KULI Air Side

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drivetrain components and systems

engines and engine components

axle and chassis modules

Engineering Center Steyr Gmbh & Co KG

driven by passion

Contents

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- Theoretical considerations
- cp-values
- Fans
- Uneven air flow - CFD interface

The theoretical foundation

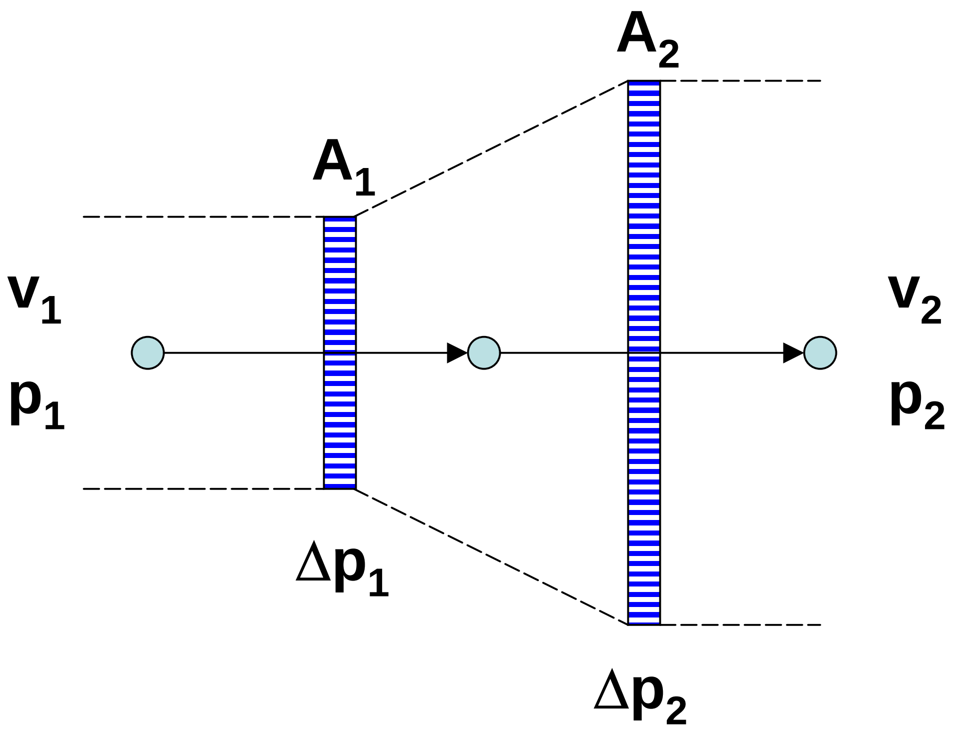
$$\underbrace{p_{\text{stat}} + \underbrace{\frac{\rho}{2} v^2}_{= p_{\text{dyn}}}}_{= p_{\text{tot}}} \left(+ \rho g h \right) = \text{constant}$$

Bernoulli

- p_{stat} = static pressure
- p_{dyn} = dynamic pressure
- p_{tot} = total pressure

- ρ = density
- v = velocity
- h = height
- g = gravity

A simple air path



Assumptions:

- ρ = constant = 1
- $p_{1,stat}$ = 1 bar
- v1 = 20 m/s
- A_1 = 0,5 m²
- A_2 = 1 m²
- $\Delta p_1 = \Delta p_2$ = 200 Pa

- $p_{2,stat}$ = ??

Method 1: Bernoulli holds between components

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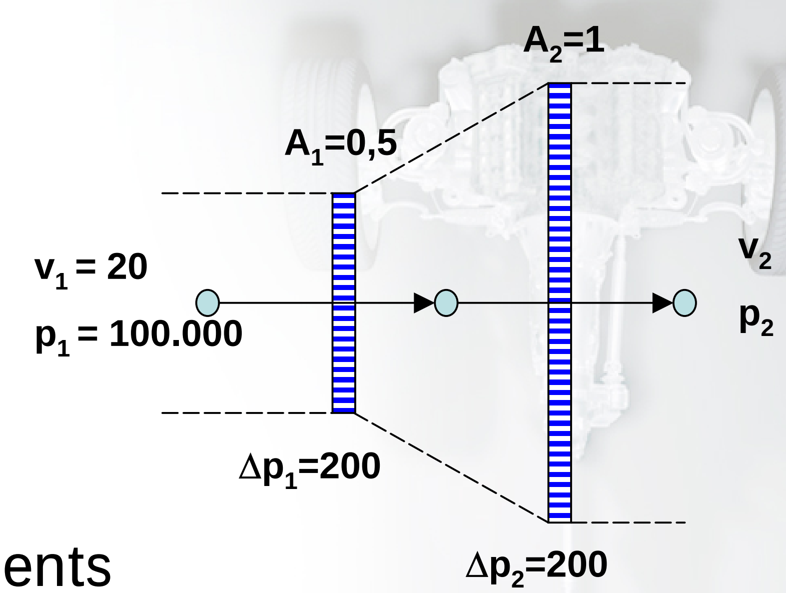
$$A_2 = 2A_1 \Rightarrow v_2 = v_1 / 2 = 10\, {}^{m}\!/\!_{s}$$

$$p_{1,\mathrm{dyn}} = \tfrac{\rho}{2} v_1^2 = \tfrac{1}{2} 400 = 200\ \mathrm{Pa}$$

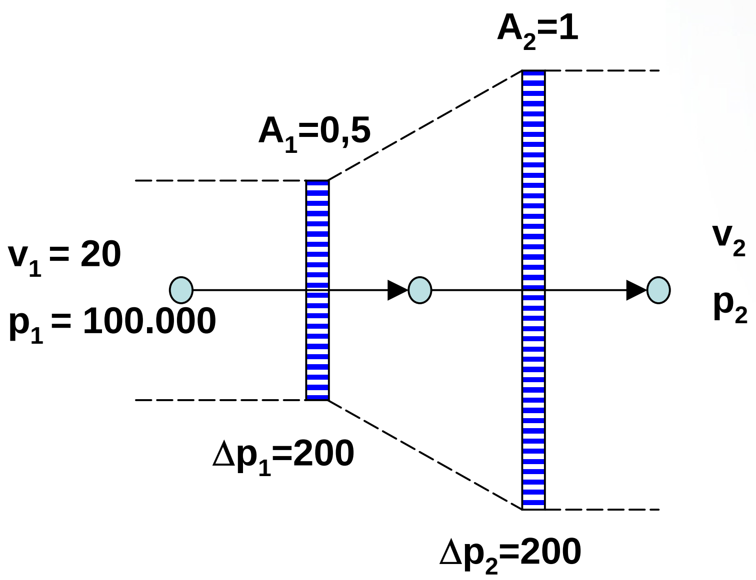
$$p_{2,\mathrm{dyn}} = \tfrac{\rho}{2} v_2^2 = \tfrac{1}{2} 100 = 50\ \mathrm{Pa}$$



Bernoulli holds *between* the components
=> p_{tot} = konstant
=> p_{stat} increases by 200-50 = 150 Pa!

$$p_{2,\mathrm{stat}} = p_{1,\mathrm{stat}} - \Delta p_1 + 150 - \Delta p_2 = 99.750\ \mathrm{Pa}$$

Method 2: Static pressure constant between components



$$p_{2,\mathrm{stat}} = p_{1,\mathrm{stat}} - \Delta p_1 - \Delta p_2 = 99.600 \text{ Pa}$$

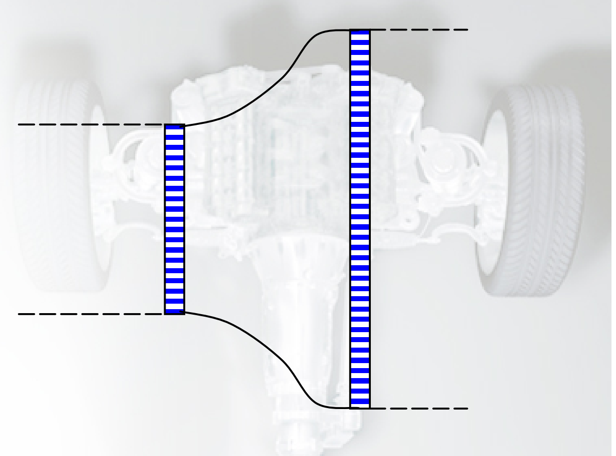
How does KULI calculate the air path?

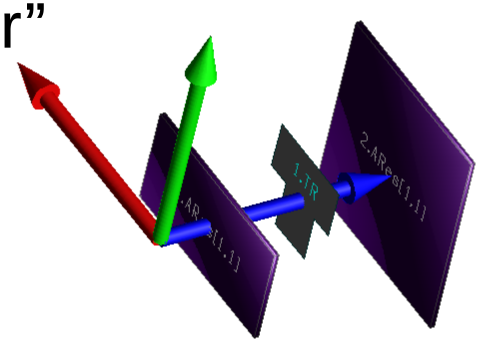
- KULI uses Method 2, i.e., p_{stat} is constant, because
  - in reality in most cases p_{dyn} cannot be regained when the area increases.
  - essentially only the area change from the first to the last component in the air path is relevant, all other changes cancel out.
  - a change of pressure due to a change of area can easily be packed into a built-in resistance.

