Experimental Evaluation of Kolmogorov’s -5/3 and 2/3 Power Laws in the Developing Turbulent Round Jet

The current work investigates the validity of two cornerstone results of the Kolmogorov K41 theory of turbulence in terms of the typical power law representations viz. the -5/3 law for turbulence spectra and the 2/3 law for second order structure functions. The developing region of the jet has been chosen since it is an equilibrium flow once fully developed (but not necessarily in the development phase), it becomes fully developed over lengths that are practical on a laboratory scale and it is a high-intensity flow with accessibly resolvable scales in time and space. The developing region of the jet is thus the perfect test bed for these investigations, which can herein be accurately mapped using our in-house laser Doppler anemometry (LDA) system. The high turbulence intensity and high shear flow is challenging from measurement technical perspective, which is perhaps why this flow is so underexplored. This software-driven LDA system was developed specifically to optimize measurement of high shear and high turbulence intensities accurately in challenging flows such as the turbulent round jet in air. The jet was investigated experimentally both in the developing (non-equilibrium) and in the developed regions (equilibrium). Velocity static moments at each point are first presented to show the time averaged flow behavior while the spatial energy spectra and second order structure functions are computed to evaluate the power laws postulated by Kolmogorov. Measurements from both the developed and from the developing parts of the jet are presented to show validity of the measurement technique and unveil the actual spectral shapes in the developing non-equilibrium region, respectively.

General information
State: Published
Organisations: Department of Mechanical Engineering, Fluid Mechanics, Coastal and Maritime Engineering, Universiti Teknikal Malaysia Melaka, Intarsia Optics, Technical University of Denmark
Authors: Yaacob, M. R. (Intern), Schlander, R. K. (Ekstern), Buchhave, P. (Ekstern), Velte, C. M. (Intern)
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Electronic versions:
Conversion of Measured Turbulence Spectra from Temporal to Spatial Domain

The spatial structure of a turbulent velocity field is of great theoretical interest as its kinematics describe the distribution of spatial scales and its dynamics describe their evolution from large energy carrying scales to smaller scales and finally to dissipation.

However, the overwhelming number of turbulence measurements results in time records from stationary probes, either hot-wire probes (hot-wire anemometers, HWA) or laser beam probes (laser Doppler anemometers, LDA). The spatial structure of the turbulent velocity field is then inferred by "Taylor's hypothesis," as first presented in [1], assuming a "frozen" velocity field carried past the probe with the local mean velocity. However, Taylor's hypothesis breaks down at higher turbulence intensities and can then only be applied with additional corrections, see, for example, [2–4].

Mass entrainment rate of an ideal momentum turbulent round jet

We propose a two-phase-fluid model for a full-cone turbulent round jet that describes its dynamics in a simple but comprehensive manner with only the apex angle of the cone being a disposable parameter. The basic assumptions are that (i) the jet is statistically stationary and that (ii) it can be approximated by a mixture of two fluids with their phases in dynamic equilibrium. To derive the model, we impose conservation of the initial volume and total momentum fluxes. Our model equations admit analytical solutions for the composite density and velocity of the two-phase fluid, both as functions of the distance from the nozzle, from which the dynamic pressure and the mass entrainment rate are calculated. Assuming a far-field approximation, we theoretically derive a constant entrainment rate coefficient solely in terms of the cone angle. Moreover, we carry out experiments for a single-phase turbulent air jet and show that the predictions of our model compare well with this and other experimental data of atomizing liquid jets.
Measurement of turbulent kinetic energy spectrum - Part 1: Convection record method

A novel exact temporal to spatial mapping for point measurements in turbulence has been developed. The spatial record is obtained based on the instantaneous velocity magnitude, $u = |u|$, creating an exact mapping between the sampling interval, $\Delta t$, and the spatial record counterpart, $\Delta s$, through the relation $\Delta s_n = u \cdot \Delta t_n$. $n$ indicates the sample number in a measurement sequence. Summation of the consecutive streakline elements, $\Delta s$, corresponding to the convection distance of the fluid, results in a spatial "convection record". The exact mapping applies to all flows, since it is based on the instantaneous velocity magnitude, thereby incorporating all relevant aspects of the flow dynamics. Even high intensity non-equilibrium spatial records can be measured using this mapping, which is most straightforwardly applied using laser Doppler anemometry measurements. Computer simulated high intensity LDA data demonstrate the technique. The method will also be demonstrated on measurements in a round turbulent jet in part 2.

General information
State: Published
Organisations: Department of Mechanical Engineering, Fluid Mechanics, Coastal and Maritime Engineering, Intarsia Optics
Measurement of turbulent kinetic energy spectrum - Part 2: Convection record measurements

A novel exact temporal to spatial mapping for point measurements in turbulence has been applied to various flow conditions existing in a round turbulent jet. The conditions range between equilibrium and non-equilibrium as well as mid to high turbulence intensities. The exact mapping applies to all flows, including high intensity non-equilibrium flows, since it is based on the instantaneous velocity magnitude, thereby incorporating all relevant aspects of the flow dynamics. Development of the jet turbulence along the stream, from non-equilibrium to equilibrium, is observed. In the developed region of the jet, Taylor's hypothesis is tested and the spectra using the novel exact mapping is validated with excellent agreement against directly measured spatial spectra in a mapped similarity space using PIV. The method is observed to produce the expected results even at turbulence intensities of the order of 450%.

General information

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Organisations: Department of Mechanical Engineering, Fluid Mechanics, Coastal and Maritime Engineering, Intarsia Optics
Authors: Velte, C. M. (Intern), Buchhave, P. (Ekstern), Hodzic, A. (Intern)
Pages: 171-176
Publication date: 2017

Measurement of turbulent spatial structure and kinetic energy spectrum by exact temporal-to-spatial mapping

We present a method for converting a time record of turbulent velocity measured at a point in a flow to a spatial velocity record consisting of consecutive convection elements. The spatial record allows computation of dynamic statistical moments such as turbulent kinetic wavenumber spectra and spatial structure functions in a way that completely bypasses the need for Taylor's hypothesis. The spatial statistics agree with the classical counterparts, such as the total kinetic energy spectrum, at least for spatial extents up to the Taylor microscale. The requirements for applying the method are access to the instantaneous velocity magnitude, in addition to the desired flow quantity, and a high temporal resolution in comparison to the relevant time scales of the flow. We map, without distortion and bias, notoriously difficult developing turbulent high intensity flows using three main aspects that distinguish these measurements from previous work in the
field: (1) The measurements are conducted using laser Doppler anemometry and are therefore not contaminated by
directional ambiguity (in contrast to, e.g., frequently employed hot-wire anemometers); (2) the measurement data are
extracted using a correctly and transparently functioning processor and are analysed using methods derived from first
principles to provide unbiased estimates of the velocity statistics; (3) the exact mapping proposed herein has been applied
to the high turbulence intensity flows investigated to avoid the significant distortions caused by Taylor's hypothesis. The
method is first confirmed to produce the correct statistics using computer simulations and later applied to measurements in
some of the most difficult regions of a round turbulent jet—the non-equilibrium developing region and the outermost parts
of the developed jet. The proposed mapping is successfully validated using corresponding directly measured spatial
statistics in the fully developed jet, even in the difficult outer regions of the jet where the average convection velocity is
negligible and turbulence intensities increase dramatically. The measurements in the developing region reveal interesting
features of an incomplete Richardson-Kolmogorov cascade under development.

General information
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Organisations: Department of Mechanical Engineering, Fluid Mechanics, Coastal and Maritime Engineering, Intarsia
Optics
Authors: Buchhave, P. (Ekstern), Velte, C. M. (Intern)
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Publication date: 2017
Main Research Area: Technical/natural sciences

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Web of Science (2017): Indexed yes
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Scopus rating (2015): SJR 1.35 SNIP 1.282
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.375 SNIP 1.414
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.419 SNIP 1.471
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 1.202 SNIP 1.44
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 1.381 SNIP 1.485
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 1.346 SNIP 1.38
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 1.607 SNIP 1.359
Web of Science (2009): Indexed yes
POD Mode Robustness for the Turbulent Jet Sampled with PIV

An important challenge in the description and simulation of turbulence is the large amount of information that is needed to describe even relatively simple flows in detail. The frequent disagreement between Reynolds averaged Navier–Stokes-based simulations and experiments is well known. Albeit, direct numerical simulations and in certain cases large eddy simulations tend to agree fairly well with experiments, their practical implementation introduces the problem of data storage. The experimentalist, however, experiences the same problem, using highspeed particle image velocimetry (PIV) systems and even high speed volumetric PIV systems providing fully three dimensional velocity fields. Another challenge is how do we verify simulations against experiments and ensure that we indeed have simulated the same flow that we have measured?

