A EUROPEAN SYNERGY
FOR
THE ASSESSMENT OF WALL TURBULENCE.

PROJECT N°: AST4-CT-2005-516008

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Why Near Wall Turbulence?

The world is entering a new age of aviation --- the age of sustainable growth --- characterized by the need for more affordable, cleaner, quieter, safer and more secure air travel. European aeronautics is committed to play a prime role in shaping aviation for this new age. Research and technology development will be essential in responding to this challenge. To do so, Europe needs upstream research to further improve the technology base and to develop innovative concepts and breakthrough technologies, thereby paving the way for a step change in aviation.

In the near future, Europe seeks to reduce significantly aircraft development and operating costs. To do so, the aeronautical industry will need improved models based on a deeper understanding of the physics, and acquired using the most advanced experimental and modeling methods. While this is true for all the aspects of the design and operation of an aircraft, it is particularly true for aerodynamics. Although aerodynamics has made tremendous progress in the last century, it still lacks reliable turbulence models (which are crucial also for many other industrial design problems) and the understanding to develop them. The search for these models remains a very active domain for research and improvement. In fact, turbulence remains one of the great unsolved riddles of engineering and natural sciences, nowhere more so than near surfaces.

The potential benefits from even modest gains in understanding and predictive ability can best be illustrated by a simple example. On an Airbus A340, approximately one-half of the drag at cruising speed is skin friction drag. Based on Airbus estimations, even a 10\% reduction of this drag would result in a fuel saving of about 100,000 Euros per aircraft per year, or 1 billion Euro saving over the world every year. In practice, it is the inner part of the boundary layer nearest the wall that is crucial in determining the skin friction drag and, in fact, it is in this region that the present turbulence models are the least reliable, most notably when the flow is close to separation or separated. Therefore, a better understanding and modelling of this region, which is fairly universal, is crucial - first to have reliable estimations a priori of the drag of a new aircraft design and - second to move toward intelligent control strategies of the near wall flow.

Which Team?

The WALLTURB consortium is composed of 16 partners (Table 1). This consortium includes high level industrials from Aeronautics, large public research organizations and well known Universities from the Mechanical Engineering and Aeronautical field. All partners are strongly involved in the research on turbulence at European and International level. They have proven their efficiency and ability to cooperate in the frame of previous European programs.

LML UMR CNRS 8107	F
ONERA	F
LEA UMR CNRS 6609	F
LIMSI UPR CNRS 3251	F
Chalmers University of Technology	SE
ENSTA/ARMINES	F
CNRS SPEC/CEA Saclay	F
University of Cyprus	CY
University of Rome la Sapienza	IT
University of Surrey	UK
Polytechnic University of Madrid	SP
Technische Universität München	G
Technical University of Czestochowa	PL
Norwegian Defence Research Establishment	NO
AIRBUS	UK
DASSAULT AVIATION	F

Table 1 : List of WALLTURB partners

What Objectives?

The WALLTURB project is a challenging research program, completely in the objectives of the FP6 in Aeronautics and of strong industrial interest at intermediate and long term.

The global aim of WALLTURB is to bring in four years a significant progress in the understanding and modelling of near wall turbulence in Boundary Layers. This goes through:

- generating and analyzing new data on near wall turbulence,
- extracting physical understanding from these data,
- putting more physics in the near wall RANS models.
- developing better LES models near the wall
- investigating alternative models based on Low Order Dynamical Systems (LODS).

For that purpose, the WALLTURB Consortium plans :

- to put in a common database, shared by the WALLTURB partners, who are all experts in turbulence, the existing relevant data they have about near wall turbulence (from both experiments and DNS),

- to generate by experiment, and by complementary DNS, equivalent data for the Adverse Pressure Gradient Turbulent Boundary Layer physics (including separated flow cases), and to put them in the common database,

- to use this database to improve near wall turbulence models such as RANS, LES and LODS, and especially to understand their relative strengths and weaknesses.

Which program?

