Knowledge
Beyond
Measure.

Fluid Mechanics Systems

A Complete Portfolio of Solutions for Fluid Mechanics Research

Over 50 Years of Contribution
To the Fluid Mechanics Research Community

Complete Portfolio
TSI's fluid mechanics measurement systems, based on many years of research and development, have been trusted by researchers to make accurate measurements of flow velocity, turbulence, and all the associated properties at a point or over a planar region in a wide range of environments, varying from simple, to complex, to hostile. They also reliably measure particle size, velocity, number density and volume flux of spherical particles, droplets, or bubbles in similar environments and make noninvasive measurements of temperature, concentration and other scalar properties.

For example, our Laser Doppler Velocimetry and Particle Image Velocimetry Systems helped researchers understand how new aircraft might better handle sudden downdrafts. The volumetric 3D3C flow product, V3V, was used in breakthrough research aimed at building better heart valves.

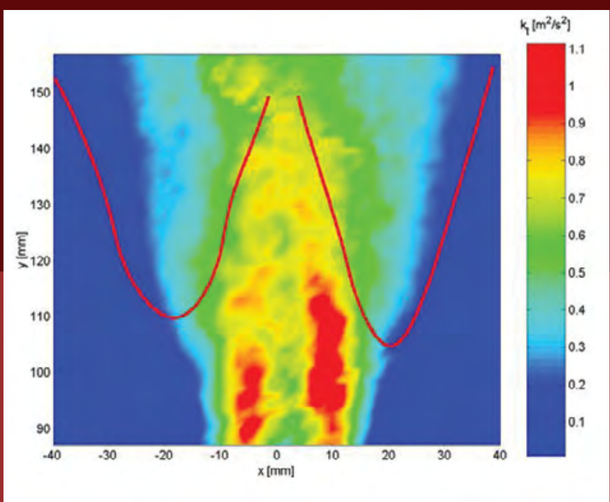
Our innovative system-based solutions include:
- Volumetric PIV (V3V™ Flex and V3V 9000 Systems)
- Particle Image Velocimetry (PIV)
- Planar Laser Induced Fluorescent System (PLIF)
- Laser Doppler Velocimetry (LDV)
- Phase Doppler Particle Analyzer (PDPA)
- Thermal or Hot Wire Anemometry (HWA)

With a worldwide reputation for providing innovative and high quality measurement solutions, TSI is adept at applying emerging technologies to meet unique measurement requirements in fluid mechanics research for a wide range of applications.

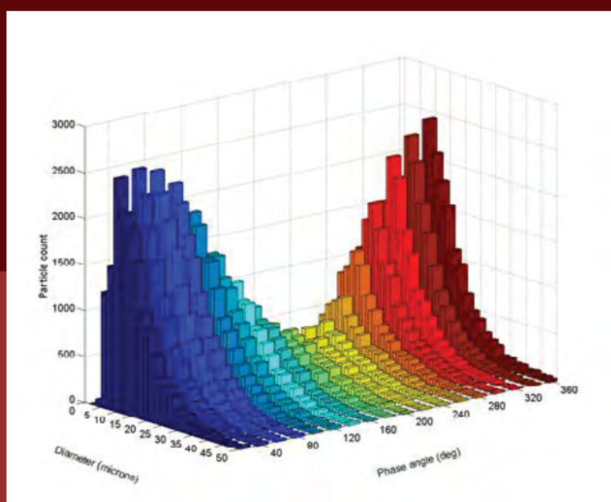
Cutting Edge Research

The Fluid Mechanics division of TSI has worked to develop superior fluid flow and particle measurement instrumentation for the global research community for over 50 years. During this time TSI has been at the forefront of developing state-of-the-art systems to meet researcher's advanced measurement requirements in the following areas:

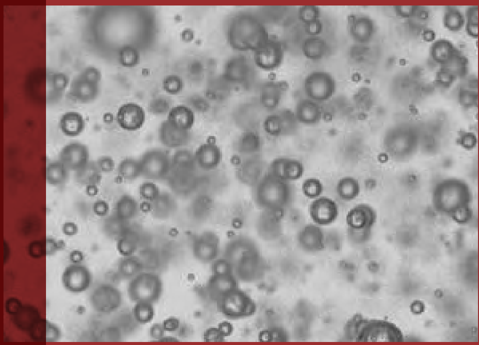
- Hydrodynamics
- Aerodynamics
- Fundamental Flow and Particle Research
- Turbulence
- Spray Diagnostics
- Bio-locomotion Studies
- Biomedical Studies
- Fluid/Structure Interaction
- Multi-Phase Flow
- Flow Studies in Micro Channels



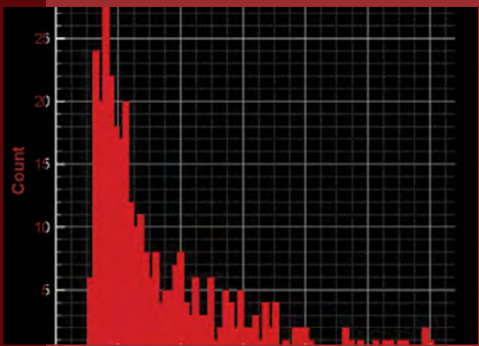
PIV measurement of Lifted flame from
Stanford University, USA



Spray droplet diameter distribution
in an acoustic driven flow

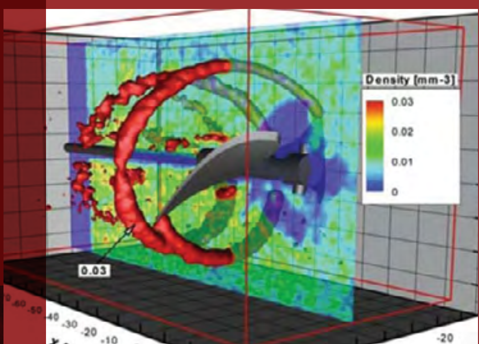


Size distribution of the bubbles



Measurement of bubble size and velocity

3D LDV System for the measurement of flow behind propeller, INSEAN, Italy



3D3C measurement for the exploration of the tip vortex generated from propeller, INSEAN, Italy

Solutions for Unique Fluid Flow Measurement Applications

Hydrodynamics
Marine hydrodynamics researchers, as well as investigators in other areas of study within this broad field, benefit from TSI's trusted solutions and knowledgeable team of experts that have helped enable them to break into 3-dimensional velocity measurements throughout a volumetric domain using TSI's award-winning V3V™ system. Hydrodynamics researchers can also investigate flow point-wise through the use of TSI's Laser Doppler Velocimetry (LDV) system, in addition to our other instrument offerings for further analysis.

