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IMPROVING DES CAPABILITIES FOR PREDICTING KELVIN-HELMHOLTZ INSTABILITIES. COMPARISON WITH A BACKWARD-FACING STEP DNS.

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INTRODUCTION

Backward-Facing Step (BFS) represents a canonical configuration to study wall-bounded flows subjected to sudden expansions. The flow separation leads to a shear layer downstream of the step, rising the well-known Kelvin-Helmholtz instabilities. These are fed along the shear layer, until they impinge at the lower wall, contributing to the recirculation bubble detachment (see Figure 1). This kind of flows has been extensively studied through experimental and numerical experiments due to its importance in many engineering applications. In a numerical context, the Detached Eddy Simulation (DES) family models, presented by Spalart et al. [3] in the late 90's, were specifically designed to simulate these flow configurations (BFS, airfoils at stall and jets). Since then, several authors have focused their efforts on addressing the main DES shortcomings, but there are still unsettled issues. In particular, delays in the transition zone from RANS to LES (Gray Area) severely affects the triggering of the shear layer instabilities, harming the flow downstream of the step-edge. In this regard, two different strategies [4] can be used for leading this issue. One of them consists on using artificial oscillations in specific areas (zonal approach), whereas the other is based on reducing the subgrid-scale viscosity, ν_{sgs}, given by

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

The second approach is preferable as it is aligned with the initial non-zonal DES philosophy. In this context, the effects of the subgrid-length scale (SLS), Δ and the differential operator, $D_{sgs}(\bar{u})$, on ν_{sgs} have been intensively studied during the last years. For instance, the possibility of providing a kinematic sensitivity to the Δ coefficient was investigated by different authors. First, a SLS resistant to mesh anisotropies was proposed by Mockett et al. [4], $\tilde{\Delta}_\omega$, defending the importance of using the maximum meaningful scale at each LES control volume. Shur et al. [5] proposed another SLS in combination with the Smagorinksy (SMG) model, Δ_{SLA}, where the $\tilde{\Delta}_\omega$ was modified for being turned off in $2D$ flow regions through a blending function, F_{KH}. This strategy is known as Shear Layer Adapted (SLA). More recently, we proposed a new SLS ,Δ_{lsq}, inherited from the LES literature [6] which was satisfactorily tested [7] for addressing the Gray Area phenomenon in DES. A comparison of $\tilde{\Delta}_\omega$ with Δ_{lsq} is presented in figure 2, observing how the Δ_{lsq} improves the triggering of Kelvin-Helmholtz structures.

Apart from the Δ kinematic sensitivity, the influence of $D_{sgs}(\bar{u})$ was also studied [8, 9]. In particular, the $\sigma-LES$ [10] was proposed as a good candidate due to its ability for turning off in $2D$ flow regions. The $\sigma-LES$ in combination with $\tilde{\Delta}_\omega$ is named $\sigma-DES$. Other techniques directly inherited from LES could also be applied, as the $S3PQR$ LES turbulence models presented by Trias et al. [11]. It is important noting here, how the Δ_{SLA} could be understood as a $\tilde{\Delta}_\omega$ with a $D_{sgs}(\bar{u})$ sensitive to $2D$ flows, $D^{2D}_{sgs}(\bar{u})$. Namely,

$$\begin{aligned}\nu_{sgs} &= (C_m\Delta_{sla})^2 D_{sgs}(\bar{u}) \\ &= \left(C_m\tilde{\Delta}_\omega\right)^2 (F_{KH}(\langle VTM\rangle)^2 D_{sgs}(\bar{u})) \\ &= \left(C_m\tilde{\Delta}_\omega\right)^2 D^{2D}_{sgs}(\bar{u}). \end{aligned} \quad (2)$$

This is, indeed, one of the most significant contributions for addressing the Gray Area shortcoming in DES models (mentioned in Shur et al. [5]).

