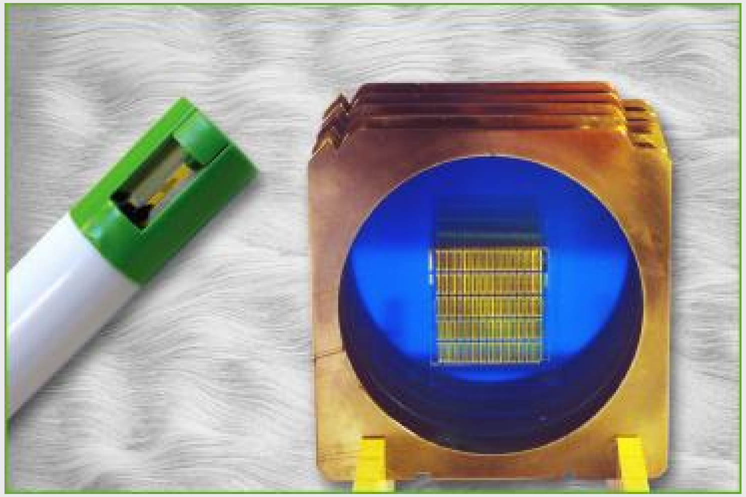
AIR FLOW MEASUREMENT

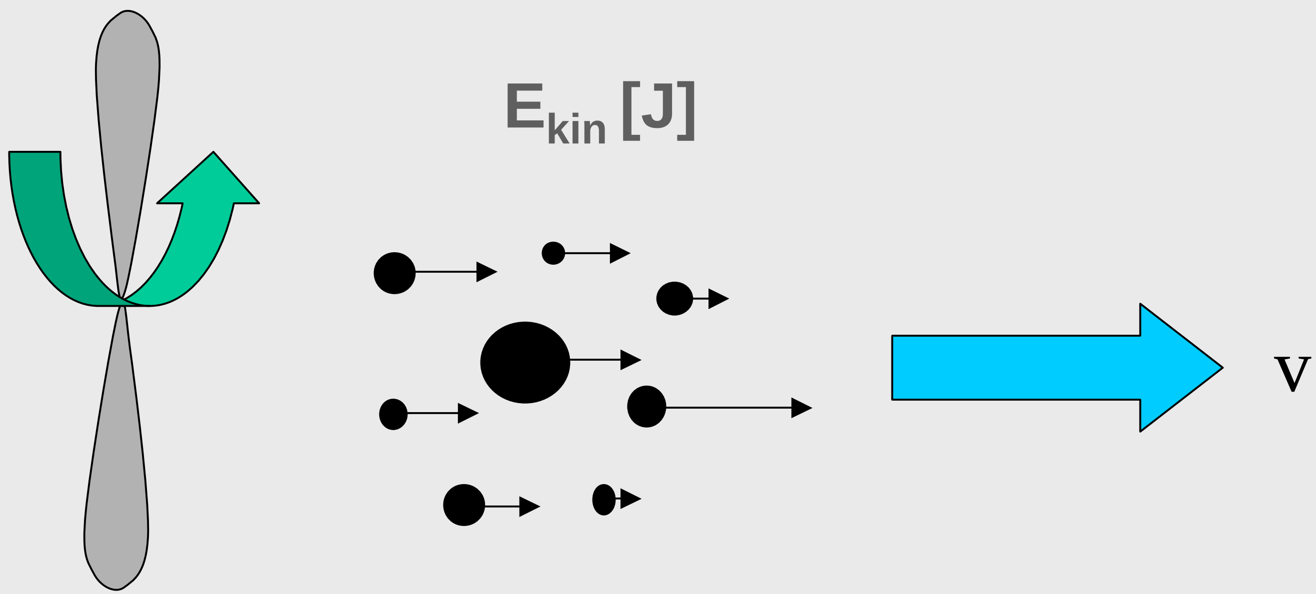
- ERIK THOR, Ph.D.

- BASIC DEVELOPMENT / FLUID MECHANICS



AIR FLOW PHYSICS

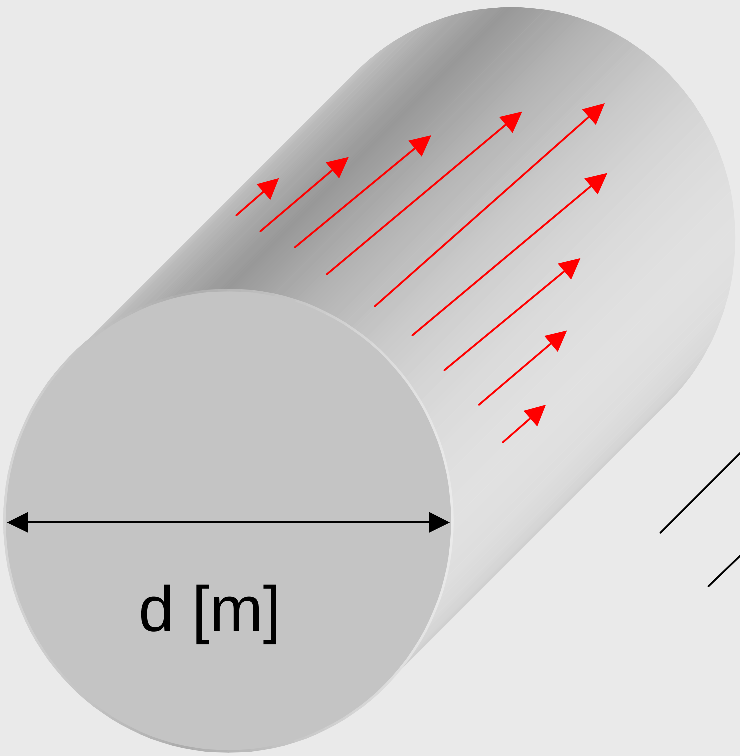
Air = Mixture of gas molecules (N_2, O_2, Ar, CO_2, ...)



