Bodyplethysmography physics

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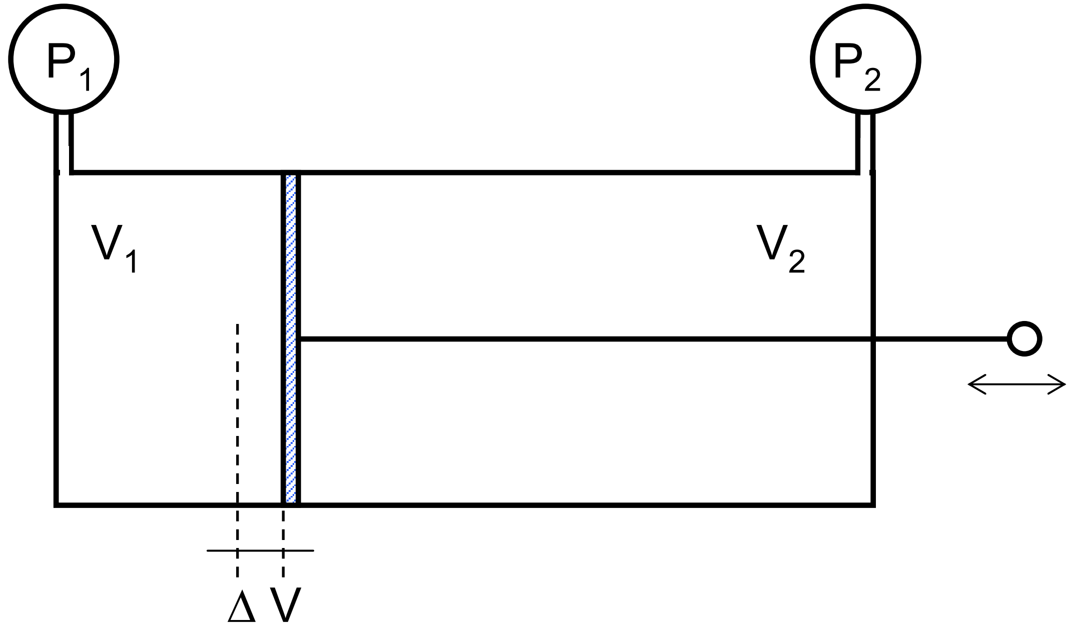
R_{aw} images: Dr. H. Eschenbacher

Ideal gas law: $P.V = n.R.T$

$P.V = n.R.T$
$N.m^{-2}.m^{3} = mol.J.mol^{-1}.K^{-1}.K$
$Nm = J$

P	pressure	[Pa; $N.m^{-2}$]
V	volume	[m^{3}]
N	molecules	[mol]
R	gas constant	[$J.mol^{-1}.K^{-1}$]
T	Temperature	[K]

In a closed volume, if temperature is constant: $PV = c$



Closed volume, assume temperature constant: PV = c

Moving the piston to the left…

$P_1.V_1 = c_1 = P_1' (V_1 - \Delta V)$ and $P_2.V_2 = c_2 = P_2' (V_2 + \Delta V)$

$$P_1.V_1 = c = P_1' (V_1 - \Delta V)$$

$$P_1.V_1 = P_1'.V_1 - P_1'.\Delta V$$

$$V_1 (P_1 - P_1') = - P_1'.\Delta V$$

$$V_1 = \frac{P_1'.\Delta V}{(P_1' - P_1)}$$

$$P_2.V_2 = c = P_2'\,(V_2 + \Delta V)$$

$$P_2.V_2 = P_2'.V_2 + P_2'.\,\Delta V$$

$$V_2\,(P_2 - P_2') = P_2'.\,\Delta V$$

$$\Delta V = \frac{(P_2 - P_2')}{P_2'}\;V_2$$

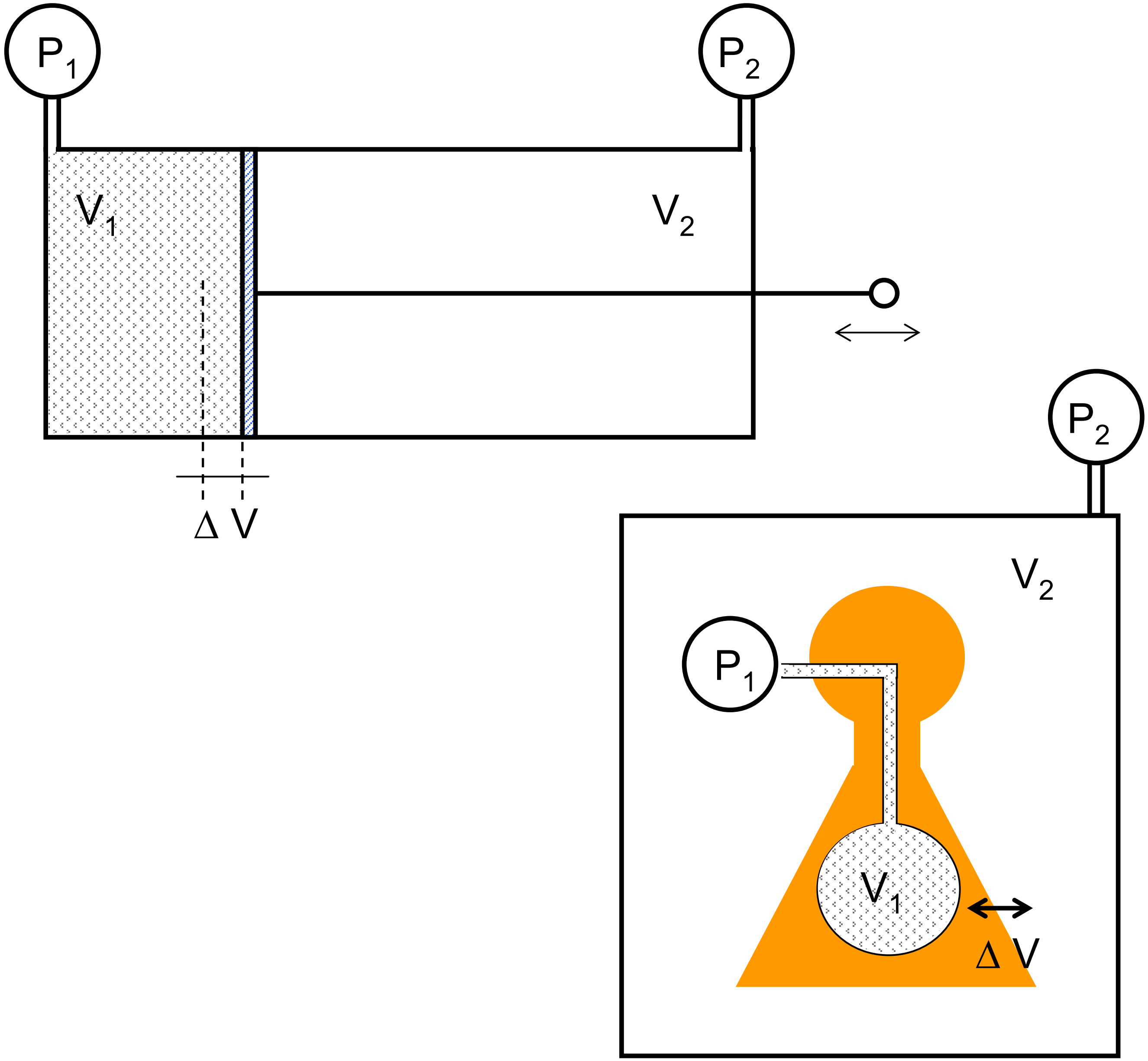
$$V_1 = \frac{P_1' \cdot \Delta V}{(P_1' - P_1)}$$