To reach the above objectives, the WALLTURB Consortium will take advantage of :

- the recent progress in the experimental and numerical approaches of turbulence,

- the complementary skills of leading teams in Europe working on turbulence.

It will generate a large and original database, with recent and relevant data about near wall turbulence (from both experiments and DNS already available at the partners). This database will be shared by the partners to extract relevant physical data.

The consortium will also generate new experimental and DNS data, allowing to assess Adverse Pressure Gradient Turbulent Boundary Layer physics, with and without separation, to go in the common database.

This database will be extensively used by all the partners to improve RANS, and LES near wall turbulence models and to develop a LODS/LES coupling near the wall.

The work performed will allow to make available new turbulence models based on a detailed physical characterisation and to assess the relative merits and drawbacks of these models. These models will be assessed by two leading industrial in the field of aeronautics : AIRBUS and DASSAULT AVIATION.

The WALLTURB project is organized in 6 work packages, as summarized in table 2 :

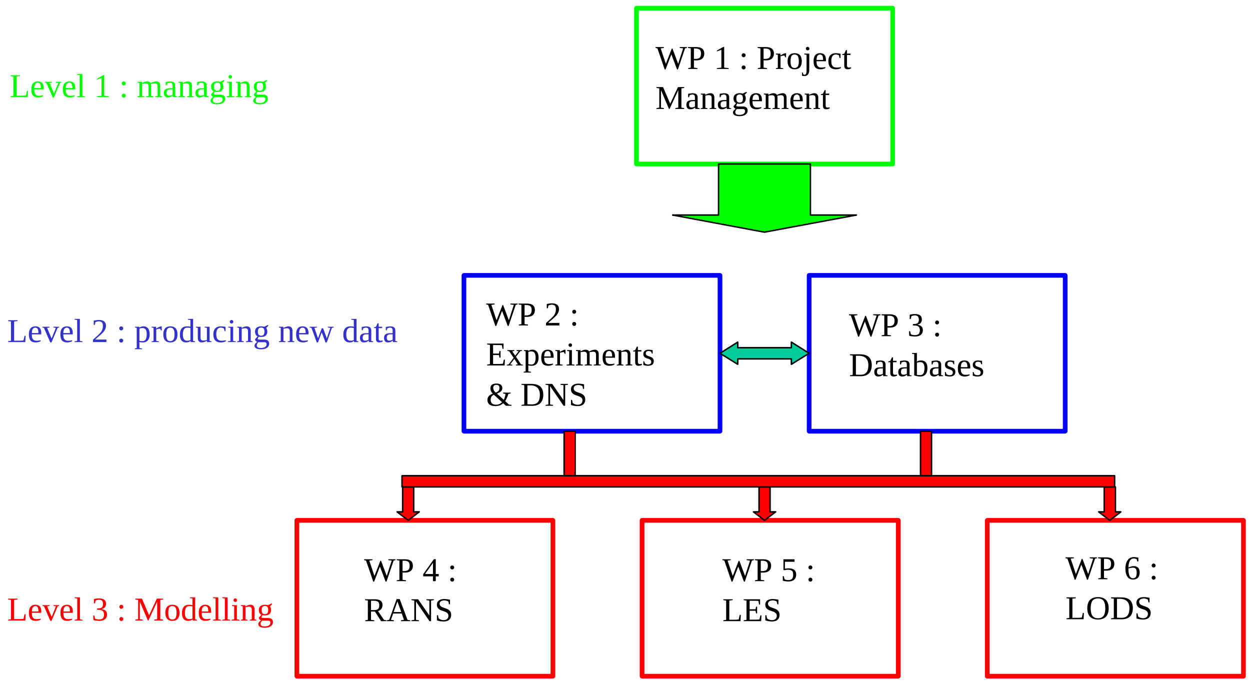


Table 2 : Work program Structure

WP2 : Experiments and DNS

The overall objective of the planned experiments and DNS is to complement the existing databases with time and space resolved data at high Reynolds numbers for ZPG and APG attached flows and to provide well documented test cases for the RANS modeling of separated flows. The unsteady data will be suitable for LES initial and boundary conditions, as well as of value to the POD and LODS evaluations. Experiments are carried out at LML, Chalmers, Surrey and Czestochowa, in both ZPG and APG boundary layers, with and without wall curvature and separation.