Aerodynamically shaped vortex generators

An aerodynamically shaped vortex generator has been proposed, manufactured and tested in a wind tunnel. The effect on the overall performance when applied on a thick airfoil is an increased lift to drag ratio compared with standard vortex generators. Copyright © 2015 John Wiley & Sons, Ltd.
Multiple vortex structures in the wake of a rectangular winglet in ground effect

Patterns of vorticity in the wake of a single rectangular winglet (vortex generator) embedded in a turbulent boundary layer have been studied using Stereoscopic Particle Image Velocimetry (SPIV). The winglet was mounted normally to a flat surface with an angle to the oncoming flow. A parametric study varying the winglet height (constant aspect ratio) and angle has shown, contrary to the common classical single tip-vortex conception, that the wake generally consists of a complex system of multiple vortex structures. The primary vortex has previously been discovered to contain a direct coupling between the axial and the rotational flow. In the current work, even the longitudinal secondary structures detected from measured streamwise vorticity display similar behavior. A regime map depicting the observed stable far wake states of the multiple vortices as a function of winglet height and angle reveals complex patterns of the flow topologies not only with the primary tip vortex, but with the additional secondary structures as well. A bifurcation diagram shows distinct regimes of the various secondary structures as well as how the primary vortex is in some cases significantly affected by their presence. These data should serve as inspiration in the process of generating longitudinal vortices for enhancement of heat and mass transfer in industrial devices since the multiple vortex regimes can help improve the conditions for these exchanges. Further, these results point to a weakness in existing inviscid models not accounting for the possibility of multiple vortical structures in the wake. © 2015 Elsevier Inc. All rights reserved.
Testing of self-similarity and helical symmetry in vortex generator flow simulations

Vortex generators (VGs) are used increasingly by the wind turbine industry as flow control devices to improve rotor blade performance. According to experimental observations, the vortices generated by VGs have previously been observed to be self-similar for both the axial (u<sub>z</sub>) and azimuthal (u<sub>θ</sub>) velocity components. Furthermore, the measured vortices have been observed to obey the criteria for helical symmetry. These are powerful results, as it reduces the highly complex 3-D flow to merely four parameters and therefore significantly facilitates the modeling of this type of flow, which in a larger perspective can assist in parametric studies to increase the total power output of wind turbines. In this study, corresponding computer simulations using Reynolds-averaged Navier–Stokes equations have been carried out and compared with the experimental observations. The main objective is to investigate how well the simulations can reproduce these aspects of the physics of the flow, i.e., investigate if the same analytical model can be applied and therefore significantly facilitate the modeling of this type of flow, which in a larger perspective can assist in parametric studies to increase the total power output of wind turbines. This is especially interesting since these types of flows are notoriously difficult for the turbulence models to predict correctly. Using this model, parametric studies can be significantly reduced, and moreover, reliable simulations can substantially reduce the costs of the parametric studies themselves. Copyright © 2015 John Wiley & Sons, Ltd.

General information

State: Published
Organisations: Department of Mechanical Engineering, Fluid Mechanics, Coastal and Maritime Engineering, Department of Wind Energy, Aeroelastic Design, University of the Basque Country, Polytechnic University of Catalonia
Authors: Fernández-Gámiz, U. (Ekstern), Velte, C. M. (Intern), Réthoré, P. (Intern), Sørensen, N. N. (Intern), Egusquiza, E. (Ekstern)
Number of pages: 10
Pages: 1043–1052
Publication date: 2016
Main Research Area: Technical/natural sciences
Reduction of noise and bias in randomly sampled power spectra

We consider the origin of noise and distortion in power spectral estimates of randomly sampled data, specifically velocity data measured with a burst-mode laser Doppler anemometer. The analysis guides us to new ways of reducing noise and removing spectral bias, e.g., distortions caused by modifications of the ideal Poisson sample rate caused by dead time effects and correlations between velocity and sample rate. The noise and dead time effects for finite records are shown to tend to previous results for infinite time records and ensemble averages. For finite records, we show that the measured sampling function can be used to correct the spectra for noise and dead time effects by a deconvolution process. We also describe a novel version of a power spectral estimator based on a fast slotted autocovariance algorithm.

General information
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Organisations: Department of Mechanical Engineering, Fluid Mechanics, Coastal and Maritime Engineering, Intarsia Optics
Authors: Buchhave, P. (Ekstern), Velte, C. M. (Intern)
Number of pages: 17
Publication date: 2015
Main Research Area: Technical/natural sciences
Dead time effects in laser Doppler anemometry measurements

We present velocity power spectra computed by the so-called direct method from burst-type laser Doppler anemometer (LDA) data, both measured in a turbulent round jet and generated in a computer. Using today's powerful computers, we have been able to study more properties of the computed spectra than was previously possible, and we noted some unexpected features of the spectra that we now attribute to the unavoidable influence of a finite measurement volume (MV). The most prominent effect, which initially triggered these studies, was the appearance of damped oscillations in the higher frequency range, starting around the cutoff frequency due to the finite size of the MV. Using computer-generated data mimicking the LDA data, these effects have previously been shown to appear due to the effect of dead time, i.e., the finite time during which the system is not able to acquire new measurements. These dead times can be traced back to the fact that the burst-mode LDA cannot measure more than one signal burst at a time. Since the dead time is approximately equal to the residence time for a particle traversing a measurement volume, we are dealing with widely varying dead times, which, however, are assumed to be measured for each data point. In addition, the detector and processor used in the current study introduce a certain amount of fixed processing and data transfer times, which further contribute to the distortion of the computed spectrum. However, we show an excellent agreement between a measured spectrum and our modeled LDA data, thereby confirming the validity of our model for the LDA burst processor.

General information

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Organisations: Department of Mechanical Engineering, Fluid Mechanics, Coastal and Maritime Engineering, Intarsia Optics, Princeton University
Authors: Velte, C. M. (Intern), Buchhave, P. (Ekstern), George, W. K. (Ekstern)
Number of pages: 10
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Main Research Area: Technical/natural sciences

Publication information

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Scopus rating (2017): SNIP 1.505 SJR 1.281 CiteScore 2.71
Web of Science (2017): Indexed yes
Estimation of burst-mode LDA power spectra

The estimation of power spectra from LDA data provides signal processing challenges for fluid dynamicists for several reasons: acquisition is dictated by randomly arriving particles, the registered particle velocities tend to be biased toward higher values, and the signal is highly intermittent. The signal can be interpreted correctly by applying residence time weighting to all statistics and using the residence time-weighted discrete Fourier transform to compute the Fourier transform. A new spectral algorithm using the latter is applied to two experiments: a cylinder wake and an axisymmetric turbulent jet. These are compared with corresponding hot-wire spectra as well as to alternative algorithms for LDA signals such as the time-slot correlation method, sample-and-hold and common weighting schemes.

