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Large Eddy Simulation: The Demand for a Universal Measure of Resolution

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> *"Whether you can observe a thing or not depends on the theory which you use. It is the theory which decides what can be observed."*
>
> **Albert Einstein, 1926**

The topic of turbulence modeling has trapped my attempts to write this editorial for the second volume of CFD Letters. The two editorials of the first volume described the modern skepticism about the governing laws of turbulence as well as the challenges raised by the recent advances in DNS of turbulent boundary layer. In the matter of fact, the debate about the governing laws of turbulence does not affect the vast majority of modern CFD fields of endeavor. Virtually all topics of concern to industrial CFD, for example, can be described within the frame of continuum fluid mechanics. Therefore, classical turbulence modeling keeps its stand as an unrelenting research topic that stimulates, literally, all fluid dynamicists and engineers. One of the most important topics in the recent fluid dynamics literature is the resolution of Large Eddy Simulation (LES). In a LES formulation, a specific filter length is defined to separate the resolved from the modeled scales of turbulence. This filter length depends, in the most common practice, on the resolution of spatial discretization in a specified problem. The implication of the "filtering" technique, which is the backbone of LES, is the question about the resolution of the resolved scales in comparison with the total turbulence budget in the flow. Without serious attempts to provide a comprehensive answer for such questions, LES shall be in a persistent need for physical validation. It will lose the privilege of resolving the anisotropic turbulence. Stephen Pope (New J. Phys. 2004, 6-35) has proposed a parameter, namely M , to measure the quality of LES resolution. This parameter is the ratio between the resolved turbulence kinetic energy to the total turbulence kinetic energy. This factor, in order to be resolved, it necessitates the total turbulent kinetic energy of a specific problem to be computed prior to the LES solution. Consequently, such computation must involve implementing the Kolmogorov cascade model for the sub-grid scales. In addition, the computation of the largest length scale of turbulence will also encounter some challenges that might affect the accuracy of the *M* parameter.

The *M* parameter was shown to be inadequate for estimating the quality of a LES solution by Lars Davidson (Int. J. Heat Mass Transf. 2009, 1016-1025). In his recent paper on the evaluation of LES resolution, Davidson postulated that such evaluation can be undertaken in several ways, among them is the method proposed by Pope. However, even with 80% resolved turbulent kinetic energy (which was assumed to be a well-resolved resolution by Pope) the solution was found to be rather coarse. It was also suggested that some other approaches might be used to measure the quality of a LES solution, such as the comparison between the modeled to the resolved Reynolds stresses.

Earlier this year, Simon Gant (Flow Turbulence Combust. 2010, 325-335) has reviewed recent efforts to provide a reliability platform for LES in industrial CFD applications. An emphasis was made in this article on the evaluation of LES based on prior RANS simulations. The comparison between the RANS turbulence integral length scale $(l_i = k^{3/2}/\varepsilon)$ to the LES filter length (Δ) was shown to be a method to verify the resolution of LES. Another method to qualify LES resolution based on prior RANS simulations was the ratio between the LES filter length (Δ), and the Kolmogorov length scale (η). These approaches for assessing LES based on prior RANS simulations are mainly motivated by two factors. First is the demand to have a gradient (i.e. not a single-value) of the LES quality to enable a smart enhancement for the grid. The second factor is the low computational resources required by RANS simulations. However, extended caution should be taken while applying these approaches in specific regions of the flow, such as near to the wall, in the separation regions or where the flow is dominated by large turbulent scales. Some other measures for LES quality were based on the sub-grid scale turbulent viscosity, such as in the work of Celik et al (J. Fluids Eng. 2005, 949-958). However, this transfers the problem of qualifying the quality of LES to another problem which is the accuracy of the sub-grid scale model. In fact, Spalart (Int. J. Heat Fluid Flow 2000, 252-263) has reported that a LES can be performed without a sub grid scale model at all. Instead, an upwind numerical scheme can be used in order to offset the energy cascade and maintain the smoothness of the solution. Thus, evaluating the LES resolution based on the sub-grid scales is not deemed to provide a possible end to the problem.

To that end, there is no universal measure for the resolution of LES. Perhaps, the present approaches may facilitate the implementation of LES in some of the industrial applications, where eventually the comparison with finely tuned measurements is critical to trust the solution. In such applications where LES is mostly important (i.e. atmospheric physics, metrology, oceanology, biofluid mechanics…etc.) and the existence of measurements is rare or insignificant, the absence of a universal measure for LES resolution shall sustain as the major impediment against its reliability and predictability.