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TAWFIVE: A USERS' GUIDE

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ABA: Author

ABS: The Transonic Analysis of a Wing and Fuselage with Interacted Viscous Effects (TAWFIVE) was developed. A finite volume full potential method is used to model▒

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SUMMARY

A program for the Transonic Analysis of a Wing and Fuselage with Interacted Viscous Effects (TAWFIVE) has been developed. A very brief discussion of the engineering aspects of the program is provided for completeness. A general discussion of the input data and strategies for running the program are given. Tables and figures giving detailed definitions of the input data are included to aid in the preparation of data sets once the user is familiar with the program.

GENERAL COMMENTS

In recent years, research has produced significant improvements in the mathematical modeling of transonic flow fields over increasingly complex configurations. The first calculations of transonic flow about simple airfoils were performed in the early seventies using a nonconservative potential formulation. In the last half of the decade, computational abilities progressed up to the point where wing and wing-body configurations could be calculated using inviscid, conservative, full-potential formulations. Some of the calculations for wing-alone configurations also included two-dimensional strip boundary-layer corrections. The present work adds to the progression of increasing computational capabilities by providing the ability to model a wide class of transport-type wing and fuselage configurations using a conservative, finite-volume, potential flow model interacted with a three-dimensional boundary-layer method.

The program described in this report is called TAWFIVE, an acronym for Transonic Analysis of a Wing and Fuselage with Interacted Viscous Effects. It was developed on the CDC CYBER 203 at the NASA Langley Research Center. Details of the math modeling used in the program and output of sample cases are available as references 1-3. Important points from those papers are summarized in the following paragraphs.

The input to TAWFIVE is limited to geometric definition of the configuration, free-stream flow quantities, and iteration control parameters. The geometric input consists of the definition of a series of airfoil sections to define the wing and a series of fuselage cross sections to define the fuselage. The wing may have an arbitrary airfoil shape which may change with span location. Due to grid limitations in the inviscid outer flow calculations, the wing cannot have large amounts of taper or sweep. High-aspect-ratio wings are modeled more accurately than low-aspect-ratio wings. The fuselage may have an arbitrary shape. With the proper choice of input options, a simple circular cross section may be used for the fuselage or an arbitrary cross-section shape may be defined by reading coordinate pairs. The fuselage may be closed at both ends, a circular sting may extend to either upstream or downstream infinity, or both. The program finds the wing-fuselage intersection by linear extrapolation of the wing surface to the fuselage surface.

The outer inviscid flow is modeled by a conservative, finite-volume, full-potential method based on the Caughey-Jameson program FLO 30 (ref. 4). The computations are performed on a body-fitted, sheared, parabolic coordinate system.

To account for viscous effects, the TAWFIVE code uses first-order, weak, self-consistent interactions, in the sense of Melnik (ref. 5). All important first-order effects are included - displacement on the wing surface and in the wake and curvature/pressure jump in the wake. The reader is directed to references 1-3 for more detail.

The fully three-dimensional boundary layer on the wing is computed using a compressible integral method, capable of computing either turbulent or laminar boundary layers, with a fixed transition point. The turbulent method is based on the work of Smith (ref. 6) with extensions (ref. 1), and the laminar technique was developed by Stock (ref. 7). Small regions of separation are also modeled.

The wake is computed in streamwise strips using a two-dimensional entrainment integral technique (ref. 8). Starting conditions for the wake calculation are derived from the computed boundary-layer parameters at the wing trailing edge, consistent with first-order weak interaction theory. For transport-type configurations for which the TAWFIVE code is well suited, it has been found that the two-dimensional strip wake is an adequate model.

TAWFIVE computing costs can be very high and so several characteristics of the program have been included to help reduce these costs. First, the amount of output printed is controlled by input parameters. The "short" printout option should be used for most production runs and the "long" option should be used only as a debugging aid when severe problems occur. A restart ability is also available to continue calculations which are considered insufficiently converged. Both the inviscid and viscous solutions are saved as part of the restart option.

INPUT

A general description of the input necessary to run the TAWFIVE program is given in this section. Detailed descriptions of each of the input variables are given in tables at the end of the report. Once the user is familiar with the program, the tables should provide sufficient information to prepare input for the program. For first-time users, sample input files are also included as tables at the end of the report.

The input for TAWFIVE is divided into three areas: (1) Geometric data, (2) inviscid iteration and global interaction control parameters, and (3) restart data. Each of these three areas are read from different tape units. (See Table 1.)

Geometry Data

The geometric data are read from Unit 7 and include the definition of the wing and fuselage. The wing should have a high aspect ratio and limited taper ratio and sweep angle. The wing tip is not modeled accurately enough to allow the analysis of very low-aspect-ratio wings and grid problems are encountered for high taper ratio or sweep angle. Since problems with aspect ratio, taper ratio, and sweep angle may be cumulative, it is impossible to give specific limits on each.

The wing is defined by the input of successive airfoil section shapes, ordered from the wing root to the tip. A minimum of two airfoil sections is required to define the wing. Up to twenty-one sections may be read to define complex wing geometries. All input airfoil sections must have the same number of defining coordinate pairs and the points must be at the same percent chord locations for all of the sections.

The location of the first wing section at the root of the wing is very critical. The root section must be defined as close as possible to the wing-fuselage intersection. However, it must be defined outside of the fuselage, since linear extrapolation along the wing surface is used to determine the wing-fuselage intersection.

The wing airfoil-section data are used to generate a well-defined "hard" surface used internally in the program to apply the boundary-layer displacement thickness corrections. This internal hard surface is created using linear lofting between the input airfoil sections. The number of sections added between each of the defining sections is an input. The internal hard surface strategy is used to reduce the amount of data necessary to define the wing surface while retaining a sufficient number of points for application of the boundary-layer correction.

The fuselage is defined by the input of successive cross-section definitions ordered from the nose of the fuselage to the tail. A maximum of twenty-five cross sections may be read to define an arbitrarily-shaped fuselage. An optional circular fuselage is available which requires significantly less input. With either the arbitrary or the circular fuselage, circular cylinders extending to upstream infinity or downstream infinity, or both, may be used.

The relative placement of the wing and fuselage is described through the combination of the fuselage cross-section definitions and the location of the wing airfoil-section leading-edge points. It is important to note that the fuselage station locations, their defining coordinates, and the wing airfoil-section locations, their leading-edge-point locations and their chord lengths, must all be in the same units. The wing airfoil-section coordinates may be in whatever units are convenient, since they are scaled by the input section chord length.

Detailed definitions of the geometry input variables are given in Table 2 and a sample data set is given in Table 3. In general, each of the data card images are preceded by a descriptive card which simply lists the variable names. These descriptive cards are either read with a character format and stored in a dummy array or the card is just skipped. Either way, whatever appears on the descriptive cards is not used by the program. The cards are in the data set to aid in the interactive preparation of the input file. This same descriptive-card-followed-by-a-data-card format is also used for the inviscid iteration and global interaction control input. All geometry and iteration and interaction control inputs on these two files are real numbers; no integer formats are used.

Inviscid Iteration and Global Interaction Control Parameters

The inviscid iteration control and the inviscid boundary-layer interaction control parameters are read from Unit 5. (See Table 1.) These inputs contain a block of information which is repeated for each global iteration. Within each block are three sections.

The first section is read by seven read orders in the inviscid part of the code. (A read order is a read statement in the program or an order to read.) The first read order is for the title of the global iteration. The second and third are for inviscid grid and printer output, inviscid initial condition, and boundary-layer correction parameters. The fourth and fifth read orders define inviscid iteration control parameters and the sixth and seventh give free-stream flow parameters.

The second section within each block contains input information read by the boundary-layer and wake-treatment part of the program. This section contains five read orders. The first read order reads a two-card title. The second and third read orders contain the data for the boundary-layer calculation and the last two read orders contain the lag-entrainment flag and boundary-layer print-control parameter.

The third section within each block of input data contains variables which control the interpolation of the boundary-layer information from the boundary-layer grid points to the wing hard-surface coordinate points. There are only two read orders in this section.

The blocks of data containing the inviscid-data section, the boundary-layer-wake-data section, and the interpolation-data section are repeated for each of the global iterations. The "BLCP" parameter in the inviscid section is varied in the initial global iterations to control what boundary-layer and wake corrections are made before each inviscid calculation. Blocks of input data are repeated and global iterations are continued until terminated by the input of a value of zero for the variable FNX.

