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INPUT DESCRIPTION FOR JAMESON'S THREE-DIMENSIONAL TRANSONIC AIRFOIL ANALYSIS PROGRAM

By Perry A. Newman and Ruby M. Davis
February 7, 1974

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16. Abstract This paper describes the input parameters for a computer program which has been developed by Antony Jameson of the Courant Institute of Mathematical Sciences, New York University under NASA Grant NGR-33-016-167. The program performs calculations for inviscid isentropic transonic flow over 3-D airfoils with straight (may be yawed but not swept) leading edges. The free-stream Mach number is restricted only by the isentropic assumption. Weak shock waves are automatically located where ever they occur in the flow. The finite-difference form of the full equation for the velocity potential is solved by the method of relaxation, after the flow exterior to the airfoil is mapped to the upper half plane. The mapping procedure allows exact satisfaction of the boundary conditions and use of supersonic free stream velocities. The finite difference operator is "locally rotated" in supersonic flow regions so as to properly account for the domain of dependence. The relaxation algorithm has been stabilized using criteria from a time-like analogy. The brief description contained in this paper should enable one to use the program until a formal user's manual is available.

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INPUT DESCRIPTION FOR JAMESON'S THREE-DIMENSIONAL TRANSONIC AIRFOIL ANALYSIS PROGRAM

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Langley Research Center

SUMMARY

This paper describes the input parameters for a computer program which has been developed by Antony Jameson of the Courant Institute of Mathematical Sciences, New York University under NASA Grant NGR-33-016-167. References 1 and 2 describe the method and give several sample results; however, a user's manual (ref. 3), is not yet available. A version of the program which was successfully demonstrated on the CDC system here at NASA Langley is available as Langley Program A4231. This paper gives a description of the input parameters and a listing of input data cards and some output results for a sample case. It should enable one to use this program until a final version with its formal user's manual is available.

A brief description of the program and type of problems it will handle is given in the computer program abstract which is reproduced as Figure A1 of Appendix A. Further details concerning the method are given in references 1 and 2. An overlay diagram and a list of subroutine names and functions are given as Figures A2 and A3 respectively.

Computer storage and time requirements for a three-dimensional problem limit what can reasonably be done on present computers. Therefore, in practice, this 3-D program does not have the flexibility (with respect to grid size, number of grid halvings, and multiple case runs) of similar 2-D analysis programs (refs. 4-7) which are based on the full nonlinear potential formulation. In this program, the potential function G is a large three-dimensional array which, in essence, determines both the central memory storage and the computational time. Typical runs, at the dimensions stored on the data cell, require (a) 15-30 minutes CPU time on a CDC 6600 (using a run compiler) to reach a convergence criterion of about 10^{-5} and (b) 322K (base 8) central memory storage. These runs would start on a coarse grid (64 x 8 x 16) and be halved only once. Iterations take very close to 8 times as long on the resulting fine grid (128 x 16 x 32). The maximum values quoted here and on the following pages are those consistent with the data cell dimensioning and one halving of the grid; these, of course, can be changed somewhat. In practice there is little advantage in using the multiple case capability; thus it is recommended that single cases be run.

INPUT DESCRIPTION

Read Order	Number Cards	Description and Comments
1	1	TITLE. - Descriptive title of case or sequence; Format (8A10) Appears on Varian Plots and beginning of output.
2	1	DESC. - Description for card in Read Order 3 Format (8A10).
3	1	FNX, FNY, FNZ, FPLOT Format (8E10.7)
		Note: A number of quantities are read in as floating-point numbers and converted to integers within the program.
		FNX. - Number of computational grid points in "chordwise direction" from downstream infinity, around the leading edge and back to downstream infinity on coarsest mesh. Maximum is 64 (128 with no grid halving).
		FNY. - Number of computational grid points in "normal direction" from airfoil surface to infinity on coarsest mesh. Maximum is 8 (16 with no grid halving).
		FNZ. - Number of computational grid points in "spanwise direction" from infinity, across the wing span and to infinity on coarsest mesh. Maximum is 16 (32 with no grid halving).
		FPLOT. - Plot trigger. Selects type of plot for chordwise surface pressure coefficients. FPLOT = 0. Printer plots, one at each spanwise grid plane section with CP versus the computational grid chordwise variable.

Read Order	Number Cards			Description and Comments
				FPLOT = 1. Varian plots (from THREED). These are superimposed plots, with all span sections shown on two figures, an upper surface and a lower surface plot of CP versus physical space chordwise variable.
				FPLOT = 2. Varian plots (from THREED) as above plus section plots (from GRAPH). These latter plots, one per section, give upper and lower surface CP versus physical space chordwise variable.
				Defaults to zero
4	1	DESC.	-	Description for card in Read Order 5 Format (8A10).
5	1 card for each computational grid. Maximum essentially 2, dimensioned 3.	FIT, COVO, P10, P20, P30, BETAO, STRIPO, FHALF		Format (8E10.7)
		FIT.	-	Maximum number of iterations on this gird, called MIT in program.
		COVO.	-	Convergence criterion on the maximum change in reduced velocity potential (G) from one iteration cycle to the next on this grid.
		P10.	-	Subsonic point relaxation factor on this grid; <u>must be <2.</u>. Typically 1.6 on coarse grid.
		P20.	-	Supersonic point relaxation factor; <u>must be ≤ 1.</u>. Should use 1.0 for stability on all grids.
		P30.	-	Circulation relaxation factor. May be > 1.0 .
		BETAO.	-	Stabilization factor used at supersonic points in finite difference operator if BETAO > 0. Most needed when M_∞ >1., many cases operate satisfactorily with BETAO = 0. Convergence is slowed but stability enhanced when BETAO >0.

Read Order	Number Cards		Description and Comments
		STRIPO. -	Line relaxation control. Computational X-Y planes are relaxed by horizontal lines (YSWEEP) in central strip, vertical lines (XSWEEP) in outer strips. STRIPO specifies the fraction of computational plane included in central strip: $0. \leq \text{STRIPO} \leq 1.$, where STRIPO=1. gives all horizontal line relaxation.
		FHALF. -	Grid halving trigger. $\lvert\text{FHALF}\rvert \geq 1.$ read another card (Read Order 5 format) containing computational parameters to be used on grid with mesh size halved in all directions. $\lvert\text{FHALF}\rvert < 1.$ must appear on finest grid card (last one read). Calculation proceeds automatically through the sequence of computational grids.
6	1	DESC. -	Description for card in Read Order 7 Format (8A10).
7	1	FMACH, YA, AL, CDO	Format (8E10.7)
		FMACH. -	Freestream Mach number.
		YA. -	Yaw angle (in degrees).
		AL. -	Angle of attack (in degrees) measured in plane normal to leading edge, not in plane containing freestream direction.
		CDO. -	Drag coefficient due to skin friction (CD FRICTION on output). This input number is added to the drag coefficient obtained by integrating the surface pressures (CD FORM on output).

Read Orders 8 through 19 are used to specify the wing geometry (in physical space, of course). One can define the wing at up to 11 span stations. A set of airfoil coordinates must be read in at the first station. It need not be read in at other stations, if one is changing only combinations of the following three airfoil section parameters: chord, thickness ratio or angle of attack (twist). The wing shape at intermediate span positions (i.e., the computational grid planes for example) is obtained by linear interpolation in the spanwise direction in the physical space.

Read Order	Number Cards	Description and Comments

A multiple run capability for the same wing geometry at several flow conditions is available and controlled by the parameter FNC in Read Order 9. One does not have to re-read the wing geometry to use it. The following description of Read Orders 8 through 19 is that required for a single case.

Read Orders 8 and 9 are read only once: 10 and 11 are read FNC (see 9) times; 12 through 17 (19 if non-symmetric airfoil section) must be read at first section and may be required at other sections, depending on the wing geometry.