- Investigations showed that there can even be a static pressure drop from small inlet grille areas to the larger radiator area, mainly due to swirls and turbulences.

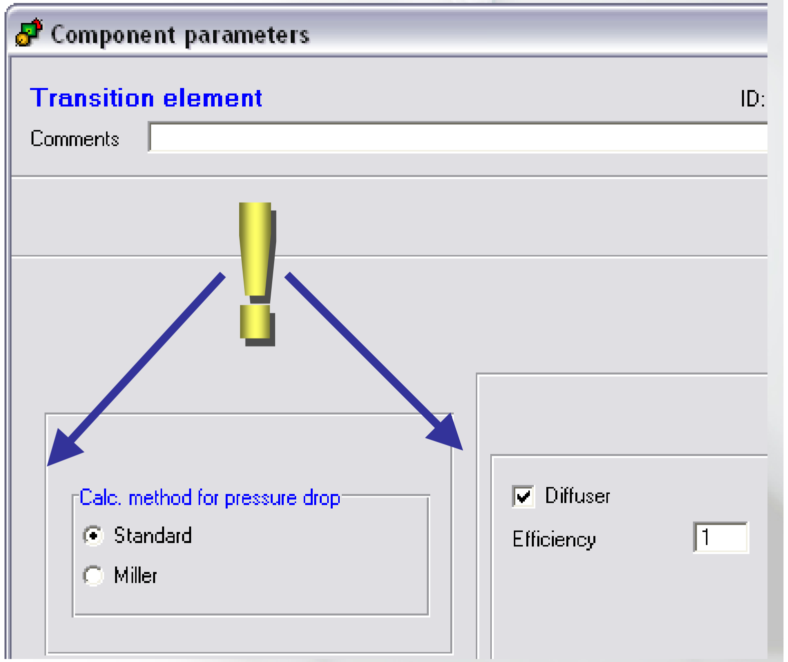
Constant total pressure in KULI

- In special conditions it makes sense to use constant total pressure, e.g. for diffuser-like configurations without turbulences.
- In KULI use a transition element and choose "Diffuser"





- The "Efficiency" defines the part of the dynamical pressure difference that will be converted into static pressure.



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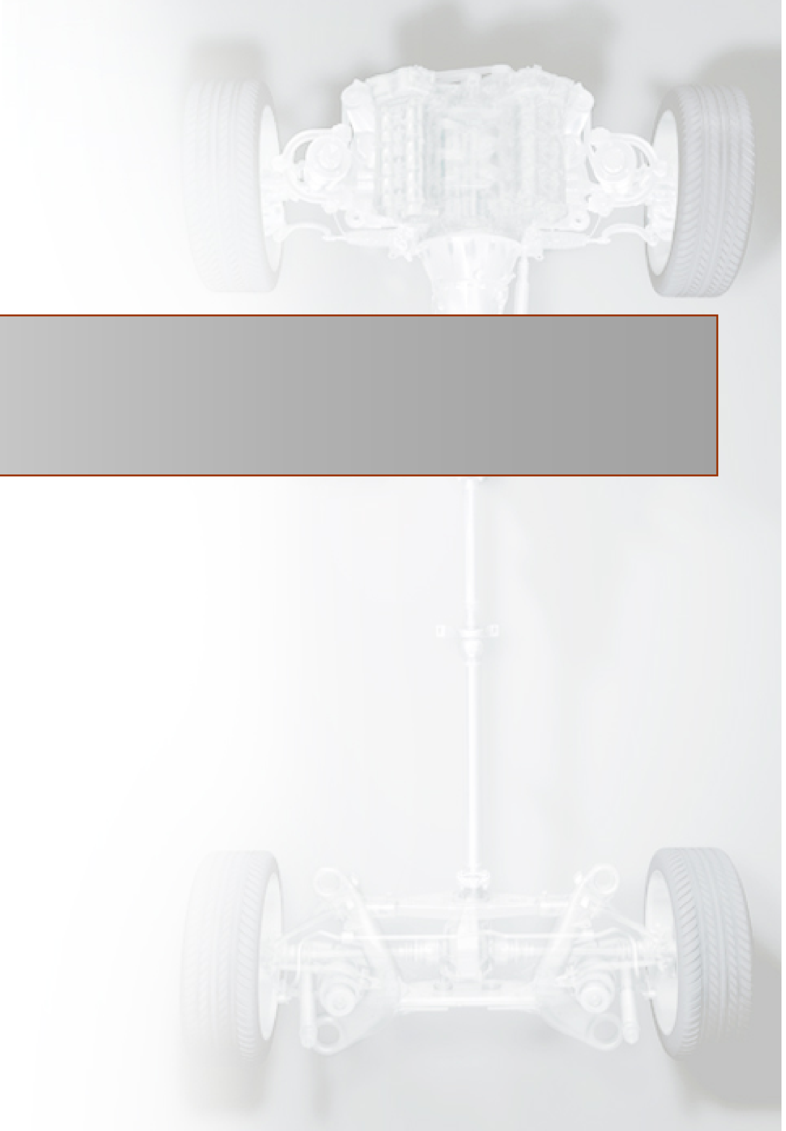

Air flow at air inlet: cp-values

p_∞, p_i: static pressure ambient and entry, resp.

v_∞, v_i: driving speed and air entry velocity

New options for cp value

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Determination of pressure difference

- (selected) Relative Method
  Measurement: closed; Analysis: open
- Absolute Method
  Measurement: open or Values from CFD; Analysis: open
- Total Pressure Method
  Measurement: closed; Analysis: open

$$\text{rel.}: \quad \Delta p = cp \times \frac{\rho}{2} \times \left(v_\infty - v_{inlet}\right)^2$$

$$\text{abs.}: \quad \Delta p = cp \times \frac{\rho}{2} \times \left(v_\infty\right)^2$$

$$\text{tot.}: \quad \Delta p = \frac{\rho}{2} \times \left(cp \times v_\infty^2 - v_{inlet}^2\right)$$

cp-values - the 3 methods

$$\left(\Delta p = p_i - p_\infty\right)$$

"Absolute method"

$$c_p = \frac{\Delta p}{\frac{\rho}{2} v_\infty^2} \quad \Leftrightarrow \quad \Delta p = c_p \frac{\rho}{2} v_\infty^2$$

"Relative method"

$$c_p = \frac{\Delta p}{\frac{\rho}{2} (v_\infty - v_i)^2} \quad \Leftrightarrow \quad \Delta p = c_p \frac{\rho}{2} (v_\infty - v_i)^2$$

"Total pressure method"

$$c_p = \frac{\Delta p + \frac{\rho}{2} v_i^2}{\frac{\rho}{2} v_\infty^2} \quad \Leftrightarrow \quad \Delta p = \frac{\rho}{2} (c_p v_\infty^2 - v_i^2)$$

cp-value: Absolute method

$$c_p = \frac{\Delta p}{\frac{\rho}{2} v_\infty^2} \quad \Leftrightarrow \quad \Delta p = c_p \frac{\rho}{2} v_\infty^2 \quad \Leftrightarrow \quad p_i = p_\infty + c_p \frac{\rho}{2} v_\infty^2$$

- cp-value defines which part of the dynamical pressure can be converted into static pressure.
- The determination of the cp-value must be carried out for open condition (i.e. with engine compartment air flow)
- The cp-value and thus the pressure increase only depend on the driving speed; the area of the cp-value has no influence!
- The area of the cp-value is used in the postprocessor to compute the flow velocity in the cp-value component; this however is only an output value and does not influence the computation.

cp-value: Relative method

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$$c_p = \frac{\Delta p}{\frac{\rho}{2}(v_\infty - v_i)^2} \quad \Leftrightarrow \quad \Delta p = c_p \frac{\rho}{2}(v_\infty - v_i)^2$$

- Purpose of this method: Determination of the cp-value for closed condition, simulation then for open condition => different formulas for determination and usage (simulation)

Determination (closed)

$$c_p = \frac{\Delta p}{\frac{\rho}{2} v_\infty^2}$$

Usage (open)

$$\Delta p = c_p \frac{\rho}{2}(v_\infty - v_i)^2$$

- The pressure increase depends on v_i and thus on the area of the cp-value (since v_i = volume flow / area)! This dependency can be significant!

cp-value: Total pressure method (suggested by VW)

$$c_p = \frac{\Delta p + \frac{\rho}{2} v_i^2}{\frac{\rho}{2} v_\infty^2} = \frac{p_{i,\mathrm{tot}} - p_\infty}{\frac{\rho}{2} v_\infty^2} \quad \Leftrightarrow \quad \Delta p = \frac{\rho}{2}\left(c_p v_\infty^2 - v_i^2\right)$$

- Idea of this method: Total pressure at entry should be constant, no matter if the entry is open or closed => this method should be useable for open and closed models!

