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Theoretical Investigations of High Lift Aerodynamics

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Summary

Significant progress has been made in two areas. A program is operational to generate a coordinate system for a two-element airfoil with the mesh points concentrated in areas of significant vorticity, i.e., boundary layer and wake. The development of the method was more difficult than anticipated. The "imbedded" grid method developed allows a transition from the scale of the main airfoil to the scale of the flap. This requirement is essential for the modeling of viscous flows over the flap and slat of a multi-element airfoil. Attached to the report is a proposal for additional computer time over the current request to explore the fine grid generation problem.

Progress has also been made in the formulation of the airfoil mounted in a 2-D windtunnel. A Ph.D. thesis has been completed and the program is ready for a fine grid and a large number of planes to explore the characterisitics of a Navier-Stokes solver in a quasi-3D case. The program was converted to a form suitable for the STAR computer. Runs will be made to map a 3 dimensional flow field for a wall-airfoil intersection with and without lift.

Phase I. Mesh Generation for Multi-element Airfoil

The present work deals with the generation of boundary-fitted coordinate systems for a multi-element airfoil by extending the procedure developed by Thompson, et. al. (Ref. 1). Figures 1 and 2 show a physical plane and the corresponding transformed plane in case of two-element airfoil. However for the convenience of extending the method to an airfoil having more than two elements, an alternative arrangement of transformed plane that corresponds to exactly the same coordinate system in the physical plane is used. These are shown in Figures 3 and 4.

Now the main objective of the further work is to obtain the control functions, i.e., the nonhomogeneous terms of the Poisson's equations, so as to get the desired distribution of grid lines in the field. At present, two methods are being investigated for obtaining these control functions.

The first scheme is based on Sorenson's method (Ref. 2 and 3). In this method, the entire region is divided into three zones (in the case of two-element airfoil). Then the Grape code is used to generate grids for each of the zones. In the Grape code, the specification of spacing of the first grid line with respect to boundary, and of angles at which ξ lines intersect the boundary, are used to obtain the control functions p,q,r and s at the top and bottom η lines. Thereafter these functions are interpolated to obtain the values in the field

$$P(\xi,\eta) = p(\xi)\ e^{-a(\eta-1)} + r(\xi)\ e^{-c(\eta_{max} - \eta)}$$

$$Q(\xi,\eta) = q(\xi)\ e^{-b(\eta-1)} + s(\xi)\ e^{-d(\eta_{max} - \eta)}$$

Here a, b, c and d are constants. The continuity across the zonal boundary is achieved through these control functions. For example, along

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a zonal boundary separating two particular zones, it is required that the lines, which intersect that boundary do so at the same angles with respect to boundary (orthogonally in the present case), and with the same spacing in the direction normal to the boundary. Also, the zonal boundary is obtained as a part of the solution, so as to maintain the continuity of higher derivatives.

The second scheme is similar to the first one as far as continuity across the zonal boundary is concerned. However the control functions in the field are obtained by interpolating the control functions calculated at all the four boundaries of a zone. The point distribution and the spacing of first grid line with respect to boundary are specified at all the boundaries. Thus on the top and bottom η lines, r_ξ is specified and, therefore $\underset{\sim}{r}_{\xi\xi}$ can be calculated. Using the orthogonality condition at the boundary and the spacing $t(\xi)$, x_η and y_η can be calculated as

$$x_\eta = -\frac{y_\xi t(\xi)}{|\underset{\sim}{r}_\xi|}$$

$$y_\eta = \frac{x_\xi t(\xi)}{|\underset{\sim}{r}_\xi|}$$

Thereafter the control functions, P and Q, at the top and bottom η lines are obtained as

$$P = -\frac{\underset{\sim}{r}_\xi \cdot \underset{\sim}{r}_{\xi\xi}}{|\underset{\sim}{r}_\xi|^2}$$

$$Q = -\frac{\underset{\sim}{r}_\eta \cdot \underset{\sim}{r}_{\xi\xi}}{|\underset{\sim}{r}_\xi|^2}$$

