07121 Abstracts Collection
Experimental Fluid Mechanics, Computer Vision & Pattern Recognition
— Dagstuhl Seminar —

Etienne Mémin[1], Christoph Schnörr[2] and Cam Tropea[3]

[1] INRIA Rennes, F
[2] Univ. Mannheim, DE
[3] TU Darmstadt, DE
ctropea@sla.tu-darmstadt.de

Abstract. From .. to .., the Dagstuhl Seminar 07121 "Experimental Fluid Mechanics, Computer Vision & Pattern Recognition" was held in Schloss Dagstuhl – Leibniz Center for Informatics. During the seminar, several participants presented their current research, and ongoing work and open problems were discussed. Abstracts of the presentations given during the seminar as well as abstracts of seminar results and ideas are put together in this paper. The first section describes the seminar topics and goals in general. Links to extended abstracts or full papers are provided, if available.

Keywords. To be done

Stochastic Estimation Techniques for Turbulent Flows

One of the many challenges for studying the coherent structures that are responsible for the turbulent transport of heat, mass and momentum through the mean flow is the ability to not only capture the fully three dimensional structure, but also its dynamical characteristics. To circumvent this obstacle, stochastic estimation techniques, originally introduced in the 1970's, continues to provide alternative means by which the experimentalist can study both. A general background to Stochastic Estimation techniques is presented in the context of modeling turbulent flow events from unconditional sources. Different forms of the technique will be covered, including linear, quadratic, spectral, and multi-time analysis, as they have been developed for different scientific objectives and offer a toolbox of analytical instruments for predicting the dynamical mechanisms of turbulent structures.

Keywords: Stochastic Estimation; coherent structures; turbulent flows; dynamical systems;

Joint work of: Tinney, Charles; Delville, Joel; Bonnet, Jean-Paul

Vorticity, interfaces and wakes

I will talk about vorticity as a signature of interfaces and wakes.

I will first consider free surface flows, where interfaces can separate fluids of variable density, or fluids interacting with solids.

I will then discuss vorticity in wakes, and show in particular the impact of vorticity orientation in the drag values.

All the illustrations I will give were obtained by a class vortex particle methods which combines Lagrangian and Eulerian approaches. I will finally discuss some aspects of these methods.

Keywords: vortex methods, vorticity dynamics, free surface flows, wakes

Joint work of: Cottet, Georges-Henri

Dealing with noisy signals

Niels A. Andersen (Dantec Dynamics - Skovlunde, DK)

Great emphasis is often put on enhancing PIV methods in terms advanced correlation schemes etc. with the prerequisite that the underlying images are nearly perfect. This is very often not the case, and care must be taken in post processing the actual particle images before the performing the vector calculations

The presentation presents various classes of noise in the particle images, and presents methods to counter some of them.

A specific method is presented with which is it possible to process extremely noisy particle image data and extract a Proper Orthogonal Decomposition of the vector data which is not influenced by correlated noise patterns

Keywords: PIV images, noise, POD, correlated noise

Full Paper:
2 www.dantecdynamics.comwww.dantecdynamics.com

Schlieren Image Velocimetry applied to EHD airflows

Guillermo Artana (University of Buenos Aires, RA)

We analyze the problem of estimating the motion of fluid flows driven by electrohydrodynamic forces. The fluid motion is visualized through a Schlieren technique. Such a technique is well known in fluid mechanics as it enables in many cases pictures of the flow without the use of "strange" tracers. As the images exhibit in general very low photometric contrasts, classical motion estimation methods based on the brightness consistency assumption (correlation-based approaches, optical flow methods) are rather inefficient. This work aims at proposing a sound energy based estimator dedicated to these images. The energy function to be minimized is composed of (a) a data term describing the fact that the observed luminance is linked to the gradient of the fluid density and (b) a specific div curl regularization term. The relevance of our estimator is demonstrated on air flows forced with surface plasma actuators

Keywords: Schlieren Image Velocimetry

Lagrangian Particle Tracking in Fully Developed Turbulence of Dilute Polymer Solutions

Eberhard Bodenschatz (MPI für Dynamik und Selbstorganisation - Göttingen, D)

It is well known that viscoelastic solutions of long-chain polymers exhibit behavior that can be markedly different from that of their solvent alone. In turbulent, wall-bounded flows, small concentrations of polymers lead to the famous drag reduction effect. Less is known, however, about the effect of polymers in the bulk of a turbulent flow. By tracking small particles in an intensely turbulent flow, we show that even a very small concentration of polymers disrupts the usual turbulent energy cascade. Moreover, we find that the polymer effects can be captured by considering the time scale on which they are stretched by the flow, rather than that on which they relax, as has previously been assumed.