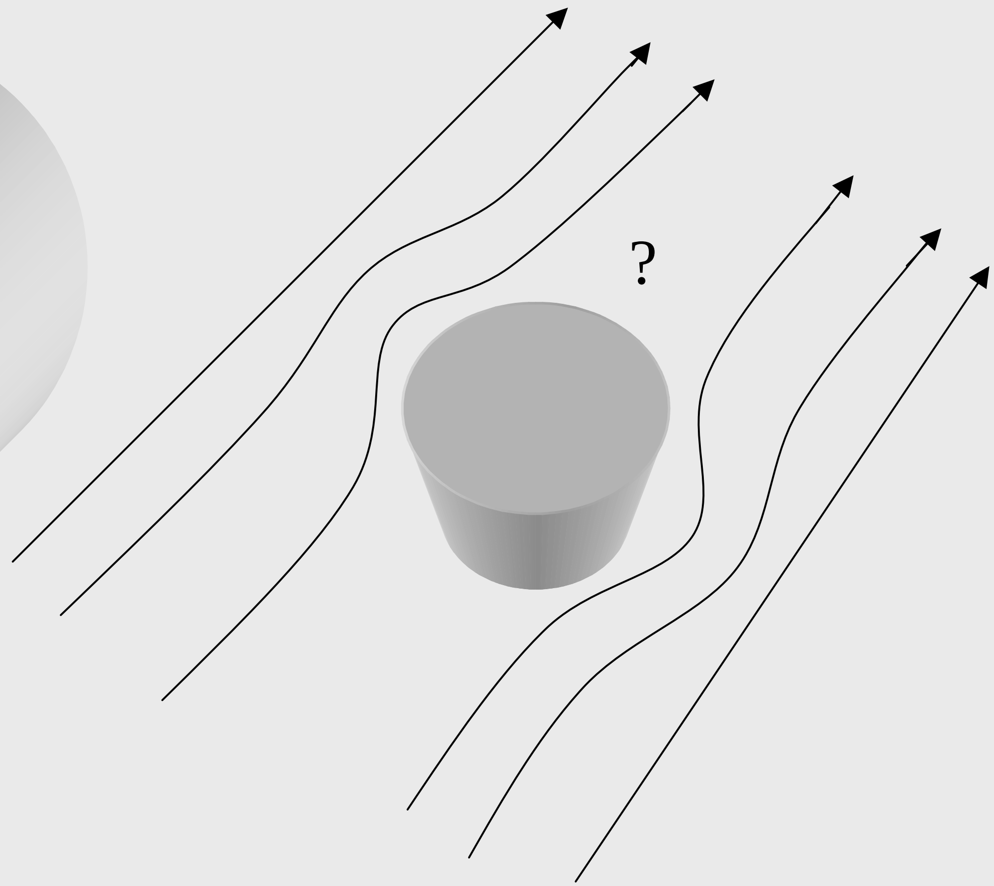
Air velocity v [m/s] =

mean travelled distance per time of an air molecule

closed channel air flow

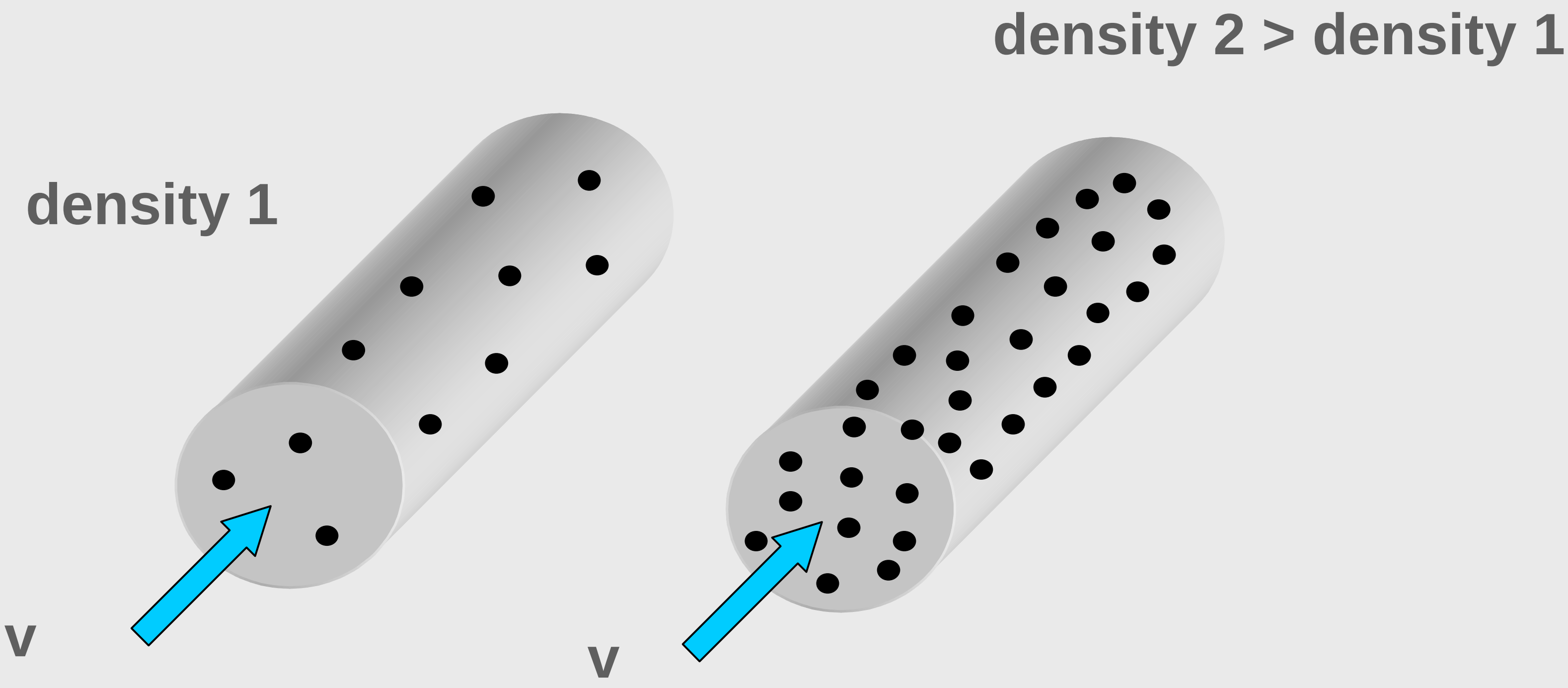


air flow past immersed body

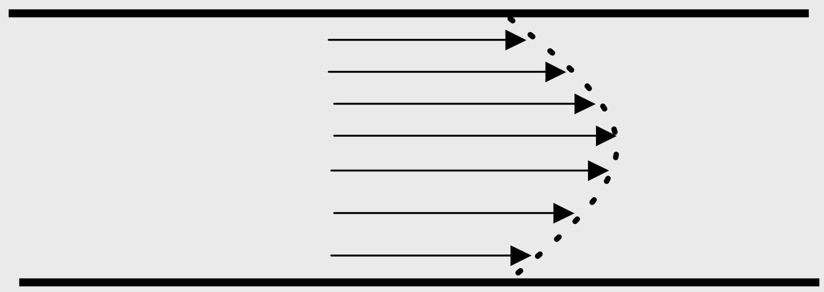


Mass flow = transferred mass per time and area [kg/(m^2 × s)]

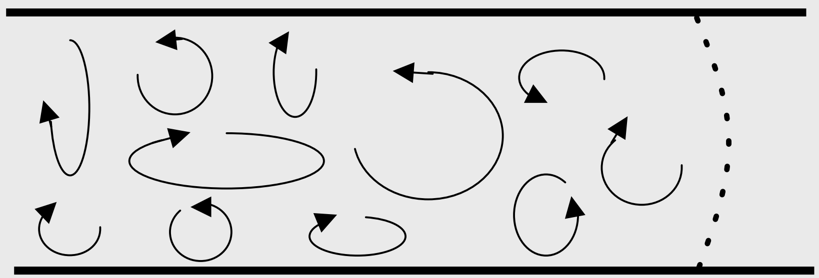
= Air Density [kg/m^3] × Air Velocity [m/s]



„low“ velocity ® regular (“ laminar “) flow



„high“ velocity ® irregular (“ turbulent flow “)



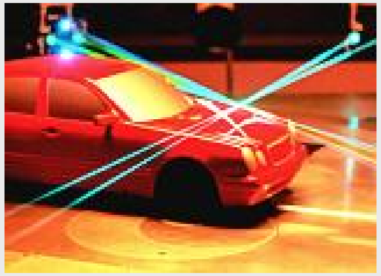
“low - high“ velocity ® „Reynolds number“

Re= inertial force / viscous force

$$\mathrm{Re} = \frac{d \cdot v \cdot r}{h} = \frac{diameter[m] \cdot velocity\,[\frac{m}{s}] \cdot density[\frac{kg}{m^3}]}{vis\cos ity\,[\frac{kg}{m \cdot s}]}$$

Re < 2000 for laminar flow in a pipe

TYPOLOGY OF (AIR) FLOWMETERS



Flowmeter Type	Liquid	Gas	Steam	Pipe size	Clean Fluid	Dirty Fluid
Coriolis	x	x		1/6 to 6 in,	x	Ltd.
Differential Pressure	x	x	x	½ in. and up	x	Ltd.
Magnetic	x			1/10 to 100 in.	x	x
Positive Displacement	x	x		2 – 30 in.	x	
Thermal (HW, HF, Calorimetric)	**Ltd.**	**x**		**Insertion**	**x**	**no problem for HF !**
Turbine	x	x		2 – 30 in.	x	
Ultrasonic-Transit Time	x	x	Ltd.	½ inch and up	x	Ltd.
Ultrasonic-Doppler	x			½ inch and up		x
Vortex	x	x	x	½ inch to12 in.	x	

Flowmeter Type	Advantages	Disadvantages
Coriolis	High accuracy; Low maintenance; Insensitive to flow profile	High initial cost, depending on size and model; Bent tubes subject to fouling; Not available for pipe sizes over six inches
Differential Pressure	Low initial cost; Ease of installation; Well understood; Many industry approvals	Limited rangeability; Permanent pressure drop; Uses square root method to calculate flowrate; Requires periodic maintenance
Magnetic	Obstructionless; High accuracy; No pressure drop	Cannot meter nonconductive fluids (e.g., hydrocarbons); Relatively high initial cost; Electrodes subject to coating
Positive Displacement	High accuracy; Insensitive to flow profile; High rangeability	Cannot handle dirty fluids; Subject to wear; Pressure drop
Thermal (Calorimetric, Hot Wire, Hot Film)	**Relatively low initial cost; Good for low velocity flows**	**Limited accuracy; Sensitive to problems of dirty fluids except HF**
Turbine	High accuracy; Well-known technology; Medium purchase price	Cannot handle dirty fluids; Bearings subject to wear; Pressure drop
Ultrasonic-Transit Time	High accuracy, depending on model; Obstructionless; Clamp-on convenience; No pressure drop	Limited ability to handle dirty fluids; Can be affected by flow profile; Some models have high initial cost
Ultrasonic-Doppler	Can meter dirty flows; No pressure drop; Clamp-on convenience	Low to medium accuracy; Reynolds number limitations
Vortex	Highly versatile: can measure liquid, gas, and steam; Good accuracy	Limited ability to handle low flows; Vibration can affect accuracy; Few industry approvals

Model DS-400

Rate the importance of factors you use when specifying or purchasing flowmeters (scale is 1 to 5)

Criteria	Ranking	Minimum	Maximum
Reliability	4.81	4	5
Compatibility	4.80	4	5
Repeatability	4.78	4	5
Application	4.69	2	5
Technical support	4.67	3	5
User friendly/simplicity	4.60	4	5
Accuracy	4.45	1	5
Maintainability/Repair	4.30	3	5
Price	3.77	1	5

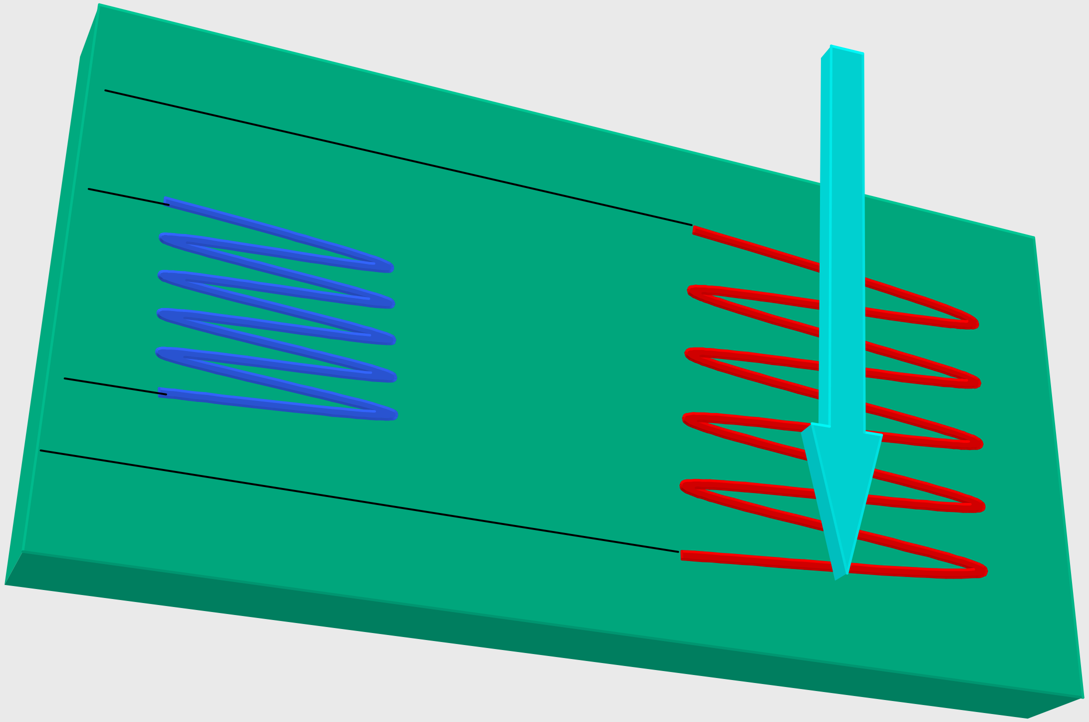
Jesse Joder, “Flowmeter Shootout Part III“, http://www.flowresearch.com/articles.htm

