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An Optimization of Turbulent Flows by using Data Assimilation

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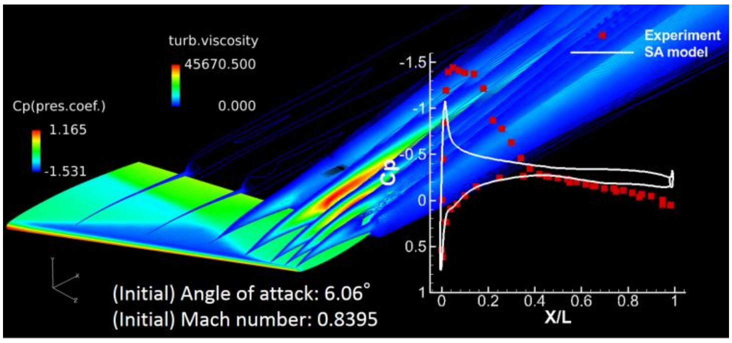
The Reynolds-averaged Navier–Stokes simulation (RANS) is an efficient tool to compute turbulent flows. In most cases for RANS, eddy viscosity turbulence models are employed to represent the Reynolds stress term appeared in the RANS equation. While eddy viscosity turbulence models have successfully computed turbulent flows, they have still difficulties in computing complex turbulent flows, such as a flow involved in a shock-boundary layer interaction. Thus, eddy viscosity turbulence models are sources of uncertainty of computational fluid dynamics (CFD). Obviously, the large eddy simulation (LES) and direct numerical simulation (DNS), which have lower-approximations for the Navier–Stokes equations than the RANS equation, can compute turbulent flows more accurately than RANS. However, LES and DNS require immense computational resource, therefore, realizations of LES and DNS in the field of aeronautical engineering to require immense number of computational grids and immense computational time for turbulent flows at a high Reynolds number are not practical. Therefore, developments of advanced eddy viscosity turbulence models will be required for the field of aeronautical engineering.

One of the reasons that current eddy viscosity turbulence models fail to compute complex turbulent flows seems to lack of information regarding complex turbulent flows. Current turbulence models are based on information regarding turbulent theories and database of experiments and DNS. However, the turbulent theories and the database are not for flows around complex geometries and at high Reynolds number but for flows around simple geometries and at low Reynolds number, because experiments and DNS have difficulties in representing turbulence around complex geometries and at high Reynolds number with a high degree of accuracy.

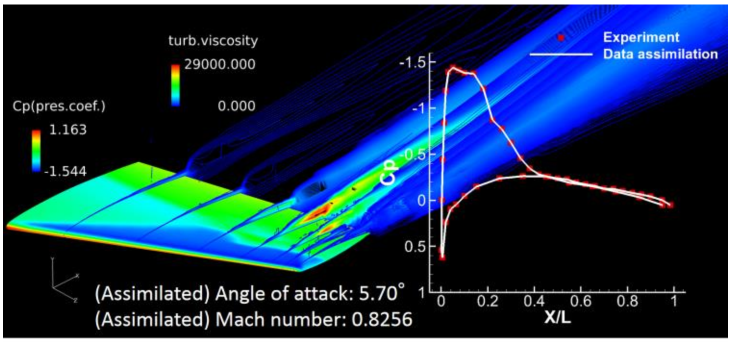
In this study, data assimilation [1] is employed to represent optimal turbulent viscosity, which represent turbulence in eddy viscosity turbulence models, in a complex flow at a high Reynolds number. Data assimilation can propagate uncertainty from experimental data to computational data, and can represent optimum data combining experimental data and computational data. Since present experimental and computational approaches cannot represent turbulent viscosity in flows at high Reynolds number, optimal turbulent viscosity represented by data assimilation can be a new information, and can contribute to design the next best eddy viscosity turbulence models.

As a data assimilation method, the ensemble Kalman filter (EnKF) [2] is employed. The

EnKF is one of advanced sequential data assimilation methods. In this study, the transonic flow around the ONERA M6 wing is employed to optimize the turbulent viscosity. The flow conditions are Reynolds number of 11.7 million, Mach number of 0.8395, and angle of attack of 6.06 degree. The Spalart–Allmaras model [3] that is the one-equation eddy viscosity turbulence model fails to capture experimental pressure coefficients on the wing surface as shown in Fig. 1 a). Figure 1 b) shows a current result of data assimilation. In the result, the angle of attack and Mach number, which are sources of uncertainty of experiments and computations, are optimized, along with the turbulent viscosity. The result shows that data assimilation can improve the discrepancy of the pressure coefficients on the wing surface between the experimental and the ordinary computation.



a) The Spalart–Allmaras turbulence model



b) Data assimilation

Figure 1. Comparison of the flow fields around the ONERA M6 wing (contours on wing surface: pressure coefficient; contour lines on planar slice: turbulent viscosity; right figure: comparison of pressure coefficients between experiment and computation at the spanwise direction y/b = 0.95).

In the final manuscript, details of this approach and results would be presented.

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