Research strategy for
High Reynolds number turbulence including geophysical flows

Background

Hydrodynamic turbulence is the archetype of highly nonlinear chaotic systems possessing many degrees of freedom and a wide span of scales. As such, it has often been described as ”the last unsolved problem of classical physics”. If we by a solution mean a closed theory that would dramatically reduce the complexity of the problem and enable us to predict various statistical properties of turbulence flows in a simple and accurate way, then the problem will probably remain unsolved. However, the very rapid development of computer power and numerical simulation techniques during recent decades has changed our expectations on what a solution may look like. By means of Direct Numerical Simulations (DNS) and Large Eddy Simulations (LES), knowledge on turbulence flows is accumulated through the efforts of many research groups around the world. We have now come to the point where it is meaningful to make detailed comparisons between low Reynolds number laboratory flows and DNS/LES. The rapid increase of knowledge also enables us to make improvements of simple turbulence models for different flow situations. The turbulence research at the Department of mechanics has made important contributions in the development of turbulence models and experiments of high Reynolds number flows, also including multiphase and reactive flows. More recently work dealing with turbulence and geophysical flows has been added and now forms a growing part of the activity.

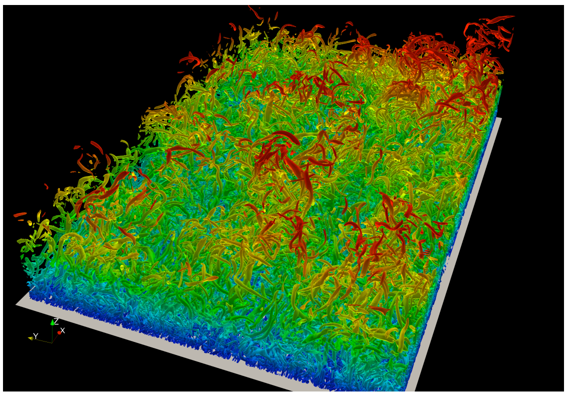

Figure 1. Vortical structures in a turbulent boundary layer at Re_q=4300.

Research environment

The research environment in the turbulence area is based on the turbulence simulation and modelling activities that have been carried out during the last decade at KTH Mechanics. The strength of the environment is the combination of theoretical, numerical, modelling and experimental activities. A list of people currently involved in turbulence research, with specific projects, follows (see Table 1). Table 2 lists projects, which have been finalized.

Projects	PhD.stud postdocs	Senior researchers	Proj. Start	Sponsor
Turbulence modelling and simulation				
Simulation and modelling of turbulent flows		Johansson Brethouwer	2004	VR, KTH
Simulation and modelling of turbulent flows and combustion	Pouransari	Johansson Brethouwer	2009	Cecost/ Energimynd.
Modelling of turbulent gas-particle flows	Strömgren	Johansson Amberg	2004	Energimynd.
Large eddy simulations of turbulent flows	Rasam	Johansson Brethouwer	2009	VR
Direct numerical study of high-Reynolds number turbulent pipe flow	Lenaers	Johansson, Brethouwer, Schlatter	2009	FLOW
Large-scale simulations of turbulent flows, including transition and separation		Schlatter	2007	VR
Simulations of turbulent boundary layers with passive scalars	Li	Henningson Schlatter	2007	KTH
Spectral-element simulations of turbulent separation	Ohlsson	Henningson Schlatter	2007	FLOW
Lagrangian particles in turbulent wall flows	Sardina (Uni Roma)	Schlatter Brandt	2008	VR, KTH
Experimentally low Re turbulent boundary layer investigation	Örlü	Fransson Alfredsson	2008	KTH
Nordita program on turbulent combustion		Brandenburg, Johansson	2010	KTH, VR, Nordita, Energimynd
High Reynolds number wall bounded flows				
Turbulent boundary layers at high Reynolds number - CICLoPE		Johansson Alfredsson Fransson	2004	VR/EU
ICET: coordinated measurements in high Reynolds number turbulent boundary layers from three wind tunnels	Kurian Örlü	Fransson Alfredsson	2008	KTH FLOW
Nordita program on turbulent boundary layers		Brandenburg, Alfredsson,Johansson	2010	KTH, VR, Nordita
Geophysical flows				
Stratified turbulence		Lindborg Brethouwer	2001	VR
Energy transfer and coherent structures in quasi-geostrophic turbulence	Vallgren	Lindborg Brethouwer	2007	VR
Stratified wall bounded flows	Deusebio	Lindborg, Schlatter, Brethouwer	2010	VR

Table 1: Ongoing research activities within FLOW.

Project titles	PhD.stud. Postdoc	Senior researcher	Proj. end	Sponsor
Swirling turbulent pipe and jet flow	Örlü	Alfredsson	2009	Energimynd.
Extreme climate conditions in Sweden in a 100 000 year time perspective		Brandefelt	2008	Swedish nuclear fuel and waste management company (SKB)

Table 2: Finished projects within FLOW.

