Investigation of length scale definition influence in LES models

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Context of the work

Large Eddy Simulation

- Filtered Navier-Stokes for incompressible flows:

$$\partial_t \bar{u} + (\bar{u} \cdot \nabla)\bar{u} = \nabla^2 \bar{u} - \nabla \bar{p} - \nabla \cdot \tau(\bar{u}) \qquad \nabla \cdot \bar{u} = 0$$

- Closure problem $\Rightarrow$ SGS eddy viscosity

$$\tau(\bar{u}) = \overline{u_i u_j} - \bar{u_i}\bar{u_j} \approx -2\nu_e D_m(\bar{u})$$

where

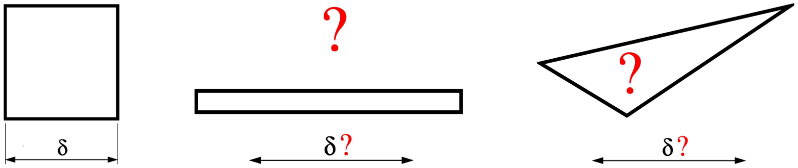
$$\nu_e = (C_m \underbrace{\Delta}_{Def?})^2 \mid \bar{D_m} \mid$$

Core of LES approach:

- "Scale invariance means that some features of the flow remain the same in different scales of motion"- Meneveau & Katz (2000)
- "The smallest resolved-scale motions provide info that can be used to model the largest SGS motions" -Germano & alia (1991)

Scope of this study:

- Model's differential operator $D_m \Rightarrow$ Smagorinsky (1963), WALE (1999), Vreman (2004), $\sigma-$model, S3PQR [1] , vortex-stretching-based model[2], ...
- Model's constant $C_m \Rightarrow$ Kolmogorov constant, Germano's dynamic model (1991) , ...
- And Δ?



The problem that arises in highly anisotropic or unstructured grids

- Assessing the influence of the characteristic length-scale definition on the performance of LES models in highly anisotropic structured grids.

[1] F.X.Trias, D.Folch, A.Gorobets, A.Oliva. **Physics of Fluids**, 27: 065103 (2015)
[2] M.H.Silvis, R.A.Remmerswaal, R.Verstappen, **Physics of Fluids**, 29: 015105 (2017)

LES Deltas

- The first 3 depend only on the mesh, the remaining are function also of $\bar{u}$

$$
\begin{cases}
\Delta_V = (V)^{1/3} \quad \text{[1]} \\
\Delta_{max} = max(dx_i) \quad \text{[2]} \downarrow \text{ from DES community} \\
\Delta_{min} = min(dx_i) \\
\Delta_\omega = \sqrt{N_x^2 dy\, dz + N_y^2 dx\, dz + N_z^2 dx\, dy} \quad \text{[3]} \\
\Delta_{SLA}\text{[4]}, \Delta_{lsq}\text{[5]} \ldots
\end{cases}
\tag{1}
$$

- OpenFOAM library: implementation of DES Deltas definitions for LES simulations

`https://github.com/jruanoperez/TurbulenceModels`

[1] Deardorff et al. (1970)
[2] Spalart et al. (1997)
[3] Chauvet, Deck, Jacquin (2007)
[4] Shur, Spalart, Strelets, Travin (2015)
[5] F. X. Trias, A. Gorobets, M. H. Silvis, R. W. C. P. Verstappen, and A. Oliva, **Physics of Fluids** 29, 115109 (2017)

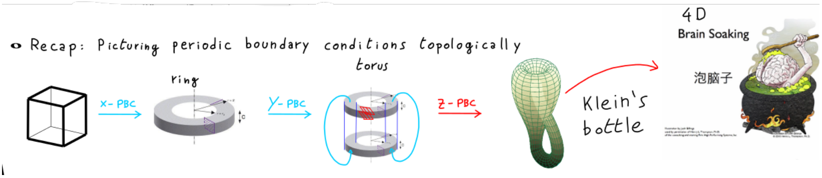
The work

HIT and PPC

Homogeneous Isotropic Turbulence decay

- Mesh 64x64xN_z with $N_z \in (64, 128, 256, 512, 1024)$
- Reference: CBC [1] Re$= 34000$
- Model: Smagorisnky
- backward 2^{nd}order , $dt = 1e - 3$
- $L_{box} = 0.09 \cdot 2\pi$

- Each case have been run with the following characteristic lenght-scale definitions: Δ_{Vol} , Δ_{Max}, Δ_{min} , Δ_{ω} , Δ_{lsq}



