LABORATORY GUIDE

Testing of air vents (air registers)
Leakage air flow and velocity field measurement

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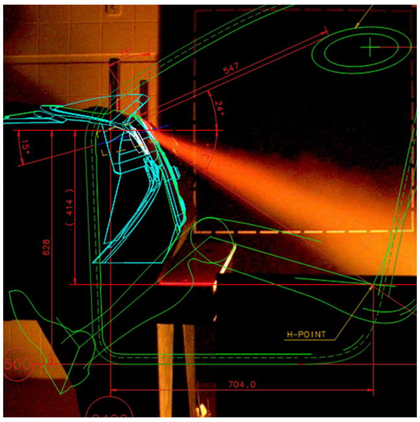


Subject of investigation

Passenger compartment (dashboard) air registers of passenger cars. One single unit is to be tested in course of the 90min laboratory session.
Ordinary marking of the dashboard air registers are the followings:

Table 1.: Ordinary marking of the air register refer to the position in the dashboard

„SL”	„CL”	„CR”	„SR”
side **l**eft	**c**enter **l**eft	**c**enter **r**ight	**s**ide **r**ight
driver's left side	left on center console	right on center console	passenger's right side

Aims of the investigation

The testing of the selected air register contains two main parts:

- Measuring of the leakage air flow rate of the fully shut-off (closed) air register at a given prescribed upstream overpressure.
- Measuring of the velocity field of the fully shut-off (closed) and/or open air register with heated shpere probe. Also, the the flow rate of the airflow is to be calculated based ont he velocity distribution measurements.

The testing is to be performed and analysed due to the strict regulations given in the car manufacturer's specifications. The air register is to be marked with „*pass*” or „*fail*” mark based on the measured leakage air flow rate. Moreover, the velocity field of the air register is to be characterised by a unique defined „non-uniformity” factor.

Experimental facility, equipment:

- blower & rpm regulation unit (blower, frequency shifter, potentiometer)
- tubing (D=59,4mm / 63mm, tube's wall thickness s=1,8mm)
- orifice plate (diameter of the orifice d=15mm) PLEASE CHECK: d=….mm!)
- pressure measuring tubing
- stagnation chamber
- TESTO heated sphere probe (if available)
- two EMB-001 type digital manometer (please, note the Nr. of the used manometer)
- ambient pressure p_0 and temperature t_0 in the laboratory (to be read on the lab-PC screen)

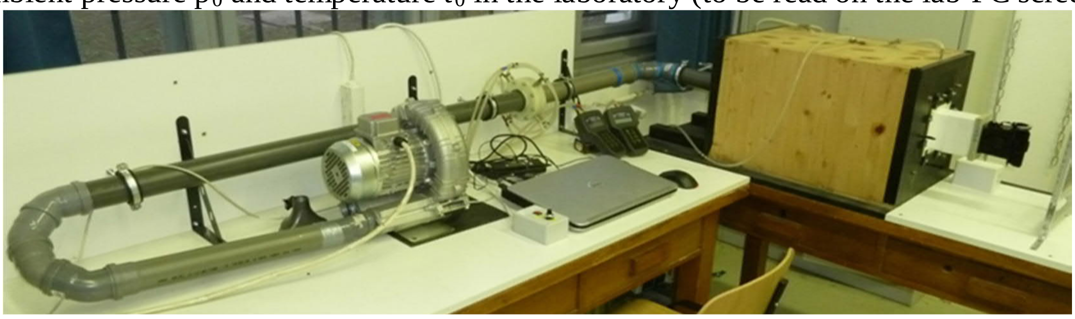


Fig.1.: Experimental facility (Note, that the actual set-up differs from this photo!)

