Computation of High Reynolds Number Internal/External Flows

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Abstract

A GENERAL user-oriented computer program called VNAP2 has been developed to calculate high Reynolds number, internal/external flows. VNAP2 solves the two-dimensional, time-dependent Navier-Stokes equations. Turbulence is modeled with mixing-length and transport equation models. Interior grid points are computed using the explicit MacCormack scheme with special procedures to speed up the calculation in the fine grid. All boundary conditions are calculated using a reference plane characteristic scheme with the viscous terms treated as source terms. Presented here are six internal, external, and internal/external flow calculations.

Contents

The geometries for the types of flow calculations presented here are shown in Fig. 1, where the dashed lines represent the computational boundaries. For details of the VNAP2 code and these flow calculations, see Refs. 1 and 2, respectively.

The first case is planar nozzle B-3 in Ref. 19 of Ref. 2. The grid and Mach number contours are shown in Fig. 2, while the wall and midplane pressures are shown in Fig. 3. The Reynolds number based on the throat height is 7.7×10^5. At the specified pressure ratio the flow separated from the nozzle wall. This calculation used 45×21 grid points and 2.1 hours of CPU time (CDC-7600).

The second through fifth cases are flow about the axisymmetric boattail afterbodies in Refs. 20 and 22 of Ref. 2. Cases 2 (configuration 3) and 3 (configuration 1) have a solid simulator in place of the exhaust jet, while cases 4 (configuration 3) and 5 (configuration 1) include the exhaust jet. The grid for case 4 is shown in Fig. 4, while the grid for case 2 is that part of the case 4 grid above the body. Cases 3 and 5 employ similar grids. The surface pressure for cases 2 and 3 are shown in Figs. 5 and 6, respectively. The Reynolds number based on length is 1.05×10^7 while the freestream Mach number is 0.8. The flow remained attached in case 2 and separated in case 3. Cases 2 and 3, employing the mixing-length model, used 40×25 and 47×29 grids and required 1.0 and 2.1 h of CPU time, respectively.

Cases 4 and 5 shear layer total pressure profiles are shown in Figs. 7 and 8, respectively. Cases 4 and 5, employing the two-equation model, used 40×38 and 47×42 grids and required 5.6 and 9.0 hours of CPU time, respectively. The lengthy CPU times for these two cases are due to the large turbulent viscosity in the center of the shear layer, where the grid is very fine, severely limiting the time step. This problem is less severe near a wall where the turbulent viscosity is small.

The sixth case is NACA 1-89-100 inlet in Ref. 24 of Ref. 2. The grid and surface pressures are shown in Figs. 9 and 10,

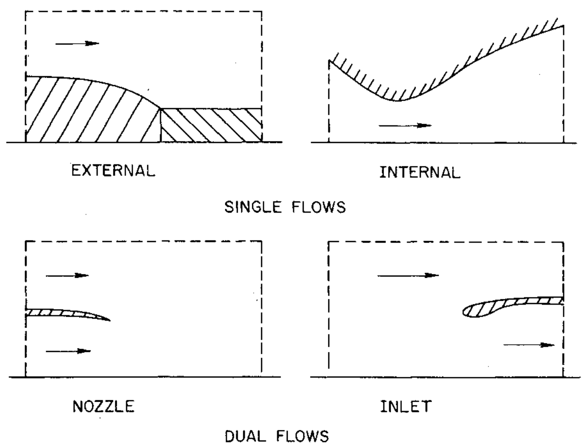

Fig. 1 Typical internal, external, and internal/external geometries.

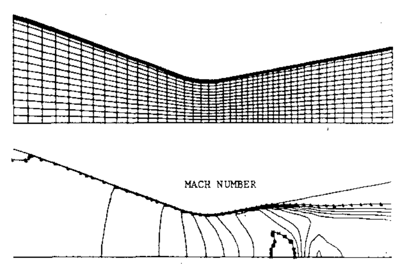

Fig. 2 Internal flow physical space grid and Mach number contours.

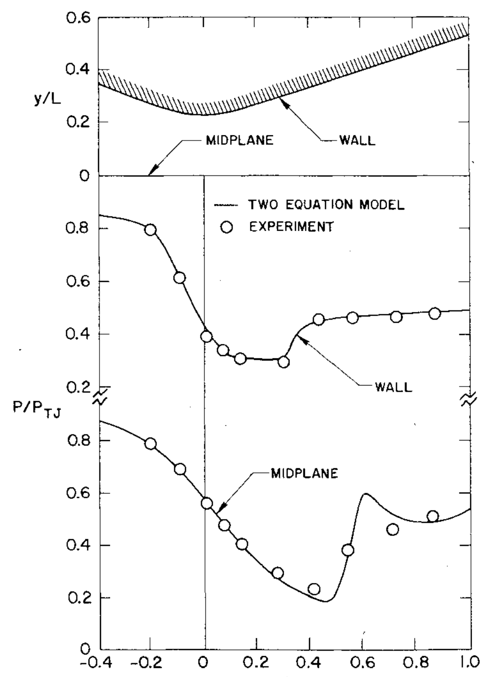

Fig. 3 Internal flow wall and midplane pressure ratio.

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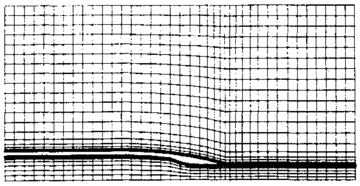

Fig. 4 Internal/external flow (configuration 3) physical space grid.

