[4]Goldberg, U. C., and Chakravarthy, S. R., "Separated Flow Predictions Using a Hybrid k-L/Backflow Model," *AIAA Journal*, Vol. 28, No. 6, 1990, pp. 1005–1009.

[5]Chakravarthy, S. R., Szema, K.-Y., and Haney, J. W., "Unified 'Nose-to-Tail' Computational Method for Hypersonic Vehicle Applications," AIAA Paper 88-2564, June 1988.

[6]Bachalo, W. D., and Johnson, D. A., "An Investigation of Transonic Turbulent Boundary Layer Separation Generated on an Axisymmetric Flow Model," AIAA Paper 79-1979.

[7]Kussoy, M. I., and Horstman, C. C., "Documentation of Two- and Three-Dimensional Hypersonic Shock Wave/Turbulent Boundary Layer Interaction Flows," NASA TM 101075, Jan. 1989.

[8]Coleman, G. T., and Stollery, J. L., "Heat Transfer in Hypersonic Turbulent Separated Flow," Dept. of Aeronautics, Imperial College of Science and Technology, London, Rept. 72-05, March 1972.

Simple Algebraic Technique for Nearly Orthogonal Grid Generation

S. Saha* and B. C. Basu†
Indian Institute of Technology, Kharagpur, India

I. Introduction

GRID generation is a very important aspect of solving computational fluid dynamics (CFD) problems where a set of partial differential equations has to be solved in a given domain. It is desirable for the grid to have good orthogonality properties, and the grid generator should be able to produce an arbitrary amount of clustering near the body surface when necessary. Generation of body-fitted coordinates meeting these requirements using algebraic techniques are described by Eiseman[1] and Smith.[2] It is well known that the most efficient way of dividing the domain for external flow problems is by generating an O-type grid for a two-dimensional case or an O-O topology grid for a three-dimensional case, since they give the maximum resolution near the body surface with the minimum number of grid points. A simple algebraic technique has been developed for generating an O-type grid or an O-O topology grid for a geometry with sharp edges having a high grid density near the body surface while maintaining orthogonality. The present method generates the grid by distributing spacings in the outward normal direction from a closed contour as a function of the rate of change of arc length in that direction. This procedure, when applied to subsequently generated contours, evolves a nearly orthogonal grid with a circular outer boundary. A similar procedure applied to a closed three-dimensional surface produces a spherical outer boundary, thereby generating an O-O topology grid.

II. Method

In this method, at every point on the body surface and subsequently generated constant j contours (i and j represent the wraparound and outer boundary directions, respectively), the rate of change of i-direction arc length $s(i)$ in the outward normal direction ($ds(i)/dn$, n being the outward normal vector) is computed. The value of $ds(i)/dn$ for a panel of length $s1$ is given by $(s2-s1)/d$ where $s2$ is the distance between the points obtained by moving a small distance d along the normals at the panel endpoints. The value of $ds(i)/dn$ at a node is taken as the average of $ds(i)/dn$ at neighboring panels. The distribution of maximum physical spacing between the constant j contours [i.e., $S\max(j)$] is prescribed. Now the spacings $S(i)$ in the normal direction are distributed such that where $ds(i)/dn$ is small, the spacing is large and vice versa, the maximum spacing being $S\max(j)$ for the particular constant j contour. The $j+1$ contour obtained by this procedure has a smoother variation of curvature or $ds(i)/dn$, and as j increases, the curvature tends to become equal everywhere. Thus, starting from an arbitrary body surface geometry, the outer boundary evolves as a circle and an O-type grid is generated.

Near the body surface, where there is a large difference between maximum and minimum values of $ds(i)/dn$, the ratio between minimum spacing $S\min/S\max$ [i.e., $S\max = S\max(j)$] is kept small (0.1, say) to smooth the variation of $ds(i)/dn$ rapidly. As j increases, the variation of $ds(i)/dn$ decreases, and $S\min/S\max$ is gradually increased to the value of unity at the outer boundary. In the present work, an exponential distribution has been considered, i.e.,

$$S\min/S\max = f\min + (1 - f\min)\times \exp[sr\min - sr\max)c0]$$

where $f\min$ is the smallest value of $S\min/S\max$ for a particular grid, $sr\min$ and $sr\max$ are the minimum and maximum values of $ds(i)/dn$ for the particular j contour, and $c0$ is a constant.