The experimental program dealing with spatial data is carried out jointly between LML, ONERA, LEA, Chalmers, using the LML wind tunnel (Figure 1 and 2).

Experiments on both flat plate and APG Boundary Layers are under way. A hot wire rake of 143 single hot wires has been designed and manufactured by LEA (Fig. 3.). This rake covers an area of 30 x 30 cm^2, corresponding more or less to δ^2. Chalmers has set up and is operating the 143 hot wire anemometers. LML is operating 4 stereoscopic PIV systems synchronized with the Hot Wire acquisition system (Fig. 4.). This includes a high repetition stereo PIV system allowing to get 3000 velocity fields/s at R_θ = 20 000. Experiments are performed at R_θ = 20 000 and 10 000 on the flat plate and R_θ = 20 000 in the APG Boundary Layer.

Precise skin friction measurements are performed on both configurations by ONERA and LML. The oil droplet interferometric technique is used for that purpose (Fig. 5)

Fig. 1 : LML Boundary Layer Wind Tunnel

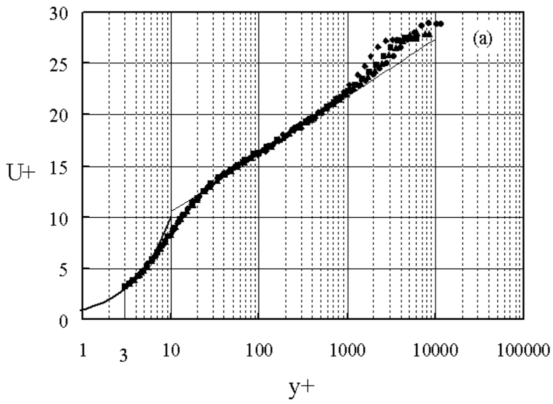


Fig. 2 : LML Boundary Layer velocity profiles for R_θ = 8 100, 11 500, 14 800 and 20 600

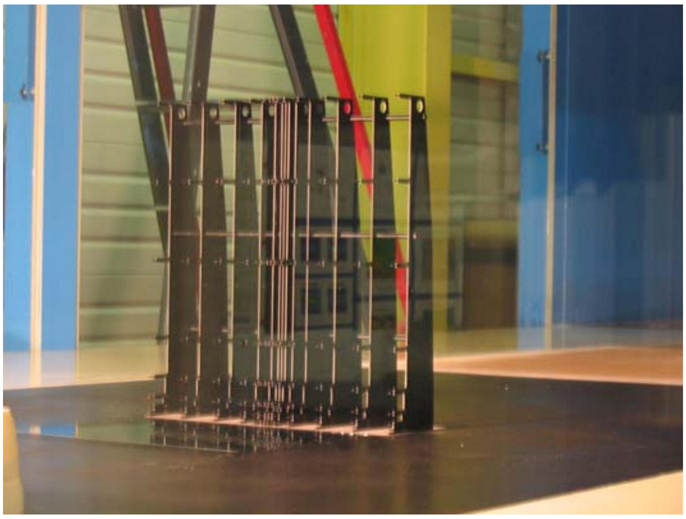


Fig. 3 : Hot Wire Rake mounted in the LML Wind Tunnel.

