A SURVEY OF COMPOSITE GRID GENERATION FOR GENERAL THREE-DIMENSIONAL REGIONS

Joe F. Thompson
Department of Aerospace Engineering
Mississippi State University
Mississippi State, MS

The generation and use of composite grids for general three-dimensional physical boundary configurations is discussed, and the availability of several codes or procedures is noted. With the composite framework, the physical region is segmented into sub-regions, each bounded by six curved sides, and a grid is generated in each sub-region. These grids may be joined at the interfaces between the sub-regions with various degrees of continuity. This structure allows codes to be constructed to operate on rectangular blocks in computational space, so that existing solution procedures can be readily incorporated in the construction of codes for general configurations.

Numerical grid generation has become an integral part of the numerical solution of partial differential equations and is one of the pacing items in the development of codes for general configurations. The numerically generated grid frees the computational simulation from restriction to certain boundary shapes and allows general codes to be written in which the boundary shape is specified simply by input. The boundaries may also be in motion, either as specified externally or in response to gradients in the developing physical solution. In any case, the numerically generated grid allows all computation to be done on a fixed square grid in the computational space, which is always rectangular by construction. Boundary conditions can be represented entirely by differences along grid lines without need of interpolation, and hence finite difference methods are readily applicable to general regions. These grids can also serve in finite-element formulations based on quadrilaterals (hexahedrons in 3D), and finite volume constructions can be represented as conservative finite difference forms.

Considerable progress is being made toward the development of the techniques of numerical grid generation and toward casting them in forms that can be readily applied. A comprehensive survey of numerical grid generation procedures and applications thereof through 1981 is given in reference 1, and the conference proceeding published as reference 2 contains a number of expository papers on the area, as well as current results. Other collections of papers on the area have also appeared (refs. 3 and 4), and a later review through 1983 has been given in reference 5. Some other earlier surveys are noted in reference 1. A recent survey by Eiseman is given in reference 6. Surveys particularly on three-dimensional grid generation (refs. 7 and 8) and on adaptive grids (refs. 9 and 10) have also been given. A general text on numerical grid generation and its applications has now appeared (ref. 11).

Since one of the curvilinear coordinates is constant on each segment of the physical boundary, the transformed (computational) field is rectangular with a uniform square grid by construction. The grid is generated from specified grid point distributions and/or grid line intersection angles on the boundaries. The computational region may be an empty rectangular block with all the physical boundary segments corresponding to portions of the sides thereof, or some of these segments may correspond to slits or slabs in the interior of the computational block. Although in principle it is possible to establish a correspondence between any physical region and a single empty rectangular block, for general three-dimensional configurations the resulting grid is likely to be much too skewed and irregular to be usable when the boundary geometry is complicated.

A better approach with complicated physical boundaries is to segment the physical region into contiguous sub-regions, each bounded by six curved sides (four in 2D), and each of which transforms to a rectangular block in the computational region, with a grid generated within each sub-region. Each sub-region has its own curvilinear coordinate system, irrespective of that in the adjacent sub-regions. This then allows both the grid generation and numerical solutions on the grid to be constructed to operate in a rectangular computational region, regardless of the shape or complexity of the full physical region. The full region is treated by performing the solution operation in all of the rectangular computational blocks. With the composite framework, partial differential equation numerical solution procedures written to operate on rectangular regions can be incorporated into a code for general configurations in a straightforward manner, since the code only needs to treat a rectangular block. The entire physical field then can be treated in a loop over all the blocks.

The generally curved surfaces bounding the sub-regions in the physical region form internal interfaces across which information must be transferred, i.e., from the sides of one rectangular computational block to those of another. These interfaces occur in pairs, an interface on one block being paired with another on the same or a different block, since both correspond to the same physical surface. The locations of the interfaces between the sub-regions in the physical region are, of course, arbitrary since these interfaces are not actual boundaries. These interfaces might be fixed, i.e., the location completely specified just as in the case of actual boundaries, or might be left to be located by the grid generation procedure. Also, the grid lines in adjacent sub-regions might be made to meet at the interface between with complete continuity, with continuous line slope only, with discontinuous slope, or perhaps not to meet at all. Naturally, progressively more special treatment at the interface will be required in numerical solutions as more degrees of grid line continuity at the interface are lost. Procedures for generating composite grids with these various degrees of continuity at the interfaces are discussed in general in references 1, 2, and 11.

Three-dimensional grid codes should hopefully become suitable for general use in the near future. Further development is now needed in automation of the field segmentation decisions (work on an artificial intelligence approach to this is in progress) and refinement of the geometric procedures for construction of the physical boundaries. The incorporation of dynamically adaptive grids in the composite framework is only just emerging and should prove to be of considerable importance to general flow solutions.

REFERENCES

1. Thompson, Joe F.; Warsi, Z. U. A. and Mastin, C. W., "Boundary-Fitted Coordinate Systems for Numerical Solution of Partial Differential Equations - A Review", Journal of Computational Physics, 47, 1, 1982.

2. Thompson, Joe F. (Ed.), Numerical Grid Generation, North-Holland 1982. (Also published as Vol. 10 and 11 of Applied Mathematics and Computation, 1982).

3. Smith, Robert E., (Ed.), Numerical Grid Generation Techniques, NASA Conference Publication 2166, NASA Langley Research Center, 1980.

4. Ghia, K. N. and Ghia, U.,(Ed.), Advances in Grid Generation, FED-Vol. 5, ASME Applied Mechanics, Bioengineering, and Fluids Engineering Conference, Houston, 1983.

5. Thompson, Joe F., "Grid Generation Techniques in Computational Fluid Dynamics", AIAA Journal, 22, 1505, 1984.

6. Eiseman, Peter R. "Grid Generation for Fluid Mechanics Computations", Annual Review of Fluid Mechanics, 17, 1985.

7. Thompson, J. F. and Warsi, Z. U. A., "Three-Dimensional Grid Generation from Elliptic Systems", AIAA-83-1905, AIAA 6th Computational Fluid Dynamics Conference, Danvers, Mass., 1983.

8. Smith, R. E., "Three-Dimensional Algebraic Grid Generation", AIAA Paper 83-1904, AIAA 6th Computational Fluid Dynamics Conference, Danvers, Mass., 1983.

9. Thompson, Joe F., "A Survey of Dynamically-Adaptive Grids in the Numerical Solution of Partial Differential Equations", Applied Numerical Mathematics, 1, 3, 1985.

10. Anderson, D. A., "Adaptive Mesh Schemes Based on Grid Speeds", AIAA Paper 83-1981, AIAA 6th Computational Fluid Dynamics Conference, Danvers, Mass., 1983.

11. Thompson; Joe F.; Warsi, Z. U. A. and Mastin, C. Wayne, Numerical Grid Generation: Foundations and Applications, North-Holland, 1985.