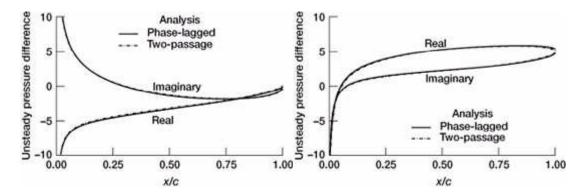# Time-Shifted Boundary Conditions Used for Navier-Stokes Aeroelastic Solver

Under the Advanced Subsonic Technology (AST) Program, an aeroelastic analysis code (TURBO-AE) based on Navier-Stokes equations is currently under development at NASA Lewis Research Center's Machine Dynamics Branch. For a blade row, aeroelastic instability can occur in any of the possible interblade phase angles (IBPA's). Analyzing small IBPA's is very computationally expensive because a large number of blade passages must be simulated. To reduce the computational cost of these analyses, we used time-shifted, or phase-lagged, boundary conditions in the TURBO-AE code. These conditions can be used to reduce the computational domain to a single blade passage by requiring the boundary conditions across the passage to be lagged depending on the IBPA being analyzed. The time-shifted boundary conditions currently implemented are based on the direct-store method. This method requires large amounts of data to be stored over a period of the oscillation cycle. On CRAY computers this is not a major problem because solid-state devices can be used for fast input and output to read and write the data onto a disk instead of storing it in core memory.
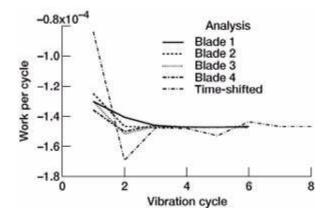
In aeroelastic analyses using TURBO-AE, the unsteady aerodynamic loads are obtained by solving the Reynolds-averaged Navier-Stokes equations. The aerodynamic equations are solved via a finite volume scheme. Flux vector splitting is used to evaluate the flux Jacobians on the left side, and a higher order Total Variation Diminishing (TVD) scheme based on Roe's flux vector splitting is used to discretize the fluxes on the right side. Newton subiterations are used at each time step to maintain higher accuracy. Then, symmetric Gauss-Sidel iterations are applied to the discretized equations, and a dynamic grid deformation technique is used to simulate the blade motions. TURBO-AE updates the grid at each time step by recalculating it using linear interpolation and by assuming the far field to be fixed. It determines the aeroelastic characteristics of the blade row by calculating the energy exchange between the vibrating blade and its surrounding fluid for all possible frequencies and IBPA's of interest. Positive work on the blade indicates instability.
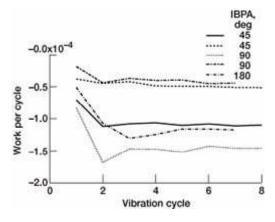
Comparison of the unsteady pressure difference variation at midspan for 180° IBPA oscillations; distance along chord from leading edge, x; chord, c. Left: Pitching. Right: Plunging.

To verify and validate the time-shifted analysis, we used a flat-plate, helical-fan geometry. The helical fan consisted of 24 flat-plate blades with zero thickness. The inflow conditions and stagger angle were set to induce an inflow with a relative Mach number of 0.7 at an incidence of zero at the midspan. The results were obtained for several IBPA's and compared with those of the analysis using multiple blade passages. Only a few typical results are shown here; for more detail please refer to the reference. The preceding graphs show the unsteady pressure difference for the 180° IBPA pitching and plunging cases. The time-shifted results were compared with results from a two-passage analysis. A very good comparison was obtained in both cases, indicating that the time-shifted boundary condition was properly implemented and reproduced the results of the multiple-passage analysis.

In the next graph, the rate of convergence for the time-shifted analysis for -90° IBPA pitching is compared with that of the multiple-passage analysis. From this figure, it can be seen that the work-per-cycle for the four-passage analysis converged within four to five oscillation cycles, whereas roughly seven to eight cycles were required for the time-shifted analysis. Even though approximately 40-percent more cycles were required for convergence, the computational time was reduced by almost 60 percent. This is because only one blade passage was needed in the time-shifted analysis. We also found that the convergence rate for the time-shifted analysis was independent of the IBPA analyzed (see the final graph).

Comparison of the work-per-cycle convergence for a time-shifted analysis with multiple passages.

Comparison of the work-per-cycle convergence history for various interblade-phase-angle pitching oscillations.

Bibliography

Srivastava, R., et al.: Application of Time-Shifted Boundary Conditions to a 3D Euler/Navier-Stokes Aeroelastic Code. ASME Paper 98-GT-42, 1998.