Details of the inviscid iteration and global interaction control input variables are given in Table 4. A sample data set is given in Table 5. Since the inviscid portion of the calculation is performed by code which was based on FLO 30, the input is similar to that described in reference 9. Therefore, much of Table 4 repeats the Input Description section of reference 9.

Restart Data

The restart data are read from Unit 4 and are in unformatted binary form. The restart file is generated by the program and is written on Unit 3. The file contains the three-dimensional array of potential values from the inviscid calculation as well as the one-dimensional array containing the values of the jump in the potential across the vortex sheet along the trailing edge of the wing. From the boundary-layer and wake calculations, the restart file also contains the two-dimensional array of displacement thickness on the wing and in the wake. Also in the restart file is the two-dimensional array containing the wake momentum.

The restart information is written by subroutine SAVE which is called in two places by the main program, INTRACT. The file is rewound before the data are written in each call to SAVE. The first call to SAVE is after the inviscid calculation. The second call to SAVE is after the boundary-layer and wake calculations. The two calls to SAVE make possible a restart of the calculation from the previous step if a problem develops in either the inviscid or viscous calculation.

The restart file is also used when a case is stopped before it is fully converged. Global iterations may be continued using the information on the restart file. The restart option is invoked when "FCONT" is set equal to three (3.0).

INTERACTION STRATEGY

There are two important constraints which must be considered when making calculations with TAWFIVE. The first and most important is the requirement that the iterations be stable and converge to the correct answer. The second constraint is that the converged solution be reached with the minimum amount of work. This section of the report is an attempt to outline some strategies which will help assure that the aforementioned criteria are satisified.

TAWFIVE runs must begin with the calculation of the inviscid flow about the wing-fuselage configuration (BLCP=0.0). To develop the flow quickly, grid refinement should be used. The initial calculation on the fine grid should not be allowed to converge very far, since this would slow down the overall convergence of the run. There are two reasons for this slowdown. First, additional fine-grid iterations would not lead to better results in the following boundary-layer calculations since the inviscid solution contains no viscous corrections and is therefore limited in accuracy even if numerically converged. Second, the lift could possibly develop too quickly and overshoot the value of lift at convergence. (The boundary layer reduces and redistributes lift.) Experience has shown that faster overall convergence is obtained if lift monotonically increases throughout the run.

After the initial inviscid calculation, the first boundary-layer calculation is performed. Displacement thickness corrections should be made to the wing and wake based on this calculation. The boundary-layer transition point for the upper and lower surfaces should be set to zero, forcing the boundary layer to be purely turbulent. The displacement thickness corrections should be underrelaxed using a value of RELI of approximately -0.9. (RELI is defined negative for the first boundary-layer calculation to serve as a trigger to indicate that there are no previous values of displacement thickness available for underrelaxation. The calculated values of displacement thickness are multiplied by the magnitude of RELI in the first global iteration.)

The second inviscid calculation is then performed on a configuration where the wing and wake have been modified by the displacement thickness generated by the first boundary-layer calculation (BLCP = 2.0). Wake curvature effects are not included. Since the displacement thickness can significantly change the shape of the wing, it is best to start the second inviscid calculation with the potential field reinitialized to zero (FCONT = 1.0). Since the potential field is reinitialized, grid refinement should be used to help speed up the redevelopment of the flow field.

The second boundary-layer calculation is then performed. From this calculation, displacement thickness corrections should be used on the wing and wake. Wake-curvature effects and lag-entrainment effects should also be included (FFLAG = 1.0). A low value of RELI should be used at this point (RELI ≈ 0.6).

The third inviscid calculation is then performed. To include all the viscous effects from the second boundary-layer calculation, BLCP should be set equal to 3.0. Since the viscous corrections applied for the third inviscid calculation should be about the same as the corrections applied for the second inviscid calculation, the inviscid flow field will not be very different. Hence, the third inviscid calculation should start with the values of the potential left from the end of the second inviscid calculation.

The third boundary-layer calculation is then performed. RELI should be equal to approximately 0.8. Full viscous treatment should be used from the third boundary-layer calculation forward in the TAWFIVE run.

The fourth and ensuing calculations of the inviscid flow field and boundary layer use the same input parameters. All inviscid calculations are performed on the fine grid and each inviscid calculation starts with the solution from the previous calculation. A nominal forty iterations should be performed in each inviscid calculation. Full boundary-layer treatment (BLCP = 3.0) and lag-entrainment effects (FFLAG = 1.0) should be included and their changes underrelaxed (RELI = 0.8). Realistic transition points for the upper and lower surface boundary layers should be used. The blocks of inviscid and viscous calculations should continue until convergence is obtained.

There are several criteria to consider when deciding if a run is properly converged. A rough measure of the convergence is the configuration lift coefficient. This may be used if the user is only interested in the overall lift. A better measure of convergence is the lift distribution in the inviscid calculation. As with the total lift, changes in the lift distribution should be observed over several global iterations to determine convergence. The number of sonic points in the inviscid flow field should also be used as a measure of convergence for calculations of transonic flow. If a run is determined to be insufficiently converged, the restart option should be used to continue the calculation.

The aforementioned running strategies are not hard and fast rules. For difficult cases, it may be necessary to reduce some of the relaxation parameters (P10, P20, P30, RELI). For very difficult cases, it may help to bring in the viscous corrections more slowly rather than having them all in place by the third global iteration. Constant-value extrapolation of the displacement thickness through regions of separation (FISEPI(1) = 0.0) and FISEPI(2) = 0.0) for the first few boundary-layer calculations may be helpful. This is especially true in the cove region of a wing with a supercritical airfoil section. Purely turbulent boundary-layer calculations (AK(1) = AK(2) = 0.0) for the first few boundary-layer calculations will not only speed convergence, but may actually help convergence of solutions for difficult cases.

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TABLE 1.- I/O UNITS

Unit	Description
3	UNFORMATTED OUTPUT - This file contains restart information. It is written by subroutine SAVE which is called by the main program, INTRACT.
4	UNFORMATTED INPUT - This file contains restart information. It is read by subroutine RESTRT which is called by subroutine FLO 30.
5	FORMATTED INPUT - This file contains iteration and interaction control input variables. See Table 4 for a detailed description of the input on this unit. This information is read from subroutine FLO 30 which is called by the main program INTRACT.
6	FORMATTED OUTPUT - This file contains the output from the program. Included are grid information; inviscid iteration histories; and wing-section aerodynamic, configuration aerodynamic, wing-boundary-layer, and wake-calculation data.
7	FORMATTED INPUT - This file contains the geometry definition input, including both body-section and wing-section definitions. These data are read in subroutine GEOM which is called by subroutine FLO 30 which is called from the main program INTRACT. See Table 2 for a detailed description of the input on this unit.
9	FORMATTED OUTPUT - This file contains plotting data for use by the postprocessor plotting package. It includes data for section C_p vs chord plots and C_p contour plots.

TABLE 2.- GEOMETRY INPUT DESCRIPTION (UNIT 7)

Read Orders 1-13 are used to specify the wing geometry and Read Orders 14-19 are used to define the fuselage. The wing can be defined with up to 21 span stations. A set of airfoil coordinates must be read in at the first (root) section. 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 shapes at computational span locations between the input span locations are obtained by linear interpolations in the spanwise direction in physical space.

Read Orders 1-3 are read only once.

Read Order	Number of Cards	Description and Comments
1	1	TITLE. - Title of geometric configuration. This title is written on unit 6 with the geometric information at the beginning of the inviscid calculation. FORMAT (20A4)
2	1	DESC. - Description for card in Read Order 3.
3	1	FNC, SWEEP1, SWEEP2, SWEEP, DIHED1, DIHED2, DIHED FORMAT (8F10.6)
		FNC. - Number of input wing sections used to define the wing geometry. A maximum of 21 and a minimum of 2 is allowed.
		SWEEP1. - Sweep angle of wing leading edge at root section (in degrees) as shown in figure 1. (Not used.)
		SWEEP2. - Sweep angle of spanwise grid lines at farfield boundary (off tip of wing) (in degrees) as shown in figure 1.
		SWEEP. - Sweep angle of wing leading edge at tip section (in degrees) as shown in figure 1.

