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TURBULENCE MODELING FOR HIGH SPEED COMPRESSIBLE FLOWS

by

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There is an enormous need in aeronautics and other fields for the capability of calculating two- and three-dimensional compressible turbulent flows. Turbulence models are necessary in numerical simulations because of the impracticality of computing all scales of turbulent motion. Since these scales compose a range many orders in magnitude, the computer storage required to resolve all scales is much larger than the storage capacity currently available on the most powerful computers. Even if computers did exist with the required capacity, the computational speed of current computers is too slow to handle all but the simplest of problems. Thus, approximate methods, or models of turbulence, are introduced to simplify and make the computations practical.

There are several approaches to turbulence modeling, depending on how many of the turbulent scales are included in the modeling process. A rigorous approach is to use subgrid-scale modeling (also known as large eddy simulation) in which only turbulent eddies equal to or smaller than the numerical grid sizes are modeled. In this case, the largest eddies are computed, and because they move and deform in time, the calculations are necessarily unsteady. This results in relatively large computer times and restricts the applicability of subgrid modeling to fundamental studies.

A more practical approach is to model all the scales of turbulent motion. The equations solved in this case are the Reynolds-averaged Navier-Stokes equations, and the numerical solutions, which represent long time averages of the flow variables, are usually steady in time.

Numerous eddy viscosity and Reynolds stress turbulence closure models have been developed in recent years. Computations of supersonic and hypersonic flows obtained by using several of these models are also available in the turbulent flow literature. In many instances, computations based on turbulence models are compared with available experimental data. Specific examples include attached boundary layer flows, shock wave-boundary layer interactions, and compressible shear layers. In all situations, the effort is directed at seeking models which have reasonable accuracy over a limited range of flow conditions.

The status of turbulence modeling for hypersonic flow is still far from complete. More experimental data and computational comparisons will be necessary to verify and establish compressibility corrections made to date. In addition, more experimental and computational work will be needed, especially at low Reynolds numbers because of the frequent prevalance of this regime at hypersonic speeds. Also, more research work will be necessary before the compressible mixing layer problem (e.g. in two-stream supersonic mixing) can be considered solved. In this area, current modeling modifications are, to a considerable extent, ad hoc and have not been verified for a wide range of cases. Furthermore, they are not based on an understanding of the physical mechanisms involved. Research is underway at several NASA centers to use full simulations of compressible shear layers using the time-dependent Navier-Stokes equations to provide more complete information on the mixing phenomena. This research should lead to improved modeling of compressible shear flows and will be invaluable in numerous cases such as the effort currently underway at LaRC to develop a hydrogen-fueled supersonic combustion ramjet (scramjet) engine capable of propelling a vehicle at hypersonic speeds in the atmosphere.

Work to date includes the following aspects of the computational fluid dynamics research:

1. An understanding of the SPARK code with finite-volume methods, using compact high-order and Runge-Kutta time-stepping schemes for numerical solutions of Euler equations.

2. An understanding of the SPARK code using finite-difference MacCormack schemes.
3. Application of (2) to incorporate a two-equation turbulence model and a study of the extension of the K-E model for use in compressible flows involving high speed mixing layers.
4. An understanding of the use of wall functions as boundary conditions for two-dimensional compressible flows.

References

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