

# THE EXTENSIVE CAPABILITIES OF INSTANTANEOUS, TRULY VOLUMETRIC VELOCIMETRY

V3V™ SYSTEM



UNDERSTANDING, ACCELERATED

# BRINGING FLOW MEASUREMENTS TO THE NEXT DIMENSION

Since its launch, TSI's award winning V3V™ Volumetric 3-Component Velocimetry System\* has been used extensively in many fluid flow research studies. Its unique ability to instantaneously capture the fluid velocity field in a volume offers the most detailed flow structure imaging available, allowing researchers to uncover new insights into the field of fluid mechanics. The V3V™ system's superior volumetric measurements truly are the next generation in fluid flow research.

## Design Features

- + Flexible camera arrangement allows for multiple cameras (2-8) to be positioned in any orientation for optimal viewing.
- + Integrated frame design with 3 removable cameras.
- + Continuous data capture at full frame rate for up to allow flow statistics and higher order quantities to be measured, even for transient flow situations.
- + Patented aperture encoded technique identifies particles in locations in 3D volumetric space accurately with microv-level precision.
- + Highest resolution of 3D tracking techniques.
- + Support high resolution and high speed cameras for capture rate from 10 Hz to 50 kHz in time-resolved measurements.

## Countless Applications

- + Hydrodynamics
- + Aerodynamics
- + Environmental
- + Fundamental Flow Research
- + Biocomotive

\* R&D 100 Award 2008

\*\* US Patent # 6278847 #7006132



## Environmental

Recently, environmental scientists have benefited greatly from TSI's V3V™ system's ability to obtain volumetric measurements. The V3V™ system's immediate quantitative visualization of a multitude of flow behaviors allows researchers to improve the design of wind turbines and better understand pollution transport, improving the environment and the lives of many.

### Effect of Flow Distribution by Wind Turbine

"Water-turbine experiments are being performed to better understand the 3D structure of the turbulent flow inside the wake of a single and an array of water turbines placed in a laboratory flume. The V3V™ system is a key component of this research. It clarifies a number of questions related to the structure of the flow behind a horizontal-axis turbine, and its capability to characterize the (3D) flow is helping us to develop new parameterizations."

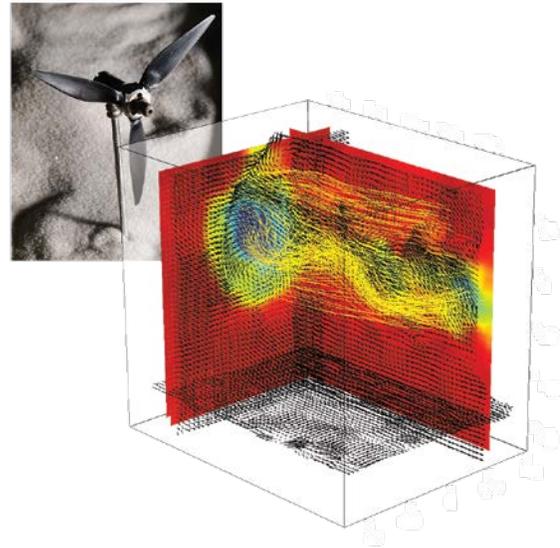
Leonardo Chamorro,  
St. Anthony Falls Laboratory,  
University of Minnesota, USA

### Pollution Transport in Urban Areas

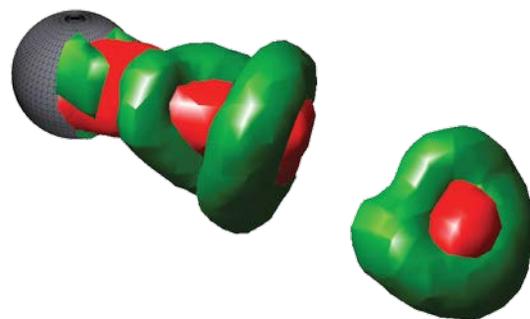
"With the global climate migrating toward more eco-friendly policies, there is a stronger push in recent times for accurate ways of understanding and clarifying pollution transport in urban environments. V3V™ was used to examine a surface mounted obstruction within a simulated atmospheric boundary layer. Three-dimensional velocity data expands significantly on previous 2D data of these phenomena."