Ford Focus: CENTER & SIDE AIR VENTs

:

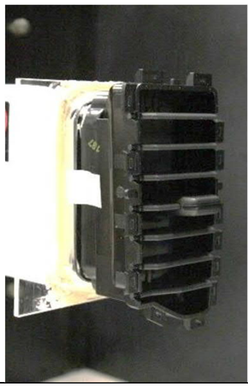
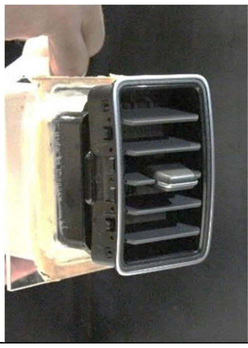
Land Rover: CENTER & SIDE AIR VENTs

Passenger car: 2 pieces CENTER + 1 piece SIDE

Fig.2.: Air registers of "A" passenger car

Passenger car: 2 pieces CENTER + 2 pieces SIDE

Fig.3.: Air registers of "B" passenger car

Kiegészítés a H07 „Személyautó utastéri légbefúvók tesztelése” méréshez	Appendix to the H07 „Testing of air registers” laboratory measurement
Az alábbi túlnyomás és résáram határértékeket vegye figyelembe légbefúvó gyártmánytól függően! EGYETLEN ÚJ ADAT a „VW Crafter WWD” típusra: 0,6 kg/h érvényes a 3,0 kg/h helyett!	Please consider the limiting values for overpressure and leakage air flow listed below! NEW DATA only for the „VW Crafter WWD” type: 0.6 kg/h is valid instead of 3,0 kg/h!
FORD FOCUS (ALL: side, center, left ,right) 	500 Pa @ 0,56 lit/sec
LAND ROVER (ALL: side, center, left ,right) 	250 Pa @ 0,08 m^3/min
VW Crafter „MITTE L” & „MITTE R” 	200 Pa @ 3,0 kg/h
VW Crafter „SEITE L” & „SEITE L” 	200 Pa @ 3,0 kg/h
VW Crafter „WWD” 	200 Pa @ 0,6 kg/h (instead of 3.0 kg/h)

Experimental facility

The air register consists of guide vanes, butterfly valve, and several elements of the manual operations.
The air flow rate is to be regulated between fully shut-off (closed) and fully open position by the manual operation of the butterfly valve.
The vertical and horizontal guide vanes are used to directional setting of the air flow. The following ordinary two-digit codes are used for marking the limiting positions of the guide vanes. Facing the air register outlet the codes are the followings:

11	12	13
21	22	23
31	32	33

A unique interface element (see Fig.4.) is used to connect the air register to the stagnation chamber.

Fig.4.: Air register (*left*), interface elements (*right*)

The air flow distribution is measured by a TESTO heated sphere probe.

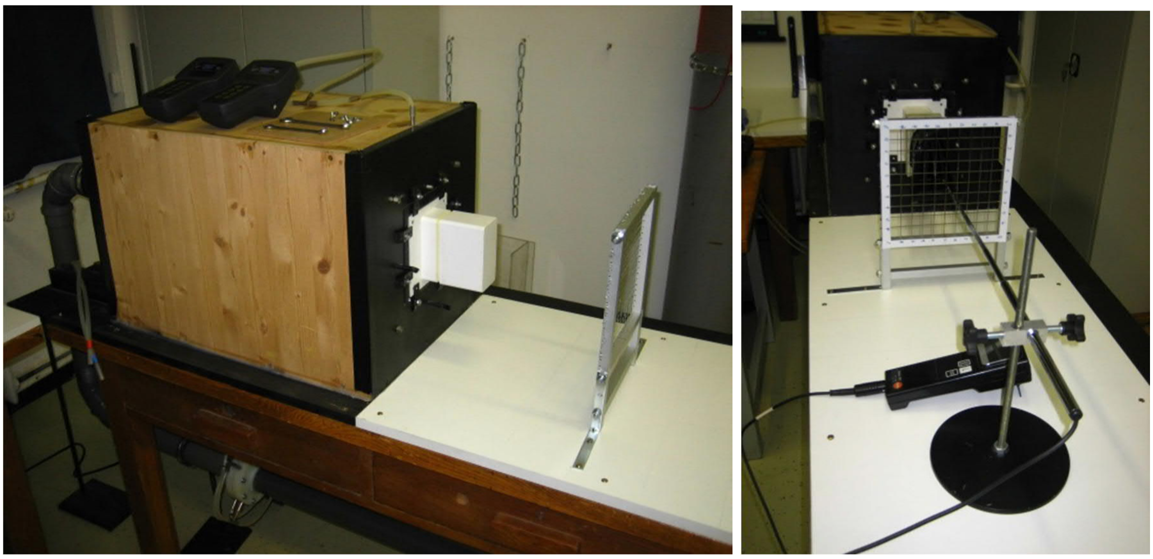


Fig.5.: Stagnation chamber's outlet side (*left*), TESTO heated sphere probe (*right*)