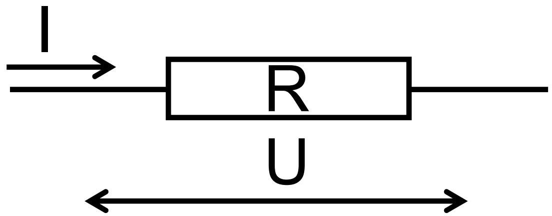
$$\Delta V = \frac{(P_2 - P_2')}{P_2'} V_2$$

$$V_1 = \frac{P_1'}{(P_1' - P_1)} \frac{(P_2 - P_2')}{P_2'} V_2$$

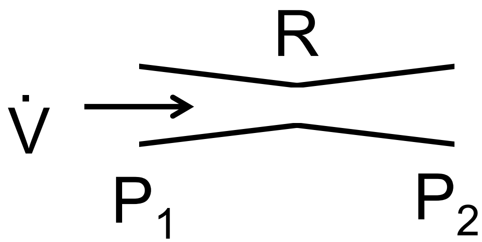
$$P_1' \approx P_2'$$

$$V_1 \approx \frac{\Delta P_2}{\Delta P_1} V_2$$


P1
P2
V1
V2
Δ V
P2
V2
P1
V1
Δ V



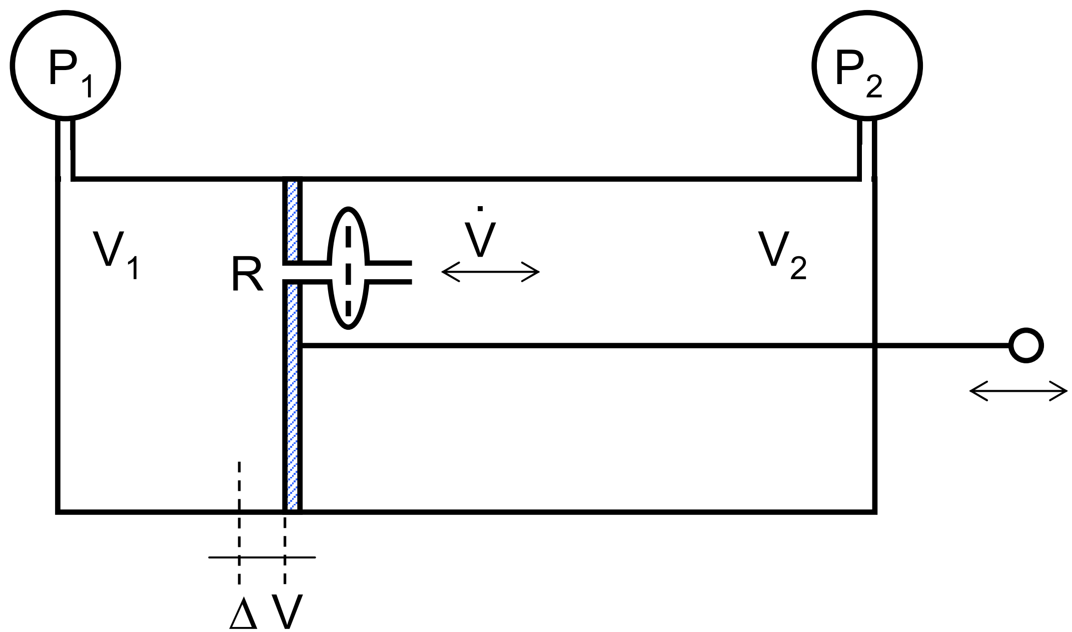
$$R = \frac{U}{I}$$



$$R = \frac{\Delta P}{\dot{V}}$$

$$R = \frac{P_1 - P_2}{\dot{V}} \qquad \frac{kPa}{l/s}$$

Resistance



Resistance:

P_1 can not be measured, so we make the assumption:

$$\frac{V_1}{V_2} = \frac{P_2}{P_1} \quad \text{or:} \quad P_1 = P_2 \frac{V_2}{V_1}$$

$$R = \frac{P_1 - P_2}{\dot{V}}$$

will be:

$$R = \frac{P_2 \frac{V_2}{V_1} - P_2}{\dot{V}}$$

Resistance

$$R = \frac{P_2 \left(\frac{V_2}{V_1} - 1 \right)}{\dot{V}}$$

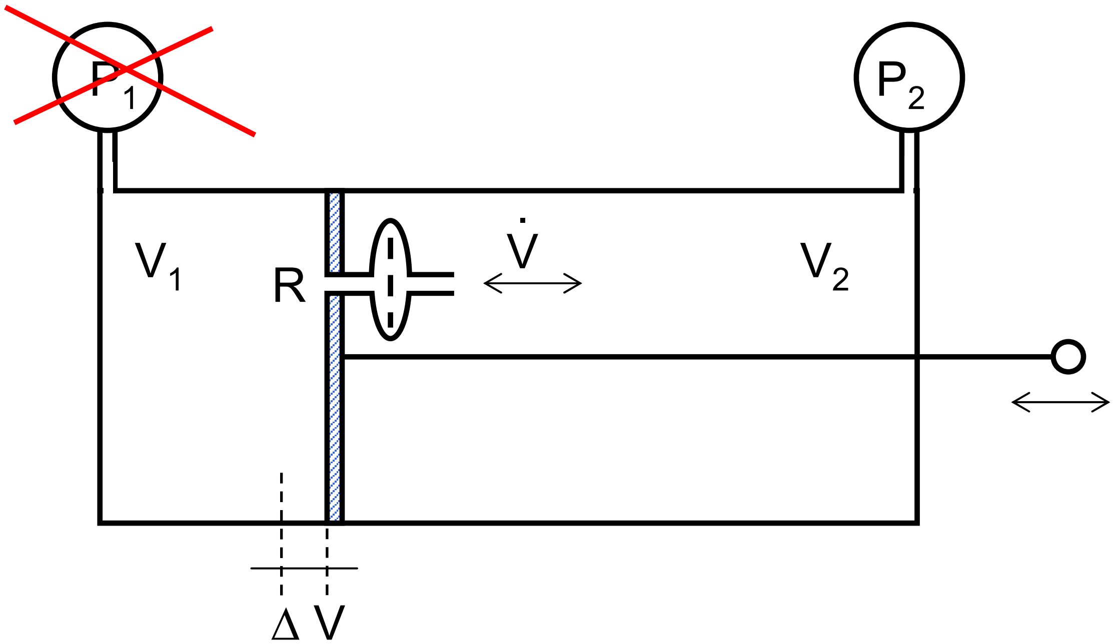
$$V_2 \gg V_1$$

$$R \approx \frac{P_2}{\dot{V}} \frac{V_2}{V_1} \qquad \frac{\text{kPa}}{\text{l/s}}$$