Dr. Wing Lai,  
TSI Incorporated

Reference: TSI Application Note V3V-006, Sphere-Wake.



The wake downstream of a water turbine is shown. Flow is from left to right. Slices represent streamwise velocity, with red indicating high speed and blue indicating low speed.



Vortex shedding downstream of a sphere in water ( $Re = 2500$ ). Flow is from left to right. Green isosurface represents vorticity magnitude and red isosurface represents slower moving fluid.



# SUPPORT DESIGN WITH TRULY VOLUMETRIC MEASUREMENTS

## Hydrodynamics

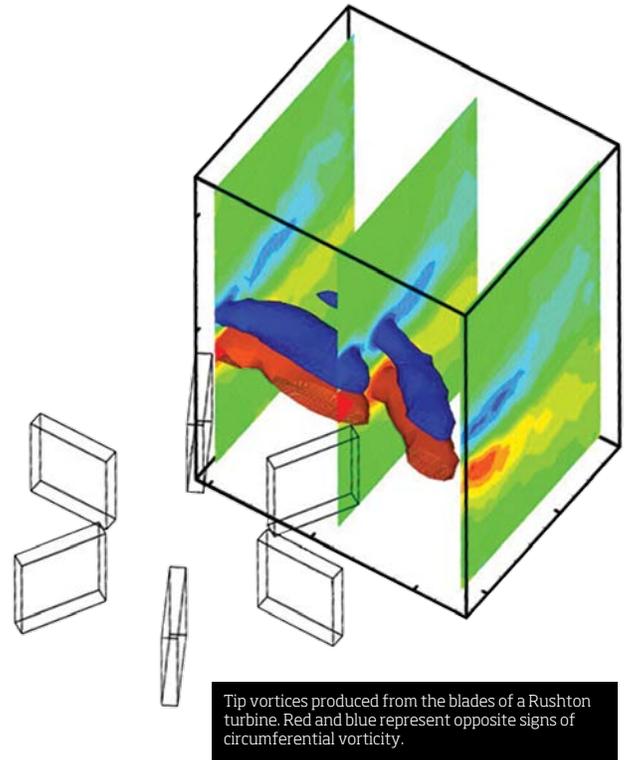
Three dimensional data in fluid dynamics flow studies are essential when designing ships and propellers, as well as mixing instruments. Capturing such data, however, has long been a challenge. Now, thanks to V3V™ system's unique ability to provide underwater measurements, three dimensional imaging of the entire flow structure is easily achieved. As a result, the design of many products has been optimized based on more comprehensive fluid dynamics studies.

## Characterization of Rushton Turbine for Mixing

"Volumetric 3-component velocimetry measurements have been taken of the flow field near a Rushton turbine in a stirred tank reactor. This particular flow field is highly unsteady and three-dimensional, and is characterized by a strong radial jet, large tank-scale ring vortices, and small-scale blade tip vortices. The volumetric nature of the data enables tip vortex identification, vortex trajectory analysis, and calculation of vortex strength."

Prof. Kendra Sharp  
Mechanical, Industrial, and  
Manufacturing Engineering,  
Oregon State University, USA

Reference: Sharp K., Hill D., Troolin D., Walters G., and Lai W. (2009) "Volumetric 3-component velocimetry measurements of the turbulent flow around a Rushton turbine," *Experiments in Fluids*, 48(1), pp. 167-183.

