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V.3

User's Manual for Axisymmetric Diffuser Duct (ADD) Code

Volume III—ADD Code Coordinate Generator

O. L. Anderson, G. B. Hankins, Jr.,
and D. E. Edwards
United Technologies Research Center

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         0       0 1*6
         0       0 1*3
         0       0 1*4
         0       0 2*6
         0       0 2*3
         0       0 2*4
   7     1       1 RN/NASA-CR-165598-VOL-3
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CORP: United Technologies Corp., East Hartford, Conn.    AVAIL.NTIS   SAP: HC
       A05/MF A01
MAJS: /*AXISYMMETRIC FLOW/*COMPUTER PROGRAMS/*FUEL FLOW/*USER MANUALS (COMPUTER
       PROGRAMS)
MINS: / COMPUTER SYSTEMS PROGRAMS/ DUCTED FLOW/ FLUID FLOW/ SUBROUTINES
ABA:  Author
ABS:  This User's Manual contains a complete description of the computer codes
       known as the Axisymmetric Diffuser Duct (ADD) code. It includes a list of
       references which describe the formulation of the ADD code and comparisons
       of calculation with experimental flows. The input/output and general use
       of the code is described in the first volume. The second volume contains a
       detailed description of the code including the global structure of the
       code, list of FORTRAN variables, and descriptions of the subroutines. The
       third volume contains a detailed description of the CODUCT code which
       generates coordinate systems for arbitrary axisymmetric ducts.
ENTER:
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USER'S MANUAL FOR
AXISYMMETRIC DIFFUSER DUCT
(ADD) CODE

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VOL. III ADD CODE COORDINATE GENERATOR

10.0 OPERATION OF CØDUCT CODE

10.1 Runstream

The following runstream for a UNIVAC 1100 operating system is used to assign input/output disc files and to execute the CØDUCT coordinate generator code.

```
@ASG,A          FILE9.,D/0/TRK/300000
@USE            9.,FILE9.

@ASG,A          FILE10.,D/0/TRK/300000
@USE            10.,FILE10.

@XQT            CØDUCT
                  .
                  .
                  .
               data cards
                  .
                  .

@FIN
```

FILE9 contains the coordinate data for a uniform mesh and FILE10 contains the data for a nonuniform mesh.

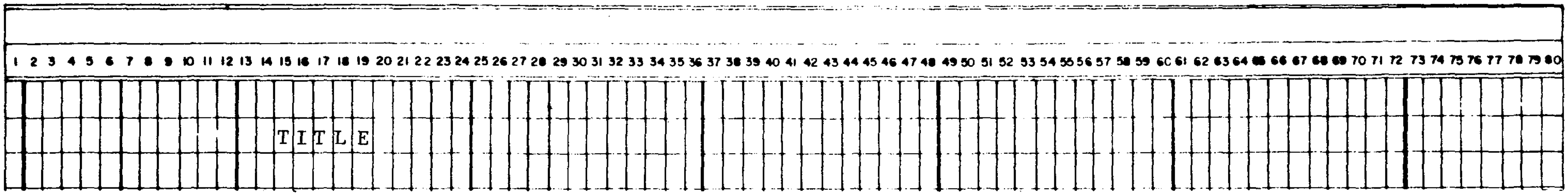
10.2 Input Format

The input format for the CØDUCT code is described on the input data coding forms which follow. With the exception of the first card (Title card) and the duct geometry cards, the input data cards follow in sets of three cards. The first of three is a blank separator card. The second of three is the input variable name and the third of three is the value of the input variable. In general the input data is read as follows:

Card 1	Title Card
Cards 2-4	Program Control Parameters
Cards 5-7	Program Control Parameters
Cards 8-10	Coordinate Generator Parameters
Cards 11-13	Coordinate Generator Parameters
Card 14	Number of duct geometry coordinates
Cards 15 +	Duct geometry coordinates

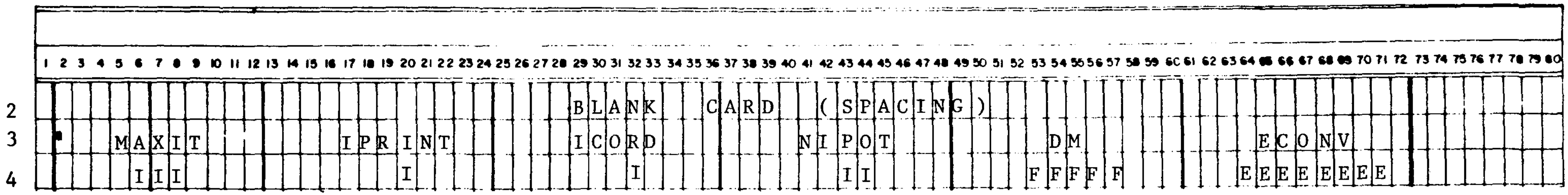
CØDUCT CODE INPUT

Card 1 Title Card (18A4)



CØDUCT CODE INPUT

Cards 2-4 Program Control Parameters (T6, I3, T20, I1, T32, I1, T43, I2, T53, F5.2, T64, E8.3)



MAXIT	Maximum number of iterations for conformal mapping solution
IPRINT	Print option: = 0 Print only input and final mapping = 1 Print iteration results = 2 Print approximate solution
ICORD	Coordinate generation option: = 0 Calculate conformal mapping only = 1 Calculate coordinates
NIPOT	Approximate solution option = 0 Program determines number of approximate potential lines > 0 User specifies number of approximate potential lines
DM	Step control in approximate solution calculations
ECONV	Convergence criterion on conformal mapping iteration

CØDUCT CODE INPUT

Cards 5-7 Program Control Parameters (T8, I1, T18, I3, T30, I3)

Card	Columns 1–17	Columns 18–28	Columns 29–80
5			BLANK CARD (SPACING)
6	IESTIM	KN	NSD
7	I (col. 8)	III (cols. 18–20)	III (cols. 30–32)

IESTIM Approximate solution option

= 0 Calculate approximate solution only
= 1 Calculate conformal mapping

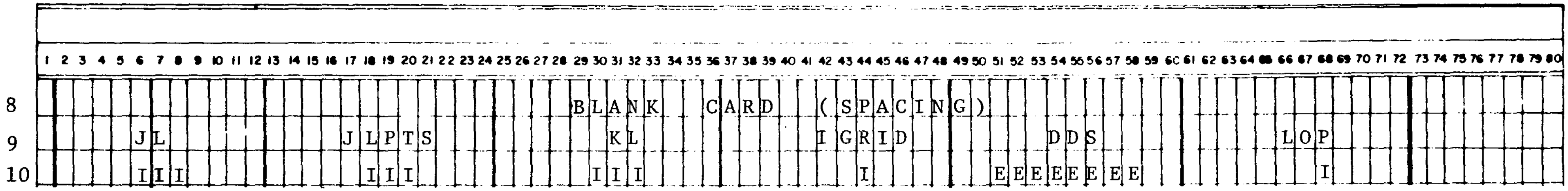
KN Number of streamlines to generate on uniform grid, number of integration steps

NSD Potential line integration step control:

= 0 KN integration steps are used
> 0 There will be NSD additional steps taken for each of the KN steps yielding
NNS = (KN - 1) *NSD + KN total steps

CØDUCT CODE INPUT

Cards 8-10 Coordinate Generation Control Parameters (T6, I3, T18, I3, T30, I3, T44, I1, T51, E8.3, T68, I1)



JL Number of streamwise stations to output

JLPTS Number of data points to output from smooth

KL Number of nonuniformly spaced streamlines

IGRID Grid option

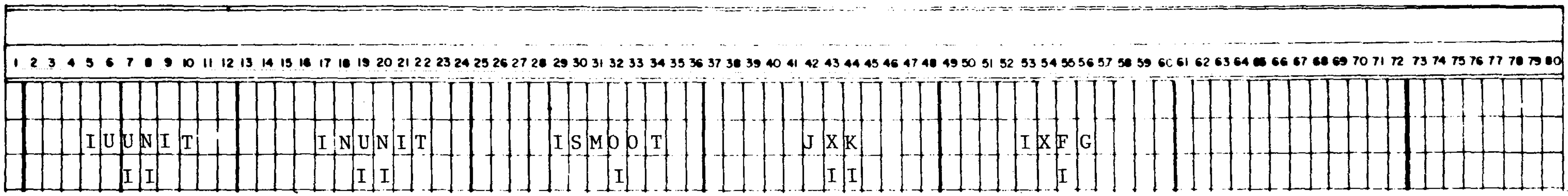
= 0 KN uniformly spaced streamlines output to unit IUUNIT
= 2 KL nonuniformly spaced streamlines output to unit INUNIT
= 1 Both meshes (0), (2) output

LOP Control option for mesh distortion

DDS Ratio of uniform/nonuniform mesh size at wall

CØDUCT CODE INPUT

Cards 11-13 Coordinate Generation Control Parameters (T7, I2, T19, I2, T32, I1, T43, I2, T55, I1)



IUUNIT Output unit number for uniform mesh

INUNIT Output unit number for nonuniform mesh

ISMOOT Smoothing option

= 0 No coordinate smoothing
= 1 Smooth data using IMSL routine ICSVKU

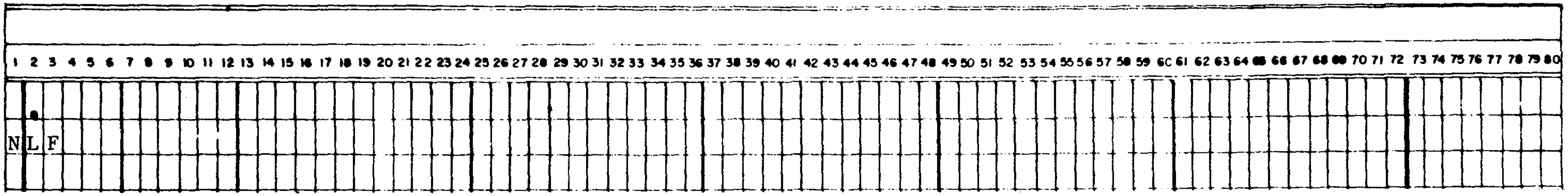
JXK Number of knots to use in spline smoothing

IXFG Transfer grid option

= 0 Conformal mapping procedure
= 1 IUUNIT data is read and interpolated to new grid in INUNIT

