FLOW MEASUREMENTS

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Vad, J. (2008), *Advanced flow measurements.* Műegyetemi Kiadó, 45085.

Interactive presentations (– „PREMIUM SCORES”):

1: Introduction. The need for flow measurements. Practical / industrial necessity of flow measurements in general. Quantities to be measured. Aspects of „being advanced”. Special notes on advanced flow measurements. Announcement of **Market research + Ökotech/Hungarotherm exhibition**: 2/4 hours?
2: Measurement of temporal mean pressures: static, total, dynamic. Probes and methods. Manometers. Pressure-based measurement of velocity magnitude and direction. Anemometers, thermal probes. Temperature measurements.
3: Measurement of unsteady pressures. Sound and vibration measurements. Flow visualization.
4: **Laboratory display:** Devices for pressure, velocity and temperature measurements. Pneumatic measurements (pressure, temperature, flow rate). Electro-pneumatic systems.

5: **Mid-term test 1** – Part A: closed book test (theory), Part B: open book test (solution of practical problems)
6: Laser optical flow diagnostics 1.
7: Laser optical flow diagnostics 2.
8: Hot wire anemometry
9: **ÖKOTECH** / Flow rate measurements with use of contraction elements and deduced from velocity data. Comparison.
10: Specialised flowmeters: ultrasonic, MHD, capacitive cross-correlation technique, Coriolis.
11: Specialised flowmeters: vortex, rotameter, turbine, volumetric. **Laboratory display.**
12: Easter holiday
13: **Mid-term test 2** – Part A: closed book test (theory), Part B: open book test (solution of practical problems)
14: **Presentation of laboratory measurement results and market research + industrial exhibition experiences. Evaluation of the course.**

Interactive seminars (lab displays, industrial case studies– „PREMIUM SCORES") + laboratory excercises:

1: ICS: Fault diagnostics of the air supply system of a gas motor power generator. Development of a dynamic fire extinguishment method. Testing a wind tunnel via ad hoc measurements.
2: ICS: Optimization of a mineral wool production process. Development of an axial fan of long throw. Visualisation of water coning in the model of an oil production well.
3: ICS: Proposal for noise reduction of an aerobic waste water treatment system. Investigation on a wood chip drying tower.
4: ICS: Optimization of a pharmaceutical fermentation process. Measurement and simulation of an electro-pneumatic brake modulator. Vibration diagnostics on a boiler combustion air supply fan.
5: ICS: Experimental investigation on a scaled-up model fuel pump. Extension of a food industry cooler system.
6: Laser optical flow diagnostics 1. **Lab display.**

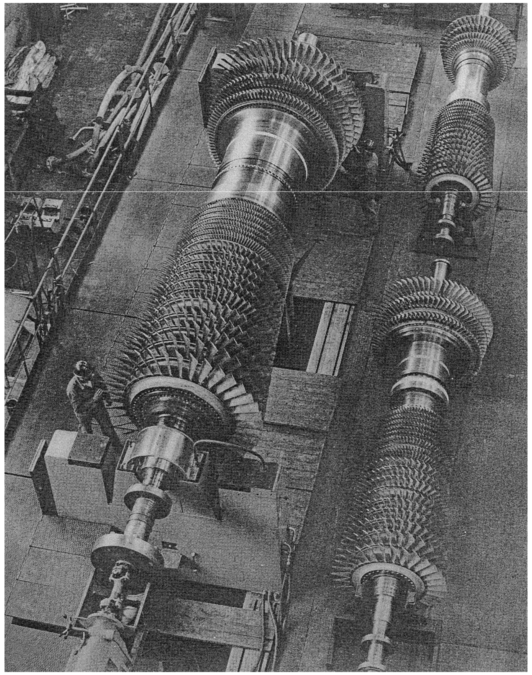
7: Laser optical flow diagnostics 2. **Lab display.**
8: Hot wire anemometry**. Lab display.**
9: ÖKOTECH
10: Preparation for the laboratory measurements. Laboratory measurements 1.
11: Laboratory measurements 2.
12: Easter holiday
13: ICS.
14: Presentation of laboratory measurement results and market research + industrial exhibition experiences. Evaluation of the course.