General information
Influence of light sheet separation on SPIV measurement in a large field spanwise plane

Stereoscopic particle image velocimetry (SPIV) is nowadays a well-established measurement technique for turbulent flows. However, the accuracy and the spatial resolution are still highly questionable in the presence of complex flow with both strong gradients and out-of-plane motions. To give guidelines for both setup and measurements of such flow configurations, a large region of overlap between two SPIV systems on the same laser light sheet is acquired in a plane normal to the streamwise direction of a high Reynolds turbulent boundary layer flow. A simple separation of the two light sheets is used to improve the accuracy of the measurements by increasing the velocity dynamic range especially. It also presents the enhancement of accuracy due to the light sheet separation for characterizing streamwise vortices (i.e. perpendicular to the sheet). The proposed technique has been demonstrated in the Laboratoire de Mécanique de Lille wind tunnel facility which has been specially designed to study fully developed turbulent boundary layers at high Reynolds numbers. The outlook is to study in detail the physics of the streamwise vortices generated from vortex generators taking advantage of the large scales of this turbulent boundary layer.
Power Spectrum Estimation of Randomly Sampled Signals

The random, but velocity dependent, sampling of the LDA presents non-trivial signal processing challenges due to the high velocity bias and the arbitrariness of particle path through the measuring volume, among other factors. To obtain the desired non-biased statistics, it has previously been shown analytically as well as empirically that residence time weighting is the suitable choice (Buchhave 1979, Buchhave et al. 1979, Velte et al. 2014). Unfortunately, due to technical problems related to the processors providing erroneous measurements of the residence times, this previously widely accepted theory has been questioned and instead a wide spectrum of alternative methods have been invented and tested (c.f. Albrecht et al. 2003). The objective of the current study is to create a simple computer generated signal for baseline testing of residence time weighting and some of the most commonly proposed algorithms; sample and-hold and the direct spectral estimator without residence time weighting. The computer generated signal is a Poisson process with a sample rate proportional to velocity magnitude that consist of well-defined frequency content, which makes bias easy to spot. The idea is that if the algorithms are not able to produce correct statistics from this simple signal, then they will certainly not be able to function well for a more complex measured LDA signal. This is, of course, true also for other methods that are based on the tested algorithms. The extremes are tested by increasing, e.g., the ‘turbulence intensity’ and the ‘shear’. In the paper, we have generated and tested these algorithms on synthetic data generated for the following signals: a Gaussian pulse, a single and multiple sine waves and a Gaussian random signal. In the abstract we have chosen to show results only for the sum of five sine waves. The conventional spectrum shows multiple erroneous mixing frequencies and the peak values are too low. The residence time weighted spectrum is correct. The sample-and-hold spectrum has lower power than the correct spectrum, and the f⁻²-filtering effect appearing for low data densities is evident (Adrian and Yao 1987). The remaining tests also show that sample-and-hold and the free-running processor perform well only under very particular circumstances with high data rate and low inherent bias, respectively. Residence time weighting provides non-biased estimates regardless of setting. The free-running processor was also tested and compared to residence time weighting using actual LDA.
measurements in a turbulent round jet. Power spectra from measurements on the jet centerline and the outer part of the jet illustrate a distinct difference between the residence time weighted and the non-weighted spectra, in particular for positions far off the jet center axis where the bias increases.

**General information**

State: Published  
Organisations: Department of Mechanical Engineering, Fluid Mechanics, Coastal and Maritime Engineering, Princeton University, Intarsia Optics  
Authors: Velte, C. M. (Intern), Buchhave, P. (Ekstern), K. George, W. (Ekstern)  
Number of pages: 1  
Publication date: 2014  

**Main Research Area:** Technical/natural sciences  
Publication: Research - peer-review › Conference abstract for conference – Annual report year: 2015

**Power Spectrum Estimation of Randomly Sampled Signals**

The random, but velocity dependent, sampling of the LDA presents non-trivial signal processing challenges due to the high velocity bias and the arbitrariness of particle path through the measuring volume, among other factors. To obtain the desired non-biased statistics, it has previously been shown analytically as well as empirically that residence time weighting is the suitable choice. Unfortunately, due to technical problems related to the processors providing erroneous measurements of the residence times, this previously widely accepted theory has been questioned and instead a wide spectrum of alternative methods attempting to produce correct power spectra have been invented and tested. The objective of the current study is to create a simple computer generated signal for baseline testing of residence time weighting and some of the most commonly proposed algorithms (or algorithms which most modern algorithms ultimately are based on), sample-and-hold and the direct spectral estimator, without residence time weighting, and compare how they perform in relation to power spectra based on the equidistantly sampled reference signal. The computer generated signal is a Poisson process with a sample rate proportional to velocity magnitude that consist of well-defined frequency content, which makes bias easy to spot. The idea is that if the algorithms are not able to produce correct statistics from this simple signal, then they will certainly not be able to function well for a more complex measured LDA signal. This is, of course, true also for other methods that are based on the tested algorithms. The extremes are tested by increasing, e.g., the ‘turbulence intensity’ and the ‘shear’. It is observed that sample and hold and the free-running processor perform well only under very particular circumstances with high data rate and low inherent bias, respectively, while residence time weighting provides non-biased estimates regardless of setting. The free-running processor was also tested and compared to residence time weighting using actual LDA measurements in a turbulent round jet. Power spectra from measurements on the jet centerline and the outer part of the jet illustrate a distinct difference between the residence time weighted and the non-weighted spectra, in particular for positions far off the jet center axis where the bias increases.

**Self-Similarity and helical symmetry in vortex generator flow simulations**

According to experimental observations, the vortices generated by vortex generators have previously been observed to be self-similar for both the axial ($u_z$) and azimuthal ($u_\theta$) velocity profiles. Further, the measured vortices have been observed to obey the criteria for helical symmetry. This is a powerful result, since it reduces the highly complex flow to merely four parameters. In the present work, corresponding computer simulations using Reynolds-Averaged Navier-Stokes equations have been carried out and compared to the experimental observations. The main objective of this study is to investigate how well the simulations can reproduce the physics of the flow and if the same analytical model can be applied. Using this model, parametric studies can be significantly reduced and, further, reliable simulations can substantially reduce the costs of the parametric studies themselves.
The Effect of a Finite Measurement Volume on Power Spectra from a Burst Type LDA

We analyze the effects of a finite size measurement volume on the power spectrum computed from data acquired with a burst-type laser Doppler anemometer. The finite measurement volume causes temporal distortions in acquisition of the data resulting in phenomena such as finite processing time and dead time. We compare analytical expressions for the bias and distortion of the velocity power spectrum computed from computer-generated data. We then compare the spectrum from the computer-generated data and a power spectrum from a measurement on a free turbulent jet in air and conclude that we have a valid understanding of the effects of the finite measurement volume on the measured velocity power spectrum.

The effect of dead time on randomly sampled power spectral estimates

We investigate power spectra of a randomly sampled stationary stochastic signal, e.g., a spatial component of a turbulent velocity. We extend the methods of previous authors that basically assumed point or delta function sampling by including features characteristic of real measurement systems. We consider both the effect on the measured spectrum of a finite sampling time, i.e., a finite time during which the signal is acquired, and a finite dead time, that is a time in which the signal processor is busy evaluating a data point and therefore unable to measure a subsequent data point arriving within the dead time delay.
Tomographic PIV measurements behind vortex generators

General information
State: Published
Organisations: Department of Mechanical Engineering, Fluid Mechanics, Coastal and Maritime Engineering, Dantec Dynamics
Authors: Meyer, K. E. (Intern), Velte, C. M. (Intern), Jaunet, V. (Ekstern), Bøtkjær, N. (Ekstern), Hess, D. (Ekstern)
Vortex Generator Induced Flow in a High Re Boundary Layer

Stereoscopic Particle Image Velocimetry measurements have been conducted in cross-planes behind three different geometries of Vortex Generators (VGs) in a high Reynolds number boundary layer. The VGs have been mounted in a cascade producing counter-rotating vortices and the downstream flow development was examined. Three VG geometries were investigated: rectangular, triangular and cambered. The various VG geometries tested are seen to produce different impacts on the boundary layer flow. Helical symmetry of the generated vortices is confirmed for all investigated VG geometries in this high Reynolds number boundary layer. From the parameters resulting from this analysis, it is observed at the most upstream measurement position that the rectangular and triangular VGs produce vortices of similar size, strength and velocity induction whilst the cambered VGs produce smaller and weaker vortices. Studying the downstream development in the ensemble and spanwise averaged measurements, it is observed that the impact from the rectangular and triangular VGs differs. For the rectangular VGs, self-similarity in the streamwise component was confirmed.

