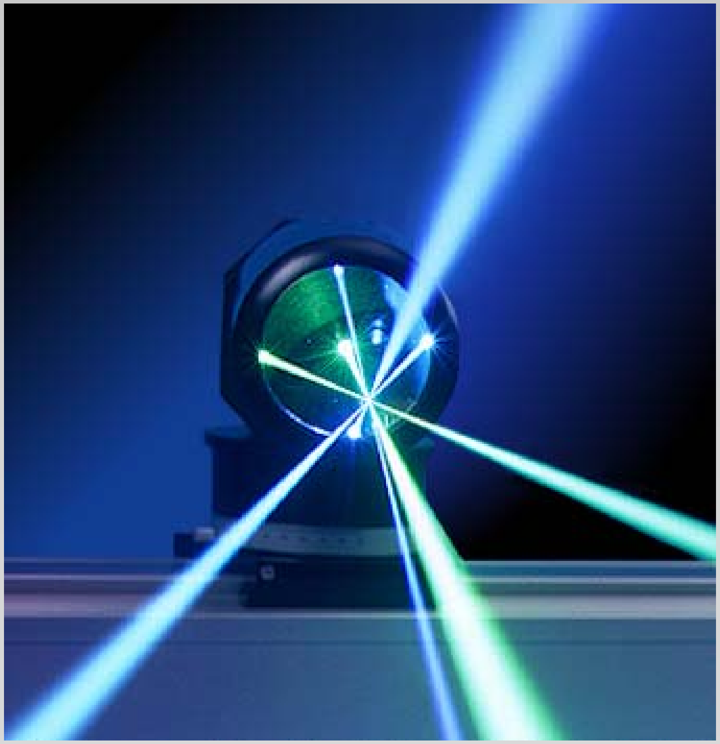
Laser Doppler Anemometry

Introduction to principles and applications



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Characteristics of LDA

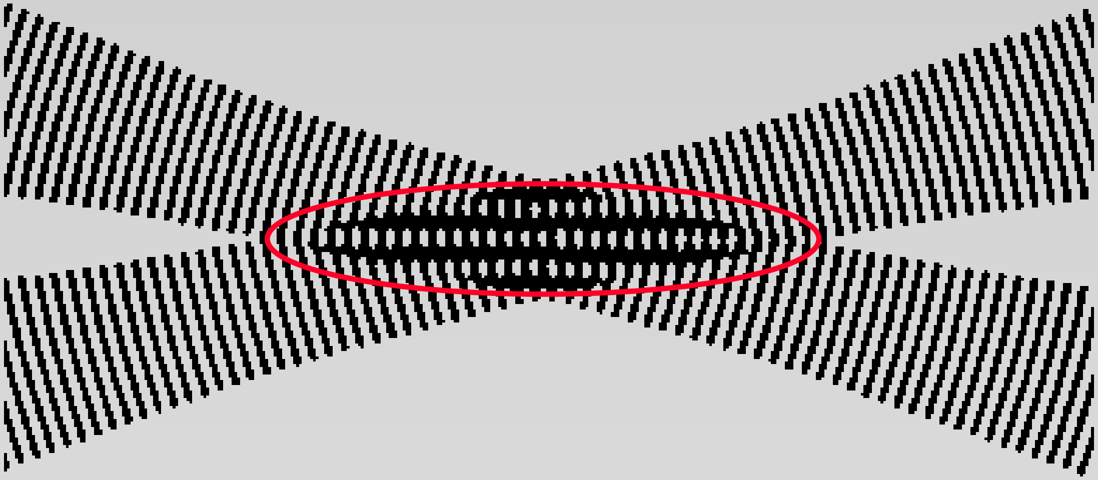
- Invented by Yeh and Cummins in 1964
- Velocity measurements in Fluid Dynamics (gas, liquid)
- Up to 3 velocity components
- Non-intrusive measurements (optical technique)
- Absolute measurement technique (no calibration required)
- Very high accuracy
- Very high spatial resolution due to small measurement volume
- Tracer particles are required

Applications of LDA

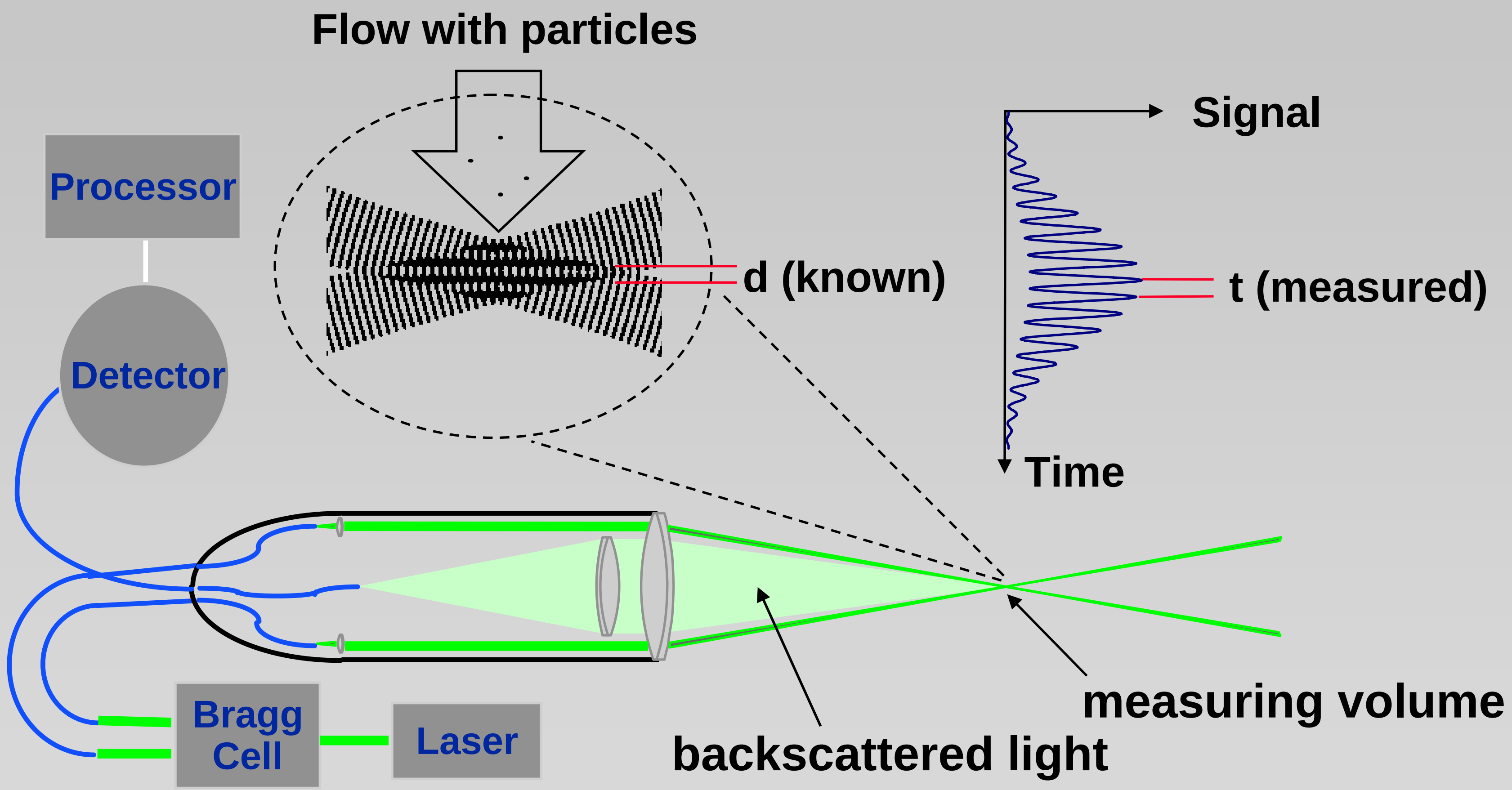
- Laminar and turbulent flows
- Investigations on aerodynamics
- Supersonic flows
- Turbines, automotive etc.
- Liquid flows
- Surface velocity and vibration measurement
- Hot environments (Flames, Plasma etc.)
- Velocity of particles
- ...... etc, etc, etc.

