

Detached-Eddy Simulation Based on the v^2 - f Model

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Abstract: Detached eddy simulation (DES) based on the v^2 - f RANS model is proposed. This RANS model incorporates the anisotropy of near-wall turbulence which is absent in other RANS models commonly used in the DES community. In LES mode, the proposed DES formulation reduces to a transport equation for the subgrid-scale kinetic energy. The constant, C_{DES} , required by this model was calibrated by simulating isotropic turbulence. In the final paper, DES simulations of canonical separated flows will be presented.

Keywords: detached eddy simulation, v^2 - f model, hybrid RANS/LES

1 Introduction

Detached-eddy simulation (DES) is a hybrid RANS/LES approach that performs RANS in attached regions and LES in detached regions using a single model. In the LES region, the length scale of the RANS model is set proportional to the grid size Δ . The RANS model thereby becomes an LES model.

Although the Spalart-Allmaras (SA) model has been widely used for DES [1], its near-wall damping does not distinguish between velocity components. In contrast, the v^2 - f formulation [2] models the suppression of wall normal velocity fluctuation caused by non-local pressure-strain effects. This anisotropy has been shown to improve prediction of separation and reattachment [3, 4]. In addition, the SA model uses the minimum distance to the wall as the turbulence length scale which is not necessarily accurate at or near separation. The v^2 - f model, on the other hand, computes a length scale based on flow properties (i.e. the kinetic energy k , the dissipation rate ϵ , and the kinematic viscosity ν). Finally, in the LES region, the present treatment gives a transport equation for subgrid-scale (sgs) kinetic energy which is less empirical than the sgs viscosity transport equation used in SA based DES.

2 The Proposed v^2 - f DES Model and Preliminary Results

The v^2 - f formulation [2] has transport equations for k , ϵ and $\overline{v^2}$ and an elliptic relaxation equation for a function f analogous to the Reynolds stress redistribution term. These equations contain length and time scales L and T . The choice between RANS and LES modes is made by setting these scales appropriately. When the grid is fine enough to capture large turbulent eddies, i.e. when $C_{DES}\Delta < k^{3/2}/\epsilon$, the LES mode is selected. Otherwise, the RANS mode is selected. As suggested by Spalart et al. [5], the DES coefficient C_{DES} is chosen to match the correct energy spectrum in isotropic turbulence. In LES mode, the time scale is obtained as $T = C_{DES}\Delta/\sqrt{k}$ where k now represents the sgs kinetic energy. Although the k equation is sufficient for purely LES simulations, the other three equations are required for the RANS mode. The v^2 - f model [2] is modified so that the entire set of the equations reduces to a transport equation for the sgs k in LES mode. In particular, coefficients in the elliptic relaxation equation are modified so that $\overline{v^2}$ becomes $(2/3)k$ in LES for isotropic turbulence. The final paper will include the formulation in detail.

To validate the modified coefficients, fully developed turbulent channel flows with friction Reynolds numbers Re_τ up to 2000 are simulated in RANS mode. Figure 1 shows that this modification maintains the performance of the unmodified RANS model with better prediction of $\overline{v^2}$ near the center. Next, to check the LES mode and calibrate C_{DES} , decaying isotropic turbulence is considered. The initial field uses 512^3 DNS data [6] at $Re_\lambda = 105$ filtered down to 32^3 . Turbulence quantities in the DES model are initialized by running for some time with a frozen initial velocity field. The flow is allowed to run about eleven initial large-eddy turnover times at which point $Re_\lambda = 61$. The v^2 - f DES simulation with $C_{DES} = 0.8$ agrees very well with DNS [6] and experiments [7] (figure 2(a)) up to the cut-off wave number. Because it allows a higher Reynolds number and a wider inertial range, forced isotropic turbulence at $Re_\lambda = 98$ is also considered using the stochastic forcing of Eswaran and Pope [8]. The v^2 - f DES gives almost exactly the energy spectrum produced by the dynamic Smagorinsky model (figure 2(b)).

3 Conclusions and Future Work

DES based on the v^2 - f model was proposed and validated for two cases: purely RANS and isotropic LES. These preliminary results are encouraging. The final paper will include DES simulations of the backward-racing step flow [9], and v^2 - f based DES will be compared with SA based DES.