Keywords: Lagrangian Particle Tracking, Polymers, Drag Reduction

Joint work of: Bodenschatz, Eberhard; Xu, Haitao, Ouellette, Nicholas

See also: submitted

Automated Topology classification method for instantaneous velocity fields

Jacques Borée (ENSMA - Futuroscope, F)

Topological concepts provide highly comprehensible representations of the main features of a flow with a limited number of elements. This paper presents an automated classification method of instantaneous velocity fields based on the analysis of their critical point distribution and Feature Flow Fields. It uses the fact that topological changes of a velocity field are continuous in time to extract large scale periodic phenomena from insufficiently time-resolved datasets. This method is applied to two test cases: an analytical flow field and PIV planes acquired downstream a wall-mounted cube. (Depardon et al 2007 - paper accepted for publication in Exp. in Fluids).

Keywords: Aerodynamic, topology, feature flow field, classification

Joint work of: Depardon, Sébastien; Lasserre, Jean-Jacques; Brizzi, Laurent; Borée, Jacques;

Pdf of the slides of "Automated topology classification method for instantaneous velocity fields"

Jacques Borée (ENSMA - Futuroscope, F)

None

Keywords: Aerodynamic, topology, feature flow field, classificassion

Joint work of: Borée, Jacques; Depardon, Sébastien; Lasserre, Jean Jacques; Brizzi, Laurent Emmanuel

Vorticity, interfaces and wakes

Georges-Henri Cottet (Laboratoire Jean Kuntzmann - Grenoble, F)

I will talk about vorticity as a signature of interfaces and wakes. I will first consider free surface flows, where interfaces can separate fluids of variable density, or fluids interacting with solids. I will then discuss vorticity in wakes, and show in particular the impact of vorticity orientation in the drag values.

All the illustrations I will give were obtained by a class vortex particle methods which combines Lagrangian and Eulerian approaches. I will finally discuss some aspects of these methods.

Keywords: Vortex methods, vorticity dynamics, free surface flows, wakes

Simplified model of fluid motion by multivariate polynomial approximation

Laurent David (LEA - University of Poitiers, F)

During flow control or data assimilation for simulations, the determination of simplified flow models is essential. In the same way, for the study of the strongly non stationary flows, the extraction of the large vortex structures is often sufficient to understand the principal physical mechanisms in flows. The techniques proposing of the low order dynamic models are based as a preliminary on an analysis by proper orthogonal decomposition. This one can be carried out directly starting from visualizations or velocity fields measured by PIV unresolved in time. The disadvantage of the POD remains that the space bases do not have physical sense and are not easily comparable of one flow with the other. This work proposes an original and general model for the approximation of flows from velocity vector fields. The method uses the orthonormal multivariate polynomials framework to approximate vector fields as combinations of these special functions. In order to evaluate the validity of the suggested model, we present a set of experiments. We study the influence of various parameters like the order of the polynomials, the resolution and the density of the field on the accuracy of this approximation. We show that the coefficients of the polynomial system have a geometrical interpretation according to simple motion like translations, rotations, shears, ... That may provide interesting information on the nature of fluid motions. We also study the robustness of the model to Gaussian and impulsive noises. Besides as the POD approximation method, this modeling can be used to get a simplified reconstruction of complex fluid motions. It is also worth noticing that the computational cost of the method stays low.

Keywords: Fluid Motion, particle image velocimetry, POD, vector fields modelization, orthogonal systems of multivariate polynomials,

Joint work of: David, Laurent;M. Druon; B. Tremblais; B. Augereau;

Full Paper:
2 http://labo.univ-poitiers.fr/lea/http://labo.univ-poitiers.fr/lea/

See also: Martin Druon and Benoit Tremblais and Bertrand Augereau, LATEX: Vector Fields Modelization Using BasisA. Santa Cruz and L. David and J. Pcheux and A. Texier, LATEX: Characterization of the passive stabi-

Wavelet tools for experimental fluid mechanics

Marie Farge (CNRS - Paris, F)

Turbulence is characterized by its nonlinear and multiscale behavior, self-organization into coherent structures and generic randomness. The number of active spatial and temporal scales involved increases with the Reynolds number, therefore it soon becomes prohibitive for direct numerical simulation. However, observations show that for a given flow realization these scales are not homogeneously distributed, neither in space nor in time, which corresponds to the flow intermittency. To be able to benefit from this property, a suitable representation of the flow should reflect the lacunarity of the fine scale activity, in both space and time.

A prominent tool for multiscale decompositions are wavelets. A wavelet is a well localized oscillating smooth function, i.e. a wave packet, which is dilated and translated. The thus obtained wavelet family allows to decompose a flow field into orthogonal scale-space contributions. The flow intermittency is reflected in the sparsity of the wavelet representation, i.e. only few coefficients, the strongest ones, are necessary to represent the dynamically active part of the flow. We will illustrate this by considering different 2D and 3D turbulent flows, either computed by direct numerical simulation (DNS) or measured by particle image velocimetry (PIV).

