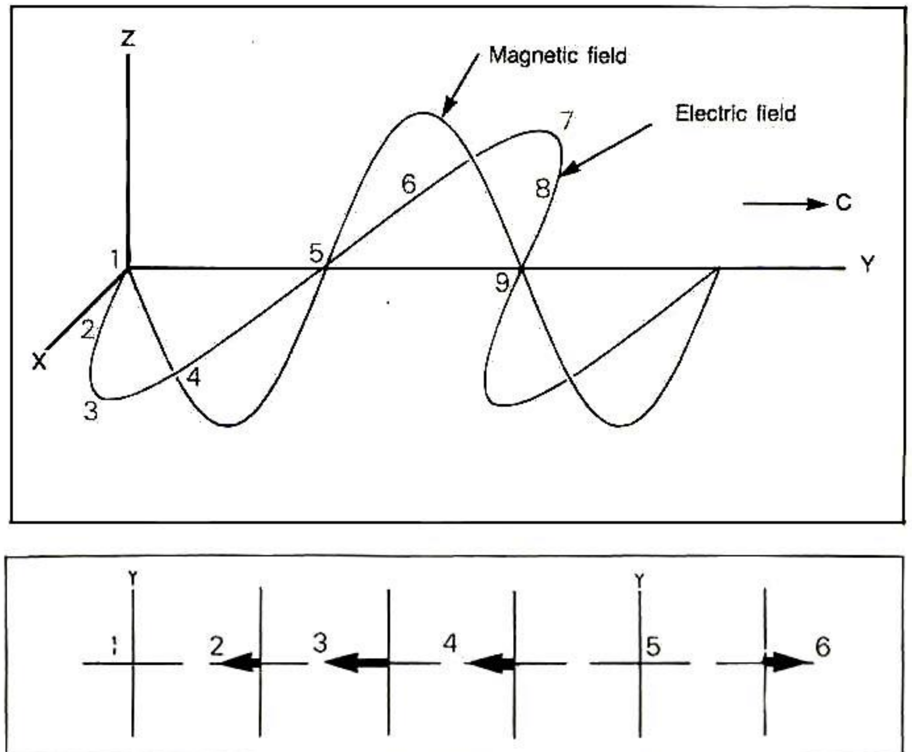
Optical Measurement Engineering

1. Introduction – Definition, Phenomenon and Nature of Light

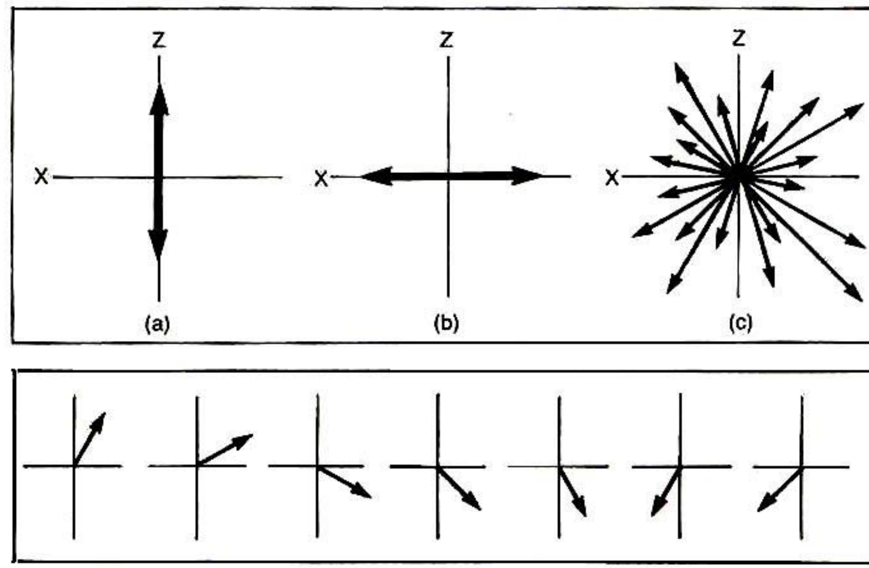
1.4. Characteristics of light (Polarization, Refraction, Reflection and Diffraction)

(1) Polarization : direction of oscillation of the electric field

(a) Horizontally Polarized Light Wave



(b) Circularly Polarized Wave

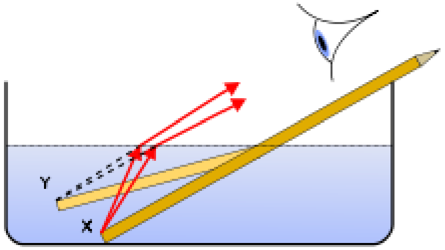


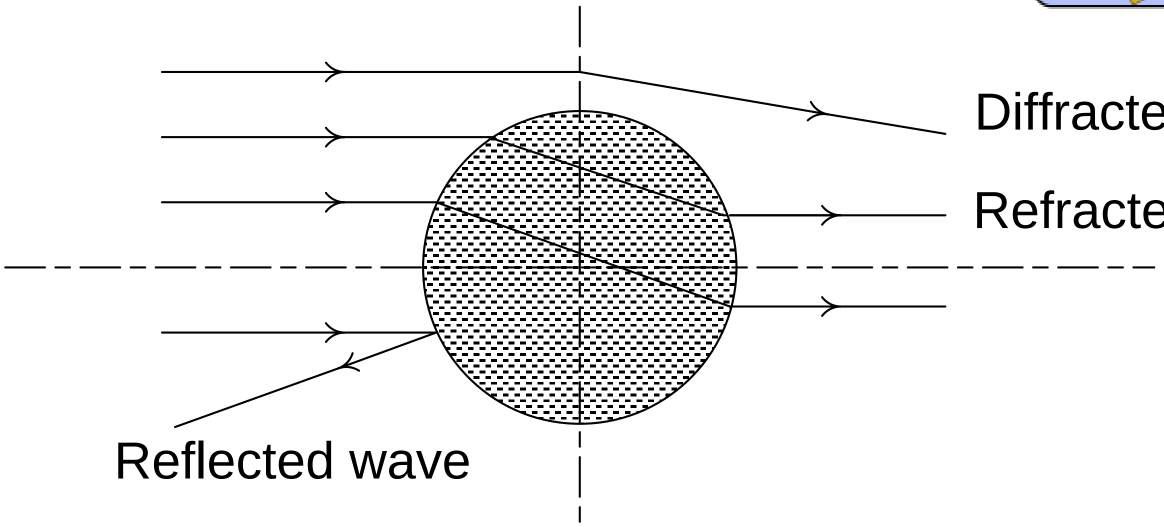
1. Introduction – Definition, Phenomenon and Nature of Light

1.4. Characteristics of light (Polarization, Refraction, Reflection and Diffraction)

(2) Refraction

Refraction is the change in direction of propagation of a wave due to a change in its transmission medium





1.4. Characteristics of light (Polarization, Refraction, Reflection and Diffraction)

(2) Refraction

Refractive index : $$n \equiv \frac{c_{vacuum}}{c_{medium}}$$

: How much light slows down in propagating through it

(C in vacuum = 3×10^8 m/s)

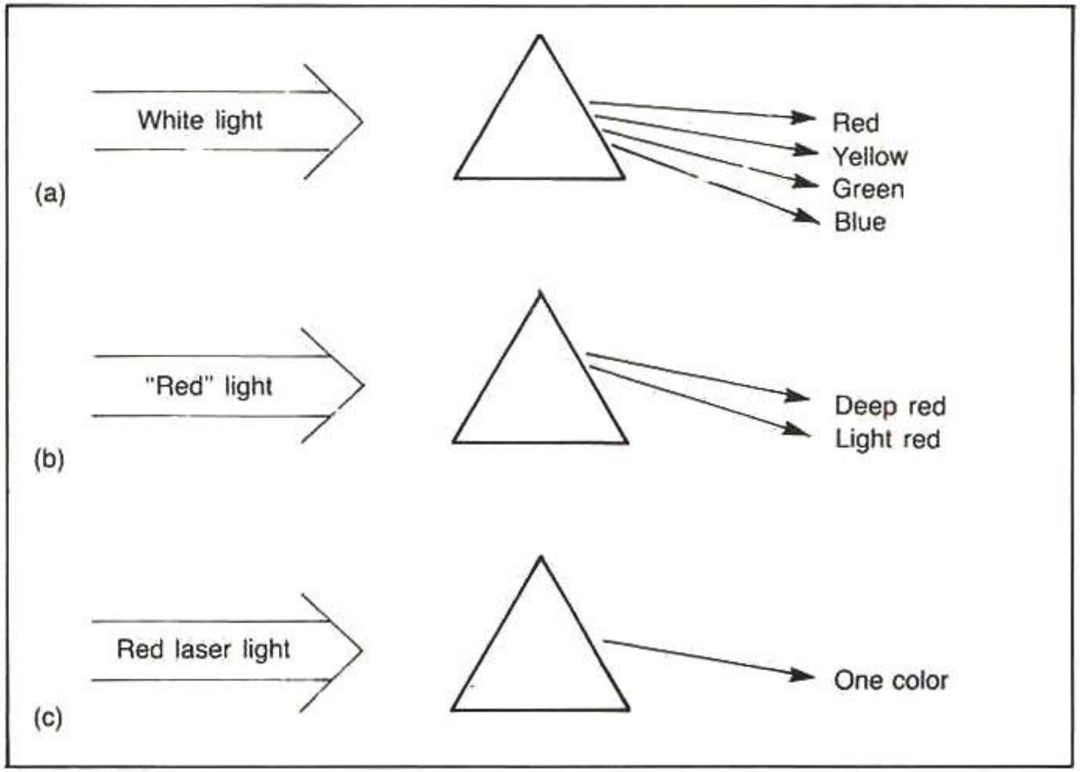
Material	n
Dry air	1.0003
Crown glass	1.517
Diamond	2.419
Ice (-8˚C)	1.31
Water (20˚C)	1.33