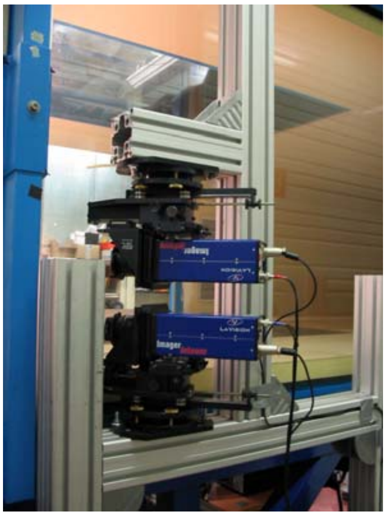


Fig. 4 : Double Stereo PIV set up to record 3C velocity fields in the plane normal to the main flow.

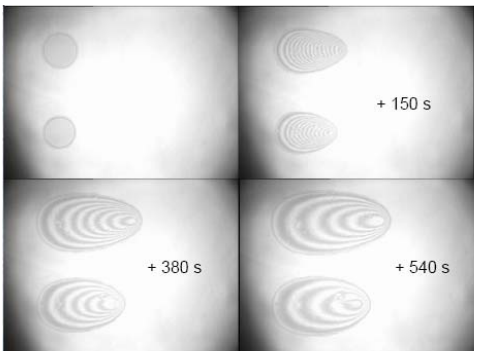


Fig.5 : Oil droplet interferometric images for the purpose of measuring wall friction.

Fig.6 : Visualization of the separation bubble on a bump on the floor of a wind tunnel at University of Surrey.

The experiments on separated boundary layers are performed at Surrey with wall curvature and Czestochowa on a configuration representative of a turbine blade geometry.

Surrey is manufacturing a bump very similar to the LML one, but leading to a small separation bubble (Fig 6.). The flow will be characterized in detail using Hot Wires, Laser Doppler Velocimetry and Pulsed Hot Wires.

Czestochowa University has adapted an existing wind tunnel to study turbulent boundary layers under adverse pressure gradient (Fig. 7). The configuration has been designed to be representative of the pressure gradient encountered on the suction side of a turbine blade with near trailing edge separation. Both boundary conditions and the boundary layer itself will be characterized in detail using pressure taps, shear stress probes and hot wire anemometry.

DNS computations on APG boundary layers will be performed at Madrid Polytechnic University. A DNS boundary layer code is under development and test (Fig. 8). It will be applied to an APG boundary layer test case.

DNS computations of Poiseuille and Couette Poiseuille flows are under way at University of Rome la Sapienza with the aim of providing specific data to help developing the RANS models (Fig. 9).

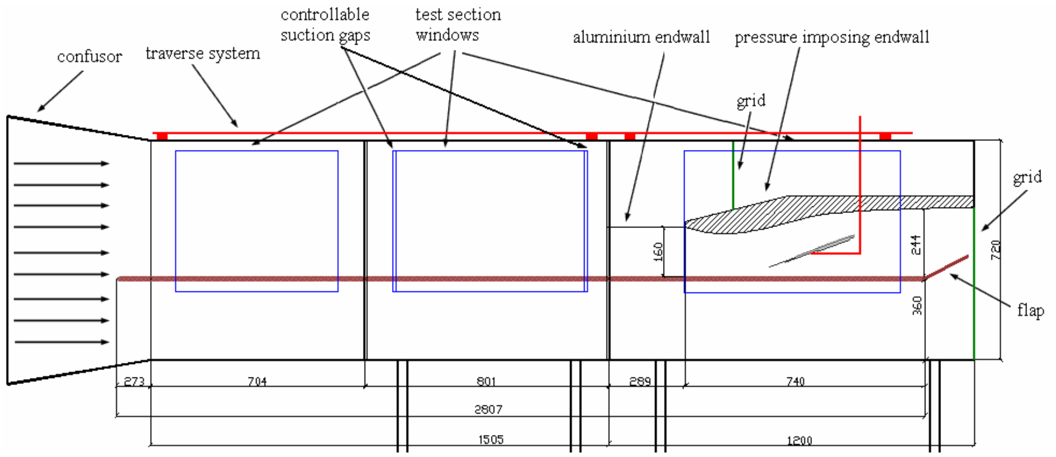


Fig. 7 : Wind tunnel configuration used at University of Czestochowa for the study of a separating Boundary Layer representative of turbine blade configuration.

