An efficient Two-Layer wall model for accurate numerical simulations of aeronautical applications.

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February 11, 2019

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Wall-bounded flows at high Reynolds number are of capital importance in the aeronautical industry. A deeper understanding of their physics would lead to more optimized aerodynamic designs. Nonetheless, the routine use of accurate numerical methodologies such as Large Eddy Simulation (LES) for these particular flow conditions, is still extremely expensive due to their heavy computational cost. Wall-Modeled LES is intended to circumvent the massive costs of accurately resolving the boundary layer while benefiting from the temporal and spatial resolution of an LES computation.

In this work, a Two-Layer Wall Model [1] with a general formulation suitable for non-equilibrium flows and complex geometries is presented. Two-Layer Models (TLM) suffer from two recurrent problems, the "log-layer mismatch" (LLM) and the resolved Reynolds stresses (RRS) inflow. Until now, complex and expensive techniques have been proposed to overcome these problems separately [2, 3]. The present strategy is based on a time-averaging filter (TAF) to deal with both issues at once, with a single and low-computational-cost technique. The filter is applied to the time-resolved LES variables at the wall model/LES interface. While this technique has already been applied to deal with LLM in simple equilibrium wall functions [4], it is used for the first time to block the RRS inflow in the TLM context. In this regard, a numerical experiment is initially performed to assess the TAF ability in suppressing the RRS inflow. Afterward, the WM is tested in regular operating conditions with a $Re_\tau \approx 3000$ Pipe Flow case and a stalled DU 91-W2-250 airfoil at Reynolds number $Re = 3 \times 10^6$ and angle of attack (AoA) of 15.2°. Good results are obtained in all the performed tests when using appropriate temporal filter lengths, showing the ability of the TAF in suppressing the LLM while avoiding the RRS inflow at the same time.

On the other hand, in order to determine the optimal filter length value, a systematic methodology has been developed and proposed. The technique is based on computing the power spectrum of the most characteristic velocity component in the WM/LES interface region. This provides insight on the time-scales of the local turbulent structures, and therefore, on the RRS temporal characteristics. It is found that LES frequencies higher than the energy-containing/inertial range limit must be suppressed. On the other hand, for strongly unsteady non-equilibrium flows, the largest characteristic time-scales must be also taken into account.

References

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