input power

Fan total efficiency
Based on fan total pressure
Typically maximum value around 80%

$$\eta_{total} = 100\% \frac{Q \cdot FTP}{P_{shaft}}$$

Fan static efficiency
Based on fan static pressure
Typically maximum value around 60%

$$\eta_{static} = 100\% \frac{Q \cdot FSP}{P_{shaft}}$$

Basic definitions – summary

- ACC user needs cooling capacity → airflow Q [m³/s]

- Air flowing through a system experiences resistance → system pressure drop Δp

$$\Delta p = k\rho Q^2$$

- A fan converts mechanical input power into aerodynamic power → Q and Δp

- Relevant quantities in fan performance:

  - airflow Q [m³/s]
  - FSP (fan static pressure) [Pa]
  - FTP (fan total pressure) [Pa]
  - Fan static efficiency:

$$\eta_{static} = 100\% \frac{Q \cdot FSP}{P_{shaft}}$$

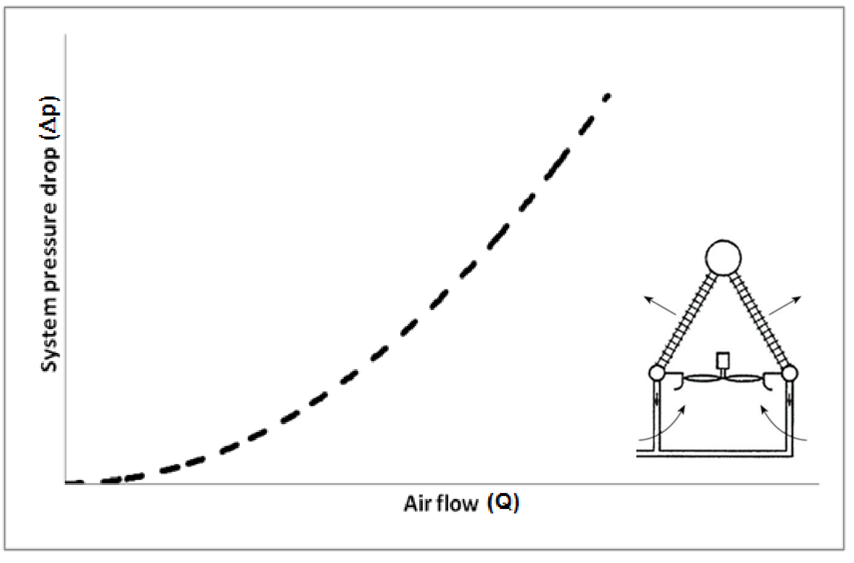
  - Fan total efficiency:

$$\eta_{total} = 100\% \frac{Q \cdot FTP}{P_{shaft}}$$

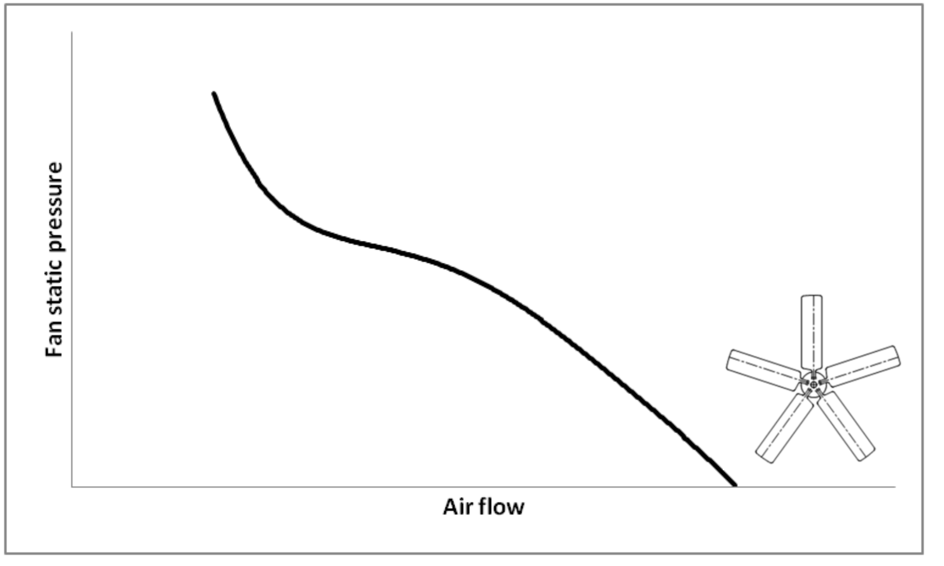
Basics of fan performance

Basics of fan performance – fan curve

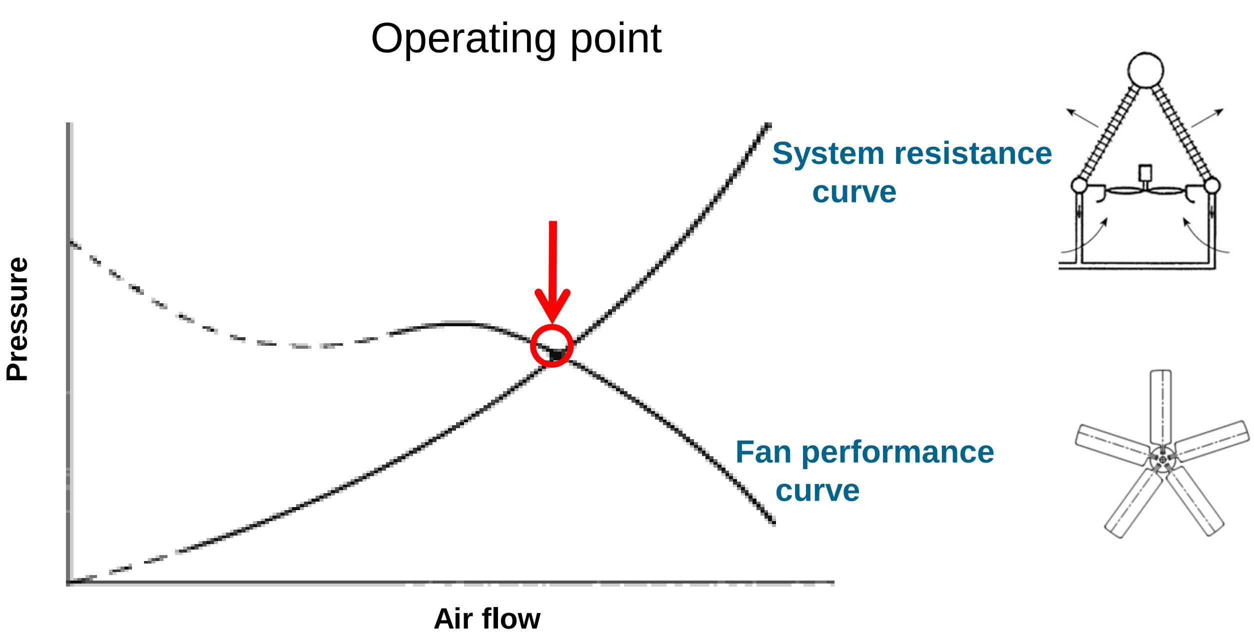
System curve



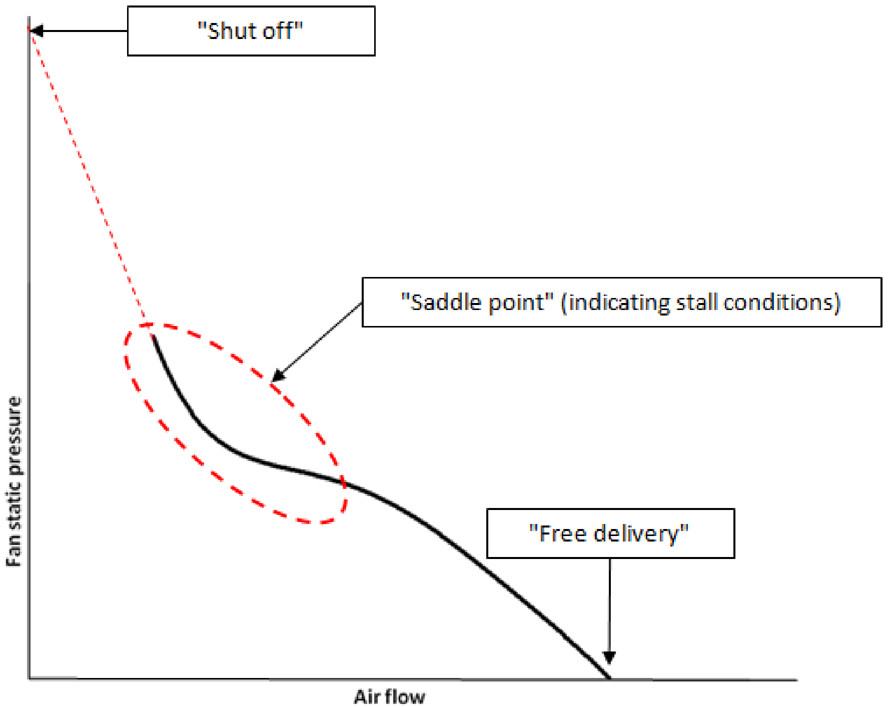
Fan curve



Basics of fan performance – fan curve

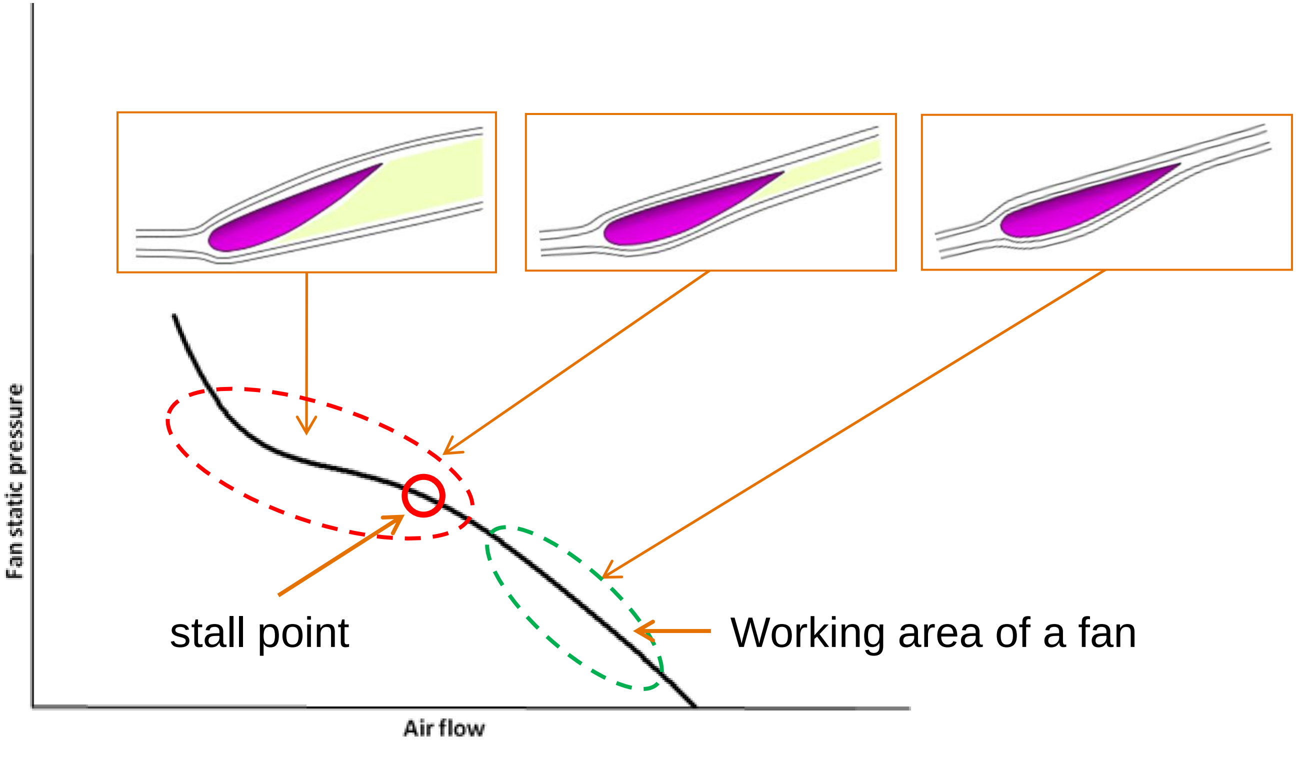


Basics of fan performance – operating stability



Basics of fan performance – fan curve

Separation of air flow from the surface of the fan blade



Basics of fan performance – summary

- The operating point is where the system curve and the fan curve cross each other
- The fan curve has a working area and a stall area
- The operating point should be in the working area of the fan curve

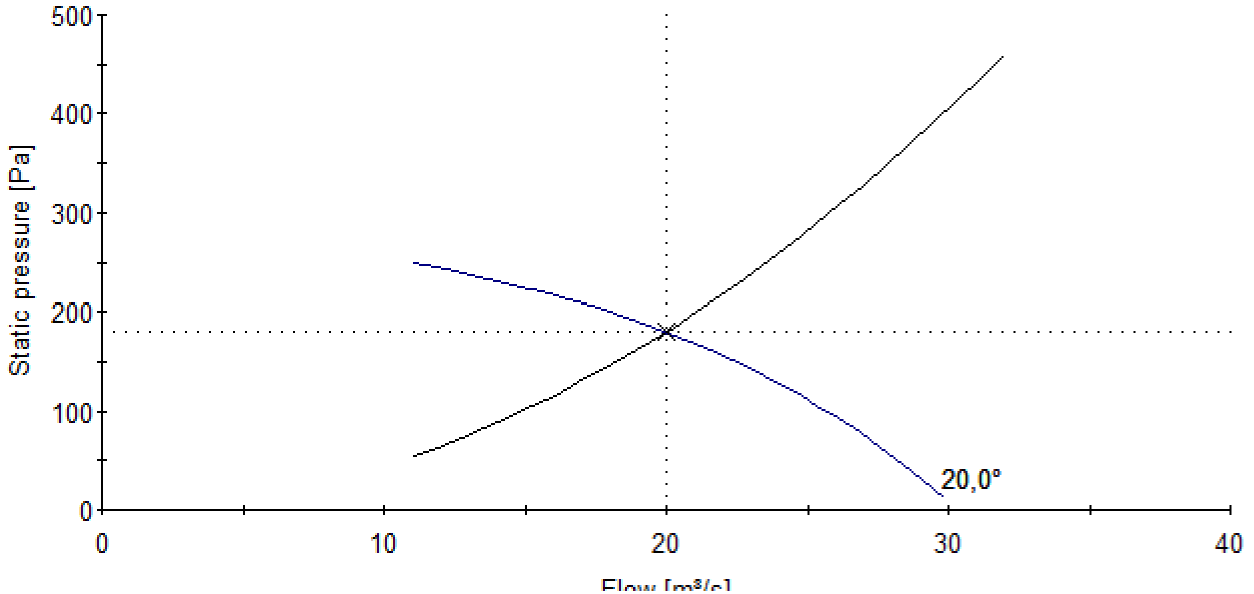
Basics of fan application

Basics of fan application

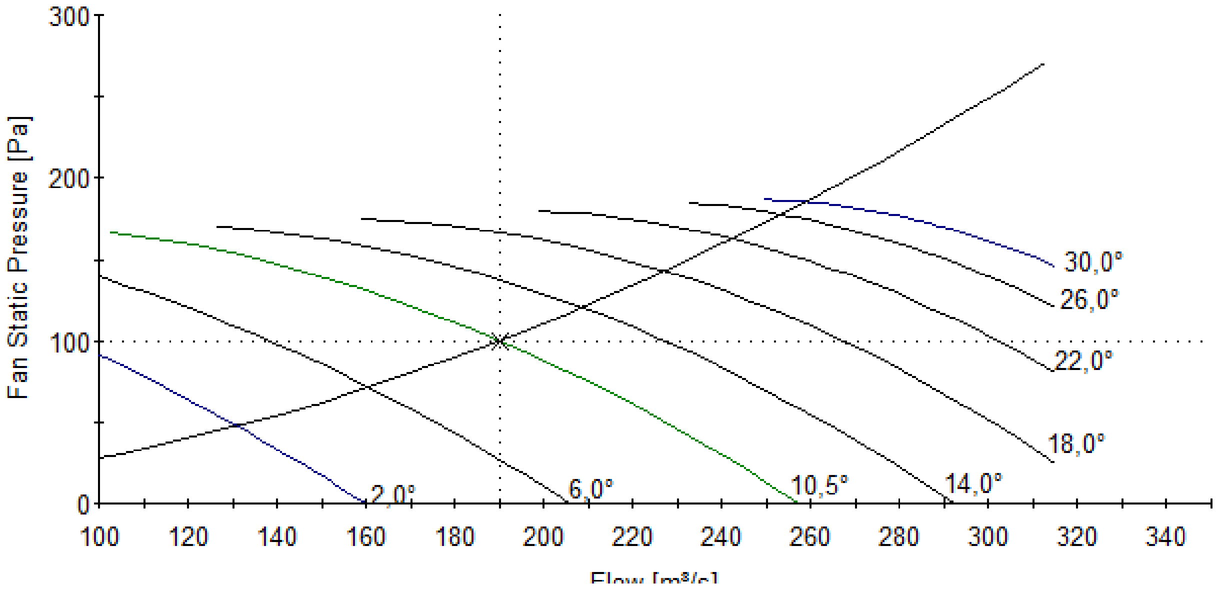
- Which quantities can be changed?
- How does it affect fan performance?