To compute the evolution of turbulent flows we have proposed the Coherent Vortex Simulation (CVS), which is based on the wavelet filtered Navier-Stokes equations. At each time step the turbulent fluctuations are split into two orthogonal parts: the first corresponding to the coherent vortices which are kept, and the second to an incoherent background flow corresponding to turbulent dissipation which is discarded.

Keywords: Turbulence, wavelets, coherent structures

Joint work of: Marie Farge, Jori Ruppert-Felsot and Kai Schneider

Full Paper:
2 //wavelets.ens.fr//wavelets.ens.fr

See also: Marie Farge, Wavelet transforms and their applications to turbulence, Annual Review of Fluid Mechanics, 24, 395-457 (1992) and Marie Farge, Giulio Pellegrino and Kai Schneider, Coherent Vortex Extraction in 3D turbulent flows using orthogonal wavelets, Physical review Letters, 87(55), 054501 (2001)

Coherent structure investigation of the near wall region using SPIV

Jean Marc Foucaut (Laboratoire de Mecanique de Lille, F)

The wall region of a turbulent boundary layer contains different coherent structures, which plays an important role in the turbulent energy generation and transport. Among them, three categories structures, namely low and high speed streaks, ejections and sweeps, and hairpin and streamwise vortices are the most documented. The objective of the present contribution is to study the characteristics of the turbulent flow in the near wall region using Particle Image Velocimetry, to observe and quantify these structures and to investigate the spatial relations.

Stereoscopic Particle Image Velocimetry (SPIV) is now an accurate method which allows the measurement of instantaneous velocity field. The recent improvements of laser and camera allow to record of a large amount of data. This requires new post-processing tools to extract the main information from the SPIV data. The present paper proposes some methods to detect and characterize coherent structures which can be of interest in a turbulent flow. The detection of coherent structures is based on a pattern recognition method. This method allows the creation of binary images of each structure using a specific procedure. Benefiting from the binary images, not only the mean statistical characteristics but also the histograms and the variations with wall distance were analyzed for the first time in such a detail. This includes mainly: frequency of appearance, spanwise angle, width, length, area, spanwise distance between the same structures.

The double spatial correlation applied on the binary images gives a good idea of the organization in this region. It can be mentioned that a strong relation between streamwise vortex and streaks has been obtained.

Keywords: Near wall turbulence, coherent structure, stereoscopic PIV, pattern recognition

Joint work of: Foucaut, Jean Marc; Laval, Jean Philippe; Lin, Jie; Carlier, Johan; Stanislas, Michel

Extraction and Visualization of Structural Flow Features

Hans-Christian Hege (ZIB - Berlin, D)

A survey is given on recent developments in scientific visualization that are of interest for visual flow analysis.

First, basic techniques are addressed for perceptually effective depiction of vector field data.

Secondly, feature based techniques are presented: both techniques for extracting (frame-dependent) topological features of vector fields as well as coherent structures based on Galilei-invariant quantities.

Additional uses of flow features that can be extracted as explicit geometrical objects are explained. Furthermore, future developments are addressed, like feature extraction and visualization techniques for instationary 3D fields, as well as methods for depicting multiple fields and techniques for displaying uncertain data.

For more information see www.zib.de/visual.

Keywords: Feature detection, feature extraction, flow visualization, scientific visualization

Joint work of: Hege, Hans-Christian; Weinkauf, Tino; Sahner, Jan

Proper orthogonal decompositon in flow control

Michael Hinze (Universität Hamburg, D)

Proper orthogonal decomposition (POD) is proposed for deriving low order models of large scale dynamical systems. These low order models serve as surrogates for the dynamical system in the optimization processes. In the context of pde constrained optimal control this approach may suffer from the fact that the POD basis elements are computed from reference trajectories containing features which are different from those of the optimally controlled trajectory. Adaptive POD concepts are discussed which avoid these shortcomings.

As numerical example tracking-type control of periodic flow around a cylinder is presented, where the flow is governed by the incompressible Navier-Stokes system. The numerical results of the adaptive approaches for different modes are compared. Furthermore they are compared to the result of the optimal control approach applied to the full Navier-Stokes system. It turns out that the quality of the controls obtained from the suboptimal approaches compares to that obtained by optimal control, while the computational costs for the optimal approach are one order of magnitude higher.