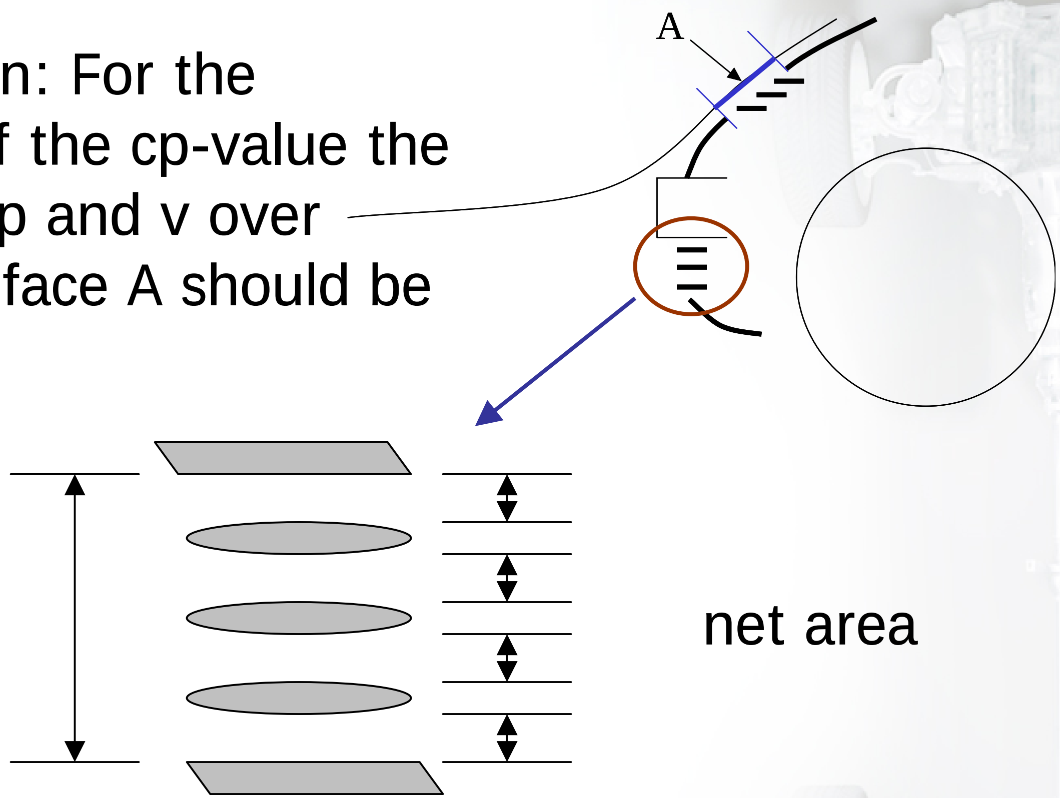
cp-value describes total pressure drop from ambient to air inlet.

$$p_{\infty,\mathrm{tot}} = p_\infty + \frac{\rho}{2} v_\infty^2 > p_\infty + c_p \frac{\rho}{2} v_\infty^2 = p_i + \frac{\rho}{2} v_i^2 = p_{i,\mathrm{tot}}$$

- The pressure increase depends on v_i and thus on the area of the cp-value (since v_i = volume flow / area)! This dependency can be significant!

Areas of cp-values

Recommendation: For the determination of the cp-value the mean values of p and v over the depicted surface A should be taken



gross area

net area

In the cp-value component the gross area should be used, since pressure drops which are due to the shape of the grille are modeled in the area resistance describing the grille.

Inlet grid

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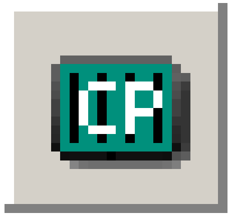

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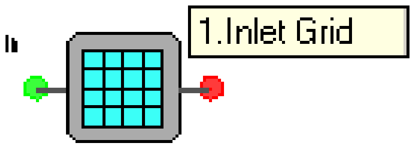
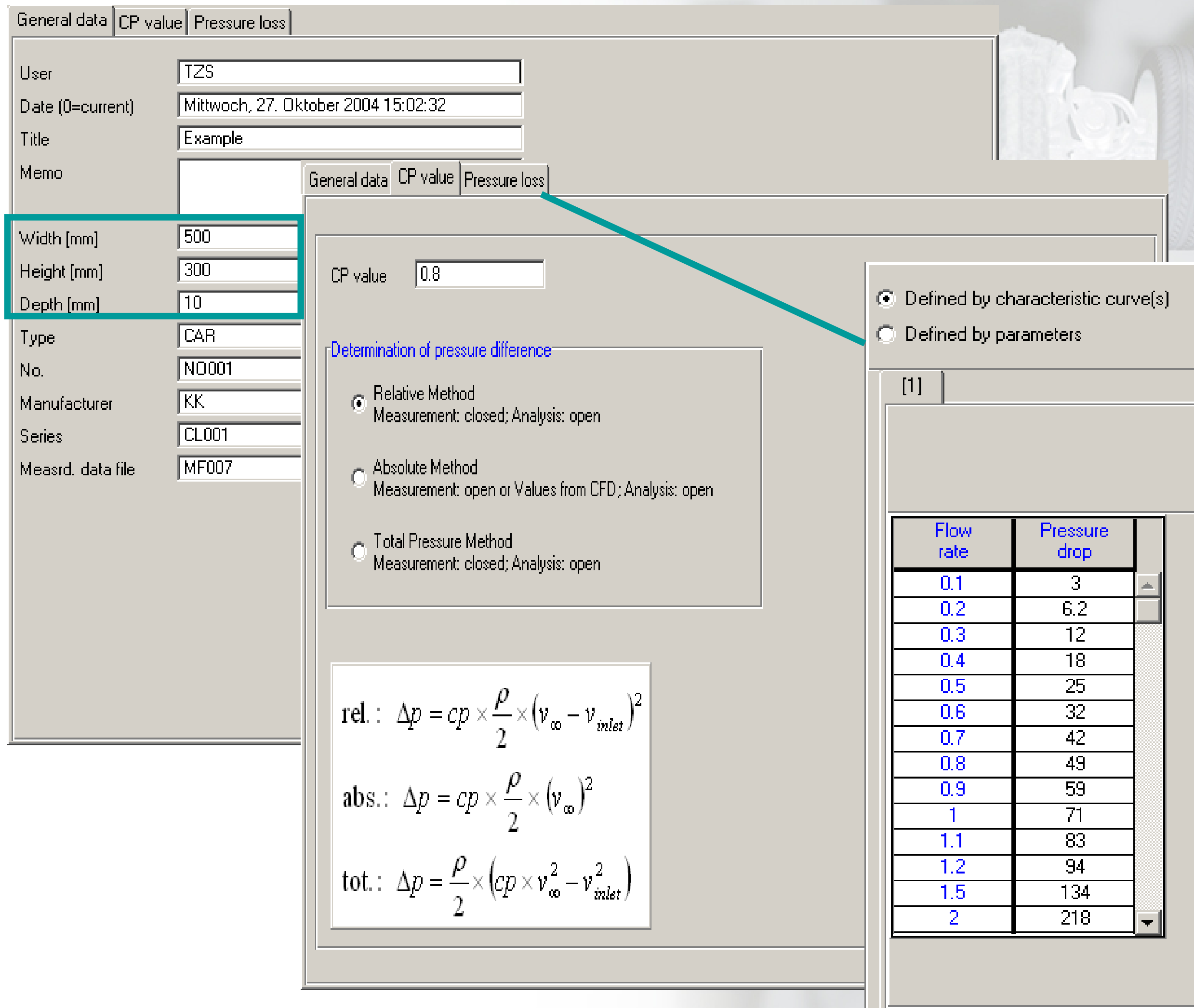