LDA - Fringe Model

- Focused Laser beams intersect and form the measurement volume
- Plane wave fronts: beam waist in the plane of intersection
- Interference in the plane of intersection
- Pattern of bright and dark stripes/planes



Velocity = distance/time



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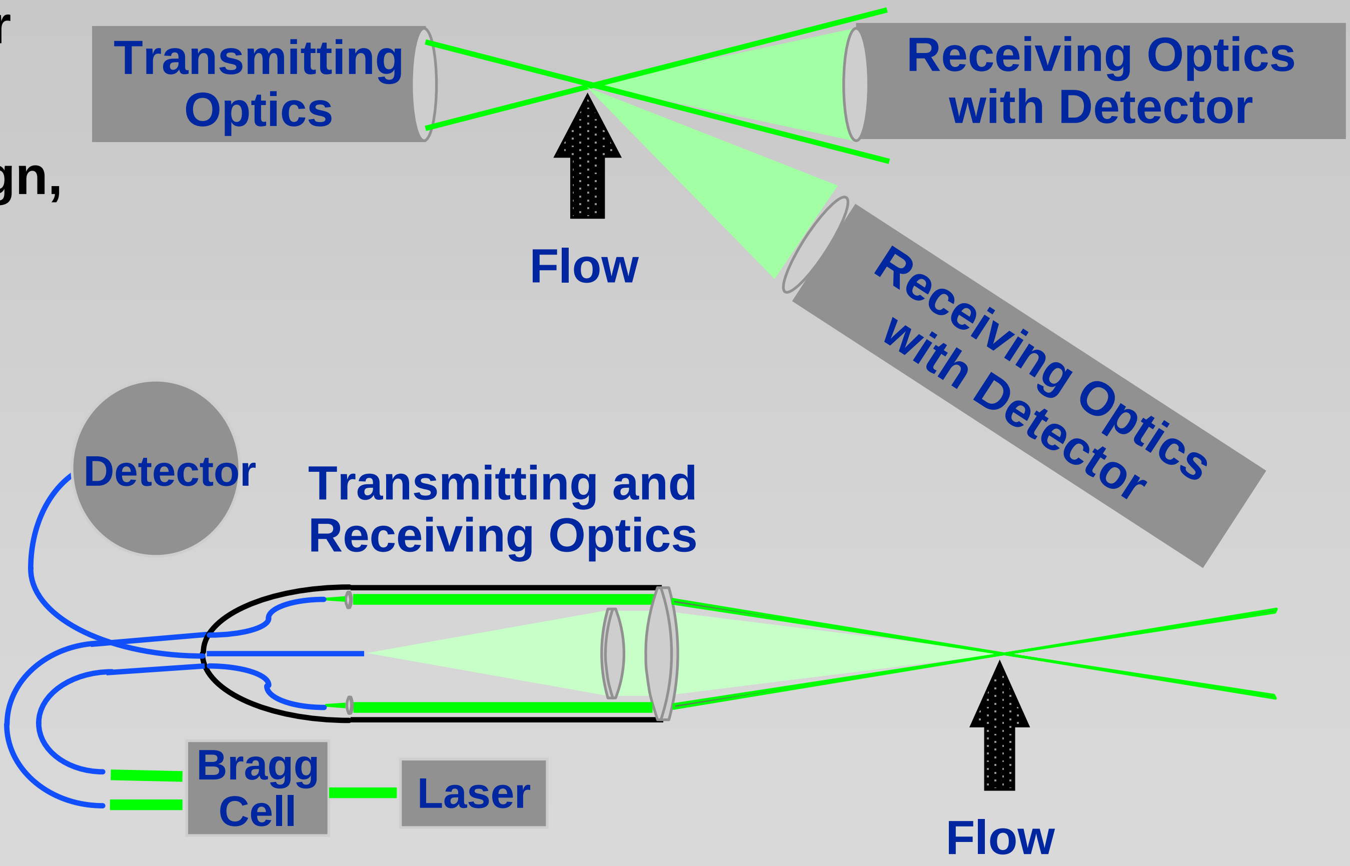
System Configurations

Forward scatter and side scatter (off-axis)