1.4. Characteristics of light (Polarization, Refraction, Reflection and Diffraction)

(2) Refraction

❖ **Dispersion :** The index of refraction of a material depends a little on the wavelength of light passing through it (➔ Dispersion).
(ex) Red light and blue light travel at exactly the same velocity in vacuum.
The red light will travel a little faster in glass.

$$n \equiv \frac{c_{vacuum}}{c_{medium}}$$

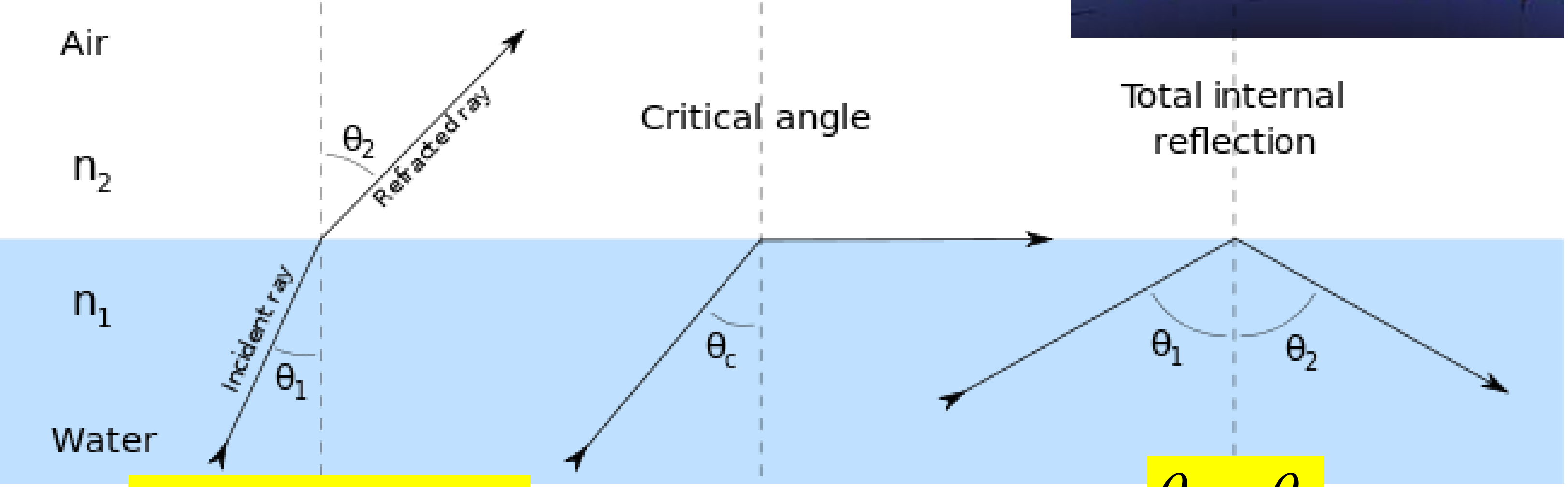


1. Introduction – Definition, Phenomenon and Nature of Light

1.4. Characteristics of light (Polarization, Refraction, Reflection and Diffraction)

(3) Reflection

Reflection is the change in direction of a wavefront at an interface between two different media so that the wavefront returns into the medium from which it originated.



$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

(Law of Refraction : Snell's Law)

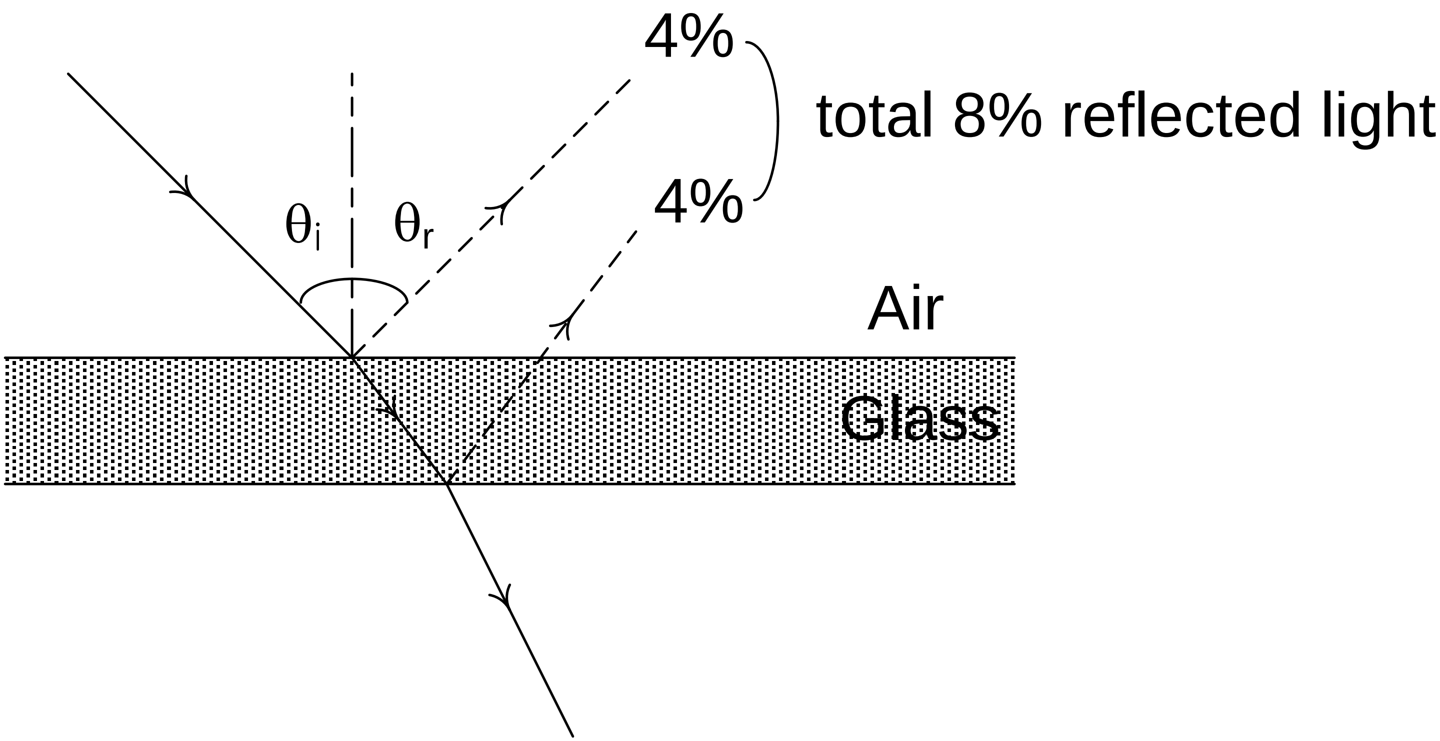
$$\theta_1 = \theta_2$$

(Law of Reflection)

