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Simulation of separation from continuous surfaces: some lessons on capabilities and limitations

Michael A. Leschziner

Imperial College London
Prince Consort Rd., London SW7 2AZ
Mike.leschziner@impetrial.ac.uk

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ABSTRACT

Statistical modelling within the RANS environment has been the overwhelmingly dominant approach to computing a broad variety of industrial flows for several decades, and it is set to remain in that position for many years to come, despite hyperbolic statements on LES as a panacea to all ills. However, the often perplexing predictive variability of even the most elaborate RANS models and their persistent failure in complex 3d flows has encouraged the view that LES is the only credible route to computing 3d flows, in general, and separated flows, in particular.

Unsurprisingly, in view of the fact that LES resolves all important large-scale dynamics of the turbulent motion, this method is indeed observed able to provide a far greater degree of predictive realism and consistency than even the most elaborate RANS models. However, LES is far from infallible, and it also poses substantial challenges that are often under-rated. Thus, it requires non-diffusive – hence, potentially unstable – discretisation schemes; it imposes restrictive cell-aspect-ratio limits; it requires a full spectral description of any turbulent inflow into the solution domain; and it is very costly if performed in such a manner as to render subgrid-scale modelling dynamically uninfluential. Particularly problematic are near-wall flows at high Reynolds numbers in which wall friction exerts an important influence on the gross flow characteristics away from the wall. Piomelli [1] shows (Fig. 1) that, at practical Reynolds numbers (say, above 5000, based on mean-flow velocity and overall geometric dimensions) near-wall-resolution constraints dictate the overall resource requirements to the extent that the number of nodes required rises as $N \propto Re^{2.5}$. Thus, if the near-wall layer is the region of prime interest, or if this region affects significantly the gross characteristics of the outer flow, wall-resolving LES quickly becomes economically untenable as the Reynolds number rises. In fact, it is the writer's experience that Piomelli's resource estimates are very conservative in complex flow applications. This experience is conveyed in Fig. 1 for several flows computed with wall-resolving grids (identified by circles in Piomelli's plot).

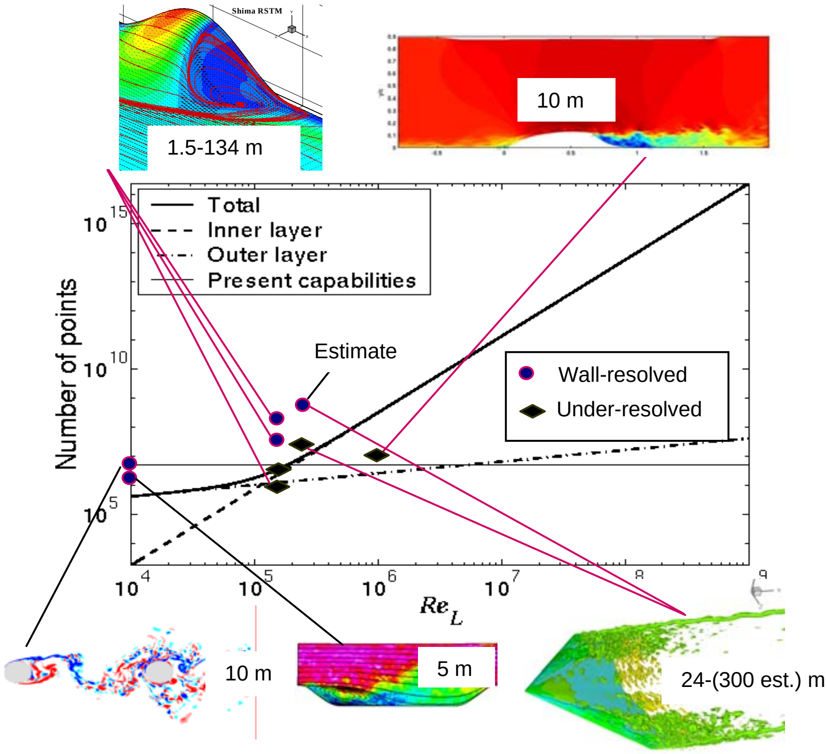

Fig. 1: Resource requirements for wall-resolving LES as suggested by Piomelli [1] and various LES/hybrid LES-RANS applications by the writer superimposed.

The very high costs of wall-resolved LES has encouraged the formulation of a whole range of approximate LES-RANS hybrid formulations (e.g. [2], [3]) that combine some near-wall RANS treatment with an outer-flow LES resolution. While this strategy appears superficially sensible, it raises many questions and uncertainties. However, practical needs dictate that pragmatic 'solutions' are formulated and tested, for without them, LES cannot currently be applied to high-Reynolds-number flows that are sensitive to frictional wall characteristics. Specifically in respect of separation from curved surfaces, an important question is whether the approximate near-wall treatment seriously compromises the ability of the baseline LES scheme to capture the dynamics of the separation process, due to the inevitable loss of structural information near the wall, in addition to the inaccuracies inherent in the use of RANS models in highly unsteady conditions. This is one of several issued reviewed in the presentation.

REFERENCES

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