Read Order	Number Cards	Variable		Description and Comments
8	1	DESC.	-	Description for card in Read Order 9 Format (8A10).
9	1	FNC		Format (8E10.7)
		FNC.	-	Number of span stations at which the wing is described or specified. Maximum is 11. Must be at least 2 for a single case or the first of a sequence. If FNC < 2. geometric wing data is assumed to be the same as in previous case and calculation begins for the new flow conditions reading no further input cards.
10	1	DESC.	-	Description for cards in Read Order 11 Format (8A10).
11	1	ZS(K), CHORD, THICK, AL, FSEC		Format (8E10.7)
		ZS(K).	-	Spanwise coordinate of the wing section being specified. It is in the same units as CHORD. These stations are ordered from tip-to-tip, in ascending algebraic order of ZS(K).
		CHORD.	-	Section chord length. The chord of the airfoil coordinates to be read in (or already read in at the prior station) will be scaled to this value.
		THICK.	-	Section thickness ratio relative to that of the airfoil coordinates to be read in (or already read in at the

Read Order	Number Cards		Description and Comment
			prior station). Note, this is a ratio of thickness/chord ratios. The thickness of the airfoil coordinates will be scaled with this value.
		AL. -	Section angle of attack or twist (in degrees). Airfoil coordinates will be rotated through this angle.
		FSEC. -	Section airfoil coordinate trigger. FSEC = 0. Do not read airfoil coordinates. Last set of airfoil coordinates read will be used at this section. They may be scaled by any combination of CHORD, THICK, or AL read above. Skip Read Orders 12 through 19 for this section. FSEC = 1. Read a new set of airfoil coordinates which will be used at this station and perhaps at other stations. They may be scaled by any combination of CHORD, THICK, or AL read above for this section. At first station (K = 1) FSEC is ignored; one must supply Read Orders 12 through 17.
12	1	DESC. -	Description for cards in Read Order 13 Format (8A10).
13	1	FSYM, FNU, FNL	Format (8E10.7)
		FSYM. -	Airfoil symmetry trigger. FSYM $\geq$ 1. Symmetric airfoil. Read in only upper surface airfoil coordinates, ordered leading edge to trailing edge. FSYM <1. Non-symmetric airfoil. Read in upper and lower surface airfoil coordinates, respectively, each set ordered leading edge to trailing edge. Note that leading-

Read Order	Number Cards			Description and Comments
				edge points are included in both sets.
		FNU.	-	Number of coordinates read in for upper surface of airfoil.
		FNL.	-	Number of coordinates read in for lower surface of airfoil.
14	1	DESC.	-	Description for cards in Read Order 15 Format (8A10).
15	1	TRL, SLT, XSING, YSING		Format (8E10.7)
		TRL.	-	Included angle of trailing edge of airfoil (in degrees).
		SLT.	-	Slope of airfoil mean camber line at trailing edge.
		XSING.	-	X coordinate of the origin of the mapping referenced to the airfoil leading edge. Recommend approximately X(LE) + 1/2 leading edge radius.
		YSING.	-	Y coordinate of the origin of the mapping referenced to the airfoil leading edge. Recommend approximately Y(LE).
16	1	DESC.	-	Description for cards in Read Order 17 Format (8A10).
17	FNU	XP(I), YP(I)		Format (8E10.7)
		XP(I).	-	X coordinate of airfoil upper surface, ordered leading edge to trailing edge.
		YP(I).	-	Y coordinate of airfoil upper surface, ordered leading edge to trailing edge. Note that there is only one pair of coordinates per card.

If airfoil section is not symmetric (FSYM<1.) the airfoil lower surface coordinates must be read here. For symmetric airfoil ($FSYM \geq 1.$), skip the two Read Orders 18 and 19.

Read Order	Number Cards		Description and Comments
18	1	DESC. -	Description for cards in Read Order 19 Format (8A10).
19	FNL	VAL, DUM -	Format (8E10.7)
		VAL. -	X coordinate of airfoil lower surface, ordered leading edge to trailing edge.
		DUM. -	Y coordinate of airfoil lower surface, ordered leading edge to trailing edge. Note that there is only one pair of coordinates per card.

Read Orders 10 through 19 complete the input for one span station. As indicated above Read Order 8, at least Read Orders 10 and 11 must be repeated for the remaining FNC-1 sections when FNC $\geq$ 2.

The above Read Orders complete the input for a computational case or a sequence of cases if obtained by having FNC < 2. Additional cases requiring different input are obtained by repeating the above Read Orders. Recommend that cases be run one at a time.

The program terminates by reading the first three Read Orders with FNX<1.; that is, last three cards for a normal stop should be:

1	1	TITLE. -	End of Calculation
2	1	DESC. -	Description for card in Read Order 3
3	1		0. . . . .

SAMPLE CASE

A simple wing, shown in Figure 1, is used here for the sample case; more realistic wing shapes are considered in references 1 and 2. This wing has a rectangular planform of aspect ratio 32/9 with a NACA 63A006 airfoil section (ref.8) at all span stations. The free stream, at Mach number .9, is at 2° incidence and 0° yaw with respect to the wing. Note that the freestream direction is consistantly indicated by a large open arrow on the figures.

Figure 2 depicts how the wing section planes are transformed from physical space to computational space for the present sample case. In Figure 3, a portion of the equally spaced computational grid in the wing section plane is plotted in physical space. This plot, however, was obtained from a separate program, supplied by J. D. Keller of NASA Langley Research Center.

Appendix B is a listing of the input cards for the sample case. Read Order notations on the right side identify these cards with the input description of the last section.

Appendix C is a collection of figures which show some typical output results for the sample case. Note that FPLOT was 2 in the input (Appendix B) so there are two types of plots: those from THREED and those from GRAPH.

The bottom line of printing is common to all plots and contains the NASA LRC computer process number, date and time of run. Another line common to all plots contains the freestream Mach number (M), yaw angle (YAW), and incidence angle (ALF). Figures C1, C2, and C3 show the plots obtained from subroutine THREED. The first shows interpolated airfoil sections at each of the spanwise computational planes for the fine grid. (For this sample case, all sections are identical.) This plot serves to locate the CP origins on the second and third plots, where curves for all sections are superimposed but shifted with respect to one another. Figure C2 shows the chordwise distributions of (negative) surface pressure coefficient on the upper surface of the wing at all spanwise computational planes of the fine grid, whereas Figure C3 gives that for the wing lower surface. The sharp downward breaks in the curves (at about 50-60% chord) are shock waves. On these plots L/D, CL and CD are for the entire wing; CL is the inviscid lift coefficient, CD is the drag coefficient (composed of that obtained from integrating the inviscid pressures plus that read in as input (CDO) due to skin friction, and L/D is the ratio CL/CD. A set of plots like these is obtained on each grid refinement; for the sample case there were two grids so two sets were obtained.

Figures C4 and C5 are typical of the plots obtained from subroutine GRAPH. In these, the chordwise distribution of surface pressure coefficient for both the upper and lower wing surfaces is shown on one figure, a separate figure for each spanwise computational plane. The value of Z, shown on the next to last line at the bottom of the plot, is the spanwise coordinate in the physical plane (See Fig. 1) and thus identifies the section location. The values of CL and CD shown on these plots are the inviscid <u>section</u> lift and drag coefficients, respectively. Figure C4 is for the root section (Z = 0.0) while Figure C5 is for the tip station (Z = 160.0). The long tick mark on the ordinate is the sonic value of pressure coefficient. A set of plots (one for each spanwise station) is obtained for each grid refinement.

Figures C6, C7, and C8 are charts which show the local Mach number (multiplied by 100) in various computational planes. Figure C6 is at the root section of the wing (Z = 0.0); minus signs on it denote the lower half plane. A solid line outlines that portion of computational grid shown in Figure 3. The supersonic bubbles on both upper and lower wing surfaces are clearly visible. Figures C7 and C8 show the Mach charts in the wing plane at the upper and lower surfaces, respectively. The wing planform (in the computational plane) is outlined on each figure and again the supersonic bubbles on both surfaces of the wing are clearly visible. One set of these charts is made on each grid refinement. Those for the fine grid of the sample case have been given in figures C7 and C8.