1.4. Characteristics of light (Polarization, Refraction, Reflection and Diffraction)

(3) Reflection

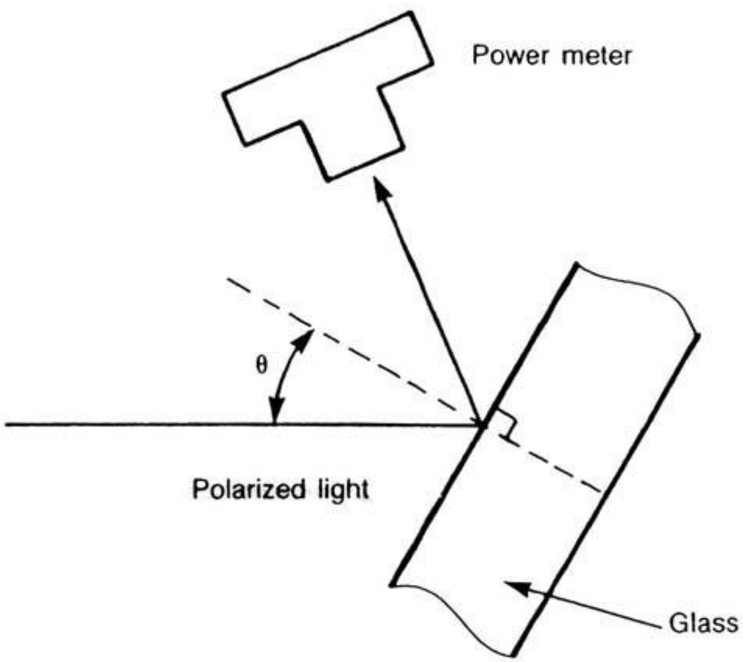
❖ Reflectivity of Glass-Air Interface

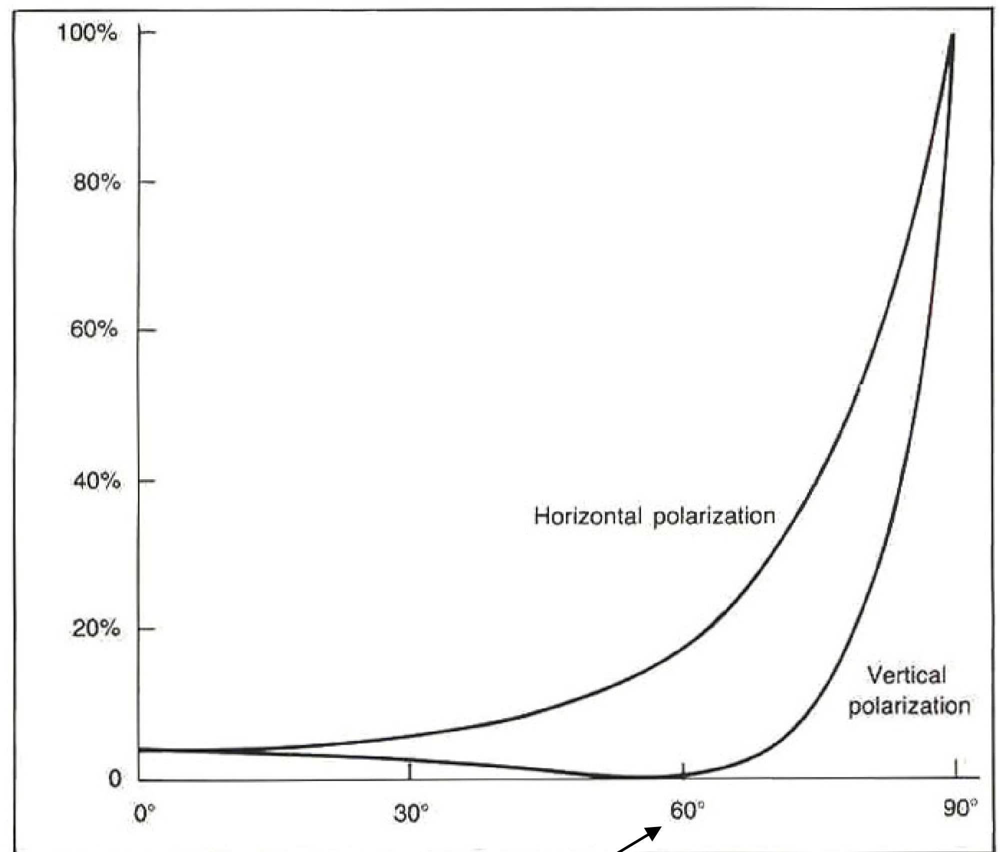


1. Introduction – Definition, Phenomenon and Nature of Light

1.4. Characteristics of light (Polarization, Refraction, Reflection and Diffraction)

(3) Reflection





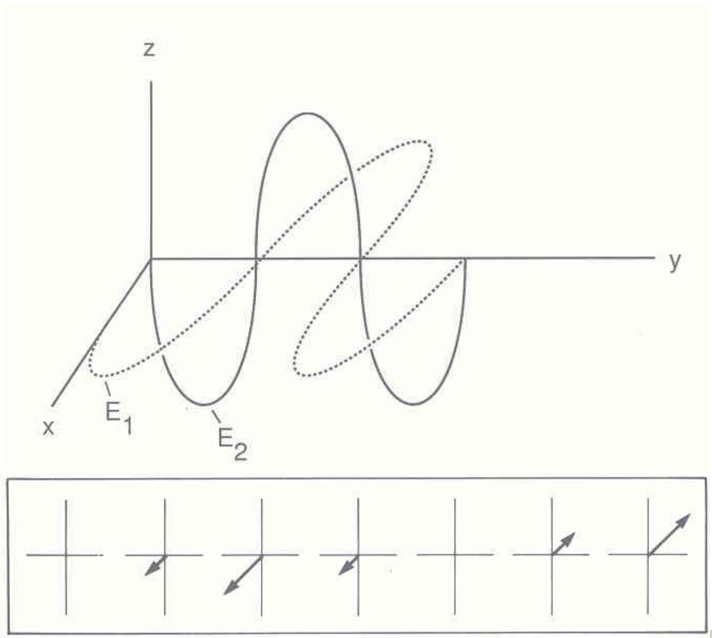
Brewster Angle

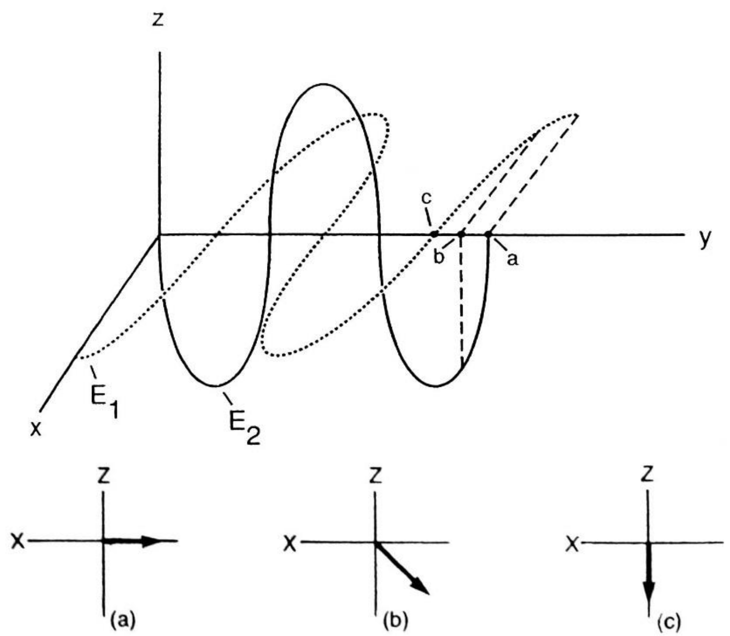
2. LASER

2.6. Polarization

- Birefringent(복굴절성의) material → has two refractive indexes.
- Quarter-wave $(\lambda / 4)$ plate
  → converts plane polarized light to circularly polarized light

cf) Two quarter-wave plates or single half-wave plate convert plane polarized light to the orthogonal plane polarization.



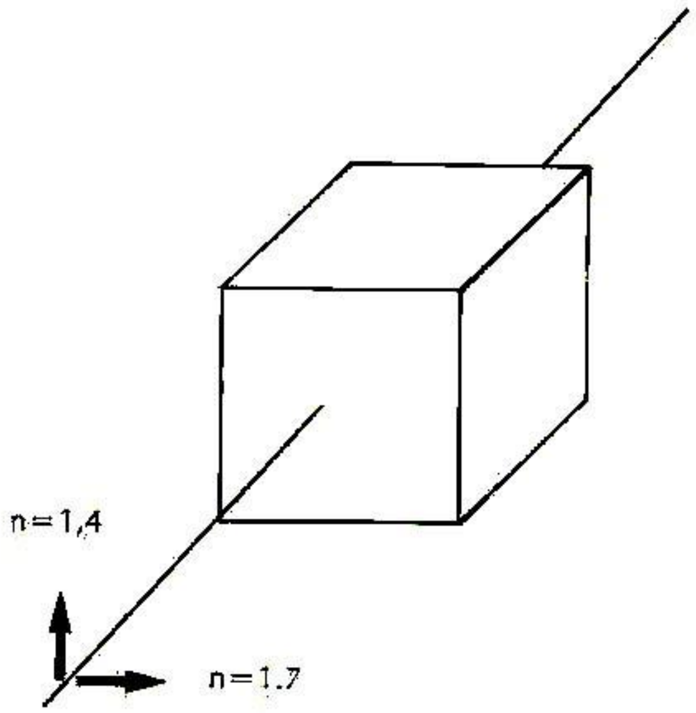


2. LASER

2.6. Polarization

❖ Refractive Index of Birefringent Material

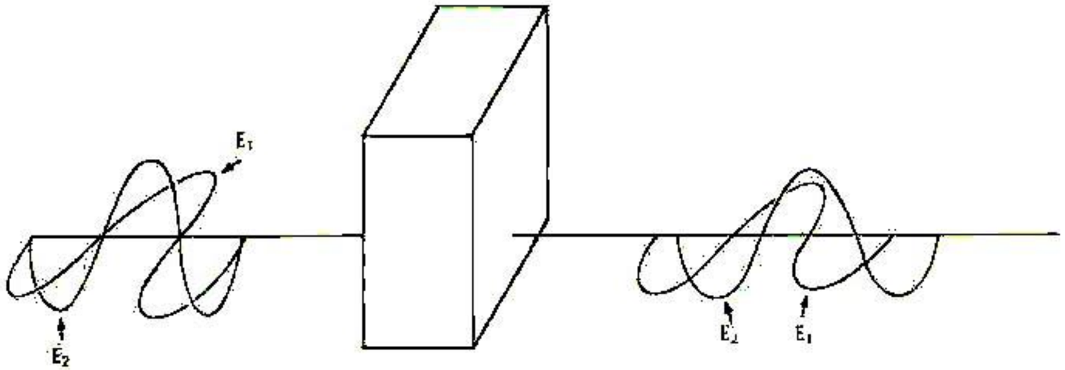
• There are two different refractive indices depending upon a direction in a birefringent material.



