NASA Contractor Report 172584

User's Manual For
Coordinate Generation Code
"CRDSRA"

Stephen J. Shamroth
Scientific Research Associates, Inc.
Glastonbury, CT 06033

JUNE 1985

NASA

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665

Problem Definition

Program COORD has been developed to generate a 'C'-type, two-dimensional coordinate system for isolated airfoil calculations. It is to be used in conjunction with a Navier-Stokes or Euler analysis. The coordinate system is an important component of such analyses. An inappropriate coordinate system may lead to difficulty in obtaining a converged solution and even exhibit physically unrealistic predictions due to geometric truncation error. Therefore, generation of a viable system is mandatory. Any coordinate system used in the analysis should satisfy conditions of (i) generality, (ii) smoothness, (iii) resolvability and (iv) allow easy application of boundary conditions. Obviously, a coordinate system must be sufficiently general to allow application to the problem of interest if it is to be practical. The metric data associated with the coordinate system must be sufficiently smooth so that the variation from grid point to grid point does not lead to a numerical solution dominated by metric coefficient truncation error; it should be noted that this requirement differs from the requirement of the existence of a specified number of transformation derivatives. The coordinate system must resolve flow regions where rapid flow field changes occur. Finally, coordinates should allow accurate implementation of boundary conditions. The coordinate system used here satisfies all these requirements.

In developing coordinate system generation methods several possibilities exist. These are approaches based upon conformal methods, approaches based upon solutions of a Poisson equation such as those of Ref. 1 and constructive approaches such as that of Refs. 2 and 3. The present procedure is a constructive approach, and is described in the following section.

Method of Solution

The coordinate system consists of a set of two families of curves; the ξ = constant curves such as lines G'G in Fig. 1, and the η = constant curves such as ABCD or A'ED' in Fig. 1. Under the present effort the coordinate generation process has been automated and the coordinate construction process is as follows. The coordinate system is constructed by first forming the inner loop A'ED' which includes the blade. The blade shape is specified either via an equation in SUBROUTINE PRFL or via discrete coordinate locations. Since the

1

code constructs a 'C'-type grid, the actual trailing edge region is replaced by a cusped trailing edge. This modification in geometry is not expected to significantly affect most airfoil flow field calculations for two reasons. First, many airfoils have relatively sharp trailing edges, and in these cases the cusped approximation represents a small approximation to the actual geometry. Secondly, when the coordinate system is used with a Navier-Stokes analysis, boundary layers appear on the blade and often the boundary layer displacement effects are much larger than the airfoil thickness itself in the trailing edge region. In these cases the cusped geometry approximation has little effect on the flow field calculations. However, there are some instances in which the cusped trailing edge may make a significant difference. One such case occurs when the near wake region is the region of high interest. In such cases the 'C' grid cusped trailing edge approximation should be used with caution.

Construction of the inner loop is followed by constructing an outer loop AGBCD. Both the inner and outer loops are then represented by parametric curves

$$x = x(s), \qquad y = y(s) \tag{1}$$

where the parameter varies from zero to unity. The present coordinate generation process utilizes a multi-part transformation for the inner loop. First x and y are expressed as a function of s', the physical distance along the curve. After normalizing s' such that its range is between zero and unity, a local parametrization focuses upon the leading edge region and places s" = 0.5 at the leading edge point where highest resolution is sought. This location must be specified by the user and in general will be in the vicinity of the expected front stagnation point. This initial transformation is done automatically once the location where maximum resolution is required is specified. Following this first parametrization, s is related to s" via a hyperbolic tangent parameterization centered about the leading edge point where s" = 0.5.

In this transformation for s" < 0.5

$$s = \frac{1}{2T} \ln \frac{1 + ks"}{1 - ks"} \tag{2a}$$

2

and for $s'' > 0.5$

$$s = 1 - \frac{1}{2T} \ln \frac{1 + k(1 - s'')}{1 - k(1 - s'')}$$

(2b)

where

$$k = 2 \tanh\left(\frac{T}{2}\right)$$

(2c)

and the parameter T controls the grid distribution. Increasing T packs points in the vicinity of $s'' = 0.5$.