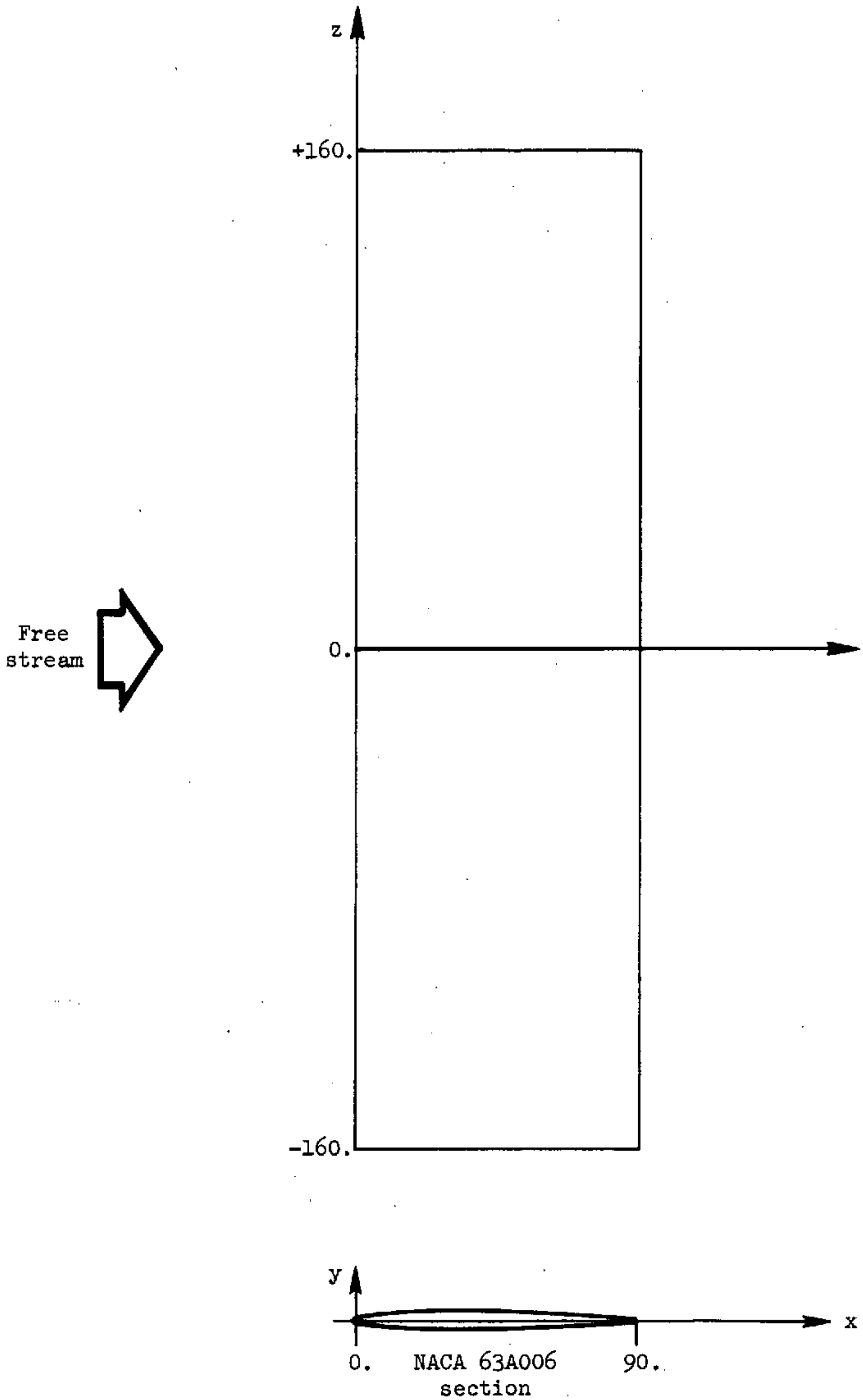
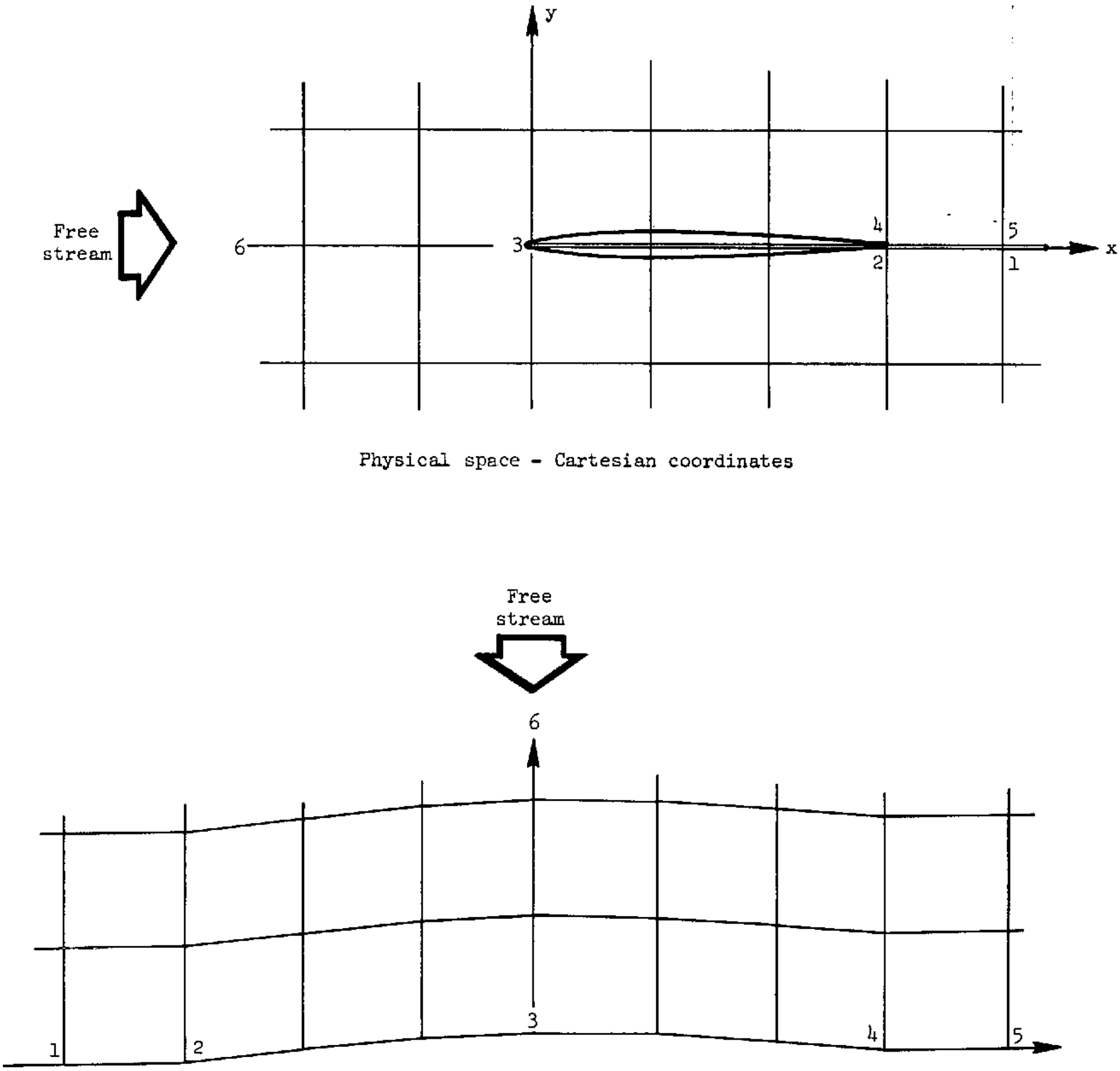


Figure 1.- Geometry of wing for sample case.



Physical space - Cartesian coordinates

Computational space - sheared parabolic coordinates

Figure 2.- Physical and computational coordinate systems in wing section planes for sample case.