Definition of cp value and pressure loss of grill in one component



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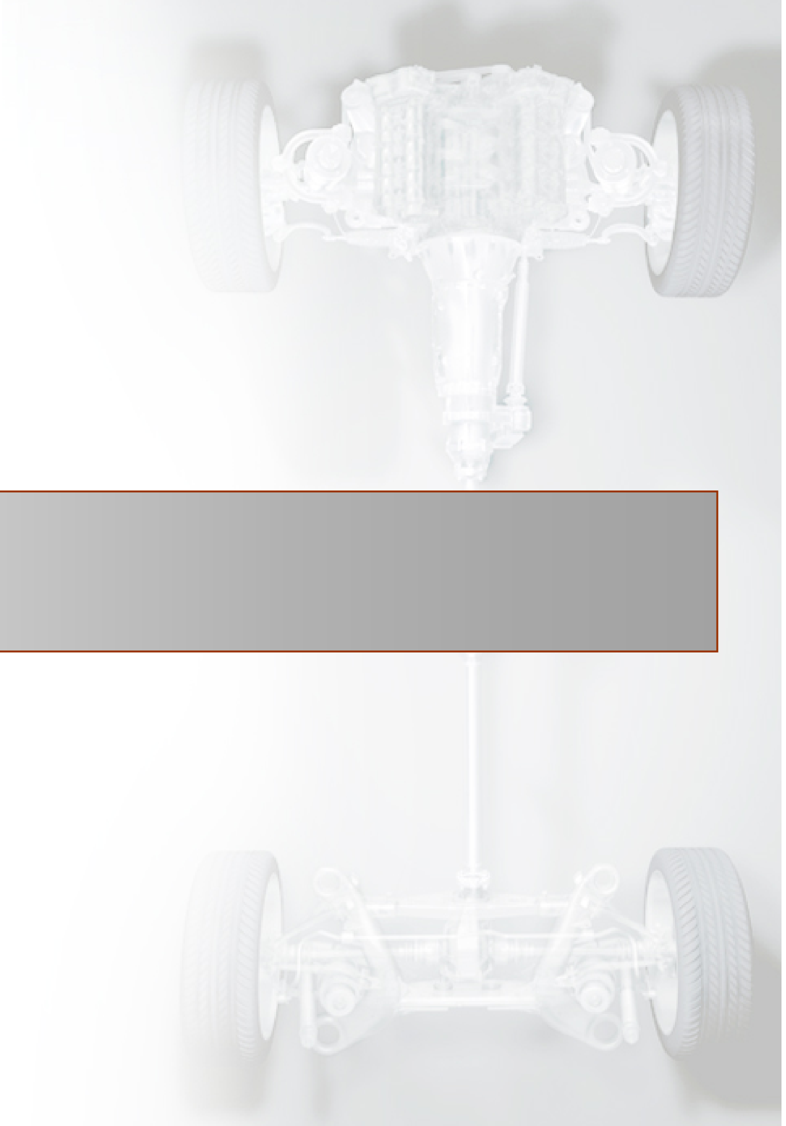

How to determine characteristic curves of fans?

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- How and where are pressures to be measured?
  - is regulated in DIN-Norm 24163
- Should I use static or total pressure differences?
  - depends on test bench; rather take static pressure differences
  - in KULI this is not a problem, since the difference between the two version can be corrected with a built-in resistance
- Should I use a deflector plate (“Prallplatte”)?
  - Measurements with deflector plate yield more realistic characteristic curves
  - The difference with/without deflector plate cannot be compensated with a standard built-in resistance
  - Problem of normalization
    - how big should be the deflector plate?
    - what would be the distance between fan and deflector plate?

Fan measurement - Standard test bench (DIN 24163)

Determination of pressure increase Part 2, Section 8.1.3

Blowing unblocked Δp_{fa}

1) Measurement of total pressure p_{t1}

$$\Delta p_{fa} = p_a - p_{t1} = 100000 - 99900 = 100\,\text{Pa}$$

2) Measurement of static pressure p_{st1}

$$\bar{c}_5 = \dot{V}_1 / A_5$$

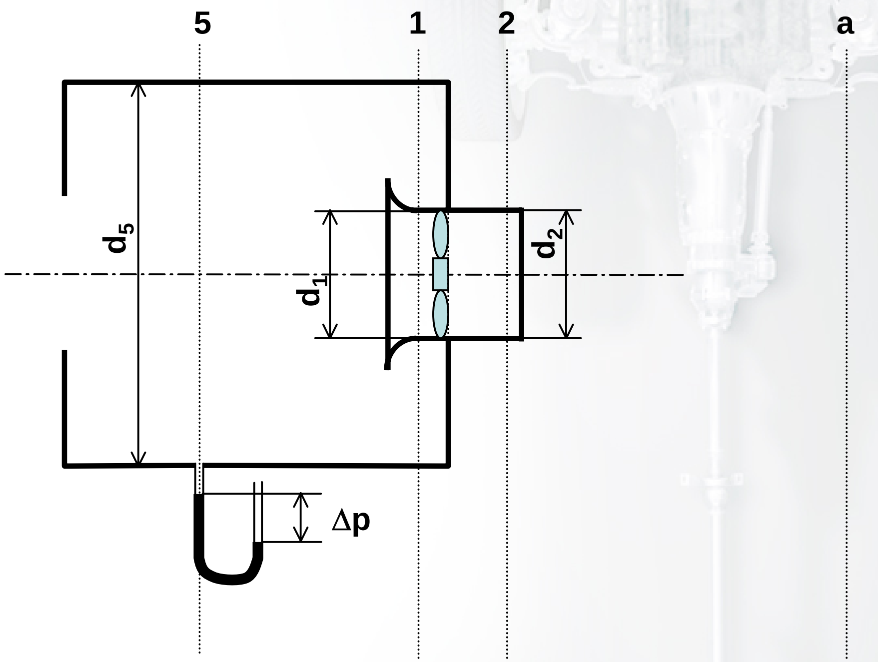
$$\Delta p_{fa} = p_a - \left(p_{st5} + \frac{\rho_1}{2}\cdot\bar{c}_5^2\right) = \Delta p - \frac{\rho_1}{2}\cdot\bar{c}_5^2$$

$$= 100000 - 99894 - 6 = 100\,\text{Pa}$$

Total pressure increase Δp_t

$$\bar{c}_2 = \dot{V}_2 / A_2$$

$$\Delta p_t = \Delta p_{fa} + \frac{\rho_2}{2}\cdot\bar{c}_2^2 = 100 + 60 = 160\,\text{Pa}$$



	5	1	2		a
p_{st}	99894	99840	99940	Bernoulli	100000
p_d	6	60	60		0
p_t	99900	99900	100000		100000