Leakage air flow of the air register ($q_{V,leak(AR)}$) and flow field (v(x,y))

The specifications of the manufacturer's of "A" and "B" passenger cars prescribe a limiting (max) value for the leakage air flow rate ($q_{V,leak(AR)}$) of the **a**ir **r**egister at a given upstream overpressure with fully shut-off butterfly valve of the air register. Moreover, at fully shut-off position it is also prescribed, that the velocity of the air flow must not exceed v_{limit}=0.55 m/s at a downstream distance of 100mm from the outlet cross section.

		prescribed upstream overpressure **Δp**	max. allowed leakage air flow rate $\mathbf{q_{V,leak(AR),limit}}$	max. allowed leakage air flow velocity $\mathbf{v_{limit}}$
"A"	:	**500** Pa	**0,56** lit/sec	**0,55** m/s
"B"	:	**1.0** w.c.inch (*„1.0 inch of water gauge pressure differential"* (249,174Pa**≈250Pa**)	**0,08** m^3/min	**0,55** m/s

Note: „w.c. inch": the pressure difference is given in „inches of water column" (in USA specification), that is to be recalculated to pascals.

The volumetric flow rate and velocity distribution is to be measured precisely at given upstream overpressure.
Evaluation of the air register is to be performed as listed below:

- value in S.I. of the calculated leakage air flow rate $q_{V,leak(AR)}$
- value in % of the calculated leakage air flow rate $q_{V,leak(AR)}$ in % of the a $q_{V,leak(AR),limit}$
- marking *„pass"* when $q_{V,leak(AR)} < q_{V,leak(AR),limit}$, or *„fail"* when $q_{V,leak(AR)} > q_{V,leak(AR),limit}$

Leakage air flow of the stagnation chamber

Since the **s**tagnation **c**hamber is cannot be manufactured to be totally sealed, its leakage air flow ($q_{V,leak(SC)}$) must be also measured.

The first step is to measure the leakage air flow ($q_{V,leak(SC)}$) of the **s**tagnation **c**hamber with closed outlet cross section. Since precise value of the prescribed overpressure (Δp) cannot be set, the characteristic curve of the leakage air flow of **s**tagnation **c**hamber vs. overpressure is to be measured. At least 3-3 points are needed in the ± Δp vicinity of the limiting flow rate and overpressure values.

$$q_{V,leak(SC)}\ [m^3/s] = f(\Delta p)$$

This characteristic line of the stagnation chamber is nearly **linear**. Use the $\Delta p = f(q_V)$ when plotting results! (see diagram in Fig.6.) Use best fit linear trendline to your measured data points, plot also its equation and value of R^2!

Leakage air flow of the air register

Mount the air register to the outlet cross section of the stagnation chamber and properly seal with the white adhesive tape! Measurement of the characteristic curve is to be performed again, now with the fully shut-off air register.

The characteristic curve of the leakage air flow of (**s**tagnation **c**hamber + **a**ir **r**egister) vs. overpressure is to be measured. At least 3-3 points are needed in the ± Δp vicinity of the limiting flow rate and overpressure values.

$$q_{V,leak(SC+AR)}\ [m^3/s] = f(\Delta p)$$

This characteristic curve now is nearly **second order polynomial**. Use the $\Delta p = f(q_V)$ when plotting results! (see diagram in Fig.6.) Use best fit second order polynomial trendline to your measured data points, plot also its equation and value of R^2!

Based on the measurements and trendlines' equations the leakage air flow rate of the air register precisely at the prescribed overpressure can be calculated:

$$q_{V,leak(AR)} = q_{V,leak(SC+AR)} - q_{V,leak(SC)}$$

The following diagram shows a sample measurement result for another car manufacturer's air register, see Fig.6. Similar type of diagram is to be proceeded and evaluated for your own measurement results of the selected unit.