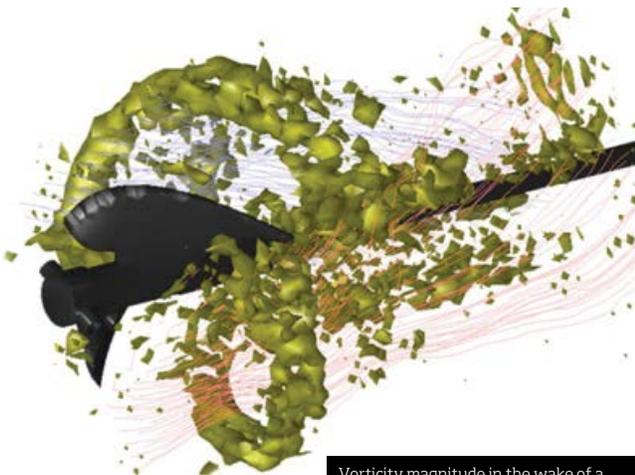


Experimental setup showing V3V™ system camera and Rushton Turbine.

## Characterization of a Propeller

"Volumetric 3-component flow measurements provide complete insight into the fluid flow structure, and are a long-awaited capability in fluid mechanics research. Over the years there have been many attempts to develop an appropriate technique for such measurements. Based on my interaction with the V3V™ system, this capability is finally realized. The measurement domain of up to 140 mm by 140 mm by 100 mm is significant and it represents a major advance in volumetric flow measurements. In fact, it is quite rare in any scientific measurement for a leap in capability of more than an order of magnitude to occur, as has been accomplished with the size of the volumetric domain that can be measured with the V3V™ system."

Leonardo Chamorro,  
St. Anthony Falls Laboratory,  
University of Minnesota, USA

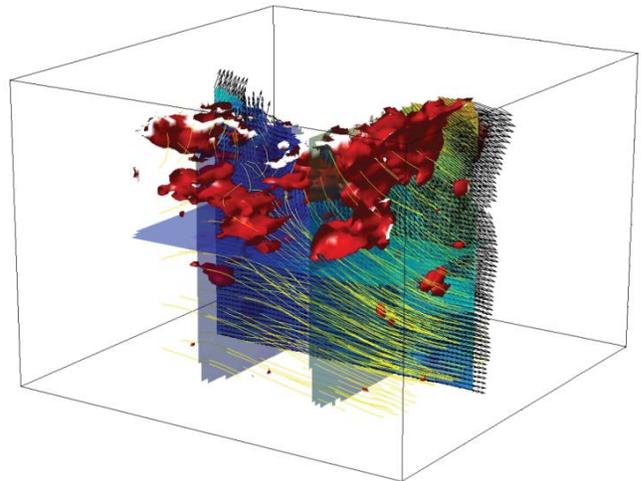


Vorticity magnitude in the wake of a model ship propeller with streamlines.

## Wave Formation Study

"The measurement of wave formation and relevant studies related to our water flume facility will be enhanced by the ability of the 3D3C measurements using the V3V™ system. The system has demonstrated the capability of getting the desirable results, which is critical to our investigations in many of the designs of hydraulic facilities."

Researcher, Zhejiang  
Institute of Hydraulics &  
Estuaries, China



Vorticity isosurfaces and streamlines indicate the velocity near the air-water interface of a surface wave.

# INSIGHT TO PREDICT AIRFOIL AND BLUFF BODY PERFORMANCE

## Aerodynamics

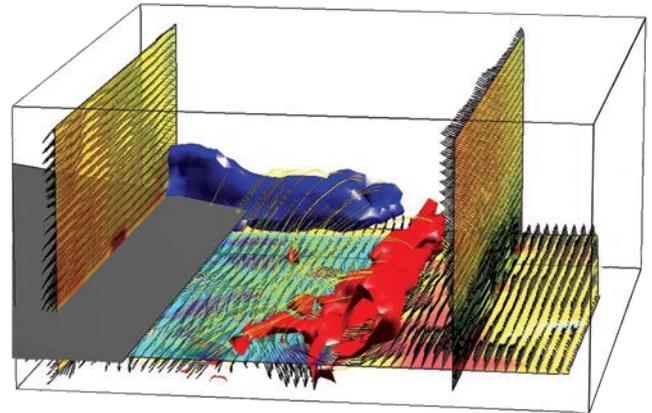
Airfoils and bluff bodies of varying design have been tested by researchers under many different conditions for decades, but because the flow separation and the wake is very three-dimensional, existing measurement technologies have been found lacking. V3V™ system's 3D3C system finally provides researchers with truly volumetric velocimetry measurements needed in complex aerodynamics research.