Hence, the present work assesses the capabilities of the standard DES strategies (Δ_{SLA},$\sigma-DES$) for predicting the shear layer instabilities in a BFS configuration. Apart from that, the newest strategies are also applied (Δ_{lsq},$S3PQR$). The flow profiles and the rms distributions along the stream-wise direction are compared with DNS data [1], as well as the growth of the Kelvin-Helmholtz instabilities in the normal and stream-wise direction.

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References

[1] A. Pont-Vílchez, F. X. Trias, A. Gorobets, and A. Oliva, "Direct Numerical Simulation of Backward-Facing Step flow at $Re_\tau = 395$ and expansion ratio 2," *Accepted in the Journal of Fluid Mechanics.*

[2] A. Pont-Vílchez, F. X. Trias, A. Gorobets, and A. Oliva, "Direct Numerical Simulation dataset.." http://www.cttc.upc.edu/downloads/BFS_Ret395_ER2, 2018.

[3] P. R. Spalart, W.-H. Jou, M. Strelets, and S. Allmaras, "Comments on the Feasibility of LES for Wings, and on a Hybrid RANS/LES Approach," 1997.

[4] C. Mockett, M. Fuchs, A. Garbaruk, M. Shur, P. Spalart, M. Strelets, F. Thiele, and A. Travin, "Two Non-zonal

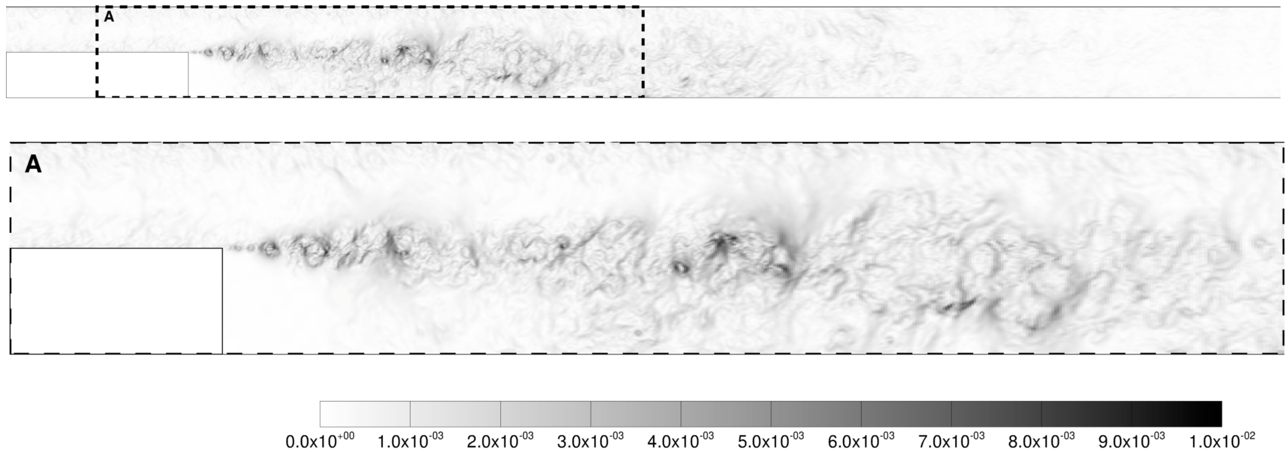

Figure 1: Instantaneous magnitude of the dimensionless pressure gradient [1] in a large part of the BFS domain (top), and a detailed view (A) of the sudden expansion (bottom). The colour meaning can be observed in the gray scale. See the film attached in the DNS data base [2].