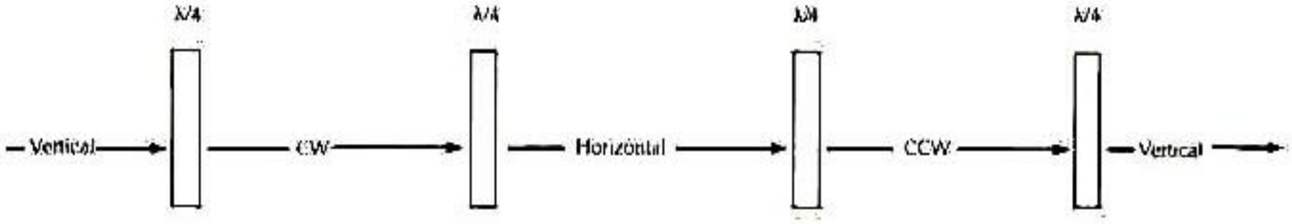
2. LASER

2.6. Polarization

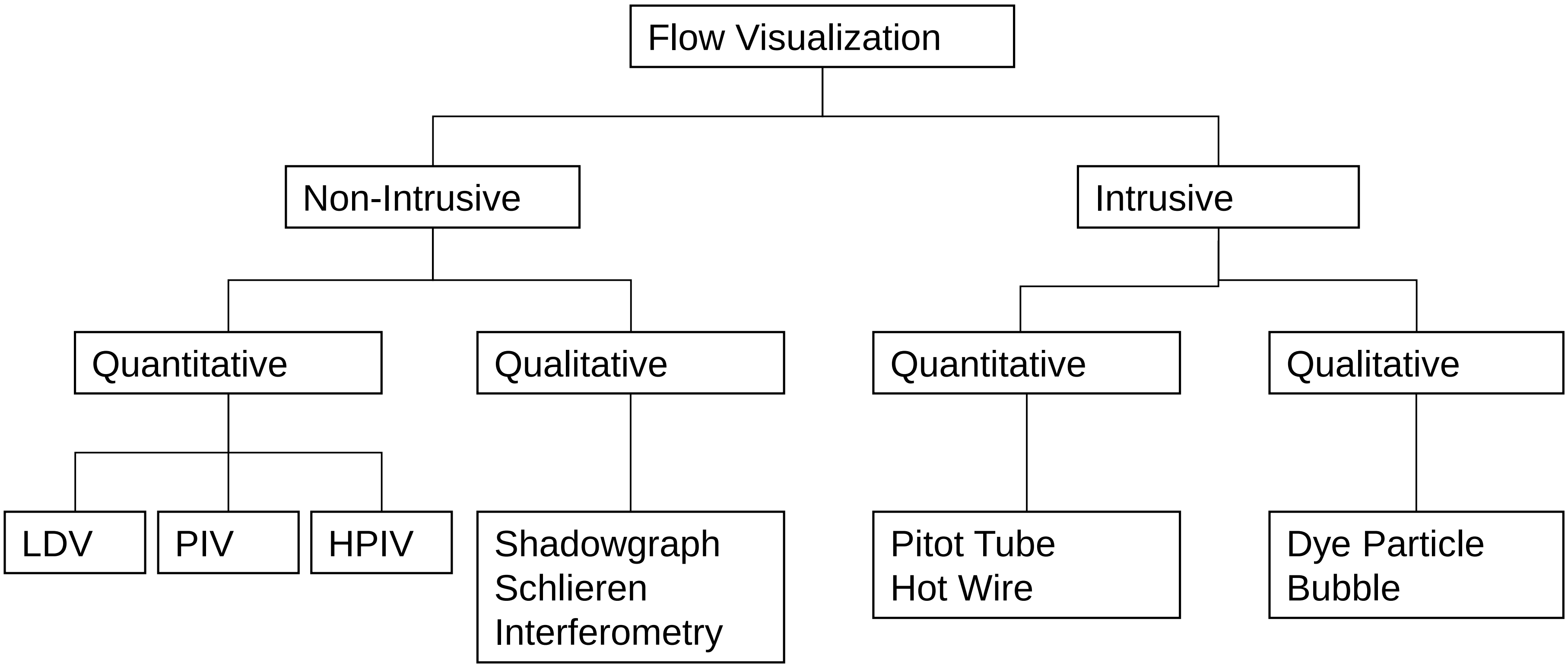
❖ **Birefringent Crystal**



Plane → Circular

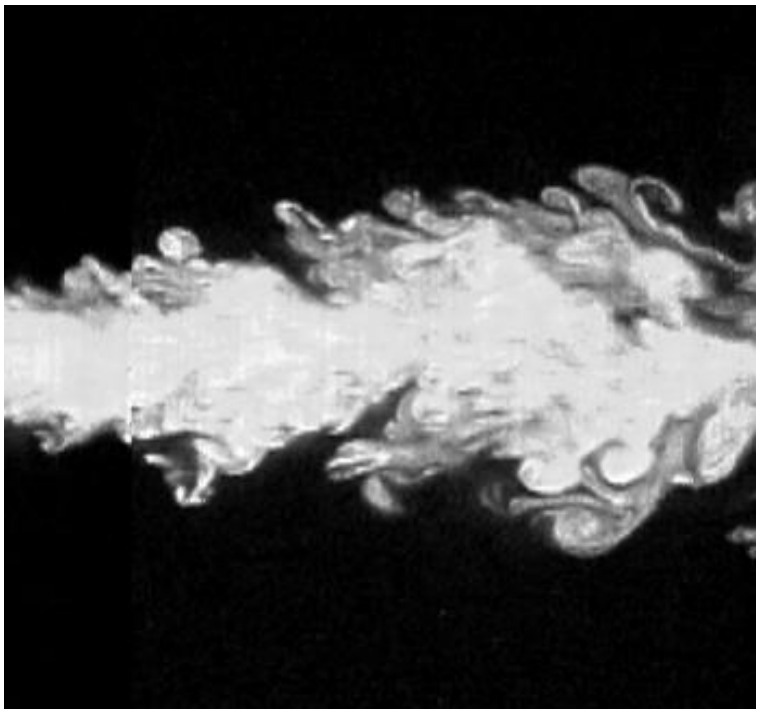


4. Flow Visualization Tools



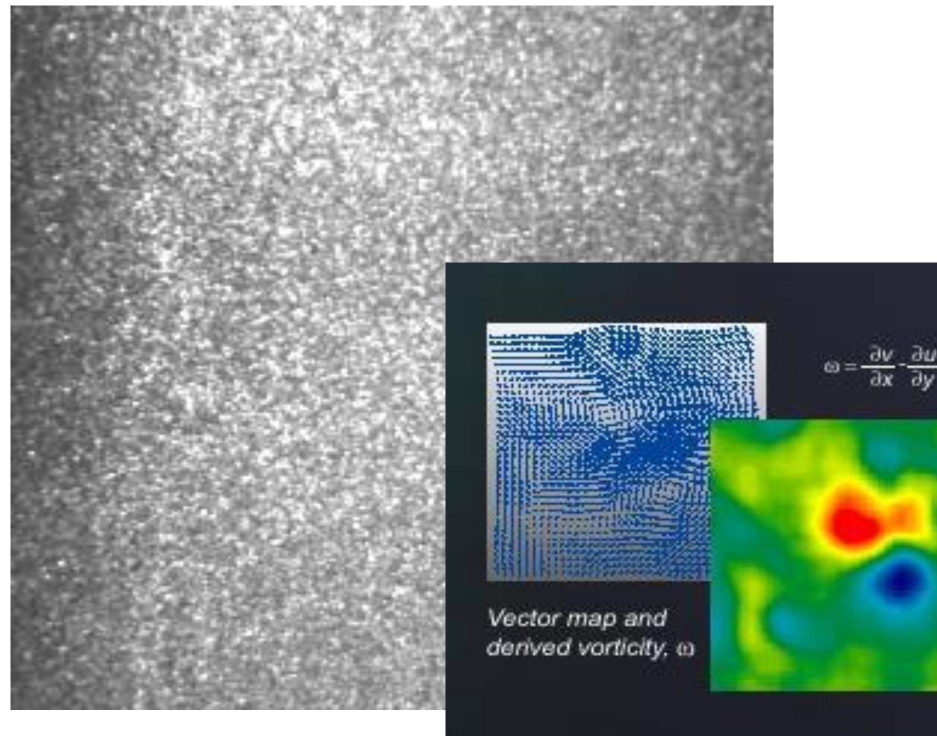
4. Flow Visualization Tools

Qualitative



Tracer particles are following streamlines of the flow

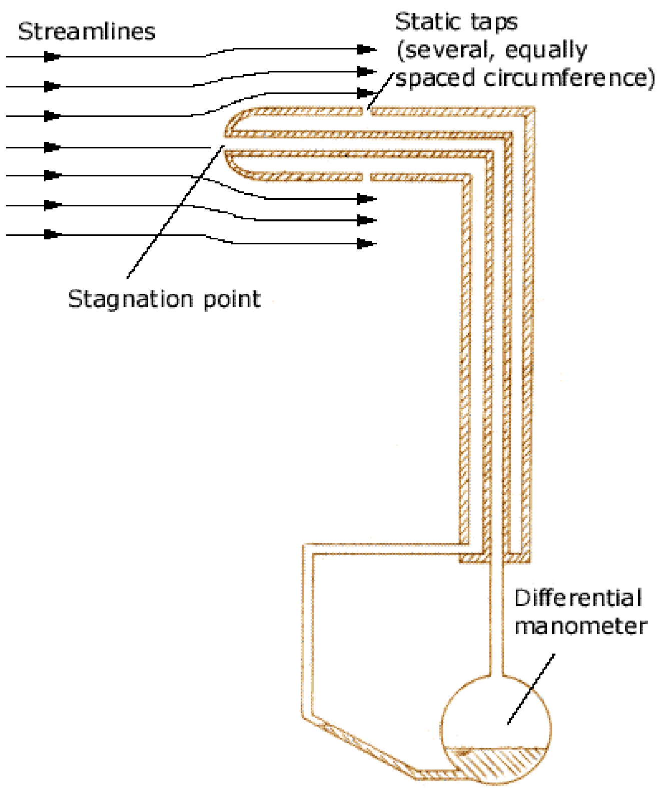
Quantitative



Tracer particles are distributed homogeneously

4. Flow Visualization Tools

- Pitot tube
  a pressure measurement instrument used to measure fluid flow velocity.
  invented by the French engineer Henri Pitot in the early 18th century.