General information

State: Published
Organisations: Department of Mechanical Engineering, Fluid Mechanics, Coastal and Maritime Engineering, Université Lille Nord de France
Authors: Velte, C. M. (Intern), Braud, C. (Ekstern), Coudert, S. (Ekstern), Foucaut, J. (Ekstern)
Number of pages: 11
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Main Research Area: Technical/natural sciences

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Scopus rating (2016): CiteScore 0.45 SJR 0.24 SNIP 0.401
Web of Science (2016): Indexed yes
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Scopus rating (2015): SJR 0.252 SNIP 0.374 CiteScore 0.35
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.264 SNIP 0.352 CiteScore 0.32
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.245 SNIP 0.293 CiteScore 0.25
ISI indexed (2013): ISI indexed no
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.293 SNIP 0.387 CiteScore 0.33
ISI indexed (2012): ISI indexed no
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.293 SNIP 0.356 CiteScore 0.43
A Vortex Generator Flow Model Based on Self-Similarity: Technical notes

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Organisations: Department of Mechanical Engineering, Solid Mechanics
Authors: Velte, C. M. (Intern)
Pages: 526-529
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Scopus rating (2017): CiteScore 2.42 SJR 0.763 SNIP 1.452
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 2.58 SJR 0.857 SNIP 1.713
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.779 SNIP 1.683 CiteScore 1.99
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.8 SNIP 1.713 CiteScore 2.28
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.832 SNIP 1.782 CiteScore 2.25
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.798 SNIP 1.811 CiteScore 1.54
ISI indexed (2012): ISI indexed yes
Coupling of theory and practice through inductive learning in experimental fluid mechanics education: A practical study

General information
State: Published
Organisations: Department of Mechanical Engineering, Fluid Mechanics, Coastal and Maritime Engineering, Office for Study Programmes and Student Affairs
Authors: Velte, C. M. (Intern), Andersson, P. H. (Intern), Meyer, K. E. (Intern)
Number of pages: 8
Publication date: 2013

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Bibliographical note
Clara M. Velte, Pernille Hammar Andersson, Knud Erik Meyer,
"Coupling of theory and practice through inductive learning in experimental fluid mechanics education - A practical study",
Source: dtu
Source-ID: u::10566
Publication: Research - peer-review › Book chapter – Annual report year: 2014
Investigation of flow behind vortex generators by stereo particle image velocimetry on a thick airfoil near stall

Steroscopic Particle Image Velocimetry measurements investigating the effect of vortex generators (VGs) on the flow near stall were carried out in a purpose-built wind tunnel for airfoil investigations on a DU 91-W2-250 profile. Measurements were conducted at $Re = 9.10^6$, corresponding to free stream velocity $U_\infty = 15\, \text{m}\,\text{s}^{-1}$. The objective was to investigate the flow structures induced by the vortex generators and study their separation controlling behavior on the airfoil. The uncontrolled flow (no VGs) displayed unsteady behavior with separation as observed from large streamwise velocity variations. The corresponding controlled flow (with VGs) showed the same unsteadiness, where the appearance of the vortex structures alternated with a much less separated or even attached boundary layer as also seen in the measured airfoil data: $CL = 1.56$, $CD = 0.116$ with VGs and $CL = 1.16$, $CD = 0.135$ without. On average, the controlled flow left an attached flow as opposed to the uncontrolled one. Mixing close to the wall, transferring high momentum fluid into the near wall region, was observed, and the hypothesis of variations in the streamwise velocity component in the boundary layer was supported by a Snapshot Proper Orthogonal Decomposition analysis. This analysis also revealed some of the dynamics of the induced vortices. Copyright © 2012 John Wiley & Sons, Ltd.
Numerical simulations on a twin-plate wake

In this work, a detailed numerical analysis of two-dimensional mean velocity profiles downstream of two parallel flat plates was carried out at a Reynolds number of \( 3.2 \times 10^4 \) (based on the plate length and free stream velocity) using Reynolds Averaged Navier-Stokes (RANS) and have been compared with experimental data. Furthermore, a self-similar study of the wake behind the twin plate was carried out based on the computer simulations. The main objective is to investigate how well the simulations can reproduce the physics of the flow behind a twin plate.

General information
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Organisations: Department of Mechanical Engineering, Fluid Mechanics, Coastal and Maritime Engineering, University of the Basque Country, Polytechnic University of Catalonia
Authors: Fernández-Gámiz, U. (Ekstern), Velte, C. M. (Intern), Egusquiza, E. (Ekstern)
SPIV investigations of correlation between streamwise vorticity and velocity in the wake of a vortex generator in a boundary layer

The current work describes the experimental parametric study of streamwise vortices generated in a boundary layer by a rectangular vane (commonly named vortex generator) mounted perpendicularly to the wall and at an angle to the oncoming flow. Stereoscopic Particle Image Velocimetry measurements have been conducted in cross-planes to obtain a full picture of the wake for each measured case. It is observed that this seemingly simple configuration produces a complicated vortex system consisting of 4 vortices: the tip vortex, a horseshoe vortex system consisting of two sleeves and a secondary vortex generated by the interaction between the tip vortex and the wall. Depending on the height and angle of the vane, some structures are enhanced and others are suppressed. Comparing the corresponding vorticity and velocity fields, a strong correlation between the two is found. Stream-wise vorticity induced velocity with the observed strong correlation found is not at all evident. This has previously been shown to be true for the primary (tip) vortex, but not for the remaining secondary structures.

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Organisations: Department of Mechanical Engineering, Fluid Mechanics, Coastal and Maritime Engineering, Department of Wind Energy, Fluid Mechanics
Authors: Velte, C. M. (Intern), Okulov, V. (Intern), Hansen, M. O. L. (Intern)
Number of pages: 6
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Airflow characteristics in the breathing zone of a seated person using desk incorporated pair of confluent jets as personalized ventilation - effect of supply velocities

A workplace with desk, desk incorporated personalized ventilation (PV) and a dressed thermal manikin with realistic body and surface temperature distribution were set in a test room (4.70 m x 1.62 m x 2.6 m). 15 L/s were supplied from a ceiling diffuser to ventilate the room at 26 °C air temperature. The PV consisted of two plane jets placed beside each other (confluent jets) and along the front edge of the desk. The slots had dimensions: 0.06 m x 0.5 m (W x L). The manikin was seated upright with abdomen pressed against the front edge of the desk. The airflow supplied isothermally and upwards from the inner jet (closest to manikin) was the same, twice bigger or twice lower compared to that of the outer jet. The mean velocity field at the breathing zone was measured by Particle Image Velocimetry: a dual cavity laser (λ = 532 nm) and a CCD camera - 35 mm lenses. Glycerol droplets (seeding) were added to the total volume air supply. The maximum absolute mean velocity measured near the manikin’s mouth was 0.25 m/s, when the two confluent jets supplied 8 L/s each. Same velocity was measured when the inner jet was supplying 8 L/s and the outer 4 L/s. The opposite combination, i.e. outer jet 8 L/s and inner 4 L/s, resulted in lower velocity (0.13 m/s) compared to that of the free convection layer alone: 0.20 m/s. The increased velocity at the face allowed more clean air to be inhaled.

General information
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Closed loop control of a flap exposed to harmonic aerodynamic actuation

Wind tunnel testing of a two-dimensional aerofoil with a load reducing flap has been conducted under the influence of a closed-loop controller (PID). Upstream synthetic perturbations for well-defined testing of the controller were generated by instrumenting the wind tunnel with two fast turning vanes placed in front of the main test wing. These were situated symmetrically above and below the airfoil in a way that created a fast turning of the air flow without directly affecting the boundary layer on the test airfoil. The Reynolds number was \( \text{Re}=500,000 \). The PID-controlled flap was able to alleviate the load variations with reductions above 80\% for reduced frequencies up to \( k = 0.028 \) and nearly 70\% at \( k=0.054 \). At about 0.108 and higher a different strategy is needed for the present setup as the reduction is low or even negative.