TABLE 2.- GEOMETRY INPUT DESCRIPTION (UNIT 7)--Continued

Read Order	Number of Cards	Description and Comments		
		DIHED1.	-	Dihedral angle of wing leading edge at root section (in degrees) as shown in figure 2. (Not used.)
		DIHED2.	-	Dihedral angle of spanwise grid lines at farfield boundary (off tip of wing) (in degrees) as shown in figure 2.
		DIHED.	-	Dihedral angle of wing leading edge at tip section (in degrees) as shown in figure 2.

Read Orders 4-10 and 12 are read once for each of the FNC wing input sections. Read Orders 11 and 13 are read FNUI and FNUL times, respectively, for each of the FNC airfoil wing sections.

Read Order	Number of Cards	Description and Comments		
4	1	DESC.	-	Description for card in Read Order 5.
5	1	ZIN, XLIN, YLIN, CHIN, TH, ALIN, FSEC, FINT FORMAT (8F10.6)		
		ZIN.	-	Spanwise coordinate of the wing section being specified. It is in the same units as CHIN, the input chord length for each section. The wing sections must be input starting with the wing root and continuing to the tip section definition. The root section should be just outside of the wing fuselage intersection. See figure 3.
		XLIN.	-	X coordinate of section leading edge in physical space (controls sweep). See figure 3.
		YLIN.	-	Y coordinate of section leading edge in physical space (controls dihedral). See figure 3.
		CHIN.	-	Section chord length. The chord of the airfoil coordinates to be read in (or already read in at a prior section if FSEC = 0) will be scaled to this value.

Read Order	Number of Cards		Description and Comments
		TH.	- Section thickness ratio relative to that of the airfoil coordinates to be read in (or already read in at a prior section if FSEC = 0). Note, this is a ratio of thickness/chord <u>ratios</u>. The thickness of the airfoil coordinates will be scaled with this value.
		ALIN.	- Section angle of attack or twist (in degrees). Airfoil coordinates will be rotated through this angle about the origin of the parabolic mapping (not the airfoil leading edge).
		FSEC.	- Airfoil section coordinate input trigger. FSEC = 0. Airfoil coordinates are not read in at this station; the last set of airfoil coordinates read in will be used at this section. The previous coordinates are scaled using CHIN, TH, and ALIN. Read Orders 6-13 are not used for FSEC = 0. FSEC = 1. A new set of airfoil coordinates will be read in at this station.
		FINT.	- Hard surface lofting control parameter. Boundary-layer corrections are added to a hard surface generated internally by the program by linear lofting between the input airfoil sections. FINT gives the number of equally-spaced sections added between this input section and the next. FINT $\geq$ 0. (FNC plus the number of sections added using FINT must be less than 21.)

TABLE 2.- GEOMETRY INPUT DESCRIPTION (UNIT 7)--Continued

Read Order	Number of Cards	Description and Comments
6	1	DESC. - Description for card in Read Order 7.
7	1	YSYM, FNUI, FNLI
		YSYM. - Airfoil symmetry trigger.
		YSYM > 0. Symmetric airfoil. Read in only upper surface airfoil coordinates, ordered leading edge to trailing edge.
		YSYM ≤ 0. Nonsymmetric airfoil. Read in upper and lower surface airfoil coordinates, respectively, each set ordered leading edge to trailing edge. Note that leading-edge point is included in both the upper and lower surface coordinate sets.
		FNUI. - Number of coordinates read in for upper surface of airfoil. (FNUI ≤ 81.) (FNUI must be the same for all input stations.)
		FNLI. - Number of coordinates read in for definition of lower surface of airfoil. (FNLI ≤ 81.) (FNLI must be the same for all input stations.)
8	1	DESC. - Description for card in Read Order 9.
9	1	TRL, SLT, XSING, YSING FORMAT (8F10.6)
		These values are <u>not</u> used by the program. Their values are generated internally. Read Orders 8 and 9 were left in only to make the geometry input compatible with earlier versions of FLO 30. For completeness and to assist readers who may use this writeup to help run FLO 30, these four variables are defined below.

TABLE 2.- GEOMETRY INPUT DESCRIPTION (UNIT 7)--Continued

Read Order	Number of Cards	Description and Comments
		TRL. - Included angle of trailing edge of airfoil (in degrees). For blunt trailing edges, it is the upper surface slope angle minus the lower surface slope angle. (Not used in present work.)
		SLT. - Slope of airfoil mean camber line at trailing edge. (Not used in present work.)
		XSING. - X coordinate of the origin of the parabolic mapping referenced to the airfoil leading edge. The recommended value is approximately X(LE) + 1/2 leading-edge radius where the leading-edge radius is in the same units as XP(I) read in below. (Not used in present work.)
		YSING. - Y coordinate of the origin of the mapping referenced to the airfoil leading edge. The recommended value is approximately Y(LE). (Not used in present work.)
10	1	DESC. - Description for cards in Read Order 11.
11	FNUI	XP(I), YP(I) FORMAT (8F10.6)
		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 the airfoil section is not symmetric (YSYM ≥ 0), the airfoil lower surface coordinates must be read here. For symmetric airfoil (YSYM > 0), skip the two Read Orders 12 and 13.

TABLE 2.- GEOMETRY INPUT DESCRIPTION (UNIT 7)--Continued

Read Order	Number of Cards	Description and Comments
12	1	DESC. - Description for cards in Read Order 13. FORMAT (8A10)
13	FNLI	XP(I), YP(I) FORMAT (8F10.6) XP(I). - X coordinate of airfoil lower surface, ordered leading edge to trailing edge. YP(I). - 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 4-13 complete the input for one span station. As indicated above Read Order 4, at least Read Orders 4 and 5 must be repeated for the remaining FNC-1 sections where FNC ≥ 2.

Read Orders 14-19 are used to define the fuselage.

Read Order	Number of Cards	Description and Comments
14	1	DESC. - Description for card in Read Order 15.
15	1	FNF, FCIRC FORMAT (8F10.6) FNF. - Number of fuselage defining stations. The stations are input starting at the upstream end and continuing to the downstream end of the fuselage. A maximum of 25 stations may be input. FCIRC. - Circular fuselage trigger. FCIRC = 0. Arbitrary fuselage shape is read in Read Orders 16-19. FCIRC ≠ 0. Circular fuselage is used. The diameter is specified by inputing the points of intersection between the fuselage section and the Z = 0 symmetry plane.

Read Order	Number of Cards	Description and Comments		

The block of Read Orders 16-19 is repeated for each of the fuselage sections used to define the fuselage.

Read Order	Number of Cards			Description and Comments
16	1	DESC.	-	Description for card in Read Order 17.
17	1	FNFP, XF(I), FSEC FORMAT (8F10.6)		
		FNFP.	-	Number of coordinate pairs read in to define fuselage section ($1 \le FNFP \le 101$). FNFP = 1. This is used to define either the nose or tail of a closed fuselage. FNFP = 2. This value is used with FSEC = 0. to allow scaling of previously input fuselage section. This value also may be used at the last fuselage station. With this, the fuselage is continued downstream as a constant area sting. This may also be used with FCIRC = 1. to input a circular fuselage. The two points input are then the intersection points of the fuselage section with the Z = 0 symmetry plane. FNFP = 3. → 101. This is simply the number of coordinate pairs used to define the fuselage section.
		XF(I).	-	X coordinate of the fuselage section being specified. It is in the same units as the wing-section chord lengths (CHIN) were input.
		FSEC.	-	Fuselage section coordinate input trigger.

TABLE 2.- GEOMETRY INPUT DESCRIPTION (UNIT 7)--Concluded

Read Order	Number of Cards			Description and Comments
				FSEC = 0. Fuselage coordinates are not read in at this station; the last set of fuselage section coordinates read in will be scaled and used at this section. To input scaling, set FNFP = 2. to input only two points and then input the two points of intersection of the fuselage section and the Z = 0 symmetry plane.
				FSEC = 1. A new set of fuselage section coordinates will be read in using Read Orders 18 and 19.
18	1	DESC.	-	Description for card(s) in Read Order 19.
19	FNFP	YF, ZF FORMAT (8F10.6)		
		YF.	-	Y coordinate of fuselage surface, ordered top of fuselage (at Z = 0 symmetry plane) to bottom of fuselage (at Z = 0 symmetry plane).
		ZF.	-	Z coordinate of fuselage surface, ordered top of fuselage (at Z = 0 symmetry plane) to bottom of fuselage (at Z = 0 symmetry plane).

