Hybrid RANS-LES Turbulence Modelling in Aeroelastic Problems, Test Case 3 from the Second AIAA Aeroelastic Prediction Workshop

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Abstract Aeroelasticity concerns the interaction between inertial, structural and aerodynamic forces. In the development process of aircraft and space vehicles aeroelasticity plays a key role in assessing the stability of the systems' modes inside a given flight envelope. Traditionally, the RANS approach is used to model turbulence while using CFD to tackle these problems, even if simulations are often time-accurate. A sufficient separation in time and space is therefore assumed between (unresolved) turbulent scales of motion the (resolved) scales of motion which have a frequency content consistent with the dynamics of the underlying aircraft structure. However, an interaction between turbulent scales and the mean flow may not be excluded in the presence of separated flow, as it may happen in some areas of the flight envelope of an aircraft, at low speed and high angle of attack or at high Mach number when shocks may cause the boundary layer to separate. Among the test cases proposed by the recent second AIAA Aeroelastic Prediction Workshop, Test Case 3 includes shock-separations and large turbulent scales of motion. Hybrid RANS-LES modelling seems therefore the most suitable technique to tackle this kind of problem, even if it does not belong to the tools aeroelasticists normally rely upon. This paper describes the simulations carried out to solve Test Case 3 with the SA-DDES modeland a conventional (U)RANS approach. The study shows that, provided sufficient spatial and temporal resolution are available, the hybrid approach does provide a physically more consistent solution. However, a proper assessment of the results would require additional test cases and experimental data. Finally, a comment is provided on time-accurate simulations based on the RANS approach, which is physically questionable but in practice often done. The remainder of this abstract presents the AIAA Workshop and shows a few results.

1 Second AIAA Aeroelastic Prediction Workshop

The second AIAA Aeroelastic Prediction Workshop [7, 2] was launched with the aim of assessing the available numerical approaches in a number of different test cases and flow conditions. It also addresses the issue of physical consistence of CFD simulation in the presence of complex flow phenomena, which has been the subject of a number of surveys and assessments such as those by Bendiksen[1], Deck[3], Edwards[4], Frölich[5], Fureby[6], Sagault[14], Spalart[15] and Tsinober[16]. The author has also investigated the role of turbulence modelling in transonic flow[12, 10, 11].

Whereas Test Cases 1 and 2 concern the response of the BSCW wing in transonic attached flow, flow conditions in Test Case 3, $M = 0.84$ and $5°$ angle-of-attack, cause a more complex flow development including shock-separations. More sophisticated and physically consistent approaches than (U)RANS are advocated, first of all those based on the hybrid RANS-LES technique. In this study, Test Case 3 has been analysed with a conventional (U)RANS approach, based on the SA model, and with a hybrid RANS-LES approach, based on the SA-DDES model.

2 Results

Fig. 1 shows the resolved turbulent structures, highlighted by Q-criterion contours, which appear with no wing motion. Both results refer to simulations run on the same grid and with the same temporal resolution. A dynamic equilibrium develops between the shock motion and the oscillations of circulation (when the shock moves upstream circulation is reduced, when circulation reduces the shock moves downstream). Numerous studies [8, 9] have been published. They indicate that similar phenomena may be investigated on the basis of URANS simulations. In this case, both modelling approaches seems capable of providing plausible turbulent structures. However, the analysis of the resolved TKE, shown in Fig. 2, reveals that using the hybrid approach and a higher spatial resolution does improve shape and level of the resolved TKE. In other words, even if the URANS simulation manages to capture unsteady turbulent structures, it is

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unclear how accurately the energy cascade is reproduced. It is consequently unclear how reliably the effects of resolved turbulence on the mean flow are assessed. Results from the hybrid simulations are more plausible. However, the effects of spatial resolution are critically important.

Fig. 3 shows the comparison of the average distribution of pressure coefficients to wind tunnel data. Fig. 4 shows magnitude and phase of the Frequency Response Function (FRF) of the aerodynamics (in terms of the distribution of pressure coefficient) following forced pitch oscillations at a frequency of 10 Hz. In both cases, the hybrid model seems to be slightly more accurate; however, additional data would be necessary to complete the assessment. Additional data can be found in Ref. [13].