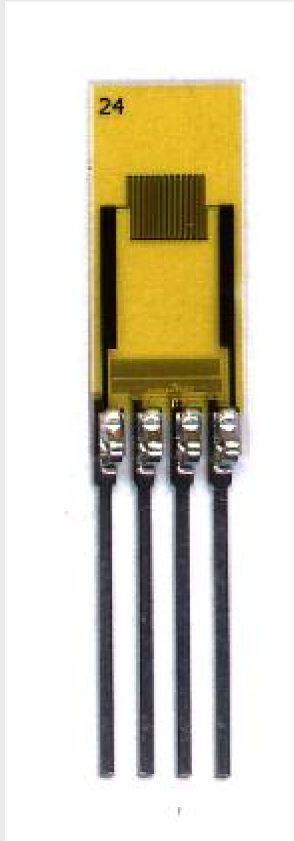
HOT FILM TECHNOLOGY

EE65

EE70

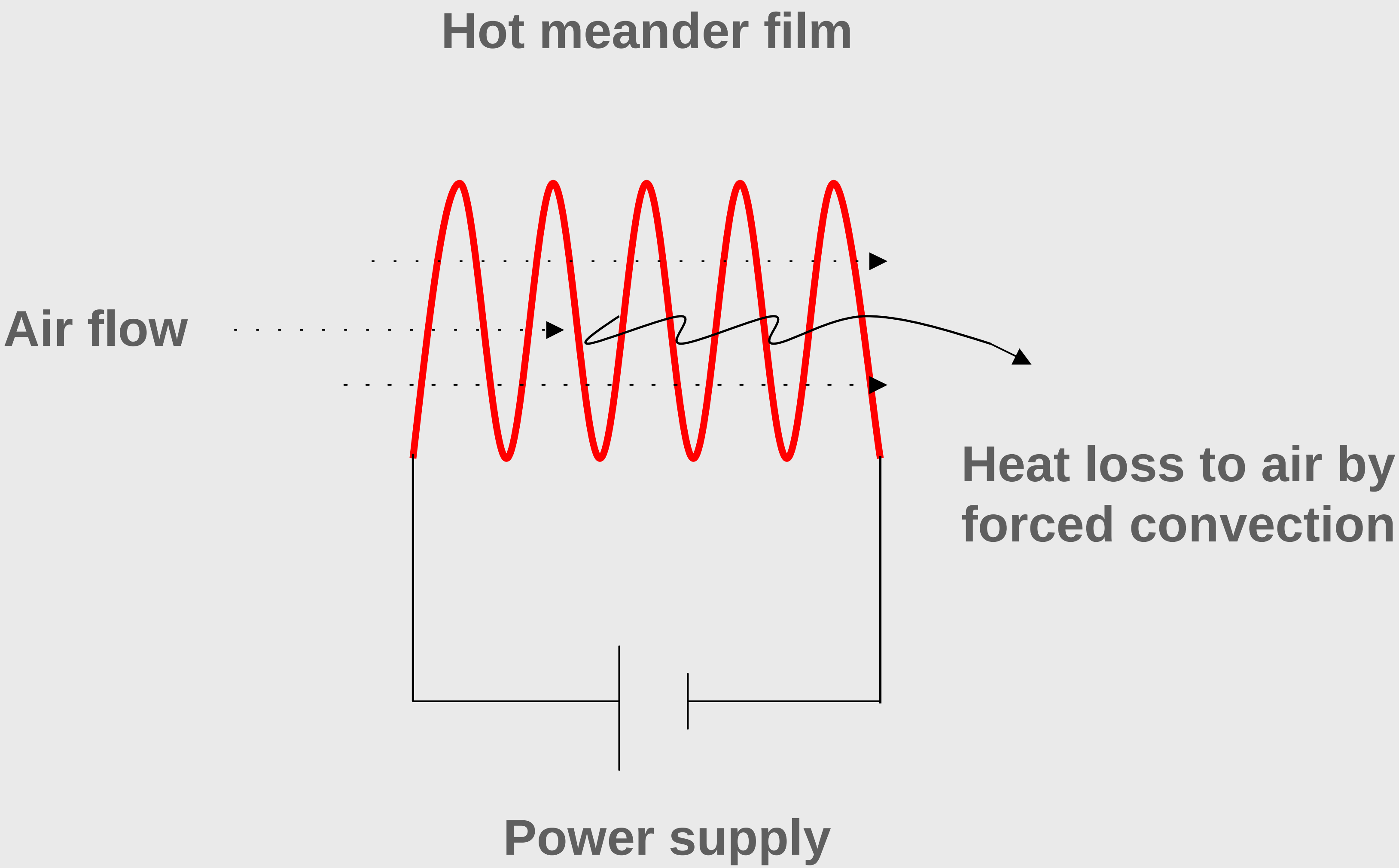
Temperature Sensor / Velocity Sensor



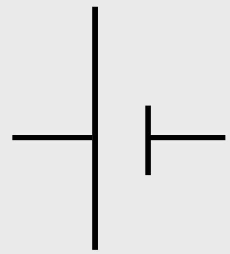


Structured Mo metal film (@ 1 µm) on thin glass substrate (150 µm) coated by polyimide protective layer

