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Hybrid V2F RANS/LES model and synthetic inlet turbulence applied to a trailing edge flow

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Introduction

The flow over a trailing edge is computed using two different techniques to reduce the computational costs of LES. A hybrid method designed to split the contributions of the averaged and fluctuating velocity fields is used in order to relax the near-wall mesh requirements. A synthetic method for turbulence generation is used at the inlet in order to avoid a costly precursor simulation. The methodology has been first tested on channel flows at high Reynolds numbers on coarse meshes. The results at different Reynolds numbers up to Re_τ are presented. They agree well with DNS data available in terms of mean velocities and stresses. The results for the trailing-edge flow are compared with the full LES with inlet boundary conditions from a precursor boundary layer simulation. Two cases are presented, one with a precursor simulation and one with the synthetic eddy method. The predictions of mean velocities and turbulent content agree well with the reference LES simulation. The finite volume *Code_Saturne* developped at EDF (Archambeau et al., 2004) has been used for all calculations.

The hybrid method

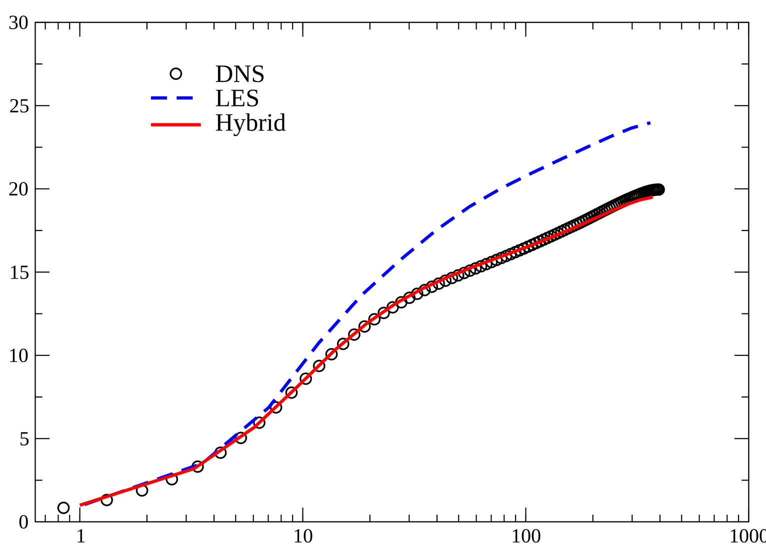
Split the residual stress tensor into two parts, the "locally isotropic" part and the "inhomogeneous" part similar to Schumann (1975)

$$\tau_{ij}^r - \frac{2}{3}\tau_{kk}\delta_{ij} = -\underbrace{2f_b\nu_r(\overline{S}_{ij} - \langle\overline{S}_{ij}\rangle)}_{\text{locally isotropic}} - \underbrace{2(1-f_b)\nu_a\langle\overline{S}_{ij}\rangle}_{\text{inhomogeneous}} \qquad (1)$$

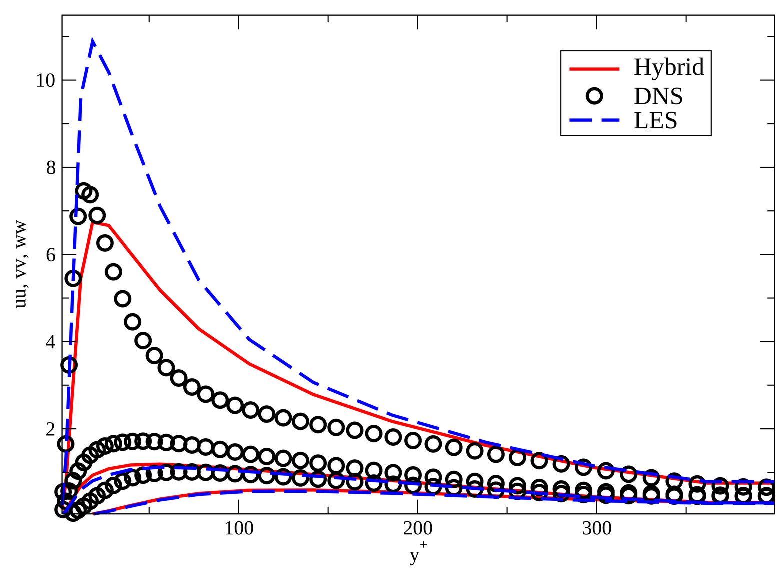
The isotropic part, which controls the dissipation of turbulent energy, is treated with a standard SGS viscosity and a fluctuating strain rate. The inhomogeneous part, which affects the flow directly has a RANS viscosity and a mean strain rate.

