CFDWARP — Convergence Acceleration Using Domain Decomposition

CFDWARP INCLUDES A IN-HOUSE-DEVELOPED convergence acceleration algorithm based on domain decomposition [4]. The algorithm consists of updating the residual only on a portion of the computational domain at one given iteration (i.e., the computational region) rather than on the entire computational domain as is generally the case. This can lead to significant savings in computational effort especially when simulating steady-state flows but also when simulating time-accurate flows using block-implicit ADI methods [1,2,3].

When solving steady-state flows, the algorithm is such that the computational region advances in the streamwise direction as the solution converges, similarly to marching schemes. The marching method used in CFDWARP is superior to other marching schemes by being applicable to the unmodified Navier-Stokes equations and by yielding the same converged solution as would be obtained through standard (non-marching) pseudotime stepping algorithms. This is in contrast to other marching algorithms which can only be applied to governing equations which are of parabolic or hyperbolic type and are hence not suited to systems of equations with streamwise ellipticity (such as the Navier-Stokes equations). Because of this, and contrarily to other marching algorithms, our algorithm can be applied successfully to viscous streamwise separated flows including shock-boundary-layer interaction problems. For typical supersonic steady-state flowfields, such decreases the work required for convergence by 20-100 times for flows with little streamwise ellipticity and by about 5-10 times for flows with large streamwise separated regions.

When solving time-accurate flows, the domain decomposition convergence acceleration technique is used alongside a dual-time stepping strategy. First proposed by Jameson [5], dual-time stepping consists of adding a pseudotime derivative to the delta form and performing subiterations using one or various convergence acceleration techniques until the pseudotime derivative becomes small compared to the other terms. In doing so, and as long as it is ensured that the residual at each physical time level is converged sufficiently by performing enough subiterations, the obtained solution does not depend significantly on the Jacobians used to linearize the residual and is consequently not tainted with significant linearization error. Therefore, large physical time steps can be specified leading to significant gains in computational efficiency. In CFDWARP, the dual-time stepping strategy of Jameson is combined with the multizone cycle acceleration technique [4] for higher computational efficiency. The multizone cycle consists of splitting the computational domain in a large number of zones of equal size and performing iterations only on the zones for which the residual is above a certain user-defined threshold. Typically, the multizone acceleration

technique leads to a two- to three-fold reduction in computational effort for unsteady flows and is such that, when convergence is attained, the residual of all nodes at each physical time level is guaranteed to lie below the user-defined threshold. As such, it does not affect the accuracy of the solution and is strictly a convergence acceleration technique.

References

[1] DW Peaceman and HH Rachford, "The Numerical Solution of Parabolic and Elliptic Differential Equations," *Journal of the Society for Industrial and Applied Mathematics*, Vol. 3, 1955, pp. 28–41.

[2] JE Bardina and TJ Coakley, "Three-Dimensional Navier-Stokes Simulations with Two-Equation Turbulence Models of Intersecting Shock-Waves/Turbulent Boundary Layer at Mach 8.3," *Proceedings of the 12th AIAA Applied Aerodynamics Conference*, Colorado Springs, CO, 1994, AIAA Paper 94-1905.

[3] RW Maccormack, "Iterative Modified Approximate Factorization," *Computers & Fluids*, Vol. 30, No. 8, 2001, pp. 917–925.

[4] B Parent and JP Sislian, "The Use of Domain Decomposition in Accelerating the Convergence of Quasi-Hyperbolic Systems," *Journal of Computational Physics*, Vol. 179, No. 1, pp. 140–169.

[5] A Jameson, "Time Dependent Calculations Using Multigrid, with Applications to Unsteady Flows Past Airfoils and Wings", AIAA 10th Computational Fluid Dynamics Conference, Honolulu HI; AIAA Paper 91-1596, 1991.