The outer loop AGBCD is then parameterized via a cubic transformation in which coefficients of the cubic are related to the inner loop transformation. Two additional transformations follow. First an exponential stretch is imposed on both the inner and outer loops downstream of the trailing edge. This transformation is of the form

$$s' = s'_L - \frac{1}{G} \ln\left[1 + G(s_L - s)\right] \qquad s < s_L$$

(3)

where S_L is the parameter value at the beginning of the transformation on both the inner and outer loop. Similarly, the parameter is stretched in an analogous manner for $s > (1 - S_L)$ so that for corresponding points M and N on opposite sides of the outer loop

$$S_L - S'_M = S'_N - S_T$$

where T and L are on opposite sides of the branch cut or outer loop as shown in Fig. 1. Finally, a local transformation is performed to pack points in the region of the trailing edge on the inner loop and in the corresponding region in the outer loop.

Following construction and parameterization of the inner and outer primary loops, two additional loops are formed which are termed the inner and outer intermediate or secondary loops. These loops are constructed as shown in Fig. 2. The first intermediate loop is constructed downstream of $x/c = 0.04$ a given vertical distance, h_1, from the inner loop. Upstream of $x/c = 0.04$, the distance is measured along a pseudo-radial line with center at $x/c = .04$ on the camber line as shown in Fig. 2. The outer intermediate loop is constructed

3

in an analogous manner at a distance h_2 from the outer loop. The inner and outer secondary loops are parameterized to correspond to the primary loop points they are connected with via the vertical or pseudo-radial lines; i.e.,

$$S_{B'} = S_B$$

Similarly,

$$S_{T'} = S_T$$

These four parameterized loops allow the construction of the pseudo-radial lines such as G'G of Fig. 1 via the multi-loop method originally developed by Eiseman (Ref. 4).

The multi-loop method requires introduction of a position vector $\vec{P}(r,s)$ with components (x, y) which will represent the coordinate location of grid points. Based upon the four-loop construction process, vectors $\vec{P}_i(s)$ are defined with $i = 1,2,3,4$. Each P_i has coordinate (x_i, y_i) associated with it at specific values of s through the previously described construction process. A radial paramter, r, is then introduced. This paramter is defined as the distance from the loop in question to the inner loop normalized by the distance from the outer loop to the inner loop. Thus, $r_1 = 0$, $r_2 = h_1/h_3$, $r_3 = (h_3 - h_2)/h_3$, $r_4 = 1$. With the definition of these quantities the general position vector $\vec{P}(r,s)$ is related to the loop position vectors $\vec{P}_1(s)$, $\vec{P}_2(s)$, $\vec{P}_3(s)$ and $\vec{P}_4(s)$ via

$$\vec{P}(r,s) = (1-r)^2(1-a_1 r)\vec{P}_1(s) + (a_1+2)(1-r)^2 r\vec{P}_2(s)$$
$$+ r^2[1-a_2(1-r)]\vec{P}_4(s) + (a_2+2)r^2(1-r)\vec{P}_3(s) \tag{4}$$

where

$$a_1 = \frac{2}{3r_2 - 1}$$
$$a_2 = \frac{2}{3(1-r_2)-1} \tag{5}$$

4

It should be noted that at r = 0, $\vec{P}(0,s) = \vec{P}_1(s)$ and at r = 1, $\vec{P}(1,s) = \vec{P}_4(s)$. Further since at r = 0,

$$\frac{\partial P}{\partial r}(0,s) = \left[\vec{P}_2(s) - \vec{P}_1(s)\right](a_1 + 2) \qquad (6)$$

and at r = 1

$$\frac{\partial P}{\partial r}(1,s) = \left[\vec{P}_4(s) - \vec{P}_3(s)\right](a_2 + 2) \qquad (7)$$

specification of the derivatives at the inner and outer boundaries is determined by the parametric representation of intermediate loops 2 and 3. Thus, the four-loop method allows specification of the boundary point locations and coordinate angles at these boundaries.

After loops 2 and 3 are parameterized to satisfy the coordinate angle at the boundary points, the grid is constructed as follows. If the grid is to contain M pseudo-radial lines (such as line G'G of Fig. 1) and N pseudo-radial lines (such as line JRS), the values of the pseudo-radial coordinate are

$$r(i) = i/(N-1) \qquad i = 0, 1, 2, \ldots, N-1$$

and the values of the pseudo-azimuthal coordinate are

$$s(j) = j/(M-1) \qquad j = 0, 1, 2, \ldots, M-1$$

Then the position vector; i.e., the grid locations x, y for each point in the grid is given by Eq. (4).