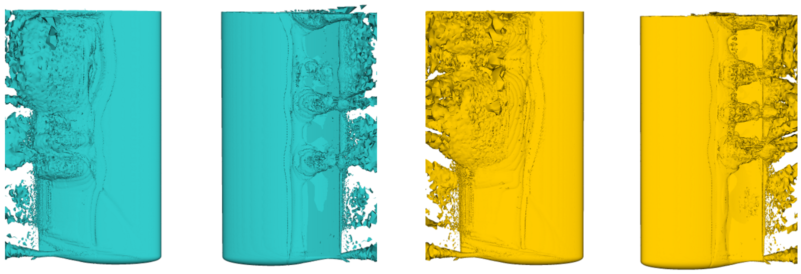

Fig. 1 Large-scale turbulent structures identified by Q-criterion, $Q = 0$ contour surface. Left-hand side: URANS, right-hand side: SA-DDES. Upper side of the wing.

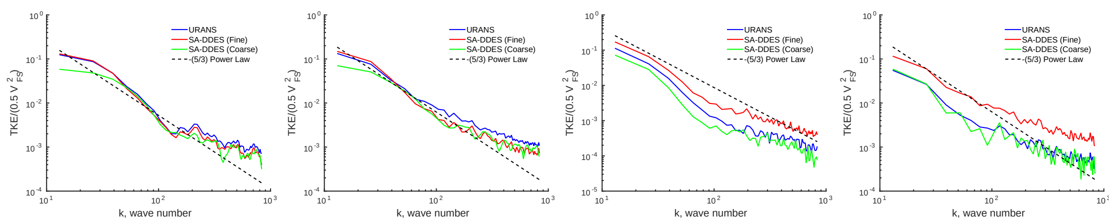

Fig. 2 Decay of TKE is shown in four different areas, top row, left-hand side: $x/c = 0.70$, top row, right-hand side: $x/c = 0.80$, bottom row, left-hand side: $x/c = 1.00$, bottom row, right-hand side: $x/c = 1.20$. Results from URANS on medium grid, SA-DDES on medium and coarse grids are shown.

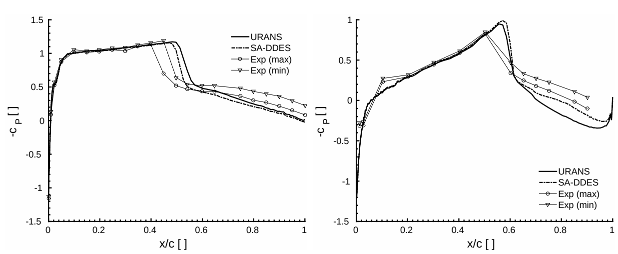

Fig. 3 Comparison between calculated and measured average c_P, $x/c = 0.60$, left hand side: upper wing side, right hand side: lower wing side

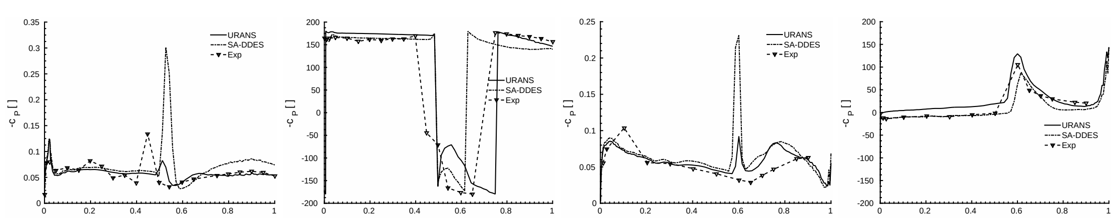

Fig. 4 FRF of c_P, $x/c = 0.60$, left hand side: upper wing side (magnitude and phase), right hand side (magnitude and phase)

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