Characteristic fan curves with and without deflection plate

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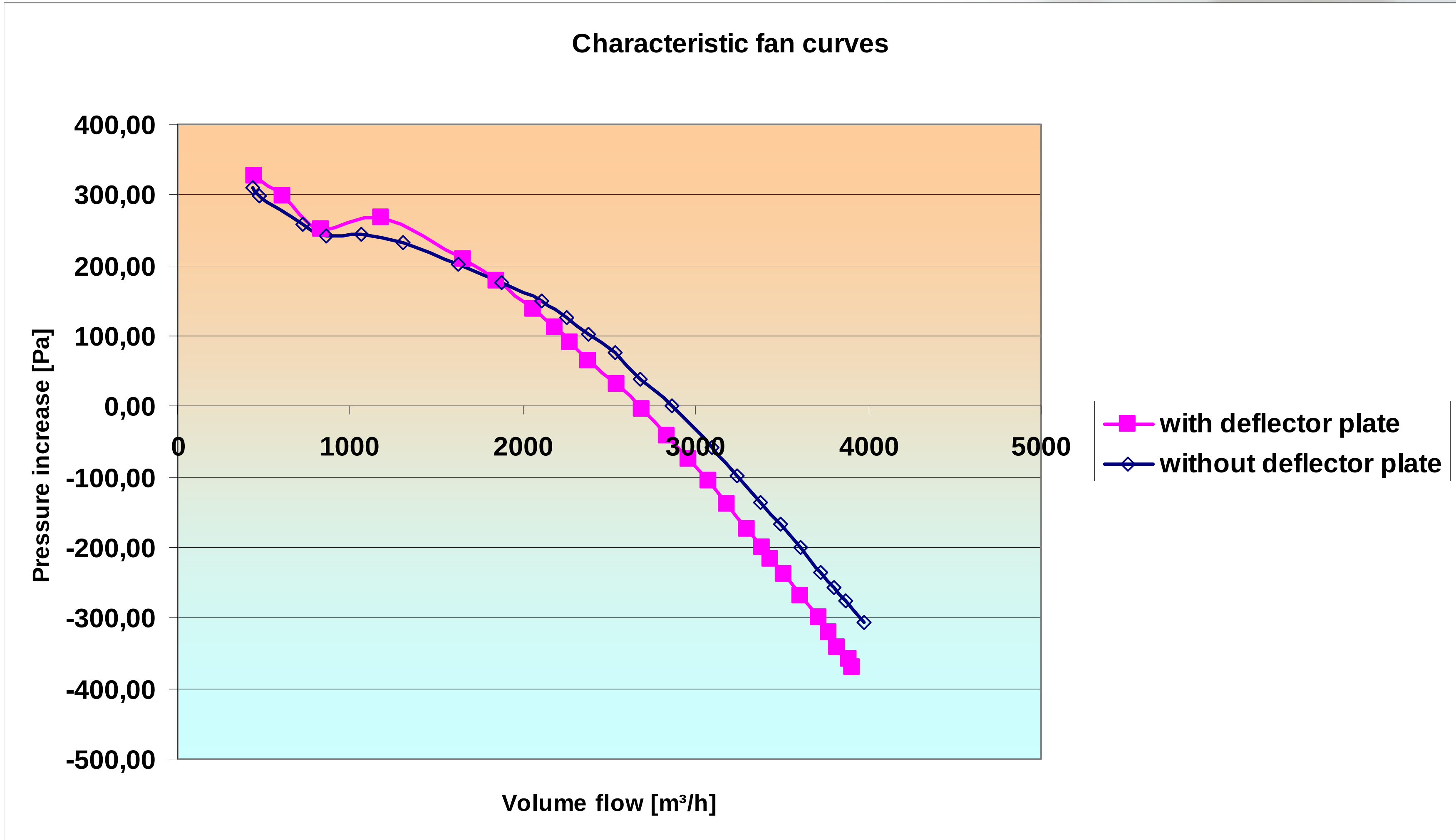
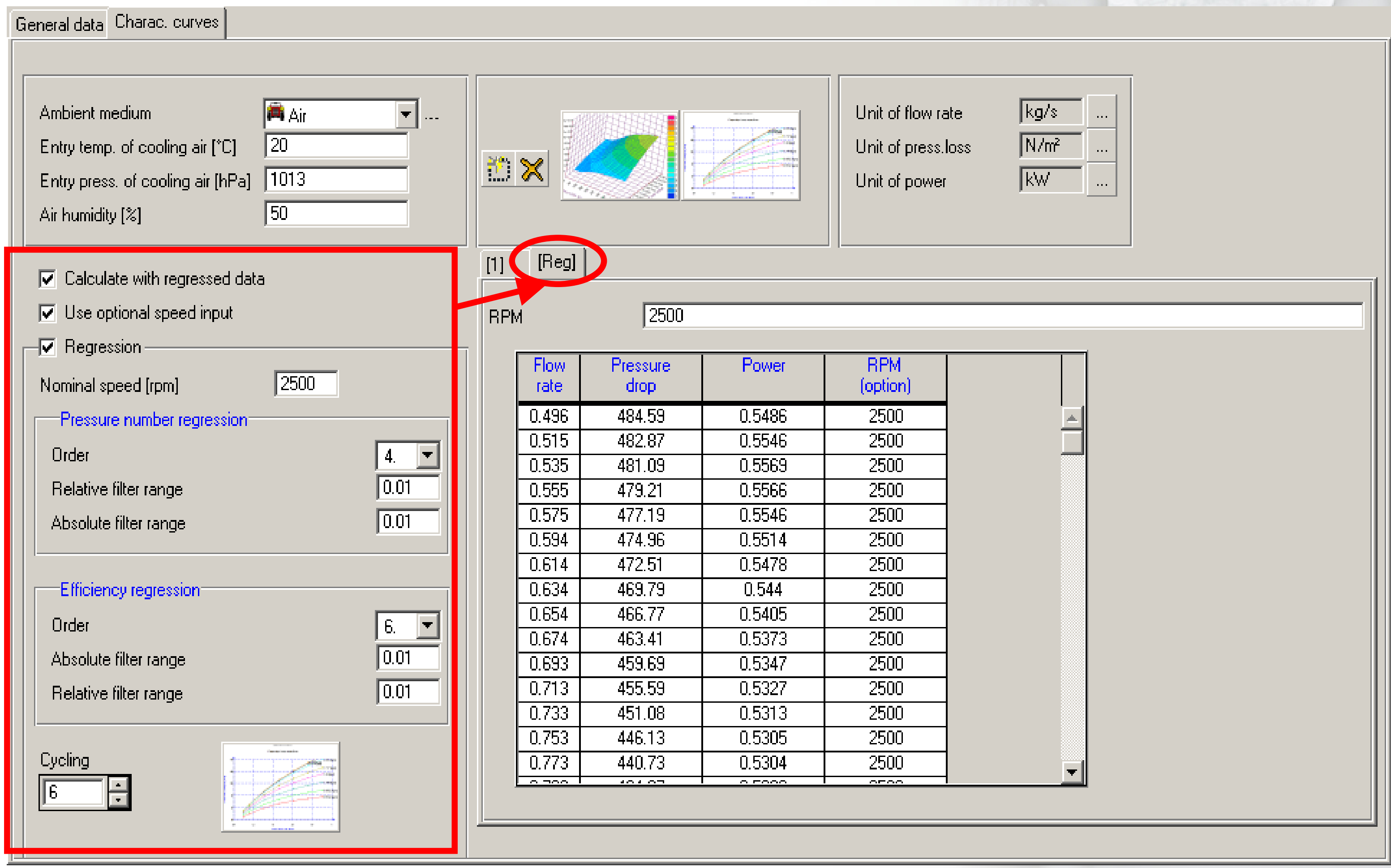
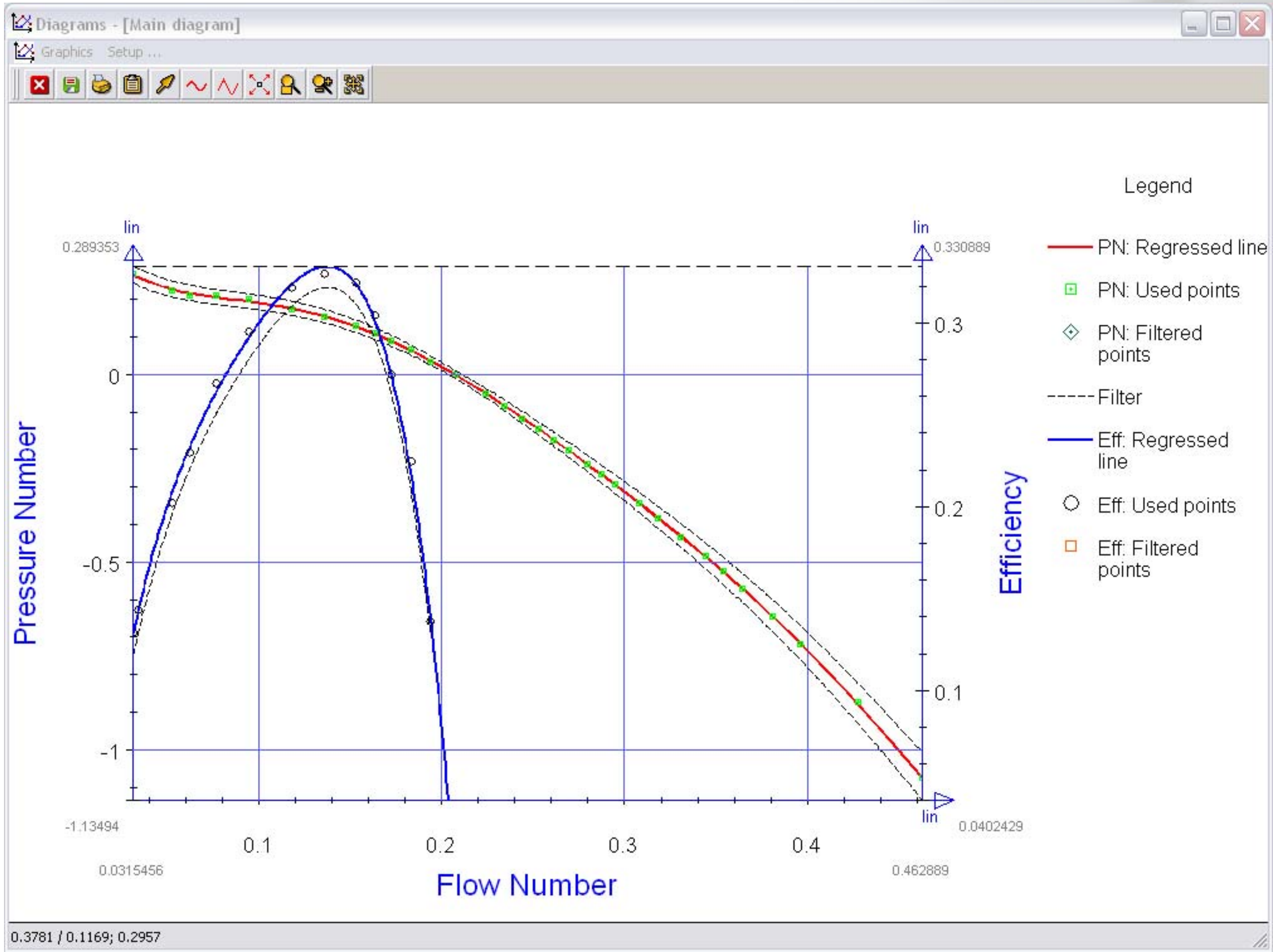


Regression of fan curves



Regression of fan curves (2)



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Fan regression - how to use it

- Regression can be used to smooth out measurement errors
- Regression can be used to combine measurement data of resistance curve (fan off) and pressure increase curve (fan on)
- Regression can be used to convert measurement data of electric fan into mechanical fan, allowing modelling of continuous electric fan
- Usually raw data is simply copied from Excel into KULI
- Description of usage in online help:
  - KULI base -> Components -> Fans -> Fan regression