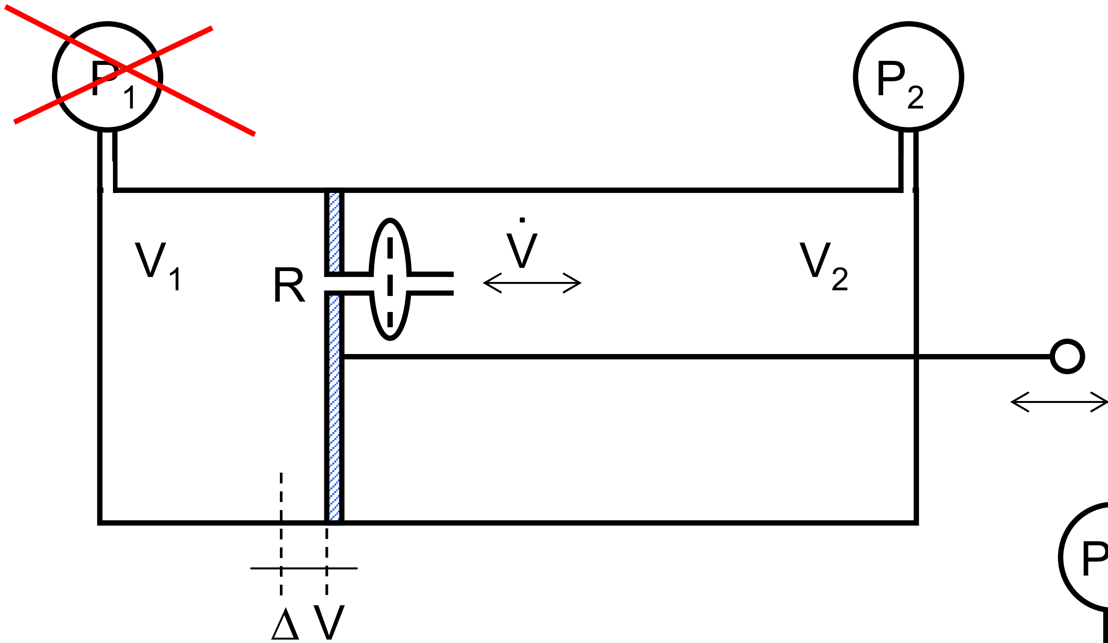
$\frac{V_2}{V_1}$ is a scaling factor

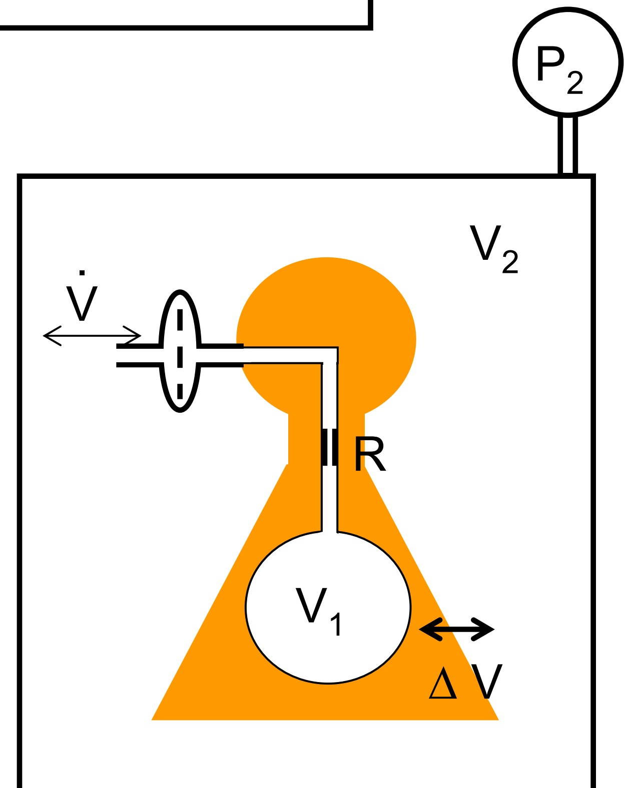
Resistance

$$R \approx \frac{P_2}{\dot{V}} \quad \frac{V_2}{V_1}$$



Resistance

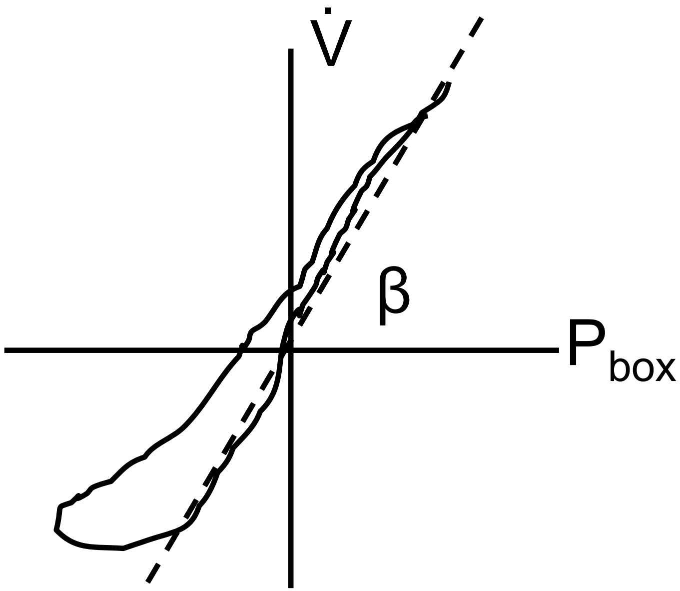


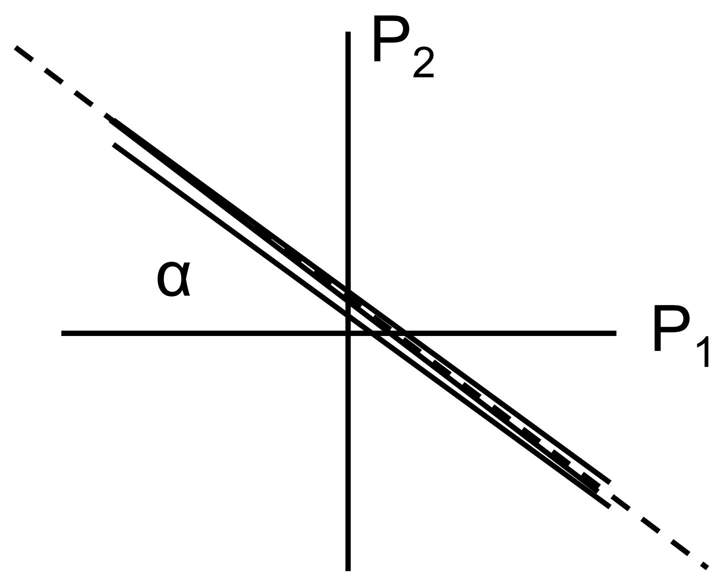


Resistance

$$R = \frac{P_2}{\dot{V}} \quad \frac{V_2}{V_1} \qquad \frac{V_2}{V_1} = \frac{P_1}{P_2}$$

$$\frac{P_2}{\dot{V}} = \text{cotg}\ \beta \qquad \frac{\text{kPa}}{\text{l/s}} \qquad \frac{P_1}{P_2} = \text{cotg}\ \alpha$$





Heating up of the bodybox

Elements heating up the box:
- Body mass/ temperature
- **IN**spiration

Elements cooling the box:
-Thermal flow, depending on T_{amb} and T_{box} ,thermal isolation box

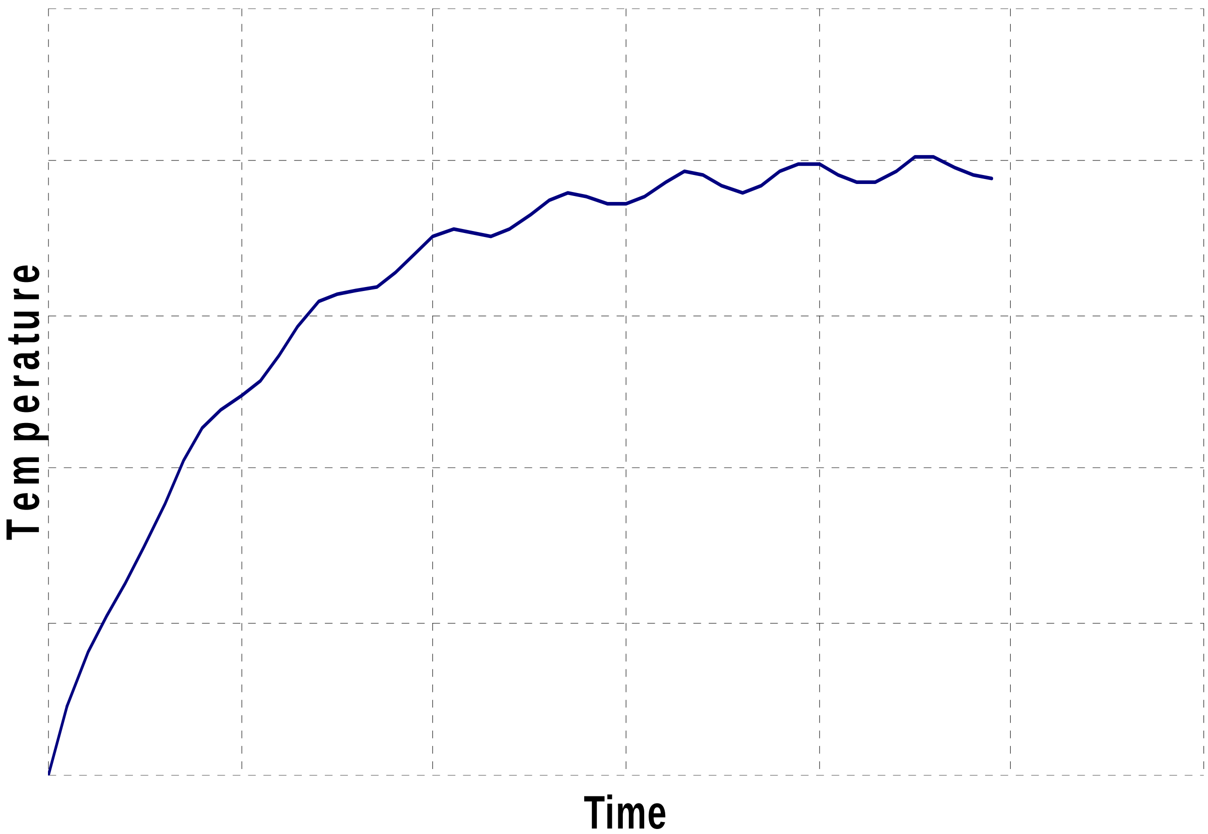
The higher the Bodybox temperature:
- the lesser the pressure builds up during inspiration
- the lesser the cooling down of an exhaled volume
- the more heat leaks away