Pitot tube mounted on airplane

$$v = \sqrt{2g\frac{(p_{st} - p_s)}{\gamma}}$$

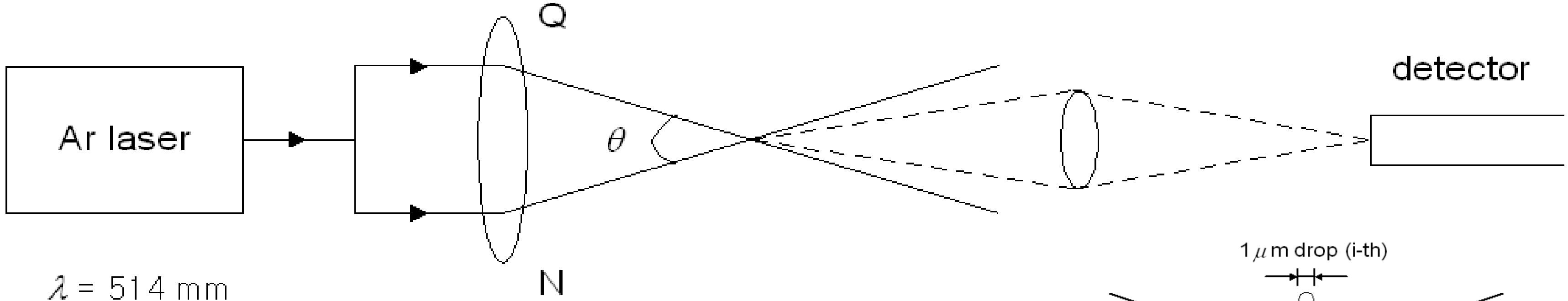
p_{st} : Stagnation pressure
p_s : Static pressure
γ : Specific Weight (=$\rho \times g$)
g : Gravitational acceleration

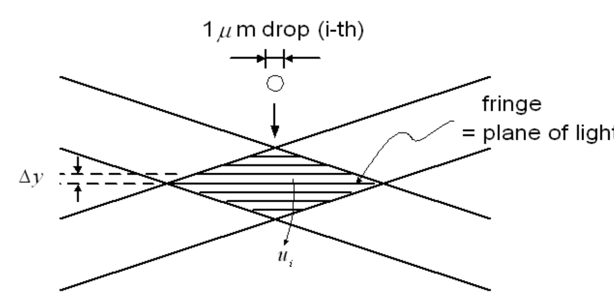
6. Laser Doppler Velocimetry (LDV)

6.1. Definition

- Also called Laser Doppler Velocimetry (LDV)
  Laser Anemometry (LA)
  Laser Doppler Anemometry (LDA)

- What is LDV?
  - LDV measures the velocity of a gas or liquid by measuring the velocity of small (1㎛ diameter) particles introduced into the flow as the particles cross a fringe pattern set up by 2 intersecting laser beams.





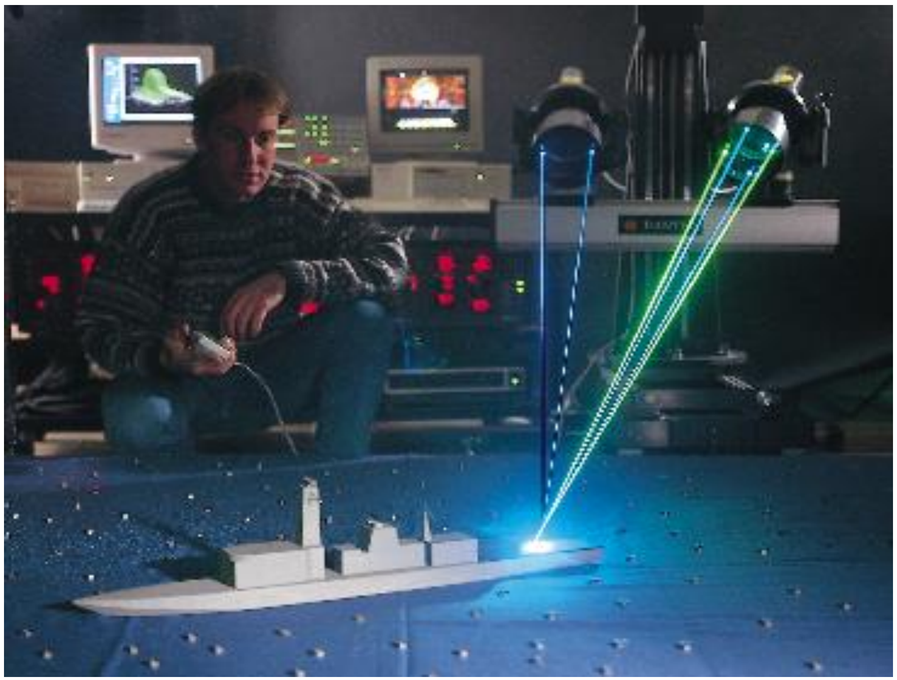
6. Laser Doppler Velocimetry (LDV)

6.2. Applications

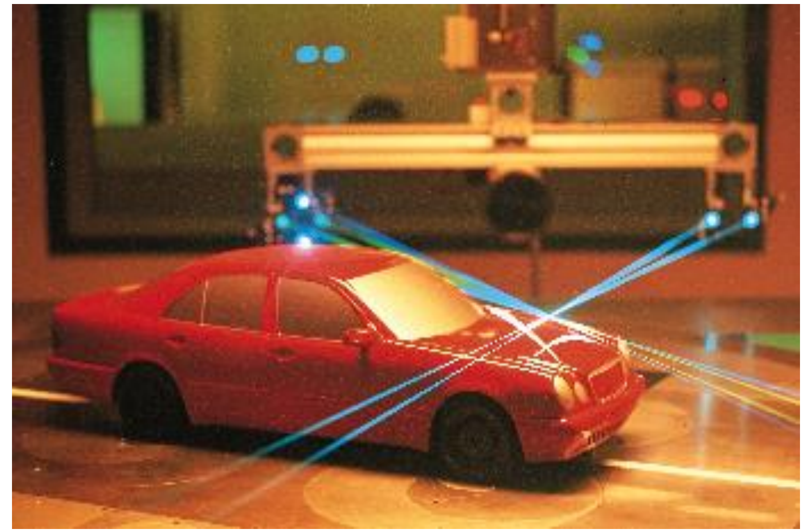
- Laminar and turbulent flows
- Investigations on aerodynamics
- Supersonic flows
- Turbines, automotive etc.
- Liquid flows
- Surface velocity and vibration measurement
- Hot environments (flames, plasma etc.)
- Velocity of particles

6. Laser Doppler Velocimetry (LDV)

6.2. Applications



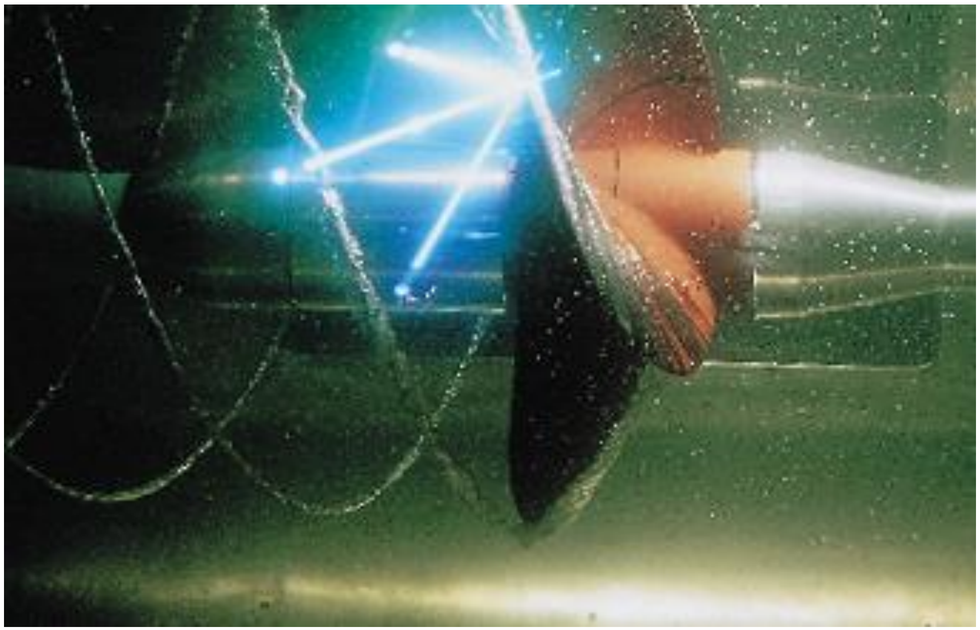
Measurement of air flow field around a ship model in a wind tunnel
(Photo courtesy of University of Bristol, UK)