[1] Comte-Bellot, Corrsin: wind tunnel (1971)

Periodic Plane Channel

- Mesh 32x32xN_z and N_xx32x32 with $N_x, N_z \in (64, 128, 256, 512, 1024)$
- Reference: KMM [2] Re$_\tau = 180$
- Model: WALE
- Courant-adaptive dt with $C_{max} = 0.3$
- $L_{chan} = (20 \cdot \pi, 2, \pi)$

- over-dissipation problem: time integration with backward 2^{nd}order
  $\Rightarrow$ To be solved with Symmetry Preserving RK3 [3]:

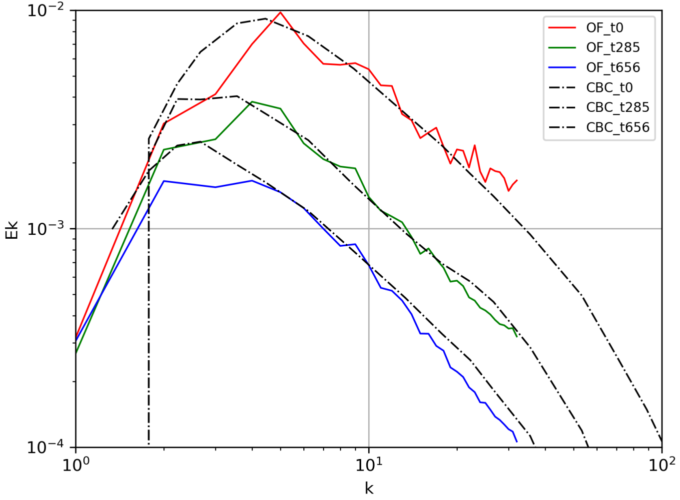
`https://github.com/janneshopman/RKSymFoam`

[2] Kim, Moin, Moser: DNS (1987)

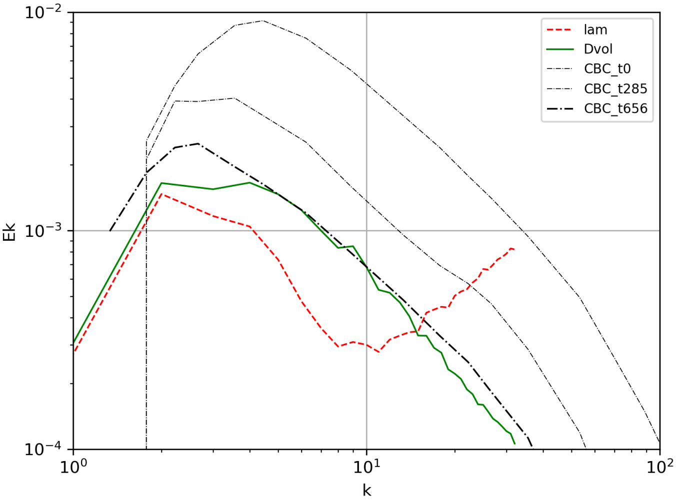
[3] E.M.J. Komen, J.A. Hopman, E.M.A. Frederix, F.X. Trias, R.W.C.P. Verstappen , **Computers & Fluids**, 225: 104979, 2021

Results

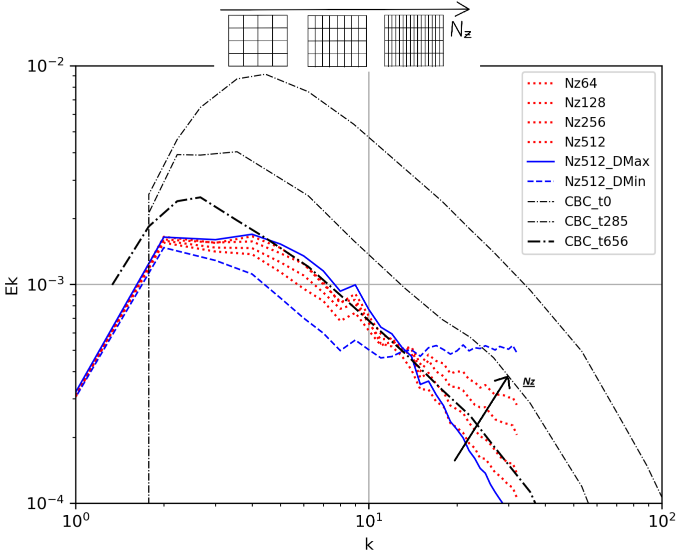
HIT Energy density spectra: Δ_{vol} , isotropic mesh