1. INTRODUCTION

1.1. Objectives of fluid flow measurements

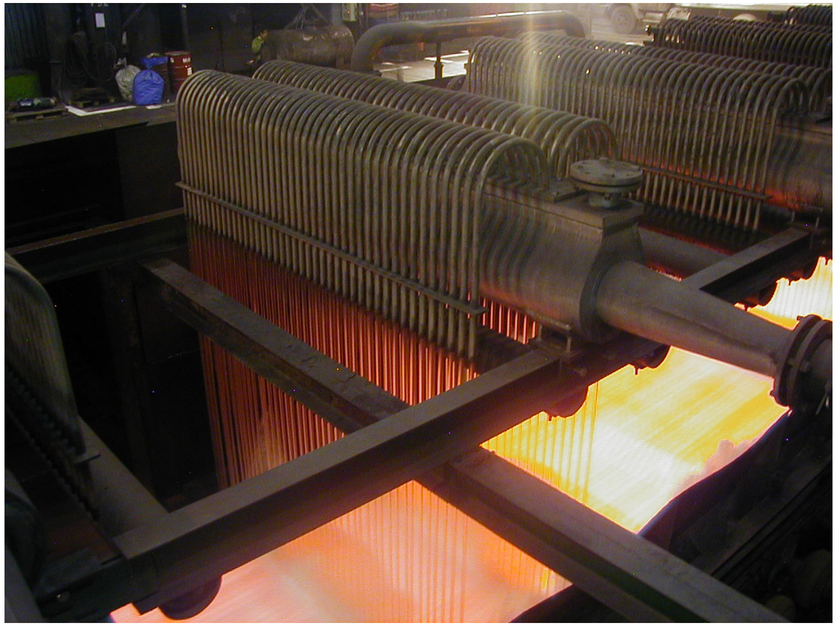
1.1.1. Global (integral) quantities

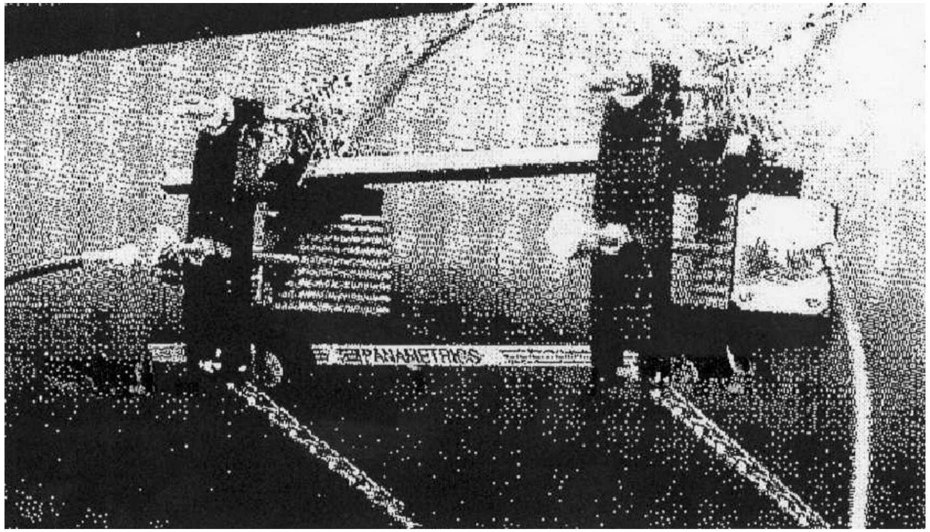
General judgment of operation of fluid machinery and the connected fluid mechanical system, fault diagnostics (occasional studies)



Mass flow rate:

$$q_m = \int_{A_{duct}} \rho \underline{v}\, \underline{dA} \approx \rho \sum_{i=1}^{n} v_{\perp i} \Delta A_i$$