Keywords: Proper Orthogonal Decomposition, Flow Control, Adaptive POD

Experimental requirements for validating numerical flow simulations

Christian Kaehler (TU Braunschweig, D)

The increasing need of reliable flow simulations in fundamental and applied fluid mechanics requires very accurate flow measurements to validate the predictions of the numerical integration of the fluid mechanical equations. The particle image velocimetry (PIV) is a very powerful tool for the validation process because it is a non intrusive multipoint measurement technique. As the accuracy and spatial resolution of this technique is often not sufficient three approaches are discussed in the presentation to show how to overcome the limits of the existing technique. Firstly, the long distance micro PIV technique is outlined along with the single pixel correlation image analysis because this technique strongly increases the spatial resolution. Secondly, the multi-frame PIV technique is discussed because this recording and evaluation approach allows to increase the accuracy significantly. Thirdly, the power and limitations of a PIV based measurement concept is demonstrated with allows to record all three velocity components in a three dimensional space in dependency on the time.

Keywords: Image analysis, micro PIV, time resolved PIV, volume PIV

Measurements 3D Flow and Particle Motion in the Laboratory and in the Ocean Using Digital Holography (Holographic Microscopy)

Joseph Katz (Johns Hopkins Univ. - Baltimore, USA)

Using several examples, the presentation introduces the principles of digital holography and holographic microscopy as a means of measuring three-dimensional flow and particle distributions in the laboratory and in the ocean. Examples of applications include: a. Studying swimming behavior of motile marine plankton to various excitations, ranging in size from a few mm to several mm, as well as measurements of flows generated by their motion. b. High speed Lagrangian measurements of small fuel droplets transport in isotropic turbulence, and determination of the associated diffusion coefficients and dispersion rates. c. Measurements of relations between near-wall, buffer layer vortical structures and distribution of wall shear stresses in turbulent boundary layers at high Reynolds numbers. Resolution of instantaneous velocity measurements is sufficient for determine the instantaneous stress distribution from velocity gradients in the viscous sublayer.

Keywords: Digital holography, holographic microscopy, holographic particle image velocimetry

Joint work of: Katz, Joseph; Jian Sheng, Balaji Goplalan, Edwin Malkiel, Woody Pfitsch

Industrial applications of image based measurement techniques in aerodynamics Ãś Progress and future needs

Jürgen Kompenhans (DLR Göttingen, D)

Image based measurement techniques have gained access to many industrial applications, firstly due to the remarkable progress made at the development of hardware such as lasers, video cameras, computers, storage capacity etc., but secondly due to the developments made with evaluation algorithms, computer vision, pattern recognition etc. in the past decade.

Examples of the application of image based measurement techniques (Particle Image Velocimetry, Pressure Sensitive Paint, Temperature Sensitive Paint, Model Deformation Measurement Techniques, Density Measurement Techniques, Acoustic Measurement Techniques) as performed by DLR in industrial environments, such as large wind tunnels will be presented. Next, typical problems appearing, when bringing such measurement techniques out of the research laboratory into the rough industrial environment will be discussed. The multidisciplinary cooperation in major international research projects with partners ranging from the operating team of the facility to the end-user of the experimental data such as the CFD community, who uses them for code validation, requires special procedures and standards for the different processes involved.

The developers of experimental methods and image processing methods, mainly coming from university or research laboratories shall be made familiar with the needs arising at the application of such methods in industrial environments, in order that they can eventually consider them already during the development process, having rather scientific objectives, in order to allow easier cooperation with industrial partners and faster transfer of new methods to industrial facilities later on.

Keywords: Particle Image Velocimetry, Pressure Sensitive Paint, Temperature Sensitive Paint, Model Deformation Measurement Techniques, Density Measurement Techniques, Acoustic Measurement Techniques

Filtering of Lagrangian velocity in turbulent flow, using a sequential Monte Carlo (SMC) method

Francois Le Gland (IRISA - Rennes, F)

Sequential Monte Carlo (SMC) methods provide a flexible way to estimate the hidden state of a noisy dynamical system (usually modeled as a Markov chain) from noisy measurements. These methods have recently been used by E. Mémin and his students E. Arnaud and A. Cuzol, to estimate a fluid motion from video sequences.

In the first part, the basic SMC methods will be presented in rather general terms, starting from the nonlinear non Gaussian models and the more general hidden Markov models, setting the hidden state estimation problem in a Bayesian framework, introducing the particle filter idea of approximating the Bayesian filter as the weighted empirical probability distribution associated with an interacting particle system, and focusing on the redistribution step as the key step in the algorithm.