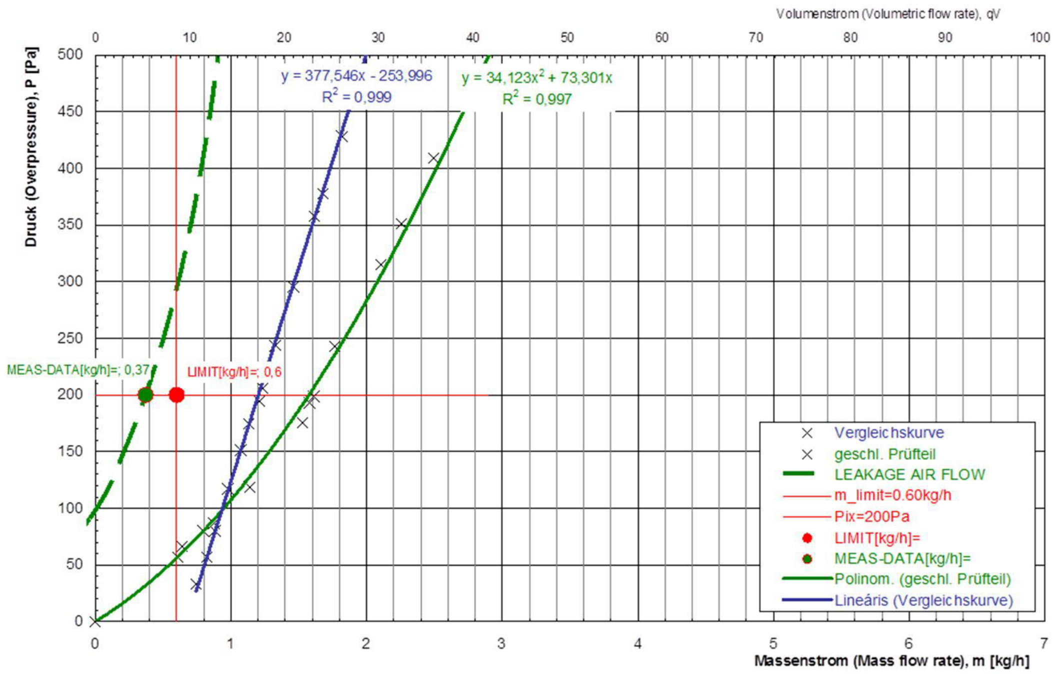


Fig.6.: Leakage air flow diagram (SAMLPE! Another "C" manufacturer's air register!)

Legend for Fig.6.

—	count. blue line:	leakage air flow characteristic curve of stagnation chamber
—	count. green line:	leakage air flow characteristic curve of stagnation chamber + air register
- - -	dashed green line:	leakage air flow characteristic curve of air register (calculated difference)
—	count. red lines:	constant lines for limiting values
●	red dot:	data point of limiting values
●	green dot:	leakage air flow data of air register at the prescribed overpressure

Two EMB-001 type digital manometer are used for measurement of the pressure difference on the orifice plate and the overpressure of the stagnation chamber.

Flow rate measurement with standard orifice plate

Standard orifice plate is built in the tubing that is connected to the blower's outlet. Inner diameter of the tube is D=59,4mm (DN63: D_{outer}=63mm, wall thickness s=1,8mm). Orifice plate's opening diameter is d=15mm. The Δp pressure difference of the orifice plate is to be measured by a connector line tubing of upstream (p_E) and downstream (p_U) pressure taps of the orifice plate.

