Capturing coherent structures and turbulent interfaces in wake flows by means of the Organised Eddy Simulation, OES and by Tomo-PIV

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Extended abstract

Context of the study and objectives

The present study aims at a physical analysis of the coherent and chaotic vortex dynamics in the near wake around a flat plate at incidence, to provide new elements in respect of the flow physics turbulence modelling for *high-Reynolds number flows around bodies*. This constitutes nowadays a challenge in the aeronautics design. A special attention is paid to capture and to model the thin shear layer interfaces downstream of the separation, responsible for *aeroacoustics* phenomena related to *noise reduction*.

Methodology

The research group of IMFT *"InteractionFluide-Structure Sous Turbulence", IFS2T* developed in the last decade the *Organised Eddy Simulation*, *OES* turbulence modelling approach in the frontier beyond classic statistical approaches and hybrid ones. OES contains appropriate turbulence modelling closures to capture coherent structures unsteadiness at high-Re number (Braza et al, 2006), *with economic grids*.
This approach is based on splitting of the energy spectrum into two parts, the first regrouping the organised coherent motion (resolved turbulence) and the second, the chaotic random turbulence (modelled part). This part is modelled in OES by improved statistical turbulence closures, able to capture non-equilibrium turbulence and ***negative turbulence production regions associated to backscatter***. As an example, we refer to the reconsideration of the turbulence viscosity in OES two-equation modelling, towards a ***tensorial eddy-viscosity concept***, sensitised in capturing turbulence stress anisotropy in the strong shearing regions (Bourguet et al, 2008). This OES modelling is able to account for stress-strain three-dimensional miss-alignment, originally put in evidence by the PIV experiments of the flow past a circular cylinder (Perrin *et al.*, 2007). This OES modelling achieves capturing of the thin shear-layers past separation by using grid refinement. Furthermore, it is worthwhile mentioning that the pure LES approach is not yet realisable at *high – Re* flows around bodies interesting the domains of applications.
The present article aims at introducing ***upscale turbulence modelling*** in OES to capture the thin shear layers past separation in high-Reynolds strongly detached turbulent flows, by using a reasonable grid refinement. This need is outmost important for the design, that demands an accurate prediction of the unsteady aerodynamic coefficients (up to the fourth decimal point) and especially of the pressure fluctuations in the near, intermediate and far wake regions, in respect of aeroacoustics. The present study is a collaboration between IMFT – CNRS (research team IFS2T - Dr. M. Braza) and UCL, (Prof. J. Hunt). Therefore, the present study's target is to enhance the benefits of OES by reverse cascade modelling. This is expected to allow capturing of the highly shearing regions by using economic numerical grids. This can be achieved by introducing during the OES solution, of a stochastic forcing as a series of random Fourier modes (Turfus and Hunt 1987), or of POD modes (Bourguet and Braza, 2009) in the region located between two sheared interfaces. This forcing produces a blocking effect towards the interface by keeping it thin (Hunt *et al.*, 2009). This mechanism produces energy transfer towards the large scales ('upscale turbulence modelling'). It is well known that classic statistical approaches are not able to capture upscale process in turbulence modelling and for this reason, they systematically produce downscale turbulence spectra and quite a lot of diffusion that causes thickening of the interfaces.
To achieve these aims, a synergy between a refined experimental and CFD study is performed. The experiments have been carried out in the S4 wind tunnel of IMFT and the simulations at the CINES and

IDRIS French supercomputing centres. The flow past a flat strut with an incident angle of 10° and Reynolds numbers 200,000 and 400,000 is considered. The experiments used the standard PIV as well as the **Tomo-PIV**, that is among quite rare studies in the state of the art concerning gas flows at high-Re by this technique. The simulations have been performed by means of the NSMB (Navier-Stokes Multi-Block) code. The phase-averaged Navier-Stokes equations are solved with a finite-volume implicit formulation. The OES-k-ε turbulence modelling is employed, as well as a DES-OES-k-□ modelling. The structured mesh consists of $3x10^5$ nodes in 2D. This unsteady flow separates at leading edge and develops a von Kármán street interacting with Kelvin-Helmholtz instability at the trailing edge. A detailed tracking of the coherent structures is performed by 2D and **3D-POD reconstruction**, compared in both, experimental and numerical approaches. The capture of the irrotational/rotational interfaces is essential to correctly define the domain where stochastic perturbation must be added. The interface thickness is a point we would like to assess, but the first step in this work is to localise the limits of the irrotational zone. Different ways have been investigated to define the entrance in shear interfaces. The criteria are essentially constructed from vorticity, as well as turbulent kinetic energy and dissipation rate. These criteria are investigated *in both, experimental and numerical approaches by using the same algorithms*. Ideally these criteria have to take into account the coherent structures frequencies created at leading and trailing edges. Iso-contours of turbulent kinetic energy (left) and vorticity (right) are depicted in the figure below. The black line corresponds to the computed interfaces. The methods developed seem to be quite relevant to capture the area of interest. The next step will be the dynamic implementation of the stochastic forcing within the area delimited by the interfaces and the comparison of the performances between OES, DES-OES and of 'Upscale-OES', with the physical experiment. This work has been supported bt French National Research Agency (ANR) through COSINUS program, project ECINADS N° ANR-09-COSI-003.