It becomes more thermally stable

Changing the temperature/ pressure in the box
- is more pronounced during inspiration

Every time we inspire, we cause a pressure artifact

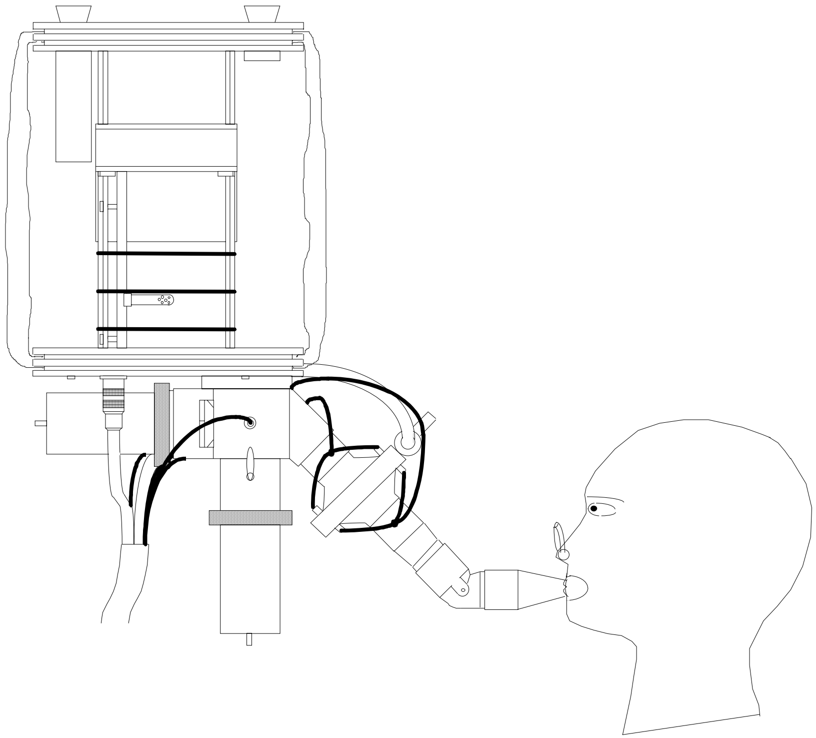
Heating up of the bodybox



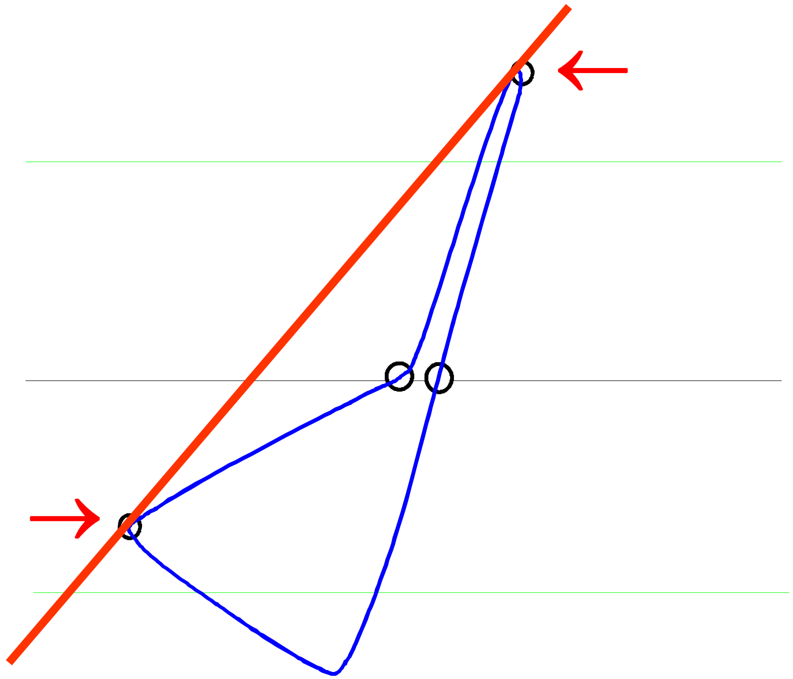
BTPS bag

No building up of pressure during inspiration

Today: corrected by software

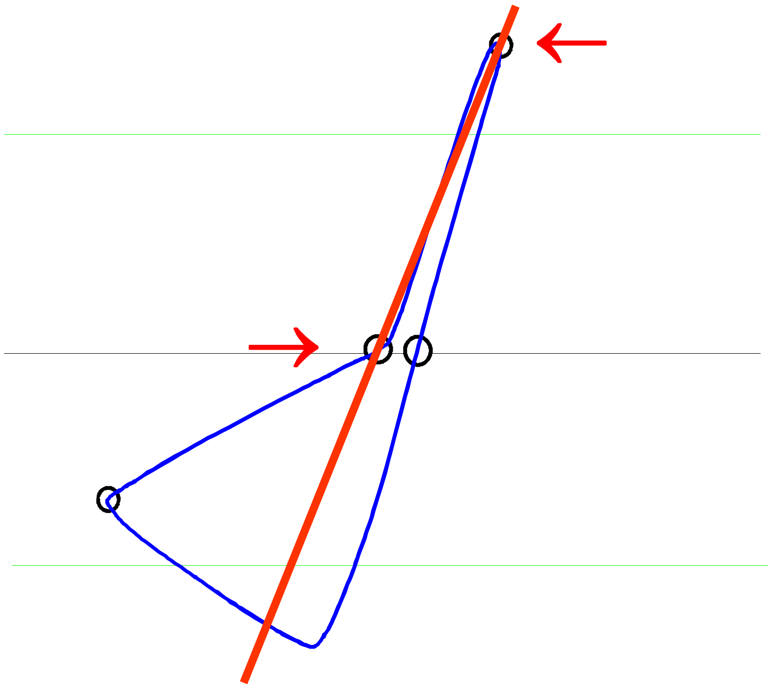


sR_{tot} (Ulmer)



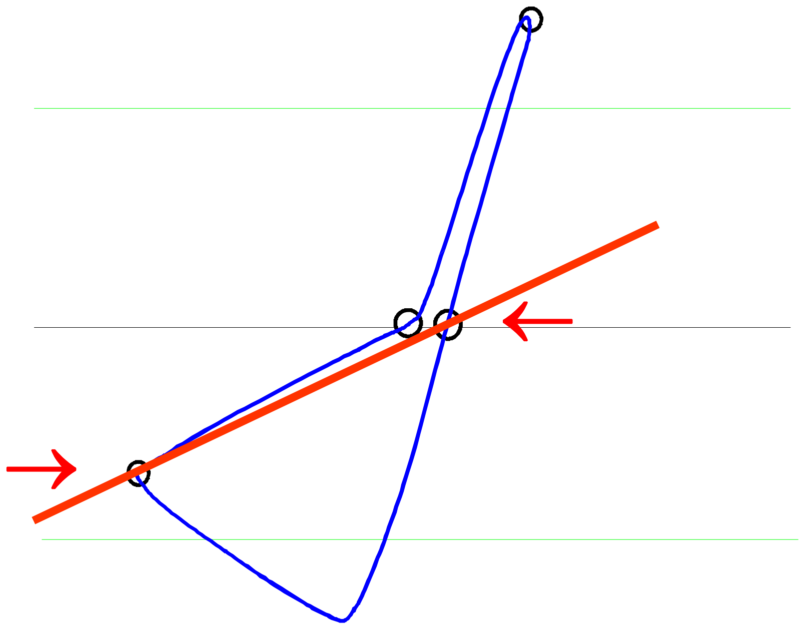
Connecting the maximal pressure points

sR_{in} (Ulmer)