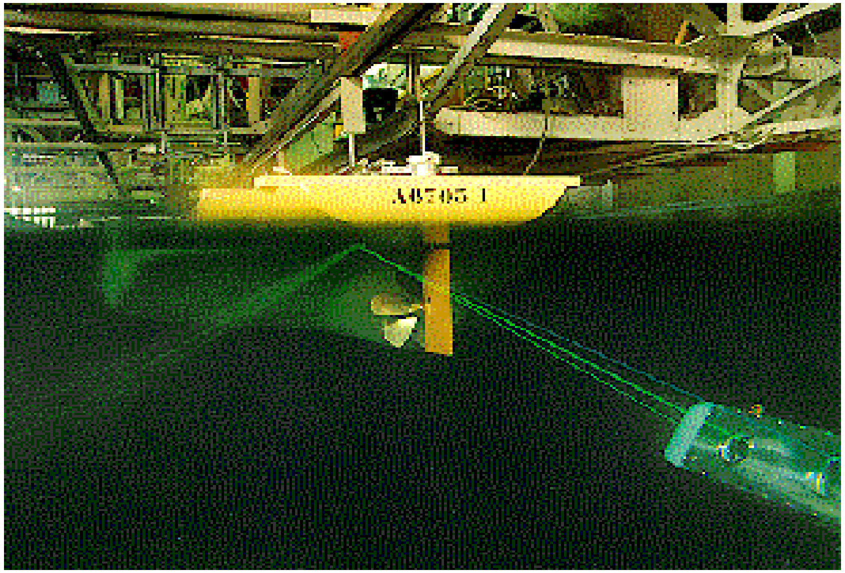
Measurement of flow field around a 1:5 scale car model in a wind tunnel
(Photo courtesy of Mercedes-Benz, Germany)

6. Laser Doppler Velocimetry (LDV)

6.2. Applications



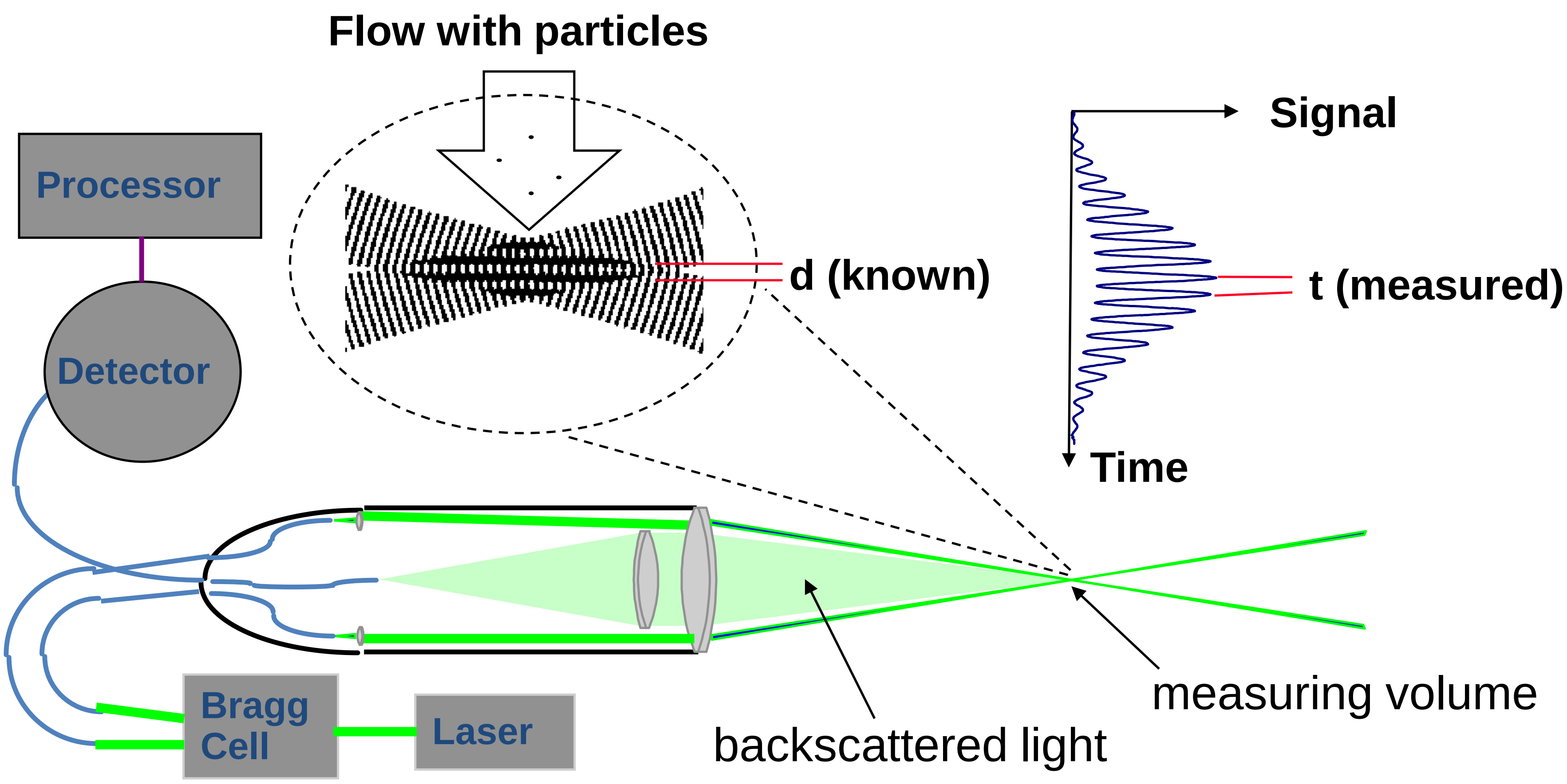
Measurement of flow around a ship propeller in a cavitation tank



Measurement of wake flow around a ship model in a towing tank
(Photo courtesy of Marin, the Netherlands)

6. Laser Doppler Velocimetry (LDV)

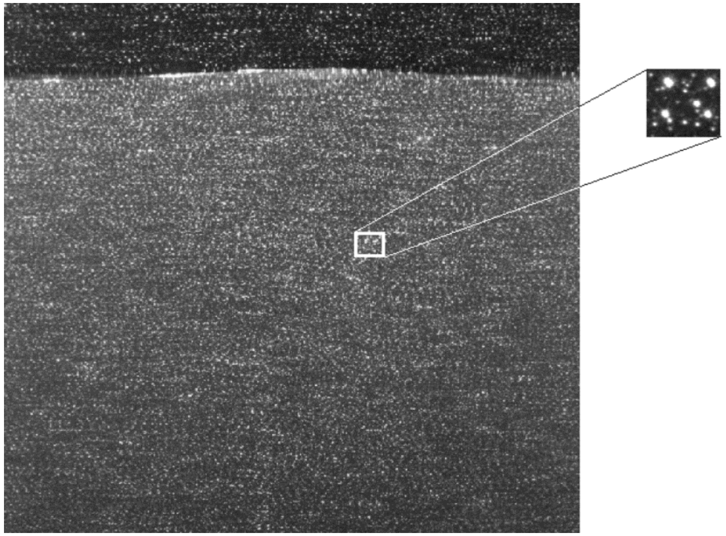
6.3. Principle

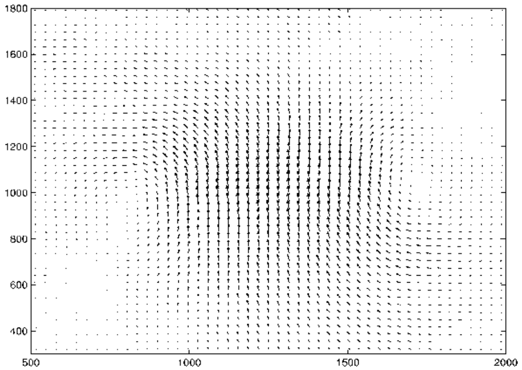


7. Particle Image Velocimetry (PIV)

7.1. Definition

Particle image velocimetry is the simultaneous measurement of fluid or particulate velocity vectors at many (e.g., thousands) points, using optical imaging techniques. The measurements are usually made in planar "slices" of the flow field. The technique can be extended for three-dimensional measurements. Accuracy and spatial resolution are comparable to LDV or thermal anemometry.