The second part will report recent results obtained by Ch. Baehr from Météo-France in Toulouse, about the filtering of noisy measurements of Lagrangian wind velocity (as collected on an aircraft itself moving within the flow) using some prior information provided by the basic Pope model for the evolution of a particle in a turbulent flow. In this approach, the ensemble average of (functions of) the Eulerian velocity is expressed in terms of the conditional probability distribution of the Lagrangian velocity given the Lagrangian position. This results in a nonlinear Markov model for the Lagrangian position and velocity, for which a Bayesian filter would be difficult to analyze and to approximate numerically, even though the derivation would be rather straightforward. Since measurements are available, the idea is to express the ensemble average of (functions of) the Eulerian velocity in terms of the conditional probability distribution of the Lagrangian velocity given the Lagrangian position and given the available measurements. This results now in a conditioned Markov model for the Lagrangian position and velocity, a generalization already considered by E. Mémin and E. Arnaud in another context, and for which a Bayesian filter can easily be derived and implemented using particle approximation. Experimental results will be presented, based on synthetic or real time series of wind velocity, artificially corrupted by additive noise. The purpose of these experiments is to illustrate the ability of our particle filter to recover the uncorrupted time series with the help of the prior information.

Dynamically consistent estimation of fluid motion from image sequences

Etienne Mémin (IRISA - Rennes, F)

Image measurement depicting fluid flow fields are in general noisy and most of the time sparse in time and space. For most flows of interest these image sequences may exhibit transfers of matter transversal to the visualization plane. This entering and disappearance of matter but also luminance variations caused by other effects than the fluid motion such as speckle noise, passive scalar diffusion, radiative transfers, small scales thermodynamic effects, makes difficult a strict use of the standard brightness consistency assumption. Sequence of image data leads also at some places to great ambiguities that are generally tackled introducing, within the estimation scheme, contextual local or global priors on the motion field. In order to recover in the most accurate way as possible the motion corresponding to different scales of the flow these priors can hardly be formally described even locally by low order polynomials. This is particularly true when the image data represents a passive scalar, or a state variable transported by the fluid. As a last difficulty considering only procedures working on image pairs to infer motion cannot guarantee the respect of conservation laws and a time consistent estimation. These conservation laws are nevertheless 3D whereas image visualization is in most of the case 2D. In addition there is in most of the case a complex relation between image data and the different state variables of interest. As a consequence of all these difficulties, we believe that motion estimation scheme must rely on adequate brightness variation model respecting in the same time an appropriate conservation laws. This comes indeed to set the motion estimation problem as a data assimilation problem. In this talk we will show different examples and different methodological frameworks on which we rely to implement such a strategy.

Advanced correlation-based PIV algorithms and their limitation

Holger Nobach (MPI für Dynamik und Selbstorganisation - Göttingen, D)

Several improvements of correlation-based PIV processing algorithms have been developed during the last years improving both, the accuracy and the resolution of the technique. Unfortunately, the performance of these techniques is usually limited to simulation test cases, whereas the situation with measured images is less convincing. A possible explanation is the effect of individual tracer particle intensity variations in consecutive images due to out-of-plane motion or light sheet misalignments. Particularly, the efficacy of Gaussian low-pass filter image interpolation for the reduction of under-sampling and the normalization of the correlation function for the reduction of truncation errors are shown under this condition.

Keywords: PIV, image processing, accuracy, resolution

Detection and statistical analysis of swirling pattern populations embedded in PIV velocity-vector-map collections: open questions and future needs illustrated from an attempt to characterize the wall region of a confined plane turbulent impinging jet.

Michel Pavageau (Ecole des Mines de Nantes, F)

The aim is to communicate about a vortex detection algorithm used to expose and statistically characterize the coherent flow patterns observable in the velocity vector fields measured by Particle Image Velocimetry (PIV) in the impingement region of air curtains. The philosophy and the architecture of this algorithm are presented briefly. Its strengths and weaknesses are discussed at the light of

the results of a parametrical analysis performed to assess the variability of the response of our algorithm to 3 user-specified parameters. Relevant effects on the size, shape, spatial distribution and energetic content of the coherent eddy structures detected in the test flow are provided. Open questions relevant to the achievement of more reliable results are put forward and discussed along with future needs with respect to coupled scalar and kinematic fields analysis.

Keywords: PIV, coherent structure eduction, plane impinging jet, air curtains, ambiance separation.

Detection, Visualization and Tracking of Coherent Structures in Digital Flow-Fields

Ulrich Rist (Universität Stuttgart, D)

New measurement techniques and computing power allow us to resolve flow fields increasingly fine with ever gradually accuracy. The day where this holds for complex three-dimensional unsteady flows is perhaps not too far ahead. Even now large data sets may be produced in a relatively short time, containing extremely large amounts of raw data (tracer particle positions or deduced velocity vectors). It would be short-sighted in light of the above foreseeable trend towards investigation of more complicated problems, to simply believe, that building equipments that allow fine-enough resolution of space and time would be the ultimate solution.

An improved description and understanding of complicated flow fields needs data reduction to the 'essentials', an appropriate modeling of the according features and their interactions, i. e. the 'dynamics' of the flow, leading to an 'understanding' of the observations. The ultimate goal would be to obtain a "mental model" that allows predictions of the future states of the flow, i. e. its dynamics. This also applies to forecasts of the influence of changing parameters or to flows in other but similar situations. Computer-based tools are necessary to reach such aims. These tools should be based on feature detection, segmentation of the flow field, feature extraction and tracking, etc.