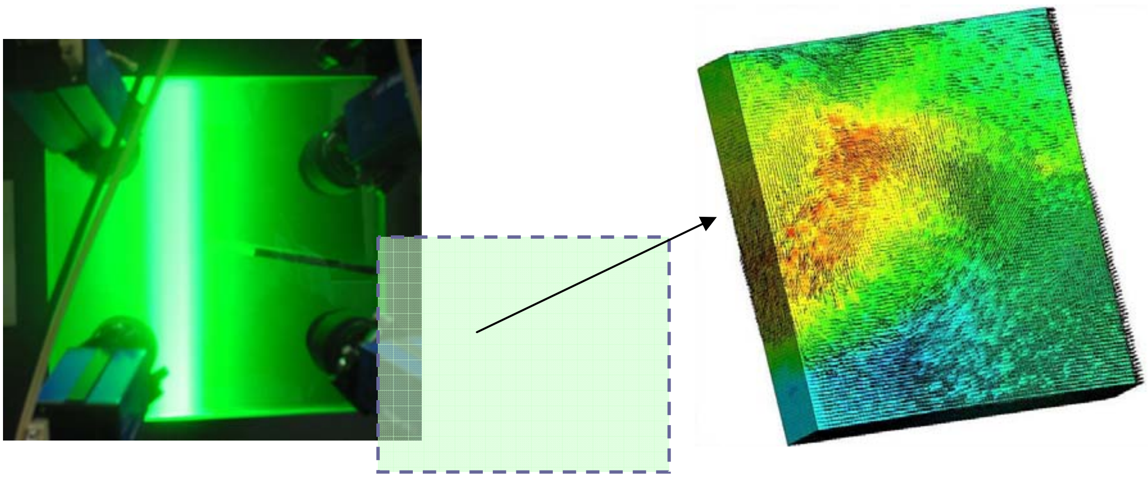

Figure 1. Experimental set-up of the Tomo-PIV, S4-IMFT wind tunnel, measurements volume (zoom) and instantaneous velocity field past the falt plate at Re=200,000.

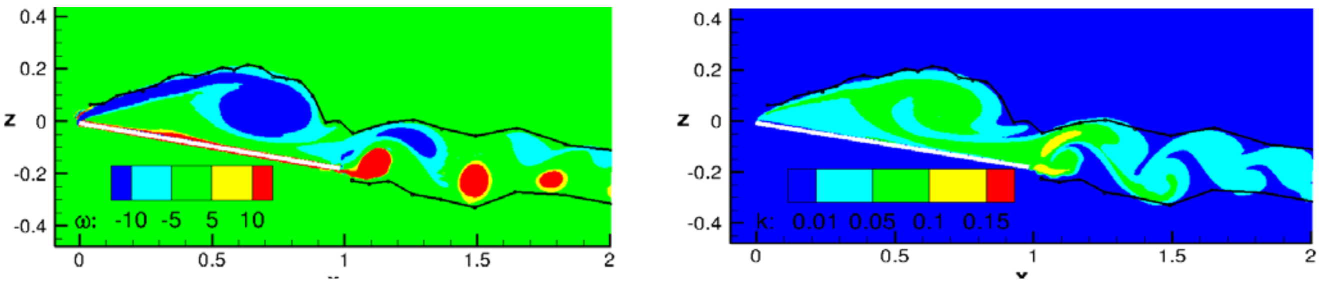

Figure 2. Numerical simulation of the flow past the flat plate, same conditions as in experiment; OES approach. Evaluation of the thin-shear-layer interface with the vorticiity gradient and dissipation rate criteria.

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