The choice of distribution function for determination of the actual spacings $S(i)$ on a particular constant j line is not unique. The one used in the present case is an exponential distribution chosen to vary the spacings rapidly near small or negative values of $ds(i)/dn$, and this helps in avoiding cross over of adjacent lines by reducing the concavity of the surface very quickly. The distribution function is given by

$$S(i) = S\min + (S\max - S\min)\times \exp[c1(sr\min - ds(i)/dn)]$$

where $S\min$ and $S\max$ refer to the maximum and minimum spacings for a particular constant j contour, $sr\min$ is the minimum value of $ds(i)/dn$ for that contour, and $c1$ is a constant.

When the variation in $ds(i)/dn$ is not very smooth, or j-direction spacings $S(i)$ are quite large compared to $s(i)$, waviness may be generated that gets amplified as j increases. To suppress this, a few smoothing sweeps are added before the final distribution of spacings is used to obtain the contour at $j+1$. The smoothing is done selectively at the points where this waviness is generated by adding a fraction (5–10%) of the second difference of $S(i)$ in the i direction. The selective smoothing is performed by excluding those points from the smoothing operation at which the newly generated contour at $j+1$ obtained with the trial spacing distribution is smoother than the previous contour, i.e., when $ds(i)/dn$ at both j and $j+1$ are positive and $[ds(i)/dn]_{j+1} < [ds(i)/dn]_j$, or when $ds(i)/dn$ at both j and $j+1$ are negative and $[ds(i)/dn]_{j+1} > [ds(i)/dn]_j$. Usually about four to six smoothing sweeps are sufficient.

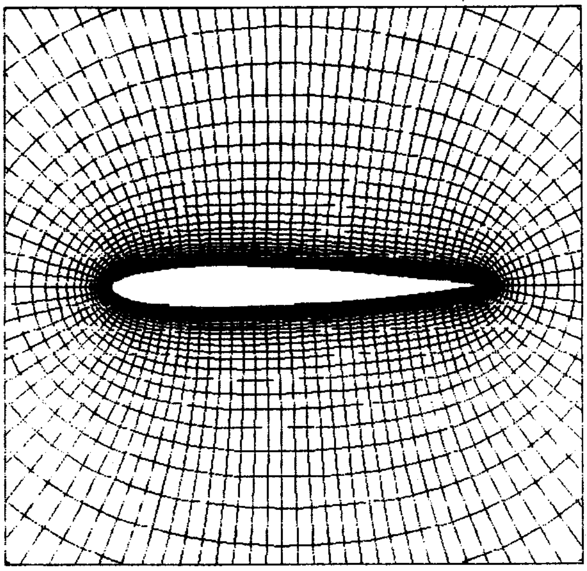
The generation procedure in three dimensions is identical with the rate of change of surface area considered instead of arc length for determination of the spacings in the normal direction. For smoothing in three dimensions, the second difference is replaced by the sum of the differences in spacings of the four neighboring points with the point in question.

For calculation of direction cosines of grid lines in the radial direction at an edge of a flat plate (with zero thickness), a thickness is temporarily added at all points except those on the edge. The average of the normals on the neighboring points on the upper and lower surfaces is now taken as the direction cosine at a point on the edge after subtracting the component along the edge. The direction cosine at a corner is obtained by taking the average of the direction cosines at neighboring points on the edges meeting at the corner.

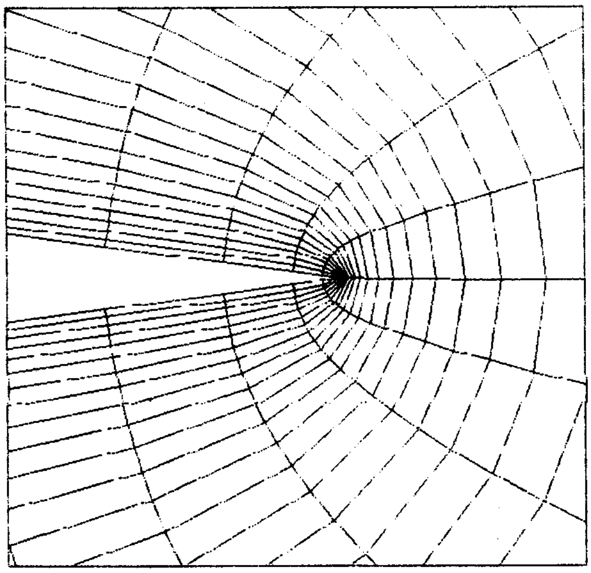
No iterations are required in the present method except for the smoothing sweeps. Other noniterative methods for grid generation, such as solution of hyperbolic partial differential equations, are equally efficient. However, with the latter approach, the slope discontinuities on the body surface are likely to be propagated into the interior grid.[3]

Received Jan. 22, 1990; revision received July 24, 1990; accepted for publication Aug. 13, 1990.