Features, loosely defined, are the interesting objects of a data set, and are often taken to be regions which satisfy certain constraints, e. g. low pressure, high vorticity magnitude, and so forth. Important features in fluid dynamics include boundary layers, high shear-layers (regions of high shear stress), and vortices, for instance. The latter are considered to be important for the role they play in understanding and predicting the behavior of complicated fluid flows, unsteady separated or turbulent flows in particular.

The talk will illustrate some recent achievements for vortex and shear layer detection, visualization and tracking based on data sets obtained from PIV measurements and direct numerical simulation. Visualization methods have been and will continue to be developed in close cooperation with the visualization experts of the computer science departments of TU Munich and Universität Stuttgart.

An open issue is to find appropriate criteria that reliably describe feature interactions, e. g. vortex-vortex and vortex-boundary-layer interactions. But research into these issues has started and a few preliminary results will be shown at the seminar.

Keywords: Detection, Visualization, Tracking, Coherent Structures, Digital Flow-Fields, Vortices, Shear Layers

Experiments on small and large scales in turbulent flows

Giovanni Romano (Univ. di Roma "La Sapienza", I)

An overview on small and large scale vortical structures in turbulent flows is given. After an introductory part on the notion of flow scales and their interactions, an example with related problems is presented by considering homogeneous and isotropic turbulence downstream a grid. A comparison between PIV and HWA is performed in relation to quantities derived from large and small scales. A new method for advanced image analysis of flow motion (Robust Image Velocimetry, RIV) is also described.

Keywords: Small scale, large scale, turbulence, PIV

See also: Experiments in Fluids, 41(1) pp. 21-33, 2006

3D and 4D patterns in circular cylinder wakes

Fulvio Scarano (TU - Delft, NL)

Wakes of bluff bodies such as cylinders are known to be dominated by vigorous unsteady motion due to the vortex shedding phenomenon. In cylinder flows a von Kármán street is formed dominated by a staggered array of span-wise aligned vortices with opposite rotation sign. The literature is abundant with numerical investigations focussing on the vortex dynamics instability occurring at a Reynolds numbers of the order of 102. In such regimes it is widely reported that the secondary instability of the vortex street occurs with the formation of prevalently stream-wise vortices connecting the primary rollers.

At higher values of the Reynolds number between 103 and 104 the situation becomes more complex due to the transition of the separated shear layers, which introduces higher frequencies and a broader range of spatial scales. Flow visualization cannot be easily applied because of the turbulent mixing due to small scale fluctuations. Moreover numerical simulations of DNS type become increasingly difficult due to the increase of computational load. Quantitative experiments by planar PIV yield evidence of the quasi periodic spanwise organization of vortex structures at Reynolds numbers up to 10,000, however the interpretation of data from planar measurements becomes increasingly difficult for the turbulent regime.

The talk will present an experimental investigation of cylinder wakes at Reynolds number covering the laminar, transitional and turbulent regime. The measurements are performed by the tomographic-PIV technique, yielding 3D velocity/vorticity fields. At lower Reynolds the flow evolution is sampled in time resolved mode, returning the dynamical evolution of the phenomenon. The attention will focus upon the characterization of the secondary vortex structures and their interaction with the primary rollers. The discussion will also touch upon the visualization and interpretation of 3D phenomena as measured by 3D techniques, however still represented on a 2D support; a new topic for discussion in relation to 3D measurement technique.

Keywords: 3D velocimetry, tomography, PIV, cylinder wake, coherent structures

Joint work of: Scarano, Fulvio; Poelma Christian; Westerweel, Jerry

Three-dimensional vorticity pattern in circular cylinder wakes

Fulvio Scarano (TU - Delft, NL)

The three-dimensional structure of the wake behind a circular cylinder is investigated in the transitional and turbulent regime (Re = 1000, 2700, 5500) by means of tomographic PIV (Tomo-PIV), a recently developed three-dimensional velocimetry technique. The unsteady vortex wake behavior is well known as the von Kármán street dominated by a staggered array of span-wise aligned vortices with opposite rotation sign. Despite the numerous works conducted by experimental means and numerical techniques the three-dimensional aspects have not yet been completely characterized in the transitional and turbulent flow regime. The work is abundant in literature for numerical investigations focussing on the vortex dynamics instability occurring at a Reynolds numbers of the order of 102. In such regimes it is widely reported that the secondary instability of the vortex street occurs with the formation of prevalently stream-wise vortices connecting the primary rollers. Mode A (vortex loops) and Mode B (stream-wise vortex pairs, Williamson, 1996) three-dimensional instabilities are well described with both DNS simulations (Thompson et al., 1994). Flow visualization studies in low speed flows (Williamson, 1995) are found in agreement with the numerical simulations. At higher values of the Reynolds number between 103 and 104 the situation becomes more complex due to the transition of the separated shear layers, which introduces higher frequencies and a broader range of spatial scales. Flow visualization cannot be easily applied because of the vigorous turbulent mixing due to small scale fluctuations. Moreover numerical simulations of DNS type become increasingly difficult to perform due to the increase of the computational load with the Reynolds number. Quantitative experiments by planar PIV yield significant evidence of the quasi periodic spanwise organization of vortex structures at Reynolds numbers between 2,000 and 10,000 (Huang et al. 2006).

