

"Quantifying Uncertainties from the Grid in CFD Solutions"

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Abstract: For most users of CFD, the mesh and the time-step size are the only parts of the solution procedure in which the user has full control. The mesh used must represent the geometry and enable the algebraic analog of the governing PDEs to resolve the relevant flow physics. For realistic engineering problems, the number of grid points or cells that can be used is restricted by either the available computer resource or a need to have a practical turn-around time in generating a solution. With such a constraint, accuracy demands grid points to be placed in regions where they are most needed to resolve the geometry and flow physics (e.g., by r- or h-refinement). Unfortunately, this non-uniform distribution could create what are referred to as poor-quality cells, which can induce considerable errors in the computed solutions. In addition, it is generally not feasible to do a grid-independent study so that there could be errors from poor quality cells and from inadequate resolution.

This talk begins with a study on grid-quality measures that assume grid-induced errors in a CFD solution at a cell is a function of the cell size and shape, the grid distribution around that cell, and the solution computed in the neighborhood of that cell. Several grid-quality measures will be presented that account for the vectorial and the tensorial nature of fluid flow, which differ from the second derivatives of pressure or velocity that are commonly used. These measures are evaluated by applying them to flows in an IC engine combustion chamber, an intake manifold, and an exhaust manifold. Next, the basis of the discrete-error-transport equation (DETE) is presented, which recognizes that gridinduced errors at a cell may have nothing to do with the cell or in the neighborhood of that cell because that error may have been generated elsewhere and then transported there. The usefulness of DETE in estimating grid-induced errors is demonstrated by applying it to three PDEs with known exact solutions: the linear advection equation, the linear wave equation, and the inviscid Burger equation with a discontinuity. This is followed by a study on methods for modelling the residual in the DETE. These methods include those that are based on a single grid and those that involve generating CFD solutions on two or more successively refined grids. The usefulness of these models are evaluated by applying them to estimate grid-induced errors in CFD solutions of the following problems: steady flow past a circular cylinder, steady transonic flow about an airfoil, unsteady flow of a translating vortex, and vortex shedding behind a circular cylinder.

Bio: Tom Shih is professor and head of Purdue's School of Aeronautics and Astronautics. Previously, he was professor and chair of the Department of Aerospace Engineering at Iowa State University (2003-09). He has also held faculty positions at Michigan State University (1998-2003), Carnegie Mellon University (1988-98), and the University of Florida (1983-88) and was a mechanical engineer at NASA – Lewis (now Glenn) Research Center (1981-82). He started his undergraduate education at West Virginia University but completed his B.S. degree at the National Cheng Kung University in Taiwan in 1976. He received his M.S.E. and Ph.D. degrees from The University of Michigan at Ann Arbor in 1977 and 1981, respectively. Professor Shih's research centers on computational fluid dynamics (CFD) – both in developing and improving it as a tool and in using it to study physical problems. He and his students have developed a number of algorithms and codes for studying reacting and non-reacting, compressible and incompressible flows. Algorithms and codes have also been developed for automatic/knowledge-based grid generation and estimating errors in CFD solutions. In using CFD, Shih and his students have studied a wide range of problems in energy, power, and propulsion systems, including piston and Wankel rotary engines, automotive torque converters, control of shock-wave/boundary-layer interactions by bleed for supersonic aircraft, aerodynamics of iced airfoils and wings, and internal and film cooling of gas turbine components. In these endeavors, Shih has authored and co-authored more than 200 technical papers in journals and conferences; presented over 160 invited seminars, lectures, and workshops; and served as advisor and co-advisor to 21 PhD and 45 MS students. Professor Shih is a Fellow of ASME and AIAA.