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Organisations: Department of Wind Energy, Fluid Mechanics, Aeroelastic Design
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Comparison of four different models of vortex generators

A detailed comparison between four different models of vortex generators is presented in this paper. To that end, a single Vortex Generator on a flat plate test case has been designed and solved by the following models. The first one is the traditional mesh-resolved VG and the second one, called Actuator Vortex Generator Model (AcVG), is based on the lifting force theory of Bender, Anderson and Yagle, the BAY Model, which provides an efficient method for computational fluid dynamic (CFD) simulations of flow with VGs, and the forces are applied into the computational domain using the actuator shape model. This AcVG Model enables to simulate the effects of the Vortex Generators without defining the geometry of the vortex generator in the mesh and makes it easier for researchers the investigations of different vortex generator lay outs. Both models have been archived by the in house EllipSys CFD code using Reynold-Average Navier-Stokes (RANS) methods. The third model is the experimental one, where measurements were carried out in a low speed closed-circuit wind tunnel utilizing Stereoscopic Particle Image Velocimetry (SPIV) with a single vortex generator positioned on a vertical wall in the center of the test section. The fourth model, used as a quantitative comparison, is the analytical model of the primary vortex based in the helical structure of longitudinal embedded vortex, which can reduce the complex flow to merely four parameters: circulation, convection velocity, vortex core radius and pitch.

The goal of this article is to validate the AcVG Model compared with a fully meshed VG, a wind tunnel experiment and an analytical VG model.

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Organisations: Department of Wind Energy, Aeroelastic Design, Fluid Mechanics, University of the Basque Country, Polytechnic University of Catalonia
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Flow diagnostics downstream of a tribladed rotor model
This paper presents results of a study of vortex wake structures and measurements of instantaneous 3D velocity fields downstream of a triblade turbine model. Two operation modes of flow around the rotor with different tip speed ratios were tested. Initially the wake structures were visualized and subsequently quantitative data were recorded through velocity field restoration from particle tracks using a stereo PIV system. The study supplied flow diagnostics and recovered the instantaneous 3D velocity fields in the longitudinal cross section behind a tribladed rotor at different values of tip speed ratio. This set of data provided a basis for testing and validating assumptions and hypothesis regarding classical theories of rotors.
Large field SPIV with separated sheets in a spanwise plane of a turbulent boundary layer with vortex generators

The Stereoscopic PIV is nowadays a well established measurement technique for turbulent flows. However, the accuracy and the spatial resolution are still highly questionable in presence of complex flow with both strong gradients and out of plane motions. To give guidelines for both setup and measurements of such flow configurations, a large region of overlap between two SPIV systems on the same laser light sheet is acquired in a plane normal to the streamwise direction of a high Reynolds turbulent boundary layer flow. A simple separation of the two light sheets is used to improve the accuracy of measurements by increasing the velocity dynamic range especially. It also presents the enhancement of accuracy due to the light sheets separation for characterizing streamwise vortices (i.e. perpendicular to the sheet). The present experiment was performed in the Laboratoire de Mécanique de Lille wind tunnel facility which has been specially designed to study fully developed turbulent boundary layer at high Reynolds number. The outlooks are to study in detail the physics of the streamwise vortices generated from vortex generators taking advantage of large scales of this turbulent boundary layer.

General information
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Parametric Study of the Device Angle Dependency of a Single Vortex Generator on a Flat Plate

A detailed study of the device angle dependency of a single vortex generator (VG) is presented in this paper. A single Vortex Generator on a test section wall case, with four different positions of the device angle to the incoming flow, has been designed and solved by computational methods. The computational fluid dynamic (CFD) simulations have been compared with a wind tunnel experiment, where the corresponding parametric study was performed over a single vane mounted on the test section wall in low-speed wind tunnel. In this experiment the flow was recorded using Stereoscopic Particle Image Velocimetry (S-PIV) in cross-planes at various positions downstream of the vane.

The main goal of this article is to study the angle dependency of a single VG mounted on a test section wall; for this purpose CFD simulations have been carried out and compared with a wind tunnel experiment and an analytical model.

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Regimes of flow past a vortex generator
A complete parametric investigation of the development of multi-vortex regimes in a wake past simple vortex generator has been carried out. It is established that the vortex structure in the wake is much more complicated than a simple monopole tip vortex. The vortices were studied by stereoscopic particle image velocimetry (SPIV). Based on the obtained SPIV data, a map of the regimes of flow past the vortex generator has been constructed. One region with a developed stable multivortex system on this map reaches the vicinity of the optimum angle of attack of the vortex generator.

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Self-similarity and helical symmetry in vortex generator flow simulations

According to experimental observations, the vortices generated by vortex generators have previously been observed to be self-similar for both the axial (uz) and azimuthal (u) velocity profiles. Further, the measured vortices have been observed to obey the criteria for helical symmetry. This is a powerful result, since it reduces the highly complex flow to merely four parameters. In the present work, corresponding computer simulations using Reynolds-Averaged Navier-Stokes equations have been carried out and compared to the experimental observations. The main objective of this study is to investigate how well the simulations can reproduce the physics of the flow and if the same analytical model can be applied. Using this model, parametric studies can be significantly reduced and, further, reliable simulations can substantially reduce the costs of the parametric studies themselves.

General information

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Organisations: Department of Wind Energy, Fluid Mechanics, Aeroelastic Design, University of the Basque Country
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Vortex Generator Induced Flow in a High Re Boundary Layer

Stereoscopic Particle Image Velocimetry measurements have been conducted in cross-planes behind three different geometries of Vortex Generators (VGs) in a high Reynolds number boundary layer. The VGs have been mounted in a cascade producing counter-rotating vortices and the downstream flow development was examined. Three VG geometries were investigated: rectangular, triangular and cambered. The various VG geometries tested are seen to produce different impacts on the boundary layer flow. Helical symmetry of the generated vortices is confirmed for all investigated VG geometries in this high Reynolds number boundary layer. From the parameters resulting from this analysis, it is observed at the most upstream measurement position that the rectangular and triangular VGs produce vortices of similar size, strength and velocity induction whilst the cambered VGs produce smaller and weaker vortices. Studying the downstream development in the ensemble and spanwise averaged measurements, it is observed that the impact from the rectangular and triangular VGs differs. For the rectangular VGs, self-similarity in the streamwise component was confirmed.
Airflow Characteristics at the Breathing Zone of a Seated Person: Passive Control over the Interaction of the Free Convection Flow and Locally Applied Airflow from Front for Personalized Ventilation Application

A workstation with a desk-mounted Personalized Ventilation (PV) unit, with circular diffuser (d = 0.185 m) supplying air from the front/above towards the face of a thermal manikin with realistic body shape and temperature distribution was set in a climate chamber (4.70 m x 1.62 m x 2.6 m). The distance between manikin’s face and the diffuser was 0.4 m. Mixing overhead ventilation at 15 L/s was used to ventilate the chamber. The room air temperature was kept at 20 oC. The PV air was supplied isothermally at 4, 6 or 8 L/s. The thermal manikin was sitting 0.1 m away from the front edge of the table. Passive method for control over the airflow characteristics at the breathing zone to increase the amount of clean air in inhalation consisted of a rectangular board (0.63 m x 0.36 m) placed below the table and pressed against the abdominal. It acted as a barrier reducing the convection flow upcoming from the lower body. The resultant velocity field at the breathing zone was measured with Particle Image Velocimetry: a dual cavity laser (λ = 532 nm) and two CCD cameras with 35 and 60 mm lenses. Seeding consisting of glycerol droplets (d = 2-3 μm) was added to the total volume supply. The blocking of the convection layer by the board decreased twice the absolute mean velocity at the mouth: from 0.2 m/s to 0.1 m/s. This made it possible for the PV flow already at 4 L/s to penetrate the free convection flow, which without the board was achieved at the PV flow rate of 6 L/s.