The need for the experimental verification of conceptual models for the vortex wake structure in the transitional and turbulent regime motivates the present three-dimensional survey of cylinder wake flows.

The Tomo-PIV technique is employed in a water tunnel to provide a quantitative visualization of the three-dimensional structure of the vorticity. The measurement volume is a domain of 8 diameters in the span wise and streamwise direction and 2 diameters in the direction normal to the flow plane of symmetry. This allows to emphasize the span-wise instability of the Kármán wake occurring within the first three shedding periods. Secondary rollers are observed interconnecting the Karman vortices and they are organized with a span-wise wavelength of approximately one cylinder diameter and their maximum occurrence is observed at approximately x/D = 3 between the first and second vortex shed. The braid three-dimensional topology is described on the basis of the instantaneous vorticity iso-surfaces. The eduction of their coherent properties performed by means of pattern recognition analysis (Ferre and Giralt, 1989, Scarano et. al., 1998). The circulation of secondary structures is found to be in the same order of that of the primary rollers. Further downstream closed-loop vortices are occasionally observed where a more chaotic flow structure indicates the onset of transition to turbulence.

Keywords: 3D-PIV, tomography, cylinder wakes, karman street

Variational Modeling and Inference in Experimental Fluid Dynamics

Christoph Schnörr (Universität Mannheim, D)

Variational models play a prominent role in almost all areas of low-level image analysis and computational vision. They provide a mathematically sound framework for combining likelihood models of image formation with prior knowledge about the quantity of interest, that is to be inferred from given image data. From the broader viewpoint of graphical models, this framework can be extended to discrete domains representing e.g., labels, classes, events, etc., as well as to the statistical learning of model parameters from experimental databases.

Few computer vision groups have recently started to adopt variational models for image analysis in experimental fluid dynamics. While the basic problems related to low-level image signal processing are similar, those related to the modeling and the use of prior knowledge are different and have led to novel approaches, including fluid flow estimation by distributed parameter control, and variational models for nonlinear scale separation and estimation of flows.

In my talk, I will outline these concepts and developments. In view of the availability of three-dimensional time-resolved image sequences of turbulent flows in the near future, the objective is to stimulate the discussion about future collaboration and work on prior knowledge modeling, probabilistic learning and variational inference in experimental fluid mechanics.

Joint work of: Schnörr, Christoph; JingYuan; Paul Ruhnau; Annette Stahl, Gabriele Steidl;

Development of PIV techniques towards 3D and time resolution

Andreas Schroeder (DLR Göttingen, D)

The spatial and temporal development of turbulent boundary layer flows is governed by the self-organization of coherent structures like hairpin-like or arch vortices and spanwise alternating wall bounded low- and high-speed streaks. For a detailed analysis of the topologies of the wall normal fluid exchange namely of the four quadrants of the 'instantaneous' Reynolds stresses Q1,Q4 a time-resolved 3D-3C measurement technique is desired.

In this feasibility study the tomographic PIV technique has been applied to time resolved PIV recordings. Four high speed CMOS cameras are imaging tracer particles which were illuminated in a volume inside a boundary layer flow at 4 kHz by using two high repetitive Nd:YAG pulse lasers. The instantaneously acquired single particle images of these cameras have been used for a three dimensional tomographic reconstruction of the light intensity distribution of the particle images in a volume of voxels (volume elements) virtually representing the measurement volume. Each of two subsequently acquired and reconstructed particle image distributions are cross-correlated in small interrogation volumes using iterative multi-grid schemes with volume-deformation in order to determine a time series of instantaneous 3D-3C velocity vector fields with 250 μsec time steps.

Work is in progress for further development of a proper hybrid 3D- cross-correlation and PTV algorithm which would help to reduce the number of unpaired particle images (s.c. ghost particles) and give direct insight into the combination of Lagrangian single particle movements and the development of corresponding flow structures within the measurement volume as the particles remain there for 10 to 20 time steps in this case.