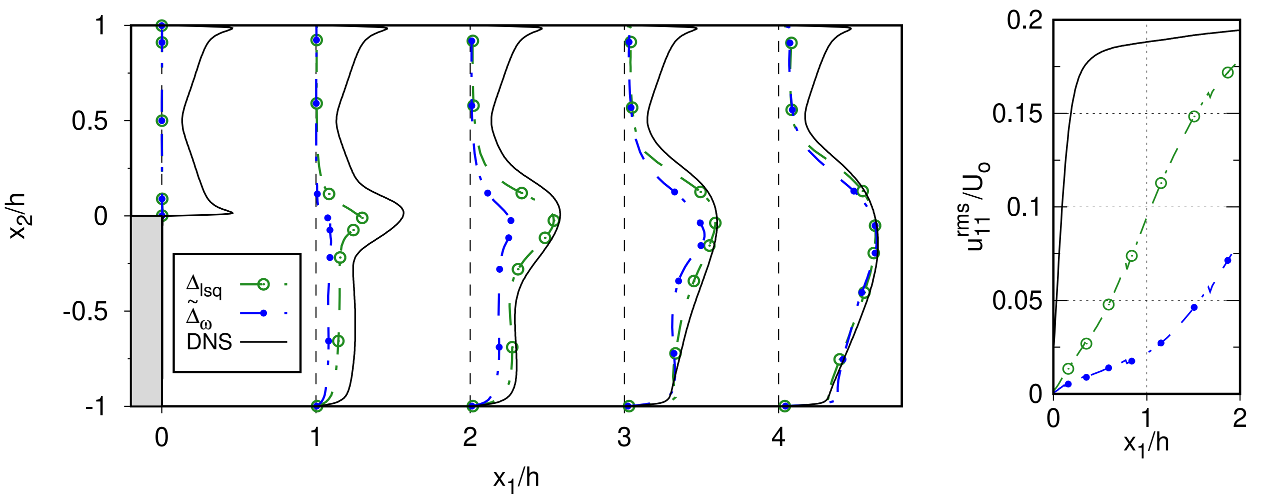

Figure 2: Resolved Reynolds stresses in the stream-wise direction ($\langle u_{11}^{rms} \rangle$) considering various subgrid length scales (left) and its evolution at $x_2 = 0$ (right). A SMG LES model is used in all cases. Where U_o refers to the inflow bulk velocity. Reference data, DNS, has been obtained from Pont-Vílchez et al. [1].

Approaches to Accelerate RANS to LES Transition of Free Shear Layers in DES," in *Progress in Hybrid RANS-LES Modelling*, (Cham), pp. 187–201, Springer International Publishing, 2015.

[5] M. L. Shur, P. R. Spalart, M. K. Strelets, and A. K. Travin, "An Enhanced Version of DES with Rapid Transition from RANS to LES in Separated Flows," *Flow, Turbulence and Combustion*, vol. 95, no. 4, 2015.

[6] F. X. Trias, A. Gorobets, and A. Oliva, "A new subgrid characteristic length for large-eddy simulation," *Physics of Fluids*, vol. 115109, 2017.

[7] A. Pont-Vílchez, F. X. Trias, A. Revell, and A. Oliva, "Assessment and comparison of a recent kinematic sensitive subgrid length scale in Hybrid RANS-LES," in *Proc. of Hybrid RANS-LES Methods 7*, 17-19 September, Berlin, Germany, 2018.

[8] M. Fuchs, J. Sesterhenn, F. Thiele, and C. Mockett, "Assessment of novel DES approach with enhanced SGS modelling for prediction of separated flow over a delta wing," in *22nd AIAA Computational Fluid Dynamics Conference*, 2015.

[9] A. Probst, D. Schwamborn, A. Garbaruk, E. Guseva, M. Shur, M. Strelets, and A. Travin, "Evaluation of grey area mitigation tools within zonal and non-zonal RANS-LES approaches in flows with pressure induced separation," *International Journal of Heat and Fluid Flow*, 2017.

[10] F. Nicoud, H. Toda, O. Cabrit, S. Bose, and J. Lee, "Using singular values to build a subgrid-scale model for large eddy simulations," *Physics of Fluids*, vol. 23, no. 8, 2011.

[11] F. X. Trias, D. Folch, A. Gorobets, and A. Oliva, "Building proper invariants for eddy-viscosity subgrid-scale models," *Physics of Fluids*, vol. 27, no. 6, 2015.