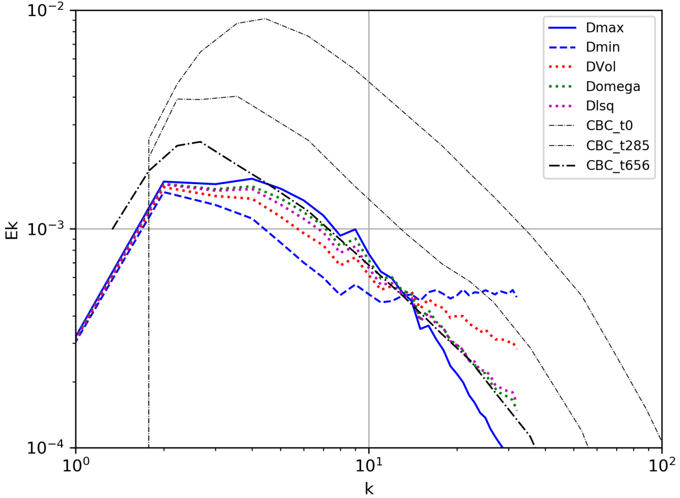
HIT Energy density spectra: comparison Δ_{vol} and without model



HIT Energy density spectra: effect of anisotropy with Δ_{vol}

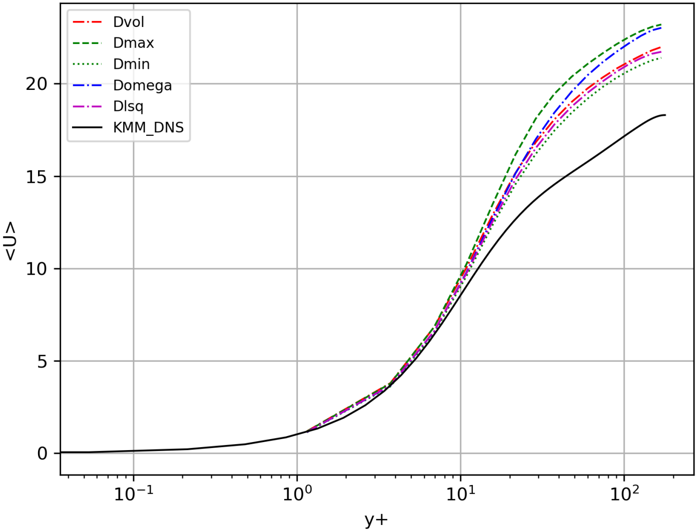


HIT Energy density spectra: different Δ in anisotropic mesh

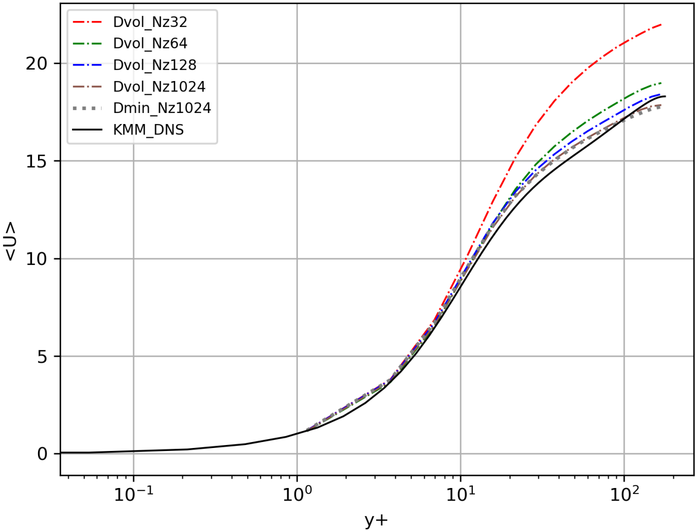


Aspect Ratio = 8

Channel Average velocities: different Δ, isotropic mesh

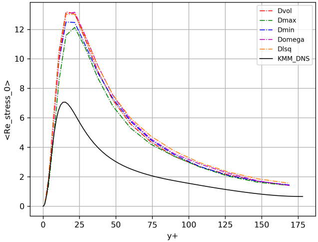


Average velocities: Δ_{vol} , different meshes



Reynolds stresses: different Δ , isotropic mesh

uu



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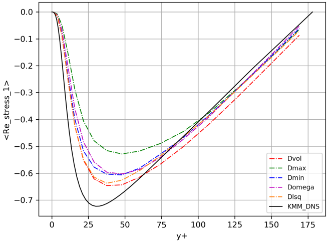