1. Fan diameter
2. Type of fan
3. Number of blades
4. **Fan operating speed**
5. **Blade pitch angle**

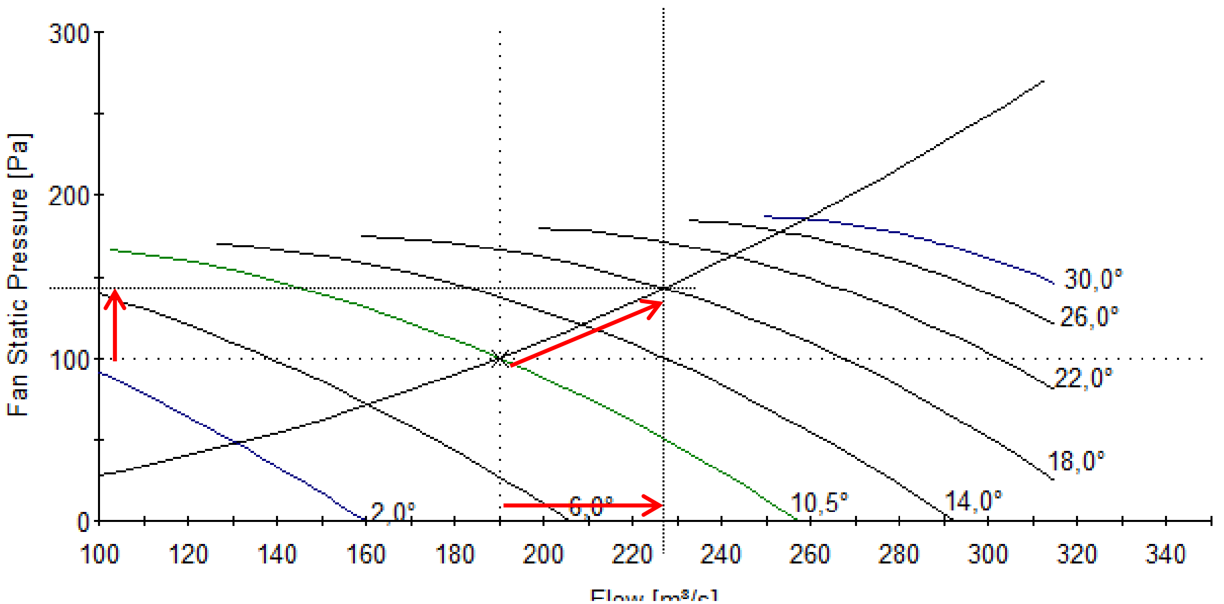
Fan application – blade pitch angle



Fan application – blade pitch angle



Fan application – blade pitch angle



Increase in blade angle

→increase in airflow Q

System resistance:

$$\Delta p = k\,\rho\,Q^2$$

→ static pressure; increase to the square

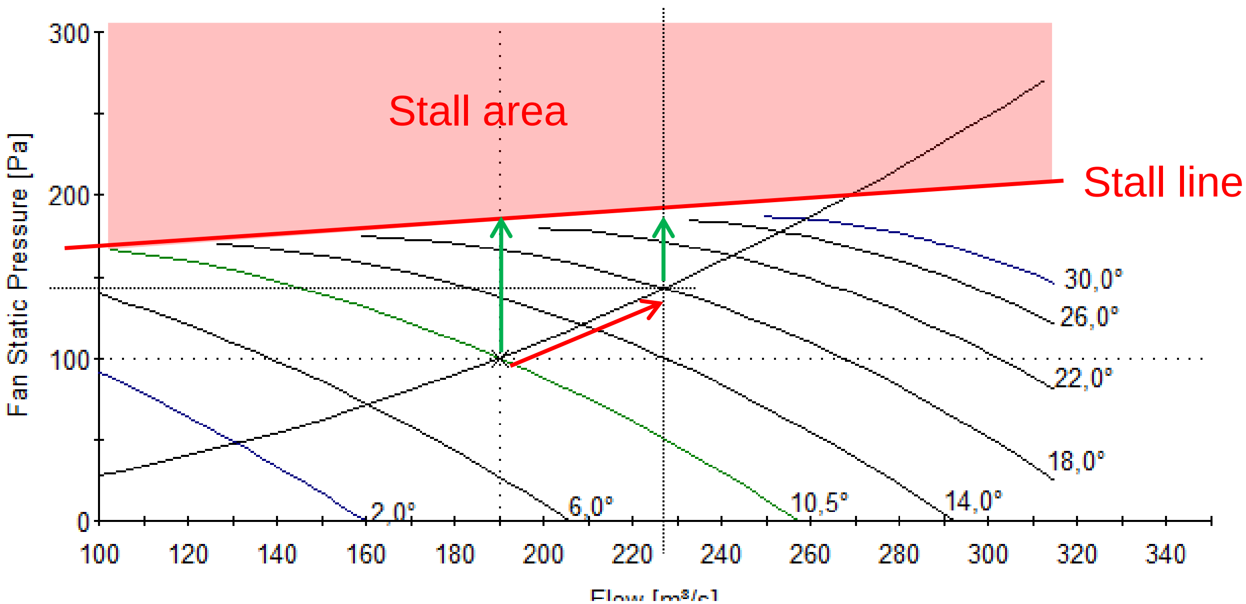
Aerodynamic power =

air flow x pressure rise

(Q x Δp)

→ Fan shaft power; increase to the 3rd power!!

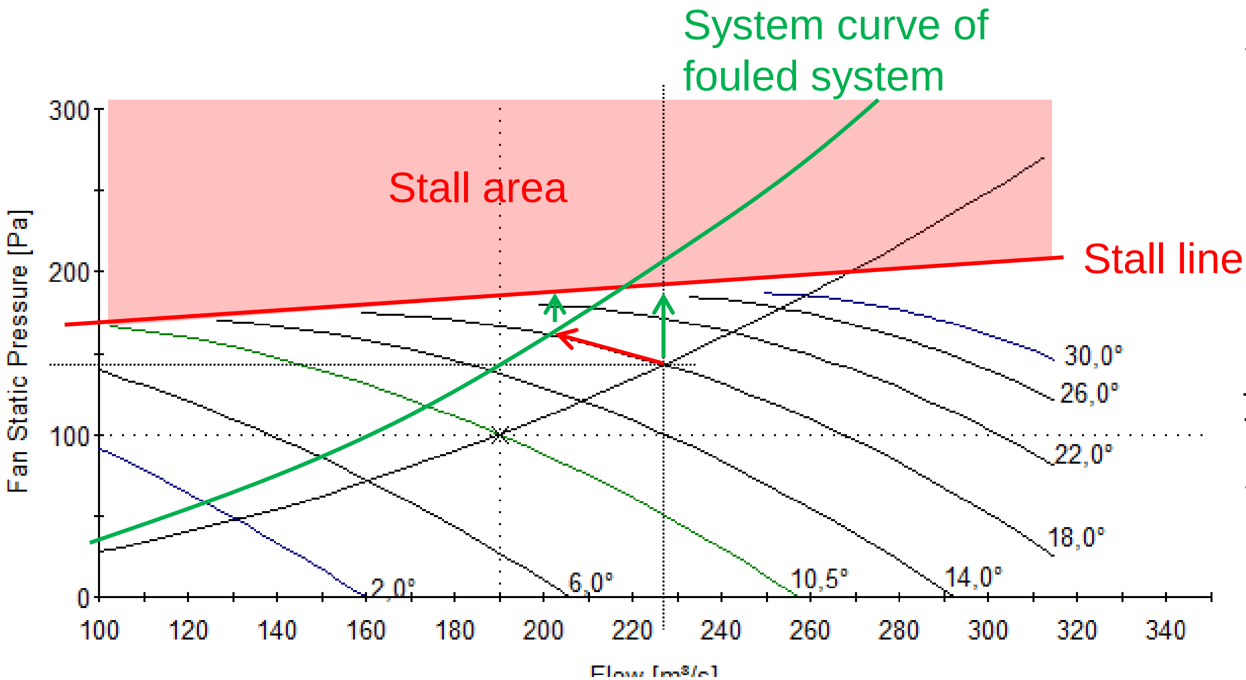
Fan application – blade pitch angle



Increase in blade angle

→Decrease in margin to the stall line

Fan application – blade pitch angle



Increase in blade angle

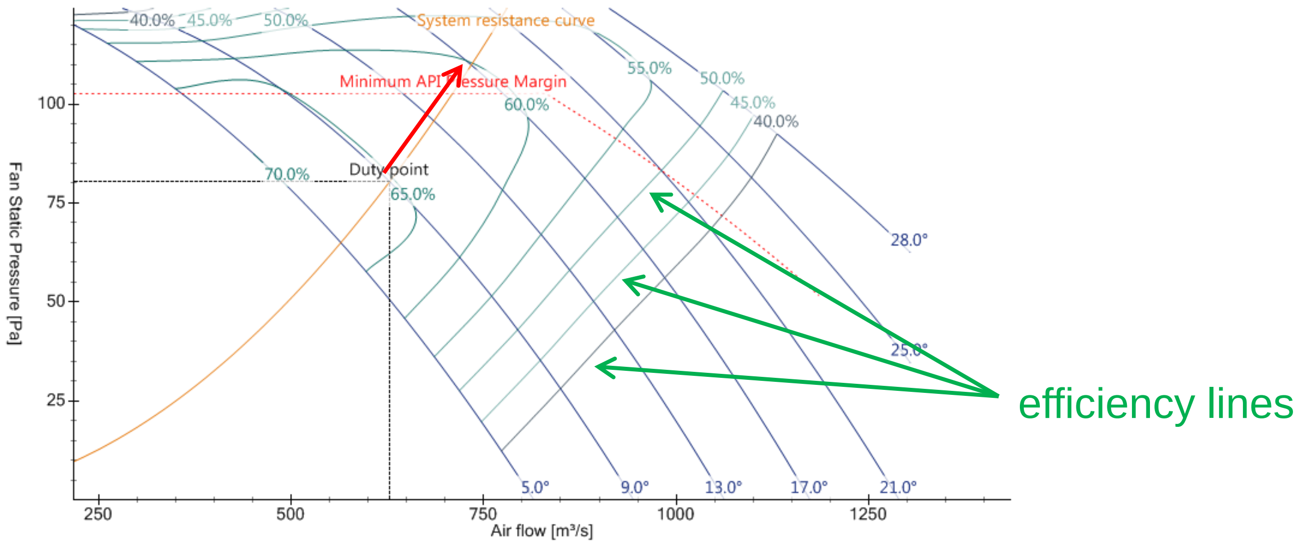
→Decrease in margin to the stall line

Pressure margin to prevent for stall conditions in a fouled system

Fan application – blade pitch angle

Increase in blade angle

→ Change in fan efficiency



Fan application – blade pitch angle

Increase in blade angle

→Increase in air volume flow Q

but also:

- Increase in fan shaft power (to the 3^{rd} power)
- Decrease in pressure margin (more risk for stall conditions)
- Loss of fan efficiency
- Effect on noise
- Mechanical considerations → <u>always consult the fan manufacturer for advice</u>

Fan application – fan speed

Fan application – fan speed

Fan scaling laws (Fan Laws)

Scaling of air volume flow rate

$$\frac{Q_1}{Q_2} = \left(\frac{n_1}{n_2}\right)\left(\frac{D_1}{D_2}\right)^3$$

Air volume flow rate scales directly with fan speed.
Air volume flow rate scales with fan diameter to the power 3.
Air volume flow rate is independent of air density.

Scaling of fan pressure rise

$$\frac{\Delta p_1}{\Delta p_2} = \left(\frac{\rho_1}{\rho_2}\right)\left(\frac{n_1}{n_2}\right)^2\left(\frac{D_1}{D_2}\right)^2$$

Fan pressure rise scales directly with air density
Fan pressure rise scales with fan speed to the power 2
Fan pressure rise scales with fan diameter to the power 2

Scaling of fan shaft power

$$\frac{P_1}{P_2} = \left(\frac{\rho_1}{\rho_2}\right)\left(\frac{n_1}{n_2}\right)^3\left(\frac{D_1}{D_2}\right)^5$$

Fan shaft power scales directly with air density
Fan shaft power scales with fan speed to the power 3
Fan shaft power scales with fan diameter to the power 5

Fan application – fan speed

Fan scaling laws (Fan Laws)

Scaling of air volume flow rate

$$\frac{Q_1}{Q_2} = \left(\frac{n_1}{n_2}\right)\left(\frac{D_1}{D_2}\right)^3$$

Air volume flow rate ~ Fan speed

Air volume flow rate scales directly with fan speed.
Air volume flow rate scales with fan diameter to the power 3.
Air volume flow rate is independent of air density.

Scaling of fan pressure rise

$$\frac{\Delta p_1}{\Delta p_2} = \left(\frac{\rho_1}{\rho_2}\right)\left(\frac{n_1}{n_2}\right)^2\left(\frac{D_1}{D_2}\right)^2$$

Fan static pressure ~ Fan speed^2

Fan pressure rise scales directly with air density
Fan pressure rise scales with fan speed to the power 2
Fan pressure rise scales with fan diameter to the power 2

Scaling of fan shaft power

$$\frac{P_1}{P_2} = \left(\frac{\rho_1}{\rho_2}\right)\left(\frac{n_1}{n_2}\right)^3\left(\frac{D_1}{D_2}\right)^5$$

Fan shaft power ~ Fan speed^3

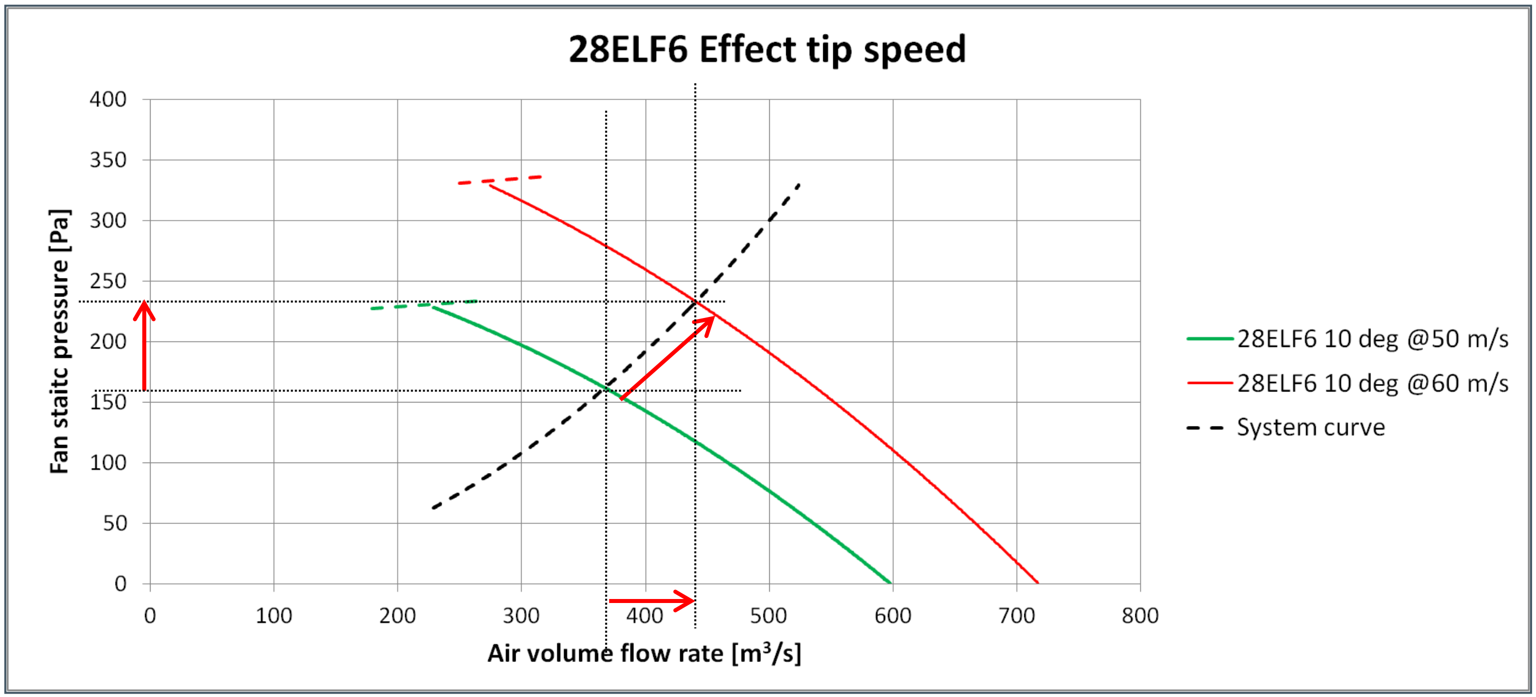
Fan shaft power scales directly with air density
Fan shaft power scales with fan speed to the power 3
Fan shaft power scales with fan diameter to the power 5

Fan application – fan speed

Air volume flow rate ~ Fan speed

Fan static pressure ~ Fan speed^2

Fan shaft power ~ Fan speed^3

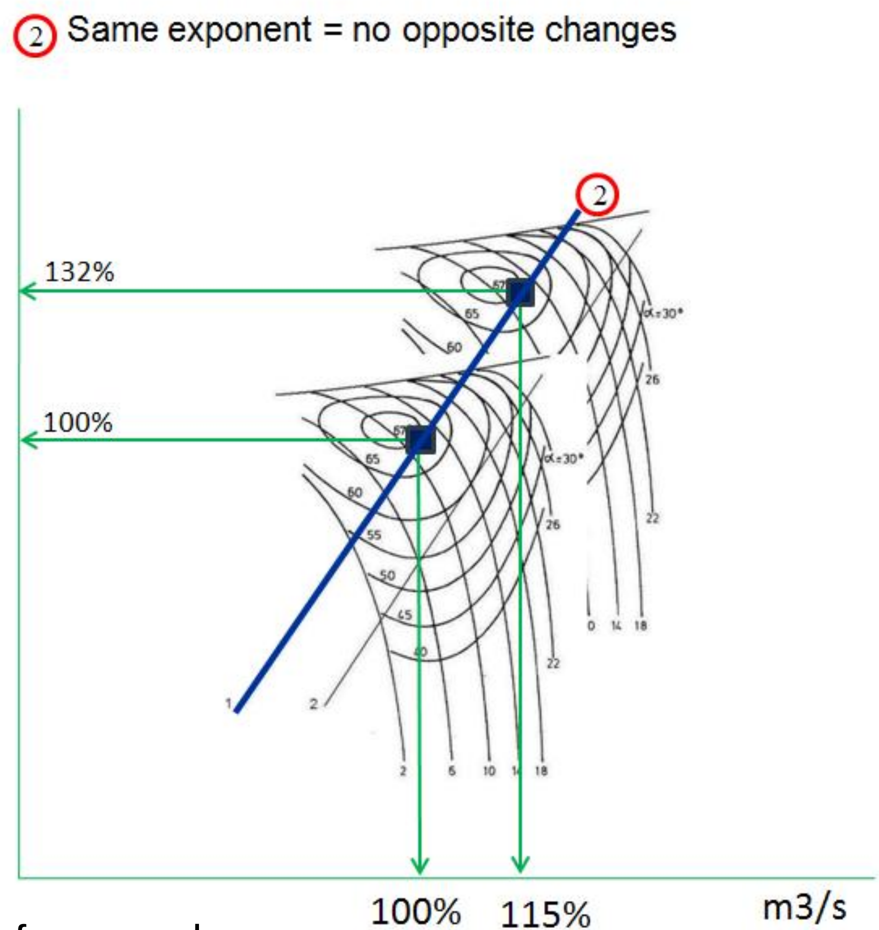


Fan application – fan speed

Air volume flow rate ~ Fan speed

Fan static pressure ~ Fan speed^2

Fan shaft power ~ Fan speed^3



Stall margin stays the same!