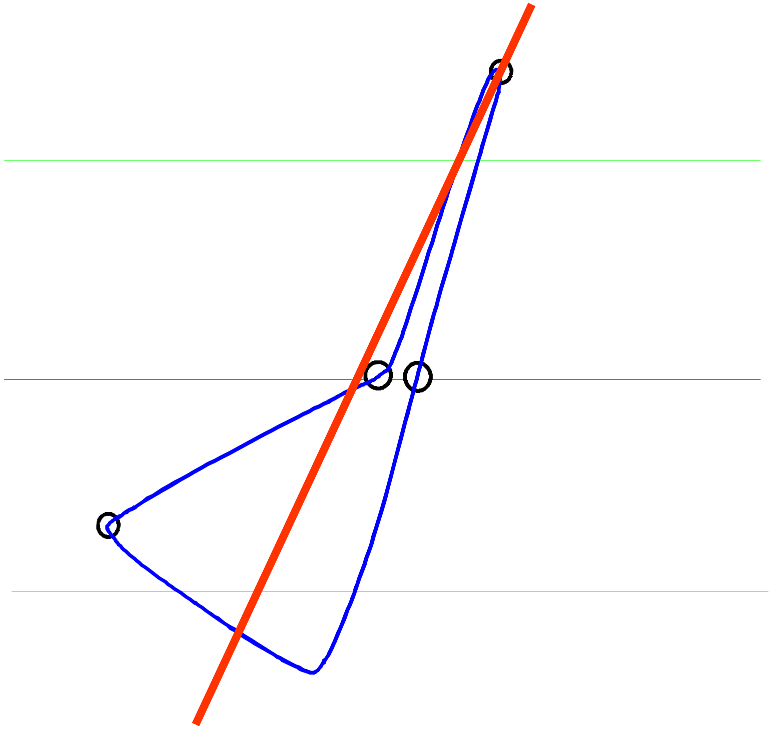
Connecting the maximal pressure points (inspiration)

sR_{ex} (Ulmer)



Connecting the maximal pressure points (expiration)

sR_{eff} (Matthys)



Area below the work of breathing-loop compared with the area below the Flow/Volume-loop (≈ least square fit)

$$\text{Raw} = \frac{\text{Work of breathing}}{\text{Area FV curve}}$$

$$\text{Work of breathing} = \text{Raw} \,.\, \text{Area FV curve}$$

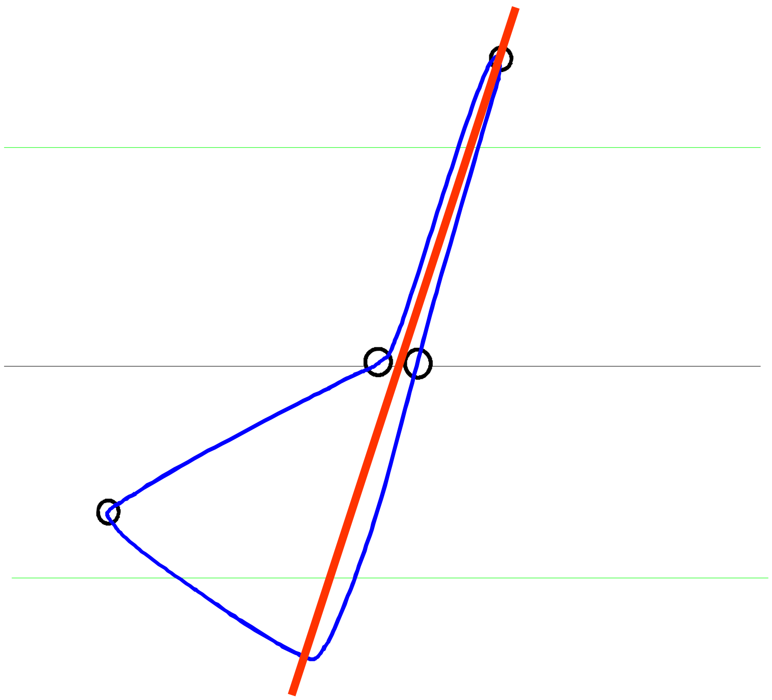
$$\text{WOB} = \frac{N}{m^2}\ \frac{s}{L}\ \frac{L}{s}\ L$$

$$\text{WOB} = \frac{N}{m^2}\ m^3$$

WOB = pressure x volume

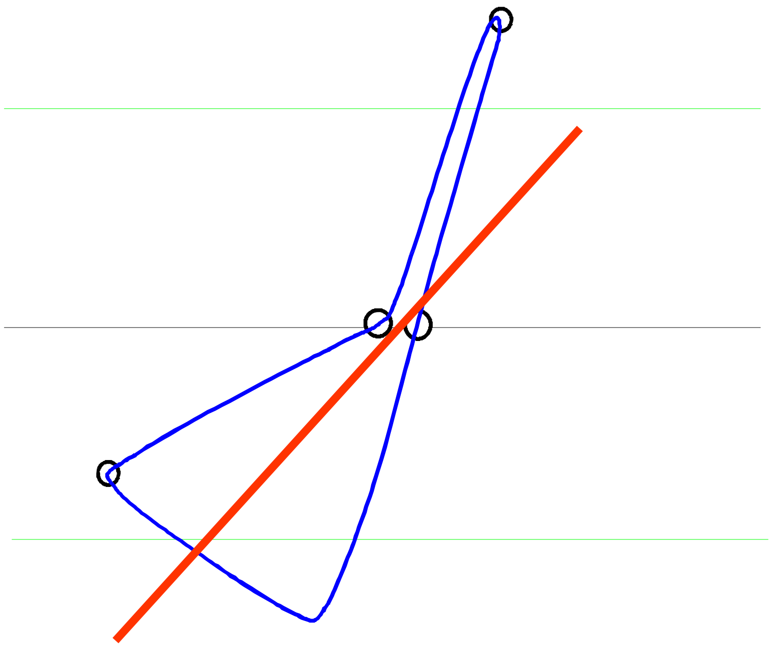
$$\text{Raw} = \frac{\text{pressure}}{\text{flow}} \times \frac{\text{volume}}{\text{volume}}$$

$sR_{eff,in}$ (Matthys)



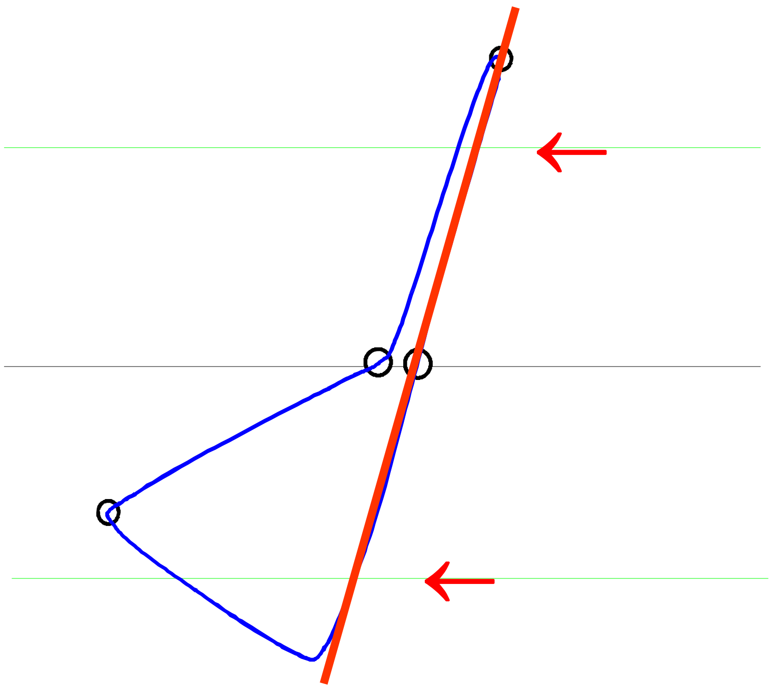
Area below the work of breathing-loop compared with the area below the Flow/Volume-loop during inspiration