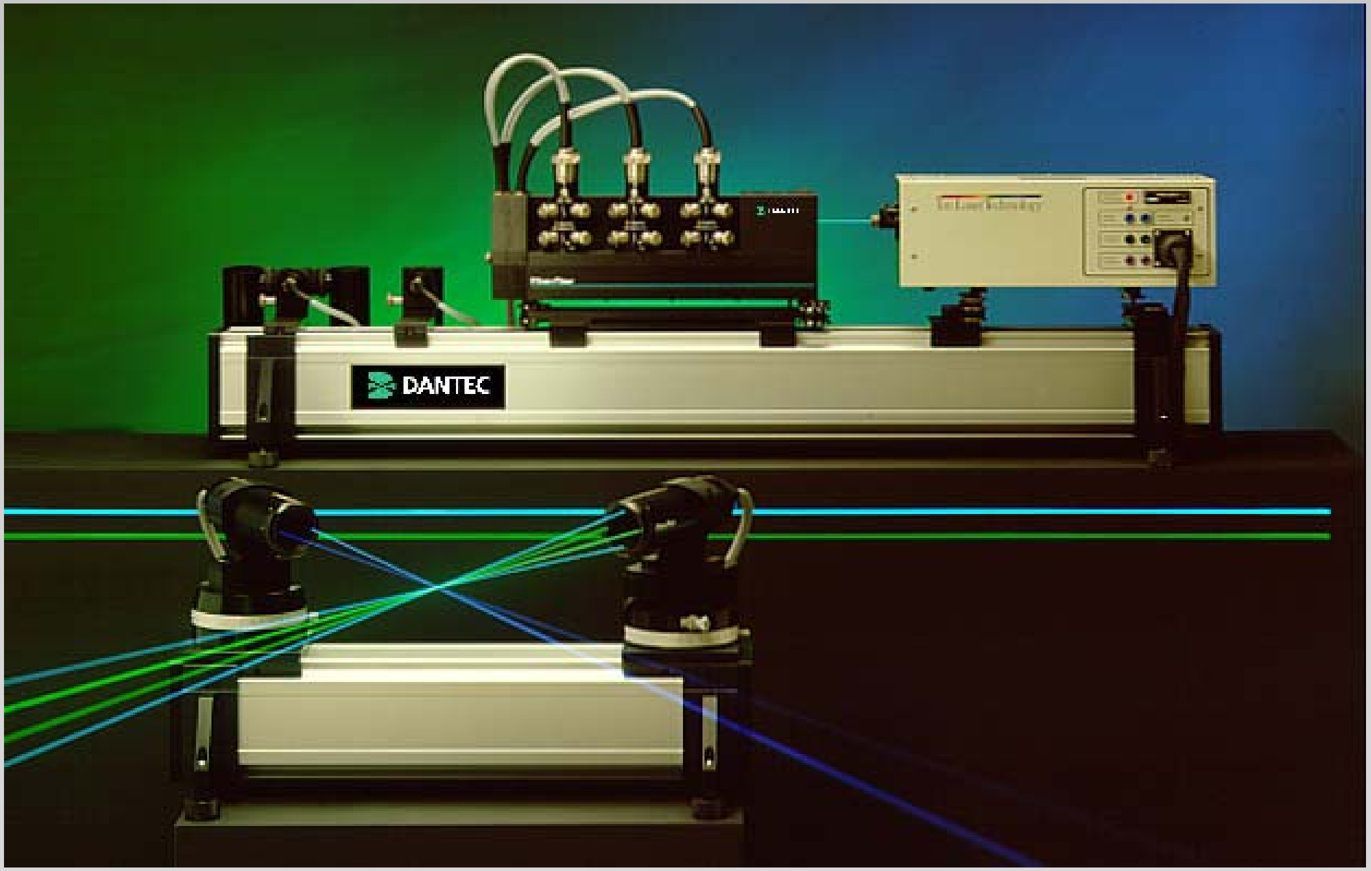
- Difficult to align,
- vibration sensitive

