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VARIABLE RESOLUTION MODELLING OF TURBULENCE: PARADIGMS OF CLOSURE

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Current turbulence simulation techniques resolve the turbulent flows fields on an *on-demand* basis depending upon the complexity of the flow and required degree of accuracy. The degree of resolution can vary with the computational flow domain – higher resolution in regions of complex flow physics and lower resolutions through the remainder of the domain. The currently popular variable resolution (VR) approach and even large eddy simulations (LES) fall in this category of simulations. To effect such a partially-resolved simulation, the velocity and pressure fields are decomposed into two parts – large resolved and smaller unresolved scales. The length scale separating the resolved and unresolved scales is the so-called cut-off scale. Germano (1992) demonstrated that the resolved flow equations are identical in form to the Navier-Stokes equation with the exception of additional unresolved-scale stress due to the resolved motion. The added stress is the generalized second moment of the total velocity field and its effect on the resolved scale requires closure modeling. In the Reynolds Averaged Navier Stokes (RANS) context, the unresolved stress is the Reynolds stress.

Much like in RANS method, in VR and LES approaches there are many levels at which closure modeling of the unresolved or sub-grid stress can be achieved. In this talk, I will discuss the different paradigms used for achieving closure. We start with two of the most popular sub-grid stress closure approaches are grid-based and viscosity-based methods.

Grid-based closure paradigm: In grid-based closures such as Smagorinsky model, the sub-grid viscosity is prescribed as a function of the cut-off length scale (Δ) and local strain rate (S):

$$\nu_t \propto |S| \Delta^2$$

The premise of this closure is that there is local equilibrium between production and dissipation at the small scales:

$$P_u = \varepsilon_u$$

Such specification of eddy viscosity ensures that scales of motion smaller than the cut-off are dissipated by viscous action in the LES calculation and therefore the cut-off length-scale (Δ) is taken to be of the order of local grid size. An important feature of this closure is that it entails no description of the unresolved scales of motion. The advantages and challenges of this approach will be identified.

Viscosity-based closure paradigm: In this approach sub-grid viscosity is first specified based on some knowledge of unresolved flow field:

$$\nu_u = \nu_u\left(k_u, \varepsilon_u\right)$$

where k_u and ε_u are the kinetic energy and dissipation of the unresolved scales.

The cut-off length scale of the resolved flow calculation is not precisely predetermined and it emerges from the calculations as a consequence of the magnitude of the specified viscosity. Such a computation is much like DNS wherein the dissipative scales are determined by fluid viscosity and Reynolds number. In such a case, it is important to ensure that the numerical resolution is in commensurate with the sub-grid viscosity.

Analogy with non-Newtonian flow simulations. Both grid-based and viscosity-based closure model calculations can be justifiably considered non-Newtonian flow calculations. Computational economy in VR/LES is achieved by the fact that the equivalent Reynolds number of the calculation is substantially smaller than the corresponding DNS as the effective viscosity in the former is larger than that in the latter.

In this talk, the main differences between grid-based and viscosity-based methods will be discussed.

REFERENCES

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