*Junior Scientific Officer, Aerospace Engineering Department.
†Professor, Aerospace Engineering Department.

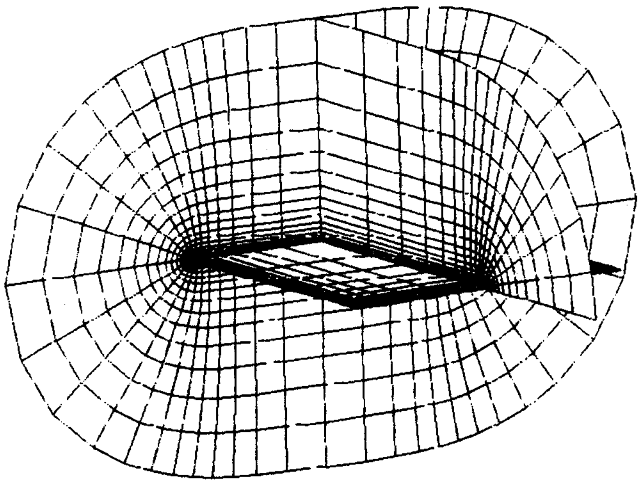


a)

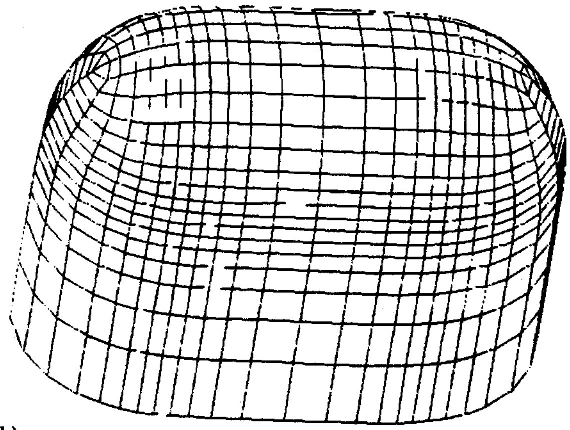


b)

Fig. 1 Grid about NACA0012 aerofoil: a) closeup near aerofoil, b) closeup near trailing edge.



a)



b)

Fig. 2 Three-dimensional grid about a flat plate wing: a) view showing one surface from each family, b) enveloping surface at $j=15$.

III. Results

In the examples of grids generated using this technique, the spacing distribution in the j direction is prescribed such that $S\max(j+1)=S\max(j)\times c$, where c is a constant for the particular grid. Figure 1 shows a highly refined grid (in the j direction) about the NACA0012 aerofoil (101×49) with $S\max(1) = 0.0006$ and $c = 1.2$. To maintain orthogonality, the spacings $s(i)$ in the trailing-edge region increase much more rapidly with increasing j compared to other points on the surface. This would cause the grid to be very sparse in the circumferential direction along the $i=\text{const}$ line from the trailing edge. To remove this drawback, more data points need be prescribed near the trailing edge. This is desirable since the flow gradients also become quite large near the trailing-edge region.

An example of a three-dimensional grid is shown in Fig. 2 for a flat plate wing with 48 wraparound and 16 spanwise divisions (on one half of the wing). Figure 2a shows a composite view with one from each of the three families of surfaces (i.e., the wing surface and the chordwise and spanwise symmetry planes). Figure 2b shows the enveloping surface at $j=15$, j being the radial direction. The surface is smooth everywhere, including those points where the flat plate corners are being mapped. The spacing distribution in the radial direction is similar to that in two dimensions with $S\max(1)=0.006$ and $c=1.24$. Data points on the wing surface have been concentrated near the edges to avoid grid spacings becoming excessively large on the enveloping surfaces near the sharp edges.

IV. Conclusion

A method has been developed for generating an O-type grid about aerofoils and an O-O topology grid about wings incorporating an arbitrary amount of clustering near the body surface. The grid has good orthogonality properties, and the generation procedure takes very little computer time since no iterations are needed.

References

[1]Eiseman, R. P., "Automatic Algebraic Coordinate Generation," *Numerical Grid Generation*, edited by J. F. Thompson, North-Holland, Elsevier, New York, 1982, pp. 447–463.

[2]Smith, R. E., "Algebraic Grid Generation," *Numerical Grid Generation*, edited by J. F. Thompson, North-Holland, Elsevier, New York, 1982, pp. 137–170.

[3]Thompson, J. F., Warsi, Z. U., and Mastin, C. W., "Boundary-Fitted Coordinate Systems for Numerical Solution of Partial Differential Equations—A Review," *Journal of Computational Physics*, Vol. 47, No. 1, 1982, pp. 1–108.