Backscatter

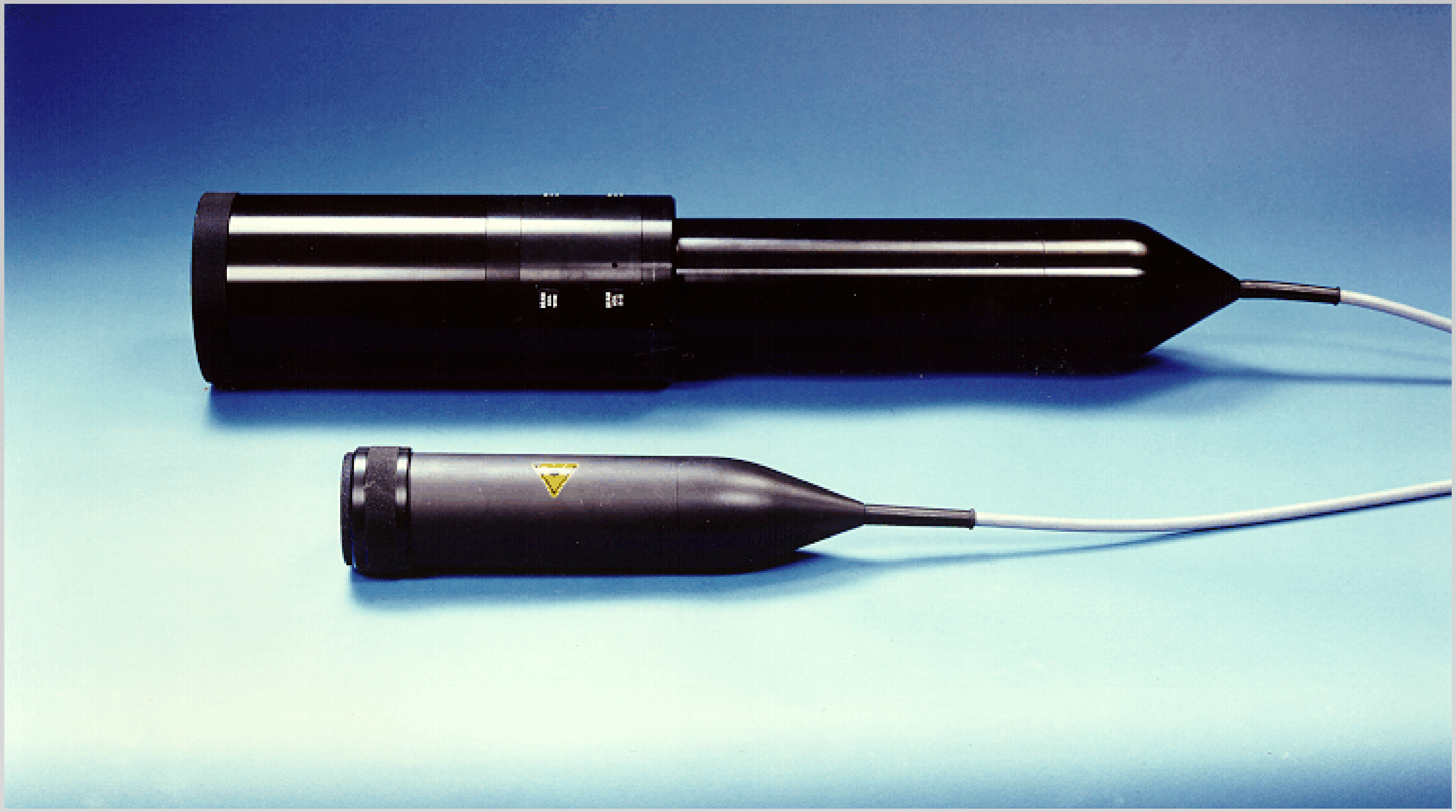
- Easy to align
- User friendly



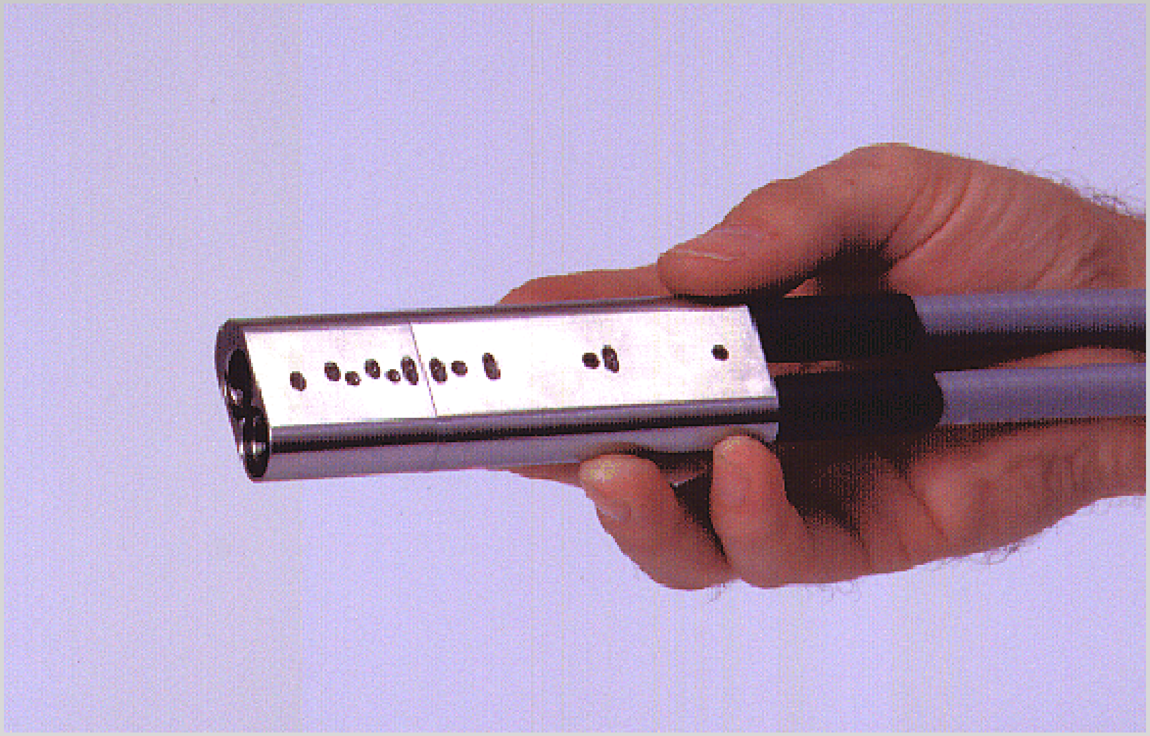
LDA Fibre Optical System



60 mm and 85 mm *FiberFlow* probes



The small integrated 3D *FiberFlow* probe



Measurement of air flow around a helicopter rotor model in a wind tunnel

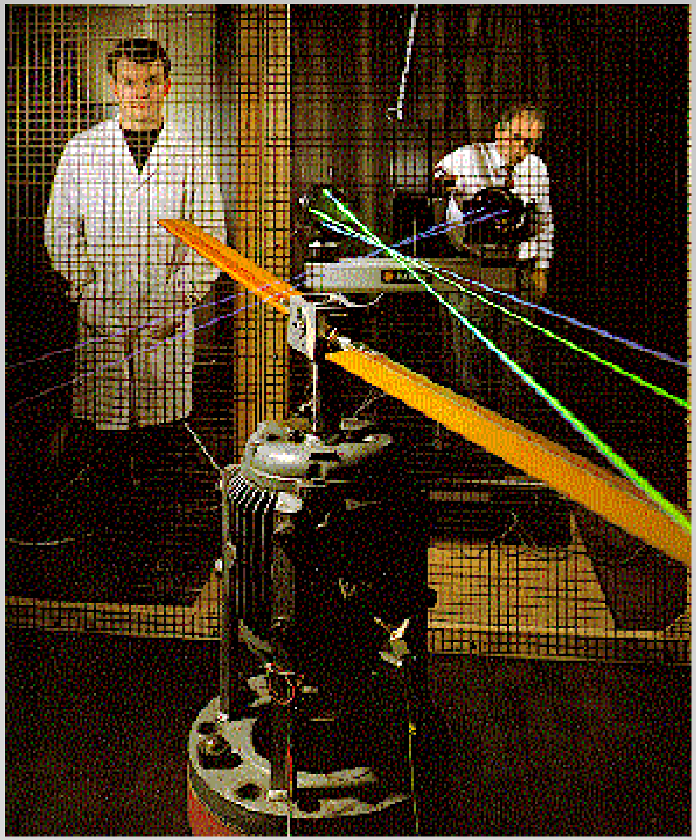


Photo courtesy of University of Bristol, UK