Similarly, on the left and right ξ lines, $\underset{\sim}{r}_\eta$ is specified and therefore $\underset{\sim}{r}_{\eta\eta}$ can be calculated. Again using the orthogonality condition and the spacing $t(\eta)$, x_ξ and y_ξ can be written as

$$x_\xi = \frac{y_\eta t(\eta)}{|\underset{\sim}{r}_\eta|}$$

$$y_\xi = - \frac{x_\eta t(\eta)}{|\underset{\sim}{r}_\eta|}$$

and the control functions, P and Q, are obtained using

$$P = - \frac{\underset{\sim}{r}_\xi \cdot \underset{\sim}{r}_{\eta\eta}}{|\underset{\sim}{r}_\eta|^2}$$

$$Q = - \frac{\underset{\sim}{r}_\eta \cdot \underset{\sim}{r}_{\eta\eta}}{|r_\eta|^2}$$

In the field, both P and Q can be interpolated as

$$F(\xi, \eta) = \frac{(I - \xi)}{(I - 1)} F(1, \eta) + \frac{(\xi - 1)}{(I - 1)} F(I, \eta) + \frac{(J - \eta)}{(J - 1)} F(\xi, 1) + \frac{(\eta - 1)}{(J - 1)} F(\xi, J)$$

where $1 \leq \xi \leq I$ and $1 \leq \eta \leq J$.

Thus a computer program for generating the grids about a multi-element airfoil has been developed. At present, two methods for obtaining the control functions, so as to get the desired distribution of grid lines in the field, are being investigated.

Phase II. Numerical Solution of the Time-Dependent, Incompressible 3-D Navier-Stokes Equations

Since the last reporting period, the formulation has been completed and run on the CYBER machines. Anutosh Moitra completed his Ph.D. thesis at this time. He made the conversion of the code to the STAR computer to allow execution of a fine mesh and multiple planes to make a meaningful simulation of the flow at large Reynolds numbers. This transition modification is now complete and the long runs will be executed soon. The initial runs will be at zero lift. Then the airfoil was placed at an angle of attack to develop flows of interest at the airfoil-wall interface. Finally an aifoil with a plain flap deflected to a large angle will be run to explore separation phenomena. The grid mesh will be modified to concentrate the mesh points in the wake regions.

References:

1. Thompson, J. F.; Thames, F. C. and Mastin, C. W., "Automatic Numerical Generation of Body-Fitted Curvilinear Coordinate Systems for Fields Containing Any Numeber of Artibtrary Bodies," Journal of Computational Physics, Vol. 15, 2gg, (1974).

2. Sorenson, R. L., "A Computer Program to Generate 2-D Grids About Airfoils and Other Shapes by the Use of Poisson's Equations," NASA TM 81198, May 1980.

3. Sorenson, R. L. "Grid Generation By Elliptic Partial Differential Equations for TH-Element 'Augmentor-Wing' Airfoil"..