The preceding has assumed a uniform spacing in the radial direction. If radial grid point concentration is desired, it is simply necessary to assume a radial distribution function. The present analysis assumed a distribution function

$$R = \left[1 - \frac{\tanh D(1-r)}{\tanh D}\right] \qquad (8)$$

which concentrates points in the wall region. Grid points are then chosen at r(i) = (i)/(N-1) and the analysis proceeds as outlined.

Grids constructed with this technique have been used successfully in conjunction with a Navier-Stokes calculation procedure for a variety of airfoil calculations. Typical results are presented in Refs. 5-9.

User Instruction

Based upon the input which is discussed in detail in the subsequent section, the code constructs a 'C'-type coordinate system. In regard to the input, the most critical item is the airfoil definition. The airfoil can be defined in SUBROUTINE PROFIL which currently can be used to define NACA 4-digit airfoils with mean line parameters XCMX and YCMX, and thickness parameter T as given by Abbott and Von Doenhoff in Sections 6.3 and 6.4 (Ref. 10). The subroutine prints the airfoil type upon the first call to the subroutine at FORMAT 1000. Other airfoils in this class can be obtained by varying XCMX, YCMX and T. In all cases, the FORMAT statement should be changed by the user to reflect the relevant airfoil.

The subroutine can be modified for other airfoil types. In all cases X is input to the subroutine and gives a dimensionless chordwise location, $0 \leq x \leq 1$. If NAIR = 1, the lower surface coordinate normalized by chord, XAIR and YAIR, must be calculated. If NAIR = 0, the upper surface coordinates must be calculated. Alternatively, the coordinates can be input as discrete points via a NAMELIST AUTO. In these cases care must be taken to adequately define the airfoil desired. Presmoothing of the points by user-supplied smoothing routine may be beneficial.

In regard to output, the code prints metric data on a loop-by-loop basis; i.e., at all grid points along a loop such as JRS. In assessing the output, the critical item is smoothness of variations of the angle between coordinate lines and of the Jacobian. Large changes in either may indicate an unsuitable grid. This is particularly true of the coordinate angle. In addition, if the coordinate angle becomes less than 45° or greater than 135°, the grid may be undesirable for computation. Finally, care must be taken to obtain adequate resolution. Obviously, this will depend upon the problem considered. However, in general the number of pseudo-azimuthal points should not be less than 81 and the number of pseudo-radial points not less than 30 for viscous flows. Most calculations run to date have utilized grids of 141 x 39 points.

The coordinate generation code has been run successfuly on the NASA Langley Research Center CYBER 203 machine using a VSOS2-1 operating system. A listing of sample control cards is found at the end of this subsection. The first three cards represent the accounting control cards. The fourth card attaches the old program library. This is followed by the UPDATE directive which creates a compile file. The next card, the TOVPS card, transfers files to the 203 for execution.

This set is followed by a 7/8/9 card indicating end of record, the UPDATE directives and another 7/8/9 card. This second 7/8/9 card is followed by the CYBER 203 control cards. The first two give accounting information. This is followed by the ATTACH which attaches the COMPILE file and the FORTRAN card. This is followed by a tape request, a LOAD and a GO. The next two cards copy the generated geometry file GEOM2 into GEOO12E and then saves GEOO12E as a permanent file.

```
ACCOUNTING CARD 1
ACCOUNTING CARD 2
ACCOUNTING CARD 3
GET(OLDPL = CRDSRA)
UPDATE,P,C,F,L = A1234.
TOVPS(INPUT,C6UD=COMPILE,UN=******,PW=******,AC=******)
7/8/9
*C COORD, INTEP, PRFL
7/8/9
ACCOUNTING CARD 4
ACCOUNTING CARD 5
RESOURCE(TL=50,WS=576,LP=4,JCAT=SMBAT)
ATTACH,COMPILE.
FORTRAN(L=OUTPUT/1000,I=COMPILE,B=BINARY,OPT= BL)
REQUEST(TAPE9/200,RT=W)
LOAD(BINARY,CN = GO/200,L=OUTPUT,GRLPALL= )
GO.
COPY(GEOM2,GEOO12E)
DEFINE,GEOO12E.
7/8/9
&AUTO
C4 = 3., DAMP=6.8, NRAD = 39, NTHETA = 141, RMAXO = 3.,
RMAX1 = .5, JDATA = 1, CCUSP = 0.9, TS = 6.,
IFLAG = 1, NE = 73, LED = 37,
ICRWR = 1, 8*0, 1, 9*0, 1, 9*0, 1, 4*0, 1, 3*0, 1,
R1 = 1.0E-06
&END
```

