Reynolds averaged modeling (RANS) – overview

In spite of recent advances in scale-resolving CFD simulation capabilities, Reynolds-averaged Navier-Stokes (RANS) methods are still widely used because of their lower expense and relative ease of use. However, RANS—which requires a turbulence closure model—is considered to be reliable only for attached flows. For flows with separation, some turbulence models fare better than others, and the level of variability and uncertainty generally increases with separation bubble size and flow complexity. For smooth-body separation bubbles in particular, most RANS models are known to underpredict the turbulence levels within the separated shear layer. As a result, reattachment and subsequent boundary layer recovery is typically delayed. If RANS models could be improved to consistently predict certain classes of aerodynamic separated flows accurately, a larger portion of vehicle design space would become readily accessible to engineers, without having to resort to the greater expense of scale-resolving simulations.

During the CTR summer program in 2012, the RANS group consisted of three projects. An underlying focus of them all was the improvement of RANS turbulence modeling for separated flows. Different approaches were used, but the projects sought to find common ground in their analysis tools and test cases. For the tools, all projects made use of phase-space analysis (for example, determining how particular models behave as a function of nondimensional strain and/or vorticity over strain). For the test cases, all projects included a variety of well-documented two-dimensional bump flows for which experimental data or scale-resolving simulations are available.

Rumsey and Jeyapaul explored a specific dissipation rate equation found in the literature, and also developed a novel modification to the pressure-strain modeling. An explicit algebraic stress model (EASM) framework was employed, and encouraging preliminary results for bump-type separated flows were obtained using the new pressure-strain model.

The second and third projects both involved the algebraic structure-based turbulence model (ASBM), which incorporates information about the structure of turbulence to provide closure to the RANS equations. Beside further improving the model's predictive capability, an additional effort was to improve the model robustness, since in the past the ASBM has occasionally had difficulties obtaining converged solutions. Pecnik et al. analyzed the functional form of the model over a range of mean deformations of homogeneous turbulence. Results were compared with reference solutions using the particle representation model (this model provides an exact closure of the Rapid Distortion Theory), and improved functional forms of the structure parameters were derived. O'Sullivan et al. focused on improving near-wall models for ASBM. Two aspects were considered: (i) improving wall blocking to include the effect of multiple walls, and (ii) improving wall functions to account for non-equilibrium effects, such as occur in separated zones. The improved model from the ASBM projects—both with and without wall functions—yielded very promising preliminary results for bump-type separated flows.

The new modeling ideas obtained during the Summer Program will continue to be refined and applied to additional complex engineering flows of interest in the future.

Christopher Rumsey