$$f_b = \tanh\left(\left(C_L\frac{L_t}{L_\Delta}\right)^n\right) \qquad (2)$$

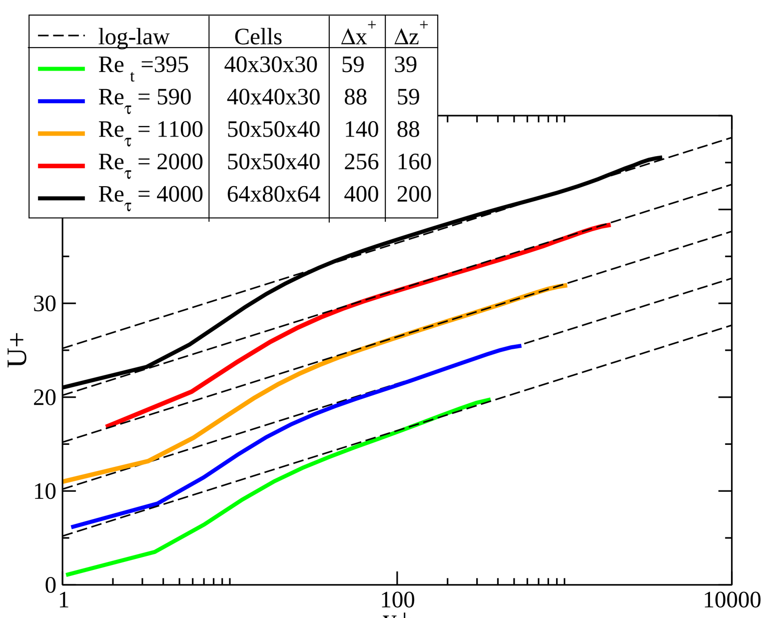
where L_t is the turbulent length scale provided by the RANS model and L_Δ is the LES filtered length scale. The subgrid-scale viscosity, ν_r is calculated using the Smagorinsky (1963) model and the RANS viscosity, ν_a is calculated from the averaged velocity field using the elliptic relaxation model Laurence et al. (2004):



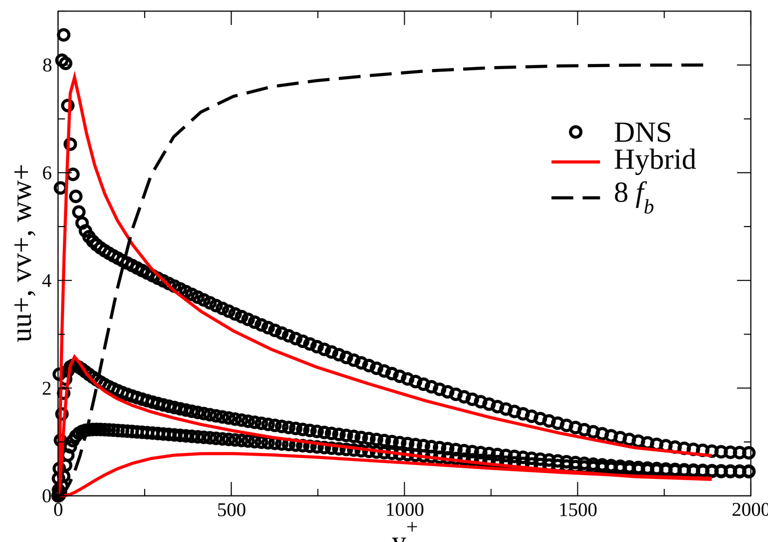
Channel Flow at $Re_\tau = 395$



Channel Flow at $Re_\tau = 395$



Channel Flow. Velocity Profiles at different Reynolds numbers



Normal stresses at $Re_\tau = 2000$

Synthetic Eddy Method

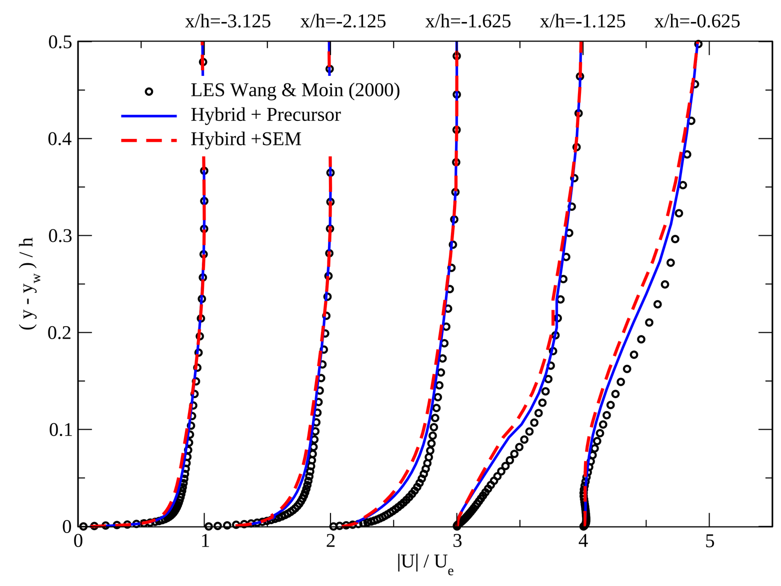
The Synthetic Eddy Method of Jarrin et al. (2006) assumes that the turbulent inflow is composed of a superposition of coherent structures with particular intensities, shapes and length-scales. Characteristics of the inflow structures are based on information provided by the RANS statistics. A random distribution of eddies with prescribed intensities, shapes and sizes is then generated. If x^k, y^k and z^k are the x, y and z coordinate of the centre of eddy k, the velocity signal generated by the SEM reads