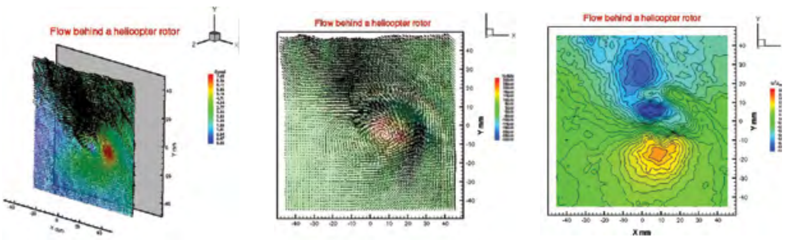
Multi-Phase Flows
TSI's Global Imaging Systems, driven by the INSIGHT 4G™ Software Platform, feature the most advanced tools and widest range of measurement techniques for detailed analysis of multiphase fluid flow properties. Measured parameters include droplet size and velocity in sprays, object size–shape–velocity analysis (including diameter, Feret diameter, ellipticity, and area) in bubbly, particle laden, or liquid-liquid multiphase flows, and void fraction.

Spray Diagnostics

Researchers in fuel spray diagnostics and zero-gravity spray measurements alike have relied on TSI's patented Phase Doppler Particle Analyzers (PDPA) for their ease-of-use, accuracy, and flexibility, permitting measurements in a wide variety of configurations to provide even the most unique of spray diagnostics measurements. In particular, TSI's PDPA systems allow spray analysts to: measure droplet size and velocity, obtain detailed statistics, including volume and flux data, with high spatial resolution, and determine size and velocity field of the spray by traversing TSI's standard PDPA system.

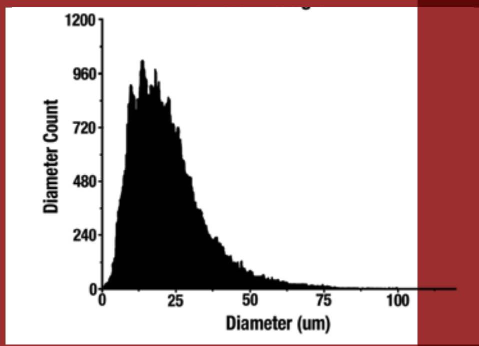
Aerodynamics

In fluid mechanics research, specifically related to aerodynamics measurements, obtaining detailed velocity measurements and associated flow properties is critical. Such information enables industrial designers to enhance the aerodynamics of bodies and vehicles — from airplanes, ships, and automobiles to micro-size devices. Advanced research like this can be carried out using Particle Image Velocimetry (PIV) systems or thermal anemometers from TSI. The BG-1000 Bubble Generator greatly enhances the measurement volume/size for PIV with neutrally buoyant seed particles.

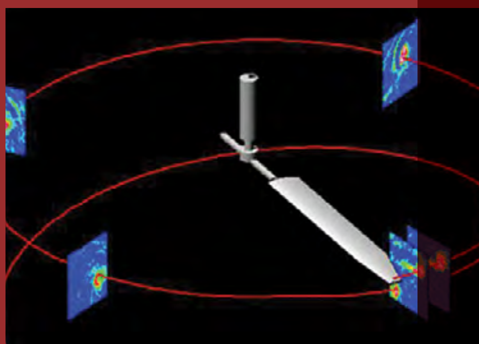


Tip vortex and velocity field from the helicopter rotor

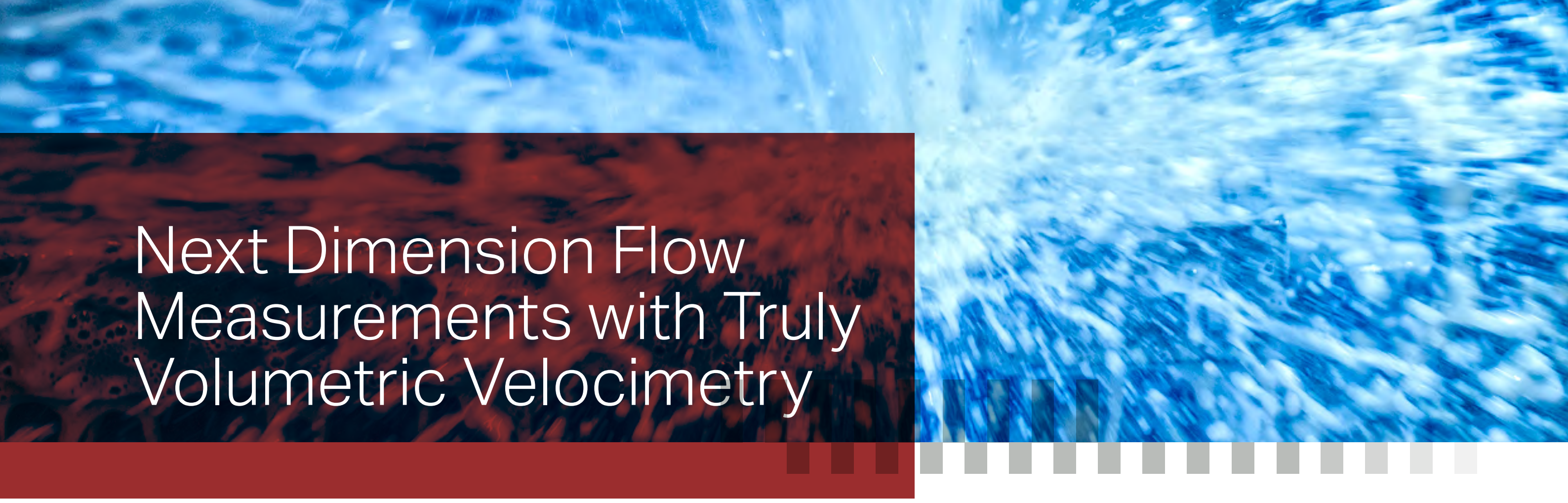
Measurement of high speed large scale dense foam spray



Droplet Diameter distribution of the dense foam spray with D10=23 um, D32 = 46.4 um and D50 = 54.4 um



Tip vortex generation at different phases of the rotor motion, University of Maryland, USA



Next Dimension Flow Measurements with Truly Volumetric Velocimetry

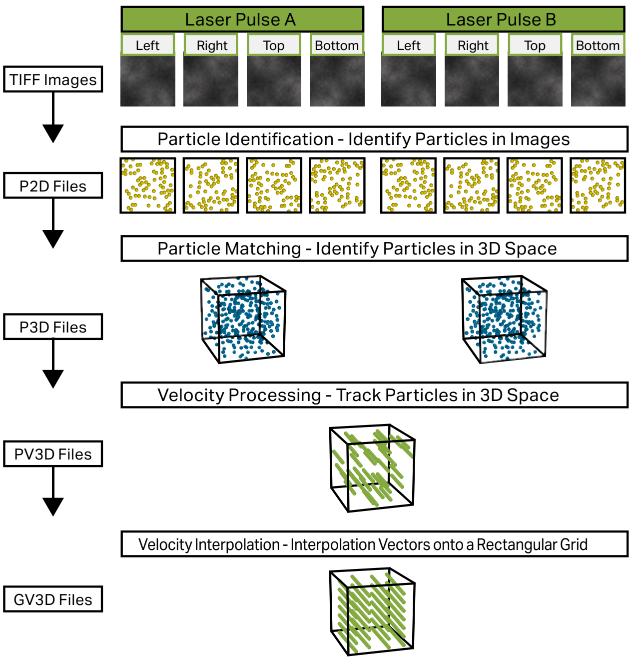
V3V™ System: Volumetric PIV

TSI's patented, award winning V3V™ Volumetric 3-Component Velocimetry System has been used extensively in many fluid flow (liquid and gaseous) research studies. Its unique ability to instantaneously capture the fluid velocity field in a volume more than 1 m x 1 m x 0.5 m offers the most detailed flow structure imaging available, allowing researchers to uncover new insights into the field of fluid mechanics. Using the BG-1000 bubble generator, naturally buoyant bubbles serve as seed particles for wind tunnel flows, allowing the volume size to be increased.