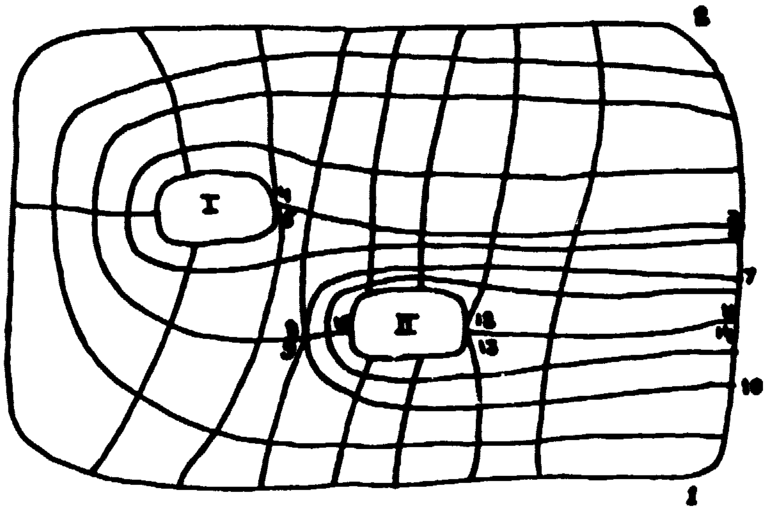

Figure 1. Physical Plane

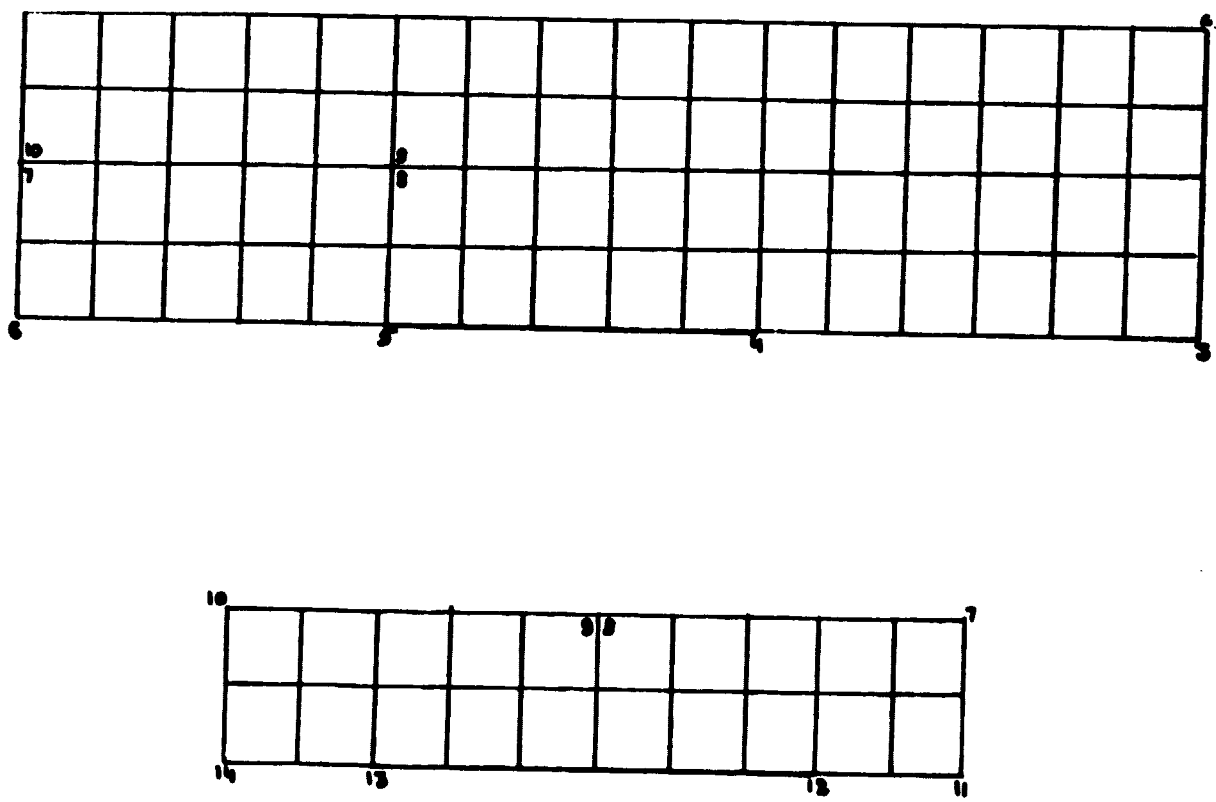

Figure 2. Transformed Plane.

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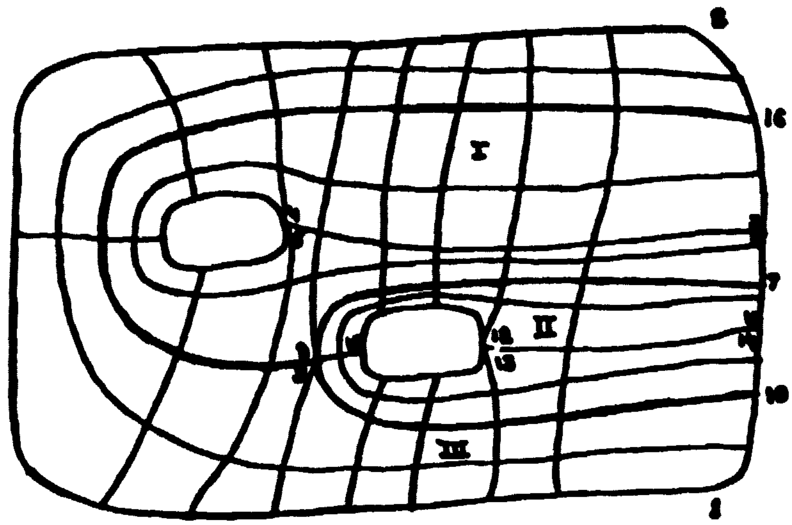

Figure 3. Physical Plane.