CØDUCT CODE INPUT

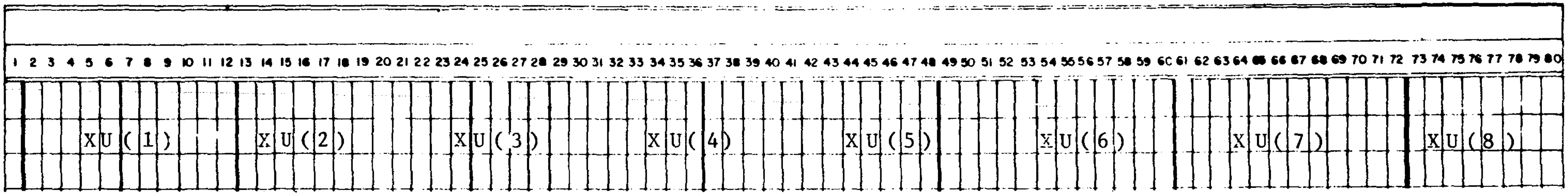
Card 14 Number of Duct Geometry Coordinates (I3)



NLF Number of coordinate pairs defining the upper/lower walls

CØDUCT CODE INPUT

Cards 15 → Duct Geometry Coordinates (8F10.6)



XU Upper wall x-coordinates

YU Upper wall y-coordinates

XL Lower wall x-coordinates

YL Lower wall y-coordinates

Where the data is read as follows

```
      READ (IRUNIT,40) (XU(J), J=1,NLF)
      READ (IRUNIT,40) (YU(J), J=1,NLF)
      READ (IRUNIT,40) (XL(J), J=1,NLF)
      READ (IRUNIT,40) (YL(J), J=1,NLF)
   40 FORMAT (8F10.6)
```

10.3 Output Format

The printed output from the CØDUCT code is given on the following pages and is largely self explanatory. These pages contain the names of the subroutines which calculate the data as well as any print options which may be involved.

Input Data Echo Page (1)

Printed by	RCNTRL
Calculated by	RCNTRL
Options	None

Description

Subroutine RCNTRL reads the input control data (cards 1-13) and prints the input control data.

Duct Coordinates Echo Page (2)

Printed by	CORINP
Calculated by	N/A
Options	None

Description

Subroutine CORINP reads the duct wall coordinates as described in Section 10.2 and prints the wall coordinates.

Pages 1-2 INPUT WALL COORDINATES

Heading	Variable		Description
PT#	J	,	Wall coordinate number
XU	X_U	,	Upper wall input X coordinate
YU	Y_U	,	Upper wall input Y coordinate
XL	X_L	,	Lower wall input X coordinate
YL	Y_L	,	Lower wall input Y coordinate

Smoothed Duct Wall Coordinate Page (2)

Printed by	CORINP
Calculated by	SMARCL, SMOOTH
Options	ISMOOT
	ISMOOT = 0, no smoothing, no printout
	ISMOOT = 1 smoothed, printed

Description

The input coordinates are read in CORINP and subroutine SMARCL is called to cubic-spline smooth the wall data.

Pages 1-2 SMOOTHED WALL COORDINATES

Heading	Variable		Description
PT#	J	,	Smoothed wall coordinate number
XU	X_U	,	Smoothed upper wall X coordinate
YU	Y_U	,	Smoothed upper wall Y coordinate
XL	X_L	,	Smoothed lower wall X coordinate
YL	Y_L	,	Smoothed lower wall Y coordinate

Calculated Duct Geometry Parameters (1)

Printed by MDAVIS, ROTATM
Calculated by MDAVIS, ROTATM
Options None

Description

Subroutine MDAVIS determines the orientation of the duct and forces the inlet walls parallel. The rotational and scaling constant M and the exit wall angle are calculated and output by subroutine ROTATM.

Page 1 CALCULATED DUCT GEOMETRY PARAMETERS

Heading	Variable	Description
None	Θ_1	Angle of inlet lower wall to horizontal
None	h	True height of duct - perpendicular distance from lower wall to upper wall
None	M	Rotational and scaling constant used in Schwartz-Cristoffel mapping
None	α_E	Relative angle at exit of duct + π

Approximate Potential Flow Page (6)

Printed by	WALLV, ESTIMP	
Calculated by	ESTIMP, ESTCOR, WALLV	
Options	IPRINT	
	IPRINT < 2	no output
	IPRINT = 2	output

Description

Subroutine ESTIMP solves for a geometric approximate potential solution in the duct using subroutine ESTCOR to determine the positions of a set of approximate potential lines. The wall velocities and curvatures at the end points of these lines are calculated and printed by subroutine WALLV. The solution along each wall is interpolated to the set of wall coordinates and an estimate of the Schwartz - Cristoffel mapping is determined. This estimate is calculated and printed by subroutine ESTIMP.

Page 1 — LOWER WALL ESTCOR FLOW ESTIMATE

Heading	Variable	Description
PT#	NP	Approximate potential line number
ARCL	S	Arc Length
VMEAN	$\overline{V}$	Duct midline velocity
VWALL	V_L	Lower wall velocity
KMEAN	$\overline{K}$	Duct midline curvature

Approximate Potential Flow Pages (Cont'd)

Page 2 — UPPER WALL ESTCOR FLOW ESTIMATE

Heading	Variable	Description
PT#	NP	Approximate potential line number
ARCL	S	Arc length
VMEAN	$\overline{V}$	Duct midline velocity
VWALL	V_U	Upper wall velocity
KMEAN	$\overline{K}$	Duct midline curvature

Pages 3-4 — LOWER WALL POTENTIAL FLOW ESTIMATE

Heading	Variable	Description
PT#	J	Wall coordinate number
VWALL	V_L	Lower wall velocity
KWALL	K_L	Lower wall curvature
TT	t	t-plane pole estimates
B	b	ζ-plane pole estimates

Pages 5-6 — UPPER WALL POTENTIAL FLOW ESTIMATE

Heading	Variable	Description
PT#	J	Wall coordinate number
VWALL	V_u	Upper wall velocity
KWALL	K_u	Upper wall curvature
TT	t	t-plane pole estimate
B	b	ζ-plane pole estimate

Iteration History Pages

Printed by	MDAVIS	
Calculated by	MDAVIS, STEP	
Options	IPRINT	
	IPRINT = 0	not printed
	IPRINT > 0	history printed

Description

The current estimate of dz/dt is integrated along the duct walls in subroutine MDAVIS by steps $t_{j+1} - t_j$ in the t-plane. The results of the integration and the error of the current iteration are printed.

Page 1 ITERATION HISTORY

Heading	Variable	Description
PT#	J	Wall coordinate number - j
TX	t_x	Real component of t_j
TY	t_y	Imaginary component of t_j
X	Z_x	Real component of Z_j
Y	Z_y	Imaginary component of Z_j
RATIO	R	Arc length ratio
ERROR		Absolute error $Zc_j - Z_j$
DZDT	$\frac{dz}{dt}$	Complex derivative of mapping

Iteration Summary Page (1)

Printed by MDAVIS, CLOSUR
Calculated by MDAVIS, CLOSUR
Options None

Description

Subroutine MDAVIS calculates the maximum relative error in the coordinate calculation for each iteration and tests for convergence of the mapping solution. Subroutine CLOSUR determines the integrated closure error of the solution.

Page 1 ITERATION SUMMARY

Heading	Variable		Description
ITERATION	ν	,	Iteration count
SCALED MAXIMUM ERROR	ε_m	,	Maximum scaled error for the iteration
None	ZCL	,	Closure error $\lvert \bar{Z}_1 - \bar{Z}_2 \rvert$
None	$\bar{Z}_1$	,	Integration path #1 endpoint
None	$\bar{Z}_2$	,	Integration path #2 endpoint

Mapped Duct Coordinate Page (2)

Printed by MDAVIS
Calculated by MDAVIS
Options None

Description

Once the mapping iteration has terminated, the final solution and errors are printed for each wa.'l coordinate.

Pages 1-2 MAPPED DUCT COORDINATES

Heading	Variable	Description
TX	t_x	Real part of t-plane pole location
TY	t_y	Imaginary part of t-plane pole location
X	X	Image of T under mappping
Y	Y	
XC	X_C	Input coordinates
YC	Y_C	
EX	ε_X	Error $\lvert X - X_c \rvert$
EY	ε_y	Error $\lvert Y - Y_c \rvert$
S	S	Arc length

Mesh Generation Page (1)

Printed by	COORD
Calculated by	COORD
Options	None

Description

The t-plane uniform mesh that is used for the coordinate generation is described.

Page 1 MESH PARAMETERS

Heading	Variable	Description
None	JL	Number of streamwise steps
None	DSTEP	Streamwise step size
None	KN	Number of uniform normal steps

10.4 Diagnostics and Failure Modes

Numerous checks are performed during the course of the calculation. If a non-fatal or correctable error occurs a DIAGNOSTIC message is printed and the calculation continues. If a fatal error occurs a FAILURE Mode error is printed and the calculation stops. A DIAGNOSTIC message is printed of the form:

** DIANGOSTIC NO. XX for 2-D COORDINATE OPERATOR and a FAILURE Mode message is of the form:

** FAILURE NO. XX for 2-D COORDINATE GENERATOR where XX refers to one of the conditions listed below.

DIAGNOSTICS

1) NUMERICAL SOLUTION OF SCHWARTZ-CRISTOFFEL TRANSFORMATION FAILED TO CONVERGE

This error is detected in subroutine MDAVIS. It indicates that the scaled maximum error in the computed wall coordinates is greater than the input value ECONV after MAXIT iterations have been completed. By examining the ITERATION SUMMARY printed above the diagnostic message, one of three courses of action may be determined.

a) The Scaled Maximum Error (SME) appears to be converging. Reset MAXIT and rerun the case.

b) The SME has converged to a value different than zero. This can often be remedied by increasing the number of sub-steps (NSD), employed in the normal direction integration. If this does not solve the problem, more wall definition coordinates may be needed.

c) The SME is not converging. This often indicates that a poor initial potential flow solution was generated.

2) UPPER AND LOWER WALLS NOT PARALLEL AT INLET. UPPER WALL FORCED PARALLEL TO LOWER WALL

This error is detected in subroutine ROTATM. It implies that the inlet upper and lower wall angles with respect to the horizontal differed by less than ten degrees but greater than 1.0-10. The upper wall endpoint is moved to force the walls parallel.