Fan stalling issues <u>cannot</u> be solved by reducing fan speed

Fan application – conclusion

Once a fan is selected, installed and in operation, there are only limited possibilities to adjust or improve the fan performance:

- Changing the pitch angle or the fan speed have strong impact on especially power consumption (capacity of e-motor and drive) and safety margin to stall

Practice of fan application

Fan application – practice

- Fouling
- Obstacles in the airstream
- Wind

→Change of the system curve

→Non uniform inlet conditions

Fan application – practice

Effect of wind

Additional pressure loss

- Adds resistance

Non-uniform inlet conditions

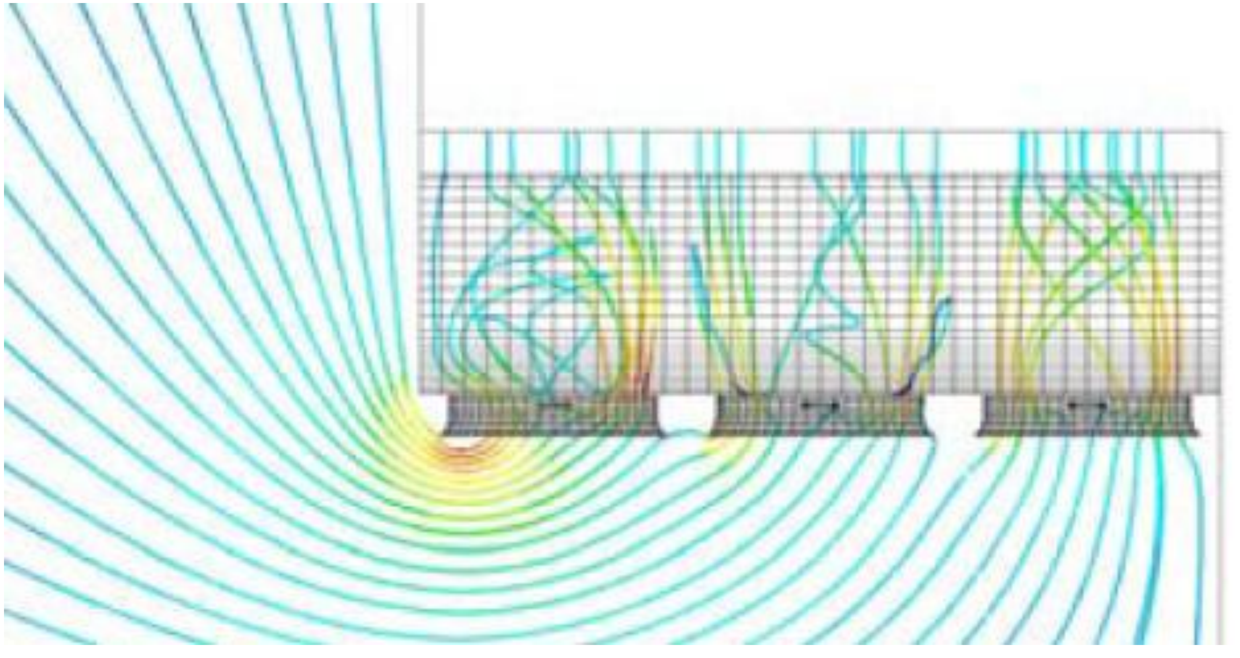
- Causes loss in fan performance
- Causes increased loading on the fan blades

Recirculation (hot exhaust air flow back into the fan inlet)