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1D-3D Principles

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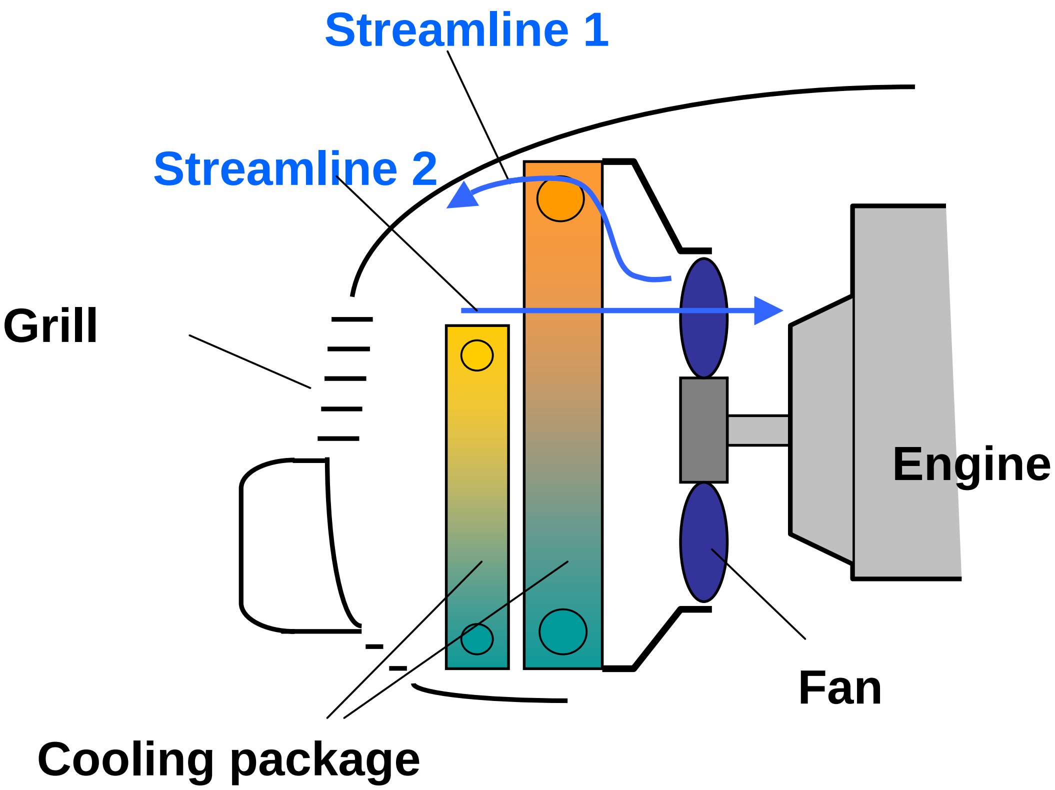
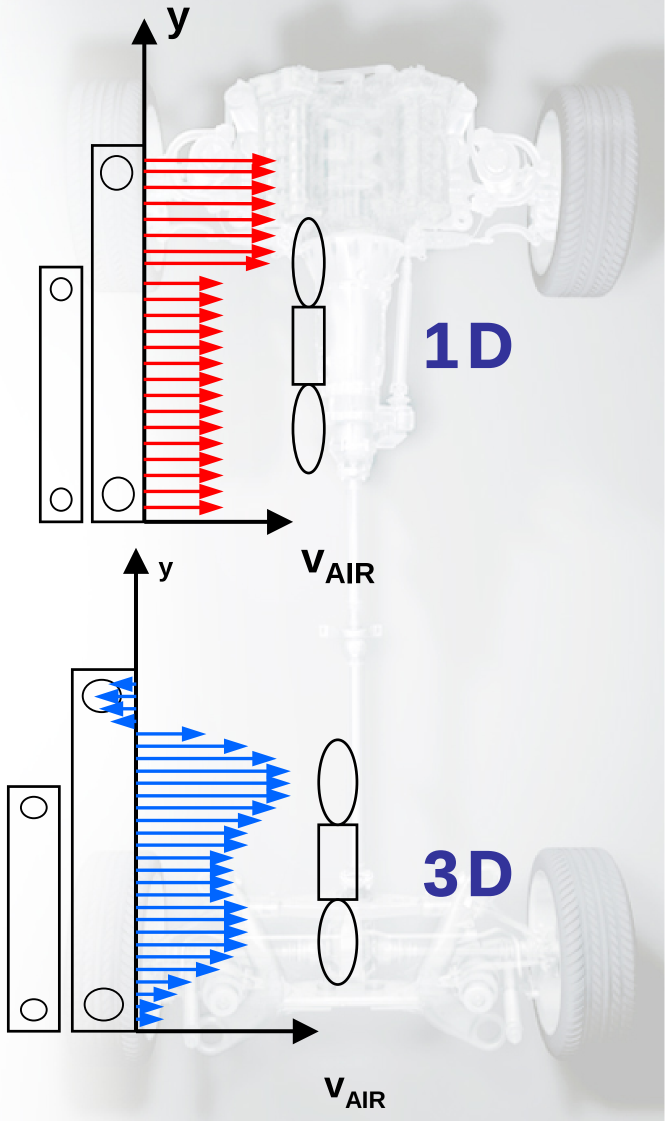
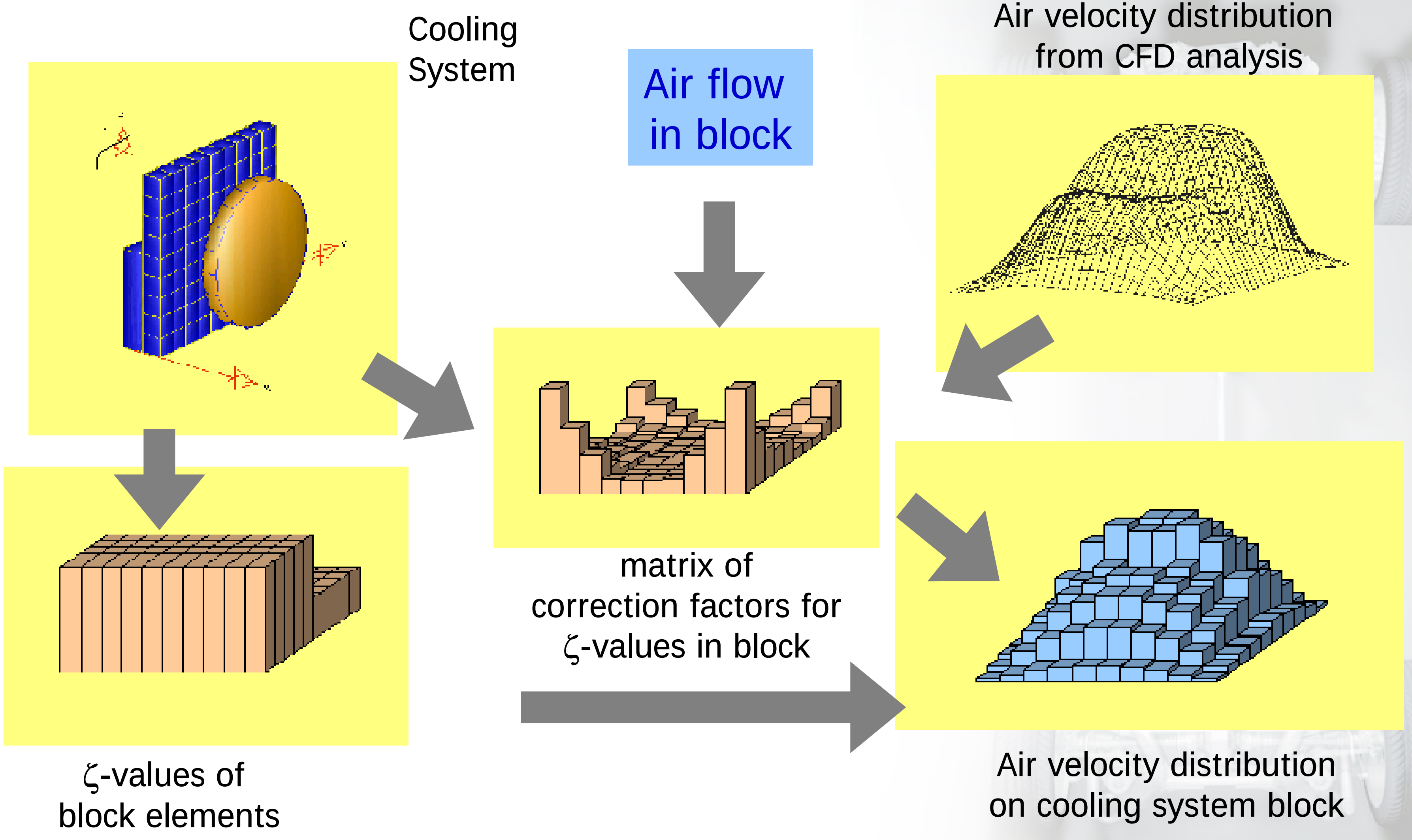




Theory


Cooling System
Air flow in block
Air velocity distribution from CFD analysis
matrix of correction factors for ζ-values in block
ζ-values of block elements
Air velocity distribution on cooling system block