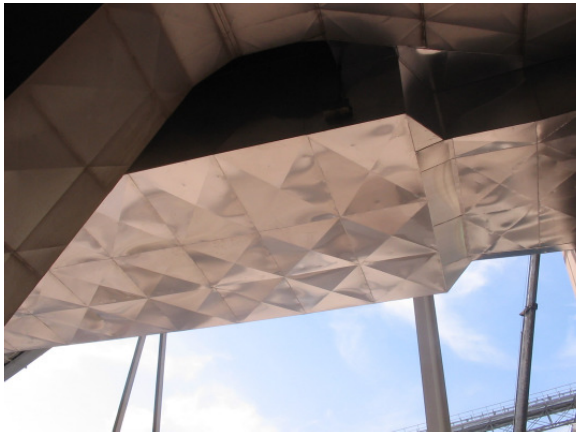
Providing measurement data for process control and automation

Volume flow rate:

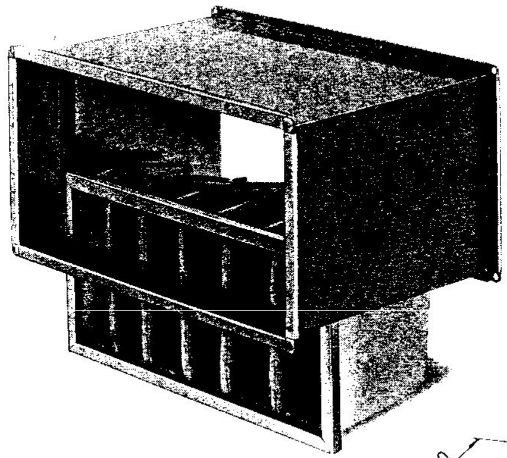
$$q_V = \int_{A_{duct}} \underline{v}\, \underline{dA}$$

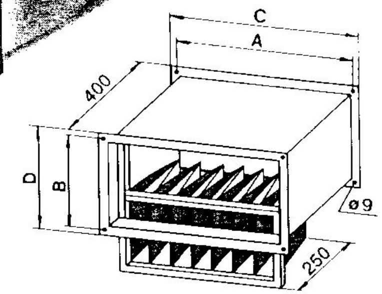
1.1.2. Local quantities, flow structure data

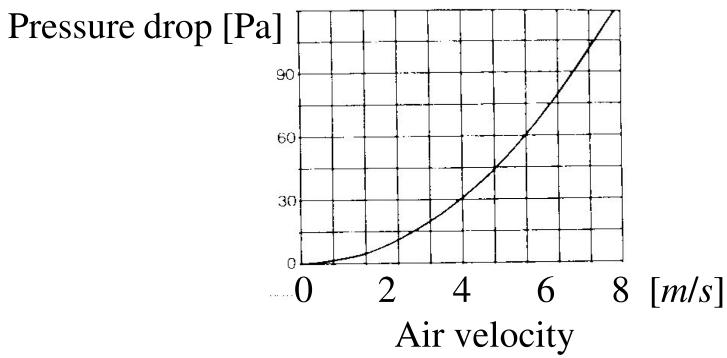
Fault diagnostics, check of operational state



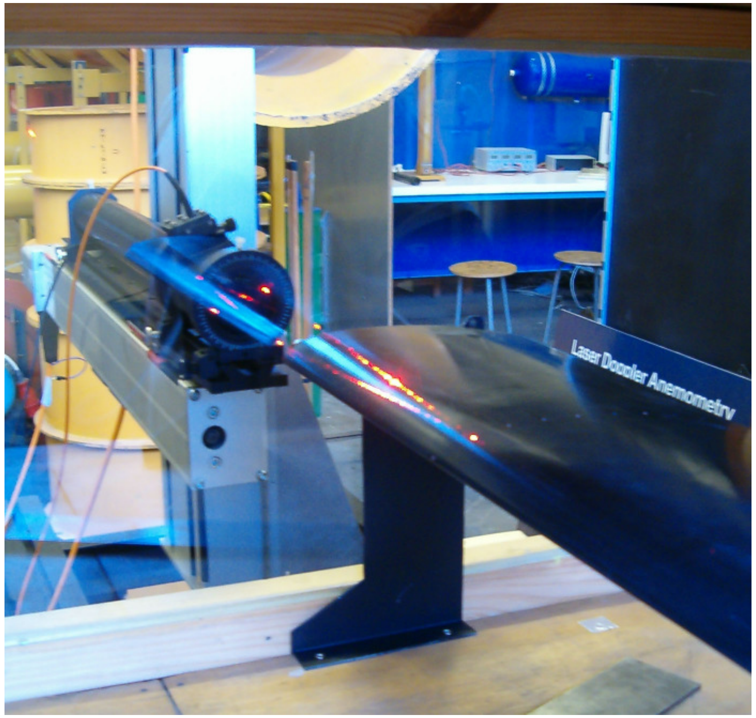
Providing measurement data for industrial process control