TABLE 3.- SAMPLE GEOMETRY INPUT FILE (UNIT 7)

```
LOCKHEED-GEORGIA WING A ON BODY (N)
       FNC     SWEEP1    SWEEP2     SWEEP     DIHED1    DIHED2    DIHED
       15.       25.       25.       25.        0.        0.        0.
       ZIN      XLIN      YLIN      CHIN        TH      ALIN      FSEC      FINT
   5.71250  34.36388   0.00000  15.27125        1.      2.16        1.       0.0
      YSYM      FNUI      FNLI
        0.       33.       33.
       TRL       SLT     XSING     YSING
      999.
 UPPER SURF
  0.000000  0.000000
   .002410   .009431
   .009610   .017547
   .021530   .024378
   .038060   .030335
   .059040   .035224
   .084270   .038977
   .113490   .041920
   .146450   .044339
   .182800   .046357
   .222210   .047957
   .264300   .049074
   .308660   .049718
   .354860   .049879
   .402450   .049539
   .450990   .048594
   .500000   .047020
   .549010   .044776
   .597550   .041986
   .645140   .038656
   .691340   .034936
   .735700   .030955
   .777790   .026833
   .817200   .022687
   .853550   .018652
   .886510   .014891
   .915730   .011475
   .940960   .008499
   .961940   .006043
   .978470   .004016
   .990390   .002502
   .997590   .001327
  1.000000   .000869
 LOWER SURF
  0.000000  0.000000
   .002410  -.008053
   .009610  -.015785
   .021530  -.022015
   .038060  -.028094
```

TABLE 3.- SAMPLE GEOMETRY INPUT FILE (UNIT 7)--Continued

```
 .059040  -.034067
 .084270  -.040153
 .113490  -.046286
 .146450  -.052377
 .182800  -.058029
 .222210  -.062922
 .264300  -.066641
 .308660  -.069171
 .354860  -.070107
 .402450  -.069789
 .450990  -.067696
 .500000  -.064276
 .549010  -.058954
 .597550  -.052350
 .645140  -.044362
 .691340  -.035878
 .735700  -.027385
 .777790  -.019447
 .817200  -.012462
 .853550  -.006715
 .886510  -.002355
 .915730   .000485
 .940960   .001871
 .961940   .002038
 .978470   .001427
 .990390   .000452
 .997590  -.000486
1.000000  -.000869
     ZIN      XLIN      YLIN      CHIN      TH      ALIN      FSEC      FINT
 8.56875  35.72581   0.00000  14.65188      1.      1.86        1.       0.0
    YSYM      FNUI      FNLI
      0.       33.       33.
     TRL       SLT     XSING     YSING
    999.
UPPER SURF
0.000000  0.000000
 .002410   .009381
 .009610   .017528
 .021530   .024416
 .038060   .030422
 .059040   .035372
 .084270   .039206
 .113490   .042235
 .146450   .044733
 .182800   .046818
 .222210   .048473
 .264300   .049639
 .308660   .050325
 .354860   .050521
```

TABLE 3.- SAMPLE GEOMETRY INPUT FILE (UNIT 7)--Continued

```
  .402450    .050209
  .450990    .049290
  .500000    .047741
  .549010    .045523
  .597550    .042756
  .645140    .039443
  .691340    .035728
  .735700    .031730
  .777790    .027562
  .817200    .023339
  .853550    .019205
  .886510    .015336
  .915730    .011815
  .940960    .008746
  .961940    .006213
  .978470    .004127
  .990390    .002576
  .997590    .001376
 1.000000    .000907
LOWER SURF
 0.000000  0.000000
  .002410  -.008084
  .009610  -.015788
  .021530  -.021996
  .038060  -.028023
  .059040  -.033925
  .084270  -.039929
  .113490  -.045974
  .146450  -.051976
  .182800  -.057545
  .222210  -.062365
  .264300  -.066033
  .308660  -.068529
  .354860  -.069458
  .402450  -.069141
  .450990  -.067063
  .500000  -.063643
  .549010  -.058319
  .597550  -.051707
  .645140  -.043732
  .691340  -.035273
  .735700  -.026825
  .777790  -.018944
  .817200  -.012029
  .853550  -.006363
  .886510  -.002088
  .915730   .000668
  .940960   .001979
  .961940   .002087
```

TABLE 3.- SAMPLE GEOMETRY INPUT FILE (UNIT 7)--Continued

```
  .978470   .001431
  .990390   .000437
  .997590  -.000517
 1.000000  -.000907
      ZIN      XLIN      YLIN      CHIN      TH      ALIN      FSEC      FINT
 11.42500  37.08775   0.00000  14.03250      1.      1.56        1.       0.0
     YSYM      FNUI      FNLI
       0.       33.       33.
      TRL       SLT     XSING     YSING
     999.
UPPER SURF
 0.000000  0.000000
  .002410   .009327
  .009610   .017508
  .021530   .024458
  .038060   .030517
  .059040   .035534
  .084270   .039455
  .113490   .042578
  .146450   .045162
  .182800   .047319
  .222210   .049035
  .264300   .050255
  .308660   .050986
  .354860   .051220
  .402450   .050938
  .450990   .050047
  .500000   .048526
  .549010   .046336
  .597550   .043594
  .645140   .040300
  .691340   .036591
  .735700   .032574
  .777790   .028355
  .817200   .024049
  .853550   .019808
  .886510   .015821
  .915730   .012186
  .940960   .009015
  .961940   .006398
  .978470   .004247
  .990390   .002657
  .997590   .001429
 1.000000   .000949
LOWER SURF
 0.000000  0.000000
  .002410  -.008116
  .009610  -.015792
  .021530  -.021975
```

TABLE 3.- SAMPLE GEOMETRY INPUT FILE (UNIT 7)--Continued

```
  .038060  -.027946
  .059040  -.033770
  .084270  -.039686
  .113490  -.045635
  .146450  -.051539
  .182800  -.057017
  .222210  -.061759
  .264300  -.065372
  .308660  -.067830
  .354860  -.068751
  .402450  -.068435
  .450990  -.066374
  .500000  -.062954
  .549010  -.057628
  .597550  -.051008
  .645140  -.043046
  .691340  -.034616
  .735700  -.026215
  .777790  -.018396
  .817200  -.011558
  .853550  -.005980
  .886510  -.001796
  .915730   .000867
  .940960   .002096
  .961940   .002140
  .978470   .001435
  .990390   .000420
  .997590  -.000551
 1.000000  -.000949
      ZIN      XLIN      YLIN      CHIN        TH      ALIN      FSEC      FINT
 14.28125  38.44969   0.00000  13.41313        1.      1.26        1.       0.0
     YSYM      FNUI      FNLI
       0.       33.       33.
      TRL       SLT     XSING     YSING
     999.
UPPER SURF
 0.000000  0.000000
  .002410   .009268
  .009610   .017486
  .021530   .024504
  .038060   .030621
  .059040   .035710
  .084270   .039728
  .113490   .042953
  .146450   .045630
  .182800   .047866
  .222210   .049649
  .264300   .050927
  .308660   .051708
```

TABLE 3.- SAMPLE GEOMETRY INPUT FILE (UNIT 7)--Continued

```
  .354860    .051983
  .402450    .051734
  .450990    .050874
  .500000    .049383
  .549010    .047223
  .597550    .044509
  .645140    .041235
  .691340    .037533
  .735700    .033495
  .777790    .029221
  .817200    .024824
  .853550    .020465
  .886510    .016351
  .915730    .012591
  .940960    .009309
  .961940    .006601
  .978470    .004378
  .990390    .002745
  .997590    .001488
 1.000000    .000995
LOWER SURF
 0.000000  0.000000
  .002410  -.008152
  .009610  -.015795
  .021530  -.021952
  .038060  -.027862
  .059040  -.033600
  .084270  -.039420
  .113490  -.045264
  .146450  -.051062
  .182800  -.056440
  .222210  -.061098
  .264300  -.064649
  .308660  -.067067
  .354860  -.067979
  .402450  -.067665
  .450990  -.065622
  .500000  -.062202
  .549010  -.056874
  .597550  -.050244
  .645140  -.042297
  .691340  -.033898
  .735700  -.025549
  .777790  -.017798
  .817200  -.011043
  .853550  -.005561
  .886510  -.001478
  .915730   .001084
  .940960   .002224
```

