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"Research Efforts in Development of NPARC 2D/3D CFD Codes"

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Main Objective

The objective of the research was to develop a capability in the NPARC computational fluid dynamics (CFD) code to efficiently solve for unsteady airflows with moving geometry and grids. The application of interest was the unsteady flow in a high-speed aircraft inlet operating at the supercritical condition in which a terminal shock resides within the diffuser.

Background

Version 3.0 of the NPARC code solves the compressible Navier-Stokes equations on a multi-block, structured grid using finite-difference numerical techniques. It was developed primarily to solve for steady airflows. The analysis of a high-speed aircraft inlet operating at the supercritical condition requires understanding the sensitivity of the terminal shock to unsteady flow perturbations. In severe cases, the inlet may unstart, which involves the terminal shock being expelled from the inlet with a drastic decrease in aircraft performance. The inlet is restarted by varying the geometry of the inlet. For an axisymmetric inlet, the centerbody is collapsed slightly and translated forward. The analysis of this unstart/restart process using NPARC required improvements to the capability to solve unsteady flows and implementation of a moving grid capability. The result of this development effort was version 3.1 of the NPARC code.

Approach

Improving the capability to solve for unsteady flows involved implementing a Newton iterative method into the implicit method of NPARC. This resulted in a nominally second-order time accurate method for the implicit time integration. Other modifications were performed to allow the specification of time parameters and control of the time step size.

The modifications for the moving grid capability assumed a moderate level of grid motion associated with the motion of segments of the boundary grid relative to the rest of the grid of the block. This motion may be a rigid-body translation and/or rotation about a point or a deformation of the segment according to a coded relation. The remainder of the grid of the block deforms to accommodate the boundary motion. This requires that some regions of the grid be regenerated at each time step. Efficiency in the grid regeneration process is obtained by limiting the regeneration to only those regions in which there is grid motion. Thus, the grid becomes a computed function of time. For three-dimensional flow domains, the grid is assumed to be "quasi-2d" or axisymmetric in which the grid consists of planar grids with respect to the "l"-coordinate.

The flow equations and boundary conditions were expressed in an absolute frame of reference with the grid motion accounted for through the grid velocities. The velocity of each grid point was calculated from a time difference of the grids at two consecutive time levels.

Results

Several test cases involving moving grids were developed and computed to demonstrate the application and accuracy of the moving grid capability. A few simple test cases involving supersonic flow over a stationary wedge, a flying wedge, and a rotating flap on a flat plate showed good comparison with steady-state oblique shock theory. A test case involving the collapse of an axisymmetric bump in an annular duct showed good comparison with unsteady experiment data. The unstart/restart operation of the NASA variable diameter centerbody (VDC) inlet, which involved the translation and collapse of the centerbody, was demonstrated to show qualitative agreement with experimentally observed behavior.