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WHAT EXACTLY IS THE FILTER LENGTH IN A FINITE-VOLUME BASED LES?

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Large eddy simulations use a subgrid model, which is characterized by a filter length that is often related to the grid. However the spatial discretization introduces a length scale too. In this paper, we show that a finite volume discretization introduces two filter lengths, one defined by the grid and the other by the interpolation rule used for approximating the convective flux. To illustrate this, we consider a simple, uniform 1D grid with spacing h. The grid points are denoted by x_i and the i-th finite 'volume' (here in 1D, we use the terminology as if it is 3D) is given by $[x_{i-1}, x_i]$, where $i = 1, ..., N$. The finite volume method represents the velocity u by

$$\widetilde{u}_{i-1/2}(t) \;=\; \frac{1}{h}\int_{x_{i-1}}^{x_i} u(x,t)\,dx,$$

where time is still continuous. In the context of large eddy simulation this is an one-dimensional box filter with filter length h. It is known as Schumann's filter. We denote it by a tilde to stress that the filter length is h. The convective flux through the faces of the control volumes is approximated using the interpolation $u_i \approx \frac{1}{2}(\widetilde{u}_{i-1/2} + \widetilde{u}_{i+1/2})$. Now by taking $\delta = 2h$, we obtain

$$\tfrac{1}{2}(\widetilde{u}_{i-1/2} + \widetilde{u}_{i+1/2}) \;=\; \frac{1}{\delta}\int_{x_i-\frac{\delta}{2}}^{x_i+\frac{\delta}{2}} u(x,t)\,dx \;=\; \overline{u}_i.$$

This shows that the interpolation rule is equivalent to taking the approximation $u_i \approx \overline{u}_i$. Importantly, it introduces a box filter with length $\delta = 2h$. So a finite volume discretization has two built-in filters, the grid filter with length h and delta filter with length $2h$. If we use a finite volume method as a basis for a large eddy simulation, this raises the question 'what exactly is the filter length'. In this presentation we will use some examples to address this question.

REFERENCES

[1] Robert Moser (ed.), Numerical Methods in Turbulence Simulation, Elsevier, 2023.