HOT FILM MEASUREMENT PRINCIPLE

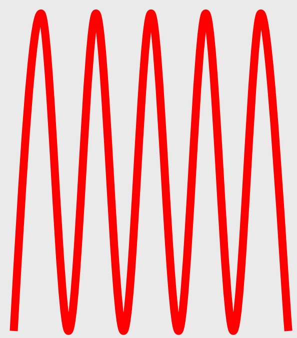

Hot meander film
Air flow
Heat loss to air by forced convection
Power supply

- Power supply ® P=U×I



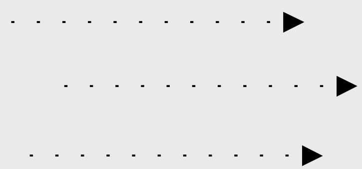
- Hot film resistance R_h ®

  heater temperature T_h

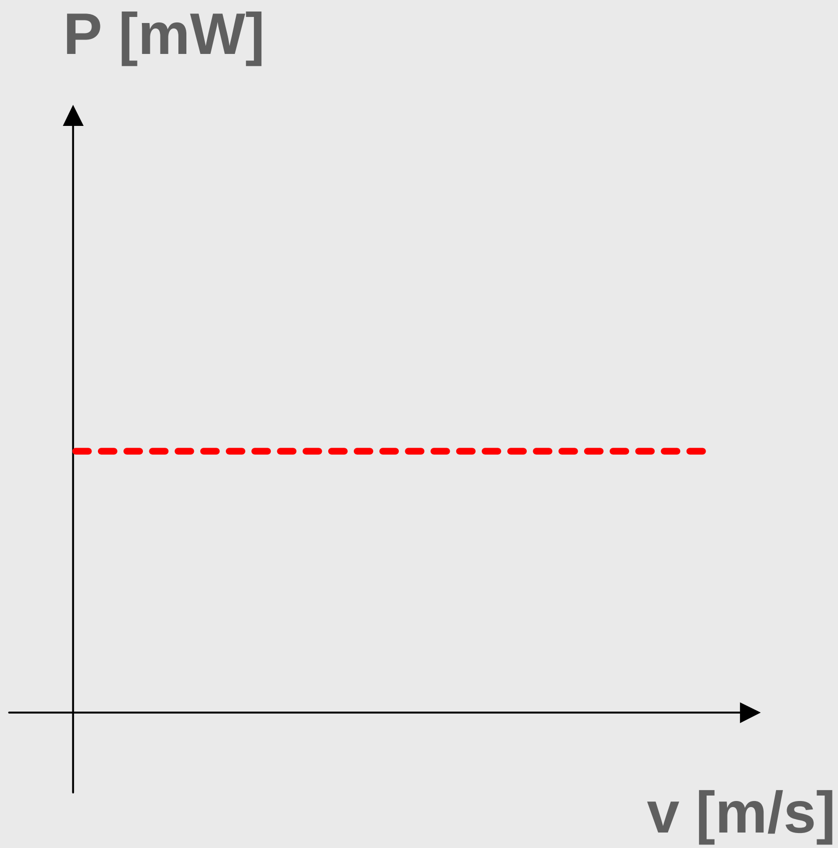


- Air flow ®

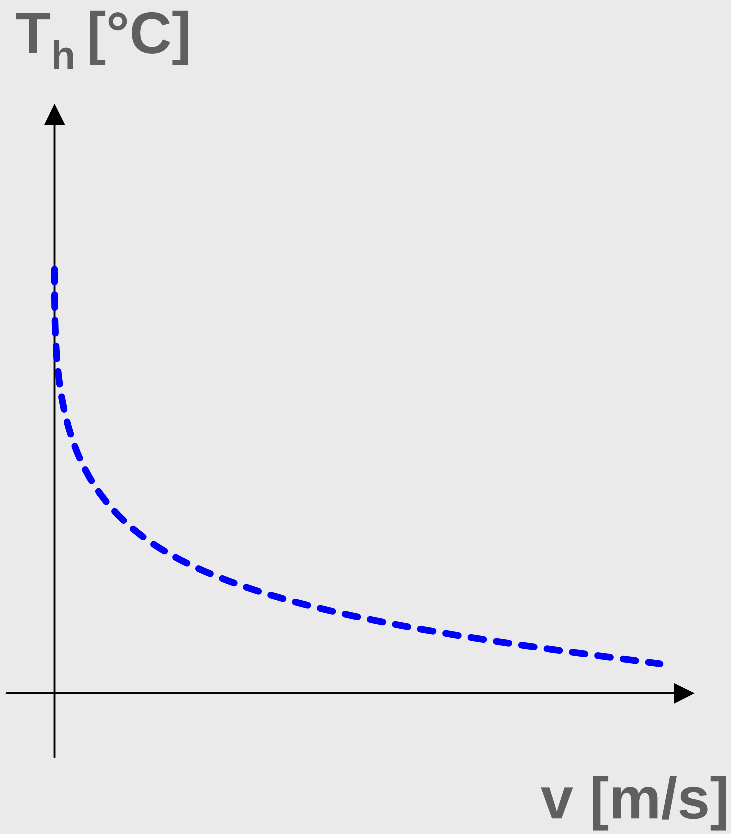
  velocity v, ambient temperature T_a



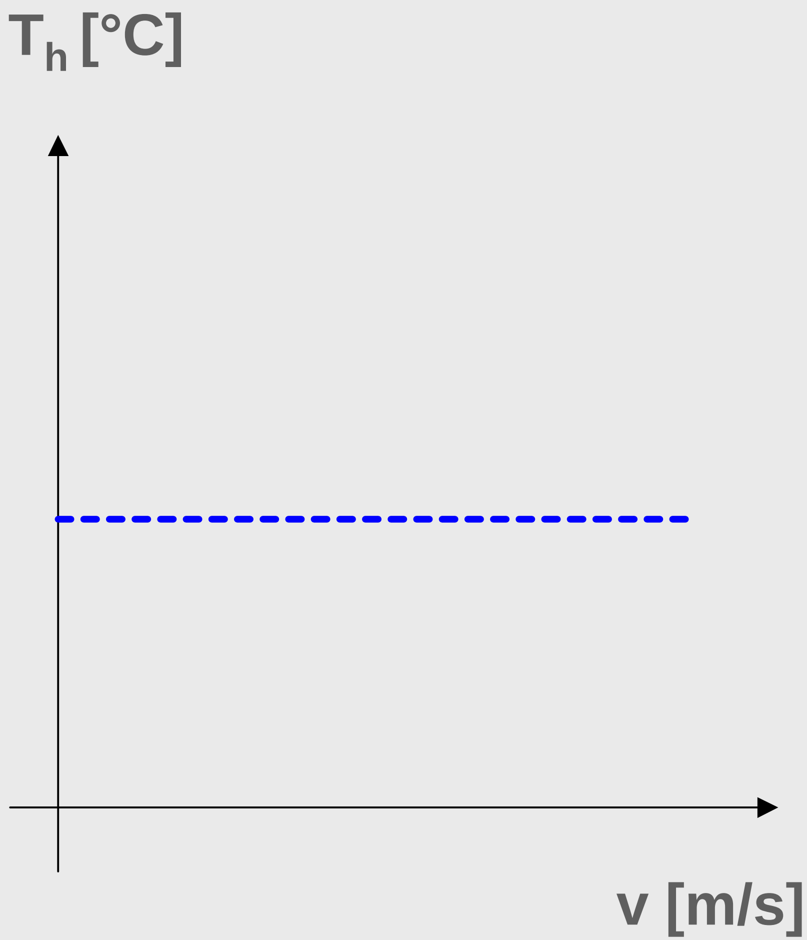
Power constant



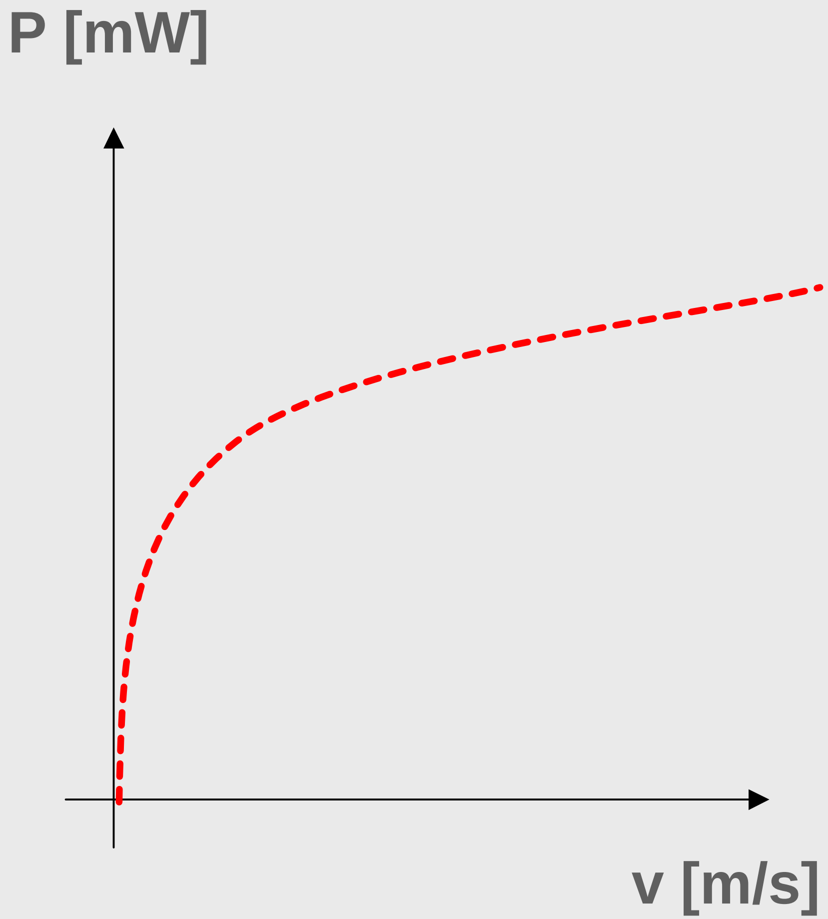
Heater cools down



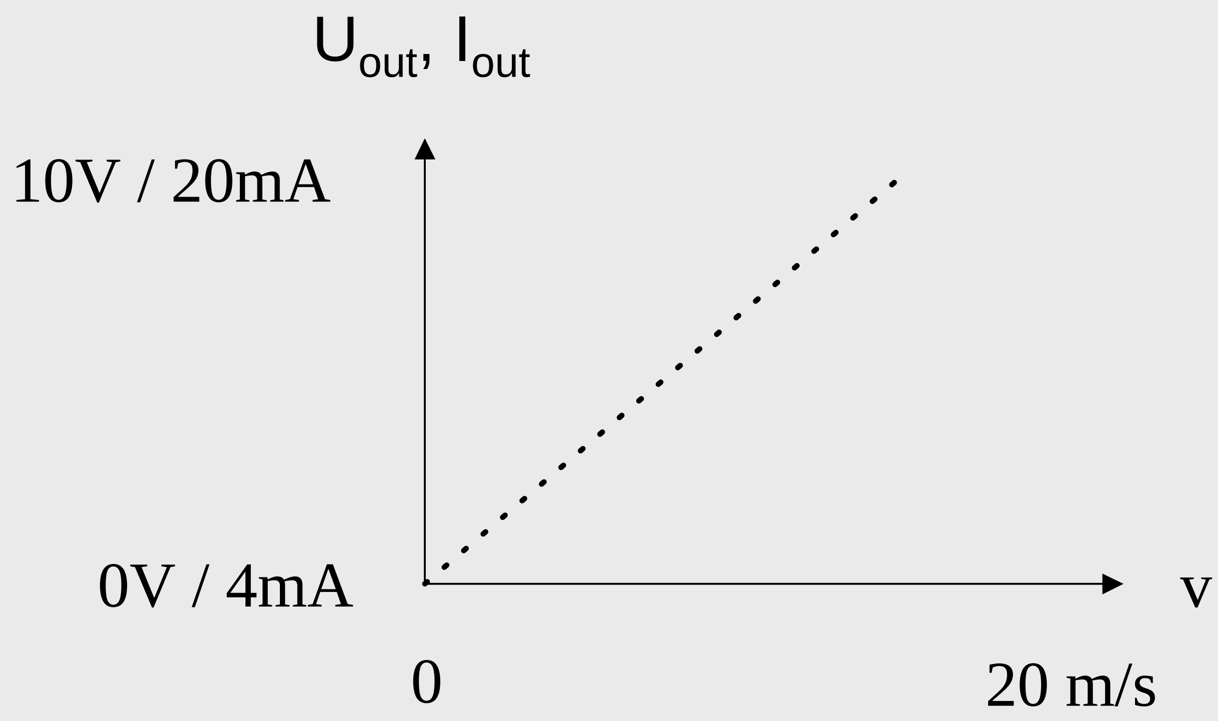
Heater temperature constant



Power function of velocity



Electronic unit converts P(v) into linearized signal U_{out} (v), I_{out} (v) for a defined velocity region



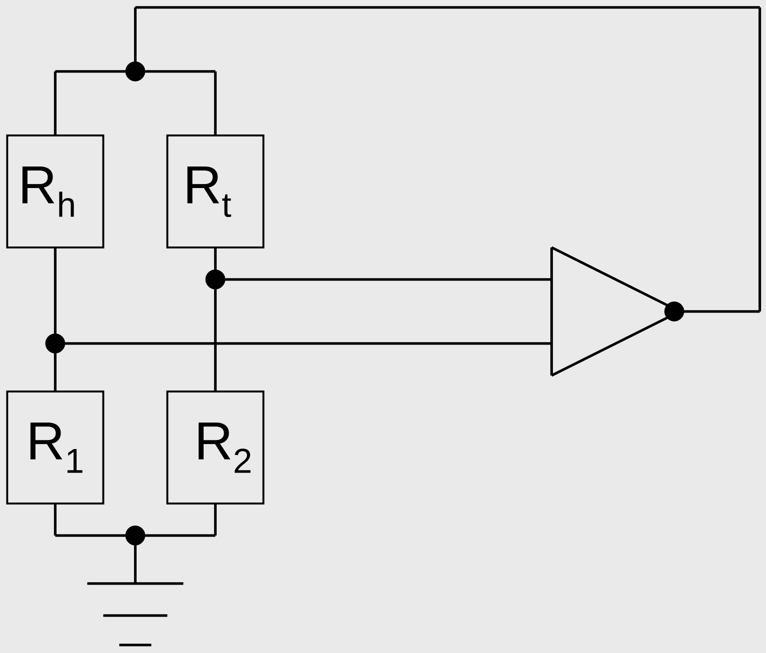
CLIMATIC INFLUENCES

Convective heat transmission depends on temperature difference between hot film and ambient air !