Overall Research Goals

The long-term goals of the turbulence research within FLOW are

- To investigate fundamental aspects of high Reynolds number and complex turbulent flows experimentally and numerically, and develop, optimise and validate new modeling tools for such flows.
- To develop LES-models for flow and (passive) scalar calculations, based on modern filtering and stochastic techniques.
- To develop fundamental understanding and improved modelling of geophysical flows based on concepts from turbulence theory.
- Apply advanced massively parallel numerical methods for the large-scale accurate simulation of turbulence in moderately complex geometries.
- To contribute to the understanding of the dynamics of the Earth's climate system utilizing inter-mediate complexity and fully coupled global climate models.

Roadmap

Turbulence modeling and simulation. The short-term goals are

- To develop subgrid scale models for LES based on explicit algebraic and stochastic expressions of the stresses and scalar fluxes in combination with modern filtering techniques. Such models have the potential of significantly improving generality of LES-predictions of complex and high-Reynolds number turbulent flows over a wide class of problems.
- To validate subgrid scale models in LES of high-Reynolds number and complex wall bounded turbulent flows.
- Application of the spectral-element method for the accurate simulation of turbulent internal flows with separation.
- Fully spectral simulations of (numerically) high Reynolds numbers in generic turbulent boundary layers on a flat plate; critical assessment of the data with experimental results at similar Re.
- Simulations of Lagrangian particles in a spatially evolving turbulent boundary layer.

- To simulate and study reactions and combustion in wall bounded shear flows. Of particular interest is the influence of a relatively cold wall on, e.g., the combustion rate and flame quenching.
- To develop an efficient and accurate algorithm for direct numerical simulations of pipe flows. This code will be used to simulate and study turbulence and large-scale structures in high-Reynolds number turbulent pipe flows.

High Reynolds number wall bounded flows. The short-term goals are

- To carry out experiments of high Reynolds number flows. A series of international workshops (started in Princeton 2004, and followed by meetings in Trieste, Bertinoro and Chicago) has taken place during the last couple of years in order to work towards the establishment of a new high Reynolds number flow facility for detailed studies of the structure of wall bounded turbulence. The planned new facility is a high Reynolds number pipe flow facility which will be hosted by Universitá di Bologna. The facility will enable spatially resolved near-wall measurements at Reynolds numbers much higher than what has earlier been achieved. This project is carried out within a strongly linked international consortium with partners from Europe, Australia, USA and Japan. The FLOW involvement is a key ingredient in the project and comprises many different aspects, such as flow facility design aspects, development of new experimental techniques in collaboration with other international groups, planning of measurements in the new facility etc.
- To analyze the data sets from the turbulence measurement jamborees by the ICET team. ICET stands for International Collaboration on Experiments in Turbulence, which is an international team consisting of research groups from KTH, Univ. of Bologna, Shinshu Univ., Nagoya Univ., University of Melbourne, Princeton Univ., CalTech, and Illinois Institute of Technology. The focus is to study if universality of certain flow parameters can be obtained in different but similar facilities using highly sophisticated measurement techniques.

International collaborators in this area of research are Prof. Marusic, Univ. of Melbourne, Prof. Smits, Princeton, Prof. Nagib, IIT, Prof. McKeon, CalTech, Prof. Matsubara, Shinshu University, Prof. Tsuji, Nagoya Univ., Prof. Casciola, Uni Rome, Dr. Paul Fischer, Argonne Ntl. Lab, Prof. Casciola, Uni Rome, Dr. Paul Fischer, Argonne Ntl. Lab, and Prof. Talamelli, Univ. of Bologna.

Geophysical flows. The short term goals are

- To continue the fruitful research in stratified turbulence. By means of DNS and simulations with hyperviscosity new aspects of energy transfer and layer formation in stratified turbulence will be investigated. Simulations will be carried out at higher Reynolds number than what has been possible to achieve so far. An

important task will be to gain acceptance in the international scientific community for the theory of stratified turbulence.
- To study wall bounded stratified turbulence by means of DNS and develop subgrid models for the stable atmospheric boundary layer.
- To study energy cascade processes and formation of coherent structures in quasi-geostrophic turbulence. This will be done by means of a combination of analytical methods, formulation of hypotheses and numerical simulations.
- To continue the study of Earth's past climate during the last ice age as well as during the Holocene (the period from 11 700 years ago until present day) by running and analysing climate models of inter-mediate complexity as well as fully coupled global climate models.

International collaborators in this area of research are Jim Riley at the University of Washington and Jean-Marc Chomaz and Paul Billant at the Ecole Polytechnique.