The input is found in NAMELIST $AUTO. It consists of geometry specification, grid specification and print flags. The items are

Geometry Specification

IFLAG	=	1	Airfoil shape specified via analytic formulation in SUBROUTINE PRFL
	=	2	Airfoil shape specified via discrete data points DMX, DMY
DMX(I), DMY(I)	–		x and y coordinates for discrete data point specification. $I = 1$, NE. The leading edge is at $I = $ LED. Begin specification at trailing edge $x = 1$, and proceed in a counterclockwise manner over upper surface, through $I = $ LED, over lower surface and back to trailing edge. Only required when IFLAG = 2
NE	–		See DMX, DMY
LED	–		See DMX, DMY
C4	–		Length of branch cut – recommended value = 3.0
CCUSP–	–		Location where cusped trailing edge begins – recommended value = 0.90

Grid Specification

NRAD   —   Number of pseudo-radial points

NTHETA   —   Number of pseudo-azimuthal points

RMAX0   —   Distance from branch cut to outer loop (h_3 in Fig. 2)

RMAX1   —   Secondary loop parameter – set as RMAX0/6

TS   —   Parameter to control leading edge pseudo-azimuthal resolution. Increasing TS increases leading edge resolution relative to resolution elsewhere. Recommended value = 6.0

XLE,MLE   —   Parameters to set point of maximum leading edge resolution

         MLE = 2   –   Maximum resolution at X = 0

         MLE = 1   –   Maximum resolution at X = XLE on upper surface

         MLE = 0   –   Maximum resolution at X = XLE on lower surface

R1   —   Approximate location of first point from the airfoil = R1*RMAX0

DAMP   —   If R1 is <u>not</u> set in NAMELIST \$AUTO pseudo-radial stretch is set by DAMP. Increasing DAMP increases resolution near airfoil surface. Recommendation is to set R1

ANGROT   —   Allows rotation of inner loop relative to outer loop by ANGROT radians; i.e., in Fig. 1 loop A'ED' will rotate by ANGROT radians

9

<u>Print Flags</u>

ICRWR(I)   = 1   Write metric data for loop I on ouput file

                                  = 0   Do not write metric data for loop I on
                                               output file

JDATA   = 1   Write inner and outer loop data on output
                                               file

                                  = 0   Do not write inner and outer loop data on
                                               output file

A sample set of input is given on page 7.

<div align="center">Output</div>

The first output item of the code defines the airfoil. The airfoil is
defined by name if an analytic formulation is used or by discrete coordinates
if a set of discrete specifying data is used. This is followed by
NAMELIST $AUTO and, if R1 is set, by the iteration to determine the
pseudo-radial stretching parameter. This is followed by the location of the
centerpoint used in constructing the pseudo-circular frontal coordinate
system. If JDATA = 1, the x and y coordinates as well as the parameter,
associated with each point defining the inner and outer loops follow.
If JDATA = 0, this is omitted.

The next items appearing are the x and y coordinates of each of the four
loops used to construct the mesh. ARC1 and ARC3 are the inner and outer
loops, respectively. ARC2 and ARC4 are the secondary or intermediate loops.
This is followed by the radial distribution function which gives the
dimensionless radial distance as a function of grid point. Finally, metric
data are presented for each loop, I, for which ICRWR(I) = 1. The items printed
are the x and y coordinates (PX and PY), the components of the metric tensor
g_{rr}, g_{tt}, g_{rt}, the Jacobian of the transformation, and the angle between
coordinate lines where

$$g_{rr} = \left(\frac{\partial x}{\partial \eta}\right)^2 + \left(\frac{\partial y}{\partial \eta}\right)^2$$

$$g_{tt} = \left(\frac{\partial x}{\partial \xi}\right)^2 + \left(\frac{\partial y}{\partial \xi}\right)^2$$

$$g_{rt} = \frac{\partial x}{\partial \xi} \frac{\partial x}{\partial \eta} + \frac{\partial y}{\partial \xi} \frac{\partial y}{\partial \eta}$$

The last four columns are the derivatives

$$\partial x / \partial \eta, \quad \partial y / \partial \eta, \quad \partial x / \partial \xi, \quad \partial y / \partial \xi$$

The final output item is written on TAPE9 and stores the mesh coordinates. These are written one loop at a time as x_i, y_i, $i = 1$, NTHETA as a binary write.