Accuracy and Time vs. Number of Subdivisions

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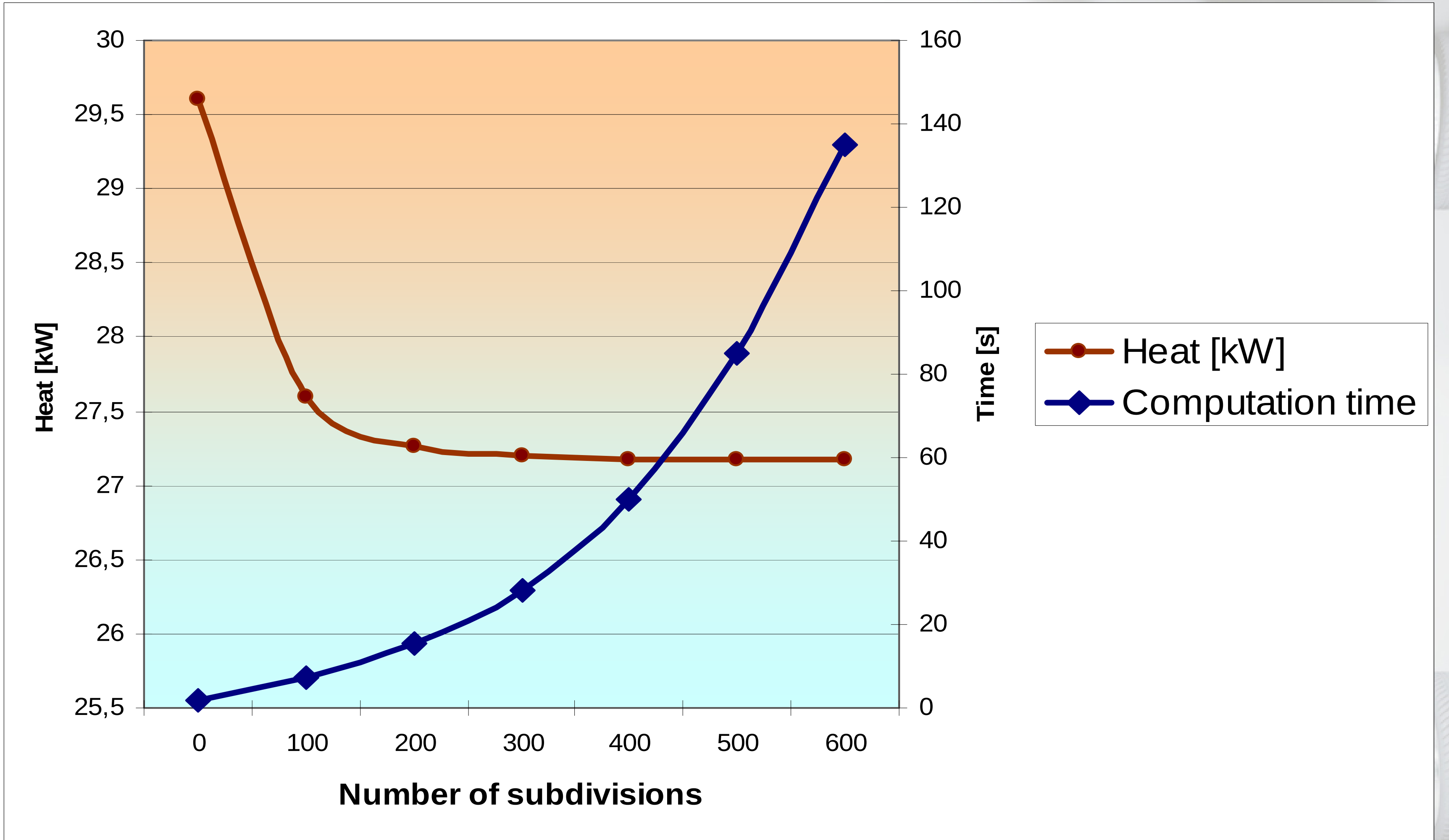

Motivation for variable resistance matrix

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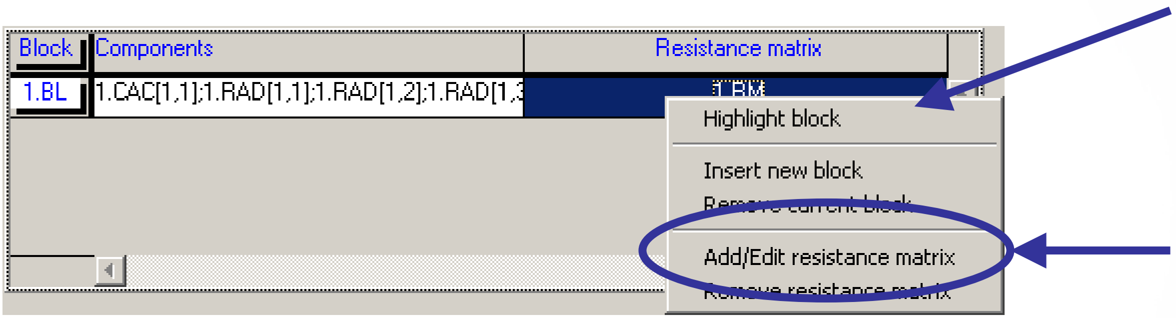
- Velocity distribution on surface of component is not equal for different conditions
- Velocity distributions may depend on
  - driving speed
  - fan rpm
  - air flaps
  - ...
- Standard implementation of resistance matrix in KULI requires separate KULI models for different configurations
- Standard implementation of resistance matrix is thus not suitable for transient simulation
- Resistance matrix needs to be more flexible during simulation

New resistance matrix method in KULI

- Generation of resistance matrix as before
- Several resistance matrices can now be assigned to a single block
- Each resistance matrix is assigned to a certain driving speed and/or one other parameter
- This second parameter is defined via COM-objects. Hence, any sensor can act as this second parameter
- During computation the zeta-correction factors are obtained via interpolation depending on the current driving speed and/or value of the second parameter

Usage (1)

A variable resistance matrix is added to a block in the same way as a standard resistance matrix



context menu

add resistance matrix

Usage (2)