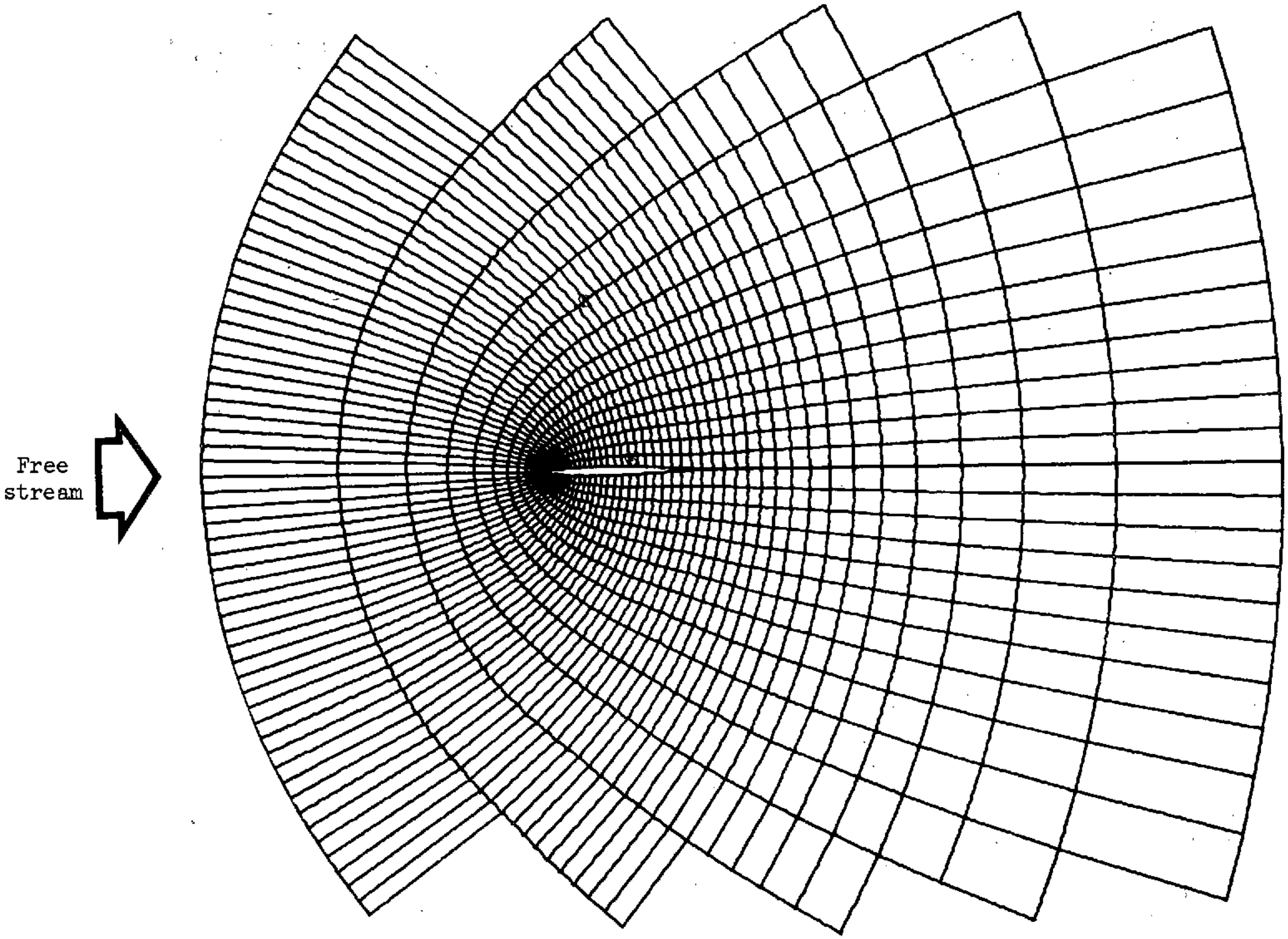


Figure 3.- Portion of wing section computational grid plotted in physical space.

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01 4	01 7 PROGRAM NO		01 14 DATE
LAR	A4231	**COMPUTER PROGRAM ABSTRACT**	081073

01 20 TITLE OF PROGRAM (61 CHARACTERS MAXIMUM): Transonic Flow Analysis-3D airfoils/Jameson(parabolic)

PARENT PROGRAM

02 14 CATEGORY	02 15 SITE	02 18 PROGRAM NO.
I	NYU	

02 26 CATEGORY	02 27 LANGUAGE NO. 1	02 32 LANGUAGE NO. 2	02 37 KEY WORDS (8 MAXIMUM, SEPARATED BY COMMAS)
I	FØR6M		transonic flow, embedded shocks, isentropic supersonic flow, subsonic flow

WHO TO CONTACT ABOUT THE PROGRAM

05 14 CONTACT	05 28 SITE	05 31 ORGN CODE	05 39 PROJECT NO	05 45 NASA CENTER	05 48 STATUS	05 43
RMDavis	LAR	33.300	R2564		☐ A. UNDER DEVELOPMENT ☒ B. OPERATIONAL ☐ C. COMPLETED	☐ A THIS PROGRAM IS NOT FOR SHARING

DATES		05 58 REVISION CODE	TIME AND COST FOR DEVELOPMENT			
05 50 INITIATED	05 54 COMPLETED		05 59 MANMONTHS	05 64 MACHINE HOURS	05 69 COMPUTER TYPE	05 74 TOTAL COST (DOLLARS)
0873		☐ A REVISION ☐ B CANCELLATION	59 60 61 62 63	64 65 66 67 68	6000	74 75 76 77 78 79 80

CARD NUMBER | COLUMN 14 | ABSTRACT | ELITE MARGIN | PICA MARGIN

This program performs calculations for inviscid isentropic transonic flow over 3D airfoils with straight (may be yawed but not swept) leading edges. The free-stream Mach number is restricted only by the isentropic assumption. Weak shock waves are automatically located where ever they occur in the flow. The finite-difference form of the full equation for the velocity potential is solved by the method of relaxation, after the flow exterior to the airfoil is mapped to the upper half plane. The mapping procedure allows exact satisfaction of the boundary conditions and use of supersonic free stream velocities. The finite difference operator is "locally rotated" in supersonic flow regions so as to properly account for the domain of dependence. The relaxation algorithm has been stabilized using criteria from a time-like analogy.

Figure A1.- Computer program abstract.

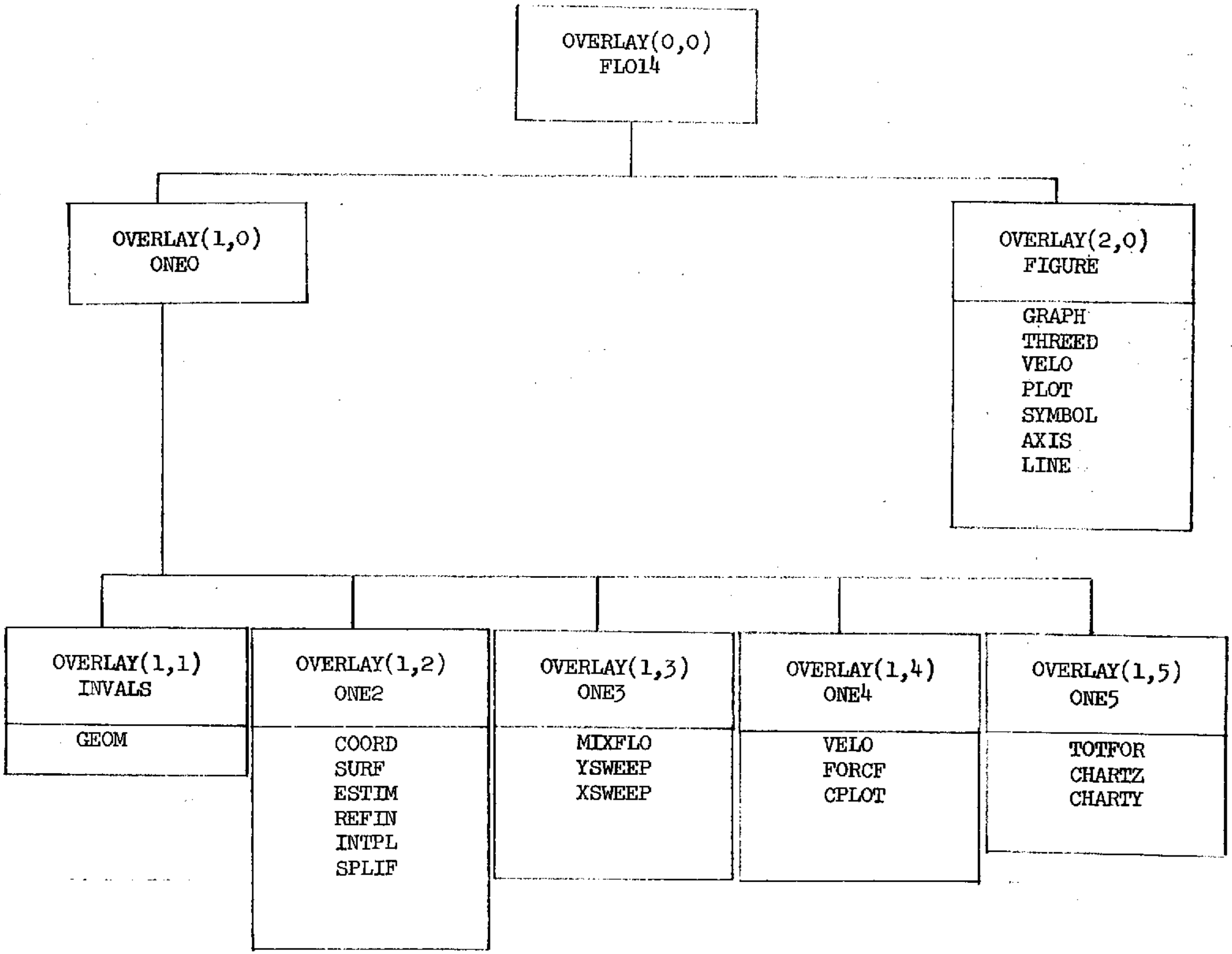


Figure A2.- Overlay diagram.