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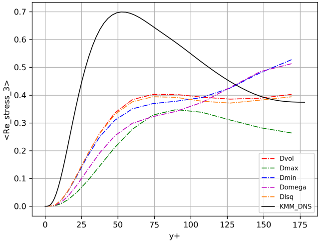

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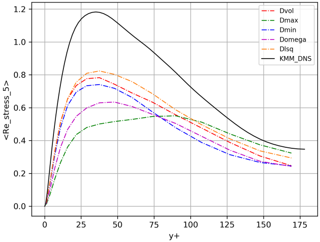

Reynolds stresses: different meshes, Δ_{lsq}

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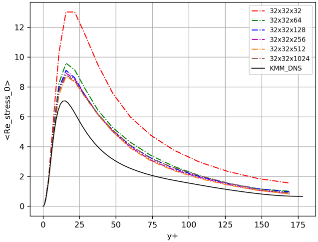

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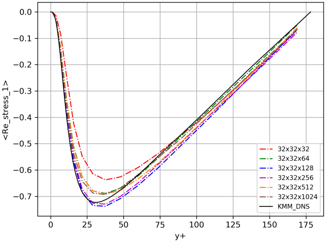

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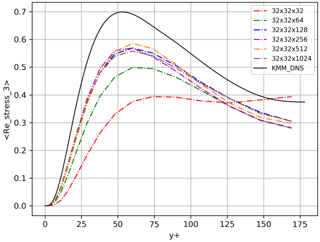

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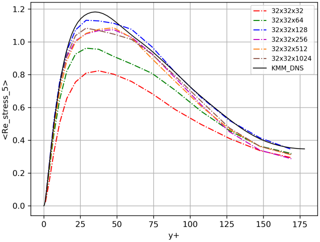
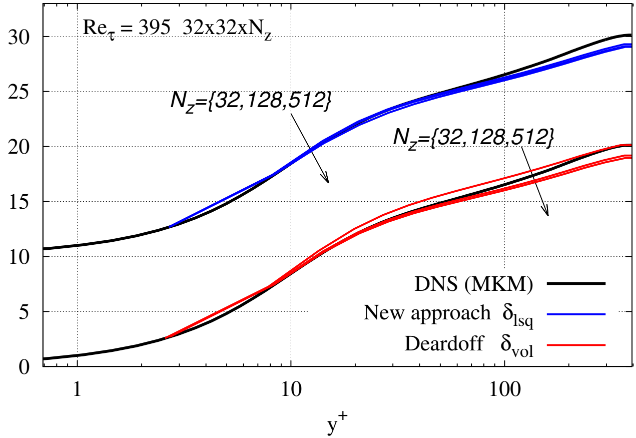
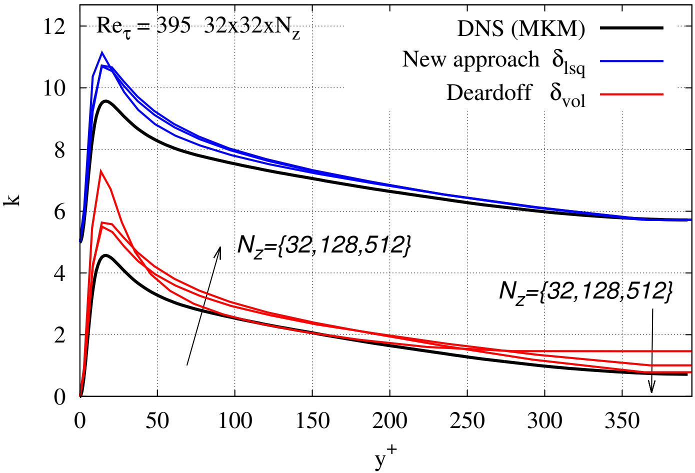


Channel average velocity with in-house Energy-Preserving code



Channel Reynolds stress Trace



Conclusions

Conclusions

- As expected, Δ_{max} and Δ_{min} are bounding the behavior of all other models

HIT:

- High anisotropies tend to deactivate the model when Δ_{vol} is used
- Instead, Δ_{max} is not affected from refinement, hence showing constant model behavior at successive refinements
- Δ_{ω} and Δ_{lsq} show to be not sensitive to anisotropies

Channel:

- Due to time integration scheme, OpenFOAM doesn't fully develop turbulence, hence presenting a much higher average velocity in the channel's bulk volume
- This effect was compensated by model deactivation due to mesh anisotropy
- This issue is expected to be solved by introducing a RK3 integration

Thanks for your attention!

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