FAILURE MODES

1) MESH DISTORTION PARAMETER EQUALS = XXXXX

This error is detected in subroutine ROBRTS.

2) MESH DISTORTION PARAMETER EQUALS = XXXXX

This error is detected in subroutine DROBRT.

3) LOWER WALL ANGLE = XXXXX DEGREES
UPPER WALL ANGLE = XXXXX DEGREES
WILL NOT FORCE PARALLEL IF DIFFERENCE IS > 10 DEG.

This error is detected in subroutine ROTATM. It indicates that the inlet walls are not sufficiently parallel, and the program will not force the walls parallel to avoid drastically changing the geometry.

4) DEGENERATE DERIVATIVE MAPPING FOR I = XXXXX

This error is detected in subroutine MDAVIS. It implies that $|\frac{dz}{dt}| < 1.D-8$ at wall point XXXXX.

5) INCONSISTENT OR INVALID INPUT

This error is detected in main program CODUCT.
Check input data set.

6) READ ERROR ENCOUNTERED IN SUBROUTINE CORINP

This error, detected while reading duct wall coordinates, indicates an error in the input data set.

7) NUMBER OF INPUT POINTS EXCEEDS MAXIMUM (XXX)

This error, detected in subroutine CORINP, indicates that too many wall values are defined.

8) UNABLE TO COMPLETE APPROXIMATE SOLUTION

This error is detected in subroutine ESTCOR. It implies that more than ten attempts have been made to compute a single potential line and is usually due to very large wall curvatures.

9) INDEPENDENT STEP SIZE TOO SMALL

This error is detected in subroutine DERIV3. It indicates that two consecutively numbered wall coordinates are equal.

10) IMSL LIBRARY ICSVKU FAILURE NO. XXX

This error is detected in subroutine SMOOTH. It implies that the IMSL program ICSVKU cannot solve the spline problem. See IMSL manual to determine remedy.

11.0 GLOBAL STRUCTURE OF CØDUCT CODE

This section of the manual is intended for the special user who wishes to modify the CØDUCT code or adapt to a different computer. The section provides a global overview of the code in terms of the principal tasks. These tasks are clearly labeled in the main program CØDUCT and agrees with the tasks listed on the Global Tree Structure Chart in Section 11.2. The global variables in labeled CØMMØN blocks are given in Section 11.3. Only the variables unique to the CØDUCT code are listed. Variables that are used by both the CØDUCT code and ADD code are listed in Section 6.0. Special problems associated with machine specific code are similar to those in the ADD code and are treated in Section 5.0.

11.1 Main Program CODUCT

Object

Main program for coordinate generator.

Options

IXFG	= 0	Full solution
	= 1	Interpolate only
IESTIM	= 0	Approximate solution only
	= 1	Schwartz-Cristoffel transformation also
ICORD	= 0	No coordinate output
	= 1	Coordinate output to disk files.

Theory

The control program CODUCT first calls subroutine RCNTRL (See Table 1) to read the user-input control parameters and options. Subroutine CORINP is then called to read the duct wall coordinates and, if requested, will smooth the wall coordinate using a cubic-spline fitting algorithm. Subroutine ESTCOR is called to geometrically determine the approximate potential flow solution necessary to start the conformed mapping iteration procedure. Then Davis' algorithm to compute the Schwartz-Cristoffel transformation is invoked by calling subroutine MDAVIS. Finally, subroutine COORD is called to generate and output the coordinate mesh parameters to disk file(s).

11.2 Global Tree Structure By Task

Read Control Input				
CODUCT	RCNTRL			
Read and Smooth Duct Wall Data				
CODUCT	CORINP	SMARCL	ARCL1 SMOOTH	 ICSVKU
Calculate Approximate Potential Flow Solution				
CODUCT	ESTIMP	ARCL1 KURVTR ESTCOR WALLV	 DER1V3 INSECT CROSS1 DER1V3 SUNBAR UNBAR	 CROSS1
Calculate Schwartz-Cristoffel Transformation				
CODUCT	MDAVIS	ROTATM INTNOR STEP TTUP CLOSUR	 STEP STEP INTNOR INTSTR	 STEP STEP

Calculate Coordinates and Metrics						
CODUCT	COORD	CONSTR	CDS			
			ROBRTS			
			DROBRT			
		COOR1D	NORLIN	STEP		
			STRSTP	STEP		
			CDVDN			
			CORSTR			
			Q2INTP			
			BLKWRT	NTRAN$		
			QPSTOR	QPCURV	INSECT	CROSS1
		COORMD	STRSTP	STEP		
			CDVDN			
			CORSTR			
			QPSTOR			
			Q2INTP			
			BLKWRT	NTRAN$		
			QPSTOR	QPCURV	INSECT	CROSS1
Transform from Uniform to Non-uniform mesh						
CODUCT	XFGRID	INITQ	BLKRED	NTRAN$		
		CONSTR				
		BLKRED	NTRAN$			
		Q2INTP				
		QPSTOR	QPCURV	INSECT	CROSS1	
		BLKWRT	NTRAN$			

11.3 List of Labeled CØMMØN Blocks

Name	Object
BSMØTH	Variables for spline smoothing
CESTP	Variables for approximate solution
CØØRCØ	Control options and parameters
CØØRT	Complex coordinates and derivative
IPDAVS	Complex solution variables
NSDAVS	Constants and parameters for mapping
ØPDAVS	Intermediate Schwartz-Christoffel variables
TITLE	Run Title

List of Variables in CØMMØN/BSMØTH/
Variables for Spline Fitting

Name	Symbol	Length	Type	Description
A		NXK	R*4	Integration constant
B		NXK	R*4	Integration constant
CK		ICK,3	R*4	Spline coefficients
WK		IWK	R*4	Work area
XK		NXK	R*4	Knot locations
YPP		NXNTD2	R*4	Second derivative of input curve

List of Variables in CØMMØN/CESTP/
Variables for Approximate Solution

Name	Symbol	Length	Type	Description
HT	h_t	NXNTD2	R*4	Approximate duct height
IL,IU		NXNTD2		Index lower/upper walls
KKL,KKU	K_L, K_U	NXNTD2	R*4	Curvature lower/upper walls
KMEAN	$\overline{K}$	NXNTD2	R*4	Curvature of mean line
SL,SU	S_L, S_U	NXNTD2	R*4	Arc length lower/upper walls
SLI,SUI	S_{LI}, S_{UI}	NXNTD2	R*4	Arc length lower/upper walls
SMID	$\overline{S}$	NXNTD2	R*4	Arc length mean line
TH	θ	NXNTD2	R*4	Angle of mean line with x axis
VL,VU	V_L, V_U	NXNTD2	R*4	Velocity lower/upper walls
VLI,VUI	V_{LI}, V_{UI}	NXNTD2	R*4	Velocity lower/upper walls
VMEAN	$\overline{V}$	NXNTD2	R*4	Velocity on mean line
XL,YL	X_L, Y_L	NXNTD2	R*4	Input coordinate lower wall
XU,YU	X_U, Y_U	NXNTD2	R*4	Input coordinate upper wall
XLI,YLI	X_{LI}, Y_{LI}	NXNTD2	R*4	Coordinates lower wall
XUI,YUI	X_{UI}, Y_{UI}	NXNTD2	R*4	Coordinates upper wall

Note: subscript I denotes intersection of approximate potential line with wall

List of Variables in CØMMØN/CØØRCØ/
Control Options and Parameters

Name	Symbol	Length	Type	Description
DDS	$(\Delta\eta/\Delta n)_1$		R*4	Ratio uniform/nonuniform grid at wall
IGRID			I*4	Grid option
INUNIT			I*4	Output unit for nonuniform grid
IRUNIT			I*4	Read unit
ISMØØT			I*4	Smoothing option
IUUNIT			I*4	Output unit for uniform grid
IWUNIT			I*4	Print unit
IXFG			I*4	Transfer grid option
JL			I*4	Number of output streamwise stations
JLPTS			I*4	Number of input stations
JXK			I*4	Number of knots for spline
KL			I*4	Number of nonuniform streamlines
KN			I*4	Number uniform streamlines
LØP			I*4	Mesh distortion option
RADR	r_r		R*4	Reference length
TTL	t_L		R*4	Maximum t-plane coordinate lower wall
TTU	t_u		R*4	Maximum t-plane coordinate upper wall

List of Variables in CØMMØN/CØØRT/
Complex Coordinates and Derivatives

Name	Symbol	Length	Type	Description
DZDTJ	$\left(\frac{dz}{dt}\right)^{J}$	KLL	C*16	Mapping derivative
DZDTJP	$\left(\frac{dz}{dt}\right)^{J+1}$	KLL	C*16	Mapping derivative
DZDTP2	$\left(\frac{dz}{dt}\right)^{J+1}$	KLL	C*16	Mapping derivative
DZDT1	$\left(\frac{dz}{dt}\right)^{1}$	KLL	C*16	Mapping derivative
ZJ	z^{J}	KLL	C*16	Coordinate in duct plane
ZJP	z^{J+1}	KLL	C*16	Coordinate in duct plane
ZP2	z^{J+2}	KLL	C*16	Coordinate in duct plane
Z1	z^{1}	KLL	C*16	Coordinate in duct plane

List of Variables in CØMMØN/IPDAVS/
Complex Solution Variables

Name	Symbol	Length	Type	Description
B	$b^{\nu-1}$	NXNT	R*8	Location of poles
BNEW	b^{ν}	NXNT	R*8	Location of new poles
TG	$t^{\nu-1}$	NXNT	C*16	t-plane wall coordinates
TT	t^{ν}	NXNT	C*16	New t-plane wall coordinates
Z	Z	NXNT	C*16	Z-plane calculated wall coordinates
ZC	Z_c	NXNT	C*16	Z-plane input wall coordinates