GEOM	reads geometric definition of wing
COORD	sets up stretched parabolic and spanwise coordinates
SURF	interpolates mapped wing surface at computational mesh points
ESTIM	computes initial estimate of reduced potential
REFIN	halves computational mesh size
INTPL	interpolates using Taylor series
SPLIF	performs cubic spline fit
MIXFLO	solves mixed-flow equations (rotated difference scheme)
YSWEEP	relaxes horizontal lines, sweeping in y-direction
XSWEEP	relaxes vertical lines, sweeping in x-direction
VELO	calculates surface velocity
FORCF	calculates section force coefficients
CPLOT	generates printer plots of CP at equal computational intervals
TOTFOR	calculates total force coefficients
CHARTZ	generates Mach number chart in plane of wing section
CHARTY	generates Mach number chart in plane of wing planform
GRAPH	generates Varian plots
THREED	generates three-dimensional plots
PLOT *	moves pen (call CALPLT)
SYMBOL *	plots symbols (call NOTATE)
AXIS *	draws axes (call AXES)
LINE *	plots arrays

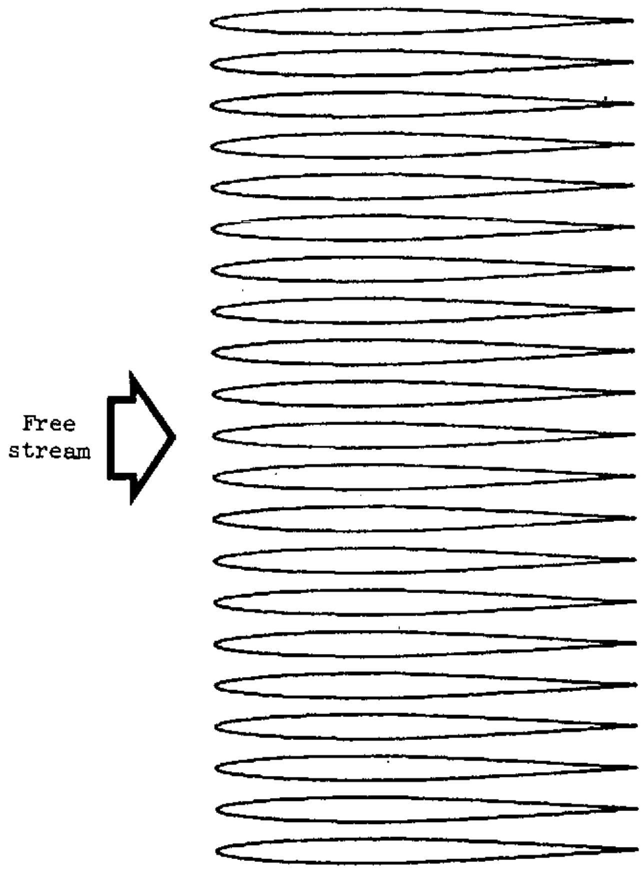
* expedient modifications were made so that NYU plotting subroutines were compatible with NASA LRC CDC system.

Figure A3. - Function of subroutines.

APPENDIX B - INPUT FOR SAMPLE CASE

```
                                                                                        Read
                                                                                        Order
RECTANGULAR WING - NACA 63A006    AR=32/9                                                 1
FNX        FNY        FNZ        FPLOT                                                    2
48.        8.         16.        2.                                                       3
FIT        COVO       P10        P20        P30        BETA0      STRIP0     FHALF        4
220.       .00001     1.6        1.         1.         0.         1.         1.           5
110.       .00001     1.6        1.         1.         0.         1.         0.
FMACH      YA         AL         C00                                                      6
.9         0.         2.         0.                                                       7
FNC                                                                                       8
2.                                                                                        9
ZS         CHORD      THICK      AL         FSEC                                         10  )
-160.      90.        1.         0.         1.                                           11  |
FSYM       FNU        FNL                                                                12  |
1.         36.        36.                                                                13  |
TRL        SLT        XSING      YSING                                                   14  |
7.0778     0.         .1325      0.                                                      15  |
XP         YP                    (UPPER SURFACE)                                         16  |
0.         0.                                                                        )       |
.055555    .16235                                                                    |       |
.11111     .22444                                                                    |       |
.22222     .32222                                                                    |       |
.33323     .401111                                                                   |       |
.44444     .46777                                                                    |       |
.55555     .52                                                                       |       |
.83333     .62277                                                                    |       |
1.11111    .71111                                                                    |       |
1.66666    .86478                                                                    |       |
2.2222     .98961                                                                    |       |
2.7777     1.0978                                                                    |       |
3.3333     1.1962                                                                    |       |  Wing data at
3.8888     1.2877                                                                    |       |  first span
4.4444     1.3696                                                                    |       |  station
5.         1.447                                                                     |       |
7.5        1.7466                                                                    |       |
10.        1.9889                                                                    |       |
15.        2.3622                                                                    |   17  |
20.        2.6311                                                                    |  (FNU |
25.        2.82                                                                      |  cards)
30.        2.9422                                                                    |
35.        2.9955                                                                    |
40.        2.9844                                                                    |
45.        2.9144                                                                    |
50.        2.7877                                                                    |
55.        2.6133                                                                    |
60.        2.3955                                                                    |
65.        2.1433                                                                    |
70.        1.8589                                                                    |
75.        1.5555                                                                    |
80.        1.2478                                                                    |
85.        .93889                                                                    |
90.        .63                                                                       |
95.        .32222                                                                    |
100.       .013                                                                      )
                                                                              omit 18 and 19*
ZS         CHORD      THICK      AL         FSEC                                         10  )  Wing data at
+160.      90.        1.         0.         0.                                           11  )  last span
                                                                                                station
END OF CALCULATION                                                                        1
FNX        FNY        FNZ        FPLOT                                                    2
0.         0.         0.         0.                                                       3
```

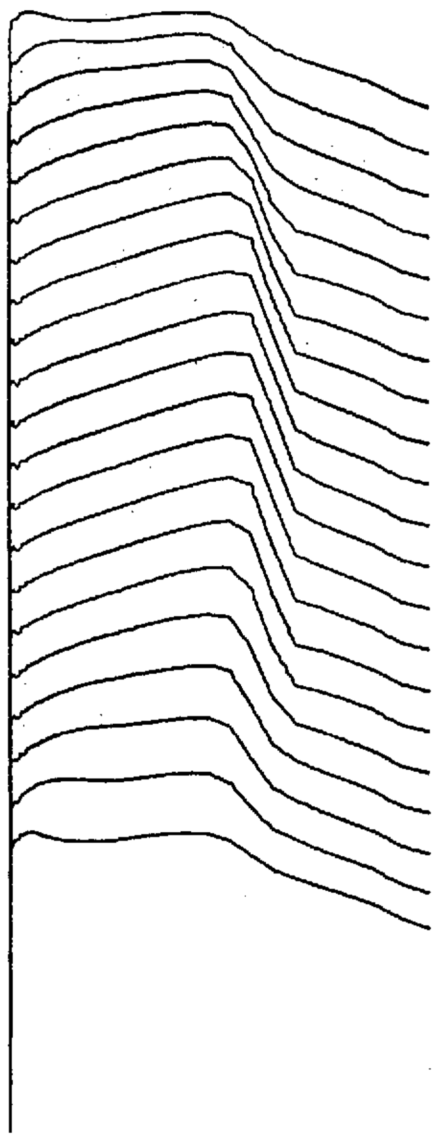
* Symmetric wing section, therefore Read Orders 18 and 19 must be omitted



<u>Note</u>: Spanwise variable is <u>not</u> scaled to chordwise variable in this plot. Instead, the wing sections shown here located the C_p origins in the following plots.