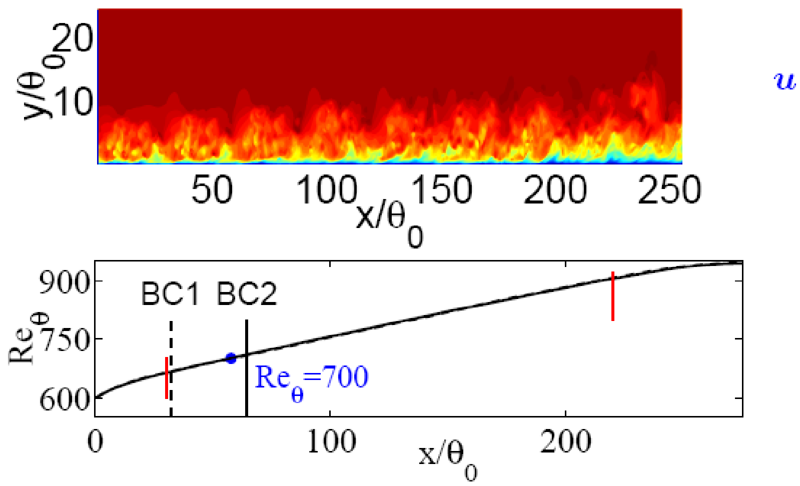


Fig. 8 : Direct Numerical Simulation of a ZPG Boundary Layer performed at Madrid University. Sample of instantaneous field of streamwise velocity component, together with the range of Reynolds number covered.