List of Variables in CØMMØN/NSDAVS/
Constants and Parameters for Mapping

Name	Symbol	Length	Type	Description
DM	d_m		R*8	Automatic step size in approximate solution
ECØVV	ε_c		R*8	Convergence criteria
IC	0. + 1.i		I*4	Complex number $\sqrt{-1}$
ICØRD			I*4	Coordinate generator option
IESTIM			I*4	Approximate potential flow option
IPRINT			I*4	Print option
MAXIT			I*4	Maximum number of iterations
N			I*4	Number of wall points (NLF+2)
NBE			I*4	Number of non-trivial angle changes
NCL,NCU			I*4	Number of lower/upper wall elements
NLF			I*4	Number of lower wall points
NM1			I*4	N-1
NNS			I*4	Number of additional steps in integration
NUI			I*4	NLF+1
NIPØT			I*4	Approximate potential flow option
ØNE	1. + 0.i		C*16	Complex 1.0
XM	M		C*16	Scale constant
ZER	0. + 0i		C*16	Complex 0.0

List of Variables in CØMMØN/TITLE/
Run Title

Name	Symbol	Length	Type	Description
ITITLE(I)		18	I*4	Run title

List of Variables in CØMMØN/ØPDAVS/

Name	Symbol	Length	Type	Description
ALPHA	α_J	NXNT	R*8	Re(β_J) + 1.
BETAM	β_J	NXNT	C*16	Change in wall angle
DELR	$b_{J+1}-b_J$	NXNT	R*8	Difference in pole locations
EXITA	α_E	1	R*8	Duct exit divergence angle + π
HEIGHT	h	1	R*8	Duct inlet height
RATIO	R_J	NXNT	R*8	Ratio of actual to calculated length
THETA1	θ_1	1	R*8	Rotation of duct from real axis
ZET	ζ_J	NXNT	C*16	Estimated pole location

12.0 DETAILED DESCRIPTION OF CØDUCT CODE

This section contains an alphabetic list of subroutines and a detailed description of each subroutine. Subroutines that are used by both the ADD code and the CODUCT code are listed and described in Section 7.0. The description of the subroutines which follow have the same format. This format consists of the object or purpose of the subroutine, any options used by the subroutine, and a list of variables not in a CØMMØN block which are used by the subroutine. Variables in CØMMØN blocks are listed in Section 6.1 or Section 11.3. Following the list of variables is a brief description of the analysis performed by the subroutine.

12.0 DETAIL DESCRIPTION OF CØDUCT CODE

12.1 List of Subroutines

Name	Object
ARCL1	Calculate arc length of input curve
BLKRED	See Section 7.2
CDVDN	Calculate streamline curvature
CØBLK	Block data (IBM version)
CØDUCT	Main program (see Section 11.1)
CLØSUR	Calculate closure error in mapping
CØNSTR	Store fixed data in Q1, Q2 arrays
CØØRD	Calculate coordinates and metrics
CØØRMD	Calculate coordinates J = 2, JL
CØØR1D	Calculate coordinates J = 1
CØRINP	Read coordinate data
CØRSTR	Store coordinates in Q1 array
CRØSS1	See Section 7.2
DERIV3	Calculate 3 point central difference derivative
DRØBRT	See Section 7.2
ESTCØR	Determine locationof approximate potential line
ESTIMP	Calculate approximate pole locations
INSECT	Determine intersection of potential line and wall
INTNØR	Calculate end point of potential line
INTSTR	Calculate end point of streamline

12.1 List of Subroutines (Cont'd)

Name	Object
KURVTR	Calculate curvature of input curve
MDAVIS	Solve Schwartz-Christoffel mapping
NØRLIN	Calculate single potential line
QPKURV	Interpolates curvatures at output location
QPSTØR	Store Q parameters in Q1, Q2 arrays
Q2INTP	Interpolate from uniform to non-uniform mesh
RCNTRL	Reads user input control parameters
RØTATM	Calculate duct rotation and scaling
SMARCL	Cubic spline smoothing on arc length
SMØØTH	See Section 7.2
STEP	Davis' integration formula
STRSTP	Integrate each streamline one step
SUNBAR	Store X, Y data into interpolation table T
TTUP	Update upper wall upstream point
UNBAR	Lagrange table interpolation
WALLV	Approximate potential flow wall velocity
XFGRID	Interpolate uniform to nonuniform grid

12.2 Description of Subroutines

Subroutine ARCL1 (X,Y,NPT,S)

Object

Calculate arc length of input curve

Options

None

Symbols

NPT		Number of input points
S(I)	S_I	Arc length
X(I),Y(I)	X_I, Y_I	Coordinates of input curve

Theory

The arc length of a curve is given by

$$S_J = \sum_{I=2}^{J} \left\{ (X_I - X_{I-1})^2 + (Y_I - Y_{I-1})^2 \right\}^{1/2} \qquad (1)$$

Subroutine CDVDN (NPT,DZDT)

Object

Calculate streamline curvature

Options

None

List of Symbols

DZDT	dZ/dt	,	Complex derivative of mapping
NPT		,	Number of points in DZDT
Q1(7,K)	$\partial v/\partial n$	,	Streamline curvature

Theory

The magnitude of the potential flow velocity is

$$V = \left| \frac{dt}{dZ} \right| \tag{1}$$

Then the streamline curvature is given by

$$\kappa = -\partial V/\partial n \tag{2}$$

The curvature is obtained by numerical differentiation using subroutine DERIV3 for K = 2, KL -1. At the wall the streamline curvature is given by the wall curvature obtained from the input data.

Subroutine CLØSUR

Object

Calculate closure error in mapping

Options

None

List of Symbols

NLF		Number of wall points
Z	Z	Duct plane coordinates
ZCL	ε_{CL}	Closure error
TT	t	t-plane coordinates

Theory

The solution is integrated from t_1 to $t_{NLF} + i$ by two paths to close the polygon. The closure error is defined by

$$\epsilon_{CL} = \left| Z(t_{NLF} + i)_1 - Z(t_{NLF} + i)_2 \right| \quad (1)$$

Subroutine CØBLK

BLOCK DATA

Object

Defines default values for program control

List of Symbols

NXNT	Maximum number of wall definition points total
NXNTD2	Maximum number of wall definition points for each wall, also maximum number of potential lines permissible
IST	Maximum number of streamlines
NVK	Maximum number of knots to use in cubic-spline fit to wall data
IPOINT	Logical unit number to read from
IWUNIT	Logical unit number to write to

Subroutine CØNSTR

Object

Store fixed data in Q1, Q2 arrays

Options

IGRID	= 0	Uniform mesh
	= 1	Nonuniform mesh
	= 2	Both meshes

Input Symbols

DDS	$(\Delta\eta/\Delta n)_1$	Mesh distortion parameter
DETA	$\Delta\eta$	Uniform transverse step size
JL		Number of streamwise stations
KL		Number of nonuniform streamlines
KN		Number of uniform streamlines
LØP		Mesh distortion option
SAVG		Average length of duct

Output Symbols

Q1	Uniform mesh block data
Q2	Nonuniform mesh block data

Theory

CØNSTR is a general setup program that stores information into the Q1 and Q2 data blocks. These stored variables are ones that do not change for J =1, JL.

$$\left.\begin{aligned} Q1(5,K) &= 1. \\ Q1(16,K) &= 0. \\ Q1(17,K) &= 0. \\ Q1(18,K) &= \eta \end{aligned}\right\} \quad K = 1,KN \tag{1}$$

$$\left.\begin{aligned} Q2(5,K) &= 1. \\ Q2(16,K) &= d\eta/dn \\ Q2(17,K) &= n \\ Q2(18,K) &= \eta \end{aligned}\right\} \tag{2}$$

Subroutine CØØRD

Object

Calculate coordinates and metrics

Options

IGRID	= 0	Uniform grid output to IUUNIT
	= 1	Nonuniform grid output to INUNIT
	= 2	Output both grids

Input Signals

DDS	$\Delta\eta/\Delta n$	Mesh distortion parameter
DETA	$\Delta\eta$	Uniform step size
JL		Number of streamwise stations
JLPTS		Number of points on wall
KL		Number of nonuniform streamlines
KN		Number of uniform streamlines
LØP		Mesh distortion option
NNS		Number of steps on potential line

Output Symbols

Q1(I,K)	Coordinate data uniform grid
Q2(I,K)	Coordinate data nonuniform grid

Theory

Once the mapping solution has converged, the location of the poles are known and the solution can be obtained for any interior point by integrating the Schwartz-Christoffel transformation. The streamwise integration step ΔS is defined in subroutine CØNSTR by

$$\Delta S = (\max(t_U, t_L) - \min(t_U, t_L))/(JL-1) \tag{1}$$

and the normal integration step is defined by

$$\Delta n = 1/(KN-1) \tag{2}$$

Then integration of dZ/dt with n constant produces a streamline and integration with S constant produces a potential line.

To start the coordinate calculation, CØØR1D is called to integrate the first potential line at the duct inlet. We note that dz/dt calculated by subroutine STEP is evaluated at the point

$$n_{K+1/2} = (n_{K+1} + n_K)/2 \tag{3}$$

such that the metric is given by

$$\left(\frac{dZ}{dt}\right)_K = \frac{1}{2}\left[\left(\frac{dZ}{dt}\right)_{K+1/2} + \left(\frac{dZ}{dt}\right)_{K-1/2}\right] \tag{4}$$

$$V_K = 1\Big/\left|\frac{dZ}{dt}\right|_K \tag{5}$$

The remainder of the computation grid is constructed by integrating all the streamlines in the streamwise direction one step using subroutine CØØRMD. Again we note that the derivative is evaluated at the mid point so that

$$\left(\frac{dZ}{dt}\right)^J = \frac{1}{2}\left[\left(\frac{dZ}{dt}\right)^{J+1/2} - \left(\frac{dZ}{dt}\right)^{J-1/2}\right] \tag{6}$$

$$V^J = 1\Big/\left|\frac{dZ}{dt}\right|^J \tag{7}$$

The integration is continued to J = JL + 1/2.