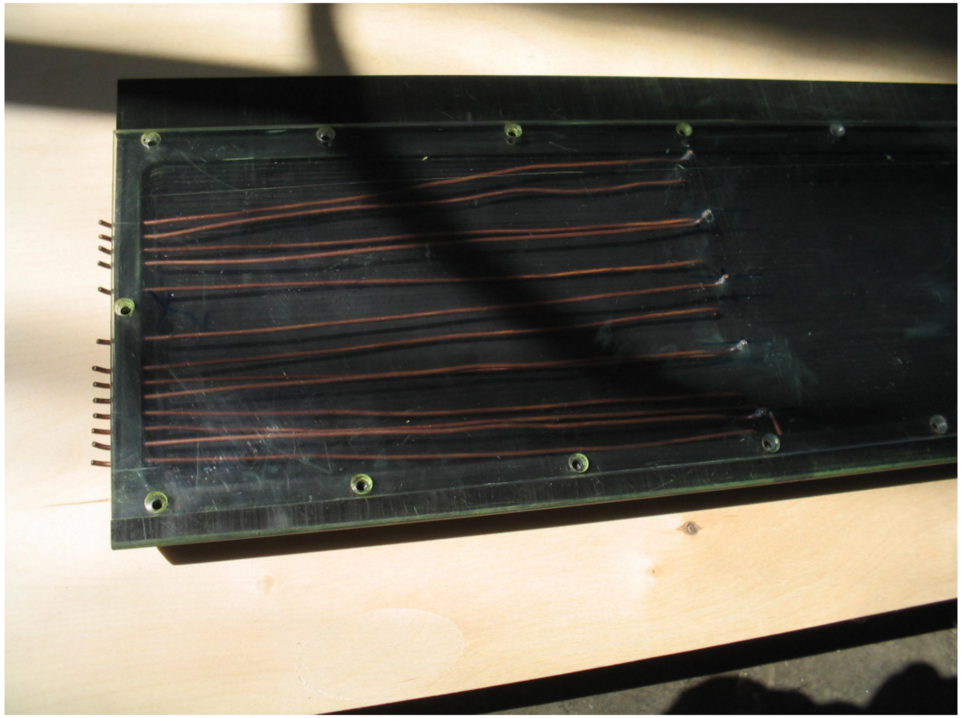




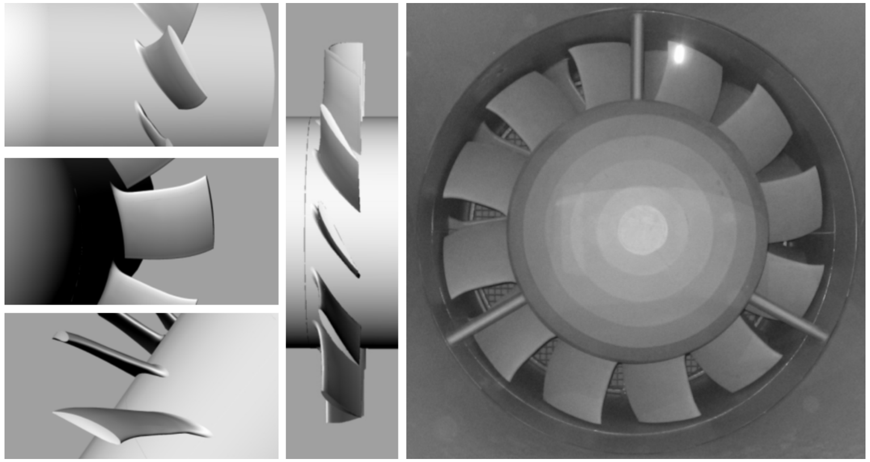


Measurement-based research and development (R&D)

