Assessment of Computational Techniques for the Prediction of Acoustic Sources From Lifting Surfaces Using LES and DNS

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ABSTRACT

Large Eddy Simulation is being used increasingly to model complex turbulent flow phenomena for a wide range of industrial problems. One area of considerable interest is hydro-acoustics. The ability to resolve the acoustically relevant scales without expending excessive computational power resolving high wavenumber, low energy scales makes LES a potentially powerful tool for such analyses. However, the complex interactions between the error sources make verification and uncertainty analysis difficult. A number of efforts have been made in this regard, for example [1], [2], [4], but significant challenges remain for many important flows. In order to use LES as a predictive tool for hydro-acoustic analyses, one wishes to have confidence that a simulation has accurately resolved the flow features and turbulent scales that are relevant to the acoustic problem.

In this study, Large Eddy Simulations are compared with Direct Numerical Simulations of the flow over a NACA0012 foil at a Reynolds number of 10^5 and a $4°$ angle of attack. The aim is to assess the ability of the LES to accurately resolve the boundary-layer transition and resulting spectral content of the trailing edge flow. The effects of resolution, discretisation scheme, filter-grid ratio and sub-filter scale model are considered. Grid independence of the DNS is achieved, providing a good level of confidence in the data.

Initial boundary-layer transition occurs due to a Kelvin-Helmholtz instability induced by a separation bubble. A secondary 3D instability then results in the development of a fully turbulent boundary layer which exhibits broadband fluctuations at the trailing edge with no tonal component. This is well captured by the DNS, with results being in good agreement with other published data, [3]. The LES results show significant nonlinearities in the convergence of the flow field towards the DNS data as the mesh is refined. The sub-filter scale model is shown to have a significant effect. The highly dissipative Smagorinsky model predicts a mostly laminar boundary layer producing tonal pressure fluctuations at the trailing edge. With the dynamic k model, certain combinations of discretisation scheme and mesh resolution lead to dispersion errors which trigger an earlier transition and prevent the separation bubble from forming.

Finally, using the best methods found in this study, the same case is assessed for $Re = 3 \times 10^5$. Here, Tollmien-Schlichting instabilities give rise to tonal fluctuations at the trailing edge. This demonstrates an important link between the transition mechanism and the frequency content of the trailing edge flow.

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