Unique V3V™ System Features

- Time-resolved volumetric PIV takes measurements at thousands times per second to track the evolution of the flow structure
- Continuous data capture at full frame rate for up to thousands of captures and allows flow statistics and higher order quantities to be measured, even for transient flow situations
- Dense Particle Identification and Reconstruction (DPIR) identifies seed particles in locations in 3D volumetric space accurately
- Highest resolution of 3D tracking techniques
- Accurate plug and play system sets up and gets results in minutes

V3V Operation with 4-Camera Arrangement



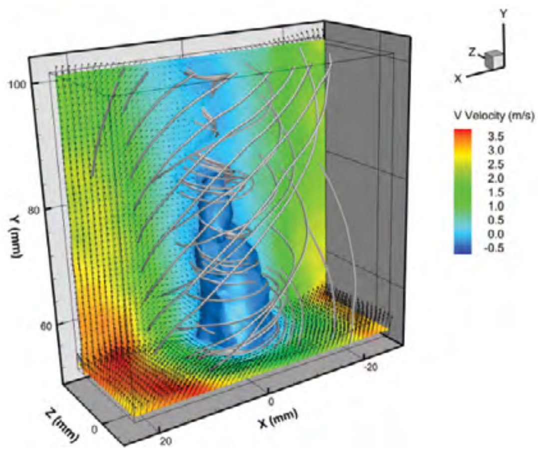
The Technology Behind the V3V™ System Imaging System Volumetric PIV system

- Flexible camera arrangement for optimized measurement volume and spatial resolution, with multiple cameras from 2 to 8
- Support of high speed cameras for time-resolved volumetric measurements with capture rate up to 50kHz
- Variety of hardware makes it possible to choose between high temporal or spatial resolution, or both
- Upgradeable from single camera PIV, stereo PIV and V3V to the latest configuration

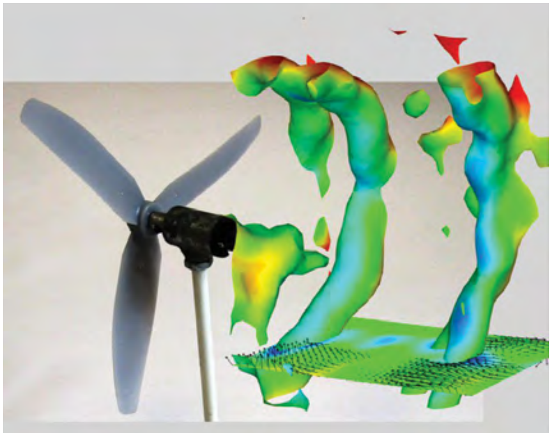
Frame Based Volumetric PIV System

- Optimal system with fixed volume size
- Use of three camera configuration with detachable camera arrangement
- High resolution cameras up to 29 MPixels with frame rate up to 180 fps
- High spatial resolution to resolve turbulent and coherent flow structure

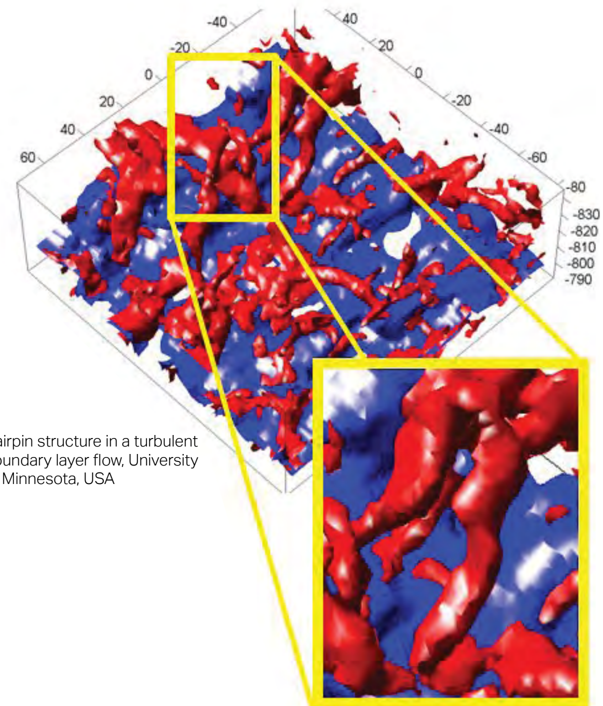
V3V™ System: Incredible 3-Dimensional Measurement Results



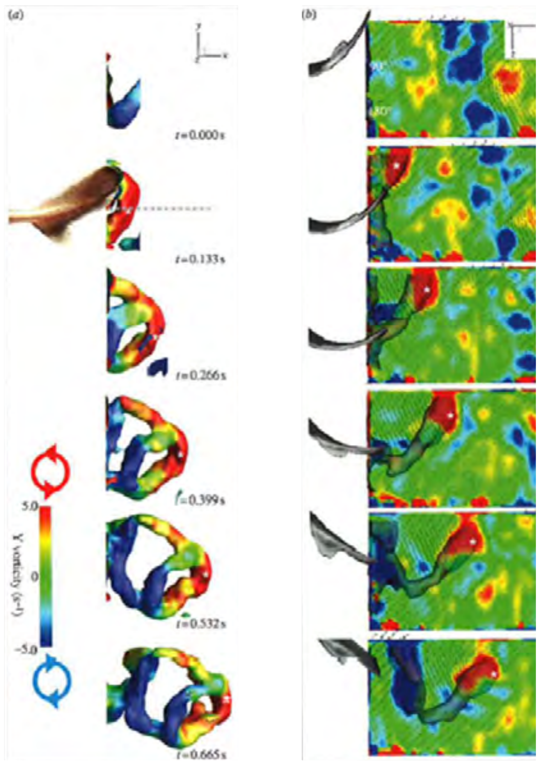
Combustion flow (non-reacting), ICARE CNRS, France



Wake downstream of a water turbine with flow from left to right. Slices represent streamwise velocity, with Red indicating high speed and Blue representing low speed fluid, University of Minnesota, USA



Hairpin structure in a turbulent boundary layer flow, University of Minnesota, USA



3D3C flow structure from a shark fin, Harvard University, USA

Global Velocity Measurements From Large Tunnels to Micro Channels

Particle Image Velocimetry
Particle Image Velocimetry (PIV) is an optical imaging technique used to measure velocity at thousands of points in a flow field simultaneously. The measurements are made in "Planar slices" of the flow field to give two components or three components of velocity. This technique provides accurate results with very high spatial resolution, while TSI's time-resolved PIV system allows for high temporal resolution of the velocity field.