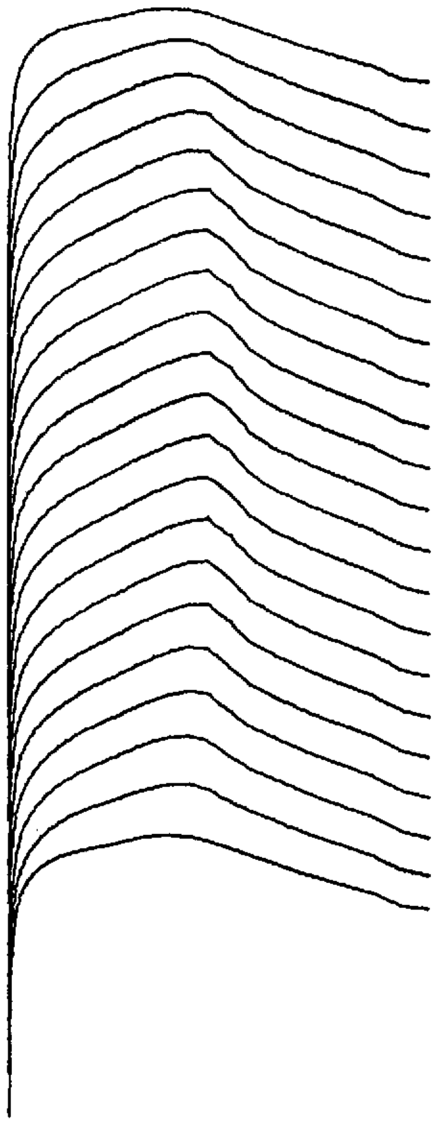
VIEW OF WING
RECTANGULAR WING - NACA 63A006 SECTION   AR=32/9
M =   .900   YAW =   0.00   ALF =   2.00
L/D = 23.05   CL =   .1876   CD =   .0081
LB71564   09/13/73   07.37.22.

Figure C1.- View of wing showing interpolated airfoil sections on fine grid.



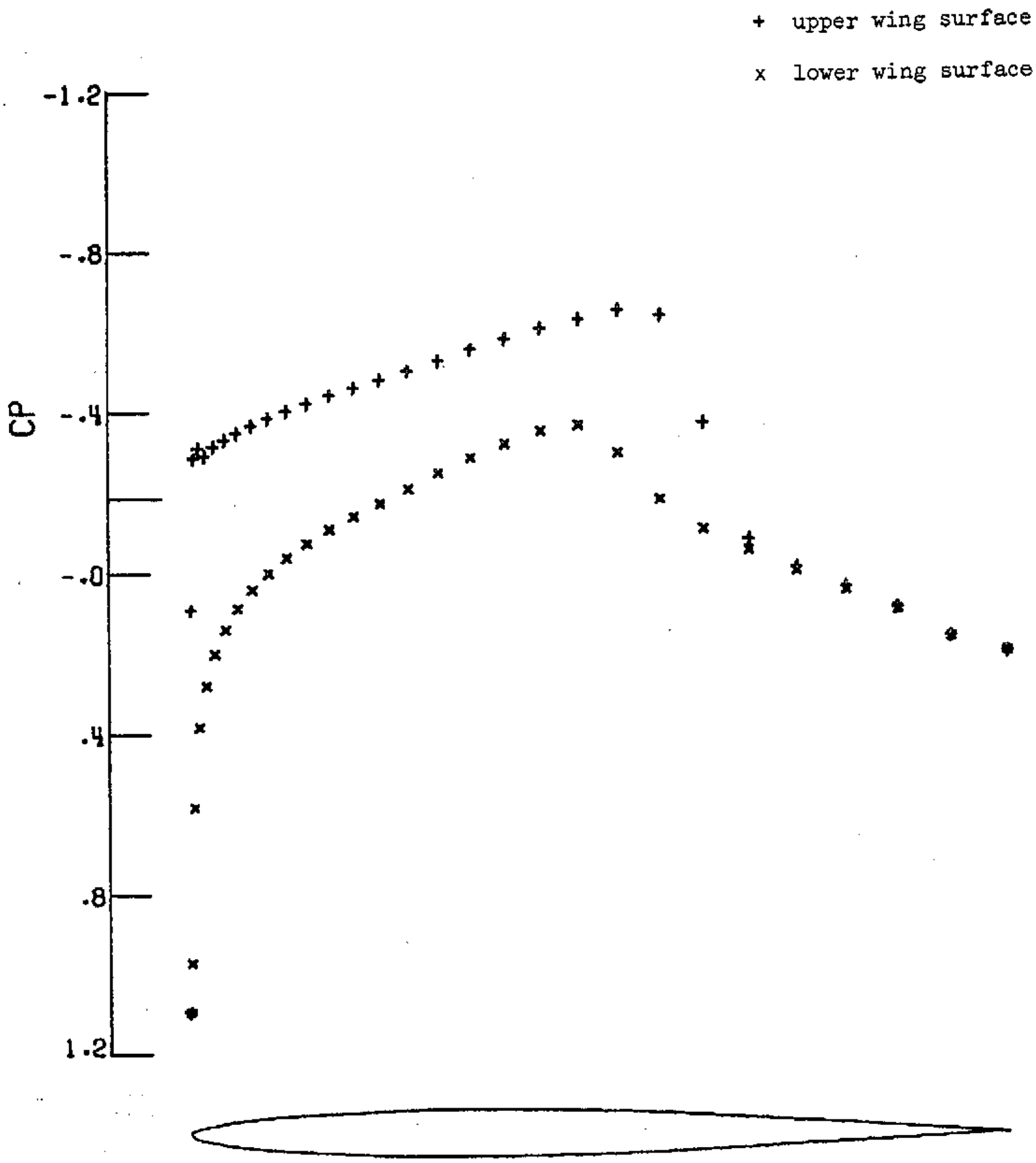
UPPER SURFACE PRESSURE
RECTANGULAR WING - NACA 63A006 SECTION AR=32/9
M = .900 YAW = 0.00 ALF = 2.00
L/D = 23.05 CL = .1876 CD = .0081
LB71564 09/13/73 07.37.22.

Figure C2.- Chordwise distributions of upper-surface wing pressure coefficients at spanwise computational planes of fine grid.



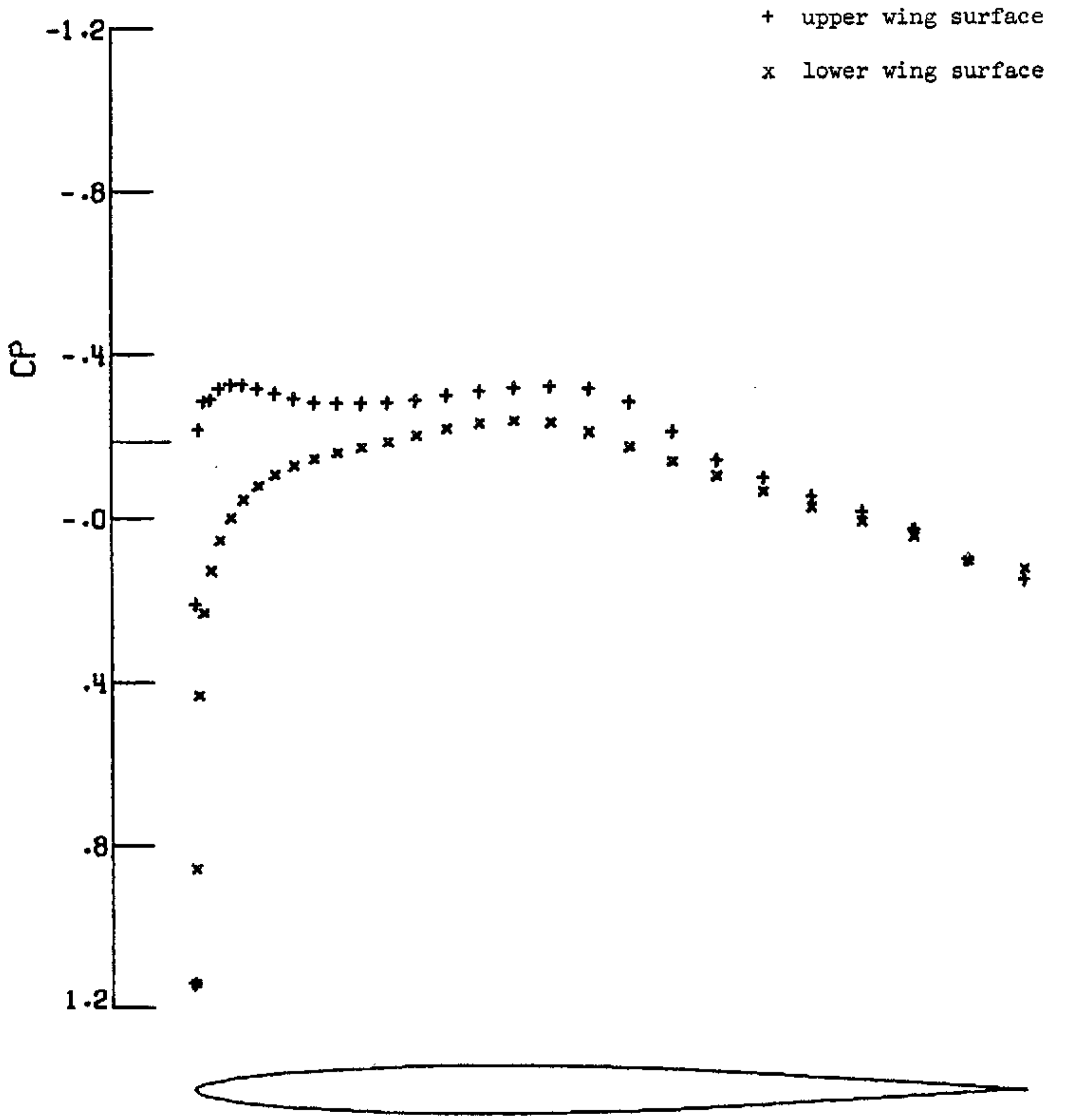
LOWER SURFACE PRESSURE
RECTANGULAR WING - NACA 63A006 SECTION AR=32/9
M = .900 YAW = 0.00 ALF = 2.00
L/D = 23.05 CL = .1876 CD = .0081
LB71564 09/13/73 07.37.22.