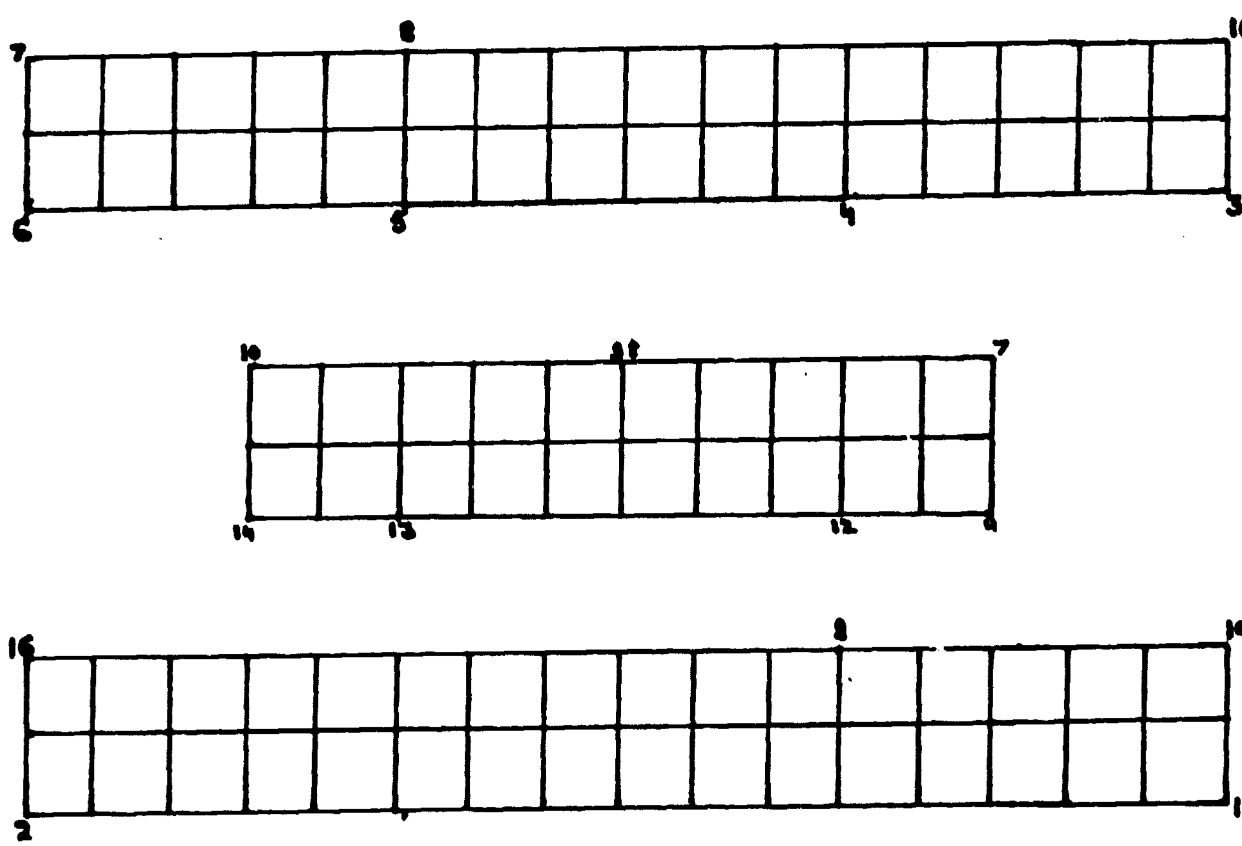

Figure 4. Transformed Plane.