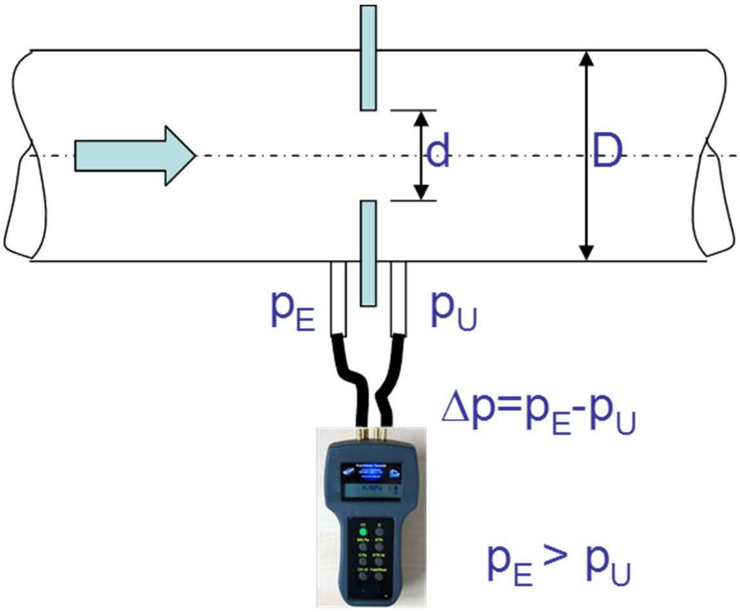


Fig.7.: Flow rate measurement with orifice plate

The volumetric flow rate q_V [m^3/s] is calculated with the expression below:

$$q_V = C \cdot \varepsilon \frac{1}{\sqrt{1-\beta^4}} \frac{d^2\pi}{4} \sqrt{\frac{2\Delta p}{\rho}}$$

where

C	[-]	flow coefficient
ε	[-]	compressibility factor
β	[-]	orifice plate's diameter ratio (β=d/D)
d	[m]	opening diameter of the orifice plate
D	[m]	inner diameter of the tube
Δp	[Pa]	measured pressure difference
q	[m^3/s]	fluid density

The coefficient C is unknown: it depends on the Reynolds-number (Re_D) of the flow in the tube and on the geometrical data (β, D). We can calculate C using expression below:

$$C = 0{,}5961 + 0{,}0261\beta^2 - 0{,}216\beta^8 + 0{,}000521 \cdot \left(\frac{10^6\beta}{Re_D}\right)^{0,7} + (0{,}0188 + 0{,}0063A) \cdot \beta^{3,5} \cdot \left(\frac{10^6}{Re_D}\right)^{0,3} + 0{,}011 \cdot (0{,}75 - \beta)\left(2{,}8 - \frac{D}{25{,}4}\right)$$

where

$$A = \left(\frac{19000\beta}{Re_D} \right)^{0,8}$$

Reynolds-number is defined as

$$\mathrm{Re}_D = \frac{v \cdot D}{\nu} = \frac{v \cdot D \cdot \rho}{\mu},$$

where ν kinematic viscosity or μ dynamic viscosity of the fluid (air) can be calculated from e.g. Lajos T: *Az áramlástan alapjai* (2008) ch.1.2.4. on p.34.
The ambient air temperature (T) is needed to read in the labPC screen.

$$\mu = \mu_0 \frac{T_0 + T_S}{T + T_S} \left(\frac{T}{T_0} \right)^{\frac{3}{2}}$$

where T_0=273,16K, μ_0=17,1·10^{-6}kg/(m·s) és T_S=122K.

$$\nu = \frac{\mu}{\rho}$$

Value for the compressibility factor ε =1 can be used taking the assumption of ρ=constant.

ITERATIVE PROCEDURE FOR CALCULATING FLOW RATE

Calculation of flow rate needs an iterative procedure since C depends on flow Reynolds-number and the flow velocity (v) in the tube is unknown.

Steps of iterative procedure:
Flow factor (α) is defined by the flow coefficient (C) and diameter ratio (β):

$$\alpha = \frac{C}{\sqrt{1 - \beta^4}}$$

Let us use for flow factor as initial value of the 0th iterative step: α'= 0,6.

$$\alpha' = \frac{C'}{\sqrt{1 - \beta^4}} = 0,6$$

(Experience shows us that using 0,6 ÷ 0,8 initial value for flow factor (α) the iterative procedure is quickly convergent.