Environmental Characteristics

The program was developed on the CYBER 170, and various versions have been used on both the CRAY1 and CYBER 203. A typical grid of 140 x 39 points requires less than 10 system time units on the CYBER 203.

REFERENCES

1. Thompson, J.F., Thames, F.C. and Mastin, C.W.: Boundary Fitted Curvilinear Coordinate Systems for Solution of Partial Differential Equations on Fields Containing Any Number of Arbitrary Two-Dimensional Bodies. NASA CR-2729, July 1977.

2. Gibeling, H.J., Shamroth, S.J. and Eiseman, P.R.: Analysis of Strong Interaction Dynamic Stall for Laminar Flow on Airfoils. NASA CR-2969, 1978.

3. Eiseman, P.R.: A Coordinate System for a Viscous Transonic Cascade Analysis, J. Comp. Physics, Vol. 26, March 1978, pp. 307-338.

4. Eiseman, P.R.: Coordinate Generation with Precise Controls over Mesh Properties, J. Comp. Physics, Vol. 47, 1982.

5. Shamroth, S.J. and Gibeling, H.J.: A Compressible Solution of the Navier-Stokes Equations for Turbulent Flow about an Airfoil, NASA CR-3183, 1979. (Also AIAA Paper 79-1543).

6. Shamroth, S.J. and Gibeling, H.J.: Analysis of Turbulent Flow about an Isolated Airfoil Using a Time-Dependent Navier-Stokes Procedure. Paper presented at AGARD Specialists Meeting on Boundary Layer Effects on Unsteady Airloads, Aix-en-Provence, France, September 1980.

7. Shamroth, S.J.: A Turbulent Flow Navier-Stokes Analysis for an Airfoil Oscillating in Pitch. IUTAM Symposium on Unsteady Turbulent Shear Flow, Eds. R. Michel, J. Cousteix, R. Houseville, Springer-Verlag, New York, 1981.

8. Shamroth, S.J.: A Navier-Stokes Calculation of the Airfoil Dynamic Stall Process. AFOSR/FJSRL/U. of Colorado Workshop on Unsteady Separated Flows, 1983.

9. Shamroth, S.J.: Calculation of Steady and Oscillating Flow Fields via the Navier-Stokes Equations, AIAA Paper 84-525, 1984.