## Moving Airfoil - Investigation of the Tip Vortex and Flow Separation

"Under these conditions a mid-chord and stable laminar separation bubble (LSB) occurs on the suction side of the airfoil. As in former investigations by means of Particle Image Velocimetry (PIV), the present study focuses on the unsteady 3D topology of the bubble. For this reason, the time-resolved Volumetric 3-Component Velocimetry (V3V™ system) technique was applied, which is highly capable of capturing a truly volumetric velocity distribution instantaneously in a nearly cubic volume."

Prof. Christian Kähler,  
Institute for Fluid Mechanics  
and Aerodynamics, Bundeswehr  
University Munich, Germany

Reference: Wolf E., Kaehler C., Troolin D., Kykal C., and Lai W. (2009) "Time-Resolved Volumetric Separation Measurement in a Towing Tank using the TSI V3V Measurement System," 8th International Symposium on Particle Image Velocimetry, Melbourne, Victoria, Australia, August 25-28, 2009.

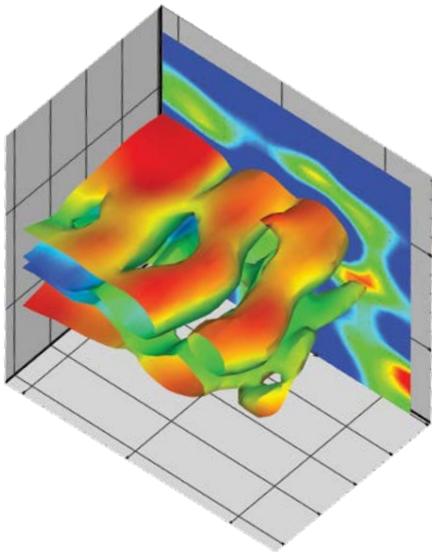


Starting vortex (red) and tip vortex (blue) generated from an impulsively initiated airfoil (gray).

## Gurney Flap for Lift Enhancement

"The presence of a Gurney flap on the trailing edge of an airfoil leads to an increase in lift with a negligible increase in drag for moderately sized flaps (approximately 2% of the airfoil chord length). Volumetric velocity data is extremely important in understanding the effect of the Gurney flap on the spanwise velocity and the transport and propagation of vortical structures generated near the trailing edge and in relating fluid structures to the increased lift increment."

Dr. Dan Troolin,  
Department of Aerospace  
Engineering and Mechanics,  
University of Minnesota, USA



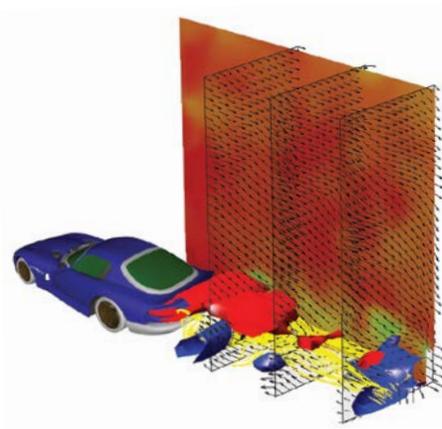
Isosurfaces of vorticity magnitude in the downstream wake of an airfoil with a Gurney flap colored by velocity magnitude. Flow is from left to right.

