A Hybrid LES-RANS Approach to Analyse Coupled Heat Transfer and Vortex Structures in Separated and Reattached Turbulent Flows

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Abstract : Experimental and computational studies investigating heat transfer in separated flows have been of increasing importance over the last 60 years, as efforts are being made to understand and improve the efficiency of components such as combustors, turbines, heat exchangers, nuclear reactors and cooling channels. Understanding of not only the time-mean heat transfer properties but also the unsteady properties is vital for design of these components. As computational power increases, more sophisticated methods of modelling these flows become available for use. The hybrid LES-RANS approach has been applied to a blunt leading edge flat plate, utilising a structured grid at a moderate Reynolds number of 20300 based on the plate thickness. In the region close to the wall, the RANS method is implemented for two turbulence models; the one equation Spalart-Allmaras model and Menter’s two equation SST k-ω model. The LES region occupies the flow away from the wall and is formulated without any explicit subgrid scale LES modelling. Hybridisation is achieved between the two methods by the blending of the nearest wall distance. Validation of the flow was obtained by assessing the mean velocity profiles in comparison to similar studies. Identifying the vortex structures of the flow was obtained by utilising the λ2 criterion to identify vortex cores. The qualitative structure of the flow compared with experiments of similar Reynolds number. This identified the 2D roll up of the shear layer, breaking down via the Kelvin-Helmholtz instability. Through this instability the flow progressed into hairpin like structures, elongating as they advanced downstream. Proper Orthogonal Decomposition (POD) analysis has been performed on the full flow field and upon the surface temperature of the plate. As expected, the breakdown of POD modes for the full field revealed a relatively slow decay compared to the surface temperature field. Both POD fields identified the most energetic fluctuations occurred in the separated and recirculation region of the flow. Latter modes of the surface temperature identified these levels of fluctuations to dominate the time-mean region of maximum heat transfer and flow reattachment. In addition to the current research, work will be conducted in tracking the movement of the vortex cores and the location and magnitude of temperature hot spots upon the plate. This information will support the POD and statistical analysis performed to further identify qualitative relationships between the vortex dynamics and the response of the surface heat transfer.

Keywords : heat transfer, hybrid LES-RANS, separated and reattached flow, vortex dynamics
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