Technical Notes

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Transonic Airfoil Calculations Using Solution-Adaptive Grids

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Introduction

THE concept of rearranging grid points in a finite difference calculation so as to improve solution accuracy (i.e., local clustering as opposed to global grid refinement) is not by itself new. Many researchers have used various types of grid clustering to improve solution accuracy for many different applications. A common example is the normal-direction grid stretching, routinely used in boundary-layer calculations. The rate of stretching used in this situation may be related to the expected boundary-layer thickness (i.e., the Reynolds number) or other user input, but in general is not influenced by the particular solution. Therefore, in the present context, this type of clustering is not considered to be solution adaptive. A solution-adaptive grid (SAG) technique is defined to be a grid-generation technique in which the flowfield solution influences the grid-generation process.

The primary motivation for using the SAG approach can be viewed in either of two ways: 1) improved accuracy for a fixed number of grid points, or 2) improved computational efficiency for fixed accuracy, i.e., fewer grid points. Generally speaking, a SAG approach uses some aspect of the flowfield solution to recluster or redistribute grid points so as to reduce the solution truncation error. The present approach uses a simple SAG formulation. Although the positioning of the grid points in this procedure is not optimal, it is shown that significant improvements in solution accuracy can be obtained.

Solution-Adaptive Grid (SAG) Algorithm

The present SAG procedure can be summarized as follows. First, a preliminary solution is computed using a standard solution procedure. The GRAPE grid generation code[1] is used to generate the mesh and the TAIR conservative full-potential code[2] is used to compute the flowfield solution. Information from this solution is used to redistribute grid points on only the airfoil surface. Next, using the newly clustered surface distribution, a new interior mesh is numerically generated using the GRAPE code. After the SAG is generated the final flowfield is recomputed with a second application of the TAIR flow-solver code.

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In the present study no attempt to minimize the total amount of computational work has been made. Instead, the main emphasis is on determining the feasibility of using SAG to improve solution accuracy. The use of a grid-sequence procedure could be coupled with the present algorithm. This would reduce the computational work associated with a single SAG solution to about the same amount as that associated with a standard solution. For more detail regarding the present SAG algorithm, see Ref. 3.

The unique concept of redistributing points only on the airfoil surface greatly simplifies the idea of SAG calculations. It essentially reduces a two-dimensional SAG problem to one dimension and a three-dimensional SAG problem to two dimensions. This concept, even though quite simple, works remarkably well, primarily because the gradients generated around a transonic airfoil are generally maximum on the surface and decay exponentially in a radial-like direction away from the airfoil. Likewise, the amount of grid-point clustering used in the present SAG approach is maximum on the airfoil surface and decays exponentially into the mesh interior.

Computed Results

The SAG algorithm discussed in the previous section is evaluated in this section by presenting a range of numerically

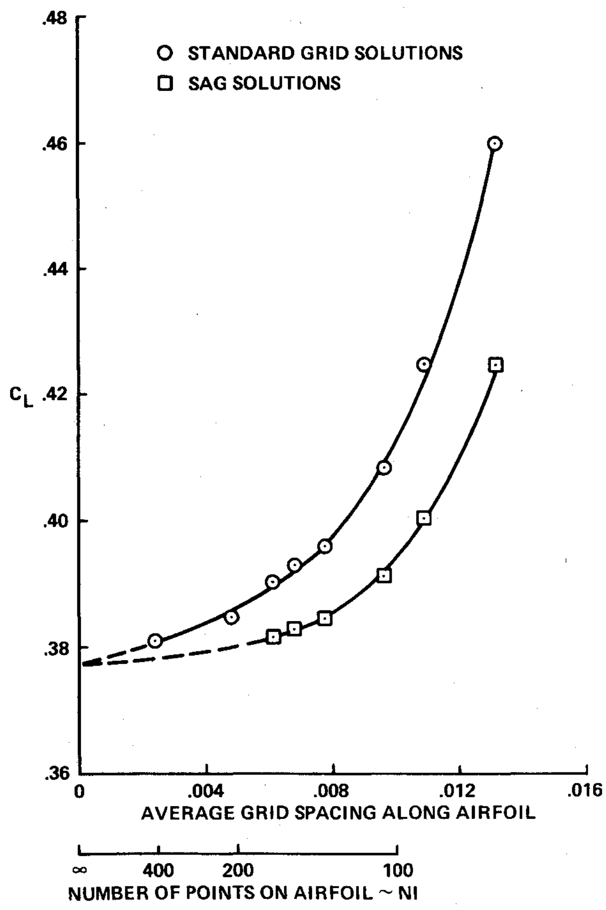

Fig. 1 Asymptotic behavior of the lift on a sequence of meshes (NACA 0012 airfoil, $M_\infty = 0.75$, $\alpha = 1.5$ deg).

