Sound Radiation from Curved Intake in Transonic Flow Field Using High-Order, High-Resolution Numerical Methods

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Abstract

Curved intakes (S-duct) in turbo fan/jet engines are commonly used for ranging from commercial aircraft to military missile. Sound radiation from the intake of air vehicle affects cabin noise, community noise and military detection. In this paper, numerical schemes for three-dimensional full nonlinear compressible Euler equations are developed to solve together the sound radiation from the curved intake and the flow at transonic speeds.

A high-order, high resolution scheme is used to capture the acoustic quantities because the acoustic energy is much smaller than the flow energy. Steady flow must be also solved using the high-order, high-resolution schemes to have at least 10^{-7} residual error because the initial acoustic disturbance is the order of 10^{-4}. An optimized pentadiagonal type of central compact finite difference scheme is used for the spatial differentiation and the fourth-order Runge-Kutta method is used for time integration. A generalized characteristic boundary conditions are used to prevent non-physical reflection of acoustic wave at the far-field boundary. The absorbing layer technique is adopted additionally to maintain the mean acoustic properties for the case of no flow in the medium. The Kirchhoff method is used for the really far-field case with the information on the Kirchhoff surface in the computation domain.

The grid generation around the curved intake is performed using conformal mappings and algebraic transformations. The numerical error for Jacobian and metrics becomes significant in the acoustics and flow calculations by using the high-order, high-resolution schemes especially in the terms related geometric conservation law (G.C.L.). The G.C.L. terms which are essential to make the conservative forms of the Euler equations, is generally not appeared explicitly in the equations because the exact value is zero. Here, the terms of G.C.L. is added to the right-hand-side of the Euler equations, instead of zero assumption.

The artificial dissipation model is very important for aeroacoustics computations for the shock in the flow and for the acoustics also. The adaptive nonlinear artificial dissipation (ANAD) model consisted of a 4^{th}-order selective background smoothing term for acoustics and a 2^{nd}-order well established terms for the shock, shows best results for the shock and the linear acoustic waves in two-dimensional computation. In axisymmetric and three-dimensional computation, the ANAD model cannot damp out spurious oscillation around the axis. The three-dimensional ANAD model is developed here by enhancing the background smoothing term.

Various validation problems are solved and the results show good agreements with analytic solution or other computational results. The flow-field of RAE 2129 intake with subsonic inflow is solved and compared with experimental and other computational results. The radiated acoustic field of JT15D engine inlet with subsonic inflow is also computed and compared.

The acoustic radiation from three-dimensional curved intake in transonic flow-field is solved. The acoustic field with transonic inflow is successfully computed by using present numerical schemes. Effects of curvature on the far-field acoustics are investigated for two-dimensional curved intake at transonic case. The whole amplitude in all direction are reduced by increasing the curvature both for low and high frequency range.

Keyword: *curved intake, computational aero-acoustics (CAA), duct acoustics, transonic flow*