Based on the measured data the initial data of the:
- flow rate: q_V',
- mean flow velocity in the tube: v'=q_V'/A, (tubes inner cross-section A=$D^2\pi/4$)
- and Reynolds-number : Re_D'

can be calculated. Next steps of iteration can be proceed to gain α" (or C"). Iterative procedure needs to be applied until the difference between values of flow factor α (or C, or flow rate q_V) of two successive iterative steps is smaller than the prescribed value, e.g. 0,1% (e.g. $\Delta\alpha$<0,1% is prescribed)!

Upstream overpressure of the stagnation chamber

The upstream overpressure (pressure difference to the ambient p_0) of the stagnation chamber is measured by the connector line tubing, see in Fig.1. & Fig.5. Another EMB-001 type digital manometer can be used for this purpose.

Flow field measurement

We can measure either the flow field of
- the **fully open** air register's or
- the leakage air flow of the **fully closed** air register.

Since the laboratory ambient are is not at fully still state, measuring the relatively low leakage air flow field having only few 0,1m/s of velocity is practically impossible.

a) **<u>at fully closed air register</u>:** It is prescribed that the velocity of the air flow must not exceed v_{limit}=0,55m/s. Measurement can be done via TESTO heated sphere probe. Note that reading the flow velocity precisely: but ±0.01m/s hard to read in real flow.

b) **<u>at fully open air register</u>:** Manually set the positions of the horizontal & vertical guide vanes as you want. Set constant flow rate via blower's rpm regulation, but note that the measured Δp applied on the sensitive silicon membrane of the EMB-001 type manometer do not exceed max. 6500Pa! Air flow field velocity distribution is to be measured and the non-uniformity is to be evaluated. Velocity measurement can be done via TESTO heated sphere probe. Note that reading the flow velocity precisely: but ±0.01m/s hard to read in real flow.

In each case the flow rate (q_V) of the free jet is to be also calculated from your velocity measurements. Investigated cross section of the free jet:

- in (x,y) plane, that is perpendicular to the main axis of the air register, at 100m distance from the central point of the outlet cross section of the air register.
- cross section: use Δx=20mm; Δy=20mm sub cross-sections for velocity measurements!

For evaluating the measured velocity field of the free jet of the selected air register use the following parameters:

1) **flow velocity map**: v(x,y) [m/s],
2) **non-dimensionalised (relative) flow velocity map** : $v_{rel,i}(x,y)=v_i/v_{mean}$ [%],
3) **LOCAL non-uniformity factor**: based on your owm knowledge and intuition please define a factor that characterises the uniformity (non-uniformity) of the velocity field! Please define this factor by equation and describe the method and evaluation of using it. Please give the value of the factor and/or plot the map of the factor!
4) **GLOBAL non-uniformity factor**: based on your owm knowledge and intuition please define a global factor that characterises the uniformity (non-uniformity) of the velocity field! Please define this factor by an equation and describe the method and evaluation of using it. The global factor will differ from the local factor. The local factor's distribution can be presented on a map, the global factor is a single number, that characterizes the flow field by it s value.
5) **flow rate:** calculate the q_V flow rate of the free jet based on the velocity measurement, and compare to the q_V calculated by orifice plate measurement.

Use engineering relevant values of equidistance lines/surfaces when plotting the velocity etc. maps in 2D / 3D diagrams! Do no forget to data tables of all measured and calculated data, with their names and units, too!

CL-07 | VELOCITY v [m/s] | qV= **3,34** [lit/s] | FAIL | v_{av}= 0,10 m/s

	-80	-60	-40	-20	**0**	20	40	60	80	
80	0	0	0	0	**0**	0	0	0	0	80
60	0	0	0	0	**0**	0	0	0	0	60
40	0	0,01	0,06	0,07	**0,09**	0,02	0,01	0	0	40
20	0	0,09	0,28	0,53	**0,44**	0,03	0,02	0,01	0	20
0	**0**	**0,04**	**0,11**	**0,32**	**0,23**	**0,05**	**0,04**	**0,01**	**0**	**0**
-20	0	0,01	0,03	0,12	**0,11**	0,05	0,03	0,04	0	-20
-40	0	0,02	0,05	0,12	**0,69**	0,62	0,08	0,02	0	-40
-60	0	0,01	0,03	0,09	**0,89**	0,74	0,09	0,02	0	-60
-80	0	0,01	0,05	0,09	**0,69**	1,06	0,08	0,04	0	-80
	-80	-60	-40	-20	**0**	20	40	60	80	

