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Assessment and comparison of a recent kinematic sensitive subgrid length scale in Hybrid RANS-LES

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In the context of turbulence simulation approaches, the subgrid length scale, Δ, clearly plays a key role in the approximation of the subgrid scale viscosity, ν_{sgs} (1). However, in spite of this, it has not been given as much prominence as other parameters such as the model constant, C_m, or the differential operator, $D_m(\bar{u})$.

$$\nu_{sgs} = (C_m \Delta)^2 D_m(\bar{u}) \qquad (1)$$

Trias et al.[1] performed a comprehensive study of the spatial length scales used to date, concerned about the lack of consensus in the scientific community. Summarising the trends in modelling and simulation research, they identified that the volume cubic root, Δ_{vol} (2)[left], was used predominantly for LES applications, whereas the maximum length scale, $\Delta_{\max}$ (2)[right], was preferred for Hybrid ones. Both definitions were observed by Mockett et al.[2] and Shur et al.[3] to be inextricably linked to unintended length scale changes due to mesh variations as neither one considers the kinematic fluid behaviour; causing a poor mesh resilience for anisotropic meshes.

$$\Delta_{vol} = (\Delta x \Delta y \Delta z)^{1/3}, \quad \Delta_{\max} = \max(\Delta x, \Delta y, \Delta z) \qquad (2)$$

In this context, a kinematic sensitive approach resistant to mesh anisotropies was proposed by Mockett et al.[2], $\tilde{\Delta}_{\omega}$ (3)[left], defending the importance of using the maximum meaningful scale at each LES control volume. This method was improved by Shur et al.[3], Δ_{SLA} (3)[right], for DDES/IDDES applications, where a rapid transition from RANS to LES is required to avoid unphysical instability delays.

$$\tilde{\Delta}_{\omega} = \frac{1}{\sqrt{3}} \max_{n,m=1,8} |(l_n - l_m)|, \Delta_{SLA} = \tilde{\Delta}_{\omega} F_{KH}(<VTM>) \qquad (3)$$

Although successful results have been obtained for a broad spectrum of fluid behaviours[2-4], a lack of physical meaning and a considerable cost

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can be attributed to $\tilde{\Delta}_{\omega}$ and Δ_{SLA}. In this regard, Trias et al.[1] suggested a new subgrid length scale only based on the velocity gradient, Δ_{lsq} (4), also resistant to grid anisotropies, robust, computationally inexpensive, with a strong physical background and adapted for structured and non-structured grids. This approach was tested in LES simulations (incompressible flow) for different kind of anisotropic meshes, showing good mesh resilience in all cases.

$$\Delta_{lsq} = \sqrt{\frac{JG^TG : JG^TG}{G^TG : G^TG}}, \; J = \begin{pmatrix} \Im_{ii}^{x} & & \\ & \Im_{ii}^{y} & \\ & & \Im_{ii}^{z} \end{pmatrix}, \; \Im_{ii}^{\lambda} = \frac{1}{\sum_{j \neq i} \left| G_{ij}^{\lambda} \right|} \qquad (4)$$

A detailed study comparing $\tilde{\Delta}_{\omega}$ and Δ_{lsq} will be carried out considering different control volumes and a set of arbitrary flow configurations, using similar methods present in Trias et al.[1]. Once the strengths and weaknesses of the two approaches would have been detected, the spatial length scale presented by Trias, Δ_{lsq}, will be adapted for DDES cases in order to trigger shear layer instabilities. Finally, the mesh resilience of the new spatial length scale will be tested in 3 different flow configurations. These are the DHIT, the experimental Backward Facing Step (BFS) carried out by Eaton and Vogel and the recent DNS of a BFS studied by Pont-Vílchez et al.[5]. Further work will investigate how the new spatial length scale performs on more challenging flow configurations, such as separations induced by adverse pressure gradients instead of geometrical reasons.

References

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