TABLE 3.- SAMPLE GEOMETRY INPUT FILE (UNIT 7)--Continued

.961940	.002199						
.978470	.001440						
.990390	.000402						
.997590	-.000588						
1.000000	-.000995						
ZIN	XLIN	YLIN	CHIN	TH	ALIN	FSEC	FINT
17.13750	39.81163	0.00000	12.79375	1.	.96	1.	0.0
YSYM	FNUI	FNLI					
0.	33.	33.					
TRL	SLT	XSING	YSING				
999.							
UPPER SURF							
0.000000	0.000000						
.002410	.009203						
.009610	.017462						
.021530	.024554						
.038060	.030735						
.059040	.035904						
.084270	.040027						
.113490	.043364						
.146450	.046143						
.182800	.048467						
.222210	.050323						
.264300	.051664						
.308660	.052499						
.354860	.052820						
.402450	.052608						
.450990	.051780						
.500000	.050323						
.549010	.048197						
.597550	.045512						
.645140	.042261						
.691340	.038566						
.735700	.034505						
.777790	.030171						
.817200	.025674						
.853550	.021187						
.886510	.016932						
.915730	.013035						
.940960	.009631						
.961940	.006823						
.978470	.004522						
.990390	.002842						
.997590	.001551						
1.000000	.001046						
LOWER SURF							
0.000000	0.000000						
.002410	-.008192						
.009610	-.015799						

TABLE 3.- SAMPLE GEOMETRY INPUT FILE (UNIT 7)--Continued

.021530	-.021926						
.038060	-.027769						
.059040	-.033415						
.084270	-.039128						
.113490	-.044857						
.146450	-.050538						
.182800	-.055808						
.222210	-.060372						
.264300	-.063857						
.308660	-.066230						
.354860	-.067132						
.402450	-.066819						
.450990	-.064796						
.500000	-.061376						
.549010	-.056046						
.597550	-.049406						
.645140	-.041476						
.691340	-.033110						
.735700	-.024819						
.777790	-.017142						
.817200	-.010479						
.853550	-.005102						
.886510	-.001130						
.915730	.001323						
.940960	.002365						
.961940	.002263						
.978470	.001445						
.990390	.000381						
.997590	-.000629						
1.000000	-.001046						
ZIN	XLIN	YLIN	CHIN	TH	ALIN	FSEC	FINT
19.99375	41.17356	0.00000	12.17438	1.	.66	1.	0.0
YSYM	FNUI	FNLI					
0.	33.	33.					
TRL	SLT	XSING	YSING				
999.							
UPPER SURF							
0.000000	0.000000						
.002410	.009131						
.009610	.017435						
.021530	.024609						
.038060	.030861						
.059040	.036117						
.084270	.040356						
.113490	.043817						
.146450	.046709						
.182800	.049129						
.222210	.051065						
.264300	.052477						

TABLE 3.- SAMPLE GEOMETRY INPUT FILE (UNIT 7)--Continued

```
  .308660   .053372
  .354860   .053742
  .402450   .053570
  .450990   .052780
  .500000   .051359
  .549010   .049270
  .597550   .046618
  .645140   .043391
  .691340   .039704
  .735700   .035619
  .777790   .031218
  .817200   .026610
  .853550   .021982
  .886510   .017572
  .915730   .013524
  .940960   .009986
  .961940   .007068
  .978470   .004681
  .990390   .002949
  .997590   .001622
 1.000000   .001101
LOWER SURF
 0.000000  0.000000
  .002410  -.008235
  .009610  -.015804
  .021530  -.021898
  .038060  -.027667
  .059040  -.033210
  .084270  -.038807
  .113490  -.044409
  .146450  -.049962
  .182800  -.055112
  .222210  -.059572
  .264300  -.062984
  .308660  -.065308
  .354860  -.066199
  .402450  -.065888
  .450990  -.063887
  .500000  -.060467
  .549010  -.055135
  .597550  -.048483
  .645140  -.040570
  .691340  -.032242
  .735700  -.024014
  .777790  -.016419
  .817200  -.009857
  .853550  -.004596
  .886510  -.000745
  .915730   .001585
```

TABLE 3.- SAMPLE GEOMETRY INPUT FILE (UNIT 7)--Continued

```
  .940960   .002520
  .961940   .002334
  .978470   .001451
  .990390   .000359
  .997590  -.000674
 1.000000  -.001101
      ZIN      XLIN      YLIN      CHIN      TH      ALIN      FSEC      FINT
 22.85000  42.53550   0.00000  11.55500      1.       .36       1.       0.0
     YSYM      FNUI      FNLI
       0.       33.       33.
      TRL       SLT     XSING     YSING
     999.
UPPER SURF
 0.000000  0.000000
  .002410   .009052
  .009610   .017406
  .021530   .024670
  .038060   .031000
  .059040   .036354
  .084270   .040720
  .113490   .044319
  .146450   .047336
  .182800   .049861
  .222210   .051886
  .264300   .053376
  .308660   .054338
  .354860   .054763
  .402450   .054636
  .450990   .053886
  .500000   .052506
  .549010   .050458
  .597550   .047843
  .645140   .044643
  .691340   .040964
  .735700   .036851
  .777790   .032377
  .817200   .027647
  .853550   .022862
  .886510   .018281
  .915730   .014066
  .940960   .010379
  .961940   .007339
  .978470   .004857
  .990390   .003067
  .997590   .001700
 1.000000   .001163
LOWER SURF
 0.000000  0.000000
  .002410  -.008283
```

TABLE 3.- SAMPLE GEOMETRY INPUT FILE (UNIT 7)--Continued

```
  .009610  -.015809
  .021530  -.021867
  .038060  -.027555
  .059040  -.032983
  .084270  -.038451
  .113490  -.043913
  .146450  -.049323
  .182800  -.054341
  .222210  -.058687
  .264300  -.062017
  .308660  -.064287
  .354860  -.065165
  .402450  -.064857
  .450990  -.062880
  .500000  -.059460
  .549010  -.054125
  .597550  -.047461
  .645140  -.039568
  .691340  -.031281
  .735700  -.023122
  .777790  -.015619
  .817200  -.009169
  .853550  -.004036
  .886510  -.000320
  .915730   .001876
  .940960   .002691
  .961940   .002413
  .978470   .001457
  .990390   .000334
  .997590  -.000724
 1.000000  -.001163
      ZIN      XLIN      YLIN      CHIN        TH      ALIN      FSEC      FINT
 25.70625  43.89744   0.00000  10.93563        1.       .06        1.       0.0
     YSYM      FNUI      FNLI
       0.       33.       33.
      TRL       SLT     XSING     YSING
     999.
UPPER SURF
 0.000000  0.000000
  .002410   .008963
  .009610   .017373
  .021530   .024738
  .038060   .031154
  .059040   .036617
  .084270   .041126
  .113490   .044877
  .146450   .048033
  .182800   .050676
  .222210   .052801
```

.264300	.054378
.308660	.055413
.354860	.055900
.402450	.055822
.450990	.055117
.500000	.053782
.549010	.051781
.597550	.049206
.645140	.046036
.691340	.042367
.735700	.038223
.777790	.033667
.817200	.028802
.853550	.023842
.886510	.019070
.915730	.014669
.940960	.010817
.961940	.007641
.978470	.005052
.990390	.003198
.997590	.001787
1.000000	.001231
LOWER SURF	
0.000000	0.000000
.002410	-.008336
.009610	-.015814
.021530	-.021833
.038060	-.027429
.059040	-.032731
.084270	-.038055
.113490	-.043360
.146450	-.048612
.182800	-.053482
.222210	-.057701
.264300	-.060940
.308660	-.063150
.354860	-.064015
.402450	-.063709
.450990	-.061759
.500000	-.058339
.549010	-.053002
.597550	-.046323
.645140	-.038453
.691340	-.030211
.735700	-.022130
.777790	-.014728
.817200	-.008402
.853550	-.003412
.886510	.000154