## Aerodynamics of Automobile Design

"Wakes generated by automobiles are highly three-dimensional and inherently complicated due to the presence of drag-inducing structures such as rearview mirrors and wheel wells. Volumetric 3-Component Velocimetry provides insight into the turbulent wake and the relation to the resulting drag which is essential to the development of more efficient vehicles."

Dr. Mike Khoo,  
TSI Singapore

Reference: TSI Application Note V3V-007, Automobile Wake.



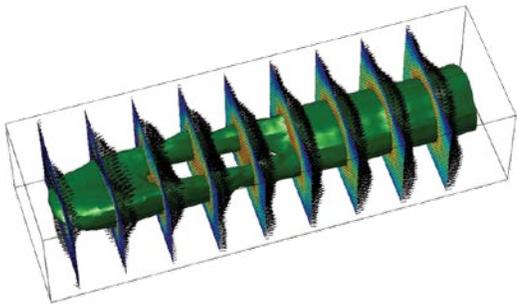
Wake downstream of a car. Red and blue indicate opposite signs of spanwise vorticity.



# EXPANDING RESEARCH BOUNDARIES WITH RELIABLE AND REPEATABLE RESULTS

## BioMedical

BioMedical investigations on heart valves and other medical devices using the V3V™ system provide detailed three-dimensional flow structure– including isosurfaces of vorticity and velocity– behind the valve at various phase locations relative to its opening. The complete, graphic data generated with TSI's V3V™ system allows researchers to test the design of these complex, life saving mechanisms, identify deficiencies, and strengthen the performance of many critical instruments.



Flow from left to right downstream of an artificial mechanical heart valve. Green isosurface represents velocity magnitude.



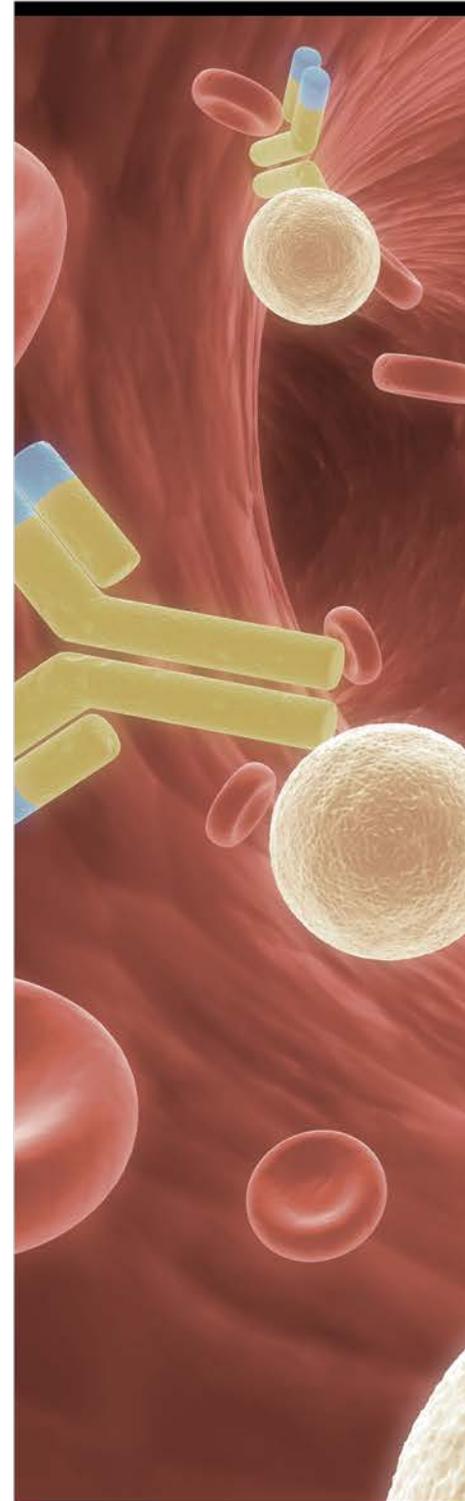
Streamlines indicating flow direction during the closed phase inside an artificial deformable silicone polymer heart valve.