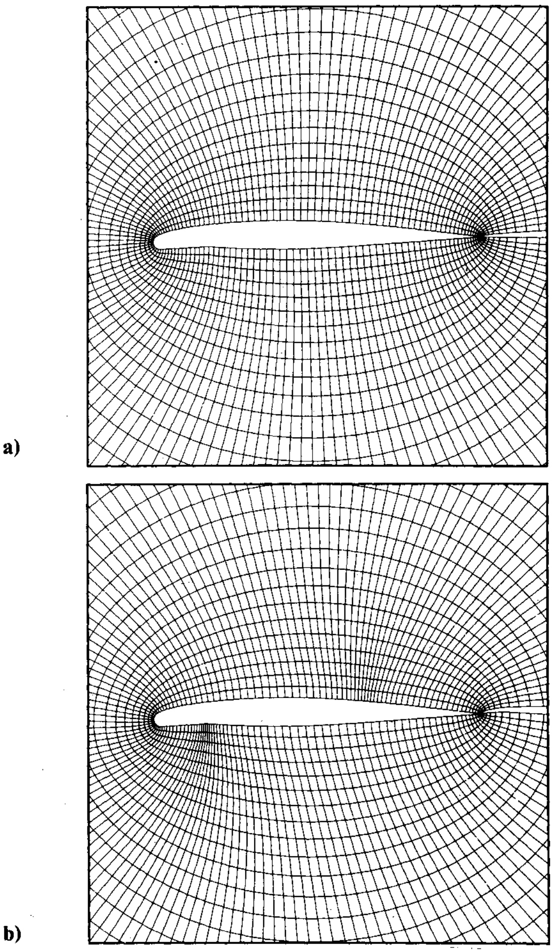

Fig. 2 Numerically generated finite difference mesh about an experimental Gates-Learjet airfoil (149 × 37): a) standard grid, b) solution-adapted grid.

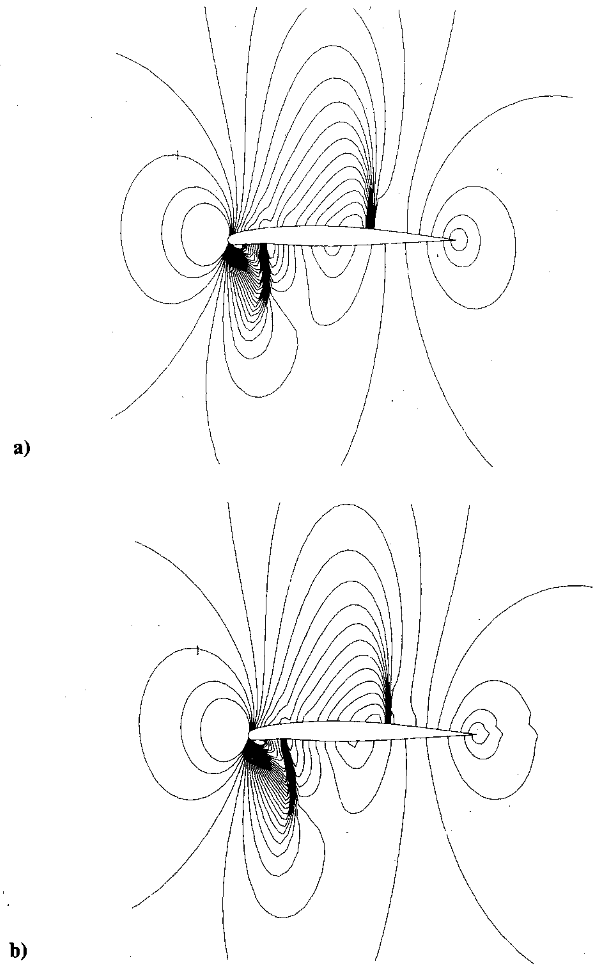

Fig. 3 Mach number contours about an experimental Gates-Learjet airfoil ($M_\infty = 0.80$, $\alpha = 0$ deg): a) standard grid solution, b) solution-adapted grid solution.

computed transonic airfoil solutions. A most important consideration for any type of finite difference calculation procedure is determining the accuracy of the solution, i.e., how well does the numerical solution approximate the governing differential equation? This question is most easily answered (for nonlinear equations) by computing a series of solutions on successively finer meshes and then noting the behavior of the solution. For consistency, an asymptotic solution should result, but the rate of approach to the asymptotic solution is also of interest.