$sR_{eff,ex}$ (Matthys)



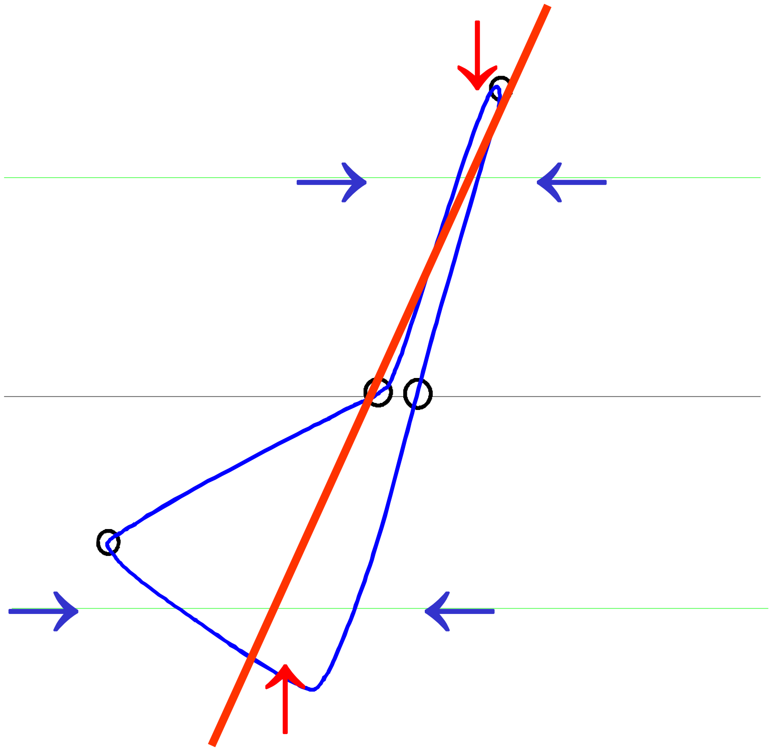
Area below the work of breathing-loop compared with the area below the Flow/Volume-loop during expiration

Resistance $sR_{0.5}$



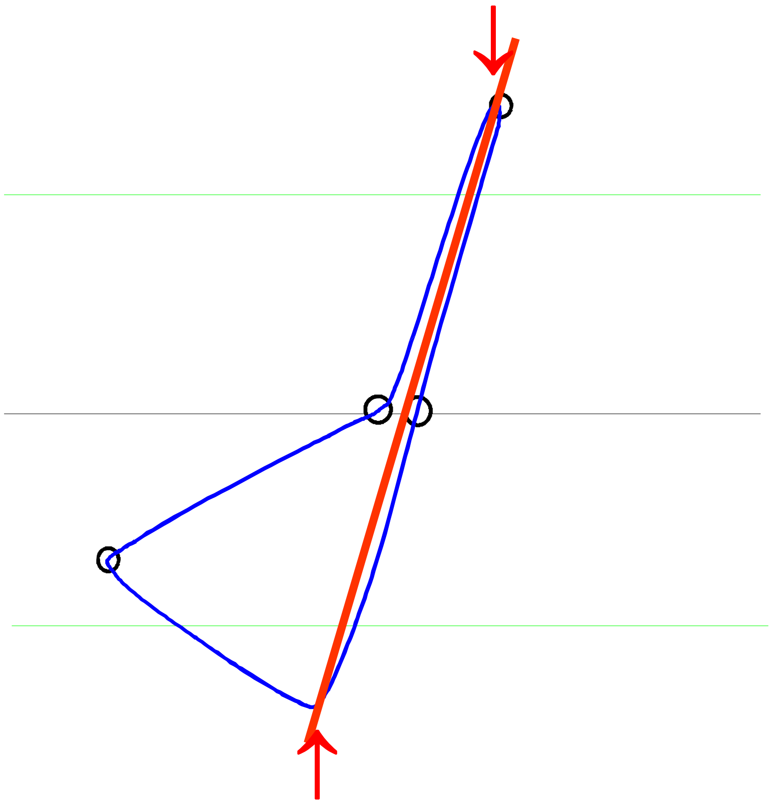
connecting the
flow-values at
+ 0.5 and - 0.5 L/sec

Resistance sR_{mid}



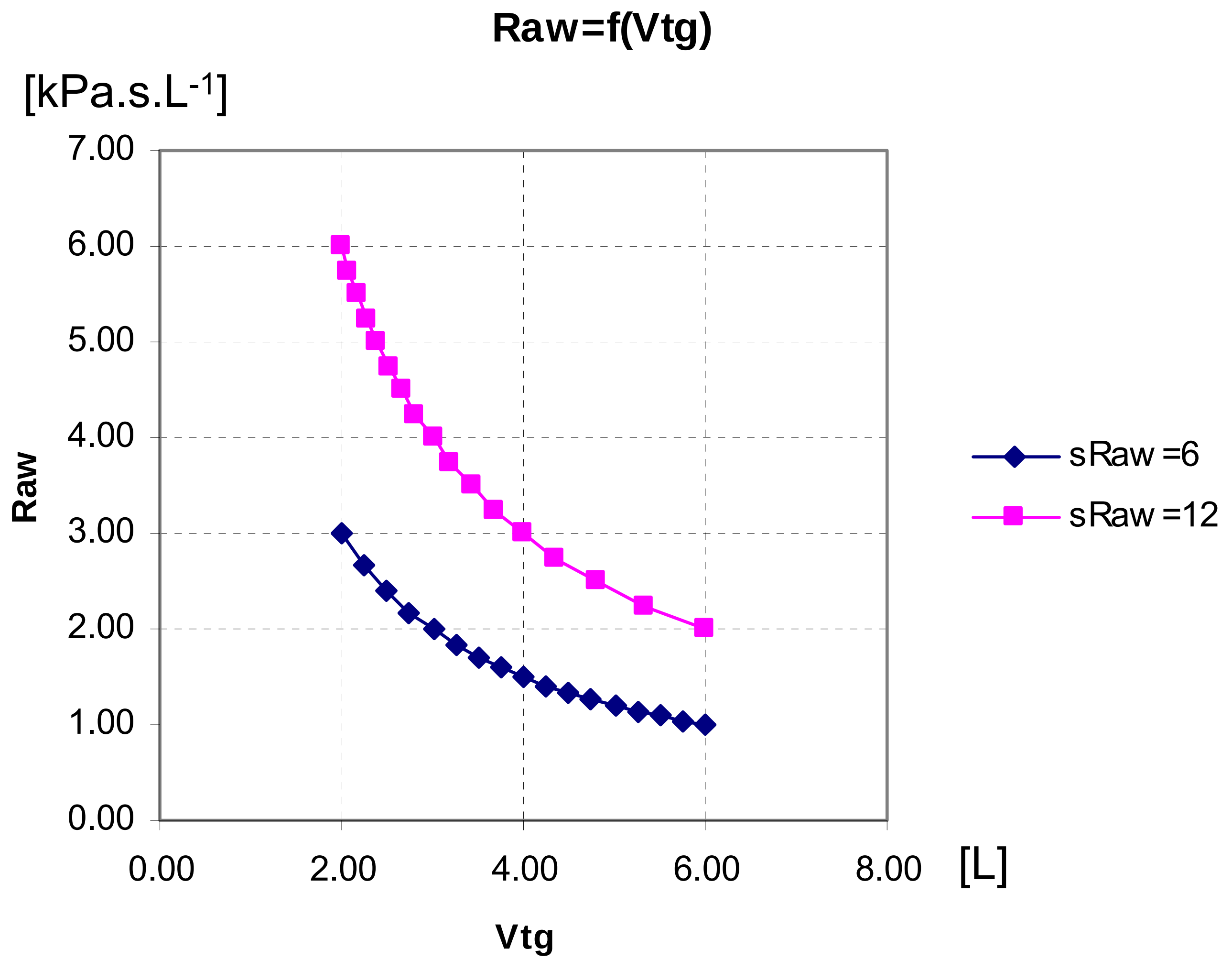
connecting the mean flow-values at
+ 0.5 and - 0.5 L/sec

