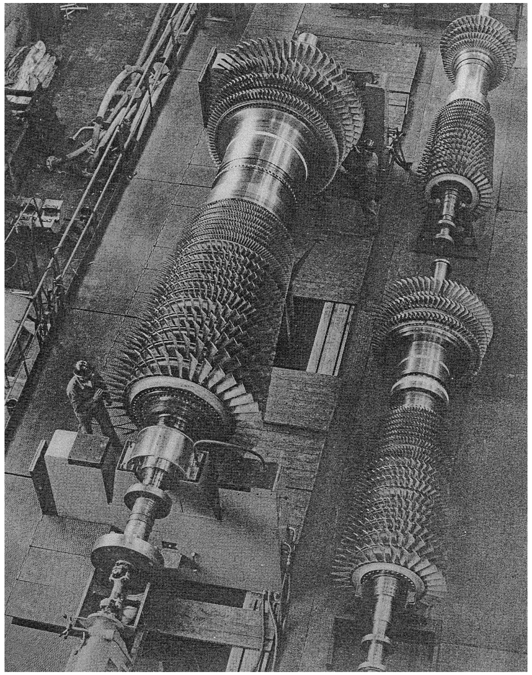
1. INTRODUCTION

1.1. Objectives of fluid mechanics measurements

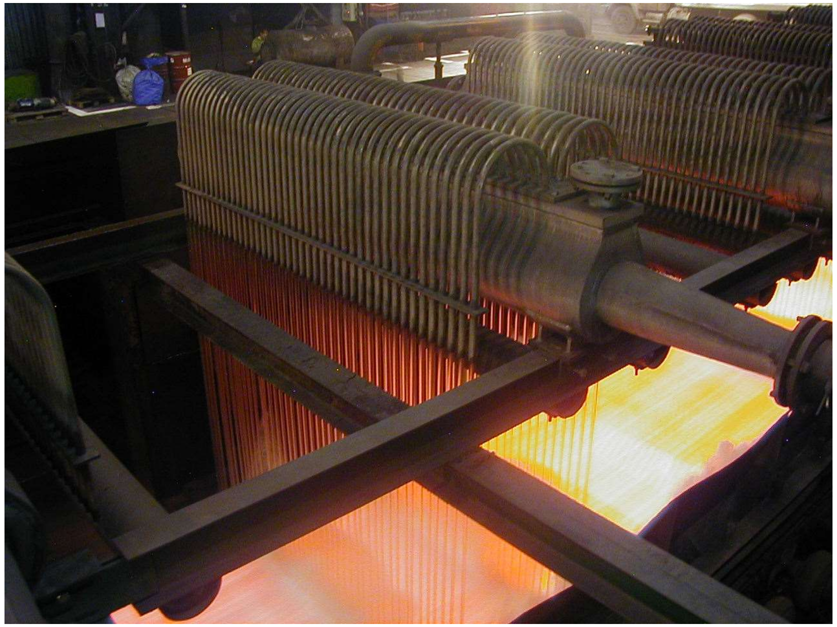
1.1.1. Global (integral) quantities

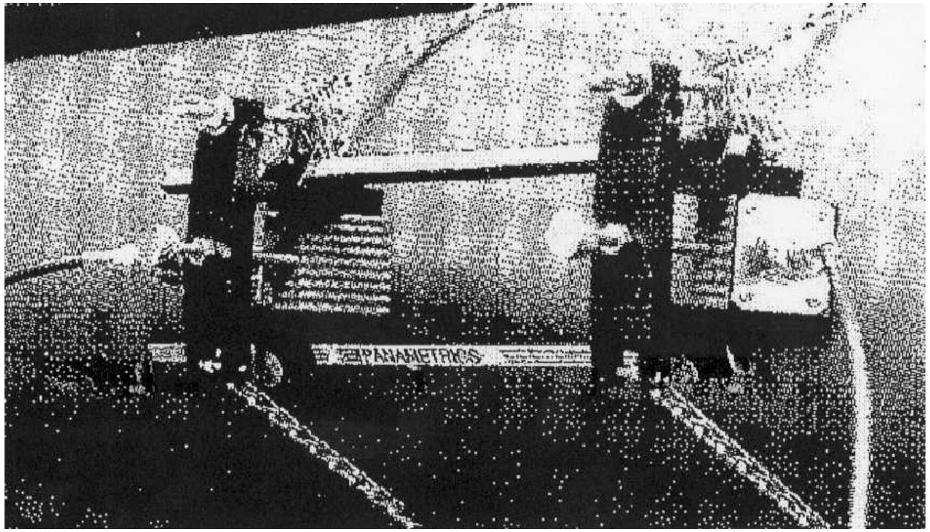
General judgment of operation of fluid machinery and the connected fluid mechanical system, fault diagnostics (occasional studies)



