A Variationally Bounded Scheme for Delayed Detached Eddy Simulation: Application to Vortex-Induced Vibration of Offshore Riser

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ABSTRACT

A novel variational method has been proposed to solve the convection-diffusion-reaction (CDR) equation which forms the most canonical form of any physical process ranging from Navier-Stokes flow, Allen-Cahn phase-field to turbulence transport. Solving these equations numerically through discretization introduces spurious oscillations due to inability of the mesh to resolve the crucial subgrid scales. The present method [1] is aimed to provide a bounded and positivity preserving solution for a broad range of parameters of subgrid-scale physics. A combined GLS-SGS methodology is chosen for the linear stabilization to have minimal phase error via Fourier analysis while consistent nonlinear stabilization is carried out with the help of discrete upwind operation to circumvent Godunov's theorem. At least second order of spatial accuracy is obtained for the method with successful capturing of the internal and boundary layers observed in two-dimensions.

One of the initial applications of this method is the delayed detached eddy simulation (DDES) transport equation which has strong production as well as destruction effects. Positivity and boundness in the solution is crucial for this equation for stable and accurate physics of turbulent wake and boundary layer at high Reynolds number. As a first benchmark study, a uniform flow across a stationary cylinder at subcritical Reynolds number is validated using the developed PPV-based turbulence model. To demonstrate the method for a practical application, the vortex-induced vibration of a long flexible riser of aspect ratio $L/D = 482$ is simulated using three-dimensional fluid-structure interaction solver [2] with unstructured parallel implementation. Crucial aspects of the flow dynamics and vibration patterns across the riser are observed and confirmed with that of the experiment.

The flow patterns observed around the riser are quite complex. The riser vibrates with a dominant second mode and the first mode in the in-line and cross-flow directions respectively. It is also observed that the dominant frequency of the in-line vibration is twice that of the cross-flow vibration. A standing wave pattern response is noticed for the riser response. Alternating regions of conditions which are favourable and unfavourable for VIV are observed for standing wave response. The results similarly depict an alternating pattern of the figure-8 trajectory along the riser and with time. A standard 2S mode of vortex shedding is noticed along most of the locations and a wider 2S with two rows configuration is seen at the locations near to the large amplitudes.

REFERENCES

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