Measurement of water flow inside a pump model

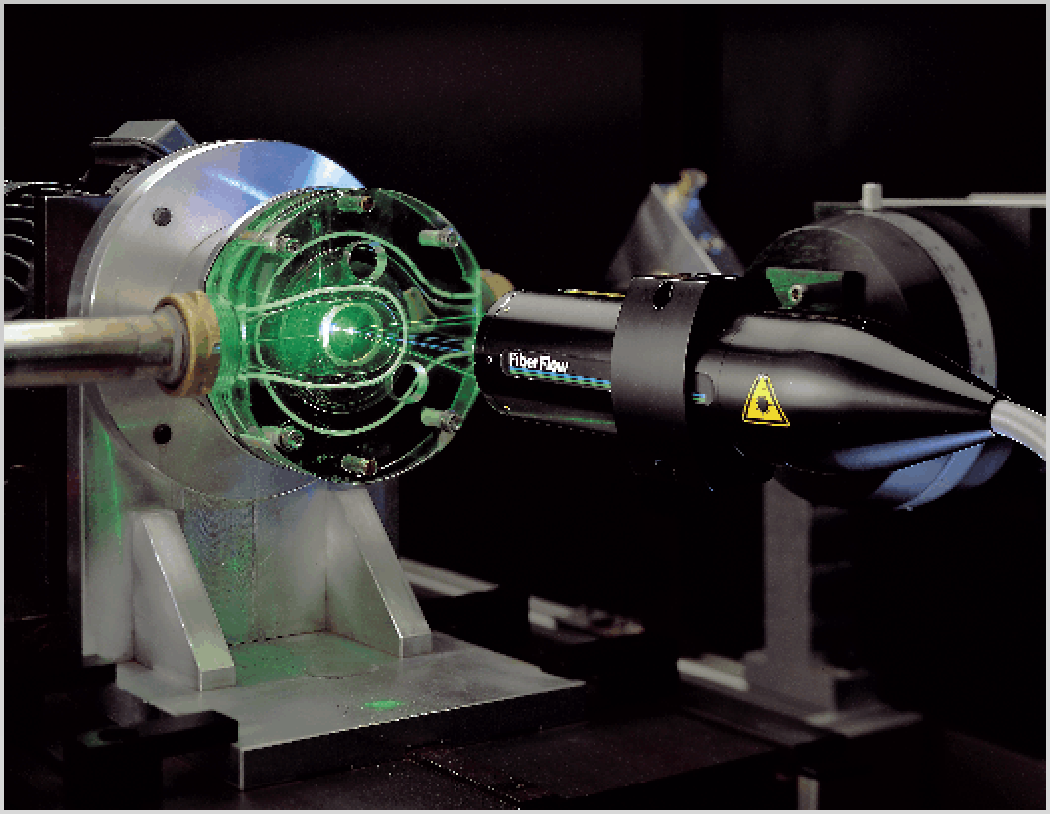
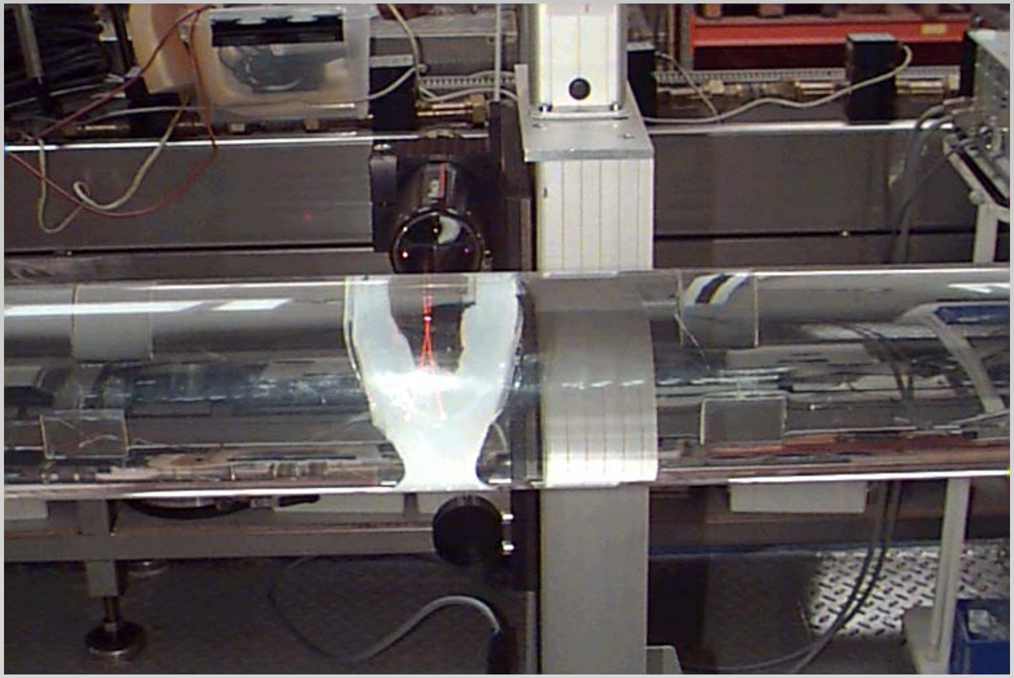
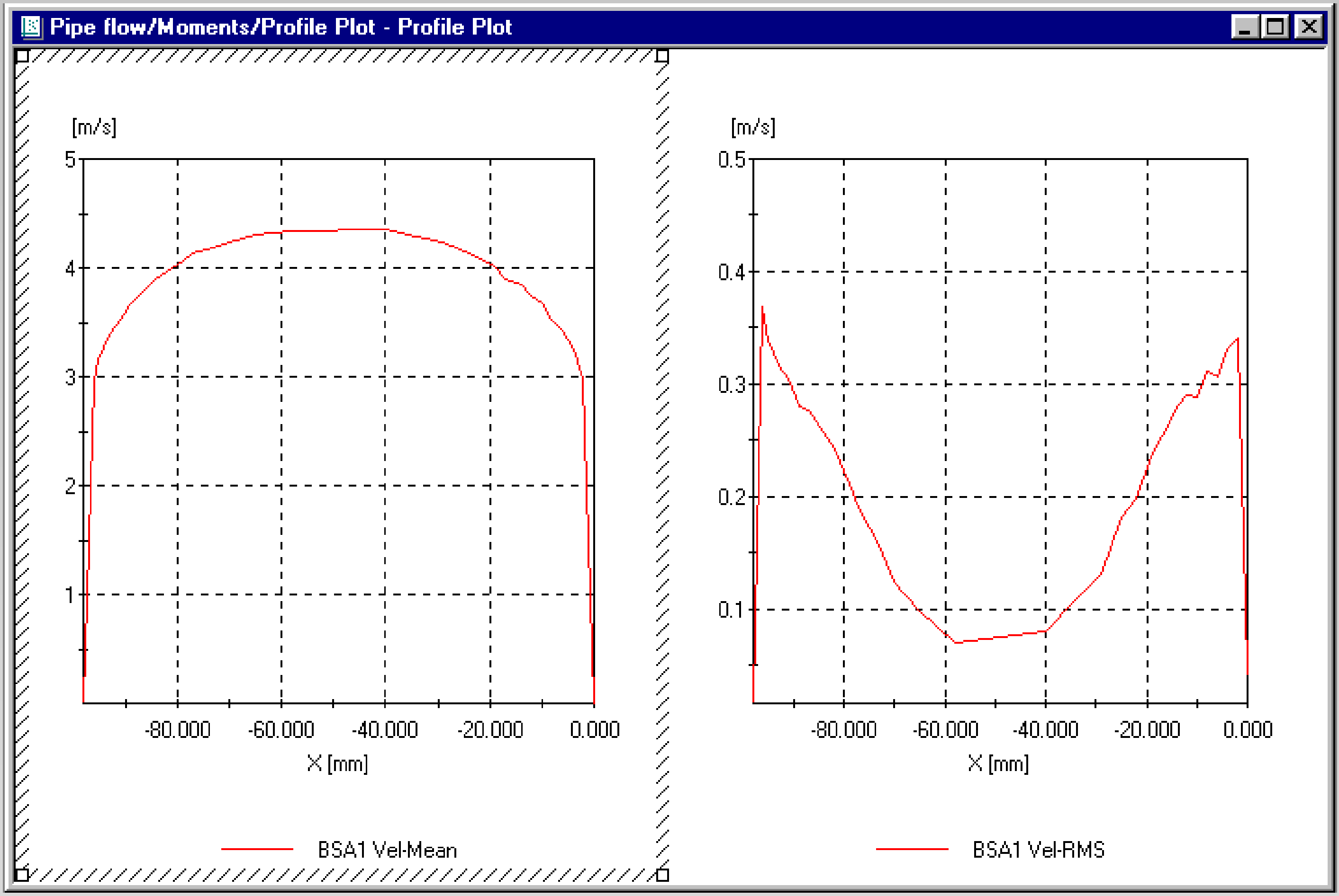


Photo courtesy of Grundfos A/S, DK

Measurement of velocity profiles in a water pipe



Velocity profile, fully developed turbulent pipe flow



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Measurement of flow field around a 1:5 scale car model in a wind tunnel