- Reduced thermal performance

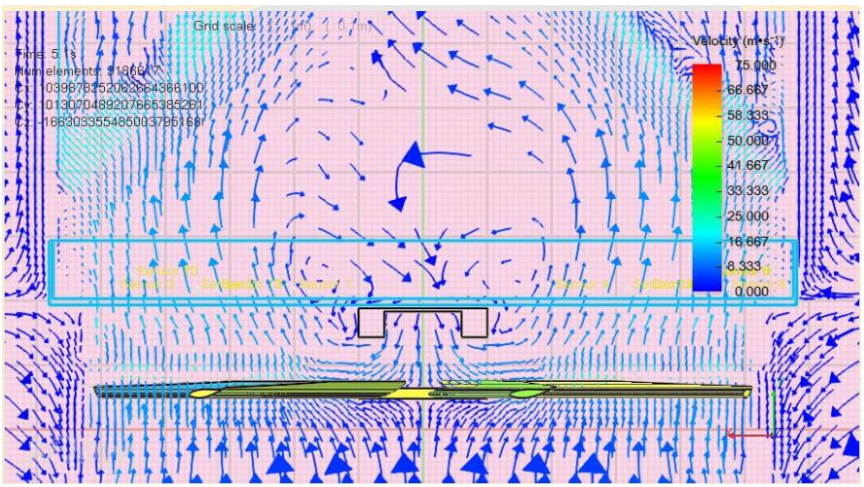
Fan application – practice

Cross wind – non- uniform inlet conditions



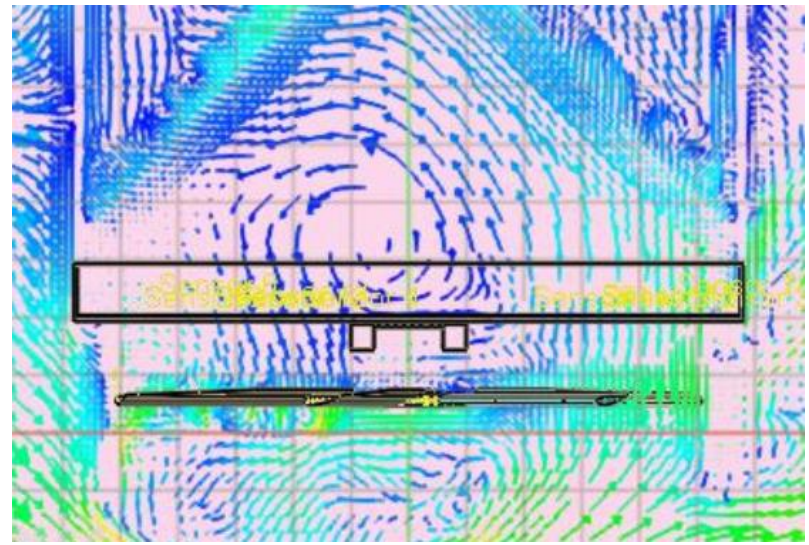
Fan application – practice

No wind – uniform inlet conditions



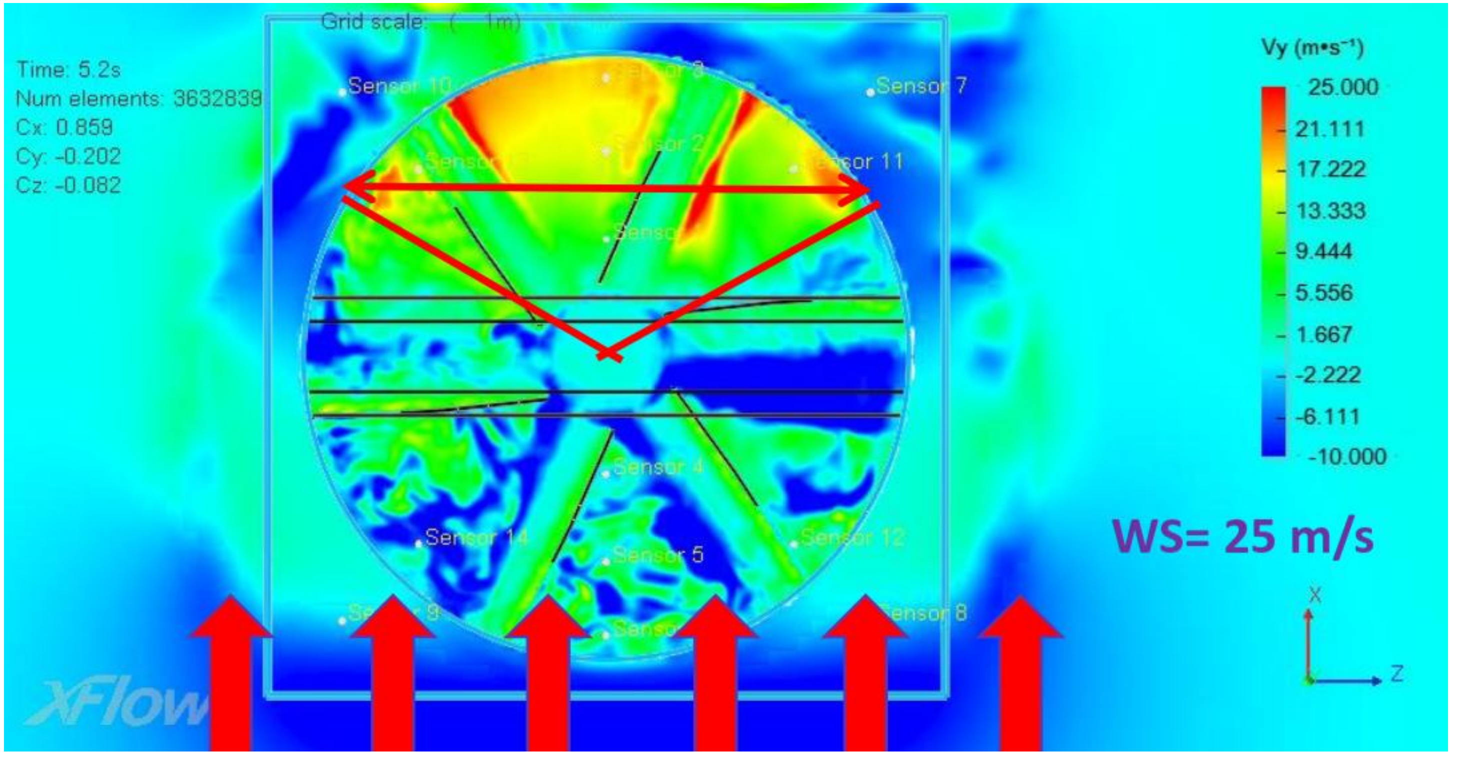
(source: ACCUG 2015 / Romano, Cofimco)

25 m/s wind speed – non uniform inlet conditions



Fan application – practice

Non – uniform inlet conditions due to cross wind



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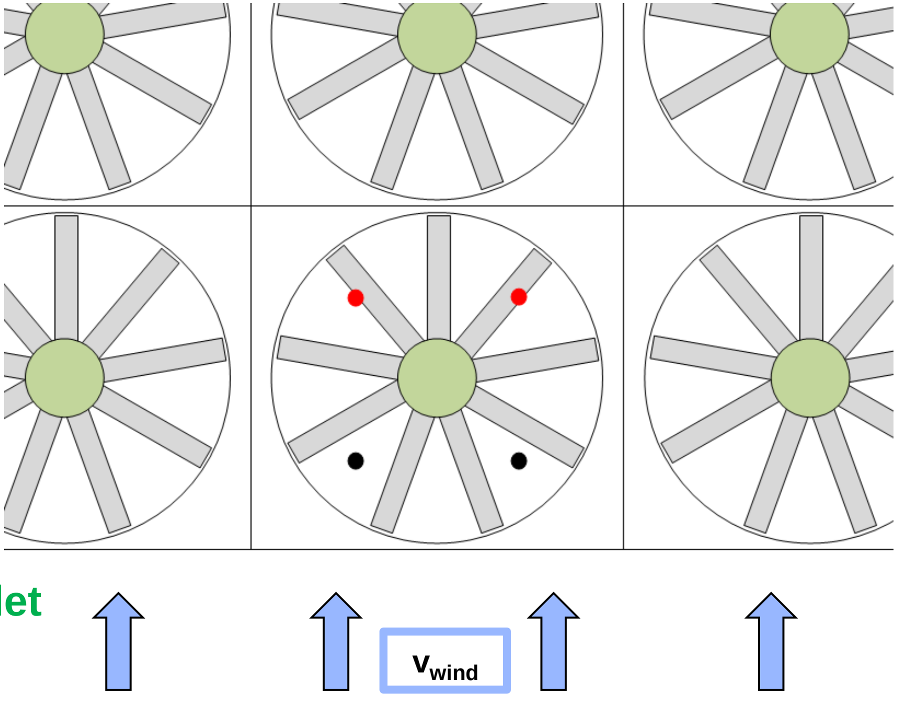
Fan application – practice