10. Abbott, I.H. and Von Doenhoff, A.E.: Theory of Wing Sections, Dover Publications, New York, 1959.
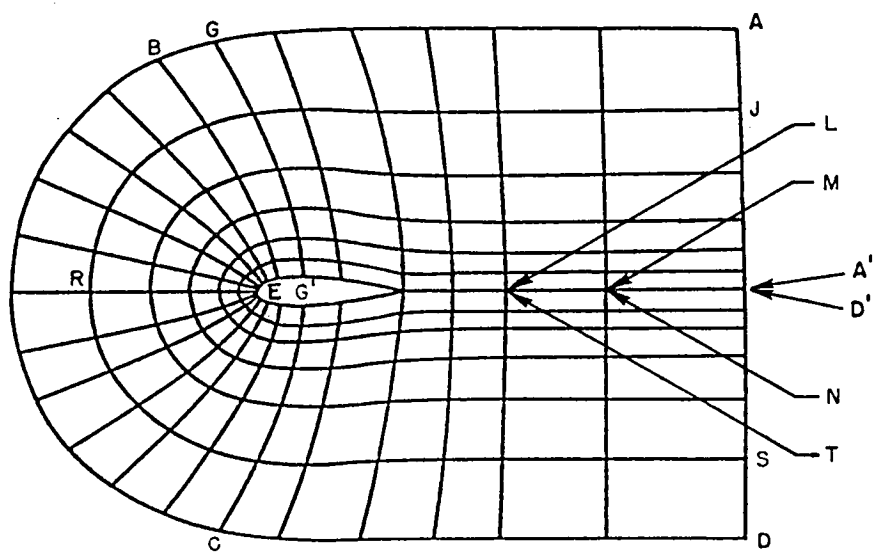
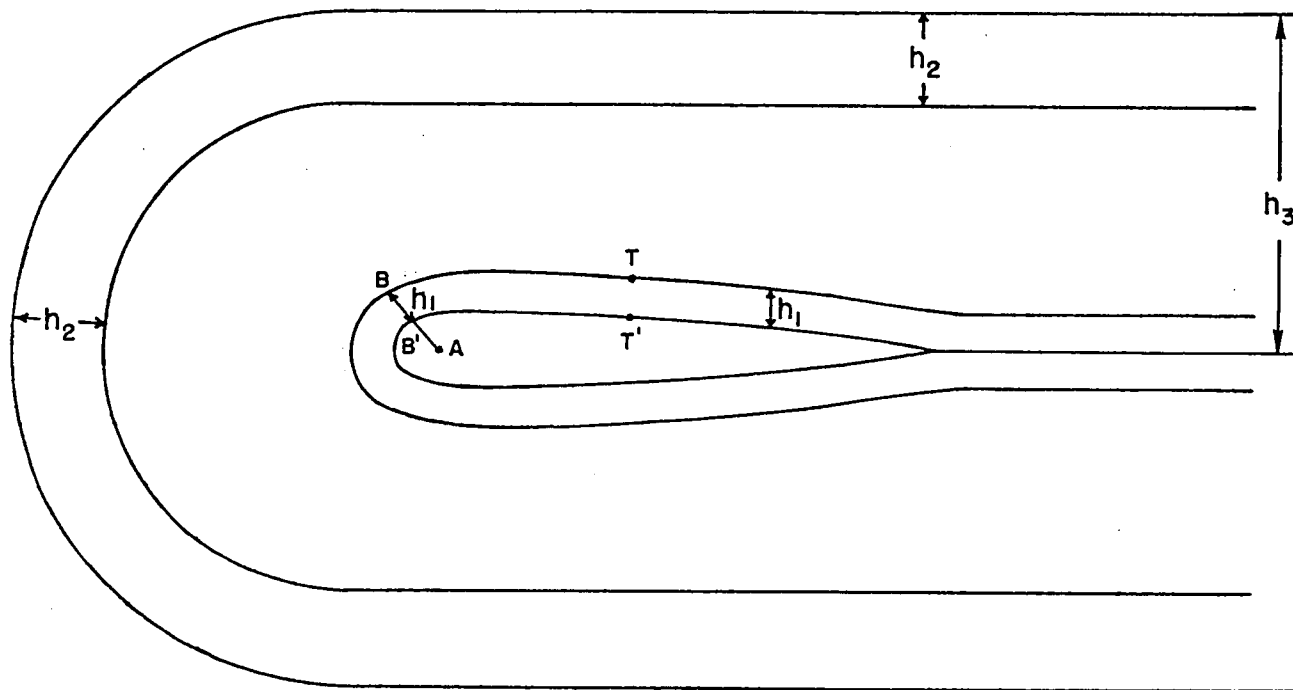Figure 1 - Sketch of constructive coordinate system

14

Figure 2 – Four loop construction

1. Report No. NASA CR-172584	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle USER' MANUAL FOR COORDINATE GENERATION CODE "CRDSRA"		5. Report Date June 1985
		6. Performing Organization Code
7. Author(s) S. J. Shamroth		8. Performing Organization Report No.
9. Performing Organization Name and Address Scientific Research Associates, Inc. P.O. Box 498 Glastonbury, CT 06033		10. Work Unit No.
		11. Contract or Grant No. NAS1-15214
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546		13. Type of Report and Period Covered Contractor Report
		14. Sponsoring Agency Code 505-33-43-09

15. Supplementary Notes

Langley Technical Monitor: James T. Howlett

16. Abstract

Generation of a viable coordinate system represents an important component of an isolated airfoil Navier-Stokes calculation. The present manual describes a computer code for generation of such a coordinate system. The coordinate system is a general nonorthogonal one in which high resolution normal to the airfoil is obtained in the vicinity of the airfoil surface, and high resolution along the airfoil surface is obtained in the vicinity of the airfoil leading edge. The method of generation is a constructive technique which leads to a 'C' type coordinate grid. The method of construction as well as input and output definitions are contained within this report. The computer code itself as well as a sample output is being submitted to COSMIC.

17. Key Words (Suggested by Author(s)) Coordinate System Isolated Airfoil	18. Distribution Statement Unclassified - Unlimited Subject Category 02

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 16	22. Price A02

N-305