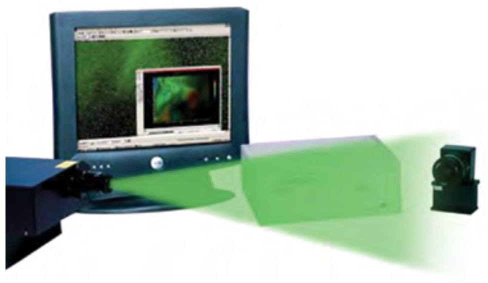
Unique PIV Systems
The PIV technique can be applied to measure flow fields in many environments, from microchannels to large scale wind tunnels, and for 2D to 3D with high spatial and temporal resolution. Example systems include:

- 2D PIV
- Stereo PIV
- Time Resolved-PIV (TR-PIV)
- Micro PIV*
- Tow Tank PIV (planar or volumetric)

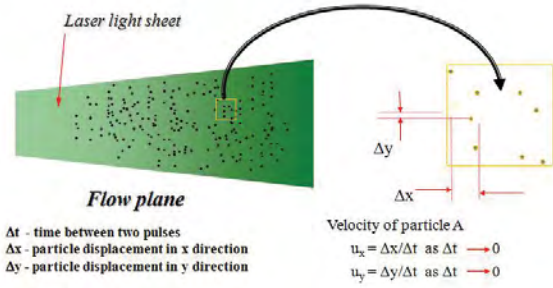
How it Works: PIV

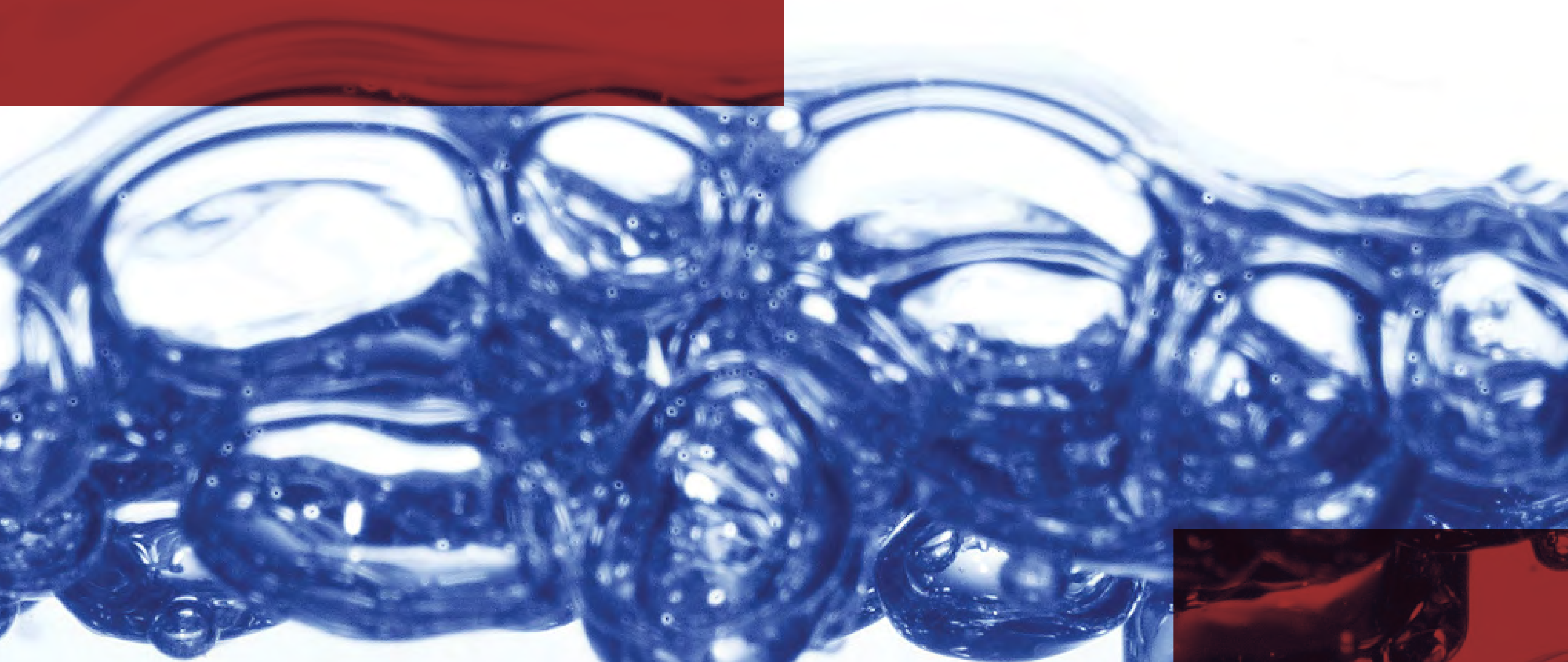
- Use of small tracer particles to follow fluid flow
- Images of particle positions, illuminated by a pulsed laser, are captured at separate times
- Particle displacements are calculated across Δt, the time between laser pulses, to determine velocity
- Measurement at many points at one instant of time
- Instantaneous vector fields are produced while time averaged statistics are obtained by averaging many image fields

*US Patent #6653651

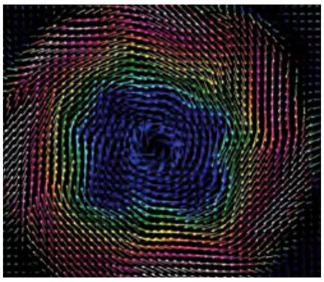


2D PIV system with a single camera and laser for planer 2D velocity field measurements.