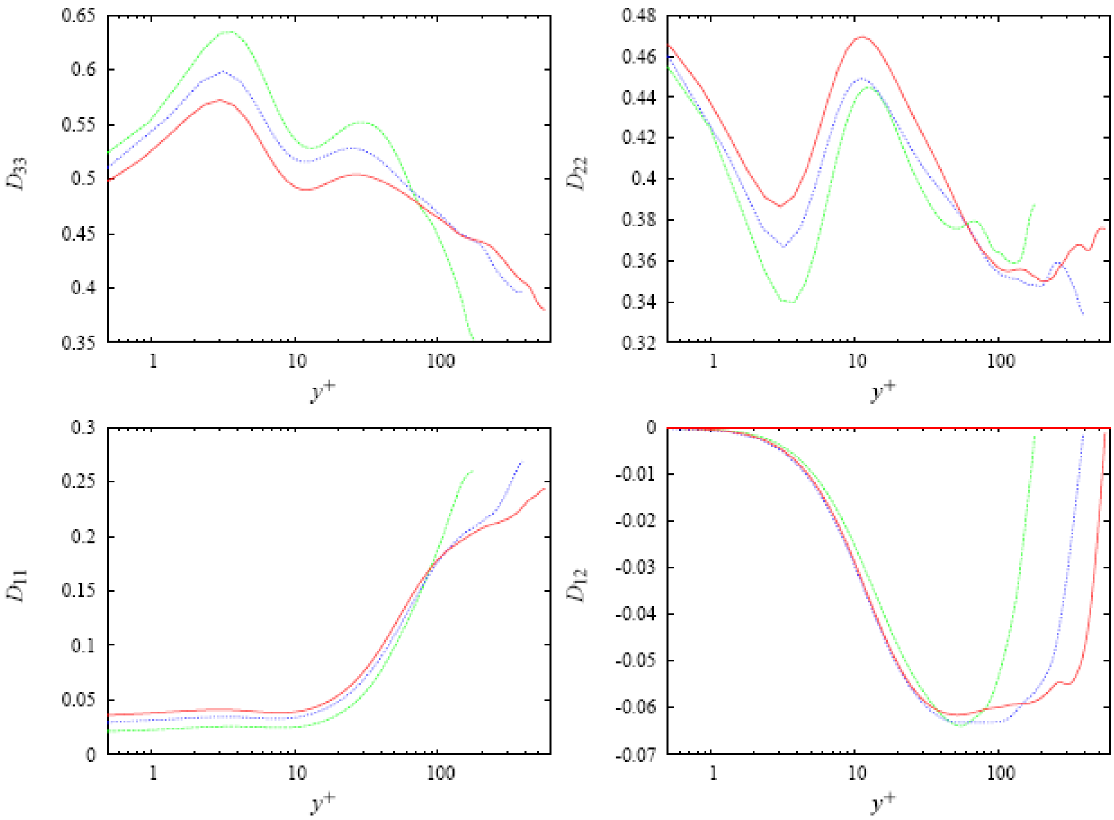


Fig. 9 : Dimensionality tensor deduced from the vector potential computed by Rome University from DNS of plane channel flow as a function of wall distance and for three values of the Reynolds number : Re_τ = 180, 395 and 580.

WP3 : Database

WP3 is the kernel of the project as it is responsible for the management and processing of the different databases (a total of 8) that will be put in common by the partners. These databases will be fed both by existing data and by the experiments and DNS performed in WP2. They will be fully documented and stored in the netcdf binary format (Fig.10). They will be accessible to all the partners of the consortium through the net in order to extract the data needed for modelling in work packages 4 to 6.

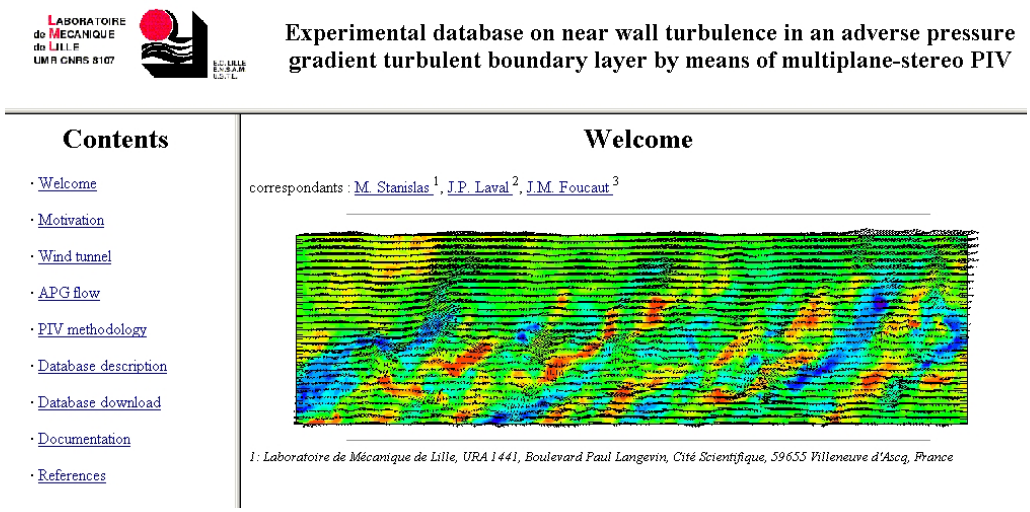


Fig. 10 : Web page of the database of PIV data for the APG Boundary Layer available to the WALLTURB partners.

WP4 : RANS modelling

WP4 is concerned mostly with the classical and industrial RANS approach and has the aim of improving the physical content of the models, especially for Adverse Pressure Gradient flows. The objective of this work package is to improve existing near-wall turbulence statistical models (RANS models) and to derive new models with the support of the experimental and DNS data provided by WP 2. The availability, during the present project, of data from channel flows and boundary layers up to $Re=20,000$ considerably helps to address many open issues, in particular concerning the validity of modelling assumptions at high Reynolds numbers. Different modelling levels (eddy-viscosity, algebraic and full Reynolds stress models) are investigated.

Another major objective of the project is to validate the models for boundary layers with adverse pressure gradient including separation. Indeed, the presence of a pressure gradient considerably modifies this picture of a boundary layer: mean shear, and thus production, occurs much further from the wall. The availability of data for APG boundary layers will allow a priori and a posteriori testing of the modelling assumptions in this challenging configuration.