Keywords: Tomo PIV, Time resolved PIV, turbulent spots

Joint work of: Schroeder, Andreas; Geisler, Reinhard; Dierksheide, Uwe

Simultaneous Higher-Order Optical Flow Estimation and Decomposition

Gabriele Steidl (Universität Mannheim, D)

We study the estimation and decomposition of optical flows from highly non-rigid motions. To this end, recent methods from image decomposition into structural and textural parts are combined with variational optical flow estimation.

The approaches we suggest amount to minimizing discrete convex functionals using second order cone programming.

Higher order regularization is necessary in order to accurately recover important flow structure like vortices, and to incorporate key physically properties such as vanishing divergence, for instance.

For proper discretization, we apply the finite mimetic difference method that preserves the identities fulfilled by the continuous differential operators. Numerical examples demonstrate the feasibility of the complex approaches.

Joint work of: Steidl, Gabriele; Yuan, Jing; SchnËĘrr, Christoph

Concentration Measurements using Mie Scattering

Cam Tropea (GK 492 - Darmstadt, D)

The measurements of local concentration and unmixedness using a laser light sheet and quantitative analysis of the Mie scattering is examined using two example flow geometries typical of combustion systems. A new measure for unmixedness is introduced.

Keywords: Mie Scattering

Flow and Mixing in a Model Gasturbine Combustion Chamber

Cam Tropea (GK 492 - Darmstadt, D)

A non-intrusive, 2D - measurement technique for investigation of a mixing process of two air flows is presented. It is based on the Mie-scattering of laser-light on particles uniformly seeded to one of the flows. Then the local intensity of scattered light in the light-sheet gives information about the local concentration and thus the mixture fraction. The assembly includes a commercial PIV-System with three cameras, a pulsed Nd:YAG laser and additional optics for generating a parallel light-sheet. One camera acquires the image of the measurement plane (light-sheet, main image) while the two other images provide (essential) additional information and are used to eliminate the objectionable influences on the main image. All required measures to get from the raw-image to the one containing the concentration distribution are discussed in detail. The technique was applied to a mixing chamber test-rig and measurements have been conducted. First results are presented to show the effectiveness and limits of this technique.

Keywords: Mie Scattering, Mixing

micro-PIV presentation

Steve Wereley (Purdue University, USA)

Micro-PIV presentation

Keywords: Micro-PIV

A new look at flows

Jerry Westerweel (TU - Delft, NL)

The characteristics of an experimental method determine how we interpret turbulent and complex flows. The unique feature of PIV is that it is capable of measuring the instantaneous vorticity. Yet, this specific feature is not very often used. I would like to give several examples on how PIV has changed (and still changes) how we look at flow phenomena. These examples are: (1) the turbulent/non-turbulent interface; (2) turbulence transition; (3) mixing in a microfluidic T-mixer; (4) flow in an embryonic heart. Also, the amount of information that is supplied by a single PIV experiment can be overwhelming; how do we cope with this?

Keywords: Turbulence, complex flows

Planar and Volumetric Self-Calibration

Bernhard Wieneke (LaVision GmbH - Göttingen, D)

Current calibration techniques are reviewed and relevant error sources are specified for different measurement techniques.

It is shown how self-calibration algorithms directly on recorded particle images can eliminate most error sources.

For Stereo-PIV a corrected mapping function can be computed from the residual disparity field.

For volumetric techniques like Tomographic PIV a new method has been developed which is capable to correct calibration errors throughout the illuminated volume down to 0.1 pixel.

Keywords: Stereo-PIV Tomographic-PIV Self-Calibration

Planar Imaging Techniques in Turbomachinery - Current Status and Future Trends

Christian Willert (DLR Köln, D)

While the development and application of planar velocimetry methods are finding an increased range of applications throughout the engineering field involving fluid mechanics, the successful application of these advanced methods remain a challenge in many of the real-world applications. The validation of numerical tools used in turbomachinery in particular requires highly spatially (ideally temporally) resolved data of oftentimes secondary flow phenomena in environments that are representative of real facilities (e.g. combination of high pressure, velocity and temperature with and without reaction). The successful implementation of modern imaging diagnostics in turbomachinery test facilities requires adequate handling of a wide variety of problems, ranging from optical access, choice of proper seeding material, image acquisition strategy, post-processing, etc. Even under seemingly ideal conditions measurements are not always successful and advanced image processing methods such as multigrid PIV algorithms with image-deformation is necessary to extract usable data. The presentation highlights several challenging applications of particle image velocimetry (PIV), Doppler global velocimetry (DGV) and OH-chemiluminescence in large combustor facilities, highly loaded compressors as well as an automotive application. Driven by the frequently high facility operational costs, the future will see the application of several imaging measurement techniques in parallel thus permitting even further insights in the underlying flow physics (e.g. simultaneous measurements of temperature, concentration and flow field).

Keywords: Planar imaging, velocimetry, turbomachinery, PIV processing

Joint work of: Willert, Christian