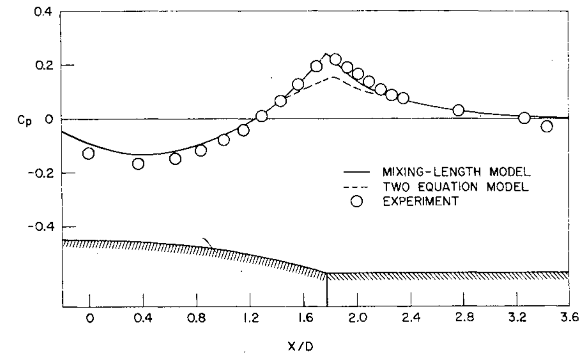

Fig. 5 External flow (configuration 3) surface pressure coefficient.

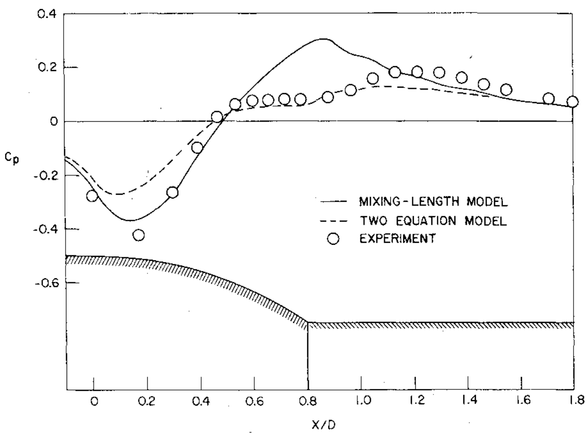

Fig. 6 External flow (configuration 1) surface pressure coefficient.

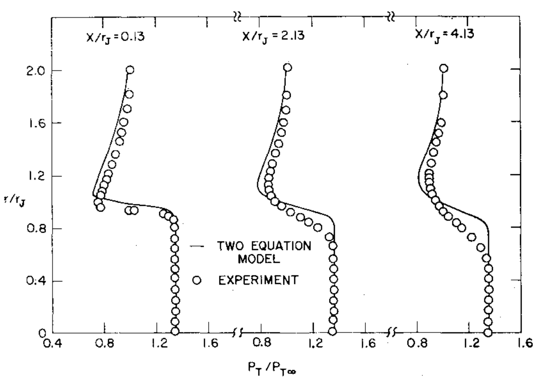

Fig. 7 Internal/external flow (configuration 3) total pressure ratio profiles in the shear layer.

respectively. The Reynolds number based on the maximum external diameter is 6.1×10^6, while the freestream Mach number is 0.8. This calculation used a 53×44 grid and required 1.0 hour of CPU time.

These computed results show that practical Navier-Stokes applications are possible; however, they also indicate the need for better turbulence modeling for separated flows and more

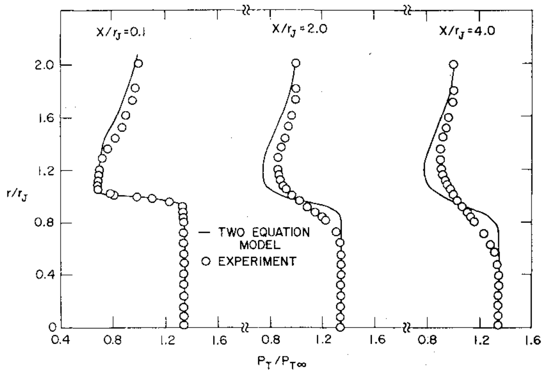

Fig. 8 Internal/external flow (configuration 1) total pressure ratio profiles in the shear layer.

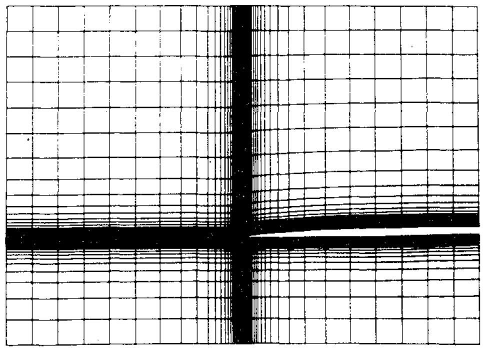

Fig. 9 Internal/external flow (inlet) physical space grid.

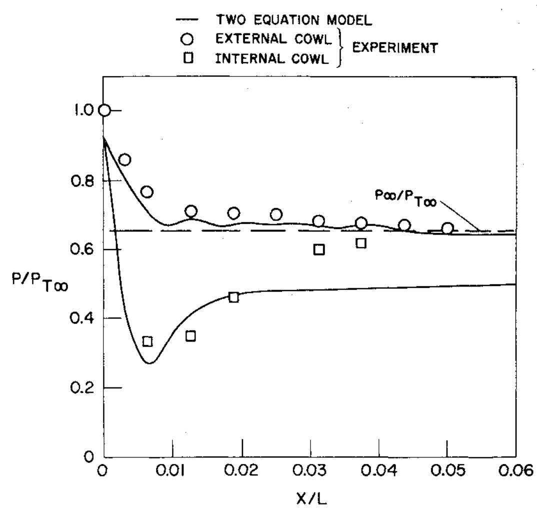

Fig. 10 Internal/external flow (inlet) surface pressure.

efficient solution algorithms for very nonuniform grid point distributions.

Acknowledgments

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References

[1]Cline, M.C., "VNAP2: A Computer Program for Computation of Two-Dimensional, Time-Dependent, Compressible, Turbulent Flow," Los Alamos National Laboratory Report LA-8872, Aug. 1981.

[2]Cline, M.C. and Wilmoth, R.G., AIAA Paper 81-1194, June 1981.