TABLE 3.- SAMPLE GEOMETRY INPUT FILE (UNIT 7)--Continued

```
   .915730   .002200
   .940960   .002882
   .961940   .002500
   .978470   .001464
   .990390   .000307
   .997590  -.000780
  1.000000  -.001231
       ZIN      XLIN      YLIN      CHIN        TH      ALIN      FSEC      FINT
  28.56250  45.25938   0.00000  10.31625        1.      -.24        1.       0.0
      YSYM      FNUI      FNLI
       0.0       33.       33.
       TRL       SLT     XSING     YSING
      999.
UPPER SURF
  0.000000  0.000000
   .002410   .008864
   .009610   .017336
   .021530   .024814
   .038060   .031328
   .059040   .036911
   .084270   .041581
   .113490   .045502
   .146450   .048814
   .182800   .051590
   .222210   .053826
   .264300   .055499
   .308660   .056617
   .354860   .057173
   .402450   .057151
   .450990   .056497
   .500000   .055213
   .549010   .053262
   .597550   .050732
   .645140   .047596
   .691340   .043938
   .735700   .039760
   .777790   .035113
   .817200   .030095
   .853550   .024939
   .886510   .019954
   .915730   .015344
   .940960   .011307
   .961940   .007979
   .978470   .005271
   .990390   .003346
   .997590   .001884
  1.000000   .001308
LOWER SURF
  0.000000  0.000000
```

TABLE 3.- SAMPLE GEOMETRY INPUT FILE (UNIT 7)--Continued

```
  .002410  -.008396
  .009610  -.015820
  .021530  -.021794
  .038060  -.027288
  .059040  -.032449
  .084270  -.037611
  .113490  -.042741
  .146450  -.047816
  .182800  -.052520
  .222210  -.056597
  .264300  -.059735
  .308660  -.061877
  .354860  -.062727
  .402450  -.062423
  .450990  -.060503
  .500000  -.057083
  .549010  -.051743
  .597550  -.045049
  .645140  -.037203
  .691340  -.029013
  .735700  -.021019
  .777790  -.013730
  .817200  -.007544
  .853550  -.002714
  .886510   .000685
  .915730   .002563
  .940960   .003095
  .961940   .002598
  .978470   .001472
  .990390   .000276
  .997590  -.000842
 1.000000  -.001308
      ZIN      XLIN      YLIN      CHIN        TH      ALIN      FSEC      FINT
 31.41875  46.62131   0.00000   9.69688        1.      -.54        1.       0.0
     YSYM      FNUI      FNLI
       0.       33.       33.
      TRL       SLT     XSING     YSING
     999.
UPPER SURF
 0.000000  0.000000
  .002410   .008753
  .009610   .017295
  .021530   .024900
  .038060   .031523
  .059040   .037244
  .084270   .042094
  .113490   .046208
  .146450   .049695
  .182800   .052620
```

TABLE 3.- SAMPLE GEOMETRY INPUT FILE (UNIT 7)--Continued

.222210	.054981
.264300	.056764
.308660	.057975
.354860	.058609
.402450	.058649
.450990	.058052
.500000	.056825
.549010	.054933
.597550	.052454
.645140	.049356
.691340	.045710
.735700	.041494
.777790	.036742
.817200	.031553
.853550	.026177
.886510	.020951
.915730	.016106
.940960	.011860
.961940	.008360
.978470	.005519
.990390	.003512
.997590	.001993
1.000000	.001394
LOWER SURF	
0.000000	0.000000
.002410	-.008463
.009610	-.015827
.021530	-.021751
.038060	-.027130
.059040	-.032130
.084270	-.037111
.113490	-.042044
.146450	-.046918
.182800	-.051436
.222210	-.055351
.264300	-.058375
.308660	-.060441
.354860	-.061274
.402450	-.060973
.450990	-.059087
.500000	-.055667
.549010	-.050324
.597550	-.043612
.645140	-.035794
.691340	-.027662
.735700	-.019765
.777790	-.012605
.817200	-.006576
.853550	-.001926

TABLE 3.- SAMPLE GEOMETRY INPUT FILE (UNIT 7)--Continued

.886510	.001283						
.915730	.002972						
.940960	.003336						
.961940	.002708						
.978470	.001481						
.990390	.000241						
.997590	-.000912						
1.000000	-.001394						
ZIN	XLIN	YLIN	CHIN	TH	ALIN	FSEC	FINT
34.27500	47.98325	0.00000	9.07750	1.	-.84	1.	0.0
YSYM	FNUI	FNLI					
0.	33.	33.					
TRL	SLT	XSING	YSING				
999.							
UPPER SURF							
0.000000	0.000000						
.002410	.008626						
.009610	.017247						
.021530	.024997						
.038060	.031745						
.059040	.037621						
.084270	.042676						
.113490	.047009						
.146450	.050696						
.182800	.053790						
.222210	.056294						
.264300	.058202						
.308660	.059519						
.354860	.060240						
.402450	.060352						
.450990	.059820						
.500000	.058658						
.549010	.056832						
.597550	.054411						
.645140	.051356						
.691340	.047724						
.735700	.043463						
.777790	.038595						
.817200	.033210						
.853550	.027584						
.886510	.022083						
.915730	.016972						
.940960	.012488						
.961940	.008794						
.978470	.005799						
.990390	.003701						
.997590	.002118						
1.000000	.001493						
LOWER SURF							

TABLE 3.- SAMPLE GEOMETRY INPUT FILE (UNIT 7)--Continued

```
 0.000000  0.000000
  .002410  -.008540
  .009610  -.015835
  .021530  -.021701
  .038060  -.026949
  .059040  -.031768
  .084270  -.036542
  .113490  -.041251
  .146450  -.045897
  .182800  -.050203
  .222210  -.053936
  .264300  -.056830
  .308660  -.058810
  .354860  -.059623
  .402450  -.059325
  .450990  -.057478
  .500000  -.054058
  .549010  -.048710
  .597550  -.041979
  .645140  -.034192
  .691340  -.026126
  .735700  -.018341
  .777790  -.011326
  .817200  -.005476
  .853550  -.001031
  .886510   .001963
  .915730   .003437
  .940960   .003610
  .961940   .002833
  .978470   .001491
  .990390   .000202
  .997590  -.000992
 1.000000  -.001493
      ZIN      XLIN      YLIN      CHIN        TH      ALIN      FSEC      FINT
 37.13125  49.34519   0.00000   8.45813        1.     -1.14        1.       0.0
     YSYM      FNUI      FNLI
       0.       33.       33.
      TRL       SLT     XSING     YSING
     999.
UPPER SURF
 0.000000  0.000000
  .002410   .008480
  .009610   .017193
  .021530   .025109
  .038060   .032000
  .059040   .038054
  .084270   .043344
  .113490   .047928
  .146450   .051844
```

TABLE 3.- SAMPLE GEOMETRY INPUT FILE (UNIT 7)--Continued

```
  .182800    .055133
  .222210    .057799
  .264300    .059850
  .308660    .061288
  .354860    .062111
  .402450    .062304
  .450990    .061847
  .500000    .060760
  .549010    .059009
  .597550    .056654
  .645140    .053649
  .691340    .050033
  .735700    .045722
  .777790    .040718
  .817200    .035110
  .853550    .029196
  .886510    .023382
  .915730    .017965
  .940960    .013208
  .961940    .009290
  .978470    .006121
  .990390    .003917
  .997590    .002261
 1.000000    .001605
LOWER SURF
 0.000000  0.000000
  .002410  -.008628
  .009610  -.015843
  .021530  -.021644
  .038060  -.026743
  .059040  -.031353
  .084270  -.035890
  .113490  -.040341
  .146450  -.044727
  .182800  -.048790
  .222210  -.052314
  .264300  -.055059
  .308660  -.056939
  .354860  -.057730
  .402450  -.057436
  .450990  -.055633
  .500000  -.052213
  .549010  -.046861
  .597550  -.040106
  .645140  -.032356
  .691340  -.024365
  .735700  -.016708
  .777790  -.009860
  .817200  -.004214
```

