Impact of Exascale Computers on the Simulation of Complex Turbulent Flows of Engineering Interest

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Exascale computing. Impact on DOE applications

With the current trends and investment in computer power, exascale supercomputers should be available sometime between 2018 and 2023. To put this in context, Tianhe-2 the largest supercomputer today, developed by China's National University of Defense Technology, can achieve 33.86 petaflops/s in a Linpack benchmark. Titan, a Cray XK7 system installed at DOE's Oak Ridge National Laboratory, is the second fastest achieving a 17.59 petaflops/s on the same benchmark. The combined power of the fastest 500 supercomputers in the world only achieves 0.31 Eflops. However, even when exascale supercomputers become available, CFD computing will not immediately benefit due to inherent inefficiencies of CFD methodologies which usually achieve between 0.1%-10% efficiency, with 1% considered a good efficiency.

Current level of CFD computations is reaching the point where turbulence is the only modeled physical phenomenon. Figure 1 shows results from the computation of a full wind turbine including the tower, nacelle, hub and blades performed by Li et al. (2015). The model includes both rotational speed and pitch controllers and blade elasticity. Body fitted grids allow an accurate representation of geometries while the overset technology together with Multibody Dynamics Solvers allow the prediction of motions and consider mechanical elasticity.

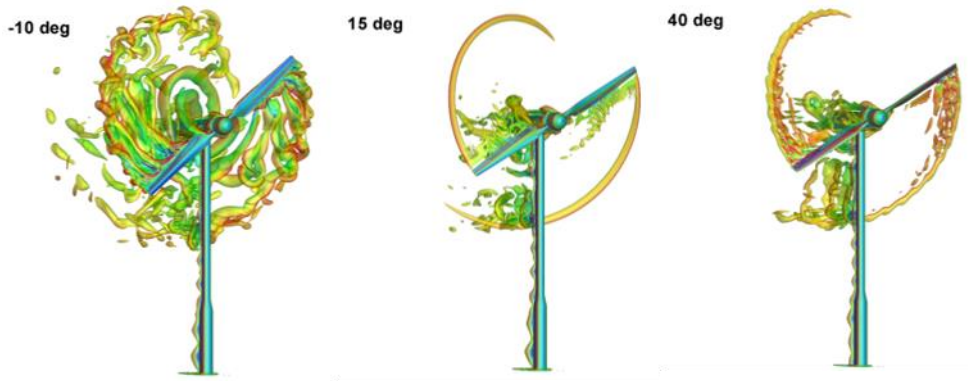

Figure 1: NREL Phase VI turbine at different blade pitch angles. Full wind turbine CFD simulations including motions and elasticity are feasible today (Li et al., 2015). Exascale computing will allow finer details of turbulence and enable real time lower resolution CFD computations.

The introduction of exascale computing would enable the computation of very finely resolved turbulence features in space and time that will push forward our basic understanding of turbulence. Moreover, exascale computing will also have a strong impact on the computation of flows with direct engineering application. Turnaround times of hours and even real time for applications of engineering interest will become possible. However, such fast turnaround computations will only be possible on a near future on coarser grids than those used for basic turbulence research usingby DNS or LES and some degree of turbulence modeling will be needed. In this regard hybrid RANS/LES computations will be a key component allowing to accurately resolve flows with massive separation and problems with turbulent transitions for which pure RANS approaches often fail.

Hybrid RANS/LES approaches for turbulence modelling

Several hybrid RANS/LES approaches are available in the literature which, in essence, are slight variations from the Detached Eddy Simulation (DES) concept by Spalart et al. (1997). Later, Spalart et al. (2006) developed the so called Detached DES (DDES) which aims to solve the problem of Grid Induced Separation (GIS) specially observed during boundary layer thickening as the grid spacing near a wall may become smaller than the boundary layer thickness causing the activation of the LES mode of the model. Spalart et al. (2006) coined the term Modeled Stress Depletion (MSD) which essentially refers to the reduction in turbulent viscosity in the transition from RANS to LES without a corresponding increase of resolved fluctuations. A similar formalism, Wall Modeled LES (WMLES), offers wall modeling in LES of high Reynolds number flows but only within a distance much finer than the boundary layer thickness as opposed to DES approaches which use RANS for the most part of the boundary layer. An Improved DDES (IDDES) is proposed by Shur et al. (2008) which essentially automatically switches between DDES and WMLES within different regions of a same simulation to use the best capable model in each of them.

Possible future directions and research opportunities

Recent research has been performed to improve the transition from RANS to LES, the so-called grey zone. An interesting idea is proposed by Francois et al. (2014) who used forced synthetic turbulence to feed the LES model with turbulent fluctuations generated with information from RANS. This kind of approach has the potential to introduce a new formalism that would allow to seamlessly transition from RANS to LES not only in regions near a wall but also within free shear regions where mesh refinement or even automatic mesh refinement (AMR) might be performed to resolve smaller features of the flow. How exactly this feedback by forced turbulence should be performed is unclear and more research is needed. Conversely, the conversion of turbulent resolved fluctuations from LES to RANS as a grid coarsens is also not well understood.

However, if properly formulated, this approach could reduce the problem of Model Stress Depletion, improve boundary layer separation and reattachment predictions while providing grid independent results.

References

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