$$\frac{dQ}{dt}[W] \propto T_h - T_a$$

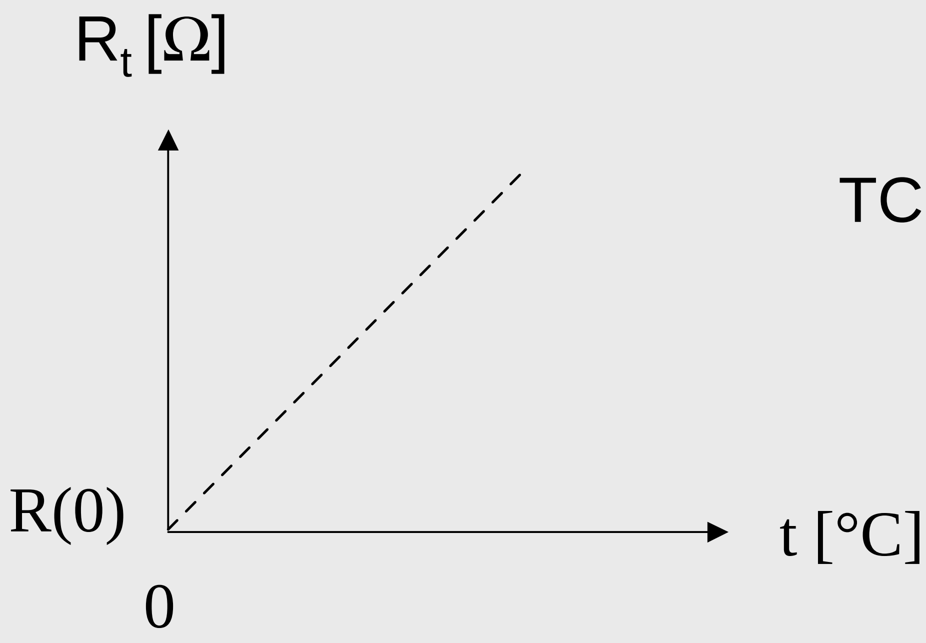
T_h-T_a kept constant by

- Microcontroller (EE70)
- Wheatstone bridge circuit (EE65)



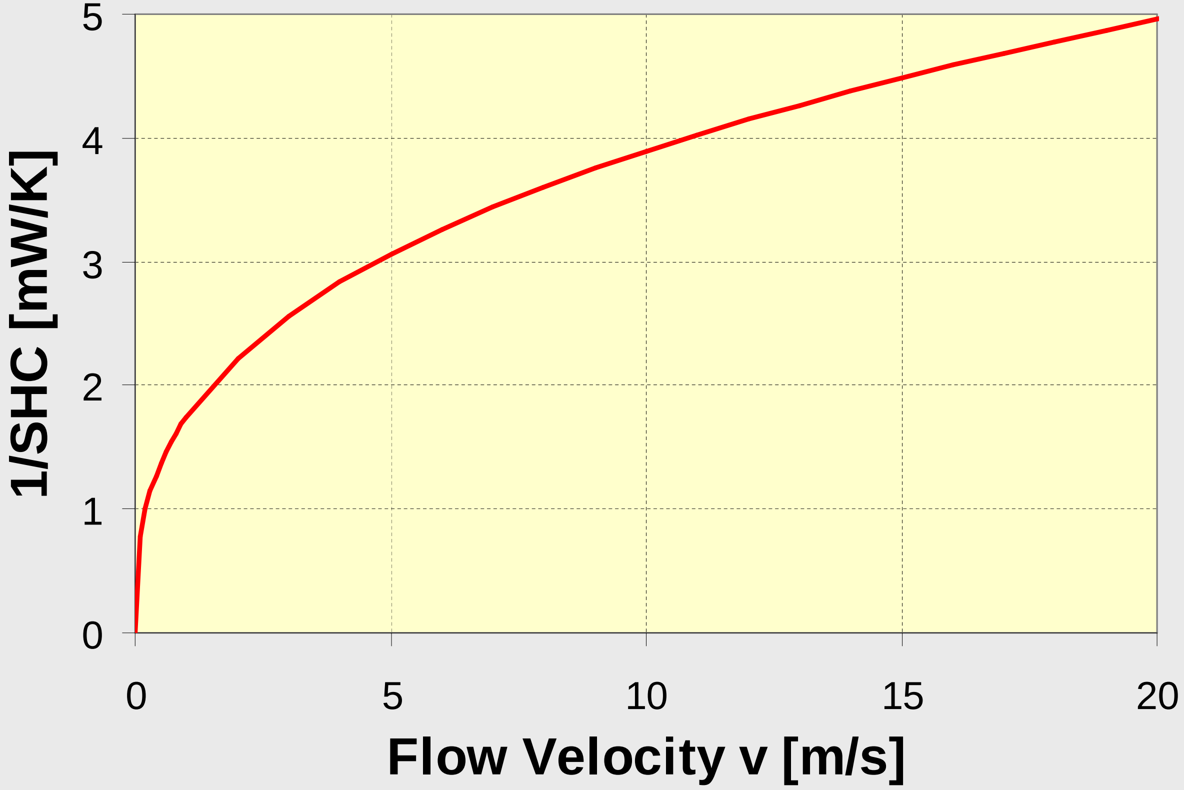
® Temperature Measurement

$$R_t(t) \cong R(0) \cdot (1 + TC \cdot t)$$



TC_{Mo}=3380 [ppm/°C]

$$\frac{1}{SHC} \equiv \frac{P(v)}{T_h - T_a} = B \cdot v^n$$



1/SHC-characteristic depends on

air fluid properties i.e.

- air density r [kg/m^3] !!!
- thermal conductivity l [W/(mxK)]
- viscosity h [kg/(mxs)]
- thermal capacity c_p [J/(kgxK)]

AIR PRESSURE -
AN UNCOMPENSATED INFLUENCE

Continuity equation + Ideal gas equation

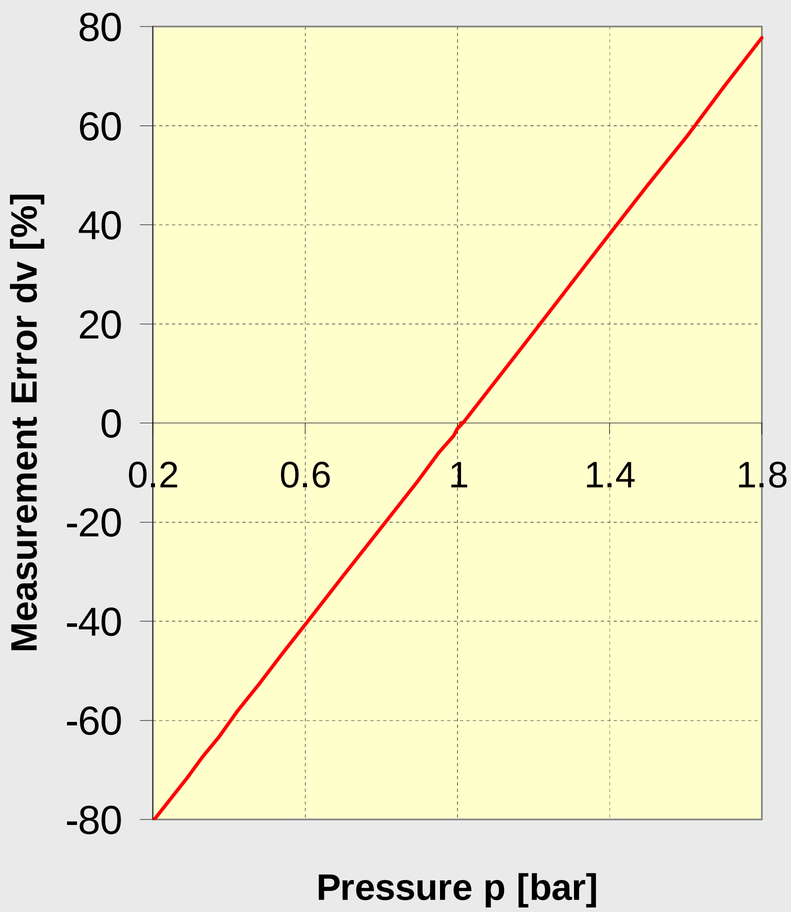
$$\frac{1}{A}\cdot\frac{dm}{dt}[kg/(m^2\cdot s)] = r\cdot v$$