The main goal of this work package is to use, extensively compare and improve different modelling approaches (Fig. 11 & 12). ONERA, LEA, University of Cyprus and FFI are leading teams in the field. Also, the two industrial partners (AIRBUS and DASSAULT) will be directly involved in the validation of the proposed models on test cases of industrial relevance.

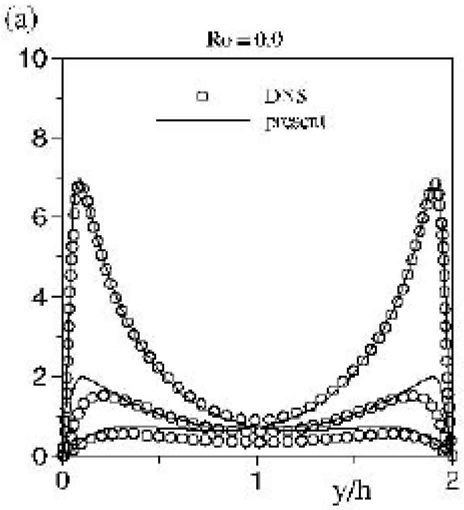


Fig. 11 : Preliminary tests of the non linear V-2f model developed by FFI on plane channel flow.

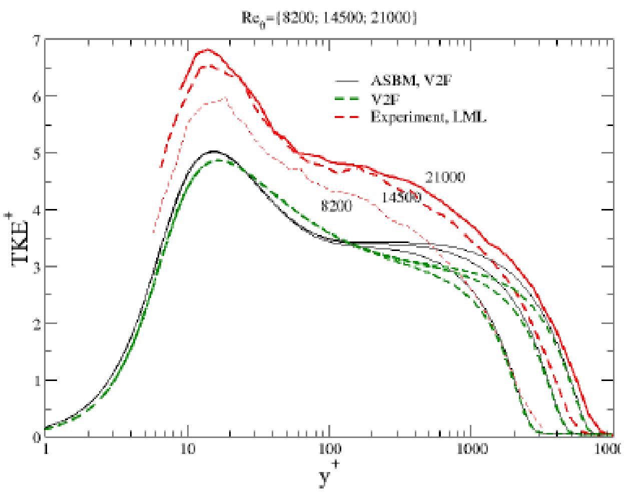


Fig. 12 : Preliminary tests of Algebraic Structure Based Model developed at University of Cyprus on flat plate Boundary Layer.

WP5 : LES modelling

WP5 is devoted to the improvement of LES modelling near the wall, and especially the investigation of new models for this region. The first objective of the current work package is the development of wall modelling approaches in the framework of existing and emerging LES techniques for industrial applications. The validity and performances of several LES models for wall bounded flows with and without APG are studied. The performance of LES models are evaluated by comparison to real solutions at high Reynolds number from measurements and Direct Numerical Simulation (Fig. 13). The second objective is to take advantage of the numerical and experimental database to improve the understanding of physical processes of turbulence in the vicinity of a wall and to test the ability of the LES models to reproduce such processes with a minimum of grid points. The third objective is to propose and to test some conceptually new models which have the ability to deal with complex flows (Fig. 14). Several teams : LML, CNRS Saclay, Munich University, Czestochowa University and FFI, develop and compare different modern LES approaches, with the target to obtain improved models for the near wall region.