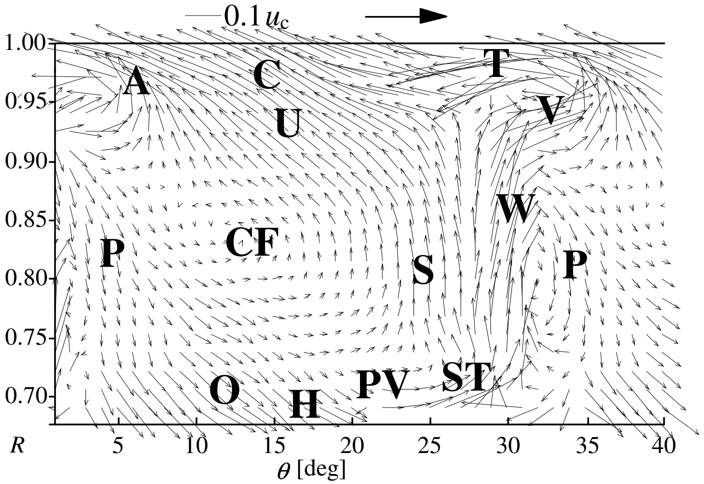




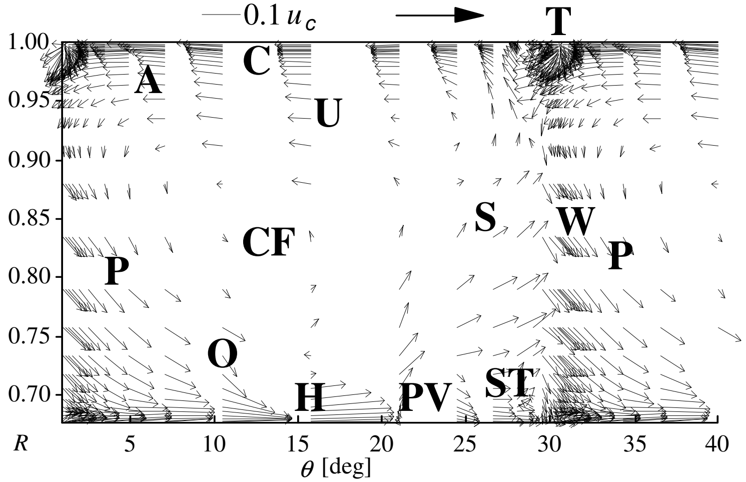
Experimental validation of Computational Fluid Dynamics (CFD) tools



LDA:



CFD:



1.2. Measured quantities under discussion

Related to industrial applications and R&D:

Global quantities:

- Volume flow rate
- Mass flow rate

Local quantities:

Scalar quantities:

- Pressure (temporal mean and fluctuating)
- Temperature
- Concentration of another phase

Vectorial quantities:

- Velocity (temporal mean and fluctuating)

1.3. “Advanced flow measurements”: aspects of being “advanced”

Demand	**Examples for instrumentation**
“Small” measurement uncertainty	Laser Doppler Anemometry (LDA): velocity measurement with 0.1 % relative uncertainty
“Wide” measurement range	LDA equipped with high-speed data acquisition card, capable for measurement of sign of velocity: velocity from 0 m/s up to supersonic flow
“High” spatial resolution	LDA: the size of the measurement volume is in the order of magnitude of 0.1 mm (⇔ Pitot-static probe)
“High” temporal resolution for investigation of time-dependent processes (e.g. turbulence)	Hot wire anemometry (Constant temperature anemometry: CTA) (⇔ Pitot-static probe)