TABLE 3.- SAMPLE GEOMETRY INPUT FILE (UNIT 7)--Continued

```
  .853550  -.000005
  .886510   .002743
  .915730   .003970
  .940960   .003924
  .961940   .002977
  .978470   .001502
  .990390   .000157
  .997590  -.001083
 1.000000  -.001605
      ZIN      XLIN      YLIN      CHIN        TH      ALIN      FSEC      FINT
 39.98750  50.70713   0.00000   7.83875        1.     -1.44        1.       0.0
     YSYM      FNUI      FNLI
       0.       33.       33.
      TRL       SLT     XSING     YSING
     999.
UPPER SURF
 0.000000  0.000000
  .002410   .008312
  .009610   .017131
  .021530   .025238
  .038060   .032294
  .059040   .038555
  .084270   .044118
  .113490   .048992
  .146450   .053173
  .182800   .056687
  .222210   .059542
  .264300   .061758
  .308660   .063338
  .354860   .064278
  .402450   .064565
  .450990   .064194
  .500000   .063193
  .549010   .061529
  .597550   .059252
  .645140   .056304
  .691340   .052707
  .735700   .048337
  .777790   .043177
  .817200   .037311
  .853550   .031064
  .886510   .024886
  .915730   .019114
  .940960   .014042
  .961940   .009866
  .978470   .006494
  .990390   .004168
  .997590   .002426
 1.000000   .001736
```

TABLE 3.- SAMPLE GEOMETRY INPUT FILE (UNIT 7)--Continued

```
LOWER SURF
 0.000000  0.000000
  .002410  -.008729
  .009610  -.015854
  .021530  -.021578
  .038060  -.026503
  .059040  -.030872
  .084270  -.035135
  .113490  -.039289
  .146450  -.043373
  .182800  -.047154
  .222210  -.050435
  .264300  -.053008
  .308660  -.054772
  .354860  -.055538
  .402450  -.055248
  .450990  -.053496
  .500000  -.050076
  .549010  -.044719
  .597550  -.037938
  .645140  -.030230
  .691340  -.022326
  .735700  -.014817
  .777790  -.008162
  .817200  -.002754
  .853550   .001184
  .886510   .003646
  .915730   .004588
  .940960   .004288
  .961940   .003143
  .978470   .001516
  .990390   .000104
  .997590  -.001189
 1.000000  -.001736
      ZIN      XLIN      YLIN      CHIN        TH      ALIN      FSEC      FINT
 42.84375  52.06906   0.00000   7.21938        1.     -1.74        1.       0.0
     YSYM      FNUI      FNLI
       0.       33.       33.
      TRL       SLT     XSING     YSING
     999.
UPPER SURF
 0.000000  0.000000
  .002410   .008114
  .009610   .017057
  .021530   .025390
  .038060   .032640
  .059040   .039142
  .084270   .045024
  .113490   .050239
```

TABLE 3.- SAMPLE GEOMETRY INPUT FILE (UNIT 7)--Continued

.146450	.054730
.182800	.058507
.222210	.061584
.264300	.063994
.308660	.065739
.354860	.066816
.402450	.067214
.450990	.066944
.500000	.066044
.549010	.064482
.597550	.062295
.645140	.059415
.691340	.055839
.735700	.051401
.777790	.046058
.817200	.039888
.853550	.033252
.886510	.026647
.915730	.020461
.940960	.015019
.961940	.010540
.978470	.006931
.990390	.004461
.997590	.002620
1.000000	.001888
LOWER SURF	
0.000000	0.000000
.002410	-.008848
.009610	-.015866
.021530	-.021501
.038060	-.026223
.059040	-.030309
.084270	-.034251
.113490	-.038055
.146450	-.041785
.182800	-.045237
.222210	-.048234
.264300	-.050604
.308660	-.052234
.354860	-.052970
.402450	-.052684
.450990	-.050993
.500000	-.047573
.549010	-.042210
.597550	-.035397
.645140	-.027739
.691340	-.019937
.735700	-.012601
.777790	-.006173

```
 .817200  -.001042
 .853550   .002576
 .886510   .004704
 .915730   .005311
 .940960   .004714
 .961940   .003338
 .978470   .001531
 .990390   .000043
 .997590  -.001313
1.000000  -.001888
     ZIN      XLIN      YLIN      CHIN        TH      ALIN      FSEC      FINT
45.70000  53.43100   0.00000   6.60000        1.     -2.04        1.       0.0
    YSYM      FNUI      FNLI
      0.       33.       33.
     TRL       SLT     XSING     YSING
    999.
UPPER SURF
0.000000   0.
 .002410   .00788
 .009610   .01697
 .021530   .02557
 .038060   .03305
 .059040   .03984
 .084270   .04610
 .113490   .05172
 .146450   .05658
 .182800   .06067
 .222210   .06401
 .264300   .06665
 .308660   .06859
 .354860   .06983
 .402450   .07036
 .450990   .07021
 .500000   .06943
 .549010   .06799
 .597550   .06591
 .645140   .06311
 .691340   .05956
 .735700   .05504
 .777790   .04948
 .817200   .04295
 .853550   .03585
 .886510   .02874
 .915730   .02206
 .940960   .01618
 .961940   .01134
 .978470   .00745
 .990390   .00481
 .997590   .00285
```

```
1.000000   .00207
LOWER SURF
0.000000   0.
 .002410   -.00899
 .009610   -.01588
 .021530   -.02141
 .038060   -.02589
 .059040   -.02964
 .084270   -.03320
 .113490   -.03659
 .146450   -.03990
 .182800   -.04296
 .222210   -.04562
 .264300   -.04775
 .308660   -.04922
 .354860   -.04992
 .402450   -.04964
 .450990   -.04802
 .500000   -.04460
 .549010   -.03923
 .597550   -.03238
 .645140   -.02478
 .691340   -.01710
 .735700   -.00997
 .777790   -.00381
 .817200   .00099
 .853550   .00423
 .886510   .00596
 .915730   .00617
 .940960   .00522
 .961940   .00357
 .978470   .00155
 .990390   -.00003
 .997590   -.00146
1.000000   -.00207
     FNF     FCIRC
     14.       0.0
    FNFP     XF(I)     FSEC
      1.        0.       1.
      YF        ZF
      0.        0.
    FNFP     XF(I)     FSEC
     21.        1.       1.
      YF        ZF
   1.301        0.
   1.285      .203
   1.237      .402
   1.159      .591
   1.052      .765
```

TABLE 3.- SAMPLE GEOMETRY INPUT FILE (UNIT 7)--Continued

.920	.920	
.765	1.052	
.591	1.159	
.402	1.237	
.203	1.285	
0.	1.301	
-.203	1.285	
-.402	1.237	
-.591	1.159	
-.765	1.052	
-.920	.920	
-1.052	.765	
-1.159	.591	
-1.237	.402	
-1.285	.203	
-1.301	0.	
FNFP	XF(I)	FSEC
2.	5.	0.
YF	ZF	
2.775	0.	
-2.775	0.	
FNFP	XF(I)	FSEC
2.	10.	0.
YF	ZFF	
3.677	0.	
-3.677	0.	
FNFP	XF(I)	FSEC
2.	15.	0.
YF	ZF	
4.177	0.	
-4.177	0.	
FNFP	XF(I)	FSEC
2.	20.	0.
YF	ZF	
4.414	0.	
-4.414	0.	
FNFP	XF(I)	FSEC
2.	22.9	0.
YF	ZF	
4.45	0.	
-4.45	0.	
FNFP	XF(I)	FSEC
2.	59.7	0.
YF	ZF	
4.45	0.	
-4.45	0.	
FNFP	XF(I)	FSEC
2.	65.	0.
YF	ZF	

TABLE 3.- SAMPLE GEOMETRY INPUT FILE (UNIT 7)--Concluded

4.361	0.	
-4.361	0.	
FNFP	XF(I)	FSEC
2.	70.	0.
YF	ZF	
4.106	0.	
-4.106	0.	
FNFP	XF(I)	FSEC
2.	75.	0.
YF	ZF	
3.647	0.	
-3.647	0.	
FNFP	XF(I)	FSEC
2.	80.	0.
YF	ZF	
2.891	0.	
-2.891	0.	
FNFP	XF(I)	FSEC
2.	85.	0.
YF	ZF	
1.422	0.	
-1.422	0.	
FNFP	XF(I)	FSEC
2.	86.	1.
YF	ZF	
.767	0.	
-.767	0.	