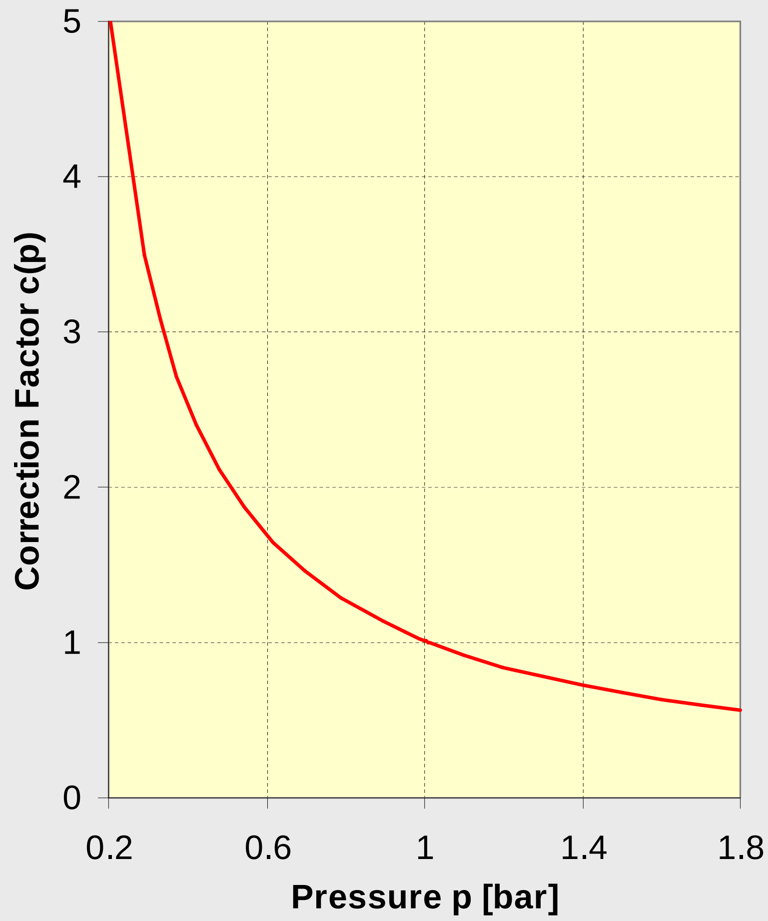
$$r\,[kg/m^3] = r_0\cdot\frac{p}{T}\cdot\frac{T_0}{p_0}$$

Measured velocity v_m „True“ velocity v

$$v_m = v\cdot\frac{p}{p_0}\rightarrow$$

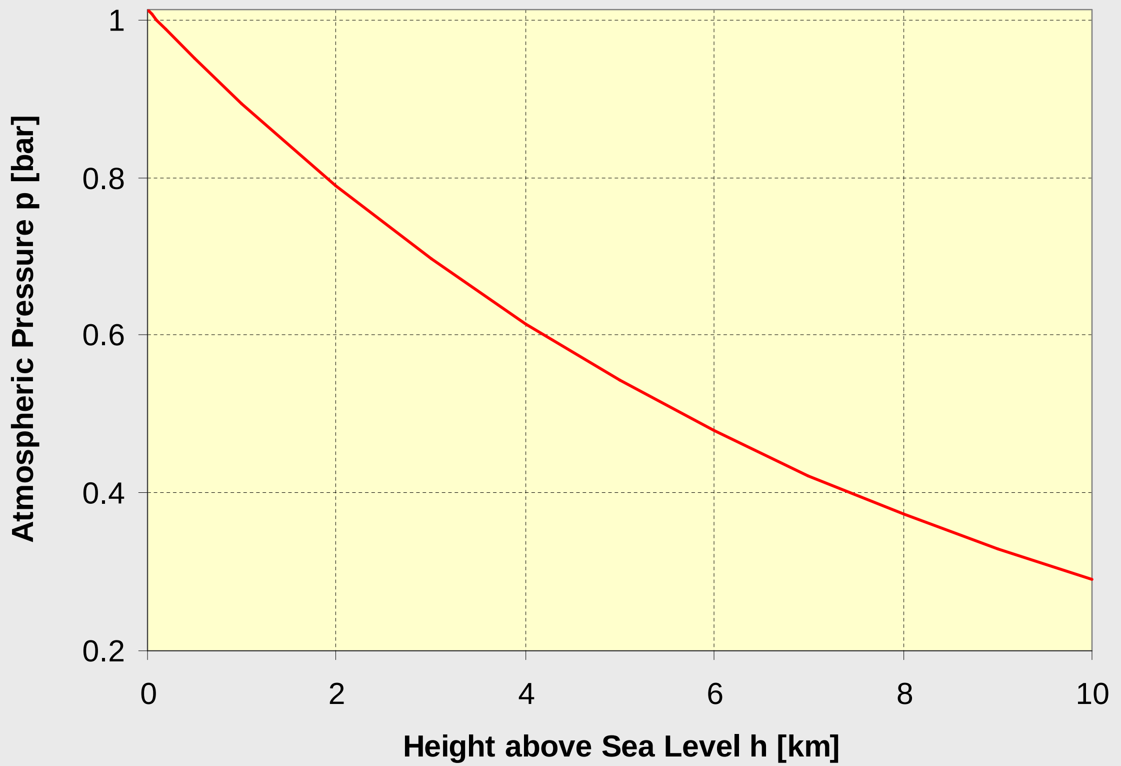
$$v = v_m\cdot\frac{p_0}{p} = v_m\cdot c(p)$$

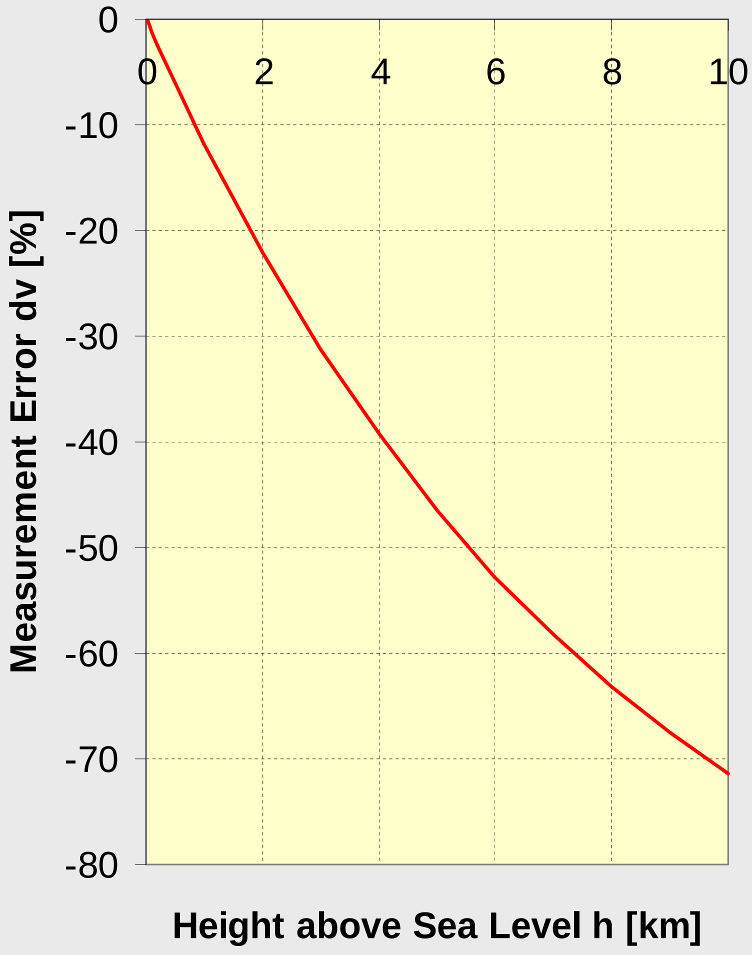

80
60
40
20
0
-20
-40
-60
-80
0.2
0.6
1
1.4
1.8
Measurement Error dv [%]
Pressure p [bar]

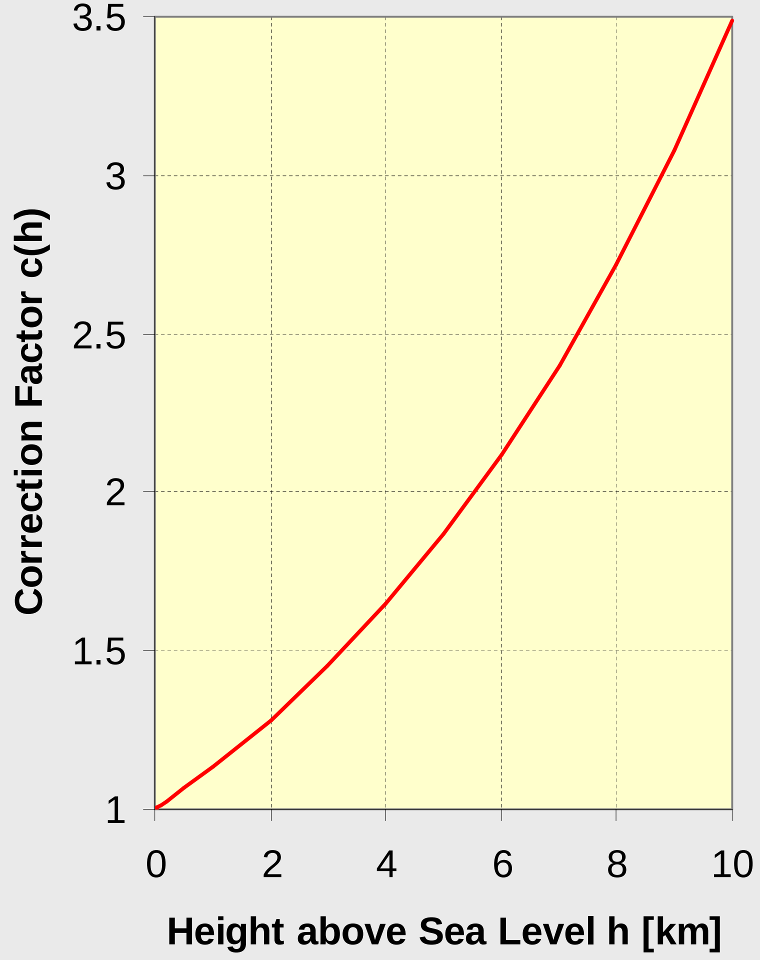

5
4
3
2
1
0
0.2
0.6
1
1.4
1.8
Correction Factor c(p)
Pressure p [bar]