Airflow Characteristics at the Breathing Zone of a Seated Person: Active Control over the Interaction of the Free Convection Flow and Locally Applied Airflow from Front for Personalized Ventilation Application

A method for active control over the interaction between the free convection flow around occupant’s body and locally applied airflow from front on the velocity field at the breathing zone of a seated person was studied. A workplace equipped with personalised ventilation (PV) generating flow from front/above against the face of a thermal manikin with realistic body shape and surface temperature distribution (used to resemble a seated human body) was set in a climate chamber (4.70 m x 1.62 m x 2.60 m). The air temperature in the chamber was kept at 20 oC. Ceiling diffuser supplied ventilation air at 15 l/s. The PV air was supplied isothermally at 4, 6 or 8 L/s. The PV diffuser with diameter 0.18 m, was located at distance 0.4 m from the face of the manikin. The distance between the lower chest of the manikin and the front edge of the desk was 0.1 m. Box with 6 small computer fans (suction box) was installed below the table board, above the thighs of the manikin, and was used to exhaust the air of the free convection flow coming from the lower body parts of the manikin. The velocity field at the breathing zone was measured with Particle Image Velocimetry consisting of a dual cavity laser and two CCD cameras. The maximum absolute mean velocity measured in the convective layer at the mouth of the manikin was
0.20 m/s and was reduced to 0.09 m/s when the suction box was used. Thus the weakend boundary layer can be penetrated by the PV flow at the lowered velocity. The use of the suction box and the PV at 4 L/s resulted in the same velocity at the breathing zone as when only PV was used at 6 L/s. The maximum absolu

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**Airflow Characteristics At The Breathing Zone of a Seated Person: Interaction of the Free Convection Flow and an Assisting Locally Supplied Flow From Below for Personalized Ventilation Application**

A workstation with Personalized Ventilation (PV) unit and a thermal manikin with realistic body and temperature distribution were set in a test room (4.70 m x 1.62 m x 2.6 m). Airflow at 15 L/s was supplied from a ceiling diffuser to ventilate the room and keep the temperature at 26 oC. The PV consisted of two plenum boxes nested in each other and placed below the desk top, with discharge slots 0.06 m x 0.5 m (W x L). The PV unit was pressed against the abdomen of the thermal manikin. Each box had a separate supply fan. The airflow supplied isothermally and upwards from the inner and outer box was the same: 4, 6, 8 and 10 L/s. The mean velocity field at the breathing zone was obtained by Particle Image Velocimetry: a dual cavity laser (λ = 532 nm) and two CCD cameras with 35 and 60 mm lenses. Seeding, glycerol droplets, was added to the total volume supply. The maximum absolute mean velocity measured near the mouth was 0.1 m/s, when the boxes were installed but not working. When the two slots supplied equal amount of air, the measured absolute mean velocity increased with increasing the supplied air with a maximum of 0.35 m/s at 10 L/s.

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**Alteration of helical vortex core without change in flow topology**

The abrupt expansion of the slender vortex core with changes in flow topology is commonly known as vortex breakdown. We present new experimental observations of an alteration of the helical vortex core in wall bounded turbulent flow with abrupt growth in core size, but without change in flow topology. The helical symmetry as such is preserved, although the characteristic parameters of helical symmetry of the vortex core transfer from a smooth linear variation to a different trend under the influence of a non-uniform pressure gradient, causing an increase in helical pitch without changing its sign.
PIV measurements of flow structures in a spray dryer

Stereoscopic Particle Image Velocimetry (PIV) measurements are made in horizontal planes in a simplified scale model of a spray dryer using water as fluid. The sample rate was sufficient to resolve phenomena at lower frequencies. Data reveal asymmetric velocity fields in both mean fields and dynamics. Data were analysed using Proper Orthogonal Decomposition (POD). An important periodic event is an elongation of the jet core cross section that results in a downstream displacement of the jet towards the chamber wall.

Regimes of Vorticity in the Wake of a Rectangular Vortex Generator

This paper concerns the study of the secondary structures generated in the wake of a wall mounted rectangular vane, commonly referred to as a vortex generator. The study has been conducted by Stereoscopic PIV measurements in a wind tunnel and supplementary flow visualizations in a water channel. The results show that the vane produces not only the anticipated primary vortex, but at least five vortex structures. Further, the vorticity map can be subject to various regimes, showing a dependency on the circulation of the primary vortex and the height of its center above the wall.
Efficient estimation of burst-mode LDA power spectra

The estimation of power spectra from LDA data provides signal processing challenges for fluid dynamicists for several reasons. Acquisition is dictated by randomly arriving particles which cause the signal to be highly intermittent. This both creates self-noise and causes the measured velocities to be biased due to the statistical dependence on the velocity and when the particle arrives. This leads to incorrect moments when the data are evaluated by arithmetically averaging. The signal can be interpreted correctly, however, by applying residence time weighting to all statistics, which eliminates the velocity bias effects. Residence time weighting should also be used to compute velocity spectra. The residence time-weighted direct Fourier transform can, however, be computationally heavy, especially for the large data sets needed to eliminate finite time window effects and given the increased requirements for good statistical convergence due to the random sampling of the data. In the present work, the theory for estimating burst-mode LDA spectra using residence time weighting is discussed and a practical estimator is derived and applied. A brief discussion on the self-noise in spectra and correlations is included, as well as one regarding the statistical convergence of the spectral estimator for random sampling. Further, the basic representation of the burst-mode LDA signal has been revisited due to observations in recent years of particles not following the flow (e.g., particle clustering), which was not covered in the previous theory. An efficient algorithm for computing the residence time weighted power spectra using Matlab is proposed and implemented. The algorithm is applied to two experiments, one with high data density (cylinder wake) and one with relatively low data density (axisymmetric turbulent jet). The burst-mode LDA spectra are compared to corresponding spectra from hot-wire data obtained in the same experiments, and to LDA spectra produced by the sample-and-hold methodology. The spectra computed from the residence-time weighted burst-mode algorithm proposed herein compare favorably to the hot-wire data for both experiments, independent of the LDA data density. The sample-and-hold spectrum produced from the same LDA data, however, is very different for the low data density due to frequency dependent filtering of the spectrum inherent in the method.

SPIV study of passive flow control on a WT airfoil

Stereoscopic Particle Image Velocimetry (SPIV) measurements investigating the effect of vortex generators (VGs) on the flow near stall have been carried out in the purpose built LM Glasfiber wind tunnel on a DU 91-W2-250 profile. Measurements have been conducted at Re=0.9*10^6, corresponding to free stream velocity U=15 m/s. The objective was to investigate the flow structures induced by and separation controlling behavior of vortex generators on the airfoil. The experimental results show strong separation of the uncontrolled flow whereas an intermittent behavior appears for the controlled flow, where the appearance of vortex structures alternate with a slightly separated turbulent boundary layer. However, the controlled case is yielding less backflow than the uncontrolled one: On average, the controlled flow leaves a nicely attached flow as opposed to the incident one. For the controlled flow, the observed vortex structures generated by the devices are similar to those found in studies at lower Reynolds numbers. Further, mixing close to the wall, transferring high momentum fluid into the near wall region, is seen. The hypothesis of intermittent fluctuations in the boundary layer is further supported by a Snapshot Proper Orthogonal Decomposition (POD) analysis. This analysis also reveals some of the dynamics of the induced vortices, such as pulsations of axial velocity across the vortex cores and oscillations of the vortices primarily in the spanwise direction.
Characterization of Vortex Generator Induced Flow

The aim of this thesis is the characterization and modeling of the longitudinal structures actuated by vortex generators. Results from generic studies performed at low Reynolds numbers have shown that the device induced vortices possess helical structure of the vortex core. Further, their ability to control separation and downstream evolution across the chord of a circular sector have been studied. Similar flow structures to the ones found in the generic experiments have been found in a higher Reynolds number setting, more applicable to realistic cases common to, e.g., aeronautical applications. The helical structure of the vortices can, however, not be confirmed by the results of these experiments due to practical concerns of obtaining a measuring signal with high enough quality and resolution. Furthermore, in order to study the dynamics of the device induced structures, power spectra from LDA time series have been constructed from the burst-mode LDA theory developed mainly by Buchhave and George [19, 46]. In the process of applying this theory to the LDA time series, a technique has been developed correcting for the effect of random noise in spectra and correlations. The power spectra obtained from the flow behind the actuating devices did not display any distinct periodicity of the flow, but rather a random, or at best quasi-periodic, behavior. In addition, commonly employed interpolation and resampling methods for estimating power spectra from LDA data were compared to the corresponding spectra derived from hot-wire data. When the flow was well resolved, these methods showed acceptable results at high LDA data rates at all frequencies except at the highest ones. However, they failed miserably at low data rates, essentially burying the entire spectrum in frequency dependent noise beyond recognition.

