Nonlinear Analysis of Unsteady Flows in Multistage Turbomachines Using the Harmonic Balance Technique

A harmonic balance technique for the analysis of nonlinear unsteady flows in multistage turbomachines is presented. The method uses a mixed time-domain/frequency-domain approach that allows one to compute the unsteady aerodynamic response of multistage machines to both blade vibration (the flutter problem) and wake interaction (the forced response problem). In general, the flow field may have multiple excitation frequencies that are not integer multiples of each other, so that the unsteady flow is (sometimes) aperiodic in time. Using our approach, we model each blade row using a computational grid spanning a single blade passage. In each blade row, we store several sub-time level solutions. For flows that are periodic in time, these sub-time levels span a single time period. For aperiodic flows, the temporal “period” spanned by these sub-time level solutions is sufficiently long to sample the relevant discrete frequencies contained in the aperiodic flow. In both cases, these sub-time level solutions are related to each other through the time derivative terms in the Euler or Navier-Stokes equations, and boundary conditions — complex periodicity conditions connect the sub-time levels within a blade passage, and inter-row boundary conditions connect the solutions among blade rows. The resulting discretized equations — which are mathematically “steady” because time-derivatives have been replaced by a pseudo-spectral operator in which the excitation frequencies appear as parameters — can be solved very efficiently using multigrid acceleration techniques. In this talk, we present a number of examples to illustrate the utility of the technique as well as some interesting steady flow problems.