Subroutine CØØRMD (J)

Object

Calculate coordinates J = 2, JL

Options

IGRID	= 0	Uniform grid output to IUUNIT
	= 1	Nonuniform grid output to INUNIT
	= 2	Output both grids

Input Symbols

DSTEP	ΔS	Streamwise step size
DZDTJ	$\left(\frac{dZ}{dt}\right)^J$	Derivative at J
DZDTJ1	$\left(\frac{dZ}{dt}\right)^{J-1}$	Derivative at J-1
J		Streamwise index
KL		Number of nonuniform streamlines
KN		Number of uniform streamlines
ZJ	Z^J	Coordinate at J
ZJ1	Z^{J-1}	Coordinate at J-1

Output Symbols

Q1	Coordinate data uniform grid
Q2	Coordinate data nonuniform grid

Theory

The derivatives of the metrics ($\partial V/\partial n$, $\partial V/\partial S$) are obtained by the three point difference formula. Thus we have

$$\left(\frac{dZ}{dt}\right)_K^J = \frac{1}{2}\left[\left(\frac{dZ}{dt}\right)_K^{J+1/2} + \left(\frac{dZ}{dt}\right)_K^{J-1/2}\right] \tag{1}$$

and

$$V_K^J = 1 \Big/ \left|\frac{dZ}{dt}\right|_K^J \tag{2}$$

Since dZ/dt are known at the mid points we have

$$\frac{dV_K^J}{ds} = \frac{1}{2\Delta S}\left\{\frac{1}{2}\left[V_K^{J+1/2} + V_K^{J+3/2}\right] - V_K^{J-1}\right\} \qquad (3)$$

The derivative $\partial V/\partial n$ is obtained using subroutine CDVDN and the remaining variables are defined and calculated for the KN points on the uniform mesh by calling subroutine CØRSTR. Subroutine Q2INTP interpolates from the KN uniform mesh points to the KL nonuniform mesh points.

Subroutine CØØR1D

Ojbect

Calculate coordinates at J = 1

Options

IGRID	= 0	Uniform grid output to IUUNIT
	= 1	Nonuniform grid output to INUNIT
	= 2	Output both grids

Input Symbols

DSTEP	ΔS	Streamwise step size
KL		Number of nonuniform streamlines
KN		Number of uniform streamlines
NNS		Number of steps in n integration

Output Symbols

DZDT2	Derivative at J = 2
DZDT3	Derivative at J = 1
Q1	Coordinate data for uniform grid
Q2	Coordinate data for nonuniform grid
Z2	Coordinate at J = 2
Z3	Coordinate at J = 3

Theory

The first potential line is calculated by calling subroutine NØRLIN. Then derivatives of the metrics ($\partial V/\partial n$, $\partial V/\partial S$) are obtained by 3 point difference formula. Thus we have

$$\left(\frac{dZ}{dt}\right)_K^J = \frac{1}{2}\left[\left(\frac{dZ}{dt}\right)_K^{J+1/2} + \left(\frac{dZ}{dt}\right)_K^{J-1/2}\right] \tag{1}$$

$$V_K^J = 1 \Big/ \left|\frac{dZ}{dt}\right|_K^J \tag{2}$$

The streamlines are integrated to J = 4 using subroutine STRSTP. Then we have

$$\left(\frac{\partial V}{\partial S}\right)_K^1 = \frac{1}{\Delta S}\left\{-3V_K^1 + 4\left[\frac{V_K^{3/2} + V_K^{5/2}}{2}\right] - \left[V_K^{5/2} + V_K^{7/2}\right]\right\} \tag{3}$$

The derivative $\partial V/\partial n$ is calculated using subroutine CDVDN and the remaining variables are defined and calculated for the KN points on the uniform grid by calling subroutine CØRSTR. Subroutine Q2INTP interpolates from the KN uniform grid to the KL nonuniform grid.

Subroutine CØRINP

Object

Read coordinate data

Options

ISMØØT	= 0	Do not smooth wall data
	= 1	Smooth wall data

Input Symbols

JLPTS	Number of smoothed wall data points
JXK	Number of knots in spline smoothing
NLF	Number of input upper/lower wall data points

Output Symbols

XL,YL	X_L, Y_L	Lower wall data points
XU,YU	X_U, Y_U	Upper wall data points
ZC	X_C	Complex coordinates of wall data points
RADR	r_r	Reference radius XU(1)

Theory

The subroutine reads the wall data in card image form. If ISMØØT = 1, a cubic spline smoothing routine SMARCL will produce a set of JLPTS data points for each wall. This subroutine also prints the smoothed and unsmoothed wall data.

Subroutine CØRSTR (J,ZI,DZDT)

Object

Store coordinates in Q1 array

Options

None

Input Symbols

J		Streamwise station number
DZDT	$\left(\frac{dZ}{dt}\right)^J$	Derivative at J
ZI	Z^J	Coordinates at J

Output Sybmols

Q1	Coordinate data block

Theory

The following coordinate data are calculated at J.

$$Q1(1,K) = \text{Im}\ (Z_K^J) = R \qquad (1)$$

$$Q1(2,K) = \text{Re}\ (Z_K^J) = Z \qquad (2)$$

$$Q1(3,K) = \text{Re}\ (dZ/dt)_K^J = \partial R/\partial n \qquad (3)$$

$$Q1(4,K) = \text{Im}\ (dZ/dt)_K^J = \partial R/\partial S \qquad (4)$$

$$Q1(6,K) = 1/|dZ/dt|_K^J = V \qquad (5)$$

$$Q1(9,K) = \int_o^{S_J} \frac{dS}{V} = X \qquad (6)$$

$$Q1(10,K) = \int_o^{n_K} \frac{dn}{V} = Y \qquad (7)$$

$$Q1(11,K) = Q1(10,K)/Q1(10,KN) \qquad (8)$$

$$Q1(12,K) = 2\pi \int_o^{n_K} \frac{Rdn}{V} = A \qquad (10)$$

$$Q1(13,K) = 2\pi\ R \qquad (11)$$

$$Q1(14,K) = 2\pi\ \partial R/\partial n \qquad (12)$$

$$Q1(15,K) = 2\pi\ \partial R/\partial S \qquad (13)$$

Subroutine DERIV3 (X,Y,NX,NPT,DYDX,D2YDX2)

Object

Calculate 3 point central difference derivative

Options

None

Input Symbols

NPT	Point at which to evaluate derivative
NX	Number of data points for X and Y
X,Y	Table of NX independent/dependent variables

Output Symbols

DYDX	dy/dx	First derivative
D2YDX2	d^2y/dx^2	Second derivative

Theory

The finite difference formula are given by:

$$\left(\frac{dY}{dX}\right)^I = \frac{Y^{I+1} - (1-r^2)\,Y^I - r^2\,Y^{I-1}}{X^{I+1} - X^I + r^2\,(X^I - X^{I-1})} \tag{1}$$

$$\left(\frac{d^2Y}{dX}\right)^I = \frac{Y^{I+1} - (1+r)\,Y^I + r\,Y^{I-1}}{(X^{I+1} - X^I)^2 + r\,(X^I - X^{I-1})^2} \tag{2}$$

$$r = \frac{X^{I+1} - X^I}{X^I - X^{I-1}} \tag{3}$$

If I = 1 or NPT a diagnostic is printed

"INPUT PØINT XX OUT OF RANGE"

and both derivatives are set to 1.0.

If $|X^{I+1} - X^{I}|$ or $|X^{I} - X^{I-1}| < 10^{-15}$ a diagnostic is printed

"INDEPENDENT VARIABLE STEP SIZE LT 1.E-15"

and both derivatives are set to 1.0.

Subroutine ESTCØR (SAVG, NPOT)

Object

Determine location of approximate potential line.

Option

NIPØT	=	0	Program determines number of lines
	>	1	NIPØT lines are calculated

Input Symbols

NPØT	N_p	Number of potential lines
SAVG	$\overline{S}$	Average duct length
XL,YL	X_L, Y_L	Lower wall coordinates
XU,YU	X_U, Y_U	Upper wall coordinates

Output Symbols

HT	h	Height of duct
IU,IL		
TH	θ	Angle of mean line
XLI,YLI	X_{LI}, Y_{LI}	Coordinates potential line lower wall
XUI,YUI	X_{UI}, Y_{UI}	Coordinates potential line upper wall

Theory

The object is to determine NPØT approximate potential lines in the duct where NPØT = NLF/3 initially. The first potential line intersects the duct at Z_{U1} and Z_{L1} where the complex notation is used.

$$Z = X + iY \quad (1)$$

We then construct a mean line Zm, (See Fig. 1), which satisfies the following con-conditions:

$$\left| Z_{m,J} - Z_{m,J-1} \right| = \Delta S \tag{2}$$

$$\left| Z_{UI,J} - Z_{m,J} \right| = \left| Z_{m,J} - Z_{LI,J} \right| \tag{3}$$

$$\left(Z_{UI,J} - Z_{LI,J} \right) \cdot \left(Z_{m,J} - Z_{m,J-1} \right) = 0 \tag{4}$$

It was found that the set of equations, Eq. (2) through (4) do not have a unique solution. Therefore Eq. (3) was replaced by a minimum condition on D where:

$$D = 1 - \frac{\left| Z_{UI,J} - Z_{m,J} \right|}{\left| Z_{m,J} - Z_{LI,J} \right|} \tag{5}$$

The algorithm consists of finding an angle θ_J which minimizes D. Thus we have from Eq. (1),

$$Z^{\nu}_{m,J} = Z_{m,J-1} + \Delta S \cdot \left[\cos \theta_J^{\nu} + i \sin \theta_J^{\nu} \right] \tag{6}$$

A straight line normal to the mean line, from Eq. (4), is defined by the point $Z^{\nu}_{m,J}$ and the point,

$$\tilde{Z} = Z_{m,J} + \Delta S \cdot \left[\cos \left(\theta_J^{\nu} + \pi/2 \right) + i \sin \left(\theta_J^{\nu} + \pi/2 \right) \right] \tag{7}$$

The intersections of the line $(\tilde{Z}, Z_{m,J})$ with the duct wall $(Z^{\nu}_{UI,J}, Z^{\nu}_{LI,J})$ is determined using subroutine INSECT. Then D is calculated and checked for a minimum. An iteration procedure determines the θ^{ν}_J which minimizes D.