Downstream Evolution of Longitudinal Embedded Vortices with Helical Structure

In the present work the downstream development of device induced vortices with helical symmetry embedded in wall bounded flow on a bump is studied with the aid of Stereoscopic Particle Image Velocimetry (SPIV). The downstream evolution of characteristic parameters of helical vortices is studied, displaying a linear variation of the helical parameters up to the trailing edge of the bump where the vortex experiences an abrupt transition in structure.
Evaluation of the Performance of Vortex Generators on the DU 91-W2-250 Profile using Stereoscopic PIV

Stereoscopic PIV measurements investigating the effect of Vortex Generators on the lift force near stall and on glide ratio at best aerodynamic performance have been carried out in the LM Glasfiber wind tunnel on a DU 91-W2-250 profile. Measurements at two Reynolds numbers were analyzed; Re=0.9·10^6 and 2.4·10^6. The results show that one can resolve the longitudinal vortex structures generated by the devices and that mixing is created close to the wall, transferring high momentum fluid into the near wall region. It is also seen that the vortex generators successfully can obstruct separation near stall.

General information
State: Published
Organisations: Fluid Mechanics, Department of Mechanical Engineering, LM Glasfiber A/S
Authors: Velte, C. M. (Intern), Hansen, M. O. L. (Intern), Meyer, K. E. (Intern), Fuglsang, P. (Ekstern)
Pages: 92-96
Publication date: 2009
Main Research Area: Technical/natural sciences
Publication information
Journal: Journal of Systemics, Cybernetics and Informatics
Volume: 7
Issue number: 3
ISSN (Print): 1690-4524
Ratings:
BFI (2018): BFI-level 1
BFI (2017): BFI-level 1
BFI (2016): BFI-level 1
BFI (2015): BFI-level 1
BFI (2014): BFI-level 1
BFI (2013): BFI-level 1
ISI indexed (2013): ISI indexed no
BFI (2012): BFI-level 1
ISI indexed (2012): ISI indexed no
BFI (2011): BFI-level 1
ISI indexed (2011): ISI indexed no
BFI (2010): BFI-level 1
BFI (2009): BFI-level 1
BFI (2008): BFI-level 1
Original language: English
Links:
http://www.iiisci.org/journal/sci/Abstract.asp?var=&id=KY812UI
Source: orbit
Source-ID: 265023
Publication: Research - peer-review › Journal article – Annual report year: 2009

Helical structure of longitudinal vortices embedded in turbulent wall-bounded flow
Embedded vortices in turbulent wall-bounded flow over a flat plate, generated by a passive rectangular vane-type vortex generator with variable angle 'beta to the incoming flow in a low-Reynolds number flow (Re = 2600 based on the inlet grid
mesh size $L = 0.039 \text{ m}$ and free stream velocity $U_{\infty} = 1.0 \text{ ms}^{-1}$) have been studied with respect to helical symmetry. The studies were carried out in a low-speed closed-circuit wind tunnel utilizing Stereoscopic Particle Image Velocimetry (SPIV). The vortices have been shown to possess helical symmetry, allowing the flow to be described in a simple fashion. Iso-contour maps of axial vorticity revealed a dominant primary vortex and a weaker secondary one for $20^\circ \leq \beta \leq 40^\circ$. For angles outside of this range, the helical symmetry was impaired due to the emergence of additional flow effects. A model describing the flow has been utilized, showing strong concurrence with the measurements, even though the model is decoupled from external flow processes that could perturb the helical symmetry. The pitch, vortex core size, circulation and the advection velocity of the vortex all vary linearly with the device angle $\beta$. This is important for flow control, since one thereby can determine the axial velocity induced by the helical vortex as well as the swirl redistributing the axial velocity component for a given device angle $\beta$. This also simplifies theoretical studies, e.g. to understand and predict the stability of the vortex and to model the flow numerically.

**General information**

State: Published
Organisations: Fluid Mechanics, Department of Mechanical Engineering
Authors: Velte, C. M. (Intern), Hansen, M. O. L. (Intern), Okulov, V. (Intern)
Pages: 167-177
Publication date: 2009
Main Research Area: Technical/natural sciences

**Publication information**

Journal: Journal of Fluid Mechanics
Volume: 619
ISSN (Print): 0022-1120
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 3.33 SJR 1.591 SNIP 1.702
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 2.82 SJR 1.744 SNIP 1.671
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.896 SNIP 1.639 CiteScore 2.57
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 1.864 SNIP 1.805 CiteScore 2.66
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 1.853 SNIP 1.88 CiteScore 2.71
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 1.678 SNIP 1.86 CiteScore 2.47
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 2.059 SNIP 2.002 CiteScore 2.72
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 2.229 SNIP 2.145
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 2.502 SNIP 1.863
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Evaluation of the Performance of Vortex Generators on the DU 91-W2-250 Profile using Stereoscopic PIV

Stereoscopic PIV measurements investigating the effect of Vortex Generators on the lift force near stall and on glide ratio at best aerodynamic performance have been carried out in the LM Glasfiber wind tunnel on a DU 91-W2-250 profile. Measurements at two Reynolds numbers were analyzed; Re=0.9·10^6 and 2.4·10^6. The results show that one can resolve the longitudinal vortex structures generated by the devices and that mixing is created close to the wall, transferring high momentum fluid into the near wall region. It is also seen that the vortex generators successfully can obstruct separation near stall.

Flow analysis of vortex generators on wing sections by stereoscopic particle image velocimetry measurements

Stereoscopic particle image velocimetry measurements have been executed in a low speed wind tunnel in spanwise planes in the flow past a row of vortex generators, mounted on a bump in a fashion producing counter-rotating vortices.
The measurement technique is a powerful tool which provides all three velocity components in the entire measurement plane. The objective of this study is to investigate the effect of vortex generators in a turbulent, separating, low Reynolds number (Re = 20 000) boundary layer over a geometry which is generating an adverse pressure gradient similar to the flow past a wind turbine blade. The low Reynolds number is chosen on the basis that this is a fundamental investigation of the structures of the flow induced by vortex generators and the fact that one obtains a thicker boundary layer and larger structures evoked by the actuating devices, which are easier to measure and resolve. The flow behaves as expected, in the sense that the vortices transport high momentum fluid into the boundary layer, making it thinner and more resistant to the adverse pressure gradient with respect to separation. The amount of reversed flow is significantly reduced when vortex generators are applied. The idea behind the experiments is that the results will be offered for validation of modeling of the effect of vortex generators using various numerical codes. Initial large eddy simulation (LES) computations have been performed that show the same qualitative behaviour as in the experiments.
Experimental and Numerical Investigation of the Performance of Vortex Generators on Separation Control

General information
State: Published
Organisations: Fluid Mechanics, Department of Mechanical Engineering
Authors: Velte, C. M. (Intern), Hansen, M. O. L. (Intern), Jønck, K. M. (Ekstern)
Pages: 012030
Publication date: 2007
Main Research Area: Technical/natural sciences

Publication information
Journal: Journal of Physics: Conference Series (Online)
Volume: 75
ISSN (Print): 1742-6596
Ratings:
BFI (2018): BFI-level 1
BFI (2017): BFI-level 1
Scopus rating (2017): CiteScore 0.48 SJR 0.241 SNIP 0.447
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 0.45 SJR 0.24 SNIP 0.401
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.252 SNIP 0.374 CiteScore 0.35
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.264 SNIP 0.352 CiteScore 0.32
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.245 SNIP 0.293 CiteScore 0.25
ISI indexed (2013): ISI indexed no
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.293 SNIP 0.387 CiteScore 0.33
ISI indexed (2012): ISI indexed no
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.293 SNIP 0.356 CiteScore 0.43
ISI indexed (2011): ISI indexed no
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.288 SNIP 0.351
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Experimental Investigation of the Effect of Vortex Generators