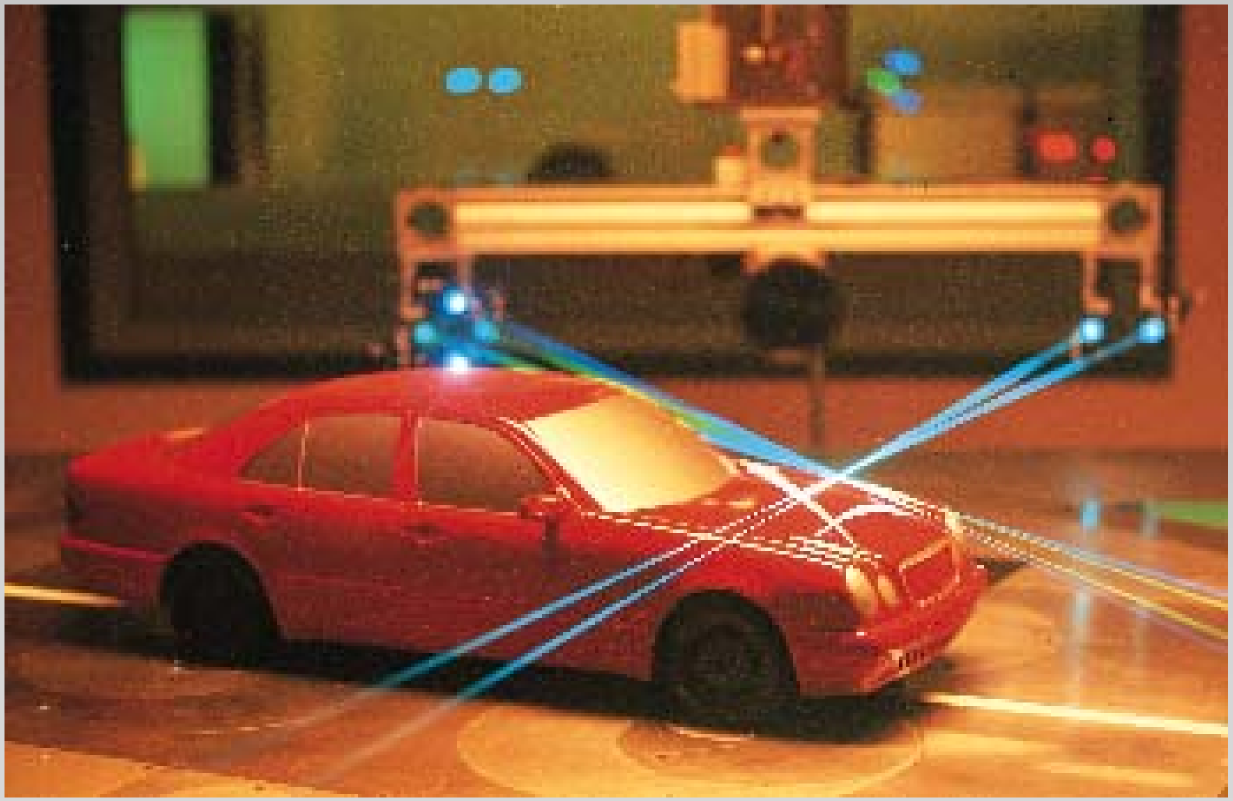

Photo courtesy of Mercedes-Benz, Germany

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Measurement of wake flow around a ship model in a towing tank

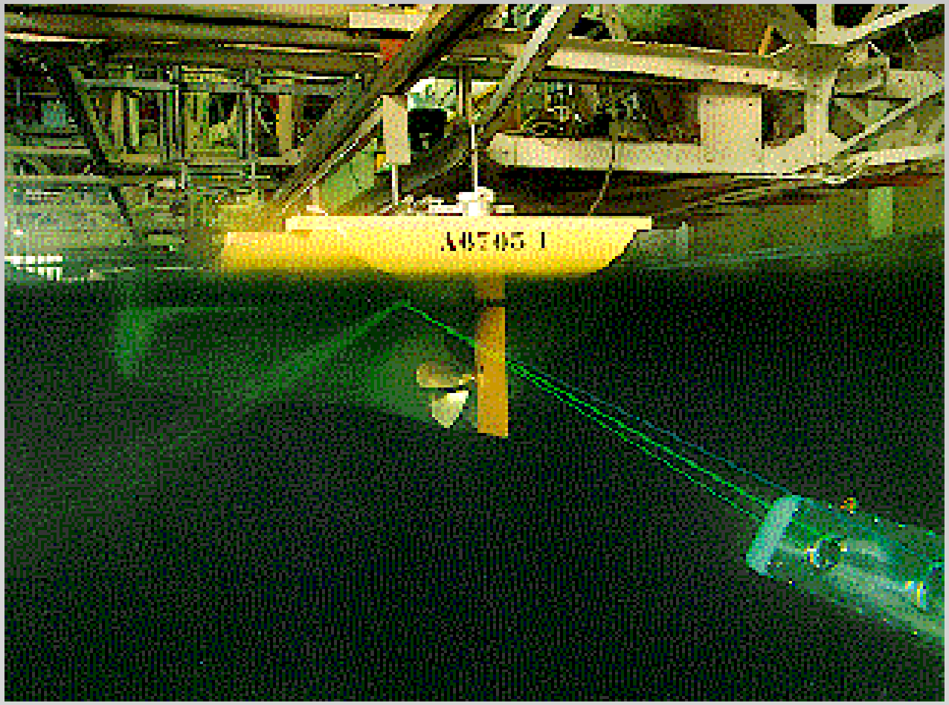

Photo courtesy of Marin, the Netherlands

Measurement of air flow field around a ship model in a wind tunnel

Photo courtesy of University of Bristol, UK

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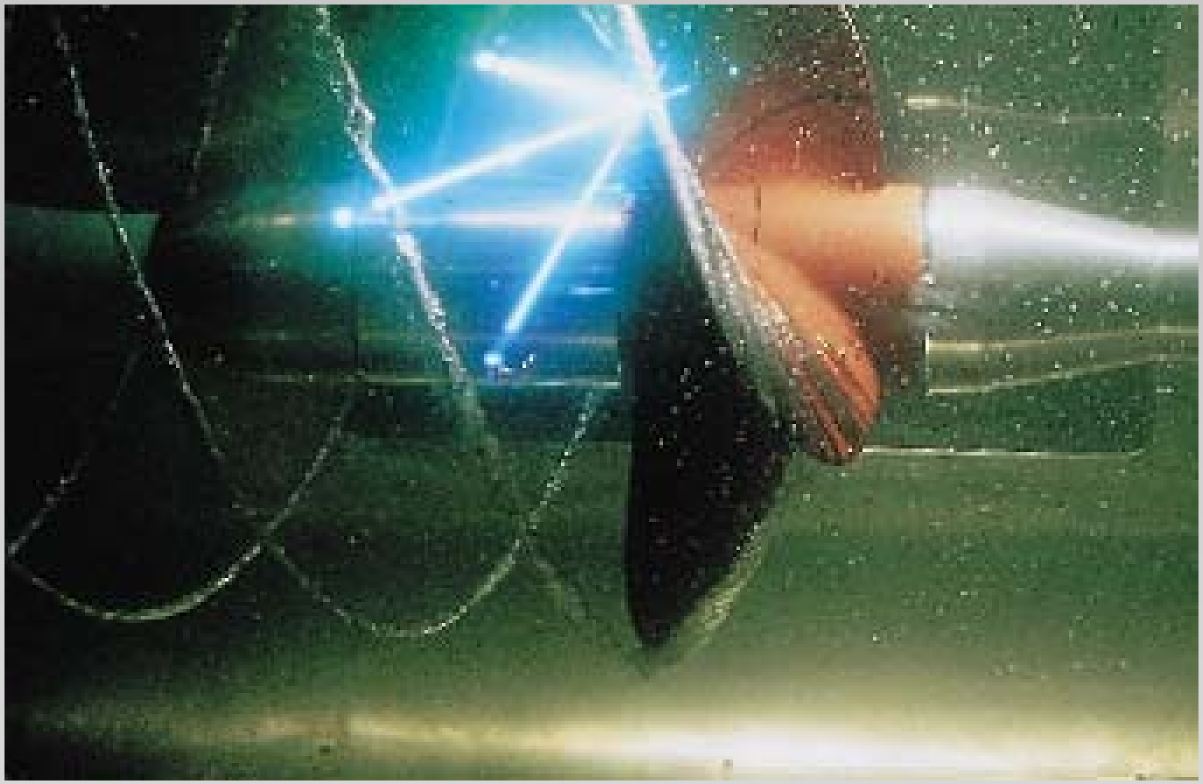
Measurement of flow around a ship propeller in a cavitation tank