Mass flow rate:

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





Ultrasonic flowmeter

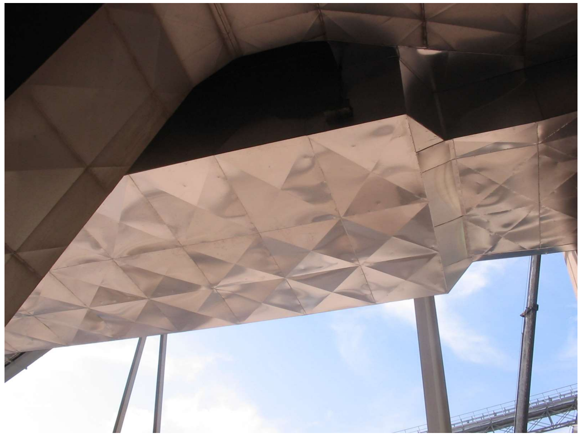
Providing measurement data for process control and automation

Volume flow rate:

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

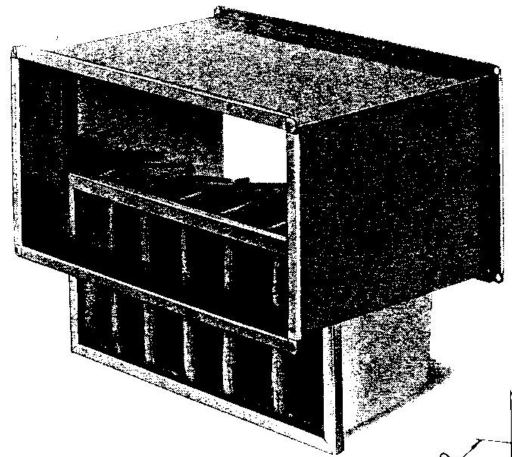
1.1.2. *Local quantities, data on details of flow*

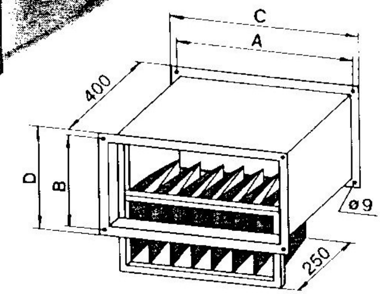
Fault diagnostics, check of operational state

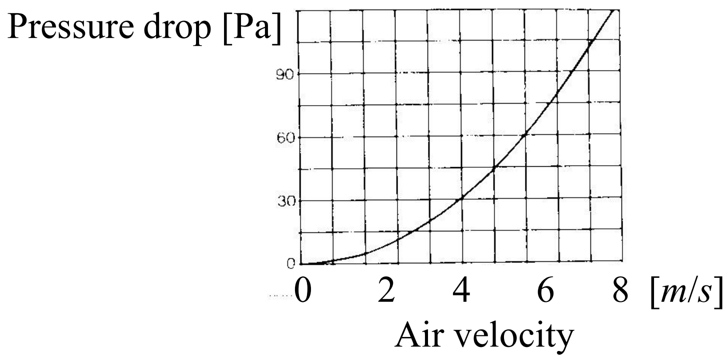





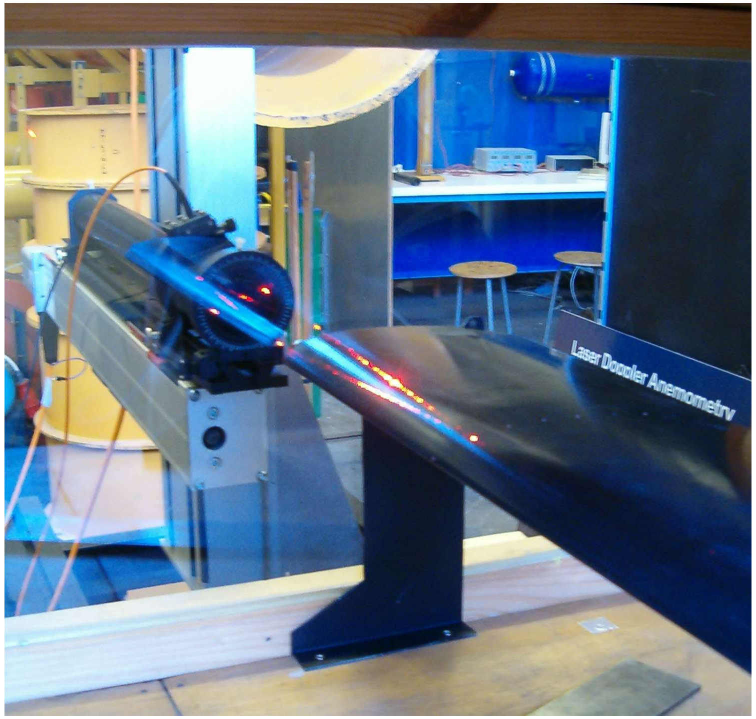
Providing measurement data for industrial process control