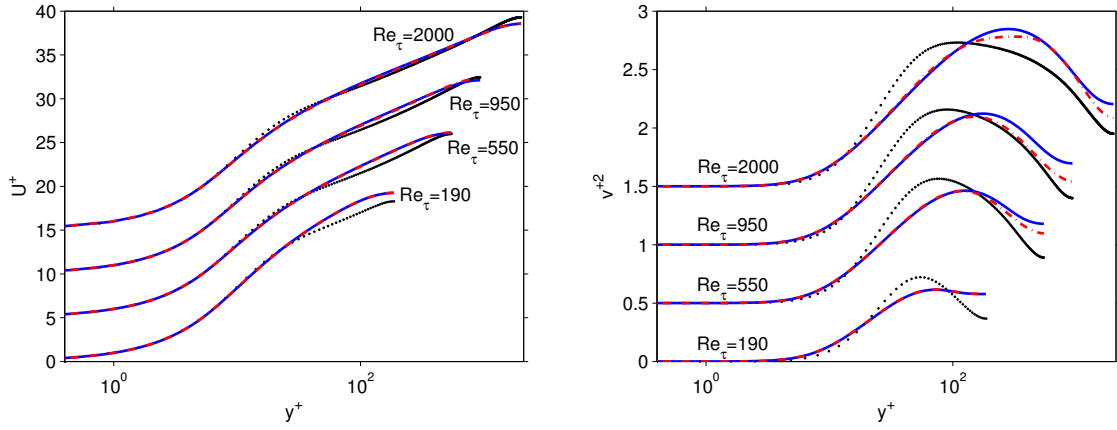


Figure 1: Profiles of U^+ and $\overline{v^{+2}}$ of DNS(dots) and RANS with the unmodified[2] (—) and the modified v2f model (-.-) in turbulent channel flows. The plus superscript indicates normalization with wall units.

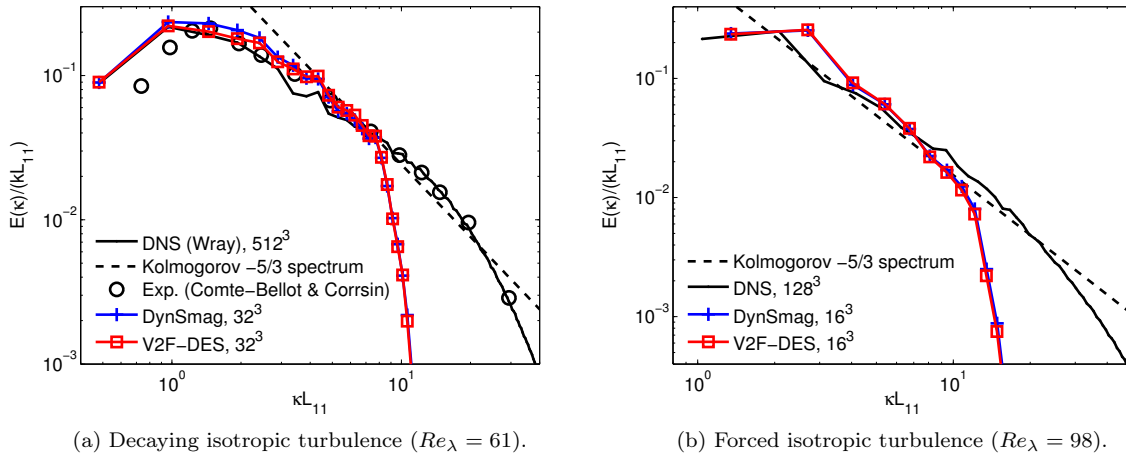


Figure 2: Energy spectrum of isotropic turbulence. The proposed DES model (V2F-DES) is simulated with $C_{DES} = 0.8$. Kolmogorov -5/3 spectrum indicates $E(\kappa) = C\epsilon^{2/3}\kappa^{-5/3}$ with the Kolmogorov constant $C = 1.5$. DynSmag indicates LES with the dynamic Smagorinsky model.

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