Figure 1 shows the results of such a study as applied to an NACA 0012 airfoil at $M_\infty = 0.75$ and $\alpha = 1.5$ deg. The lift coefficient is plotted as a function of the average grid spacing, $\Delta = 1/NI$, where NI is the number of grid points around the airfoil. Results for both standard- and solution-adaptive grids are presented. For all calculations the ratio of the number of points around the airfoil to the number of points in the near-normal direction is approximately held fixed to 4.8.

Figure 1 shows that both the standard and SAG solution sequences approach the same asymptotic value of lift. The most interesting feature, however, is the difference in the rate of approach. The SAG curve is consistently under the standard curve and therefore produces a more accurate value of lift on a coarser mesh. These curves indicate that a SAG solution produces lift accuracy equivalent to a standard grid with two or three times as many grid points. In other words, the SAG solutions have 40-65% less error in the lift than the standard grid solutions containing the same number of grid points.

The final case presented is for an experimental airfoil from Gates-Learjet at $M_\infty = 0.8$ and $\alpha = 0$ deg. Both standard and solution-adaptive grids involving 149 × 37 points are shown in Fig. 2. Mach number contours about the airfoil for both standard and SAG solutions are shown in Fig. 3. These contour maps were plotted for a Mach number range of 0.7-1.72 in increments of 0.03. For this solution three cluster points exist, the leading edge and both the lower and upper surface shocks. Notice how the solution-adaptive grid of Fig. 2b precisely adapts to the solution given in Fig. 3. Direct comparison of the two Mach number contour maps shown in Fig. 3 shows several interesting differences. First, the width of both shock waves is much smaller for the SAG solution than for the standard solution. This indicates a superior, sharper shock capture as a result of the automatic clustering process. In addition, the lower surface leading-edge expansion which is followed almost immediately by the lower surface shock wave produces a large suction pressure covering only the first 15% of chord. The sonic line produced by this sharp leading-edge expansion/shock interaction extends 30% further into the solution interior for the SAG solution than for the standard solution. This is the correct trend as supported by fine-mesh standard grid calculations. The more extensive development of this region for the SAG solution is due to the grid clustering around both the leading-edge expansion and the shock wave. This example shows that even when multiple cluster points are involved, significant solution improvements can be obtained using the present SAG approach.

Conclusions

A new algorithm for generating solution-adaptive grids about airfoil configurations embedded in transonic flow is presented. The present SAG approach uses only the airfoil surface solution to recluster grid points on the airfoil surface. Therefore, the reclustering problem is one dimension smaller than the flowfield calculation problem.

Computed results on solution-adaptive grids indicate significant reductions in the error relative to standard grids using the same number of grid points. Results computed on mesh sequences indicate that both standard grid and SAG calculations approach the same asymptotic values of lift. However, the rate of approach of the SAG sequence is much faster than that of the standard grid sequence.

References

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[2] Dougherty, F. C., Holst, T. L., Gundy, K. L., and Thomas, S. D., "TAIR—A Transonic Airfoil Analysis Computer Code," NASA TM-81296, May 1981.

[3] Holst, T. L. and Brown, D., "Transonic Airfoil Calculations Using Solution-Adaptive Grids," *Proceedings of the AIAA 5th Computational Fluid Dynamics Conference,* Palo Alto, Calif., June 1981, pp. 136-148.