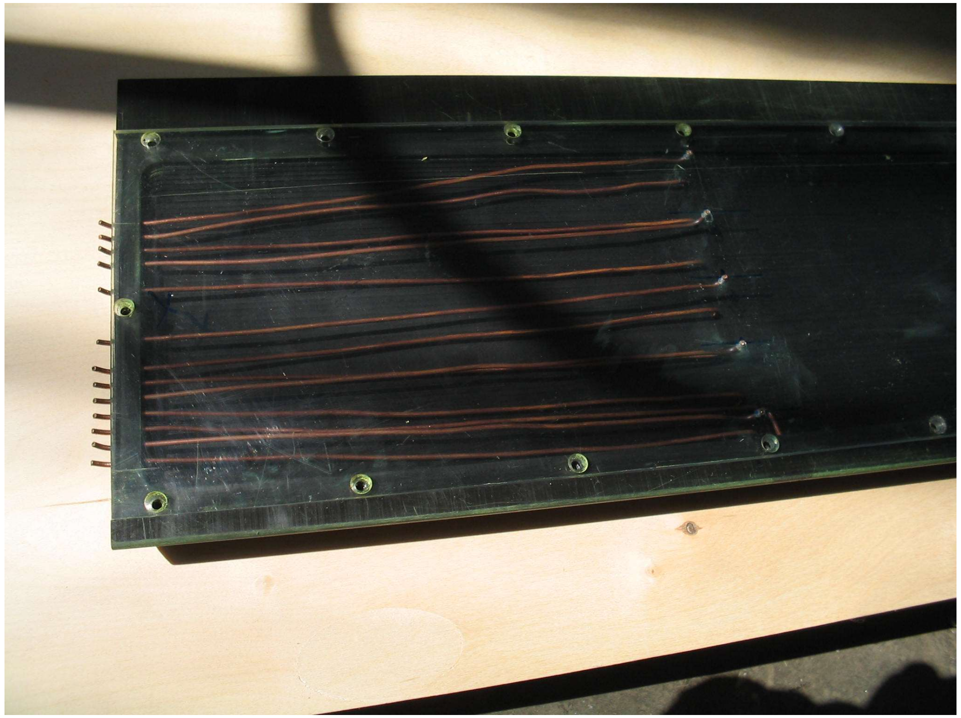




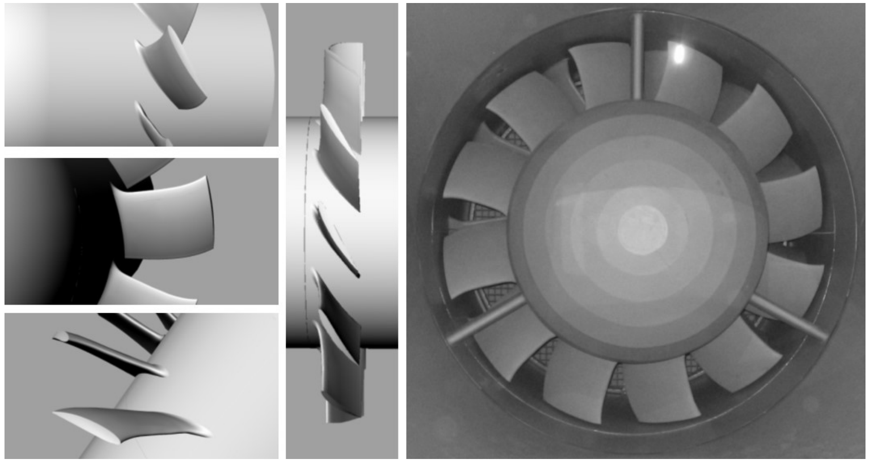


Measurement-based research and development (R&D)