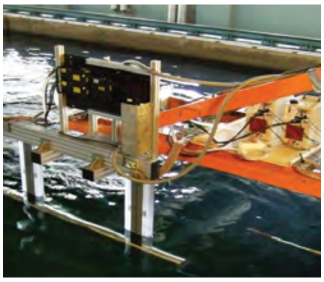




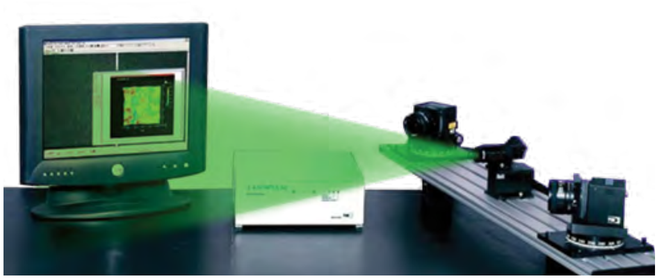
PIV System:
Diverse Applications and Measurement Results



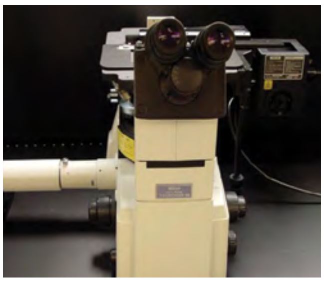
3-D planar velocity field of flow behind a propeller captured by tow tank PIV system, INSEAN, Italy



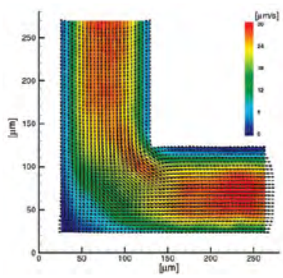
Underwater Towing Tank PIV system, Potsdam, Germany



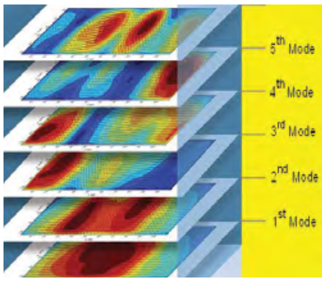
Stereo PIV system



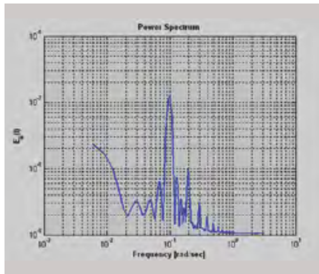
Micro PIV system using an inverted microscope



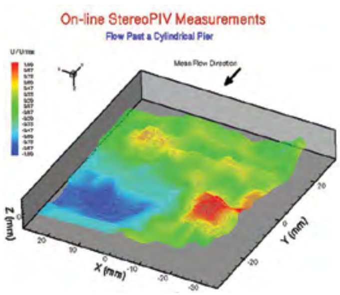
Velocity field in a 200 micron 90-deg channel, University of Tokyo, Japan



Proper Orthogonal Decomposition Analysis for Non-steady flow field captured by TR-PIV



Power spectrum and Autocorrelation function of non-steady flow field captured by TR-PIV



Stereo PIV measurement of flow past a cylindrical pier, South Dakota State University, USA

Global Imaging Systems for Measurement Diagnostics

Planar Laser Induced Fluorescence (PLIF for Simultaneous Velocity and Scalar Measurements)

PLIF systems from TSI provide measurements of scalar quantities: concentration, temperature and combustion, in addition to fluid velocity in a flow which is needed to understand flows and their transport behavior. Similar to the measurement technique behind TSI's Particle Image Velocimetry (PIV), extending a PIV system to allow for measurement of some scalar quantities is easy!

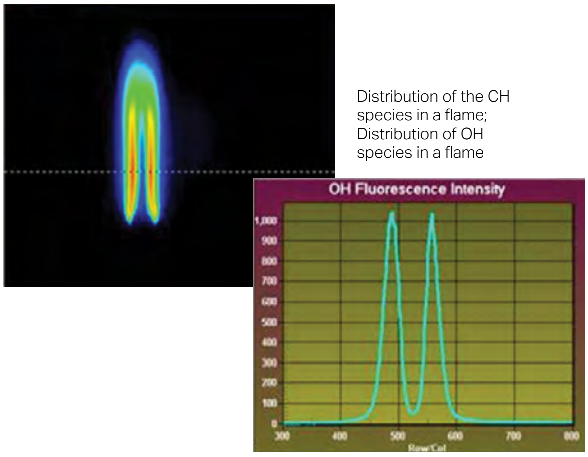
How it Works: PLIF

- A flow is seeded with miscible species, which mix with any species naturally present, and absorb laser light in a plane
- The absorbed light, relative to the wavelength of the laser, excites the species to a higher energy state until it decays, causing the species to fluoresce
- The fluorescent light is then collected by a camera and analyzed to relate the light intensity to temperature or concentration, depending on the properties of the fluorescing species and other species present in the flow
- Finally, in-situ calibration using multipoint ratio metric and linear curve fit methods, interpret the intensity scales captured by the camera to the scalar quantity

PLIF and Combustion Species

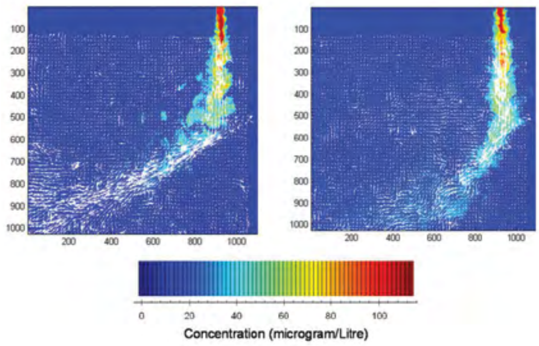
PLIF measurements of combustion species (i.e. NO, CH, OH and CO) require a Tunable Dye laser as the light source. The tunable dye laser allows the proper excitation wavelength of a particular species to be selected and ultimately measured.

PLIF System using dichoric color separation arrangement for measuring velocity and scalar quantity

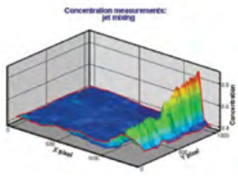


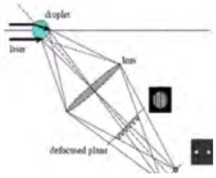
Distribution of the CH species in a flame; Distribution of OH species in a flame

Plot of velocity and concentration of an impinging jet



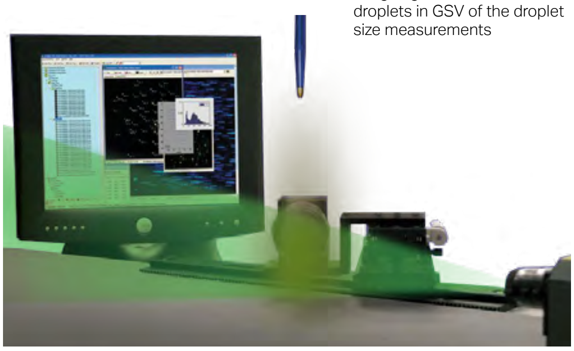
3D representation of the concentration of the jet





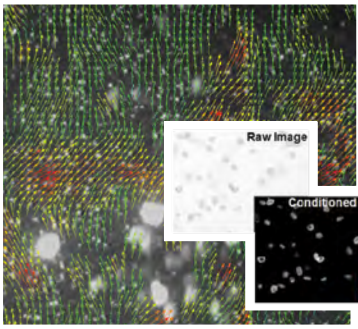
Schematic of Interferometric oscillation depicts the scattered light, generated by the light sheet on a droplet, to give the droplet size