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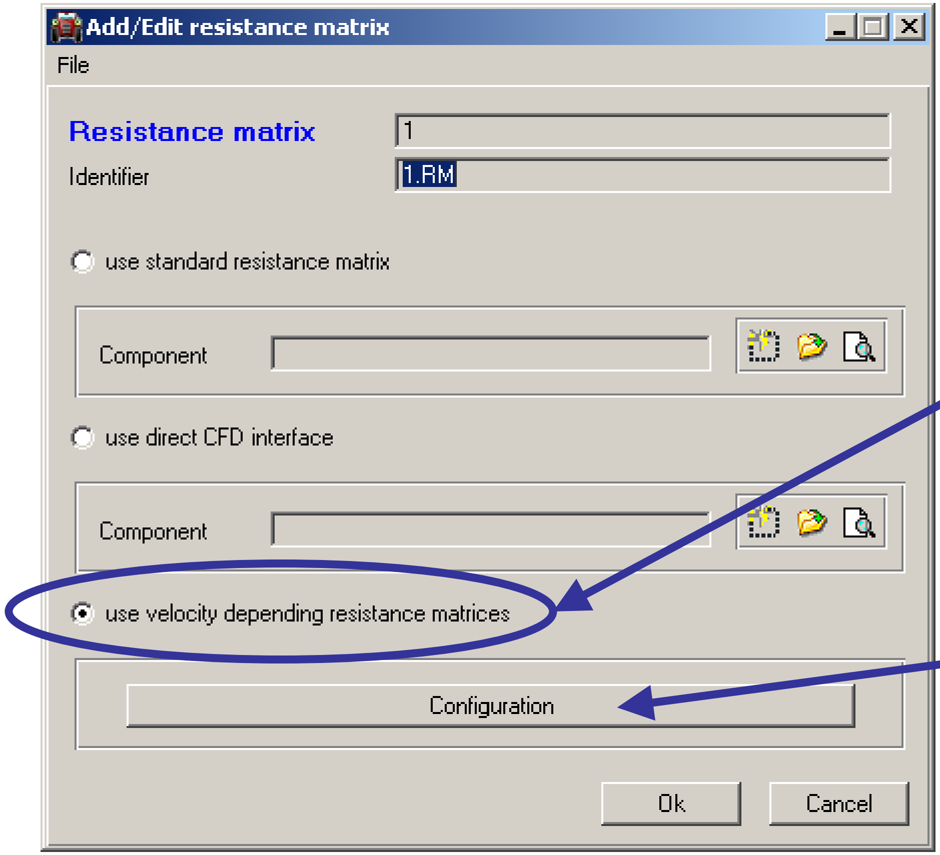
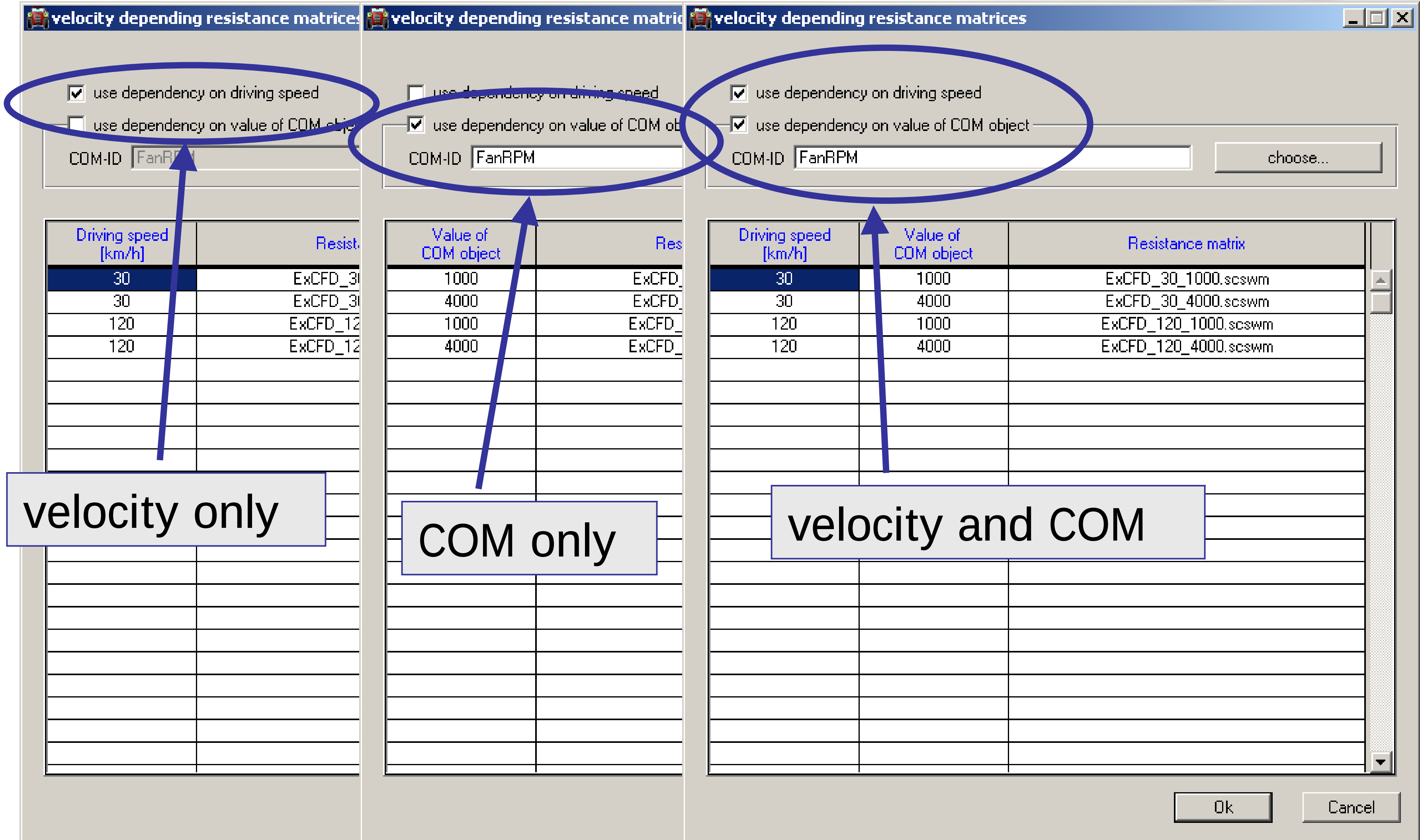


choose type of resistance matrix

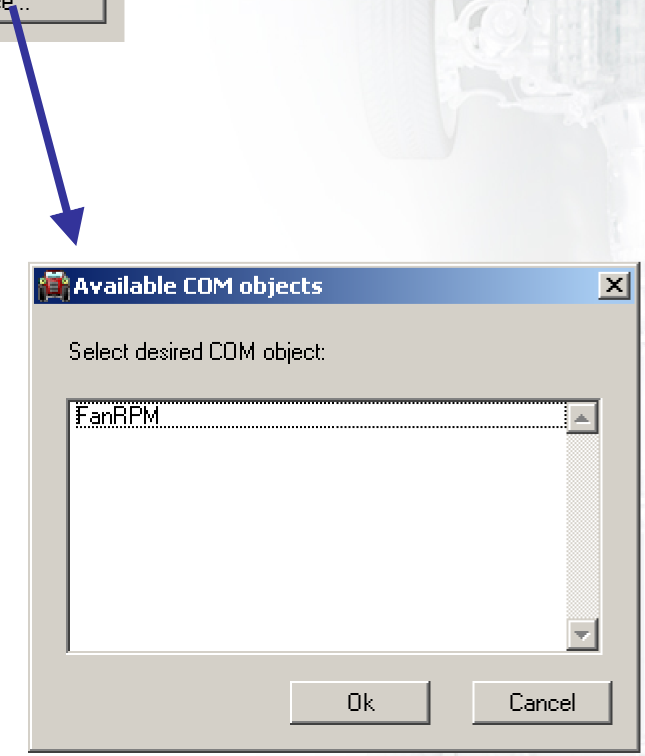
click on „Configuration“

Usage (3) - Dependence on...



Usage (4) - Choice of COM object

list of all available COM objects in model is displayed; COM ID can also be entered manually



Usage (5) - Choice of resistance matrix files

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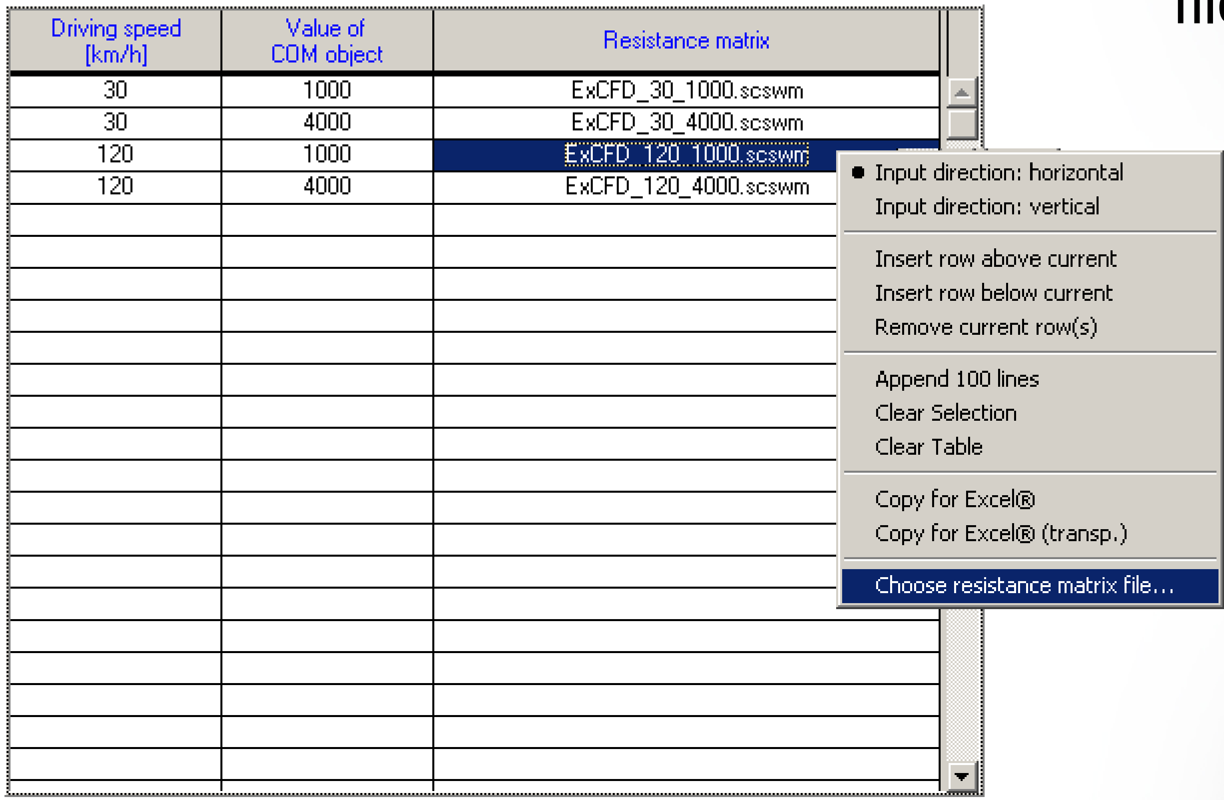
choice of resistance matrix file via context menu



Some implementation details

- Interpolation is done (bi)linear. Hence, only two values for each variable (velocity and/or COM value) are necessary
- No extrapolation is done; boundary values are taken if current operating point is outside defined range
- If dependency on two variables is selected, then for each velocity value all COM values must appear in the configuration table (and vice versa)

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Thank you for your attention!

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