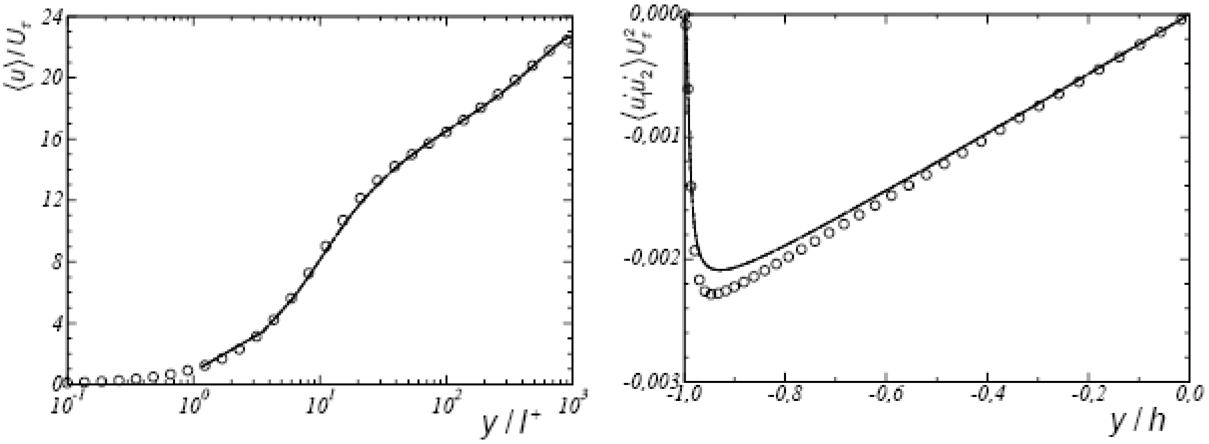
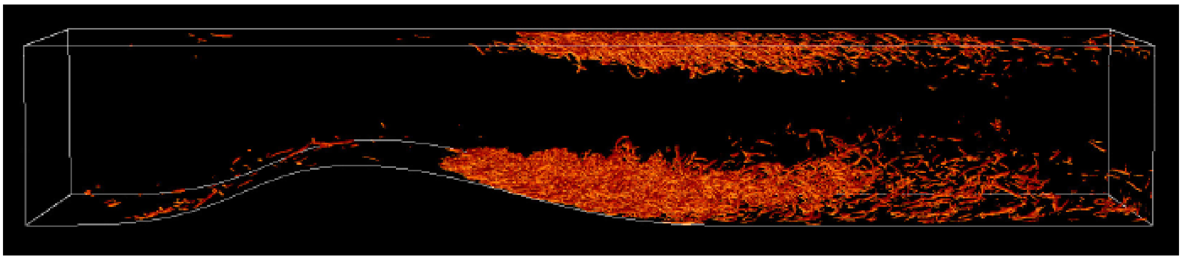


Fig. 13 : Preliminary validation of the Implicit LES model developed at Munich University, by comparison with the DNS of plane channel flow at $Re_\tau = 950$ provided by Madrid University.



Isovalue of $Q = \Omega^2 - S^2$

Fig. 14 : DNS of convergent divergent channel developed by LML to make a priori tests on LES models based on RDT theory.

WP6 : LODS modelling

Low Order Dynamical Systems is a very promising modelling approach of turbulent flows which involves difficult theoretical developments. In particular, the coupling of a LODS near the wall with a LES in the field can be a good alternative to the present wall treatment in Large Eddy Simulation.

The goal of WP6 is two-fold : First, to widen the experience with LODS and explore the relationship they hold with real flows. It is planned to use the extensive numerical and experimental databases to test the validity of various low-order models. Conversely, it is hoped that the low-dimensional approach will help to shed some new light on the dynamics of the wall layer.

Second, the aim is to use low-order dynamical systems to simulate the flow both cheaply and efficiently, using a coupling between LODS and LES. LODS aims at representing the flow in the wall region, which is poorly resolved by LES. The idea is to advance both systems of equations in time, using each of them to provide adequate boundary conditions for the other.

What next?

This news letter will appear one a year. Next issue is planned in June 2007

A one day open workshop will be organized in the first week of April 2007 in Rome (Italy). This workshop is aimed at presenting the WALLTURB progress to European scientists who are also welcome to propose contributions on near wall turbulence. A call will appear soon. Preliminary registration is already open by the WALLTURB coordinator : wallturb@univ-lille1.fr.