Direct Numerical Simulations and Modeling of a Spatially-Evolving Turbulent Wake

by

John M. Cimbala
Associate Professor, Mechanical Engineering
The Pennsylvania State University
University Park, PA 16802

Understanding of turbulent free shear flows (wakes, jets, and mixing layers) is important, not only for scientific interest, but also because of their appearance in numerous practical applications. Turbulent wakes, in particular, have recently received increased attention by researchers at NASA Langley. The turbulent wake generated by a two-dimensional airfoil has been selected as the test-case for detailed high-resolution particle image velocimetry (PIV) experiments. This same wake has also been chosen to enhance NASA's turbulence modeling efforts. Over the past year, the author has completed several wake computations, while visiting NASA through the 1993 and 1994 ASEE summer programs, and also while on sabbatical leave during the 1993-94 academic year. These calculations have included two-equation (K-ω and K-ε) models, algebraic stress models (ASM), full Reynolds stress closure models, and direct numerical simulations (DNS). Recently, there has been mutually beneficial collaboration of the experimental and computational efforts. In fact, these projects have been chosen for joint presentation at the NASA Turbulence Peer Review, scheduled for September 1994.

DNS calculations are presently underway for a turbulent wake at $Re_\theta = 1000$ and at a Mach number of 0.20. (θ is the momentum thickness, which remains constant in the wake of a two-dimensional body.) These calculations utilize a compressible DNS code written by M. M. Rai of NASA Ames, and modified for the wake by J. Cimbala. The code employs fifth-order accurate upwind-biased finite differencing for the convective terms, fourth-order accurate central differencing for the viscous terms, and an iterative-implicit time-integration scheme. The computational domain for these calculations starts at $x/\theta = 10$, and extends to $x/\theta = 610$. Fully developed turbulent wake profiles, obtained from experimental data from several wake generators, are supplied at the computational inlet, along with appropriate noise. After some adjustment period, the flow downstream of the inlet develops into a fully three-dimensional turbulent wake. Of particular interest in the present study is the far wake spreading rate and the self-similar mean and turbulence profiles.

At the time of this writing, grid resolution studies are underway, and a code is being written to calculate turbulence statistics from these wake calculations; the statistics will be compared to those from the ongoing PIV wake measurements, those of previous experiments, and those predicted by the various turbulence models. These calculations will lead to significant long-term benefits for the turbulence modeling effort. In particular, quantities such as the pressure-strain correlation and the dissipation rate tensor can be easily calculated from the DNS results, whereas these quantities are nearly impossible to measure experimentally. Improvements to existing turbulence models (and development of new models) require knowledge about flow quantities such as these. Present turbulence models do a very good job at prediction of the shape of the mean velocity and Reynolds stress profiles in a turbulent wake, but significantly underpredict the magnitude of the stresses and the spreading rate of the wake. Thus, the turbulent wake is an ideal flow for turbulence modeling research. By careful comparison and analysis of each term in the modeled Reynolds stress equations, the DNS data can show where deficiencies in the models exist; improvements to the models can then be attempted.