Non – uniform inlet conditions due to cross wind



<u>Air velocity measurements at the fan inlet:</u>

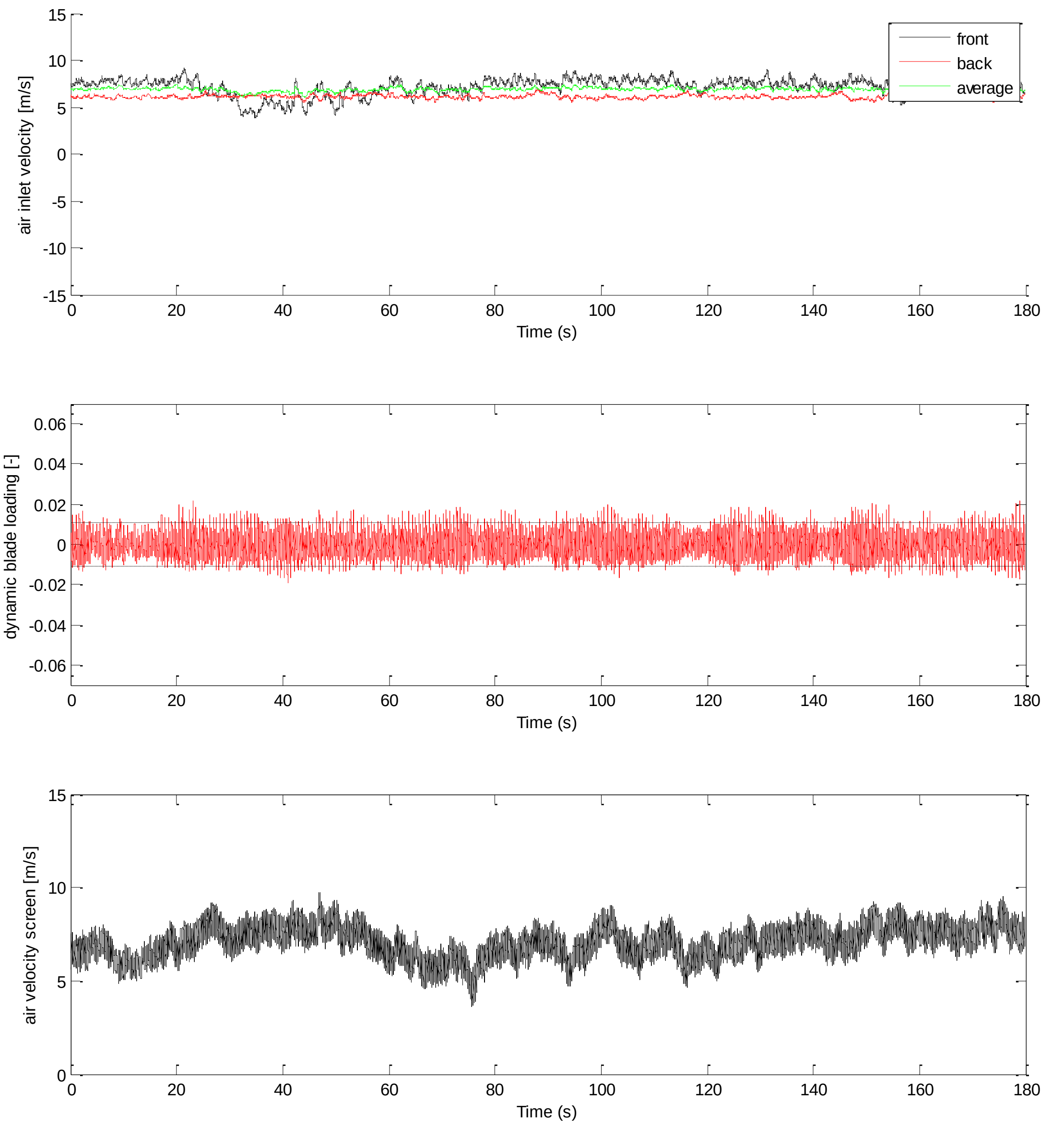
Air velocity at the front

Average air velocity at the back

Average air velocity over the entire fan inlet

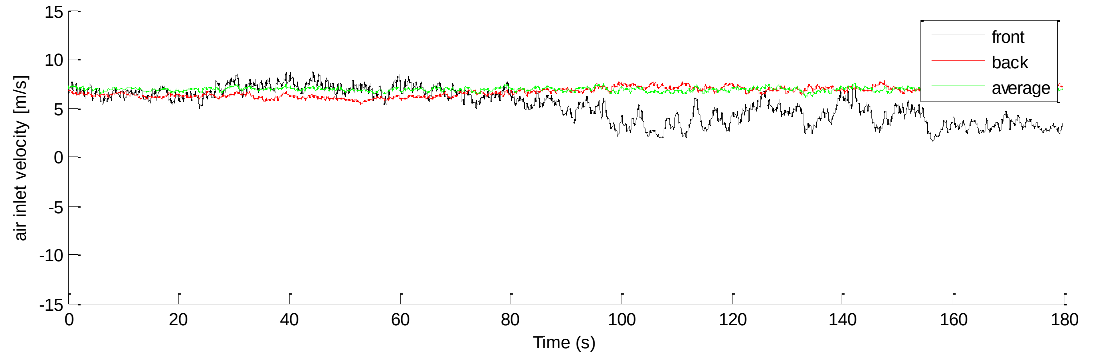
Fan application – practice

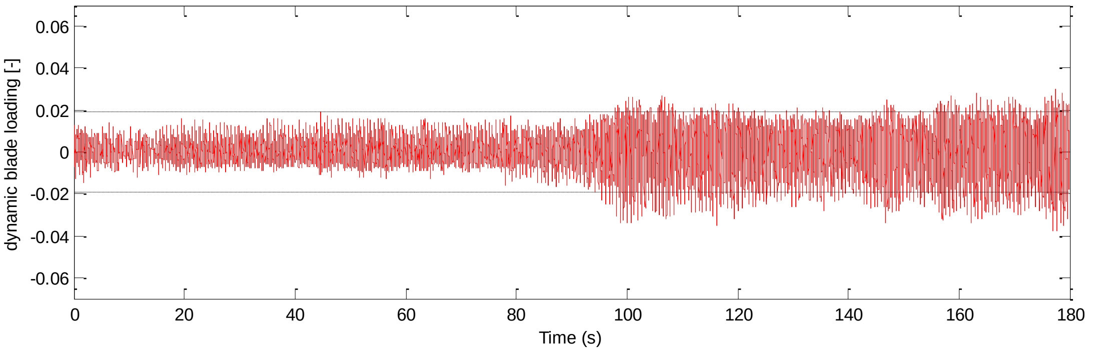
No wind – uniform inlet conditions

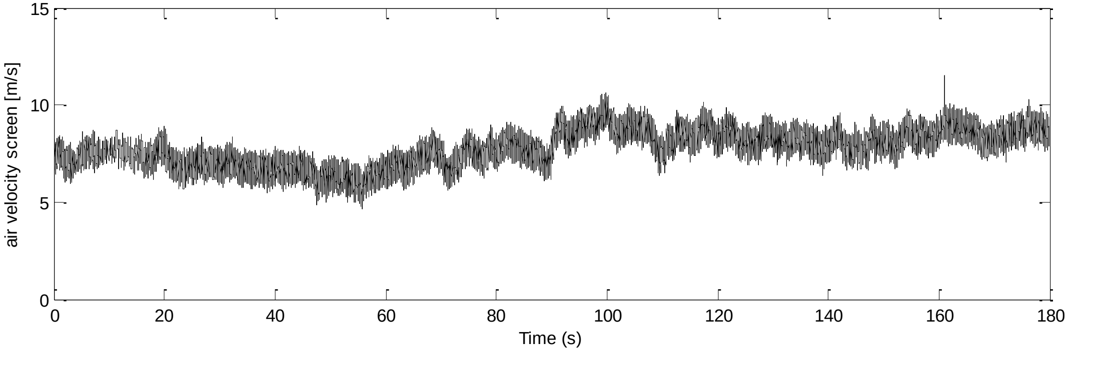


Fan application – practice

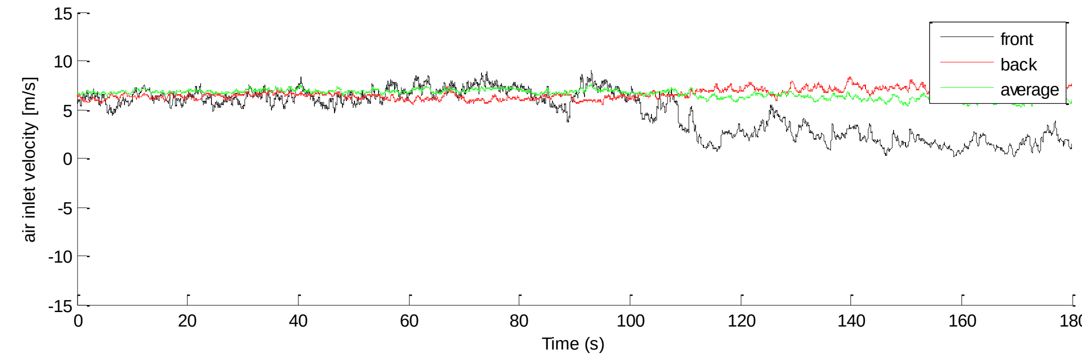
Wind – non- uniform inlet conditions



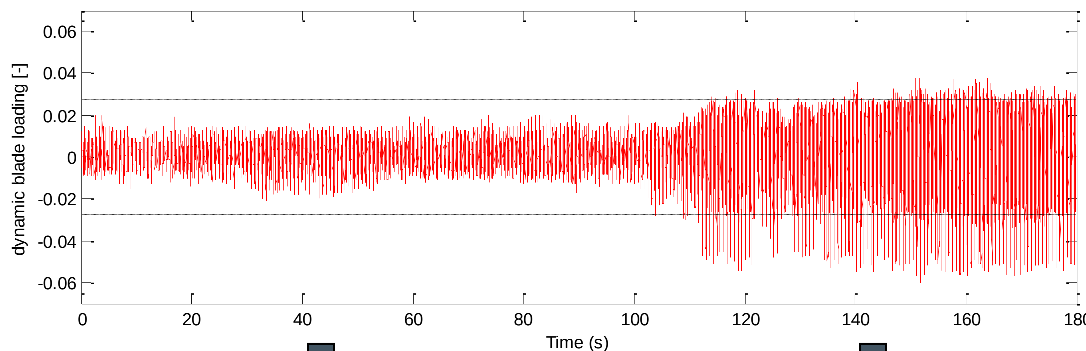




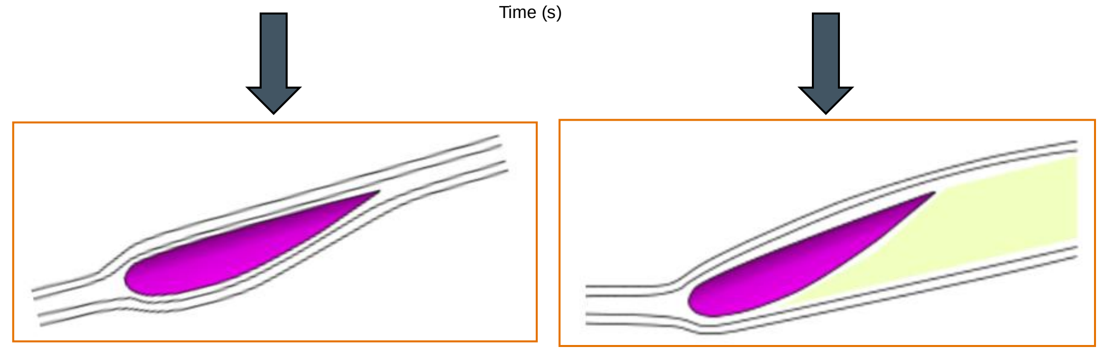
Fan application – practice



Non- uniform inlet conditions



Periodic flow separation at fan inlet bell.



Local reduction in the axial air inlet velocity

Causes excitation of fan blades

(at the fan operating frequency)