Resistance sR_{peak}



connecting the maximal and minimal flow-values

Resistance: Raw vs sRaw



Resistance: Raw vs sRaw

Hyperbolic relation: Raw = f (Vtg)

$$\text{Raw} \cdot \text{Vtg} = c$$

$$\text{Raw} = \frac{c}{\text{Vtg}}$$

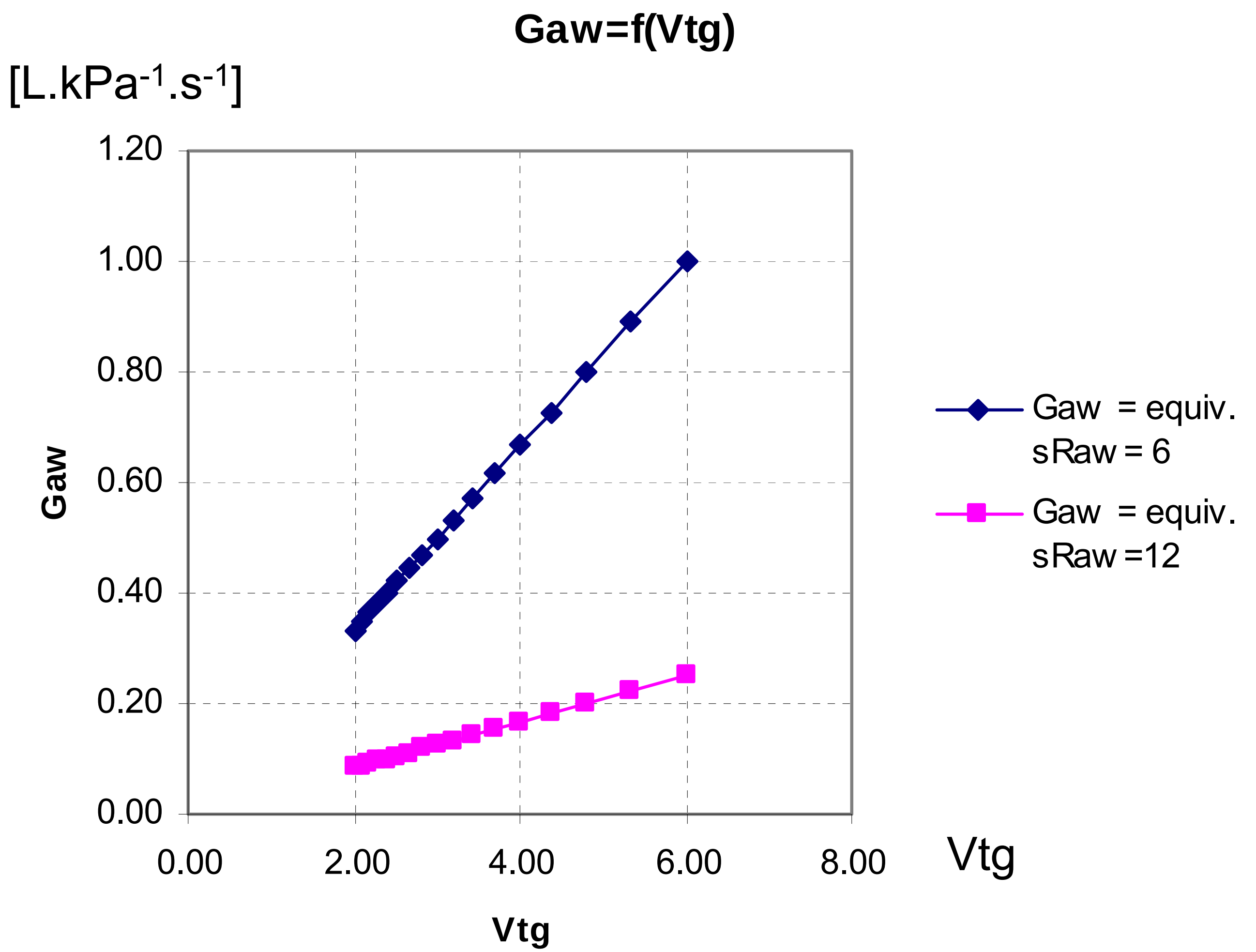
$$\frac{1}{\text{Raw}} = \frac{1}{c}\,\text{Vtg}$$

$$\text{Gaw} = c' \;\; \text{Vtg}$$

note:

$$c' = \frac{1}{\text{sRaw}} = \frac{1}{\text{Raw} \cdot \text{Vtg}}$$

Resistance: Raw vs sRaw

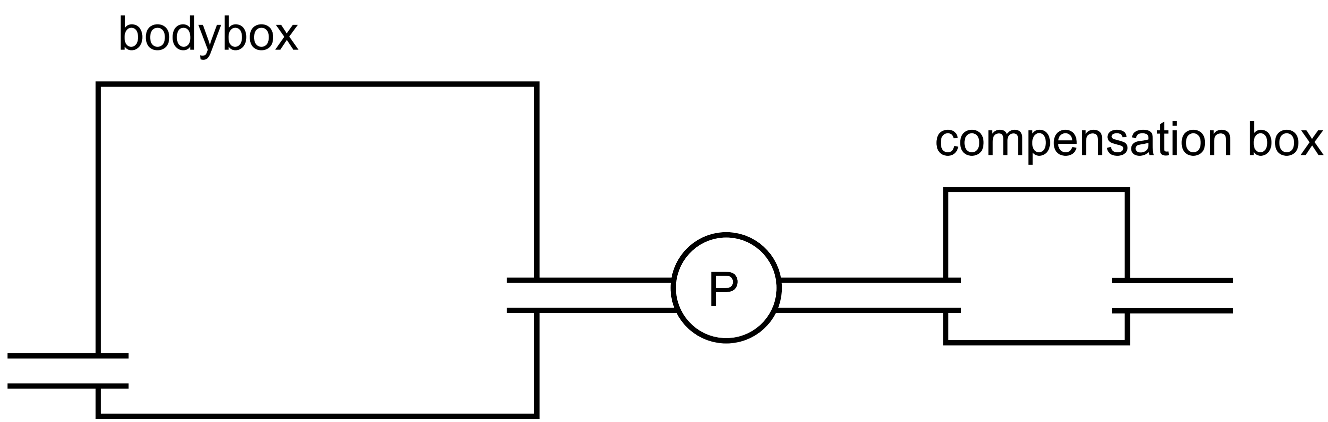


A bodybox needs a certain leak. If not: pressure would go up too much due to thermal effect

We hence deliberately make a leak of about 4…7 seconds time constant.

That is why the sinusoidal calibration pump frequency should match the breathing frequency for correct calibration. If the frequency is different, the dynamic response is not identical.