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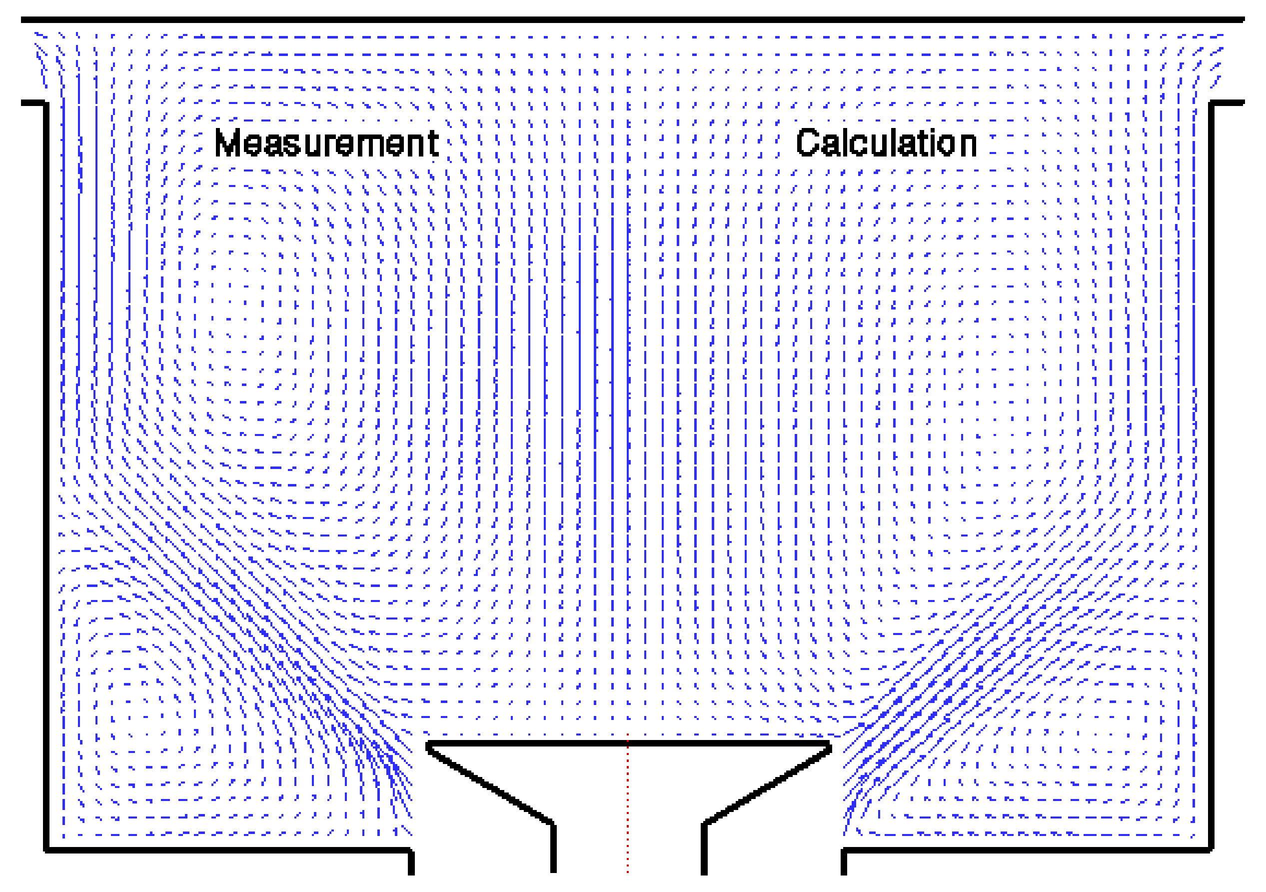
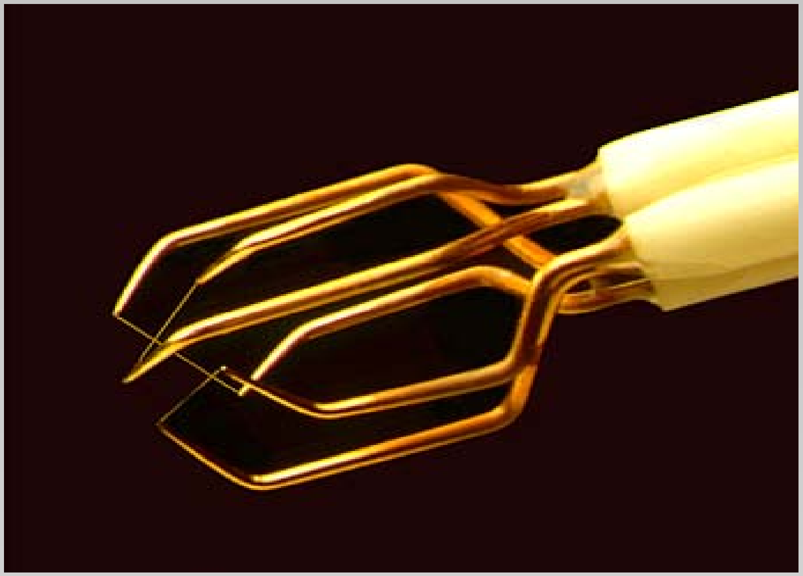
Comparison of EFD and CFD results



Hot-Wire Anemometry



- **Purpose:**

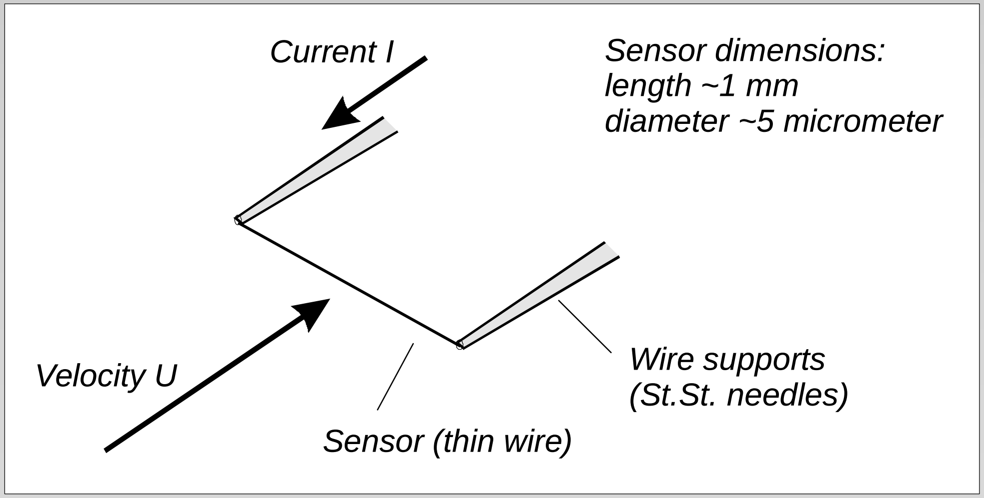
  to measure mean and fluctuating variables in fluid flows (velocity, temperature, etc.): mean velocity, turbulence characteristics – TURBULENCE STUDIES; IMPROVEMENT OF TURBULENCE MODELS

Principles of operation

- Consider a thin wire mounted to supports and exposed to a velocity *U*.