## Mechanical Heart Valve Study

“Biological flows can be spatially complex having three-dimensional features, such as the flow through a prosthetic heart valve. These three-dimensional flows may affect transport of blood and its components. The V3V™ system was used to fully reconstruct an instantaneous three-dimensional flow field surrounding a St. Jude Medical mechanical bileaflet valve. The results confirmed published measurements obtained with conventional planar PIV under steady flow. The time evolution of the three-dimensional flow across a transparent silicone polymer valve throughout a normal cardiac cycle was reconstructed with the V3V™ system. These instantaneous three-dimensional flow measurements can be used to optimize the design of prosthetic heart valves and other bioprosthetic devices.”

Dr. Devesh Amatya,  
Department of Biomedical  
Engineering, University  
of Minnesota, USA

Reference: Troolin D., Amatya D., and Longmire E. (2009) “3D3C Velocity Measurements Downstream of Artificial Heart Valves,” 8th International Symposium on Particle Image Velocimetry, Melbourne, Victoria, Australia, August 25-28, 2009.



## Fundamental Flow Research

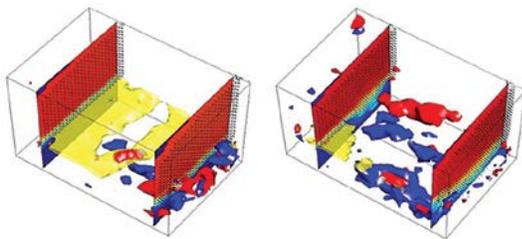
The V3V™ system has proven to be essential for fundamental fluid flow research on turbulence, flow separation, boundary layer and wake flow due to its ability to capture 3D flow structure in a true volumetric region. The complete three dimensional quantitative flow field allows the researchers to explore new information in its entirety and further verify existing models. Any external effect, for example the presence of a wall, is captured together with the main flow field which is often lacking in traditional methods.

## Flow Downstream of a Backward Facing Step

"Separated flows are of particular interest in the field of fluid mechanics due to their prevalent nature in a wide variety of engineering applications, for example in civil engineering, the flow downstream of a dam or bridge pillion. The use of vortex generators to increase the streamwise vorticity within a separating boundary layer, increase the fluid momentum near the surface, and delay separation, are being used more frequently. The V3V™ system allowed for the investigation of the vorticity field completely to decide on the effectiveness of the vortex generator."

École Supérieure de Physique  
et de Chimie Industrielles,  
Paris, France

Reference: TSI Application Note V3V-005, Smoothly Contoured Ramp with Vortex Generators.



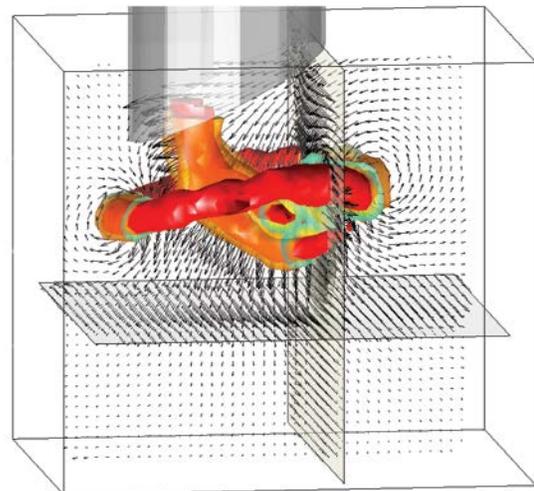
Isosurfaces of vorticity of flow at a backward facing step.