**General information**
State: Published
Organisations: Fluid Mechanics, Department of Mechanical Engineering
Authors: Velte, C. M. (Intern), Hansen, M. O. L. (Intern), Meyer, K. E. (Intern)
Pages: BL3.196
Publication date: 2007

**Host publication information**
Title of host publication: EWEC 2007 Proceedings
Place of publication: Milano
Main Research Area: Technical/natural sciences
Links:
Source: orbit
Source-ID: 205408
Publication: Research - peer-review › Article in proceedings – Annual report year: 2007

Simulation and Control of Wind Turbine Flows using Vortex Generators

**General information**
State: Published
Organisations: Fluid Mechanics, Department of Mechanical Engineering
Authors: Velte, C. M. (Intern), Jønck, K. M. (Ekstern), Hansen, M. O. L. (Intern)
Publication date: 2007

**Publication information**
Original language: English
Source: orbit
Source-ID: 205409
Publication: Research › Conference article – Annual report year: 2007

CFD study of the influence of geometric gaps and engine bay compactness on the aerodynamic characteristics of a passenger car

**General information**
State: Published
Organisations: Fluid Mechanics, Department of Mechanical Engineering, Volvo Cars Corporation, Torslanda, Göteborg, Sweden
Authors: Sebben, S. (Ekstern), Walker, T. (Ekstern), Velte, C. M. (Intern)
Pages: 126-136
Publication date: 2006

Host publication information
Title of host publication: Proceedings of the MIRA International Vehicle Aerodynamics Conference
Main Research Area: Technical/natural sciences
Conference: MIRA International Vehicle Aerodynamics Conference, 01/01/2006
Source: orbit
Source-ID: 265077
Publication: Research - peer-review › Article in proceedings – Annual report year: 2006

Projects:

**Universal Equilibrium and Beyond - Challenging the Richardson-Kolmogorov Paradigm**

Department of Mechanical Engineering

Fluid Mechanics, Coastal and Maritime Engineering
Period: 01/02/2019 → 01/02/2023
Number of participants: 1
Acronym: UniEqTURB
Number of related Ph.D. students: 3
Project participant:
Velte, Clara Marika (Intern)

**State-of-the-art laser Doppler systems development for turbulence measurements**

Department of Mechanical Engineering

Period: 15/06/2015 → 30/11/2018
Number of participants: 4
Phd Student:
Yaacob, Mohd Rusdy (Ekstern)
Supervisor:
Buchhave, Preben (Intern)
Meyer, Knud Erik (Intern)
Main Supervisor:
Velte, Clara Marika (Intern)

**Financing sources**
Source: Internal funding (public)
Name of research programme: Privatist
Project: PhD

**State-of-the-art laser Doppler systems development for turbulence measurements**

Testing and development of improved laser Doppler anemometry methods

Department of Mechanical Engineering

Fluid Mechanics, Coastal and Maritime Engineering
Period: 01/06/2015 → 31/05/2018
Number of participants: 4
Project participant:
Yaacob, Mohd Rusdy (Ekstern)
Velte, Clara Marika (Intern)
Meyer, Knud Erik (Intern)
Buchhave, Preben (Intern)

Project
Experimental and theoretical investigations of turbulent axi-symmetric jets
Fundamental turbulence study for studying the development of the jet for creating an analytical model. The results will be useful for studying the dependence upon initial/upstream condition and the development of turbulence.

Department of Mechanical Engineering
Fluid Mechanics, Coastal and Maritime Engineering

Imperial College London
Period: 15/04/2015 → 14/04/2018
Number of participants: 4
Number of related Ph.D. students: 1
Project participant:
Hodzic, Azur (Intern)
Velte, Clara Marika (Intern)
Meyer, Knud Erik (Intern)
George, William K (Intern)

Experimental and theoretical investigations of turbulent axi-symmetric jets
Department of Mechanical Engineering
Period: 01/04/2015 → 31/07/2018
Number of participants: 4
Phd Student:
Hodzic, Azur (Intern)
Supervisor:
George, William K (Intern)
Meyer, Knud Erik (Intern)
Main Supervisor:
Velte, Clara Marika (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU)
Project: PhD

State-of-the-art laser Doppler system for turbulence measurements
Department of Mechanical Engineering
Fluid Mechanics, Coastal and Maritime Engineering
Intarsia Optics
Period: 23/10/2013 → 31/12/2015
Number of participants: 2
Project ID: 76503
Project participant:
Velte, Clara Marika (Intern)
Buchhave, Preben (Intern)

Characterization of vortex generator induced structures in high Reynolds number wall bounded flow
Department of Mechanical Engineering
Fluid Mechanics, Coastal and Maritime Engineering
Ecole Centrale de Lille
Period: 01/04/2011 → 30/06/2012
Number of participants: 4
Project ID: 76177
Project participant:
Velte, Clara Marika (Intern)
Braud, Caroline (Ekstern)
Foucaut, Jean Marc (Ekstern)
Cuvier, Christophe (Ekstern)

**Project**

**Fluid Dynamic Characterization of Vortex Generators and Two-dimensional Turbulent Wakes**
A numerical investigation of the physics of the wake induced by vortex generators.

Department of Mechanical Engineering
Fluid Mechanics, Coastal and Maritime Engineering
Period: 01/10/2010 → 30/09/2013
Number of participants: 3
Number of related Ph.D. students: 1
Project participant:
Fernandez Gamiz, Unai (Ekstern)
Egusquiza Estevez, Eduard (Ekstern)
Velte, Clara Marika (Intern)

**Relations**
Publications:
Fluid Dynamic Characterization of Vortex Generators and Two-dimensional Turbulent Wakes
Documents:
Thesis_190913

**Optimization of vortex generators on wind turbine blades**
Experimental/theoretical optimization and model construction for the wake induced by vortex generators.

Department of Mechanical Engineering
Fluid Mechanics, Coastal and Maritime Engineering
Department of Wind Energy
Fluid Mechanics
Aeroelastic Design
LM Glasfiber A/S
Period: 01/02/2010 → 31/07/2013
Number of participants: 5
Project ID: 76031
Project participant:
Velte, Clara Marika (Intern)
Hansen, Martin Otto Laver (Intern)
Okulov, Valery (Intern)
Sørensen, Niels N. (Intern)
Fuglsang, Peter (Intern)

**Simulation and Control of Wind Turbine Flows using Vortex Generators**
Department of Mechanical Engineering
Period: 01/12/2005 → 04/11/2009
Number of participants: 7
Phd Student:
Velte, Clara Marika (Intern)
Supervisor:
George, William K (Intern)
Meyer, Knud Erik (Intern)
Main Supervisor:
Hansen, Martin Otto Laver (Intern)
Examiner:
Larsen, Poul Scheel (Intern)
Buchhave, Preben (Intern)
Stanislas, Michel (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Forskningsrådsfinansiering
Project: PhD

Activities:

Experimental Evaluation Of Kolmogorov's -5/3 and 2/3 Power Laws In The Developing Turbulent Round Jet
Period: 5 May 2018 → 6 May 2018
Mohd Rusdy Bin Yaacob (Speaker)
Clara Marika Velte (Other)
Preben Buchhave (Other)
Rasmus Schlander (Other)

Department of Mechanical Engineering
Fluid Mechanics, Coastal and Maritime Engineering
Degree of recognition: International
Documents:
published journal
Links:

Related event

The 1st International Symposium on Fluid Mechanics and Thermal Sciences
05/05/2018 → 06/05/2018
Kuala Lumpur, Malaysia
Activity: Talks and presentations › Conference presentations

Mapping Of Turbulent Round Jet Developing Region Using a Constant Temperature Anemometer (CTA)
Period: 2 May 2018 → 3 May 2018
Mohd Rusdy Bin Yaacob (Speaker)
Clara Marika Velte (Other)
Preben Buchhave (Other)
Rasmus Korslund Schlander (Other)

Department of Mechanical Engineering
Fluid Mechanics, Coastal and Maritime Engineering
Degree of recognition: International
Documents:
ESCon18 full paper v4

Related event

Emerging Scientists Conference 2018
02/05/2018 → 03/05/2018
Johor Bahru, Malaysia
Activity: Talks and presentations › Conference presentations