When the iteration has converged, a check is made to determine if the $Z_{m,J}$ potential line crosses the $Z_{m,J-1}$ potential line inside the duct. If it does, the distance along the mean line ΔS is increased

$$\Delta S = \Delta S \cdot 1.2 \tag{8}$$

and the algorithm is repeated starting with Eq. (6). A maximum step ΔS is fixed by some fraction of the duct height d_m. Thus

$$\Delta S = \min \left[d_m \left| Z_{UI,J} - Z_{LI,J} \right|, \Delta S \right] \tag{9}$$

Z = X + iY

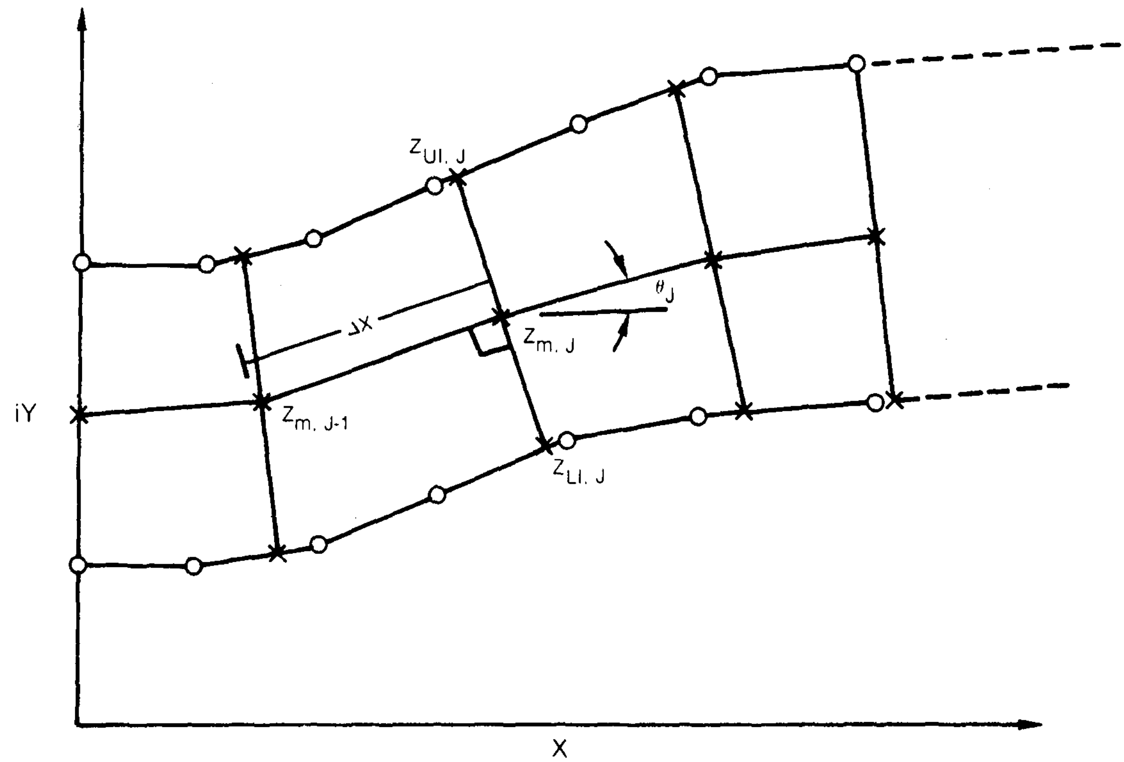


Fig. 1. Geometric Construction of Potential Flow

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Subroutine ESTIMP

Object

Calculate approximate pole locations

Options

None

Input Symbols

N		Total number of poles (2*NLF)
NLF		Number of poles on each wall
ZC	Z_C	Duct coordinates

Output Symbols

B	b_I	Pole locations in plane
TT	t_I	Pole locations in t plane

Theory

The arc lengths S_U, S_L to each pole in the duct (Z) plane is determined using subroutine ARCL1. Subroutine ESTCØR calculates the location of the approximate potential line and subroutine WALLV calculates the approximate potential flow velocities (metrics) at the pole locations in the Z plane. Then the pole locations are given by:

$$t_{UI} = \int_0^{S_{UI}} V_{UI} \, dS \tag{1}$$

$$t_{LI} = \int_0^{S_{LI}} V_{LI} \, dS \tag{2}$$

$$b_{UI} = \exp\left(-\pi t_{UI}\right) \tag{3}$$

$$b_{LI} = -\exp\left(-\pi t_{LI}\right) \tag{4}$$

Subroutine INSECT (Arg. List)

Object

Determine intermine intersection of potential line and wall.

Options

IEXTRP	=	1	Extend last line segment for intersection
	≠	1	Do not extend last line segment.

Argument List

(X1,Y1),(X2,Y2)		Points defining potential line
X,Y	Z	Points defining wall curve
NPT		Number of (X,Y) points
(XI,YI)	Z_I	Intersection point
IØ		Lower index of intersection point
IERR		Error flag = 0 intersection found = -1 no intersection found

Theory

The input coordinates (X,Y) are searched for an intersection with (X1,Y1), (X2,Y2) using subroutine CROSS1 which determines if an intersection occurs between

$$Z(I\emptyset) \le Z_I \le Z(I\emptyset + 1) \qquad (1)$$

Subroutine INTNØR (Arg. List)

Object

Calculate end point of potential line

Options

None

Argument List

ZETO	ζ_o	Starting location in ζ plane
ZO	Z_o	Starting location in Z plane
ZETU	ζ_u	Final location in ζ plane
ZU	Z_U	Final location in Z plane
NNS		Number of steps

Theory

The starting location in the t plane is given by

$$t_0 = i - \ln(\zeta_0)/\Pi \tag{1}$$

and the step size is given by

$$\Delta t = i \cdot 1./(NNS-1) \tag{2}$$

Then

$$Z_U = Z_0 + \sum_{J=1}^{NNS-1} \left\{ \int_{t_0+\Delta t(J-1)}^{t_0+\Delta t \cdot J} \frac{dZ}{dt} dt \right\} \tag{3}$$

where the term in the bracket is evaluated using subroutine STEP.

Subroutine INTSTR (Arg. List)

Object

Calculate end point of streamline

Options

None

Argument List

ZETO	ζ	Starting location in ζ plane
ZO	Z_o	Starting location in Z plane
ZETU	ζ_U	Final location in ζ plane
ZU	Z_U	Final location in Z plane

List of Symbols

NLF		Number of lower wall points
TT	t_I	Pole locations in t plane

Theory

The starting point in the t plane is given by

$$t_0 = i - \ln(\zeta_0)/\pi \tag{1}$$

Define the streamline by

$$t_n = \operatorname{Im}(t_0) \tag{2}$$

Then

$$Z_U = Z_0 + \sum_{I=2}^{NLF} \left\{ \int_{t_{I-1}+t_n \cdot i}^{t_{I-1}+t_n \cdot i} \frac{dZ}{dt}\, dt \right\} \tag{3}$$

where the bracket is evaluated using subroutine STEP.

Subroutine KURVTR (Arg. List)

Object

Calculate curvature of input curve

Options

None

Argument List

X,Y	X,Y	Coordinates of input curve
S	S	Arc length of input curve
NPT		Number of points on curve
KURV	κ	Curvature of input curve

Theory

The principal curvature of a curve is given by

$$\kappa = \frac{dX}{dS}\frac{d^2Y}{dS} - \frac{dY}{dS}\frac{d^2X}{dS^2} \tag{1}$$

Eq. (1) is evaluated by 3 point finite difference formula

Subroutine MDAVIS

Object

Solve Schwartz-Christoffel Mapping

Options

None

Input Symbols

ECØN	ε_c	Convergence criteria
NLF		Number of points on wall
TT	t	Initial pole location t plane
ZC	Z_c	Duct wall coordinates

Output Symbols

TT	t	Final pole location in t plane
Z	Z	Final pole location in Z plane

Theory

The flow chart for this subroutine is shown on Fig. 2 and takes place in the following steps:

Step 1 Initialization

a) Calculate rotation constant M

b) Calculate duct exit divergence angle α_e

c) Calculate Schwartz-Christoffel pole angle α_i

Step 2 Integrate Transformation

a) Integrate Schwartz-Christoffel transformation along each wall with a guess for the b_i's in the ζ plane using subroutine STEP.

b) Integrate Schwartz-Christoffel transformation along far upstream potential line with a guess for b_i's in ζ plane using subroutine NØRLIN.

Step 3 Update Poles

a) Update poles on lower wall in t plane by ratio of arc lengths.

b) Update first pole on upper wall using Step 2b.

c) Update poles on upper wall in t plane by ratio of arc lengths.

d) Calculate pole location b_i's in ζ plane.

Step 4 Check Convergence

a) Calculate absolute error for all poles

$$\varepsilon_i = |Z_i - Z_{Ci}|$$

b) Check convergence

$$\max (\varepsilon_i) < \varepsilon_c$$

c) Calculate closure error using subroutine CLØSUR

d) If not converged repeat Steps 2, 3, 4
If converged return

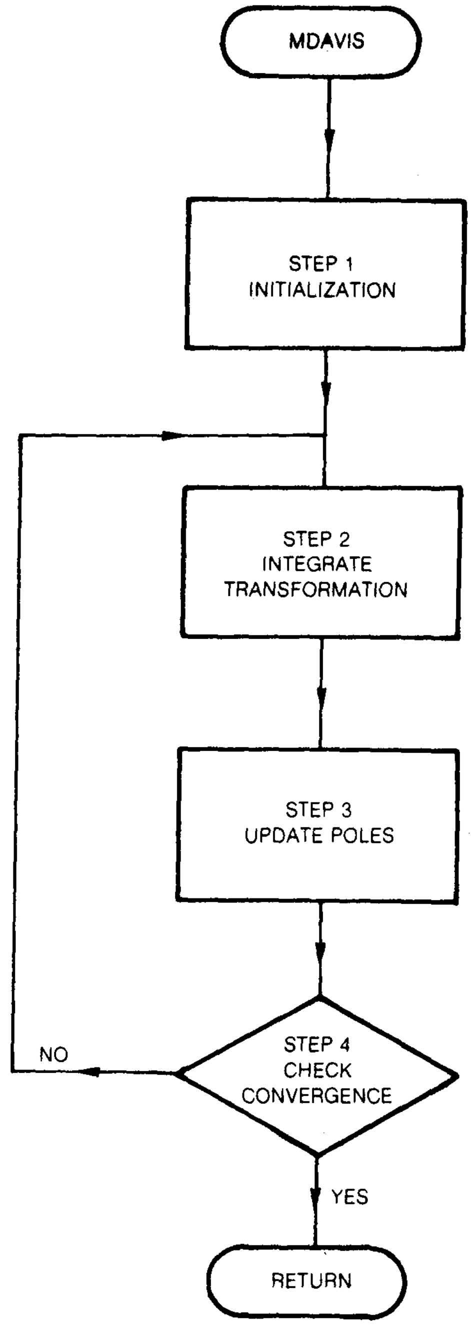

Fig. 2. Flow Chart for Subsonic MDAVIS

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Subroutine NØRLIN (J,Z)

Object

Calculate single potential line

Options

None

Input Symbols

J		Calculate Jth potential line
KN		Number of output stations
NNS		Number of integration steps
TT	t_i	Pole locations in t plane
ZO	Z_o	Initial Z location

Output Symbols

Z1	Z_K	Coordinates of potential line
DZDT1	$(dZ/dt)_K$	Derivative

Theory

After a converged solution for the pole locations is obtained, this subroutine integrates the potential line at the Jth station in NNS steps and outputs the coordinates and derivatives of KN stations. Then let us choose

$$NNS = NSD * (KN - 1) + KN \qquad (1)$$

where NSD is the number of integration steps per output station. The integration starts at Z_o in the Z plane and t_o given by

$$t_0 = DSTEP\ (J-1) - t_L/2 + 0 + i \qquad (2)$$

in the t plane. The parameter t_L is chosen in the approximate coordinate calculation to center the pole distributions about plus and minus values.