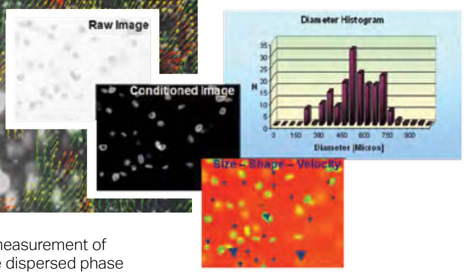
Fringes generated from the droplets in GSV of the droplet size measurements



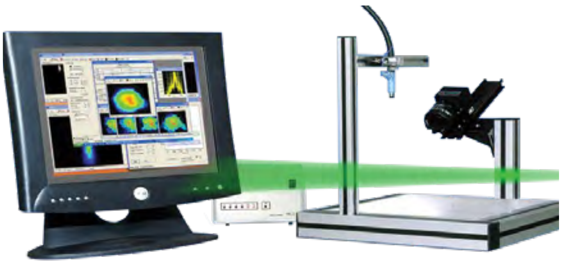
Major components of the GSV system

Measurement of the size, shape and velocity by the Insight SSA module





Velocity measurement of one of the dispersed phase



System arrangement of the Spray Diagnostic System

Global Sizing Velocimetry (GSV) system
Global Measurement of droplet size and velocity of a spray is best performed using the Global Sizing Velocimetry (GSV) system* from TSI. GSV is based on the interferometric scillation of light scattering from a droplet to provide the accurate measurement of the droplet size. Using the particle tracking technique, which requires two image captures of the droplet field, the velocity of the droplet can also be measured. TSI's GSV system is also very similar to the PIV setup- only a few additional accessories are needed to expand the PIV system hardware to be GSV compatible.

Size Shape Analysis (SSA) Package
The Size/Shape Analysis package included in TSI's Insight 4G software is ideal for measuring the size and shape of a dispersed phase in multi-phase flow environment. Like TSI's PLIF and GSV Systems, SSA measurements require a set up very close to that of TSI's PIV package. In fact, only the illumination of the dispersed phase changes from a sheet (PIV system) to a volumetric illumination (SSA system) in order to measure properties of irregularly shaped droplets / particles / bubbles, including:

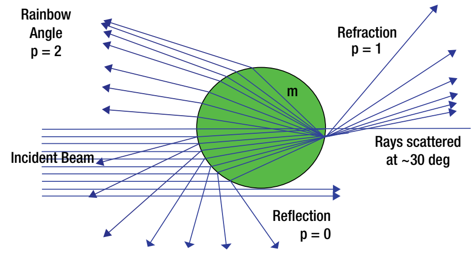
- Displacement and Velocity
- Mean Diameter
- Major and Minor Ellipse axes
- Ellipse Angle (Orientation)

Global Spray Diagnostic of Dense Spray Based on PIV's Optical Patternation Technique
This measurement technique utilizes a laser light sheet to illuminate a spray section while a camera captures the intensity of illumination in order to obtain the distribution of the droplet concentration. The concentration is representative of the size or mass distribution. Typically measurements in the vertical and horizontal sections of the spray are of interest, given the pattern of the spray (spray angle and patternation) in both orientations.

*US Patent #7362421

Laser Diagnostics of Velocity and Particle Sizing

Phase Doppler Particle Analyzer (PDPA) Systems
TSI's Phase Doppler Particle Analyzer (PDPA) system is a non-invasive laser based technique for the simultaneous measurement of velocity and particle size of a spray. The principle of size measurement is based on the detection of the phase difference using three detectors to determine when the particle goes through the measurement volume and subsequently passes through the intersection of two laser beams.

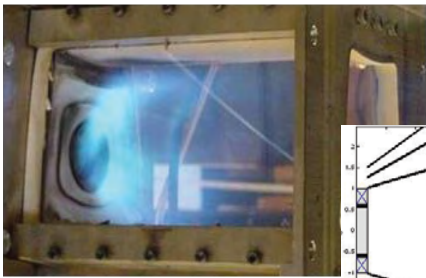


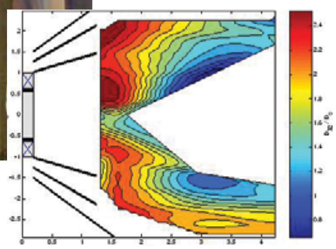
Light scattering from a spherical droplet. Collection of scattered light at 30 deg is typically used for Phase detection.

How it Works: PDPA

- Laser beams are delivered from the Powersight Module and cross to form the measurement volume where the velocity and size analysis take place
- Phase analysis is then made with the Optical Receiver, which provides size information
- Velocity measurements using TSI's PDPA system range from mm/s to thousands of m/s dependent upon the optical arrangement; particle size measurements span 0.5 micron to a few mini-meters

Two optical arrangements are available for PDPA — Itasca laser module and Powersight module. The Itasca laser module includes integrated laser to provide two laser beams readily to be coupled to a transmitting probe, while the Powersight module is an integrated laser with receiving optics to provide the two laser beams for PDPA.



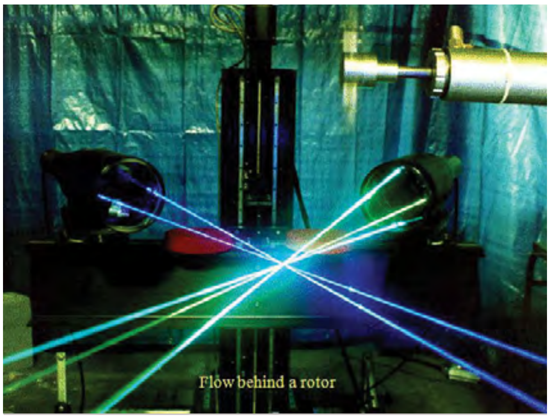


PDPA measurement of a Lean Low NOx Aircraft Combustible spray with SMD result, Georgia Institute of Technology, USA

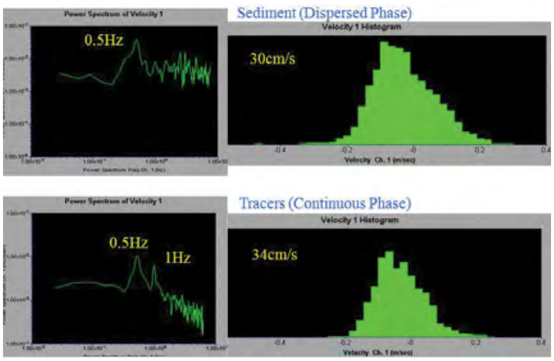
LDV arrangement also offers the Itasca laser module or Powersight module as the optics. The Itasca module is readily coupled to any transceiver fiber probe for the velocity measurement. The Powersight, as a standalone module, includes the receiving optics for LDV.