$$\mathcal{U}_i(x_j,t) = \sqrt{\frac{V_b}{N}}\sum_{k=1}^{N}\varepsilon_i^k f_L(x_1 - x_1^k) f_L(x_2 - x_2^k) f_L(x_3 - x_3^k) \qquad (3)$$

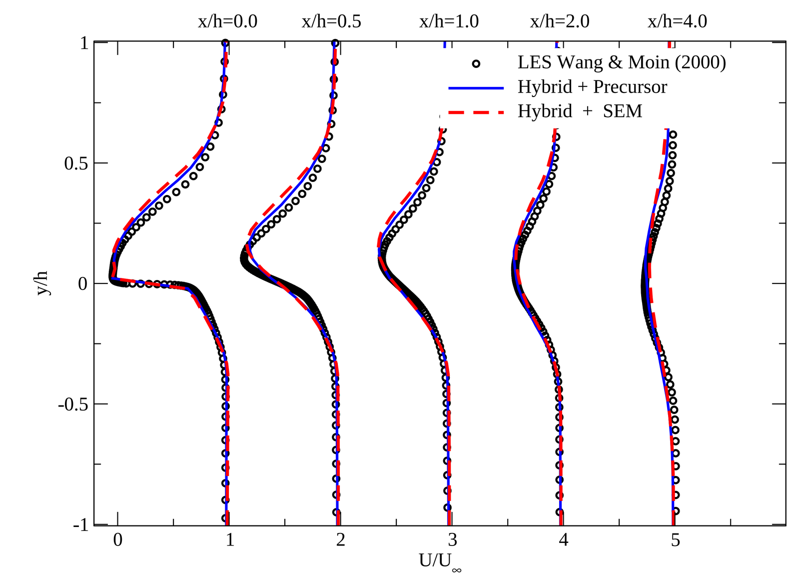
where V_b is the volume of the box over which eddies are going to be generated, N is the number of eddies, L is the turbulence lengthscale and f_L is a symmetric tent function that characterises the decay of the fluctuations generated by each eddy about its centre.

Trailing edge flow

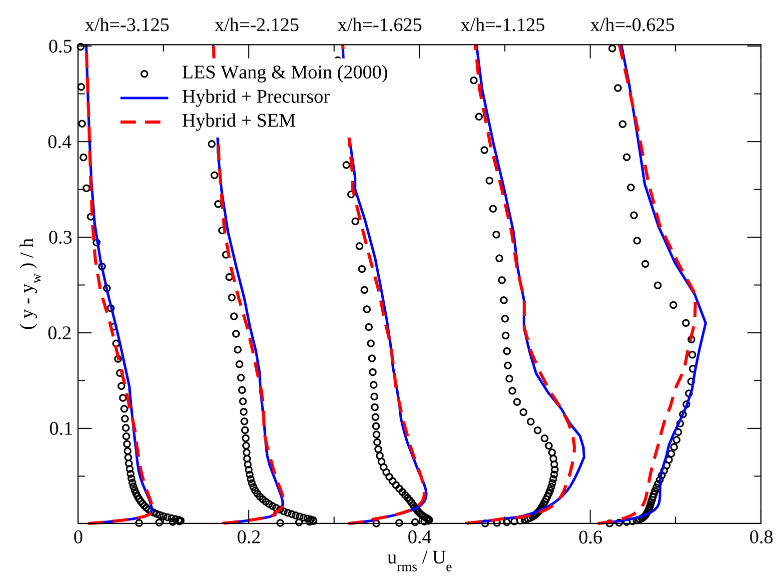
The efficiency of the hybrid approach for complex turbulent flows is assessed by considering turbulent boundary-layer flows past an asymmetric trailing-edge. The Reynolds number, based on the free stream velocity and the aerofoil chord, is 2.15×10^6. The case has been treated before by Wang and Moin (2000) using a finely resolved LES. In order to further reduce the cost of the computation, only the rear-most 38% of the aerofoil chord is computed.