"High" directional resolution for measurement of vector quantities	LDA: the interference fringe system defines the direction of velocity component being measured (⇔ Pitot-static probe)
"Low" directional resolution for measurement of scalar quantities	Pitot-static (Prandtl) probe for dynamic pressure measurements: directionally insensitive in the range of ±15° (this is a disadvantage if the velocity is to be determined for deduction of volume flow rate)
Multi-dimensionality	1D, 2D, 3D LDA and CTA, stereo PIV
Limited need for calibration (stable internal parameters)	LDA: NO need for calibration, "black box": NOT ALLOWED to adjust (⇔ CTA)
Easy-to-use, "plug and play"	Propeller anemometer (⇔ LDA)

Reliable operation in a wide application area: under heavy circumstances (dusty, hot, humid, aggressive industrial environment)	S-probe (⇔ LDA)
Application areas not servable with other methods; remote measurements	Laser vibrometer (⇔ pieso-electric accelerometer)
“Limited” disturbance of the flow to be measured: “non-contact” / “non-intrusive” / “non-invasive” techniques	Ultrasound flowmeter (⇔ Solid-state probes)
Limited necessity to manipulate the equipment to be measured	Laser vibrometer, ultrasound flowmeter (⇔ throughflow orifice meter)

Electronic output signal for advanced representation of data and for process control	Electronic pressure transducer (⇔ U-type liquid manometer)
Computer-supported, automated measurement (calibration, traversing, data acquisition, data processing, data storage, data representation…)	Particle Image Velocimetry (PIV) (⇔ Pitot-static probe)
"Low" expenses	Pitot-static probe (⇔ LDA)

1.4. Special notes on advanced flow measurements

A/ Measurement methods: selection according to the demands

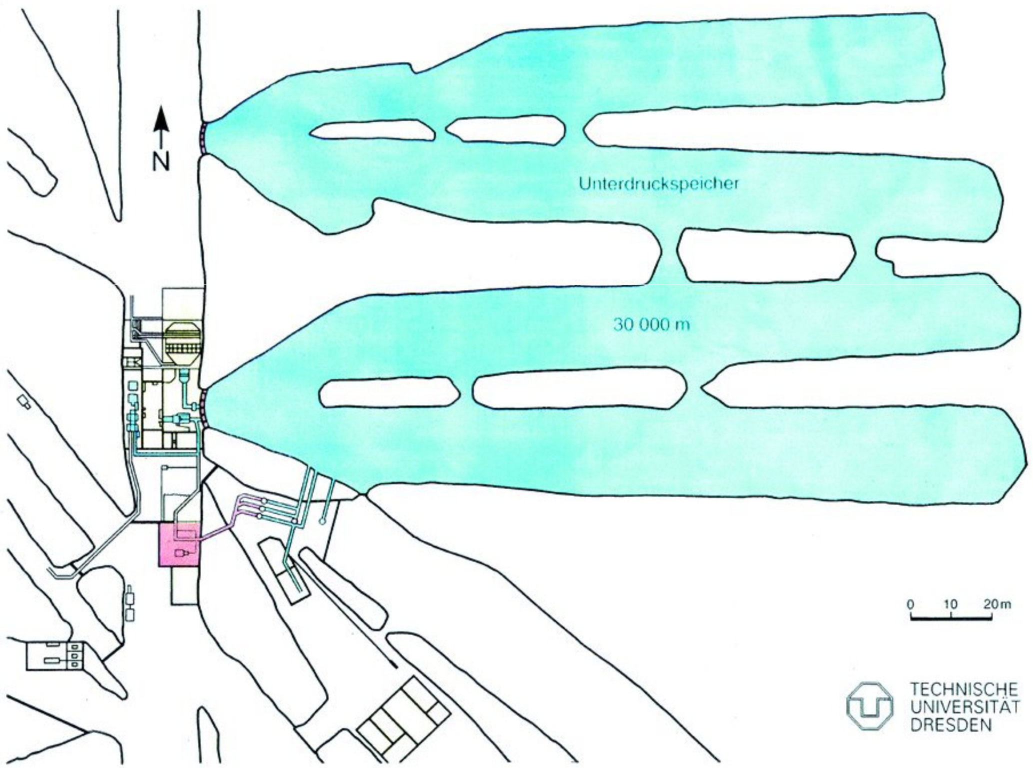
Velocity measurement:

Technique	Pitot-static probe	1-component CTA or LDA	2-component LDA
Aim	Magnitude of temporal mean velocity, point-like	1 temporal mean (and fluctuating) velocity component, point-like	2 velocity components, point-like
O. m. in expenses	0.5 kEUR	25 kEUR	100 kEUR

Technique	3-component LDA	2-component PIV	Stereo PIV
Aim	3 velocity components, point-like	2 velocity components, in a plane	3 velocity components, in a plane
O. m. in expenses	**200 kEUR**	**200 kEUR**	**400 kEUR**

B/ "Advanced" only IF: the entire experimental procedure and evaluation is also advanced

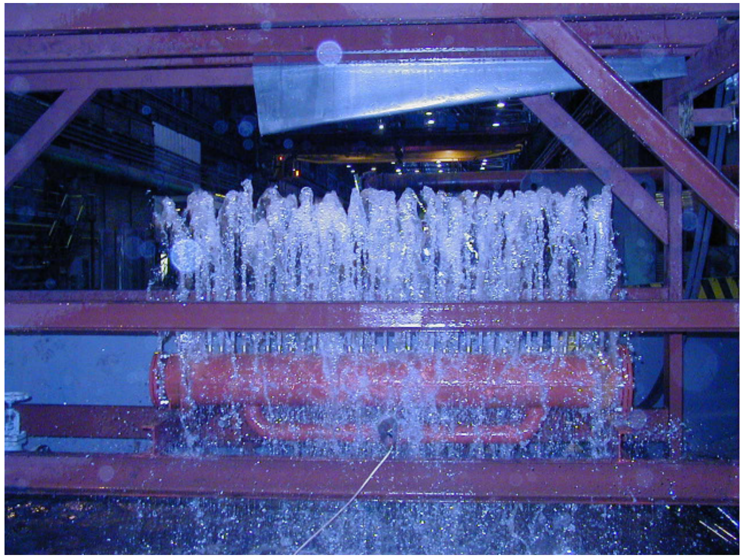
•Supersonic wind tunnel:

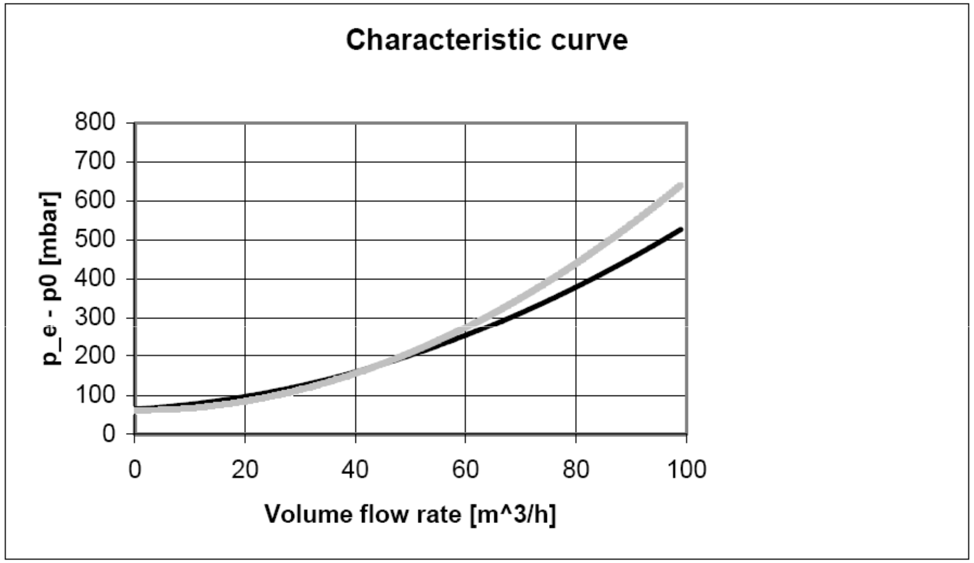


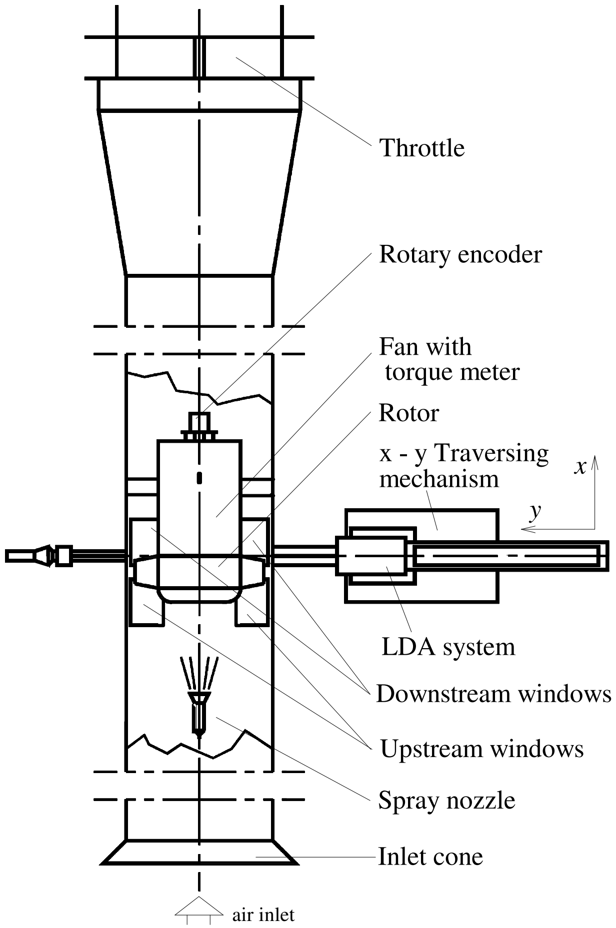
•IC test engine

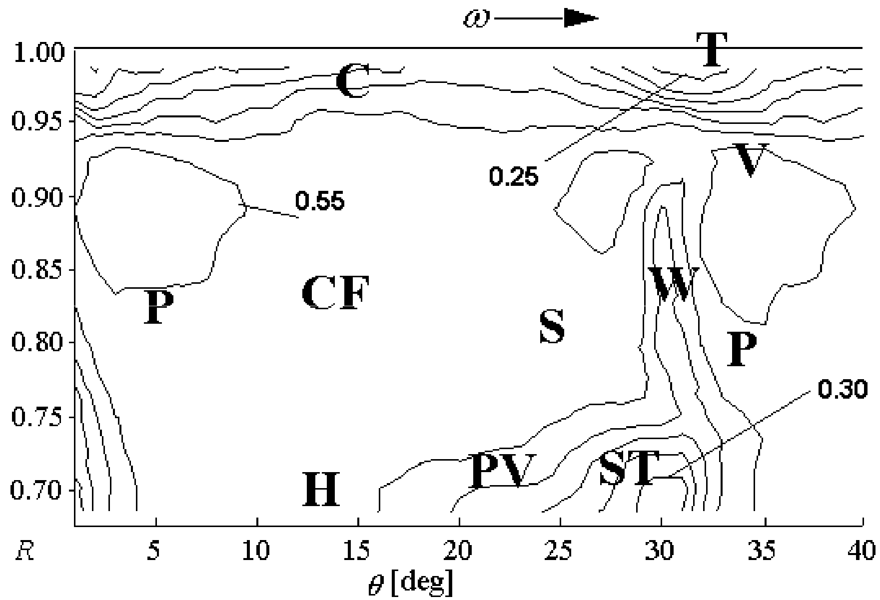
C/ Paradox: „we need to know the answer before we begin."

"Without theory the facts remain silent."






Throttle
Rotary encoder
Fan with
torque meter
Rotor
x - y Traversing
mechanism
x
y
LDA system
Downstream windows
Upstream windows
Spray nozzle
Inlet cone
air inlet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10
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40
θ [deg]
T
C
0.25
V
0.55
P
CF
W
S
P
0.30
H
PV
ST

D/ Full exploitation of the measurement technique