Figure C3.- Chordwise distributions of lower-surface wing pressure coefficients at spanwise computational planes of fine grid.



RECTANGULAR WING - NACA 63A006 SECTION AR=32/9
M = .900 YAW = 0.00 ALF = 2.00
Z = 0.00 CL = .2261 CD = .0107
LB71564 09/13/73 07.37.22.

Figure C4.- Chordwise distributions of pressure coefficient at root section of wing.



RECTANGULAR WING - NACA 63A006 SECTION AR=32/9
M = .900 YAW = 0.00 ALF = 2.00
Z = 160.00 CL = .0906 CD = .0036
LB71564 09/13/73 07.37.22.

Figure C5.- Chordwise distribution of pressure coefficients at tip section of wing.

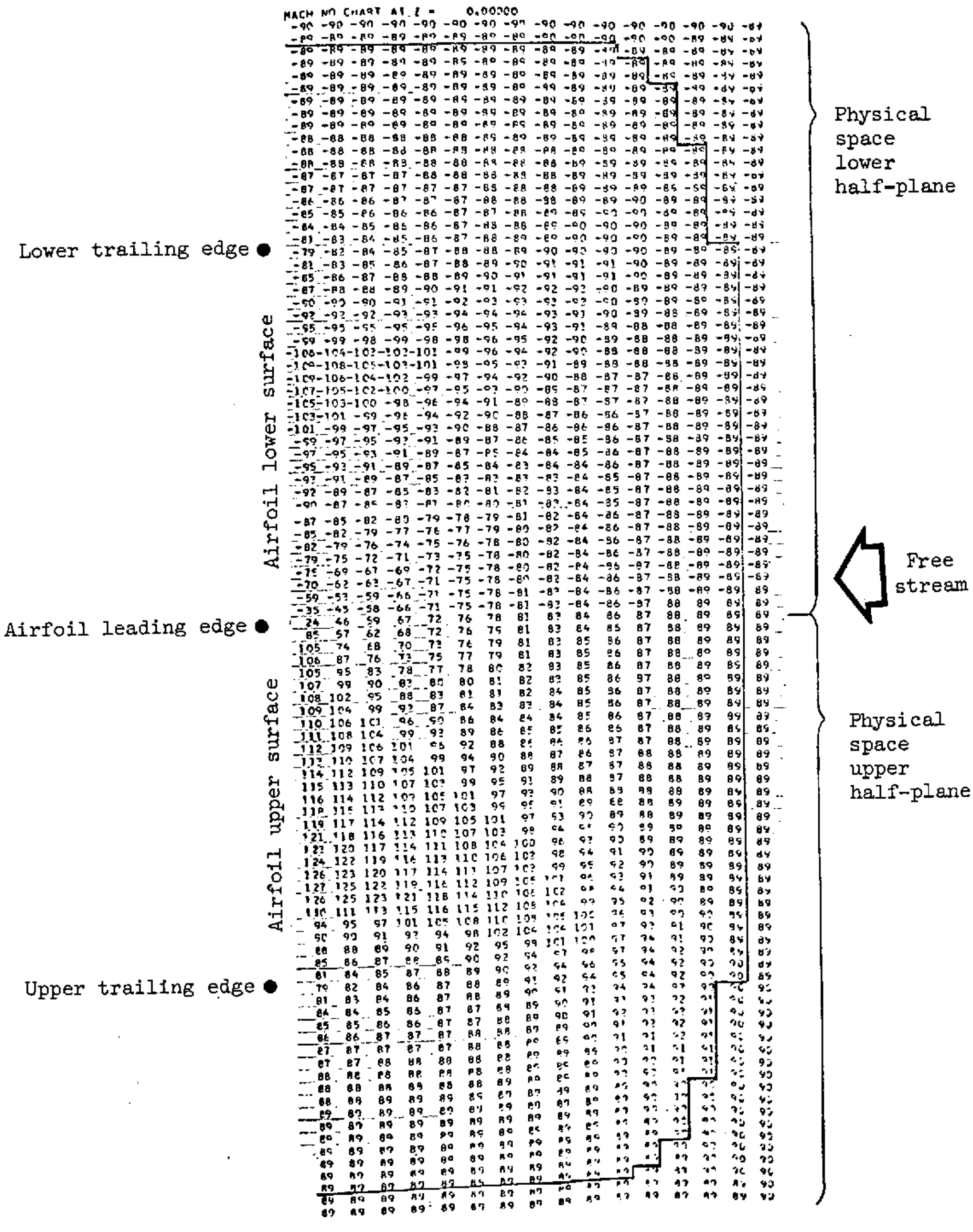


Figure C6.- Mach chart at root section of wing in computation plane.

APPENDIX C - Some Output Results For Sample Case

Free
stream

UPPER SURFACE MACH NO CHART IN WING PLANE

89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89
89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89
89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89
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89	89	89	89	89	88	88	88	88	88	87	87	87	87	87	87	87	87	87	87	87	88	88	88	88	88	88	89	89	89	89
89	89	89	89	88	88	87	87	87	86	86	86	86	85	86	86	86	86	86	86	86	86	87	87	87	88	88	88	89	89	89
89	89	89	88	87	87	86	86	85	85	85	85	85	85	84	84	84	84	85	85	85	85	85	86	86	87	87	88	89	89	89
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90	90	89	88	85	80	77	77	76	76	76	76	76	76	76	76	76	76	76	76	76	76	76	77	77	80	85	88	89	90	90
90	90	89	88	85	76	73	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	73	73	76	85	88	89	90	90
90	90	89	89	86	70	68	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	68	70	86	89	89	90	90
90	90	90	89	86	62	60	60	59	59	59	59	59	59	59	59	59	59	59	59	59	59	59	60	60	62	86	89	90	90	90
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90	90	90	89	87	78	80	81	82	83	83	83	84	84	84	84	84	84	84	83	83	83	82	81	80	78	87	89	90	90	90
90	90	90	89	87	100	101	102	103	103	103	104	104	104	104	104	104	104	104	104	103	103	103	102	101	100	87	89	90	90	90
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90	90	90	90	90	107	107	107	107	107	107	107	107	107	107	107	107	107	107	107	107	107	107	107	107	107	90	90	90	90	90
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90	90	90	91	92	107	109	109	109	109	109	109	109	109	109	109	109	109	109	109	109	109	109	109	109	107	92	91	90	90	90
90	90	91	91	93	106	110	110	110	110	110	110	110	111	111	111	111	111	110	110	110	110	110	110	110	106	93	91	91	90	90
90	90	91	92	93	105	110	111	112	112	112	112	112	112	112	112	112	112	112	112	112	112	112	111	110	105	92	92	91	90	90
90	91	91	92	94	105	110	112	113	113	113	113	113	113	113	113	113	113	113	113	113	113	113	112	110	105	94	92	91	91	90
90	91	91	93	95	104	110	113	114	114	114	114	114	114	114	114	114	114	114	114	114	114	114	113	110	105	95	93	91	91	90
90	91	92	93	96	104	110	113	115	115	115	115	115	115	115	115	115	115	115	115	115	115	115	113	110	105	96	93	92	91	90
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89	89	89	89	89	89	89	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	89	89	89	89	89	89
89	89	89	89	89	89	89	89	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	89	89	89	89	89	89	89	89
89	89	89	89	90	89	89	89	89	89	89	89	89	88	88	88	88	88	89	89	89	89	89	89	89	89	90	89	89	89	89
89	89	89	89	90	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	90	89	89	89	89
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89	89	89	89	90	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	90	89	89	89	89
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89	89	89	90	90	90	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	90	90	90	89	89	89
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89	89	90	90	90	90	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	90	90	90	90	89	89
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90	90	90	90	90	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	90	90	90	90	90

Figure C7.- Mach chart at upper surface of wing in computational plane.

