

Experiments in Turbulent Flows



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Who we are and where we work

We are graduate students based at or visiting the *Department of Mechanics* and working towards our PhD in various turbulence related topics. Although part of our work is or will be performed at partner institutions most of the experiments are planned and conducted at the *Fluid Physics Laboratory*. The experiments, of which we will present some examples of in this illustrative overview, have been conducted in various flow facilities and with a variety of measurement techniques, which will be mentioned together with the studied subjects in the following. Although our interest is on turbulence and consequently some of the studies are indeed solely turbulence related, others might be overlapping with flow stability and control.

Highly complex flows

Fully developed turbulent pipe flows as well as jets with fully developed turbulent initial conditions are of fundamental and practical interest. By rotating the entire pipe and adding heat to the flow the problem becomes highly complex and both flows, the rotating pipe flow and swirling jet flow, constitute a challenge not only for computational methods and modelling, but also for measurement techniques. Such a facility with a 6 m long rotating pipe of 60 mm diameter has been set-up and successfully operated at our laboratory [2,3]. Fully developed turbulent pipe flow as well as axially rotating pipe flow on the one hand and the emanating round and swirling jet flow were hence welldefined in terms of their velocity and temperature profiles and free of any traces of swirl generating methods constituting a unique database for model validation. The results constitute therefore a valuable database for model validation and highlight the effect of rotation.

Interacting phenomena

Having successfully applied the combined X-wire and cold-wire probe with temperature compensation in the heated swirling jet flow gave us the idea to use a similar technique in coaxial jet flows, where to date no experimental studies on joint velocity and passive scalar quantities have been reported. For this purpose a coaxial jet facility at the *University of Bologna* was used to study the mixing of the two jet flows with each other as well as with the surrounding ambient air.

Grid Generated Turbulence Study [1]

A grid generated turbulence study was undertaken aimed at a future study of receptivity. Several low turbulence level grids were obtained and characterized in terms of turbulence intensity, different length scales, energy spectra etc. These grids ranged from 0.96 mm to 4.2 mm in mesh width and all had a solidity of about 40%. The range of speeds studied gave Re_M values that are much lower than commonly used in turbulence studies.

The goal of this study was to locate the region where *isotropic homogeneous turbulence* (IHT) can first be found. This is most generally defined as $u_{rms} = v_{rms} = w_{rms}$ or also when the exponent in the decay law, $u_{rms}/U_{\infty} = A(x/M)^b$, is -1. Results have shown that the ratio u_{rms}/v_{rms} approaches an asymptotic value far downstream of the grids and that this value approaches 1 for high Re_M . It was also shown that the decay exponent, *b*, also asymptotically approaches the expected value of -1 for high Re_M . This is shown in the figures below.



A variety of novel measurement techniques had to be utilised in order to study the dynamic and passive scalar (temperature) field. Simultaneous *hot-* and *cold-wire anemometry* (HWA) by means of a combined X-wire and cold-wire probe was employed to access the velocity and passive scalar (joint) statistics [4]. Quantities not accessible by the present HWA technique were acquired by two component *laser-Doppler velocimetry* (LDV), which also validated the HWA measurements in the non-isothermal complex flow field. A stereoscopic and time resolved *particle image velocimetry* (PIV) system was furthermore used to provide all three velocity components and to study the coherent structure dynamics [5].



Besides providing experimental data on joint statistics, it was also for the first time experimentally verified that the vortex shedding phenomenon behind a thick separating wall between two coaxial jets could provide a continuous forcing mechanism for the control of the whole flow field. The dominant frequency of the *outer shear layers* (OSL) vortices is hereby triggered by the vortex shedding behind the inner separating wall and hence the synchronisation phenomenon could be shown to be present contrary to the known triggering of the *inner shear layers* (ISL) vortices by the Kelvin-Helmholtz instability of the outer shear layer.



The streamwise length scales all seemed to scale with M when the downstream position was scaled as $(x/M)/Re_M$. Below is shown the fits to the Taylor (λ) and Kolmogorov (η) length scales, which show the best agreement.



Axisymmetric jet

Since the recognition of coherent structures in fully developed turbulent flows at high Reynolds numbers a lot of effort has been devoted to understand their dynamics to both predict and control the flow. Despite the increased application of structure identification methods, as conditional sampling techniques or the proper orthogonal de*composition* (POD), much remains unknown and is highly debated. This is particularly true for the most energetic modes in the region behind the potential core of the jet. Our contribution to this topic will be to study the evolution and interaction of unstable modes by means of acoustic excitation, which has the property to highlight the coherent structures above their background turbulence. Therefore a set of loudspeakers will be arranged in the settling chamber upstream the nozzle in order to excite combinations of axisymmetric and helical modes to illuminate the resonance between them. A special hot-wire rake will be used to investigate the azimuthal coherency as well as to enable a vector implemented POD analysis.



Despite providing a database of a peerless swirling jet further experimental evidence was found that a solid body rotation can never be reached in an axially rotating turbulent pipe flow contrary to its laminar counterpart and a weakly counter-rotating core approximately 6 pipe diameters downstream of the pipe was for the first time reported [6]. Further time-resolved PIV and multipoint hot-wire studies are planed to illuminate the character and origin of the counter-rotating core.

CICLoPE

A response to the need for high Reynolds number experiments is the *Center for International Cooperation in Long Pipe Experiments* (CICLoPE) [7] of which the *Department of Mechanics* is part of. The planned huge fully developed turbulent pipe flow (0.9 m pipe diameter and a length of 115 m) facility will give good spatial resolution at even high Reynolds numbers and is in this sense unique.



In the framework of CICLOPE, a measurement jamboree will be held at KTH, the University of Melbourne and IIT Chicago during 2008 where different measurement techniques and flow facilities will be cross-checked. This will give us the opportunity to work with a variety of measurement techniques, flow facilities and leading scientists in turbulence.

Acknowledgments

None of the work would have been possible in the presented extend without the guidance of our supervisors Prof. P. Henrik Alfredsson, Prof. Alessandro Talamelli as well as Dr. Jens Fransson. Additionally we express our gratitude towards Dr. Nils Tillmark, Dr. Luca Facciolo and Prof. Yvan Maciel who all contributed in one way or another to some of the presented studies.

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