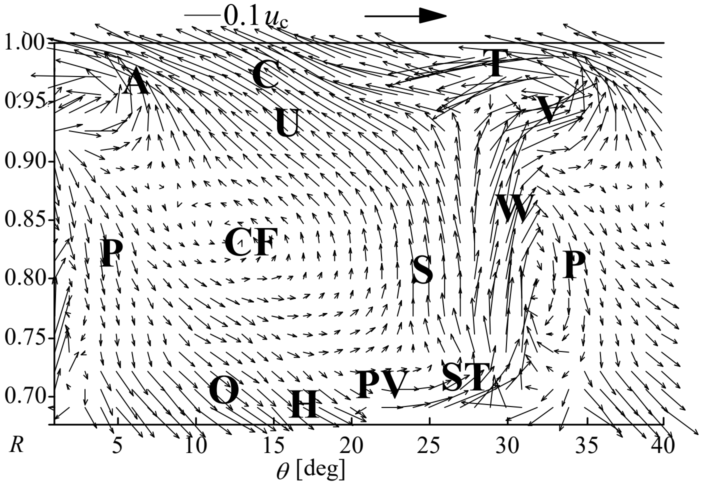




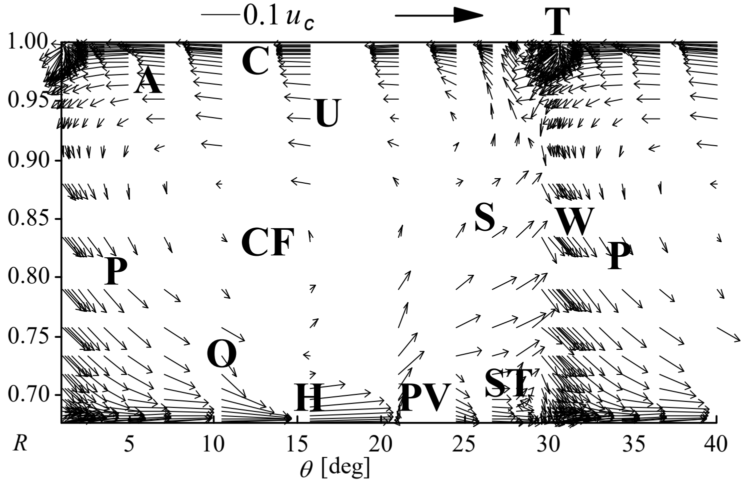
Experimental validation of Computational Fluid Dynamics (CFD) tools



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 fluid mechanics 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 vectorial 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 $\pm 15^\circ$ (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	Ultrasonic flowmeter (⇔ Solid-state probes)
Limited necessity to manipulate the equipment to be measured	Laser vibrometer, ultrasonic 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 fluid mechanics measurements

A/ Measurement methods: selection according to the demands

Velocity measurement:

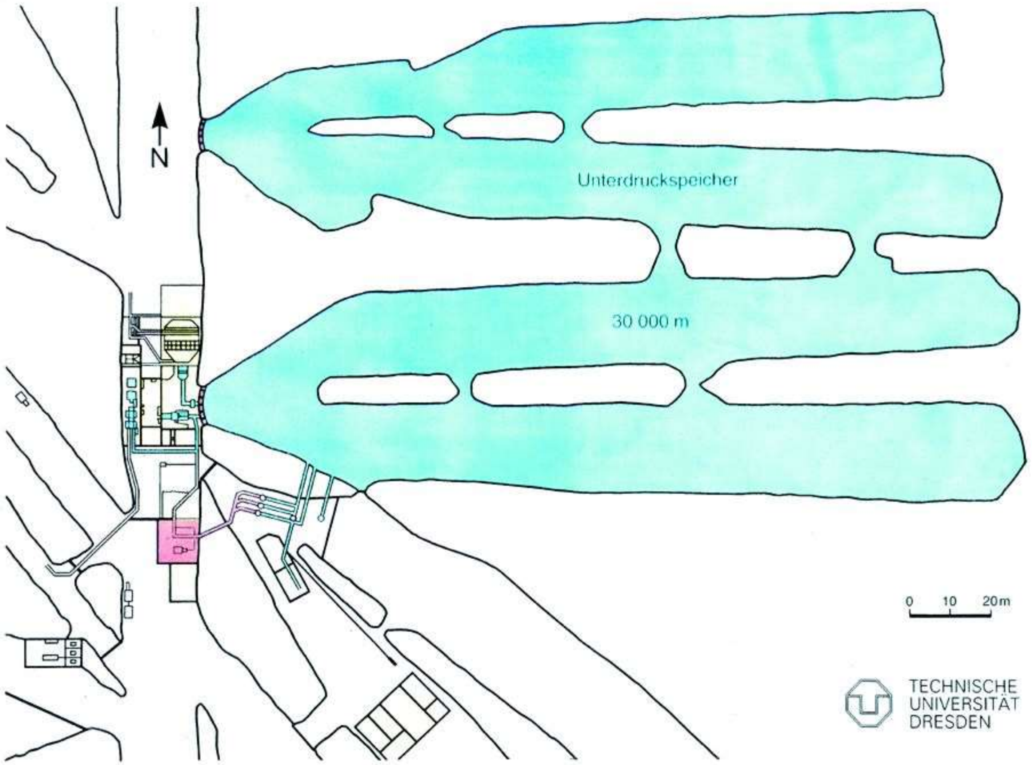
Technique	Pitot-static probe	1-component CTA or LDA	2-component LDA
Aim	Magnitude of temporal mean velocity, point-like	1 temporal mean (and fluctuating) velocity component, point-like	2 velocity components, point-like
O. m. in expenses	0.5 kEUR	25 kEUR	100 kEUR