## Vortex Ring From an Inclined Exit

"Vortex rings generated by impulses occur in many environmental, biological, and industrial applications. The flow associated with vortex rings generated from axisymmetric boundary conditions has been studied extensively and yields a standard primary vortex ring that propagates downstream at a constant velocity and a lingering trailing ring of opposite sign associated with the stopping of the piston. By contrast, an inclined nozzle yields a much more complicated set of vortices. Using V3V™, we were able to elucidate the entire, time-resolved, 3D fluid structure that consists of two trailing vortex ring structures, which initially have circulation of opposite sign, intertwining and distorting while being drawn through the center of the primary ring."

Prof. Ellen K. Longmire,  
Department of Aerospace  
Engineering and Mechanics,  
University of Minnesota, US

Reference: Troolin D.; Longmire E. (2009) "Volumetric Velocity Measurements of Vortex Rings from Inclined Exits," Experiments in Fluids, 48(3), pp. 409-420.



# UNRAVELING NATURAL PROCESSES

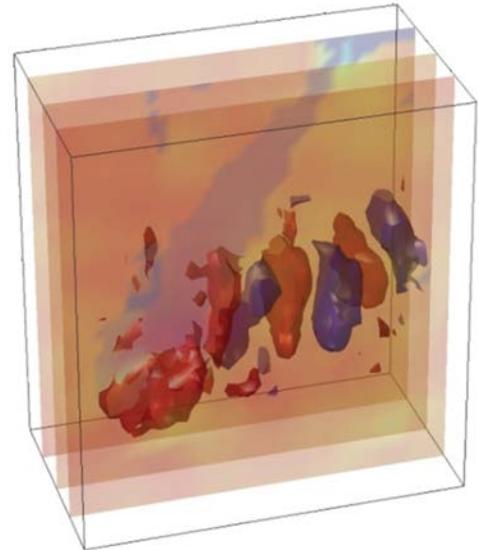
## **Biocomotion**

Understanding of the fluid motion generated from fish species is of much interest to both biologists and engineers who wish to design improved robots or mechanisms to simulate the actual live species. With its rapid processing, the V3V™ system provides instantaneous, high resolution imaging of the wave structure created by the fluid motions of a fish like never before.

## **Black Ghost Knifefish Locomotion**

"I study fishes and squids that produce complex, 3D vortex flows as they swim using coordinated motions of their multiple propulsors and systems. Providing real-time, 3-component velocity field measurements in a true volumetric domain, the V3V™ system is a powerful tool for characterizing and quantifying the three dimensionality of these wake structures and for understanding how these animals locomote in their respective environments."

Prof. Ian Bartol, Department  
of Biological Sciences, Old Dominion  
University, USA



Propulsive wake generated by a ghost knifefish. The outline of the fish can be seen as the blue region in the transparent slices. Isosurfaces of red and blue indicate opposite signs of bottom-normal vorticity.

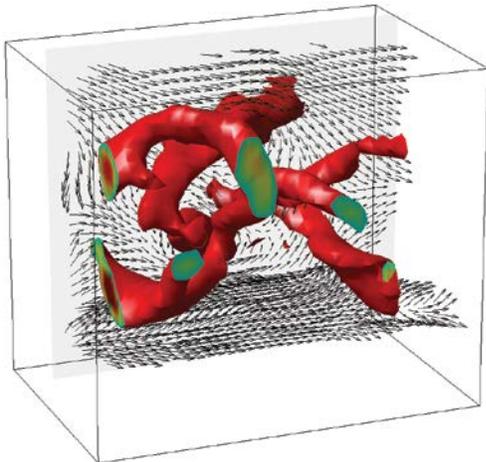


## Fish Simulation

"Flow patterns around fish and other aquatic animals have revealed interesting phenomena which have been used in the development of underwater vehicles, and in the study of the ways in which fish travel, feed, and escape. In this application, V3V™ was used to determine the primary flow features in the wake of a simulated fish, including a twisting leading edge vortex, as well as vorticity oriented along the streamwise direction shed from the trailing fin."

TSI Representative,  
TSI Incorporated

Reference: TSI Application Note V3V-009, Simulated Fish.