CL-07 | EVALUATION (PASS/FAIL) | WHISTLE= 1 | 0=NO 1=LOW 2=MED 3=HIGH

	-80	-60	-40	-20	**0**	20	40	60	80	
80	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	80
60	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	60
40	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	40
20	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	20
0	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	**0**
-20	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	-20
-40	PASS	PASS	PASS	PASS	FAIL	FAIL	PASS	PASS	PASS	-40
-60	PASS	PASS	PASS	PASS	FAIL	FAIL	PASS	PASS	PASS	-60
-80	PASS	PASS	PASS	PASS	FAIL	FAIL	PASS	PASS	PASS	-80
	-80	-60	-40	-20	**0**	20	40	60	80	

Fig.8.: Velocity field data table (leakage air flow) (SAMPLE! Another "C" car manufacturer's data)

Pressure difference measurement with digital manometer (EMB-001 type)

1) Switch on!
2) Reload factory calibration curve!
3) Set 0 point
4) Use “S” setting that uses the longest (15s) integral time for collecting pressure signals.

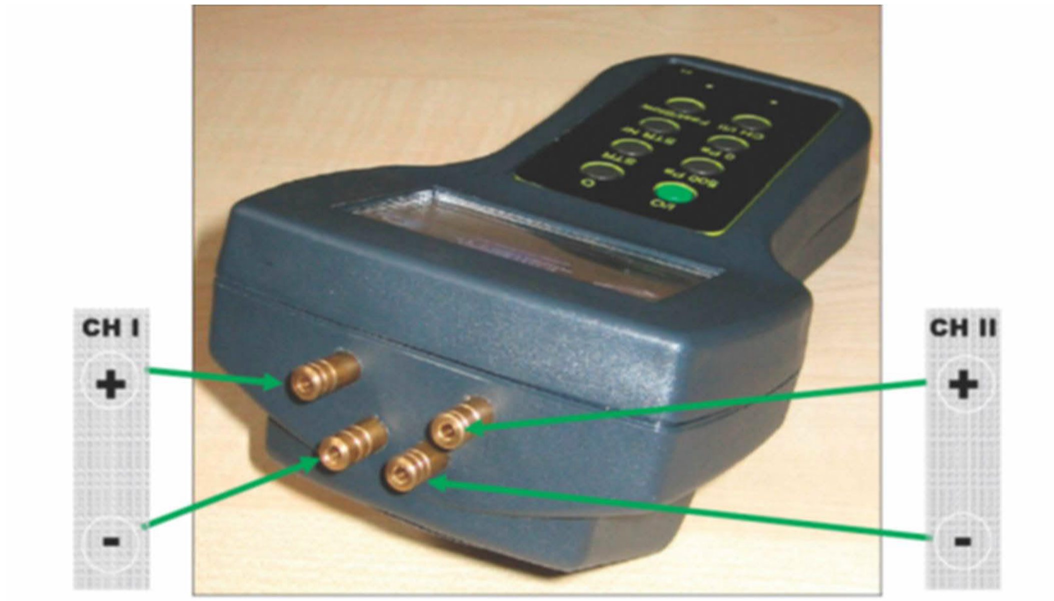
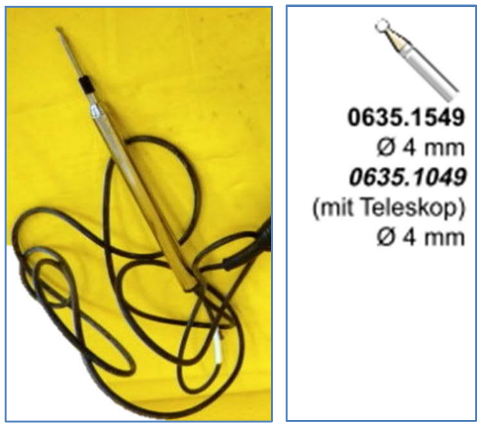