Laser Doppler Velocimeter (LDV) Component Systems
Laser Doppler Velocimetry (LDV) is an optical, laser based technique used to measure velocity at a single point with very high spatial resolution. LDV is a non-invasive method that provides accurate measurement with high frequency response. This measurement technique can be employed for flows in wind tunnels, water tunnels, open channels, hostile environments, and other areas where all three components of velocity data are required.

How it Works: LDV
- Seed particles - suspended in the flow field - pass through the measurement volume where fringes are formed based on the intersection of the two laser beams, and generate a Doppler signal detected by an optical probe
- The Doppler signal is then analyzed to measure the frequency of the signal
- Once the frequency is known, the velocity is simply the product of the fringe spacing and the frequency of the Doppler signal.
- The system can be configured to measure 1 to 3 components of velocity and with range from mm/s to thousand of m/s dependent upon the optical configuration.

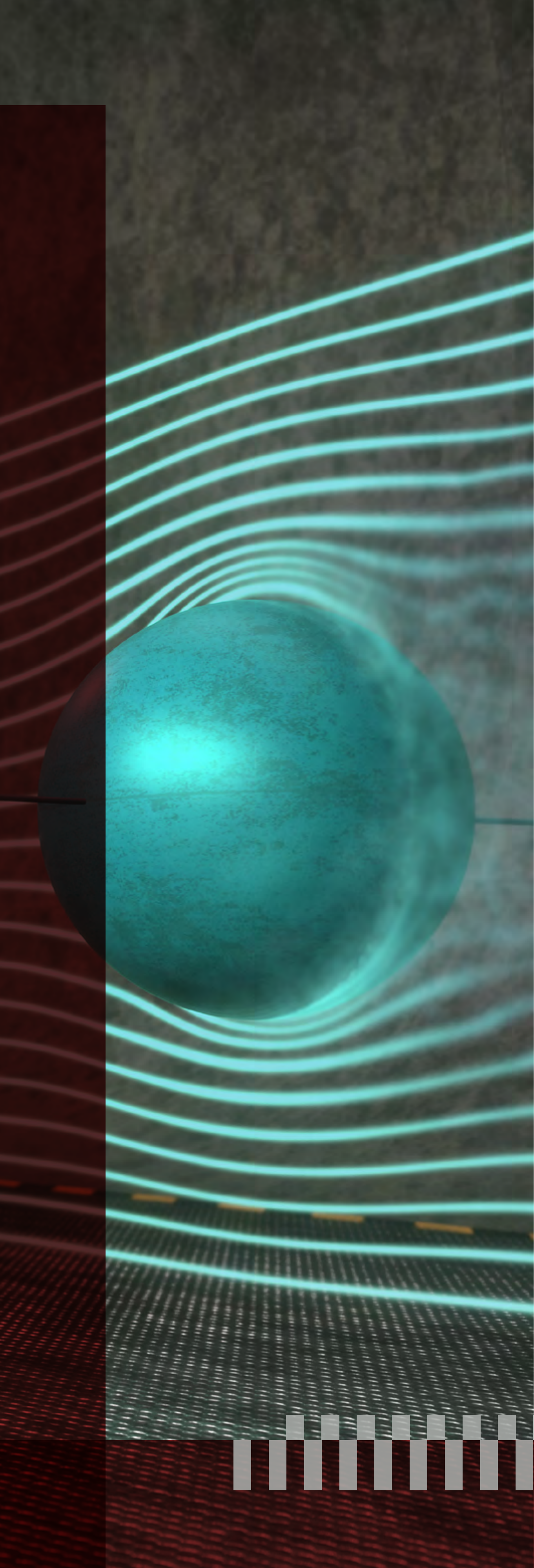


LDV with two optical probes for 3-component of velocities for flow behind a rotor, University of Maryland, USA



Two velocity histograms from the Sediment and the Tracers (water) in a sedimentation flow model. Uses intensity separation to identify the two phases

System layout of a 2D Itasca-based PDPA System with FSA Signal Processor



Thermal Anemometry for Turbulent Flow Diagnostics

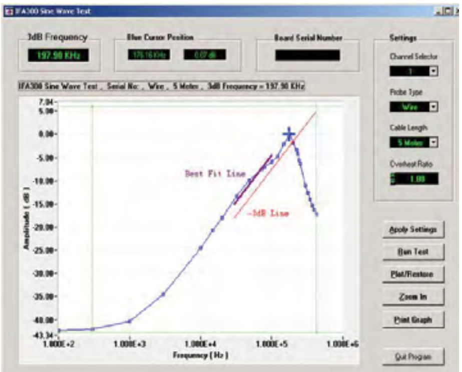
Thermal Anemometers (not available in all countries)
Thermal anemometry is a technique requiring a sensor to measure velocity at a single point with high accuracy and high frequency response. A typical thermal anemometry system has two major components, the Control circuit and the sensor. The Constant Temperature Anemometer is the control circuit for the thermal anemometry system.

There are many different types of sensors, wire or film, for 1D, 2D, and 3D velocity components, and for gaseous lows.

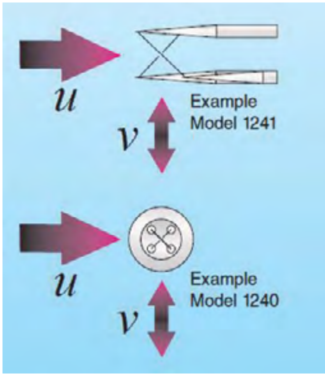
The thermal anemometry system is an excellent tool for turbulent flow because of its high frequency response to measure the fluctuation of the flow and there are many versions of sensors used in different flow environments. 1D, 2D and 3D sensors for gaseous and liquid flows are offered. There are also the sensor type, wire or film sensor, to match the required frequency response of the flow. Proper selection of the sensor is critical to the success of the measurement. Typical velocity range for a thermal anemometry system is from a few cm/s to hundreds of m/s.