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**

…3 velocity components in space… Laser holography…

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

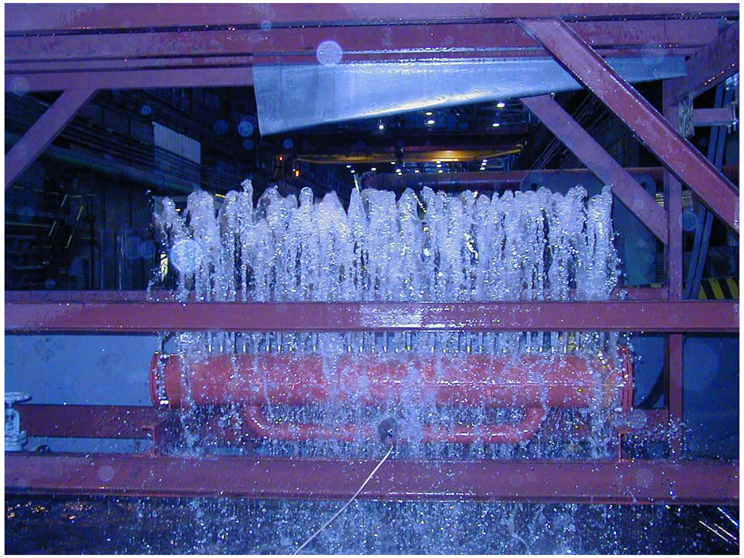
•Supersonic wind tunnel: long, expensive preparation → short meas.



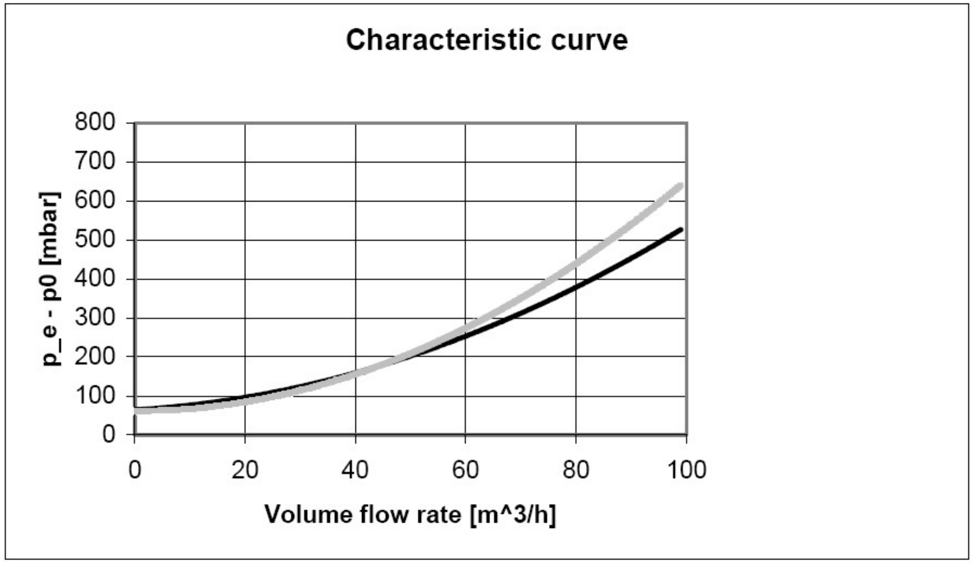
•IC test engine made of glass: expensive preparation → short meas.