Atmospheric air pressure p depends on height h above sea level

$$p = p_0 \cdot e^{-\frac{h}{8km}}$$




0
-10
-20
-30
-40
-50
-60
-70
-80
0
2
4
6
8
10
Measurement Error dv [%]
Height above Sea Level h [km]


3.5
3
2.5
2
1.5
1
0
2
4
6
8
10
Correction Factor c(h)
Height above Sea Level h [km]

CALIBRATION –
WIND TUNNEL TESTING

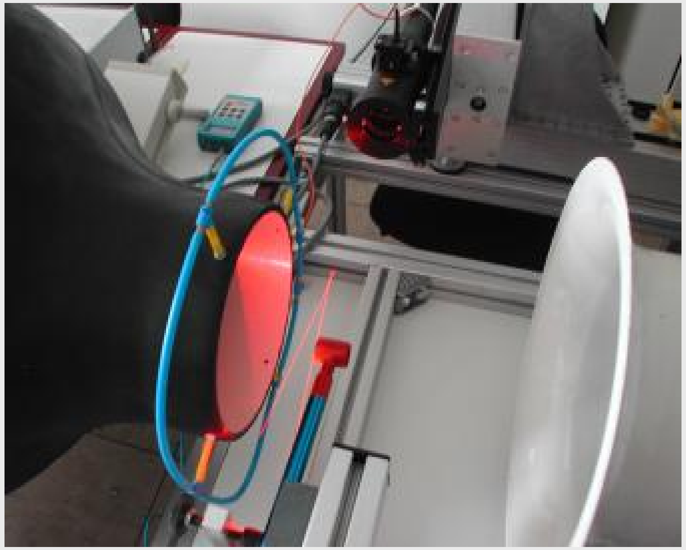
CALIBRATION

1. Velocity measurement device under test (VDUT)

2. Certificated velocity reference

calibration = measurement of the deviations of the VDUT

from the reference under controlled flow conditions



E+E ELEKTRONIK®

E+E primary velocity reference ®

Laser-Doppler Anemometer (LDA) certificated by PTB

with only 0.2 % uncertainty in velocity measurement

- Wind Tunnel for controlled flow conditions

Open Jet

Closed Jet

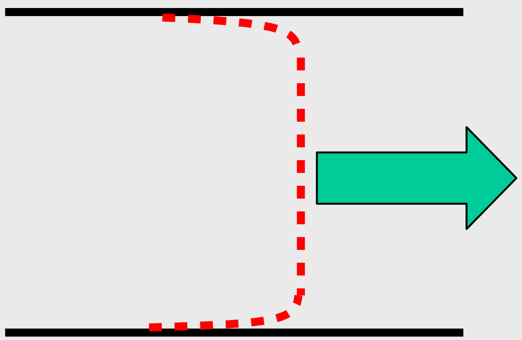
v=1 m/s

d=0.2 m

r_{Air} (20°C,1bar) =1.188 kg/m^3

h_{Air} (20°C,1bar) =1.824 x 10^{-5} kg/(m x s)

® Re=13026 >> 2000 ® turbulent flow



special tunnel design for laminar, uniform flow in test section

At E+E two closed jets with

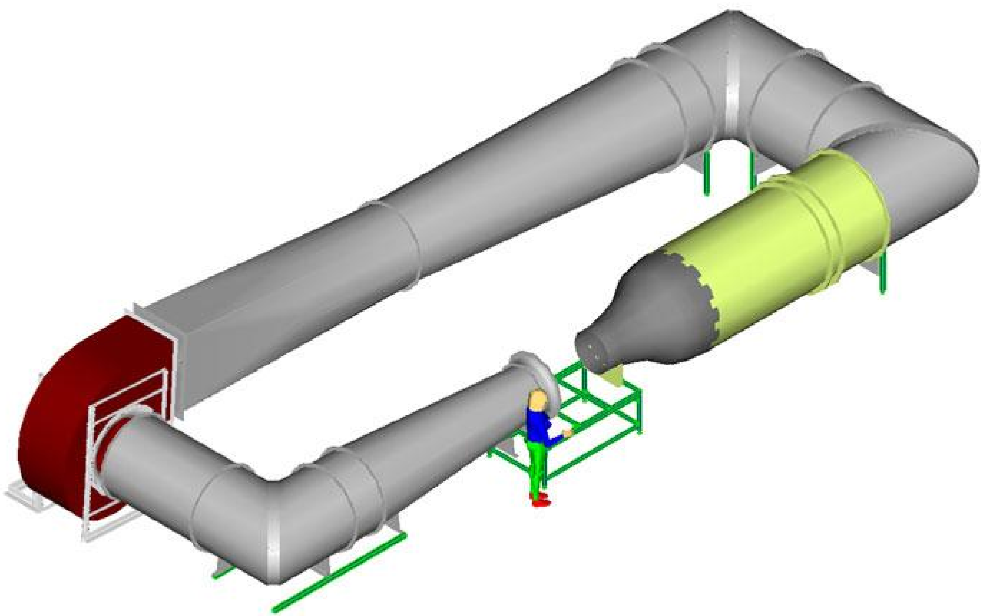
(a) closed test section (“Göttingen type“)

v=0-30 m/s
T_a=10-40°C

(b) open test section

(“Prandtl type“)

v=0-40 m/s
T_a=RT=23°C



WIND TUNNEL FOR MEASUREMENT OF TRANSMITTER CHARACTERISTICS

Testing of transmitter performance under different

- climatic conditions ® temperature, pressure, humidity
- geometric conditions ® twisting angle, probe position in the flow
- dynamic conditions ® response time

SUDDEN CHANGE IN...

(a) Velocity at constant temperature (HVAC) ®

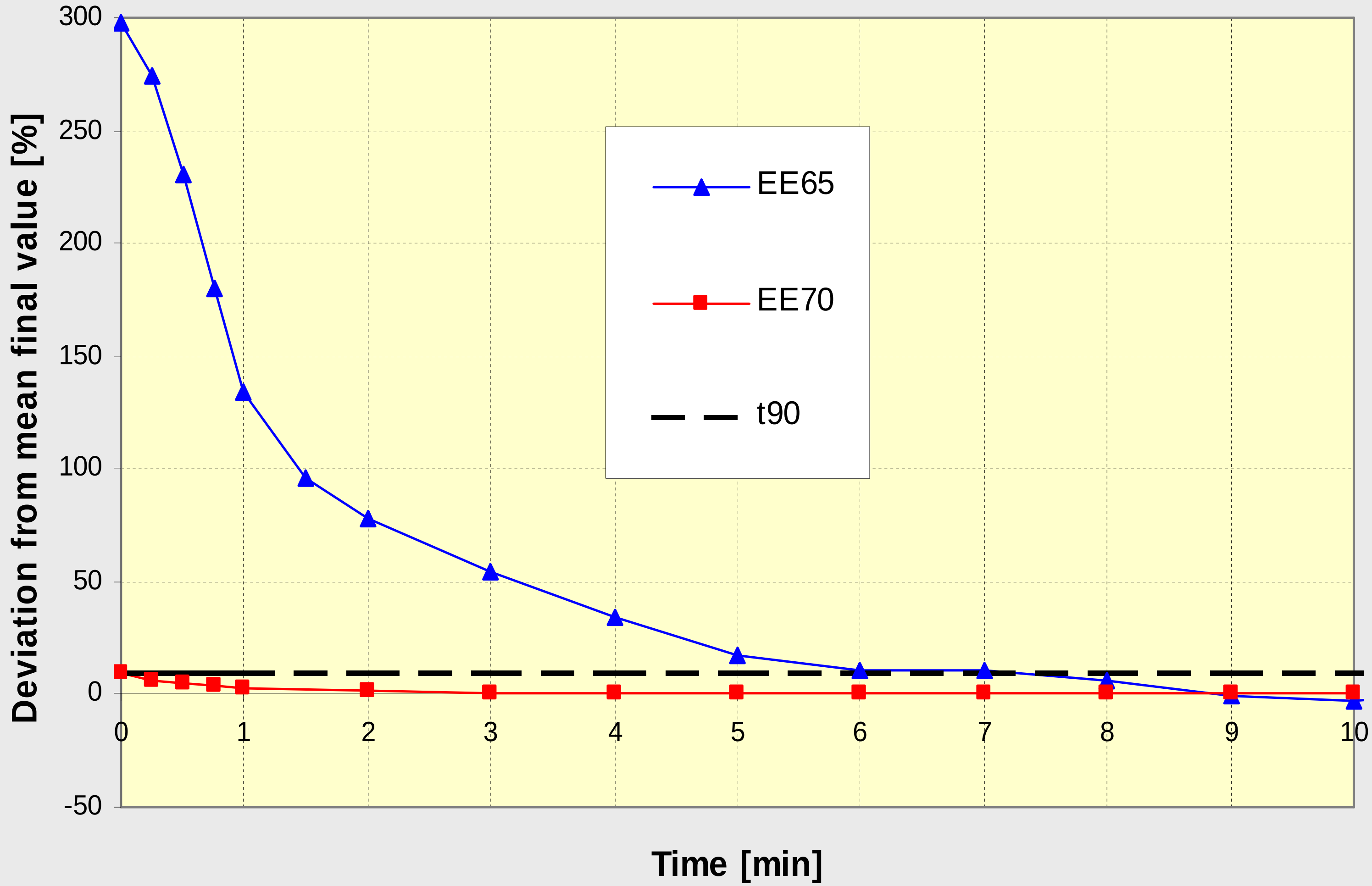
ü EE65 (0.2/2s), EE70 (1.5s)