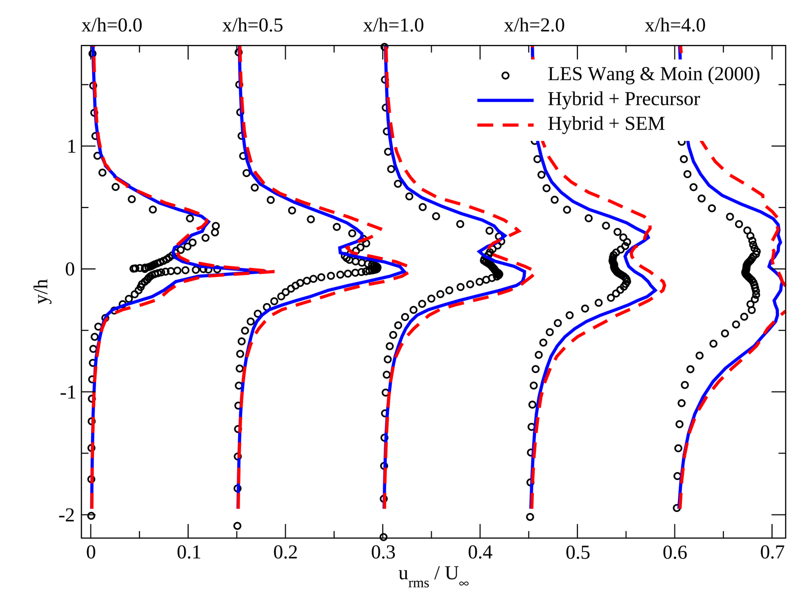
Velocity profiles (aerofoil)



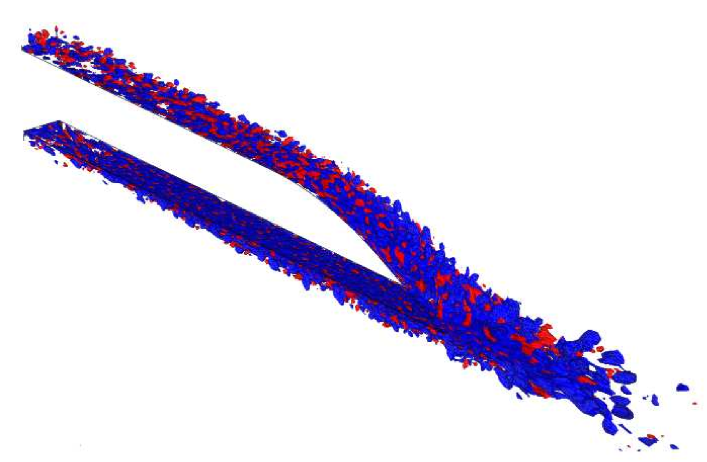
Velocity profiles (wake)

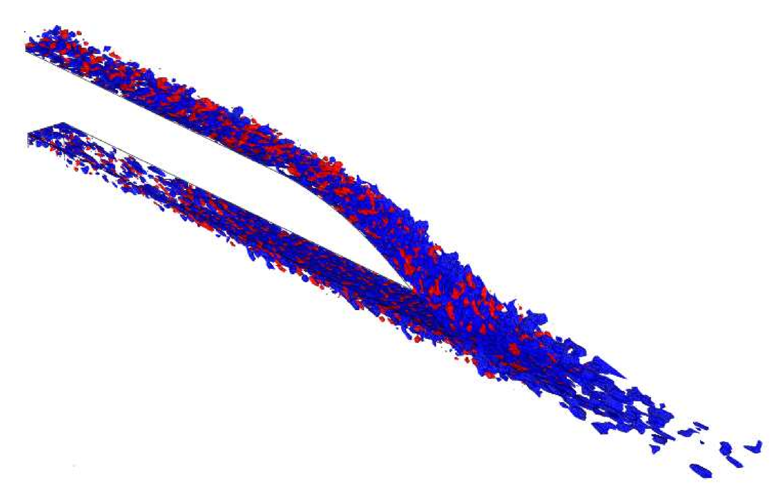


u_{rms} profiles (aerofoil)



u_{rms} profles (wake)


iso Q surfaces (SEM)


iso Q surfaces (precursor)

Conclusions

Two methods for reducing the computational requirements of instantaneos flows have been tested on a trailing edge flow configuration. The hybrid method is capable of sustaining fluctuating behaviour only limited by the size of the cells. Although the mesh is too coarse to be able to reproduce the small structures, the model successfully includes the near wall effect on mean strain via the mean velocity field, allowing a separation of dissipative effects. The use of the hybrid method allows for the use of a mesh of about ten times less number of cells when compared to the reference LES. The SEM proved to be a low-resource alternative for the inlet conditions with only mean average quantities as input. The use of the SEM saves about 30% of of the total computational time when compared to the precursor LES computations.

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