Features and Benefits
- Single Point measurement with sensor for velocity range from cm/s to hundreds of m/s
- Good spatial resolution and high frequency response
- 1, 2 and 3 components of velocity with proper sensor type
- Even time sampling with high sampling rate
- Power spectrum and statistics of flows are measured m/s

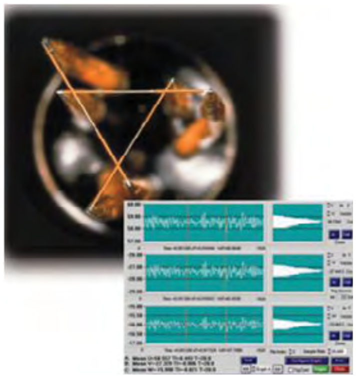
How it Works: Thermal Anemometry
- Thermal Anemometry requires that a sensor be heated to a specific high temperature
- When the sensor is exposed to a flow, it is cooled and the amount of current needed to maintain its original temperature is an indication of the velocity around the sensor
- A calibration is performed to relate voltage to velocity



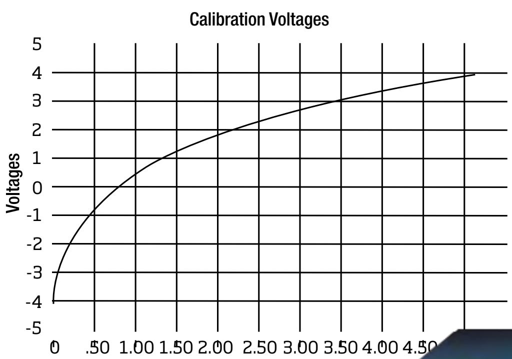
Power spectrum plot of a typical measurement
from a wire sensor in a wind tunnel flow



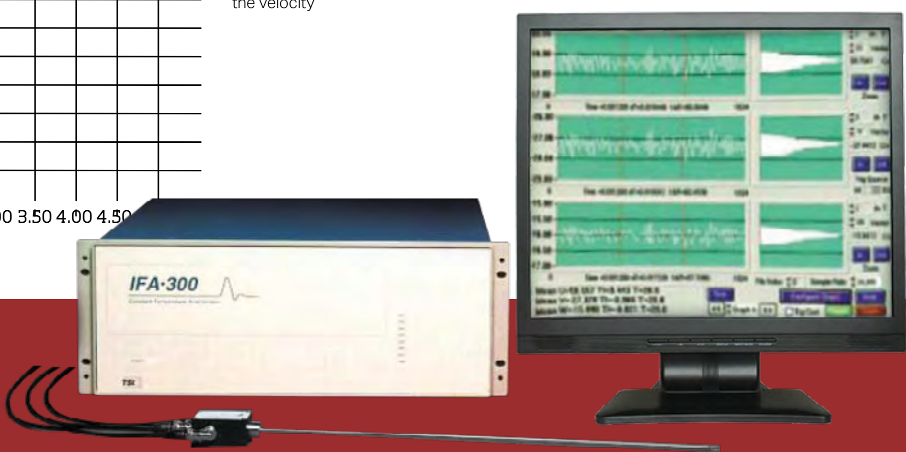
Orientation of the sensor to
the flow measurement



A typical result for a 3D sensor



Typical calibration curve to
relate the voltage output
from the anemometer and
the velocity



System layout with the control circuit
of anemometer, sensor and software

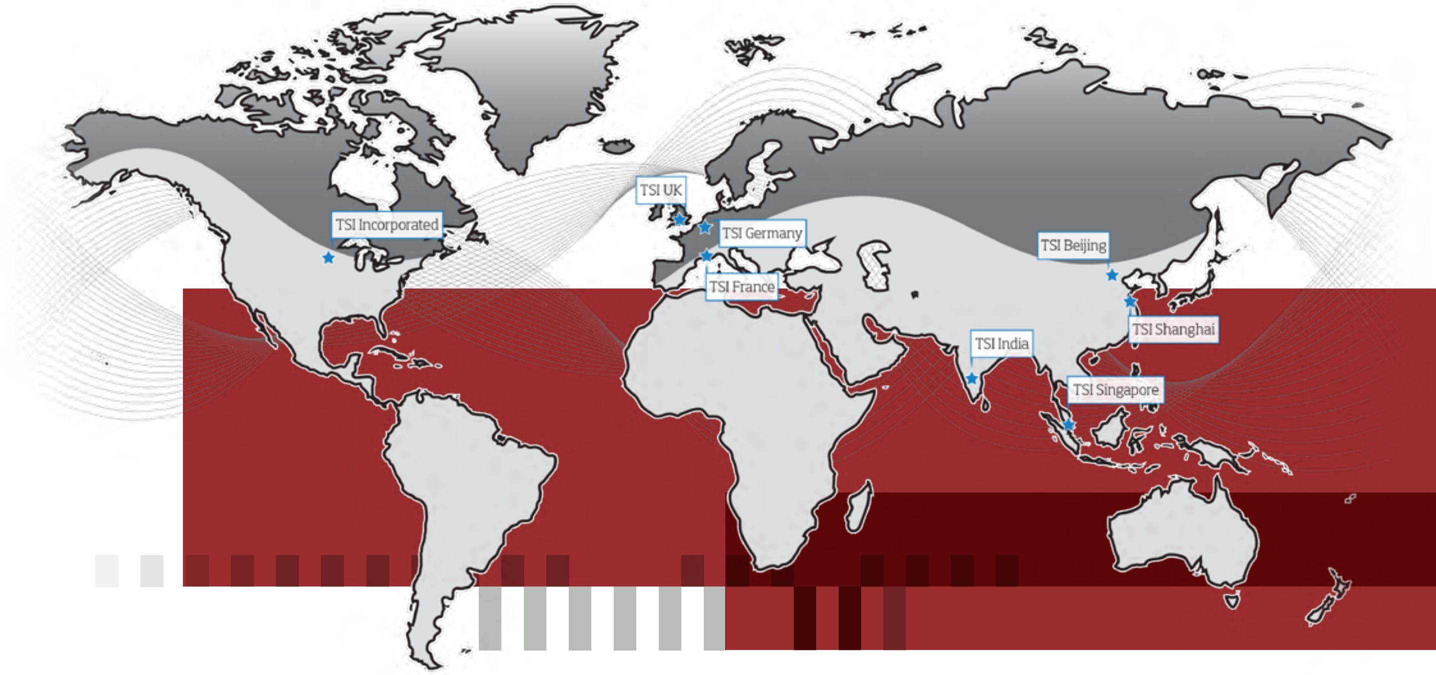
Fluid Mechanics Family Brochure

About TSI®
TSI® designs and manufactures innovative precision instruments to measure flow, turbulence, temperature, particulate and many other key parameters. TSI® serves the needs of industry, governments, research institutions, and universities, with applications ranging from pure research to primary manufacturing. Every TSI instrument is backed by our unique blend of technical expertise and outstanding quality.

TSI's world-wide presence provides technical application support to make sure you get the help needed to resolve your research problems. Our work culture gets employees out from behind desks and into the field. We hold customer-training sessions, sponsor workshops and conduct product demonstrations, serve on standards committees relating to product usage, and participate in a wide variety of technical conferences.

TSI researchers and engineers have granted more than 100 patents and have a proven record of developing instruments that are the finest, often the only, and always the best of their kind. Our staff and products are involved in current global issues such as diesel exhaust reduction, biohazard protection, homeland security, environmental pollution, workspace comfort and facility monitoring. Data provided by our instruments are used in monitoring and research applications destined to have long-term impact on humankind and the world around us.

Quality
TSI Inc. is ISO 9001:2015 registered meaning TSI's production, service, calibration, and checkout procedures comply with the requirements of ISO 9001 and are audited against those criteria.



Knowledge Beyond Measure.

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