The integration step is then given by

$$\Delta t = 1/(NNS-1) * i \tag{3}$$

Then we have the recursion formula

$$Z_1 = Z_0 \tag{4}$$

$$Z_K = Z_{K-1} + \int_{t_{K-1}+\Delta t \cdot (L-1)}^{t_{K-1}+\Delta t \cdot L} \frac{dZ}{dt}\, dt \tag{5}$$

$$\left(\frac{dZ}{dt}\right)_{t_K} = \frac{1}{2}\left[\left(\frac{dZ}{dt}\right)_{t_K-\Delta t} + \left(\frac{dZ}{dt}\right)_{t_K+\Delta t}\right] \tag{6}$$

Subroutine QPKURV

Object

Interpolates wall curvature at output location

Options

None

Input Symbols

KKL,KKU	K_L, K_U	Curvature of lower/upper wall
XL,YL	X_L, Y_L	Input coordinates lower wall
XU,YU	X_U, Y_U	Input coordinates upper wall
SL,SU	S_L, S_U	Arc length lower/upper wall
Q1		Coordinate data

Output Symbols

RHS1(3)	$K_L(J)$	Curvature lower wall
RTS1(3)	$K_U(J)$	Curvature upper wall

Theory

The streamline curvature KKL and KKU is known at the input data points (XL,YL) and (XU,YU) respectively. The coordinates are known at station J for equal streamwise steps DSTEP. Let $(\tilde{X}_L, \tilde{Y}_L)$ and $(\tilde{X}_U, \tilde{Y}_U)$ be the lower and upper wall coordinates at station J obtained from the Q1 array. A straight line is passed through these points and a serarch of the input coordinates is made using subroutine INSECT to determine the intersection on each wall. Subroutine INSECT returns an interpolation parameter which is used to calculate $K_L(J), K_U(J)$

Subroutine QPSTØR(J)

Object

Store Q parameters in Q1, Q2 arrays

Options

IGRID	=	0	Uniform grid
	=	1	Nonuniform grid
	=	2	Both grids
IXFG	=	0	Uniform grid
	=	1	Interpolate only

Input Symbols

DSTEP	ΔS	Streamwise step size
JL		Number of potential lines
KL		Number of streamlines
RADR	r_r	Reference radius

Output Symbols

RHS1,RMS1,RTS1	Wall coordinate data uniform grid
RHS2,RMS2, RTS2	Wall coordinate data nonuniform grid
QPARM1	Parameters for uniform grid
QPARM2	Parameters for nonuniform grid

Theory

The wall coordinate data and grid parameters are calculated by this subroutine.

Subroutine Q2INTP

Object

Interpolate from uniform grid to nonuniform grid

Options

None

Input Sybmols

KL	Number of output streamlines
KN	Number of input streamlines
Q1	Coordinate data for uniform grid

Output Symbols

Q2	Coordinate data for nonuniform grid

Theory

The normal coordinate for a uniform grid is Q1(19,K) K=1,KN and the normal coordinate for the nonuniform grid is Q2(18,K) K=1,KL. The Q2 variables are obtained from the Q1 variables by linear interpolation using the normal coordinate as the independent variable.

Subroutine RCNTRL

Object

Reads user input control parameters

Options

None

Input Signals

See input data Section 10.2

Theory

This subroutine reads the input control parameters, checks for inconsistencies and prints the input data.

Subroutine RØTATM

Object

Calculate duct rotation and scaling

Options

None

Input Symbols

ZC	Z_c	Input duct coordinates

Output Symbols

XM	M	Rotational constant

Theory

Far upstream of the duct inlet $\zeta \to \infty$ and the Schwartz-Christoffel transformation reduces to

$$\frac{dZ}{d\zeta} = \frac{M}{\zeta} \tag{1}$$

Integrating Eq. (1) we have

$$Z = M \ln \zeta + Z_0 \tag{2}$$

The tranformation to the t plane is given by

$$\ln \zeta' = \pi (i - t) \tag{3}$$

and Eq. (2) becomes a duct with parallel walls.

$$Z = M \pi (i - t) + Z_0 \tag{4}$$

Subtracting the lower wall from the upper wall we have

$$Z_U - Z_L = - M \pi i \tag{5}$$

The height of the duct is given by

$$H = |Z_U - Z_L| \tag{6}$$

Hence

$$Z_U - Z_L = He^{i(\theta+\pi/2)} \tag{7}$$

where θ is the angle of the duct with respect to the real axis.

Then solving for M using Eq. (5) and Eq. (7) we have

$$M = \frac{-H}{\pi} e^{i\theta} \tag{8}$$

Since this solution requires parallel walls, this subroutine will modify the Nth point of the data set to insure parallel walls at the inlet so that the correct duct height H can be determined at the inlet.

Subroutine SMARCL (Arg. List)

Object

Cubic spline smoothing on arc length

Options

None

Argument List

JX		Number of input coordinate points
JXB		Number of ouptut coordinate points
JXK		Number of knots in spline fit
X,Y	X,Y	Input coordinates
S	X	Arc length along input curve
SB	$\bar{S}$	Arc length along output curve
XB,YB	$\bar{X},\bar{Y}$	Output smoothed coordinates

Theory

The arc length along the input curve is calculated using subroutine ARCL1. Then an increment of arc length is defined by

$$\Delta\bar{S} = (S(JX) - S(1)) / (JXB - 1) \tag{1}$$

The curves X(S) and Y(S) are smoothed using subroutine SMØØTH which returns $\bar{X}(\bar{S})$ and $\bar{Y}(\bar{S})$ for JXB points spaced $\Delta\bar{S}$ in length

Subroutine STEP(ZETD1,DZETD,DZ)

Object

Calculate Integration Step For Schwartz-Christoffel Transformation

Options

None

Variables

B(K)	=	b_K	,	Location of pole in ζ plane
BETM(K)	=	$-\alpha_K/\pi$	,	Turning angle in Z plane
DZ	=	ΔZ_m	,	Step size in Z plane
DZETD	=	$\Delta\zeta_m$	,	Step size in ζ plane
		Δt_m	,	Step size in t plane
XM	=	M	,	Scale factor
ZETD1	=	ζ_m	,	Initial ζ
ZETD2	=	ζ_{m+1}	,	Final ζ
NBE	=	N	,	Number of poles
GAMA	=	γ_m	,	Exit divergence angle

Theory

The second order integration formula evaluated at the mid point is given by Davis Ref. 1 as

$$\left(\frac{dZ}{d\zeta}\right)_{M+1/2} = \frac{M}{\zeta_{M+1/2}}\,\zeta_{M+1/2}^{\alpha M/\pi}\prod_{I=1}^{N}\left\{\frac{\left(\zeta_{M+1}-b_I\right)^{-a_I/\pi+1}-\left(\zeta_M-b_I\right)^{-a_I/\pi+1}}{\Delta\zeta_M\left(-a_I/\pi+1\right)}\right\} \quad (1)$$

where

$$\Delta\zeta_M = \zeta_{M+1}-\zeta_M \quad (2)$$

$$\zeta_{M+1/2} = \frac{1}{2}\left(\zeta_{M+1}+\zeta_M\right) \quad (3)$$

The transformation to the t plane is given by

$$\left(\frac{dt}{d\zeta}\right)_{M+1/2} = -\frac{1}{\pi\zeta_{M+1/2}} \tag{4}$$

Then we have

$$\Delta Z_M = \left(\frac{dZ}{d\zeta}\right)_{M+1/2} \Bigg/ \left(\frac{dt}{d\zeta}\right)_{M+1/2} \Delta t_M \tag{5}$$

where Δt_m is chosen by the input ζ's.

$$\Delta t = -\left(\ln \zeta_{M+1} - \ln \zeta_M\right) / \pi \tag{6}$$

References

1. Davis, R. T.: Numerical Methods for Coordinate Generation Based on Schwartz-Christoffel Transformations.

Subroutine STRSTP

Object

Integrate each streamline one step

Options

None

Argument List

J		Streamwise station
ZI	Z^J	Coordinates at J
ZO	Z^{J+1}	Coordinates at J+1
DZDTO	$(dZ/dt)^{J+1/2}$	Derivative at mid point

Theory

This subroutine integrates K = 1, KN streamlines one step

$$Z_K^{J+1} = Z_K^J + \left(\frac{dZ}{dt}\right)_K^{J+1/2} \Delta t \quad (1)$$

using subroutine STEP.