Fig.9.: Digital manometer EMB-001 type

Velocity measurement with TESTO heated sphere probe

TESTO 491 type main unit



TESTO 0635.1549 type sensor head

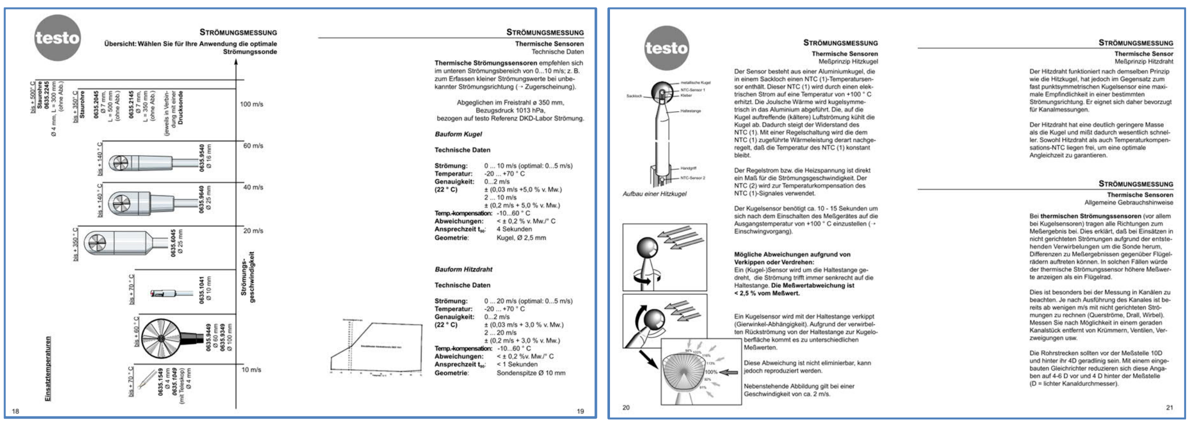


Fig.10.: TESTO heated sphere probe

Ambient data:
Ambient pressure and temperature is to be read from the screen of the laboratory PC. Fluid (air) density is to be calculated using ideal gas law:

$$\rho_{air} = \frac{p_0}{R \cdot T_0}$$

where p_0 [Pa] local ambient pressure
T_0[K]=273,16 + t_0 [°C] ambient air temperature
R=287 J/(kg·K) specific gas constant.

LABORATORY REPORT REQUIREMENTS

DONT'T USE WHEN THE REQUIREMENTS OF YOUR PRESENT SUBJECT DIFFERS!

1. Basic requirements (formal & content):

- date & place of measurement
- personnel of the laboratory session
- personnel preparing the lab report
- title of the lab session
- data of the experimental facility, actual sketch, technical drawing & photo (if exists) of the set-up
- used equipment (name, type, Nr., mark etc.)
- air vent (air register) data, type, , manufacturer, SIDE/CENTER etc.
- ambient data
- data table of all measured and calculated quantities (name, unit and value of the quantities)
- equations used for calculation
- presentation of result in diagrams and graphs
- presentation of result in form of textual evaluation

2. Further minimum requirements (calculations, diagrams, evaluations):

- Leakage air flow diagram
- Flow maps (with m/s dimension, and also the non-dimensional map %)
- Non-uniformity factor value / map
- Flow rate of the free jet
- Uncertainty analysis

DONT'T USE WHEN THE REQUIREMENTS OF YOUR PRESENT SUBJECT DIFFERS!
Submission deadline of the lab report: on the second next week's Sunday midnight (24:00h).

Report in single file PDF is to be

- uploaded to the POSEIDON system at the website, and also to be
- sent by email to suda@ara.bme.hu

in the same electronic format (single PDF file).

Consulting possibilities: based on appointment with the responsible.

The lab report submitted to the deadline is evaluated by the responsible. If needed, it can be further improved ONCE, with +1week deadline.

Budapest, April of 2016

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Further info on the subject's website