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

“Without theory the facts remain silent.”

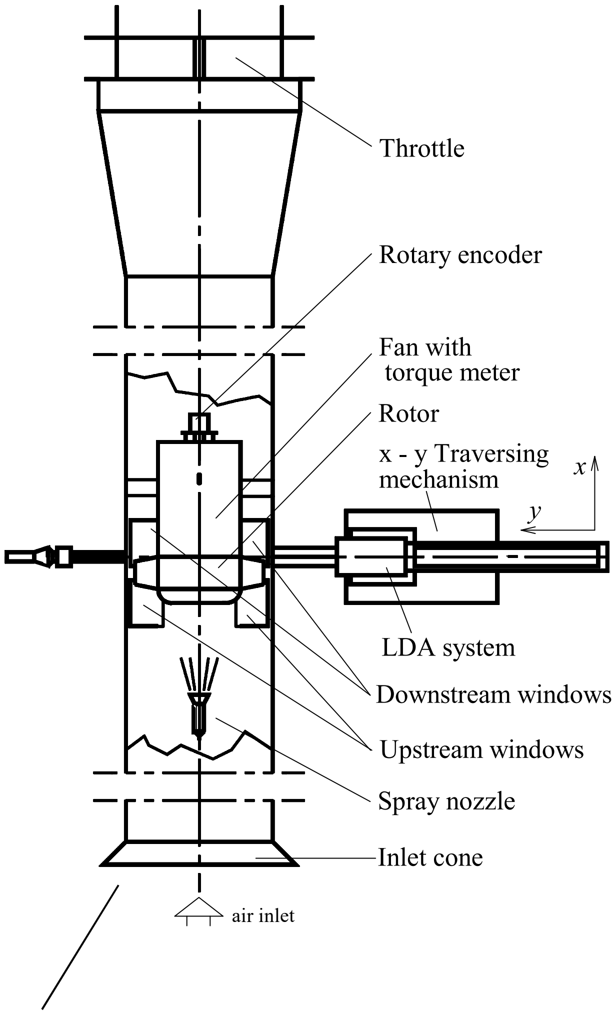


Cooling water distributor

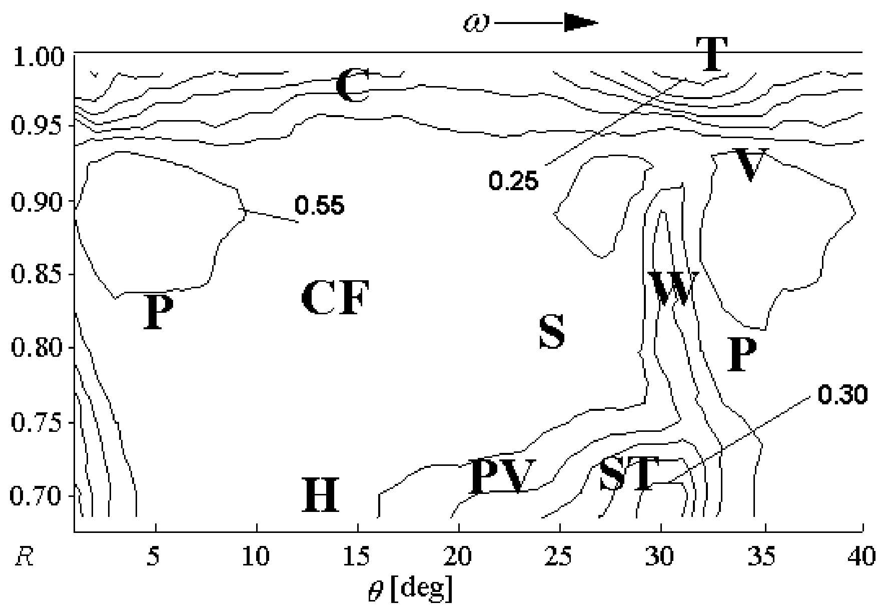


Grey: theoretical, black: measured

Laser Doppler Anemometry – how to check?



Volume flow rate meter



Axial velocity distribution downstream of one blade passage

D/ Full exploitation of the measurement technique