Subroutine SUNBAR (X,Y,T,NPT,NORDER)

Object

Stores X,Y data into interpolating Table T

Options

None

Input Symbols

X,Y	x,y	Independent variable arrays
NPT		Number of data pairs (X,Y)
NORDER		Interpolation order (= 1, 2 or 3)

Output Symbols

T	Output interpolation table

Theory

The data is stored into T as follows

```
T(1) = 1.
T(2) = NORDER
T(3) = NPT
T(4) = 0.
T(J + 4) = X(J), J = 1,NPT
T(J + NPT + 4) = Y(J), J = 1,NPT
```

Subroutine TTUP (ITER,ZU)

Object

Update upper wall upstream point

Options

None

Input Symbols

ITER	ν	Iteration number
THETA1	θ_1	Angle of duct rotation from real axis
TT	t_i^ν	Location of poles in t plane
ZC	Z_{ci}	Input wall coordinates
ZU	Z_U	End point of potential line integration

Output Symbols

TT(N)	$t_N^{\nu+1}$	Updated t plane coordinate at point N

Theory

This subroutine updates the corner point Z_N to close the polygon by jumping from the lower wall to the upper wall as shown in Fig. 3. With known t_i^ν, the point Z_N^ν is determined by integrating along the path (Z_{c1},A,Z_N^ν). The error in closing the polygon is given by

$$\mathscr{E} = \left| Z_N^\nu - Z_{CN} \right| \tag{1}$$

The update $t_N^{\nu+1}$ is determined in the following manner. Let us define upstream points t_1' and t_N' given by

$$t_1' = t_1 - \sigma \left| t_1^\nu \right| \tag{2}$$

$$t_N' = t_1' + i \tag{3}$$

where σ is a parameter chosen to move t_1' sufficiently upstream to approximate the limiting case $t \to -\infty$

$$Z = \pi M (i - t) + Z_0 \tag{4}$$

Then

$$Z_N' - Z_1' = -\pi M i \tag{5}$$

The point Z_1' is determined by integrating along the path (Z_{c1}, Z_i') and Z_N' is determined from Eq. (5). A ratio of wall lengths is defined

$$R = \frac{|Z_{CN} - Z_N'|}{|Z_N^{\nu} - Z_N'|} \tag{6}$$

and the update for t_N^{ν} is given by

$$t_N^{\nu+1} = t_N' + R\left(t_N^{\nu} - t_N'\right) \tag{7}$$

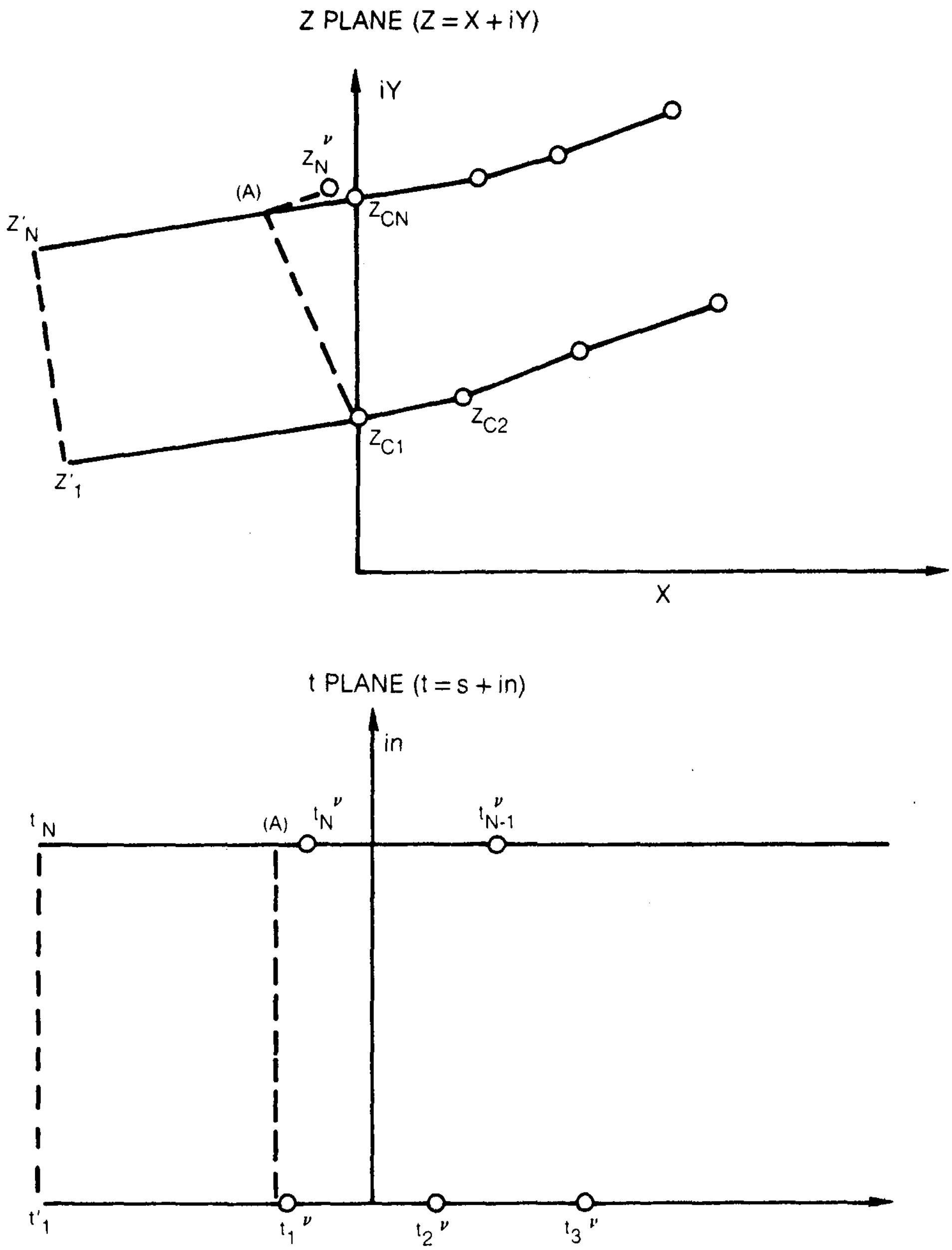

Fig. 3. Update for Corner Point

81–10–63–3

Subroutine UNBAR (T,IK,XIN,YIN,ZZ,KK)

Object

Interpolate a univariate or bivariate table.

Input Symbols

T	=	Name of the array which contains the table values.
IK	=	Element of the array at which the table starts. If you have only one table in the array, IK=ONE.
XIN	=	Independent variable in the X-sense.
YIN	=	Independent variable in the Y-sense. If the table is a univariate, then YIN is zero.

Output Symbols

ZZ	=	Dependent variable
KK	=	Off Table indicator
	=	0 Normal evaluation
	=	1 Off On X Min.
	=	2 Off On X Max.
	=	3 Off On Y Min.
	=	4 Off On X Min. and Y Min.
	=	5 Off On X Max. and Y Min.
	=	6 Off On Y Max.
	=	7 Off On X Min. and Y Max.
	=	8 Off On X Max. and Y Max.
	=	Less Than 0, Table set up wrong.

Theory

If either variable is off the table, UNBAR will return the corner value. This implies that UNBAR will not extrapolate and does not recognize any discontinuities. The table must be set up as follows-all numbers are in floating point mode.

T(IK)	=	Curve No.
T(IK+1)	=	Degree of Interpolating (1, 2, 3)
T(IK+2)	=	NX. No. of X values
T(IK+3)	=	NY. No. of Y values. (in univariate make zero)
T(IK++)	=	X values in ascending order.
T(IK++)	=	Y values in ascending order.
T(IK++)	=	Z values. Put them in following order- (Z(1.1),Z(1,2), Z(1,3)---Z(1,NY),Z(2,1),Z(2,2)---Z(2,NY)---Z(NX,1), Z(NX,2)---Z(NX,NY). For bivariate only.

A Lagrongian interpolation polynomial of degree 1, 2 or 3 will be used for the interpolation depending upon T(IK+1).

Subroutine WALLV

Object

Approximate potential flow velocity

Options

None

Input Symbols

HT	h	,	Approximate duct height
IL,IU		,	Indices for lower/upper wall potential line
NPØT	N_p	,	Number of potential lines
SAVG	$\bar{S}$	,	Average duct length
SL,SU	S_L, S_U	,	Arc length lower/upper wall
TH	θ	,	Mean line angle
XL,YL	X_L, Y_L	,	Coordinates lower wall
XU,YU	X_U, Y_U	,	Coordinates upper wall
XLI,YLI	X_{LI}, Y_{LI}	,	ESTCØR coordinates lower wall
XUI,YUI	X_{UI}, Y_{UI}	,	ESTCØR coordinates upper wall

Output Symbols

VL,VU	V_L, V_U	,	Velocity lower/upper wall

Theory

For each computed potential line, the wall velocity can be estimated as follows

$$\bar{V} = 1/n \tag{1}$$

and the curvature of the mean line by

$$\bar{K} = \frac{d\theta}{d\bar{S}} \tag{2}$$

Then define

$$\phi = \frac{1-\bar{K}/(2\bar{V})}{1+\bar{K}/(2\bar{V})} \qquad (3)$$

and the approximate velocity at the wall is given by

$$V_{UI} = \frac{2}{1+\phi}\,\bar{V} \qquad (4)$$

$$V_{LI} = \frac{2\phi}{1+\phi}\,\bar{V} \qquad (5)$$

Arc lengths S_{LI} and S_{UI} may be calculated using subroutine ARCL for the lower and uppwer walls defined by (X_{LI},Y_{LI}) and (X_{UI},Y_{UI}). The linear interpolation is used with arc length as an independent variable to interpolate V_L and V_U from the table V_{LI},V_{UI}.

Subroutine XFGRID

Object

Interpolate uniform to nonuniform grid

Options

None

Input Symbols

DDS	Mesh distortion parameter
KL	Number of output streamlines
Q1	Input coordinate data array

Output Symbols

Q2	Output coordinate data array

Theory

If IXFG option is turned on, only this subroutine is called by the main program CØDUCT. This subroutine reads in input coordinate file from unit IUUNIT, interpolates the Q1 array with KN uniformly spaced streamlines to obtain the Q2 array with KL nonuniformly spaced streamlines and stores the output on unit INUNIT.

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16. Abstract

This User's Manual contains a complete description of the computer codes known as the Axisymmetric Diffuser Duct (ADD) code. It includes a list of references which describe the formulation of the ADD code and comparisons of calculation with experimental flows. The input/output and general use of the code is described in the first volume. The second volume contains a detailed description of the code including the global structure of the code, list of FORTRAN variables, and descriptions of the subroutines. The third volume contains a detailed description of the CODUCT code which generates coordinate systems for arbitrary axisymmetric ducts.

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