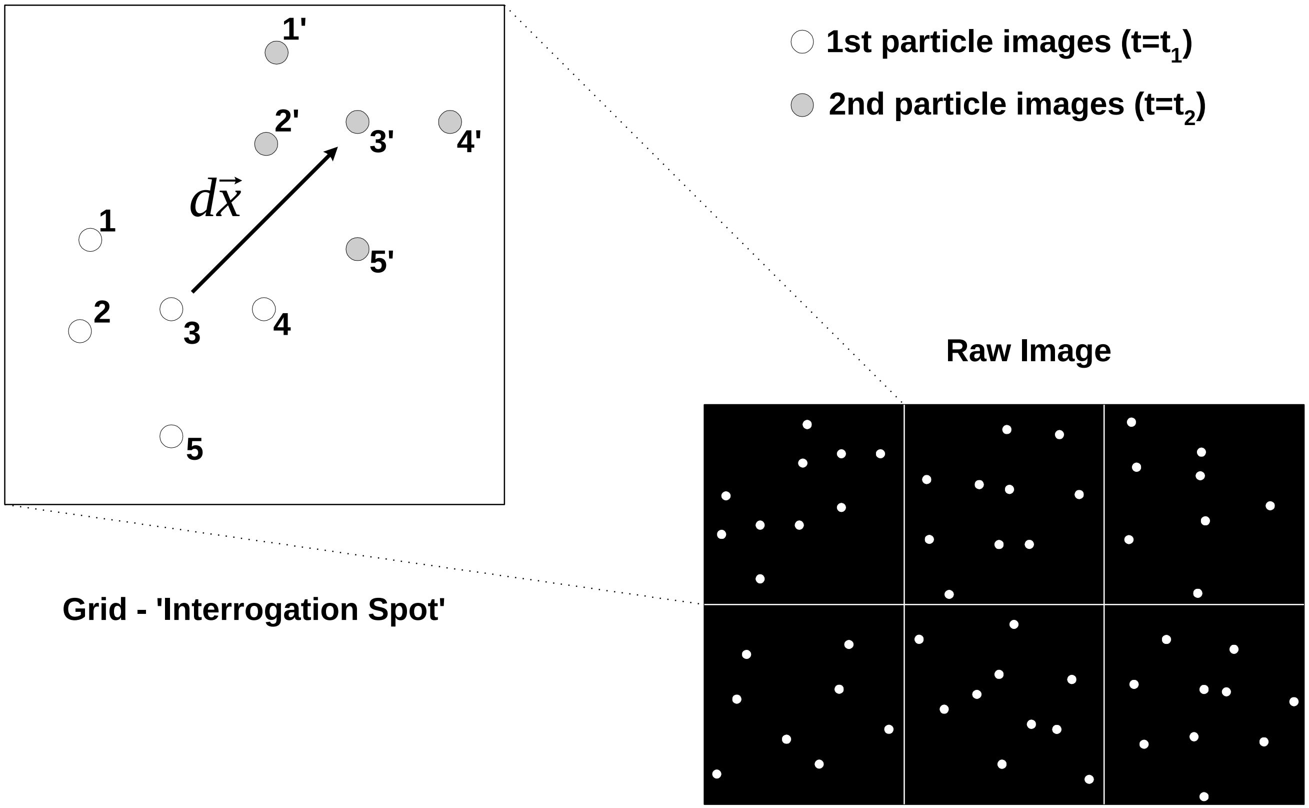


'Interrogation spot' and resultant velocity field

Correlation based analysis by digital image processing is introduced

7. Particle Image Velocimetry (PIV)

7.2. Principle



$$\vec{v} = \frac{d\vec{x}}{M\Delta t} \approx \frac{\Delta\vec{x}}{M\Delta t}$$

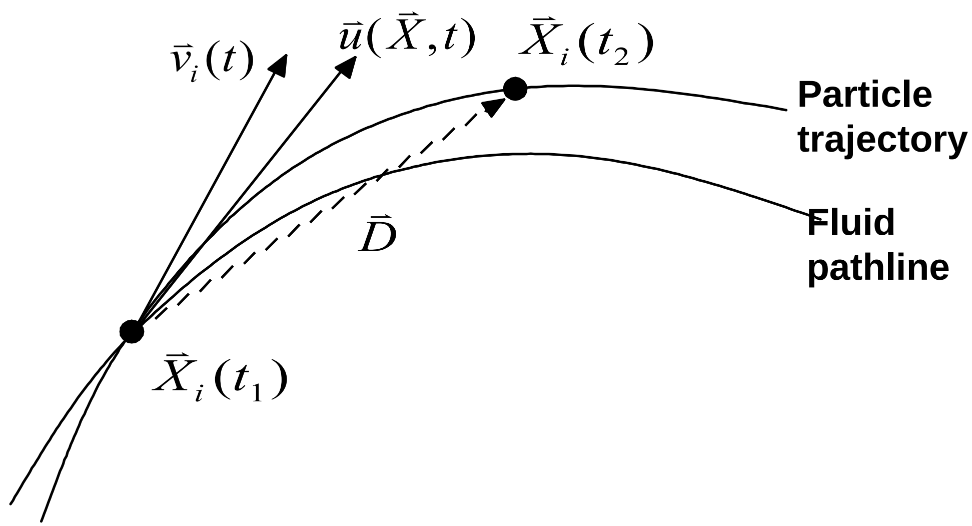
Δt = time between two pulses (given value)

$\Delta\vec{x}$ = (Δx, Δ y);particle displacement (measured value)

7. Particle Image Velocimetry (PIV)

7.2. Principle

The fluid motion is represented as a displacement field of particles

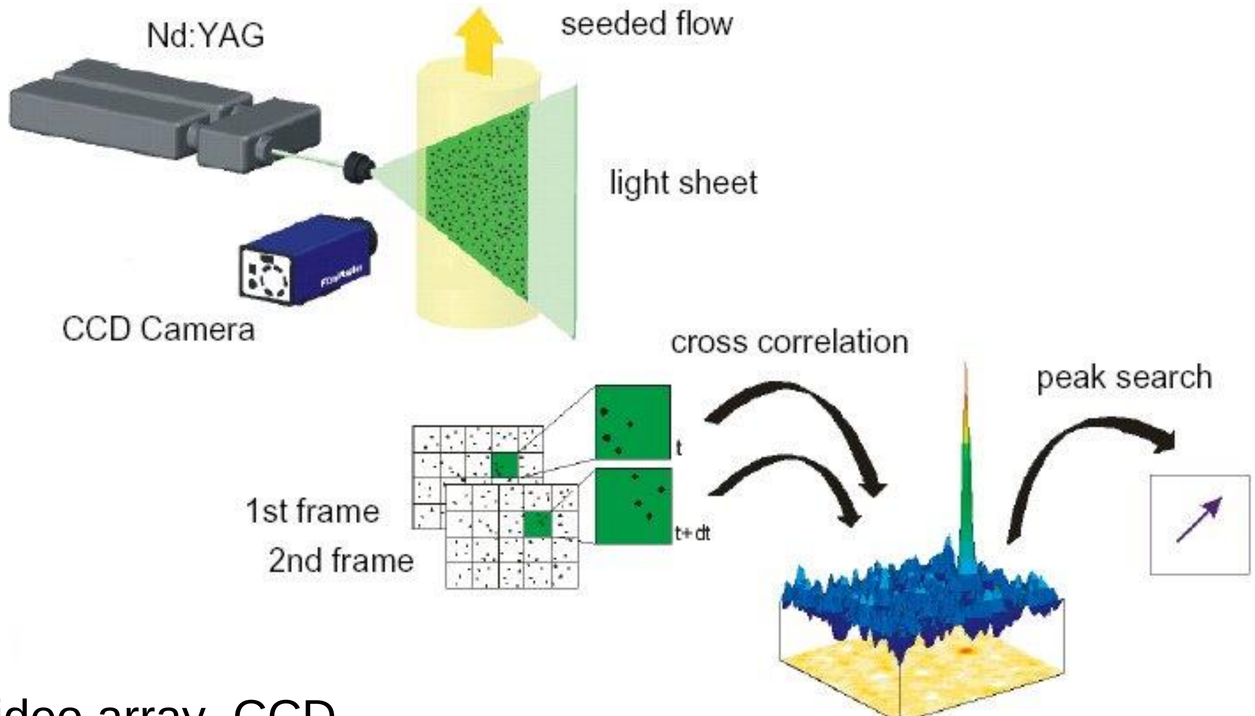


❑ Inherent assumption: tracer particles follow the fluid motion

- ❖ Small to follow fluid motion
- ❖ Should not alter fluid or flow properties
- ❖ Density matched
- ❖ Large enough to be visible