Effect of Pulsed Slot Suction on a Turbulent Boundary Layer

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Introduction

As it is now established that turbulence energy production in a boundary layer occurs intermittently in bursts,[1] it would seem logical that turbulence control also need only be intermittent. One may visualize an "ideal" system of boundary-layer control in which the controlling agent operates at just those places and times where a burst is beginning to occur; of course, this would need suitable detectors distributed over the surface on which the flow is to be controlled. As a first step toward this goal, it seemed interesting to find out the response of the boundary layer to pulsed control[2] without any conditioned selection of "favorable" times and locations at which control is to be applied. If control is applied at a point, its effect will be felt over a certain characteristic area. Precise information over the magnitude of this area is not available, but it is clear that the chances of obtaining a beneficial effect due to pulsing are higher if the control is applied at various points rather than over a line, and over a line rather than an area, because of the smaller smearing effect. To enable comparison with available data,[3] this first series of experiments was confined to control along a line, in the form of suction through a flush transverse slot on a flat plate turbulent boundary layer. Although slot suction has certain definite advantages over distributed suction,[3] it has not attracted the detailed study that it deserves. Measurements of mean velocity profiles, longitudinal turbulence intensities, and skin friction coefficients at a single downstream station are reported here for various values of suction rate and frequency of pulsation. The present study supplements investigations of periodic blowing[4] and pressure gradients[5] on boundary layers, and of periodic excitation in shear layers.[6,7]

Experiments

The experiments (of which more details are available in Ref. 8) were conducted in a low-speed open circuit wind tunnel with a 0.3×0.3-m test section; Fig. 1 shows the setup. The test surface was the top wall of the wind tunnel; transition on the surface was fixed by two 30-mm wide strips of coarse sandpaper. A rotameter capable of measuring up to 5 liter/s indicated the suction flow rate through the slot. The suction chamber housed a motor and crank-driven sliding valve which enabled suction at frequencies up to 72 Hz. Mean velocity measurements in the boundary layer were made using a flattened total head probe (size 0.56×2.2 mm). A constant temperature hot-wire anemometer was used to measure longitudinal turbulence intensities ($\hat{u}$) in the boundary layer. The hot wire used was 5-μm-diam, platinum-rhodium Wollaston process wire of length 1-2 mm.

A flush mounted hot-film gage, with a thin platinum film deposited at the center of a 6 mm pyrex rod, was used to measure skin friction. The film was heated to a constant temperature using a setup similar to the one for hot-wire measurements. The steady-state calibration for the gage followed the well-known cube-root law,[9] the constants in the law being determined by calibration in the same wind tunnel against skin friction obtained from the Clauser plot at various tunnel speeds.[8]

All measurements were made 60 mm (about 2½ boundary-layer heights) downstream of the slot, as preliminary runs

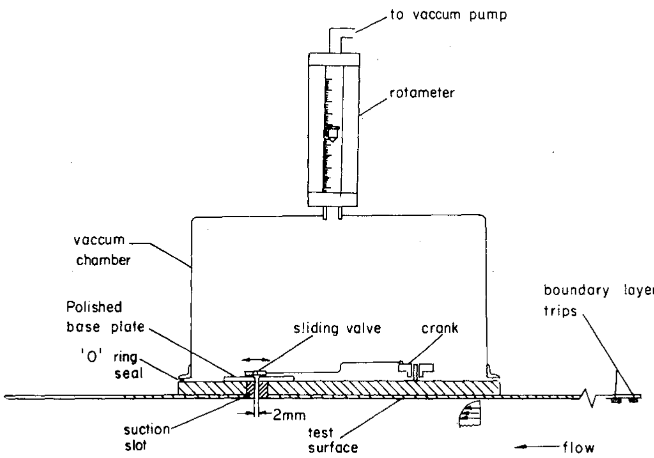

Fig. 1 A schematic sketch of the experimental setup.

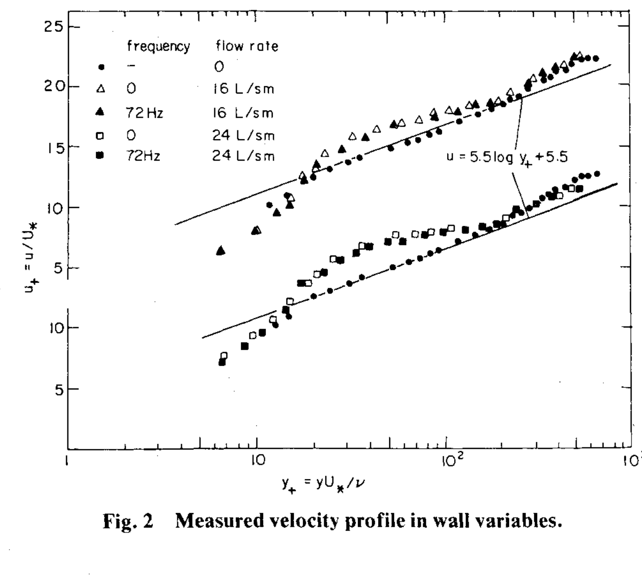

Fig. 2 Measured velocity profile in wall variables.

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