Fan application – practice

Systems to mitigate the negative effects of wind on fan performance

Fan application – practice

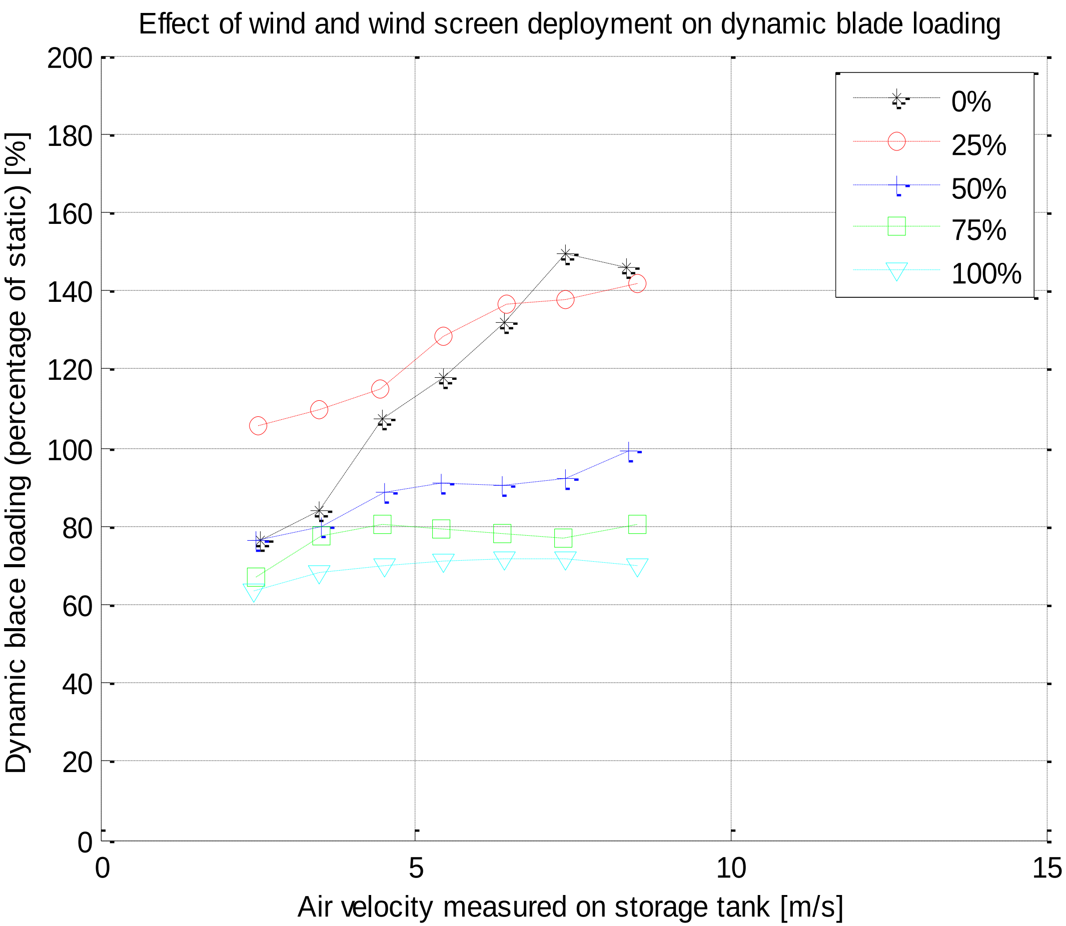
Without wind protection:

- Strong increase in dynamic blade loading

With wind protection:

- Hardly any increase in dynamic blade loading

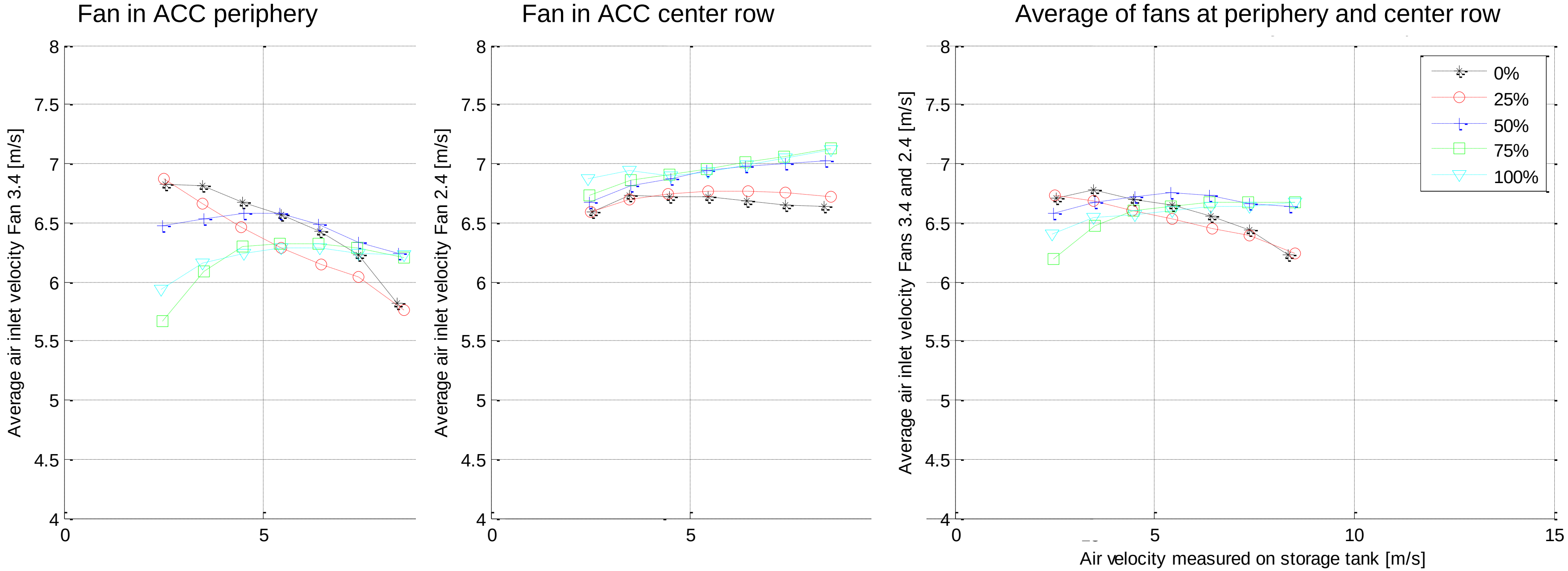
→ Wind screens have a positive effect on the expected life of the fan



Fan application – practice

Effect wind screens on aerodynamic performance:

- In the ACC periphery: reduced airflow at low wind speed (screen adds resistance); increased airflow at high wind speed
- In the ACC center row: increased airflow at all wind conditions
- On average an breakeven point at 4 m/s (possibly at lower wind speed for bigger ACC's)



Fan application – practice - summary

There are several factors influencing the actual fan performance, like:

- Fouling of the system
- Obstacles in the air flow
- Wind

The original selection and design should have sufficient margin to the stall line to cope with these factors.

Studies into the effectiveness of windscreens show that windscreens:

- reduce the dynamic loading of the fan blade → protection of the fan
- give a more constant air velocity through the fan at different wind speeds
- give on average a better fan performance

There are still several studies ongoing to optimize the configuration of wind screens.

Summary

Summary

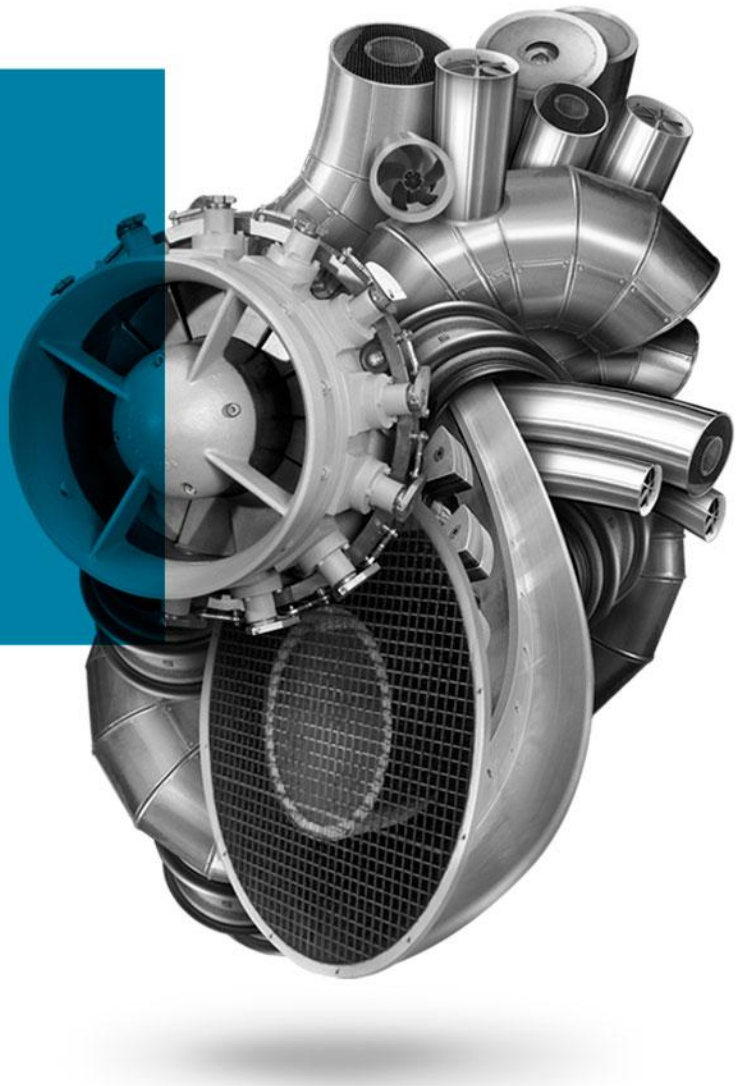
- ACC user needs <u>cooling capacity</u> → air flow (Q in [m^3/s])
- A fan is designed to move a large air volume (Q) against a low pressure (Δp)
- A fan should be operated in the stable working area of the fan curve

- A fan is sensitive to deviations in operating conditions like:
  - Fouling of the system
  - Obstacles in the airstream
  - Wind
- Therefore the fan should be selected and designed with a sufficient margin to the stall line

- Once a fan is selected, installed and in operation, there are only limited possibilities to adjust or improve the fan performance because of the strong impact on fan shaft power.
- Windscreens as a mitigating systems show a positive effect on:
  - Reduction of dynamic loading of the fan (longer life expectancy)
  - Constant and stable fan performance

Howden

At the heart of your operations



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