LOWER SURFACE MACH NO CHART IN WING PLANE

89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	69	89	89	89	89	89	89	89	89	89	89	89	89	89	89
89	99	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89
89	39	89	89	89	89	89	89	89	89	87	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89
89	89	89	89	89	89	89	89	88	88	88	88	93	88	8d	88	8d	88	88	88	88	88	88	89	89	89	89	89	89	89	89
89	39	89	89	88	88	88	88	88	88	87	87	87	87	87	87	87	87	87	87	87	87	88	88	88	89	89	89	89	89	89
89	89	89	89	89	88	87	87	87	86	86	86	86	86	86	86	66	86	86	86	86	86	97	87	87	98	98	88	89	89	89
89	89	89	88	87	87	86	86	85	85	85	85	85	85	84	84	64	64	85	85	85	85	85	86	86	87	87	88	89	89	89
90	99	89	88	87	86	85	84	84	83	83	83	83	87	83	43	83	83	82	83	83	83	84	84	85	86	87	38	89	89	90
90	89	89	88	86	84	83	82	82	81	81	81	81	81	81	81	81	81	81	81	81	81	82	82	83	84	96	88	89	89	93
90	89	89	88	86	82	81	80	79	79	79	79	79	79	78	78	78	79	79	79	79	79	79	80	81	82	86	38	89	89	90
90	90	89	88	85	80	77	77	76	76	76	76	76	76	76	76	76	76	76	76	76	76	76	77	77	80	95	88	89	90	90
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90	90	89	89	86	70	68	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	68	70	86	89	89	90	93
90	90	90	89	86	62	60	60	59	59	59	59	59	59	59	59	59	59	59	59	59	59	59	60	60	62	96	89	90	90	90
90	90	90	89	87	47	46	46	46	46	45	45	46	46	46	46	46	46	46	46	46	46	46	46	46	47	97	89	90	90	90
90	90	90	89	87	19	21	22	23	23	24	24	24	24	24	24	24	24	24	24	24	23	23	22	21	19	87	89	90	90	90
90	90	90	89	87	42	38	36	36	35	35	34	34	34	34	34	34	34	34	34	35	35	36	36	38	42	87	89	90	90	90
90	99	90	89	87	66	62	61	60	59	59	59	59	59	59	58	59	59	59	59	59	59	60	61	62	66	87	89	90	90	90
90	99	90	89	88	77	72	71	70	70	69	69	69	69	59	69	69	69	69	69	69	70	70	71	72	77	88	89	90	90	90
90	90	90	89	88	82	78	77	76	76	75	75	75	75	75	75	75	75	75	75	75	76	76	77	78	82	88	89	90	90	90
90	90	90	90	89	86	83	81	80	80	79	79	79	79	79	79	79	79	79	79	79	80	80	81	82	86	89	90	90	90	90
90	90	90	90	90	89	85	84	83	83	83	82	82	82	82	82	82	82	82	83	83	83	83	84	85	89	90	90	90	90	90
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90	91	93	95	98	102	104	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	104	102	98	95	93	91	90
90	91	93	95	99	102	105	106	107	107	107	107	107	107	107	107	107	107	107	107	107	107	107	106	105	102	99	95	93	91	90
90	91	93	95	99	102	105	107	108	108	109	109	109	109	109	109	109	109	109	109	109	108	108	107	105	102	99	95	93	91	90
90	91	93	95	98	101	103	105	107	108	109	109	109	109	109	109	109	109	109	109	109	108	107	105	103	101	98	95	93	91	90
90	91	93	94	97	99	100	101	102	103	104	105	105	105	106	106	106	105	105	105	104	103	102	101	100	99	98	95	93	91	90
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90	91	91	92	93	93	93	93	93	93	93	93	93	93	93	93	93	93	93	93	93	93	93	92	92	93	93	92	91	91	90
90	91	91	91	92	91	91	91	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	91	91	91	92	91	91	91	90
90	90	90	90	91	89	89	88	88	88	88	88	87	87	87	87	87	87	87	88	88	88	89	88	89	89	91	90	90	90	90
90	90	90	90	90	87	86	86	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	86	86	87	90	90	90	90	90
90	90	90	89	88	84	83	82	82	82	92	81	81	81	81	81	81	81	81	82	82	82	82	82	83	84	88	89	90	90	90
90	93	89	89	88	83	81	80	80	80	80	80	79	79	79	79	79	79	79	80	80	80	80	80	81	83	88	89	89	90	90
90	39	89	89	88	85	82	83	82	82	82	82	81	81	81	81	81	81	81	82	82	82	82	83	83	85	88	89	89	90	90
90	99	89	89	88	87	86	85	85	84	84	84	84	84	84	84	84	84	84	84	84	84	85	85	86	97	88	99	89	89	90
90	89	89	89	88	86	87	86	86	86	86	85	85	85	85	85	85	85	85	85	86	86	86	86	97	88	88	89	89	89	90
90	89	89	89	89	88	88	87	87	97	95	86	86	86	86	86	86	86	86	86	86	87	87	87	88	88	88	89	89	89	90
89	89	89	89	89	88	88	88	87	87	97	87	87	87	87	87	67	87	87	87	87	87	87	88	88	88	89	89	89	89	90
89	89	89	89	89	89	88	88	88	88	88	88	88	87	87	87	67	87	88	88	88	89	88	88	88	89	89	89	89	89	89
89	89	89	89	89	89	89	88	88	88	88	88	88	88	98	88	88	68	88	88	88	88	88	88	89	89	89	89	89	89	89
89	89	89	89	89	89	89	89	89	88	88	88	88	89	88	88	68	88	88	88	88	88	89	89	89	89	89	89	89	89	89
89	89	89	89	90	89	89	89	89	89	89	89	89	89	89	88	89	89	89	89	89	89	89	89	89	89	90	89	89	89	89
89	89	89	89	90	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	90	89	89	89	89
89	89	89	89	90	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	90	89	89	89	89
89	89	89	89	90	90	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	90	89	89	89	89
89	89	89	90	90	90	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	90	90	90	89	89	89
89	89	89	90	90	90	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	90	90	90	89	89	89
89	89	90	90	90	90	90	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	90	90	90	90	90	89	89
89	90	90	90	90	90	90	90	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	90	90	90	90	90	89	89
90	90	90	90	90	90	90	90	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	90	90	90	90	90	90	90	89
90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90

Figure C8.- Mach chart at lower surface of wing in computational plane.

REFERENCES

1. Jameson, A.: Numerical Calculation of the Three Dimensional Transonic Flow over a Yawed Wing. Proceedings of the AIAA Computational Fluid Dynamics Conference. Palm Springs, California, July 19-20, 1973. pp. 18-26.

2. Jameson, A.: Three Dimensional Flows Around Airfoils with Shocks. Proceedings of the IFIP Symposium on Computing Methods in Applied Sciences and Engineering, 17-21 December 1973, Versailles, France. To be published by Springer-Verlag (available in Colloques IRIA Methodes Calqul Scientifique et Technique, 1973).

3. Bauer, F.; Garabedian, P.; Jameson, A.; and Korn, D.: Handbook of Supercritical Wing Sections. To be published as a NASA SP.

4. Jameson, A.: Transonic Flow Calculations for Airfoils and Bodies of Revolution. Grumman Rep. 390-71-1, 1971.

5. Garabedian, P.; and Korn, D.: Analysis of Transonic Airfoils. Comm. Pure Appl. Math., Vol XXIV, 1971, pp. 841-851.

6. Bauer, F.; Garabedian, P.; and Korn, D.: Supercritical Wing Sections. Springer-Verlag, New York, 1972.

7. Jameson, A.: Iterative Solution of Transonic Flows Over Airfoils and Wings Including Flows at Mach 1. Accepted for publication in Comm. Pure Applied Math., 1974.

8. Loftin, L. K., Jr.: Theoretical and Experimental Data for a Number of NACA 6A-Series Airfoil Sections. NACA Rept. 903, 1948.