(b) Velocity and temperature ®

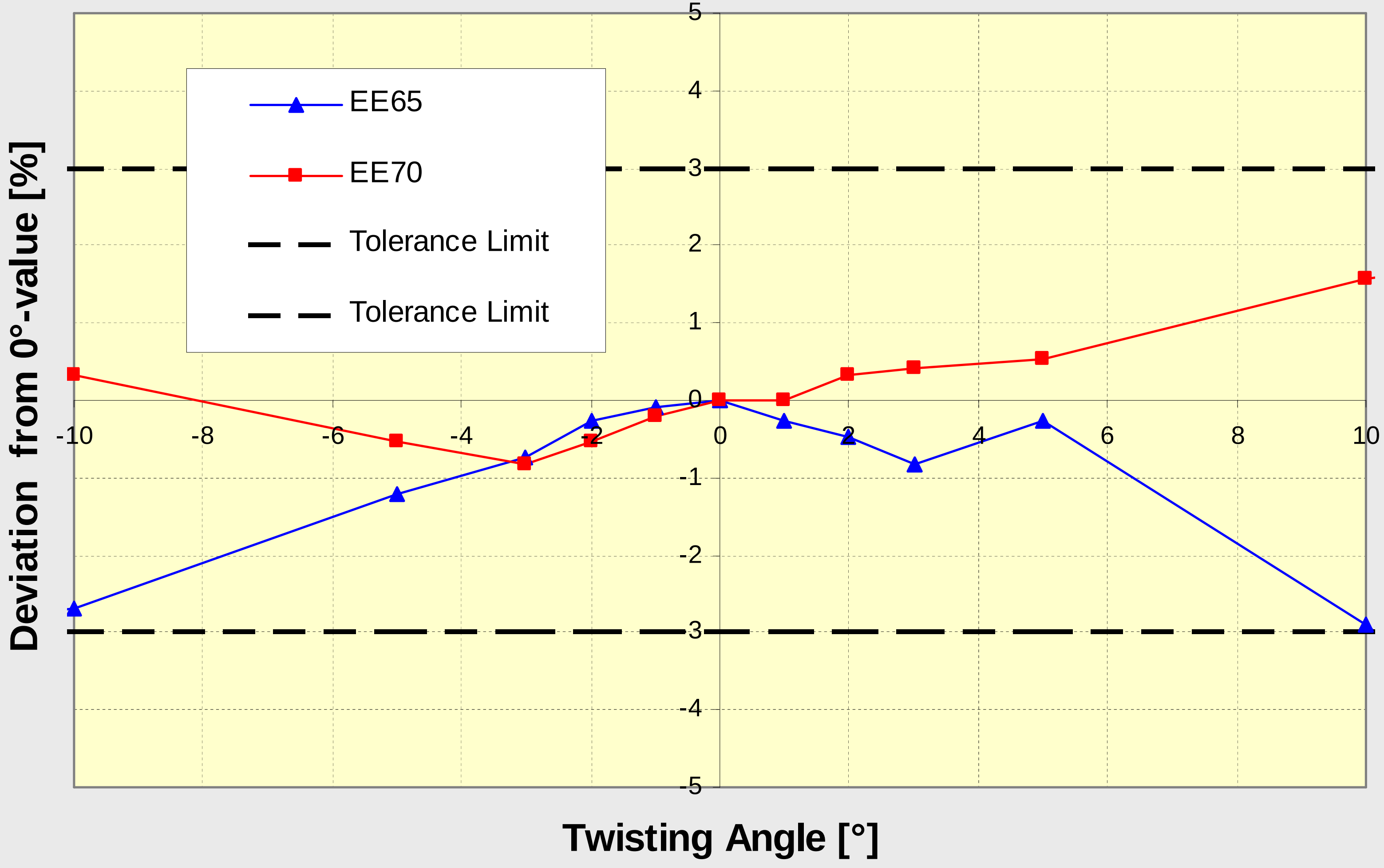
ü EE70

EE65 optional but slow

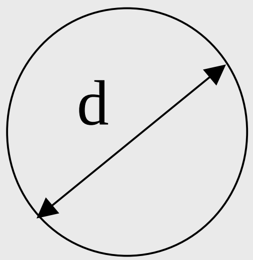
Response times for a change from (0m/s,50°C) to (0.5m/s,23°C)



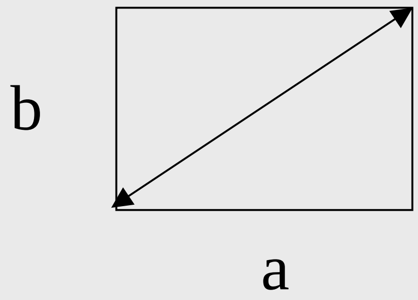
Direction Characteristics at 10 m/s



GUIDELINES FOR GETTING REALISTIC MEASUREMENT RESULTS...

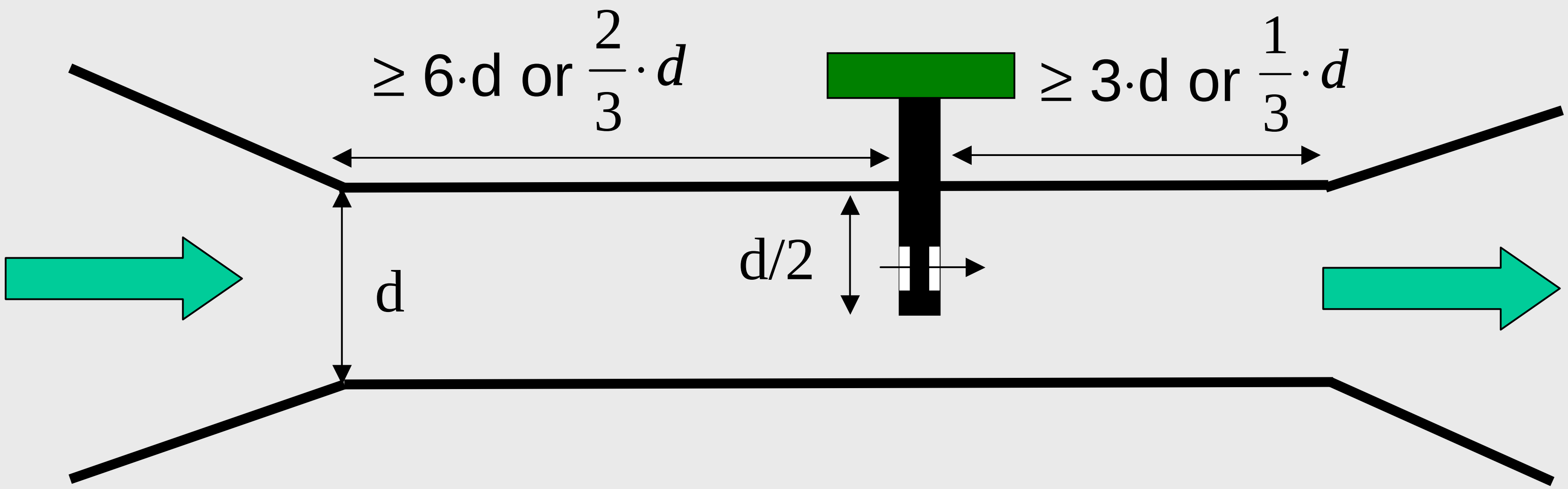


circular duct shape



$$d = \sqrt{a^2 + b^2}$$

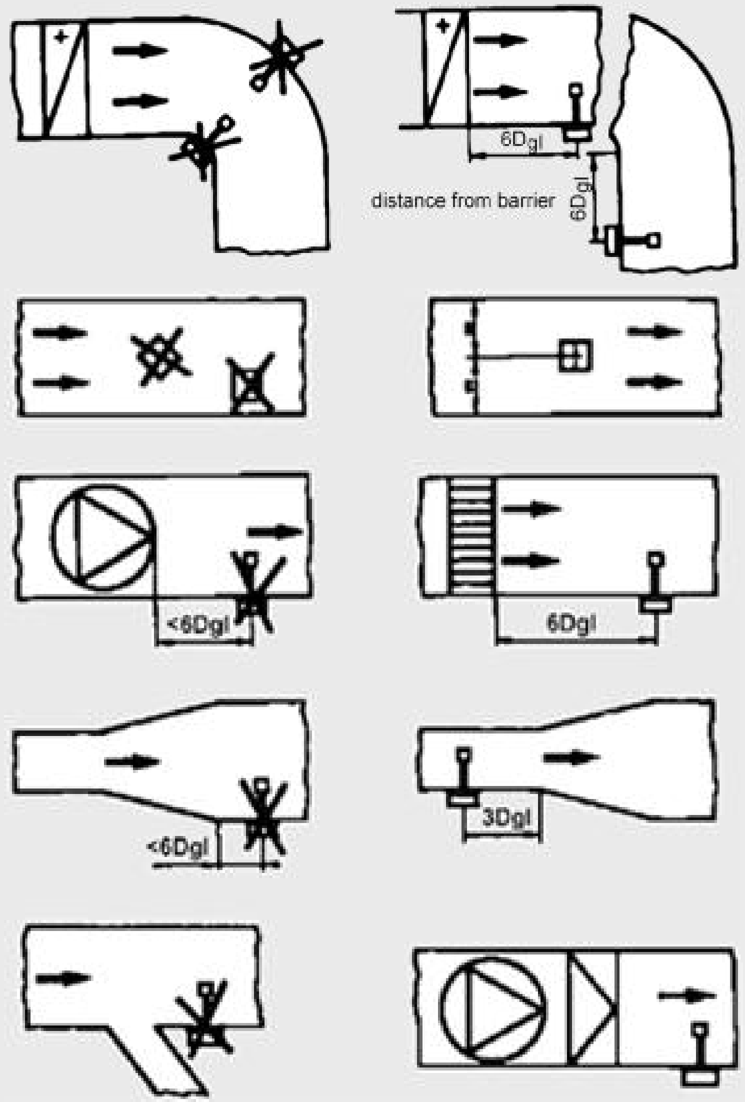
rectangular duct shape



Take care to...

Dont‘s and Do‘s

- avoid corners
- avoid walls
- keep parallel to the flow
- avoid flow interrupting elements
- avoid contractions, diffusers



ELEKTRONIK®

Thank you for your attention !