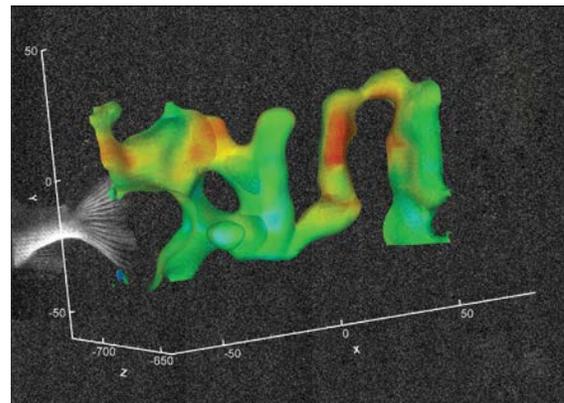
Vortical structures in the downstream wake of a simulated fish. Flow is from left to right.

## Measurements of Blue Gill Fish Movement

"Previous studies concerning the hydrodynamics of wakes produced by swimming fishes have relied on two-dimensional PIV to hypothesize the vortex structure. Now, using the V3V™ system, we have confirmed that the three dimensional structure of the vortex ring produced by the homocercal tail fin is indeed as predicted. In addition, multiple lateral passes of the tail produced a linked chain of vortex rings. V3V™ has enabled us to instantaneously capture the three-dimensional wake interactions of the dorsal and anal fins with the caudal fin in both live fishes and robotic analogs."

Prof. George Lauder,  
Museum of Comparative  
Zoology, Harvard  
University, USA

Reference: Flammang B., Lauder G., Troolin D., and Strand T. (2010)  
"Instantaneous Volumetric Wake Analysis of Locomotion in Teleost Fishes,"  
Best Poster, SICB Conference, Jan. 2010.



The wake generated by a bluegill is superimposed on the actual data image. The caudal fin of the fish is visible on the left. Isosurfaces are vorticity magnitude colored by streamwise velocity.

# THE TECHNOLOGY

## BEHIND TSI'S V3V™ SYSTEM



	V3V-9000-TS	V3V-9000-CS	V3V-Flex
<b>Number of Cameras</b>	3	3	2 to 8
<b>Camera type</b>	High resolution camera with pixel resolution up to 24 Megapixels	High resolution camera with pixel resolution up to 29 Megapixels	+ High pixel resolution cameras with up to 29 Megapixels + High frame rate cameras with frame rate up to 50 kHz
<b>Laser</b>	High energy lasers pulsed dual cavity Nd:YLF laser		High speed pulsed lasers + Dual-cavity Nd:YAG laser with up to 400 W power and 50 kHz pulse rate + Dual-cavity Nd:YLF laser with up to 100 W power and 5 kHz pulse rate  Low-speed Nd:YAG laser + Dual-cavity laser up to 400 mJ energy per pulse and pulse frequency of up to 15 Hz
<b>Calibration system</b>	V3V-CAL-TS calibration module; target of 100 mm by 100 mm with dot spacing of 2 mm	V3V-CAL calibration module; target of 200 mm by 200 mm with dot spacing of 5 mm	V3V-CAL calibration module; target of 200 mm by 200 mm with dot spacing of 5 mm and 100 mm by 100 mm target with dot spacing of 2 mm
<b>Camera Mount (PCM)</b>	V3V-9000-TS mount with camera lenses	V3V-9000-CS mount with camera lenses	Flexible frame arrangement using Bosch rails
<b>Synchronization</b>	Synchronizer timing unit with 0.2 ns resolution		
<b>Capture and analysis software</b>	Insight V3V 4G image capture and analysis software package		
<b>Sample Applications</b>	+ Turbulent Structure measurements + Boundary layer flows + Flows interaction with airfoil	+ Coherent Structure measurements + Wake flows; propellor flows + Flows of biolocomotive	+ Turbulent boundary layers + Flow/body interactions + Internal flows + Biological flows

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