A bodybox needs a certain leak. If not: pressure would go up too much due to thermal effect



τ_1 should be τ_2

If time constants not equal, enormous pressure artefacts

Calibrating the pressure transducer of the box:

$$P_2.V_2 = c = P_2' (V_2 + \Delta V)$$

$$P_2.V_2 = P_2' V_2 + P_2' \Delta V$$

$$V_2 (P_2 - P_2') = P_2' \Delta V$$

$$(P_2 - P_2') = \frac{P_2' \ \Delta V}{V_2}$$

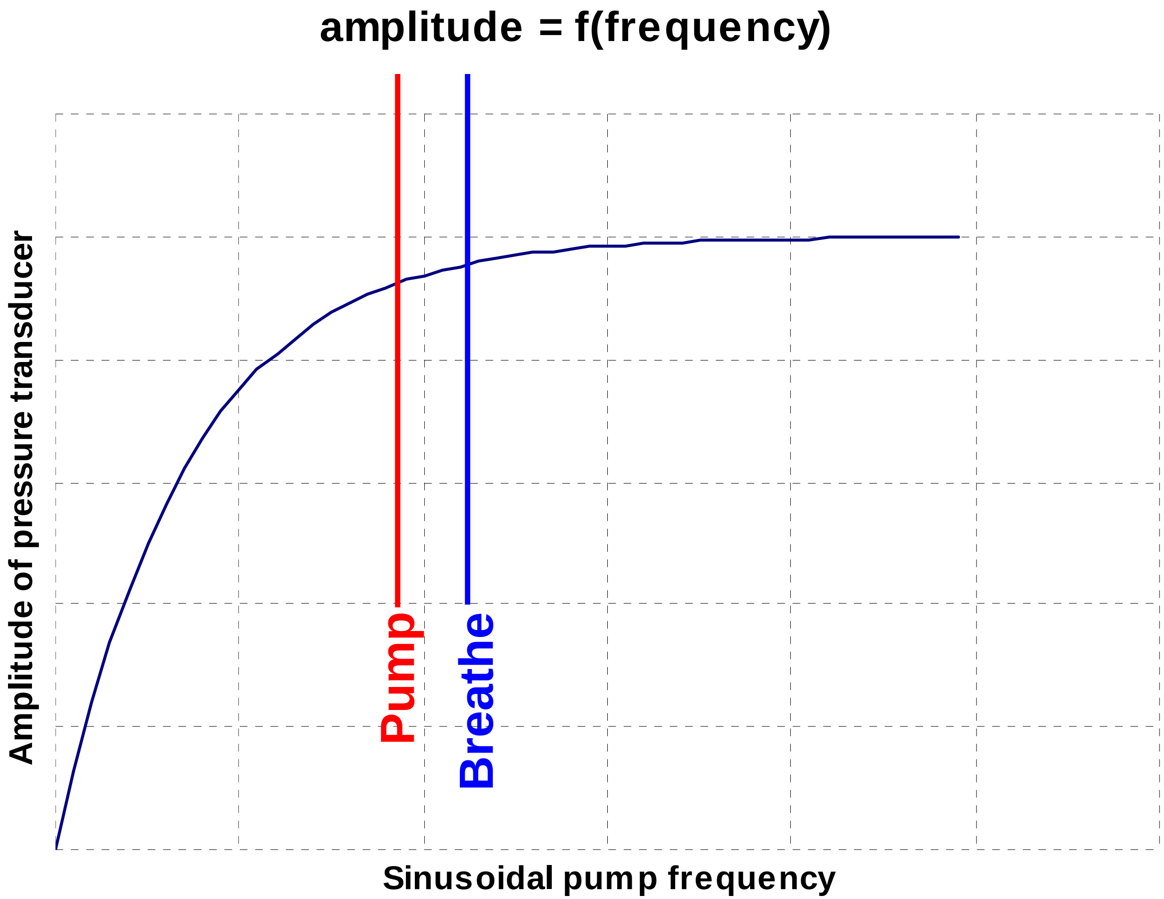
ΔV : calibration pump volume

V_2 : volume of the box

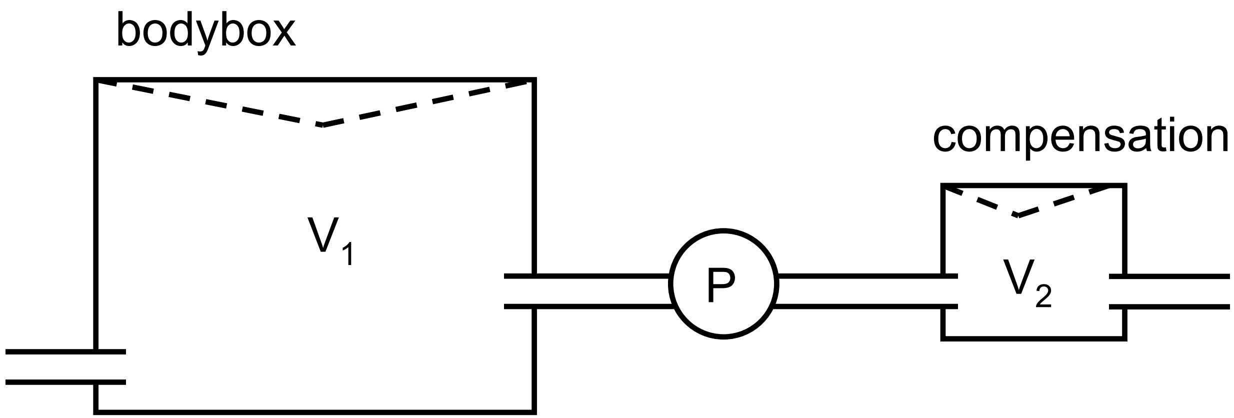
$P_2' - P_2$: amplitude of the pressure transducer

This is only valid in a box which has no leak!!

Calibrating the pressure transducer of the box:



Pressure effect: deformation of box and compensation box



$$P_1.V_1 = c_1 \qquad P_2.V_2 = c_2$$

$$P_1' = \frac{c_1}{V_1 - \Delta V_1} \qquad P_2' = \frac{c_2}{V_2 - \Delta V_2}$$

Pressure effect: deformation of box and compensation box

$$P_1' \approx P_2'$$

$$\frac{c_1}{V_1 - \Delta V_1} = \frac{c_2}{V_2 - \Delta V_2}$$

$$\frac{P_1.V_1}{V_1 - \Delta V_1} = \frac{P_2.V_2}{V_2 - \Delta V_2}$$

$$P_1 \approx P_2$$

$$\frac{V_1}{V_1 - \Delta V_1} = \frac{V_2}{V_2 - \Delta V_2}$$

Pressure effect: deformation of box and compensation box

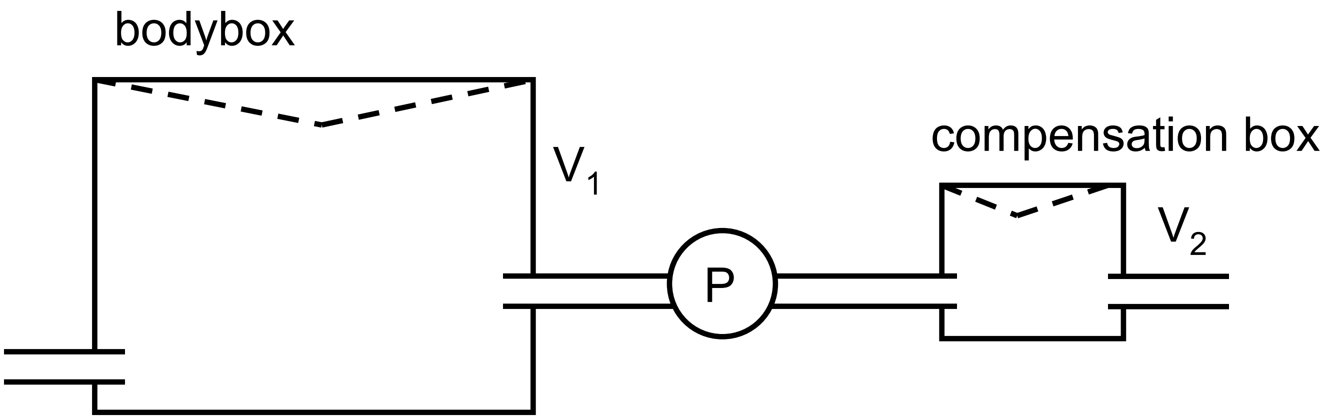
$$V_1 \left(V_2 - \Delta V_2\right) = V_2 \left(V_1 - \Delta V_1\right)$$

$$V_1 V_2 - \Delta V_2 V_1 = V_2 V_1 - \Delta V_1 V_2$$

$$- \Delta V_2 V_1 = - \Delta V_1 V_2$$

$$\Delta V_2 = \frac{\Delta V_1 \, V_2}{V_1}$$

Pressure effect: deformation of box and compensation box



$\Delta V_2 . V_1 = \Delta V_1 . V_2$

Δ V depends on both material properties and mechanical construction