7. Particle Image Velocimetry (PIV)

7.2. Principle – Methods



1. Particle Seeding

- 0.1~100 micron size

2. Illumination

- Laser

3. Data Acquisition

- Photographic film, video array, CCD

4. Image Processing

- Pre-processing
- Post-processing : interrogation spot, correlation, validation

7. Particle Image Velocimetry (PIV)

7.3. Application

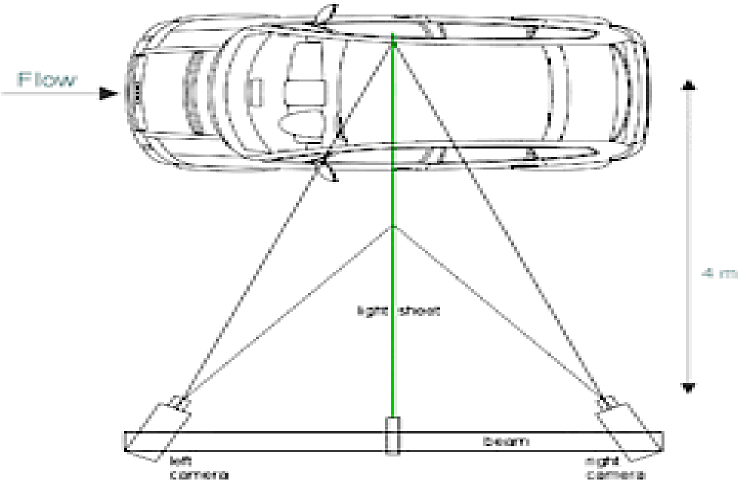


Fig.1 3D stereoscopic PIV set-up

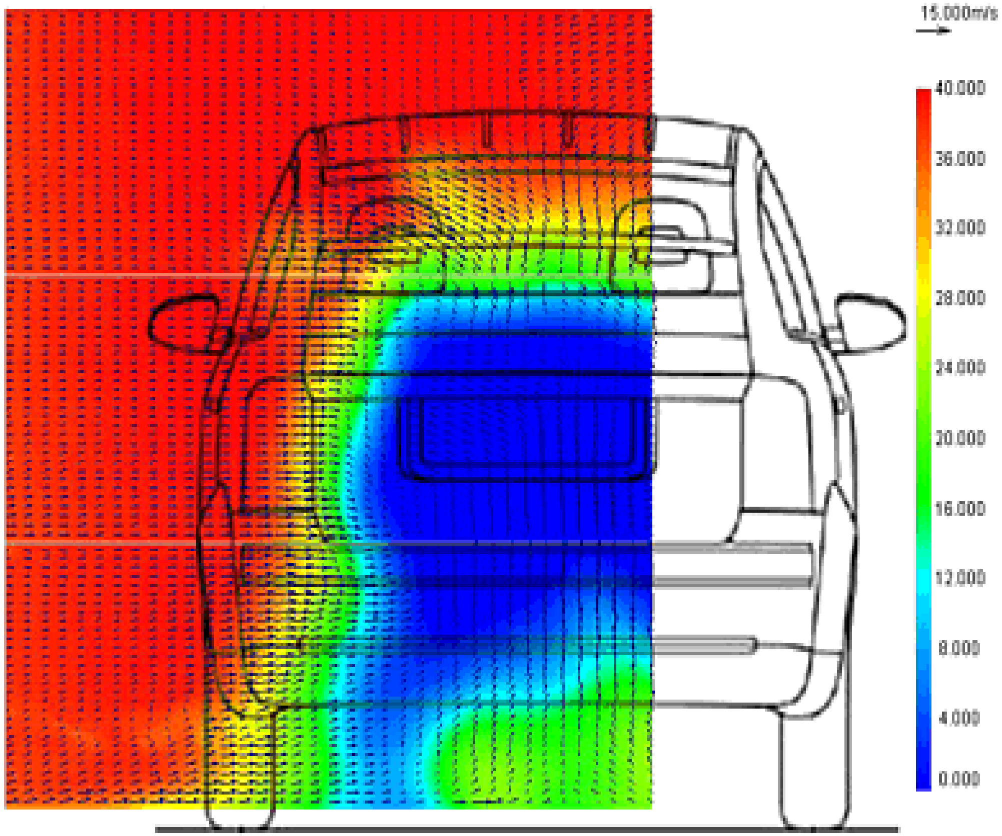
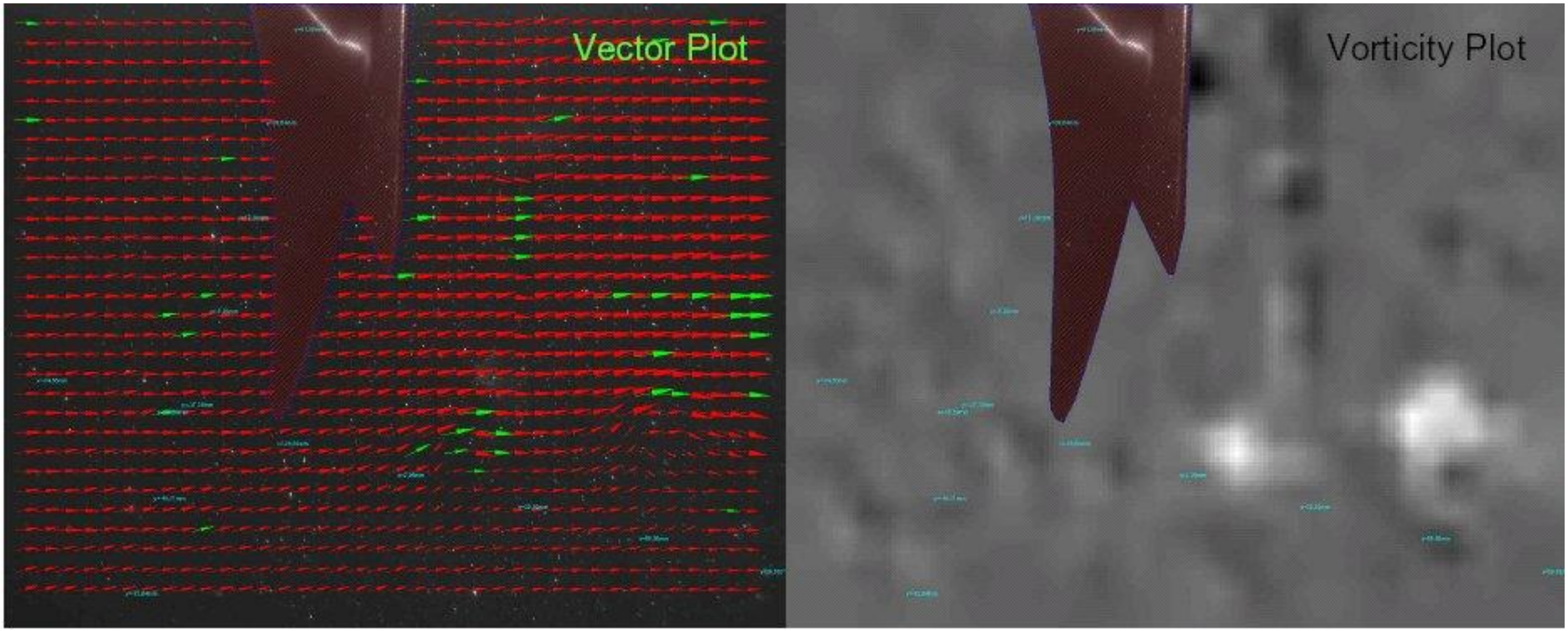


Fig. 3 airflow velocity through the plane from 0 to 40 m/s (blue to red)

7. Particle Image Velocimetry (PIV)

7.3. Application

Tip vortices of impeller

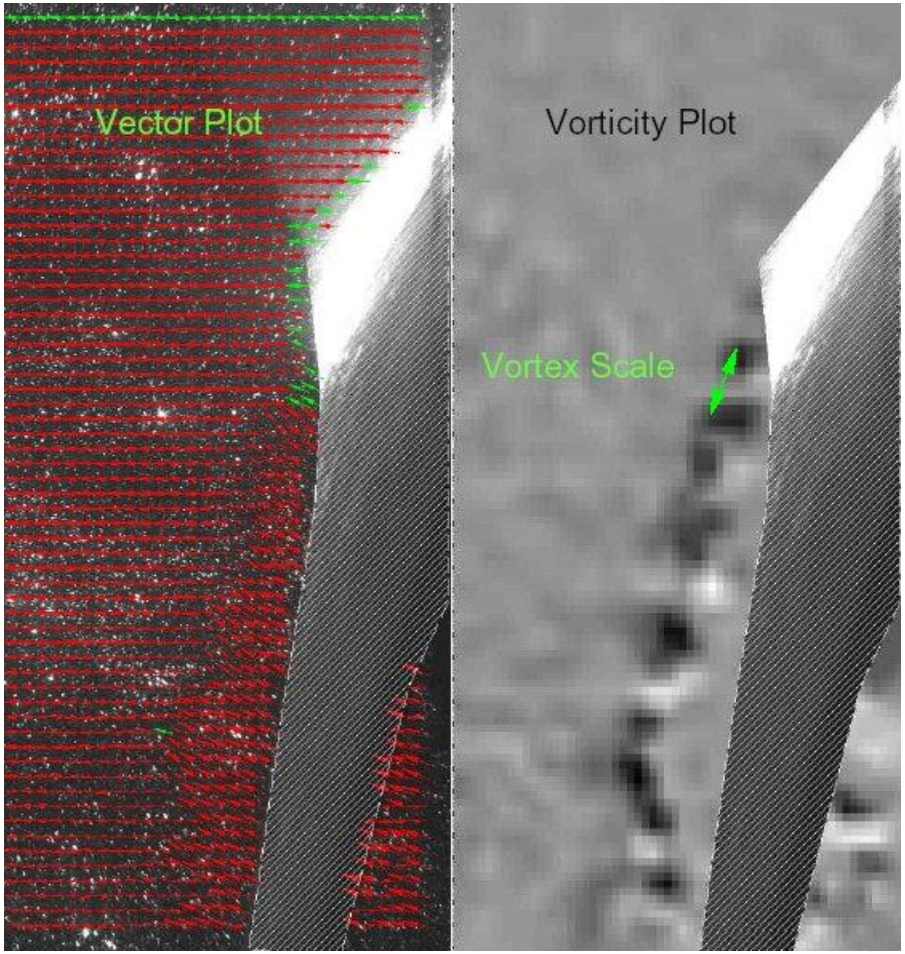


The tip vortex of a propeller is investigated – low seeding density.

7. Particle Image Velocimetry (PIV)

7.3. Application

Wake behind ship propeller

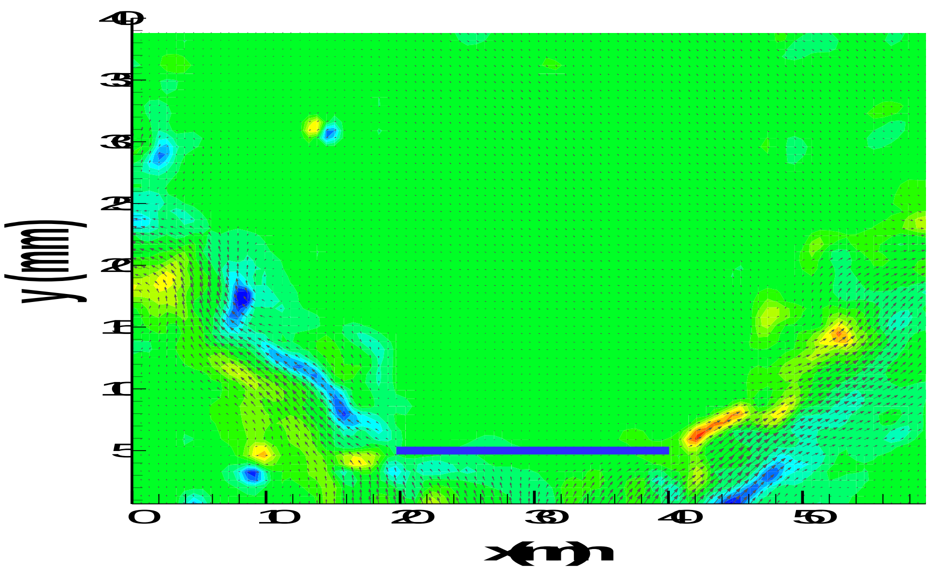


The Wake of a ship propeller was investigated for flow induced acoustic excitation of the blade. The vortex scale can give an idea of the vibration frequency.

7. Particle Image Velocimetry (PIV)

7.3. Application

Jet + Plate



Jet + Cylinder