  When a current is passed through wire, heat is generated (I^2R_w). In equilibrium, this must be balanced by heat loss (primarily convective) to the surroundings.

- If velocity changes, convective heat transfer coefficient will change, wire temperature will change and eventually reach a new equilibrium.



Governing equation

- **Governing Equation:** $$\frac{dE}{dt} = W - H$$

E **= thermal energy stored in wire**

$E = C_w T_w$

Cw **= heat capacity of wire**

W **= power generated by Joule heating**

$W = I^2 R_w$

recall $R_w = R_w(T_w)$

H **= heat transferred to surroundings**

Simplified static analysis I

- For equilibrium conditions the heat storage is zero:

$$\frac{dE}{dt}=O \quad \therefore W=H$$

and the Joule heating W equals the convective heat transfer H

- Assumptions

- Radiation losses small
- Conduction to wire supports small
- *Tw* uniform over length of sensor
- Velocity impinges normally on wire, and is uniform over its entire length, and also small compared to sonic speed.
- Fluid temperature and density constant

Simplified static analysis II

Static heat transfer:

$$W = H \Rightarrow I^2Rw = hA(Tw - Ta) \Rightarrow I^2Rw = Nukf/dA(Tw - Ta)$$

h = film coefficient of heat transfer
A = heat transfer area
d = wire diameter
kf = heat conductivity of fluid
Nu = dimensionless heat transfer coefficient

Forced convection regime, i.e. $Re > Gr^{1/3}$ (0.02 in air) and $Re < 140 \Rightarrow$

$$Nu = A_1 + B_1 \cdot Re^n = A_2 + B_2 \cdot U^n$$

$$I^2Rw^2 = E^2 = (Tw - Ta)(A + B \cdot U^n)$$ "King's law"

The voltage drop is used as a measure of velocity ⇒ data acquisition, processing

A, B, n: BY CALIBRATION

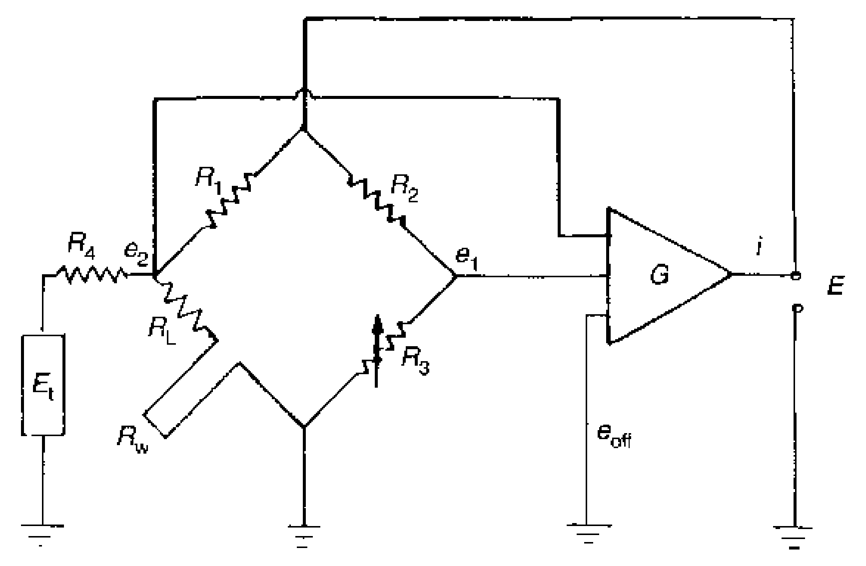
Constant Temperature Anemometer CTA

- **Principle:**

  Sensor resistance is kept constant by servo amplifier

- **Advantages:**
  - **Easy to use**
  - **High frequency response**
  - **Low noise**
  - **Accepted standard**

- **Disadvantages:**
  - **More complex circuit**



Probe types I

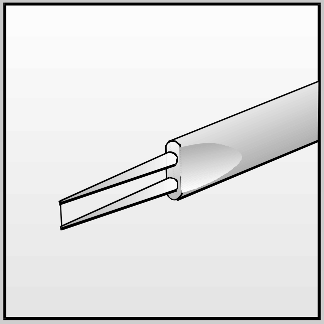
- **Miniature Wire Probes**

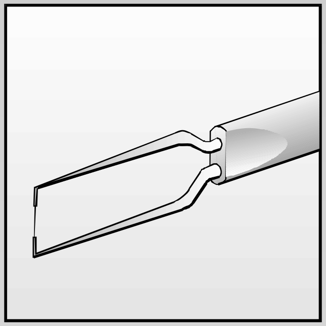
  Platinum-plated tungsten,
  5 µm diameter, 1.2 mm length

- **Gold-Plated Probes**

  3 mm total wire length,
  1.25 mm active sensor
  copper ends, gold-plated

__Advantages:
__- accurately defined sensing length
- reduced heat dissipation by the prongs
- more uniform temperature distribution along wire
- less probe interference to the flow field

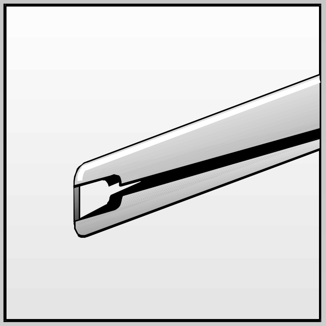




Probe types II

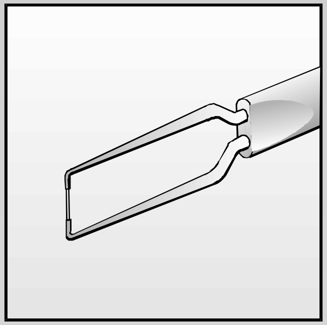
- **Film Probes**

  Thin metal film (nickel) deposited on quartz body. Thin quartz layer protects metal film against corrosion, wear, physical damage, electrical action



- **Fiber-Film Probes**

  “Hybrid” - film deposited on a thin wire-like quartz rod (fiber) “split fiber-film probes.”



Probe types III

- **X-probes for 2D flows**

  2 sensors perpendicular to each other. Measures within ±45^o.

- **Split-fiber probes for 2D flows**

  2 film sensors opposite each other on a quartz cylinder. Measures within ±90^o.

- **Tri-axial probes for 3D flows**

  3 sensors in an orthogonal system. Measures within 70^o cone.