TABLE 4.- INVISCID ITERATION AND GLOBAL INTERACTION CONTROL INPUT DESCRIPTION (UNIT 5)

Read Order	Number of Cards	Description and Comments
		INVISCID CALCULATION INPUT (Read in subroutine FLO30)
1	1	TITLE. - Descriptive title of inviscid calculation. This title appears on the formatted output on unit 6. FORMAT (8A10)
2	1	DESC. - Description for card in Read Order 3.
3	1	FNX, FNY, FNZ, FPLOT, FCONT, BLCP FORMAT (8E10.7)
		FNX. - Number of inviscid computational grid points in the "chordwise direction" from downstream boundary, around the leading edge, and back to downstream boundary on coarsest mesh for that set of inviscid calculations. Maximum is 40. (160 for no grid halving.) FNX is set to less than 1.0 to terminate calculations.
		FNY. - Number of inviscid computational grid points in "normal direction" from airfoil surface to outer boundary on coarsest mesh. Maximum is 6. (24 with no grid halving.)
		FNZ. - Number of inviscid computational grid points in "spanwise direction" from fuselage across wing semispan to maximum distance off the wing tip. Maximum is 8. (32.0 with no grid halving.)
		FPLOT. - Printout trigger.
		$FPLOT \leq 1$. Prints out wing and fuselage data at input stations and generates printer plots of calculated C_p's at each section.
		$FPLOT > 1$. Wing and fuselage data at input stations are not echoed in printout and C_p printer plots at each wing section are not printed.

TABLE 4.- INVISCID ITERATION AND GLOBAL INTERACTION CONTROL INPUT DESCRIPTION (UNIT 5) - Continued

Read Order	Number of Cards		Description and Comments
		FCONT.	- Program starting/restarting trigger. FCONT = 0. Inviscid calculation begins at iteration zero with potential and boundary-layer (B.L.) quantities equal to zero everywhere. FCONT = 1. Inviscid calculation begins at iteration zero with potential equal to zero. Previously calculated values of B.L. quantities are used. FCONT = 2. Inviscid calculation continues from previously obtained values of potential. Previously obtained values of B.L. quantities are used. FCONT = 3. Inviscid calculation continues from previously obtained values of potential which are read in from the restart file, unit 4. Previously obtained values of B.L. quantities (read from restart file, unit 4) are used. For restart, FNX, FNY, and FNZ must correspond to values of data on the restart file. Restart is on fine grid only.
		BLCP.	- B.L. control parameter for inviscid iterations. BLCP = 0.0. No viscous corrections are applied on wing or wake. BLCP = 1.0. Displacement thickness B.L. correction is applied on wing. No viscous wake treatment is applied but the boundary conditions in the wake are different from original FLO 30 program. The enforced wake boundary conditions are: strict flow tangency at vortex wake sheet and no jump in pressure across the wake. BLCP = 2.0. Displacement thickness B.L. correction is applied on wing and wake. (No wake curvature effects included.)

TABLE 4.- INVISCID ITERATION AND GLOBAL INTERACTION CONTROL INPUT DESCRIPTION (UNIT 5) - Continued

Read Order	Number of Cards	Description and Comments		
				BLCP = 3.0. Displacement thickness B.L. correction is applied on wing. Full wake treatment is used including wake thickness and curvature effects.
				BLCP = -1.0. Displacement thickness B.L. correction is applied on wing. Original FLO 30 wake boundary conditions are used.
4	1	DESC.	-	Description for card(s) in Read Order 5.
5	1 card for each computational grid. Maximum is 3.	FIT, COVO, P10, P20, P30, FHALF, FACS FORMAT (8E10.7)		
		FIT.	-	Maximum number of iterations on this grid. FIT is set equal to the integer MIT in the 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. P10 must be < 2., typically 1.6-1.8.
		P20.	-	Supersonic point relaxation factor on this grid. P20 must be ≤ 1. A value of 0.8 is a reasonable value.
		P30.	-	Circulation relaxation factor. P30 may be > 1.0 but a value of 1.0 is recommended.
		FHALF.	-	Grid halving trigger.
				FHALF = 1. indicates grid will be refined in all directions after iterations on present grid are finished. This implies that another card must be read (Read Order 5) containing computational parameters to be used on grid with mesh size halved in all directions.

Read Order	Number of Cards	Description and Comments
		FHALF = 0. No grid refinement after this grid is calculated. FHALF = 0.0 must appear on the finest grid card (last one read of Read Order 5). Calculation will proceed automatically through the sequence of successively refined computational grids.
6	1	DESC. - Description for card in Read Order 7.
7	1	FMACH, ALDEG FORMAT (8E10.7)
		FMACH. - Freestream Mach number.
		ALDEG. - Angle of attack (in degrees) measured in plane containing freestream direction.

BOUNDARY-LAYER CALCULATION INPUT (Read in subroutine EINLES)

Read Order	Number of Cards	Description and Comments
8	2	TITLE.- Identification title used on printout and plots. FORMAT (20A4/20A4)
9	1	DESC. - Description for card in Read Order 10.
10	1	UINF, RINF, AK(1), AK(2), XPROZ, XDRUCK FORMAT (8F10.5)
		UINF. - Reference velocity. Its value is usually unimportant but it must not be equal to 0.0. (Used only to scale surface velocity in output for IPRINT = 2.0.)
		RINF. - Freestream Reynolds number (in millions/unit length).
		AK(1). - Upper surface B.L. laminar-to-turbulent transition location (in chord fraction).
		AK(2). - Lower surface B.L. laminar-to-turbulent transition location (in chord fraction).

TABLE 4.- INVISCID ITERATION AND GLOBAL INTERACTION CONTROL INPUT DESCRIPTION (UNIT 5) - Continued

Read Order	Number of Cards	Description and Comments
		XPROZ. - Rear limit of B.L. calculation starting location (in chord fraction).
		XDRUCK. - Output step (in chord fraction). The output from the B.L. calculation is given at chord stations XDRUCK from each other. Results for the upper surface are given first, leading edge to trailing edge; and then the lower surface results are given, leading edge to trailing edge.
11	1	DESC. - Description for card in Read Order 12.
12	1	FFLAG, FFIPRNT FORMAT (8F10.6)
		FFLAG. - Lag entrainment control parameter. FFLAG = 0. No lag entrainment in wing B.L. FFLAG = 1.0. Lag entrainment included in wing B.L. calculation. For high Re, lag-entrainment effects are small. FFLAG = 1.0 may be destabilizing for high Re where the lag-entrainment model used in the code is not valid.
		FFIPRNT. - B.L. print control parameter. FFIPRNT = -1.0. Print δ^* on upper and lower surfaces at the B.L. computational points and short map of δ^* at hard geometric points. FFIPRNT = 0.0. Shortest printout δ^* at B.L. computational points (recommended for most runs). FFIPRNT = 1.0. Print inviscid velocities used to drive the B.L. calculations at the inviscid grid points. Print δ^* on upper and lower surfaces at the B.L. computational points and short map of δ^* at hard geometric points.

TABLE 4.- INVISCID ITERATION AND GLOBAL INTERACTION CONTROL
INPUT DESCRIPTION (UNIT 5) - Continued

Read Order	Number of Cards	Description and Comments		
				FFIPRNT = 2.0. Print inviscid velocities used to drive the B.L. calculations at inviscid grid points. Print δ^* on upper and lower surfaces at the B.L. computational points and short map at the hard geometric points. Print δ^* at inviscid computational points (AUSGB). (This point option generates an extremely large amount of output and should be used <u>only</u> when necessary.

BOUNDARY LAYER TO INVISCID INTERPOLATION PARAMETERS
(Read in subroutine LINKVI)

Read Order	Number of Cards			
13	1	DESC.	-	Description for card in Read Order 14.
14	1	RELI, FISEPE(1), FISEPE(2) FORMAT (3F10.0)		
		RELI.	-	Relaxation factor for δ^* corrections in interaction. RELI must be $\leq$ 1.0. A value of 0.8 is recommended. RELI < 0.0 is used for first boundary-layer correction to indicate no previous values of δ^* are available for underrelaxation.
		FISEPE(1).	-	Upper surface linear extrapolation flag. Transitory regions of separation in initial global iteration may cause instabilities. Constant value extrapolation of δ^* is used through the region of separation if FISEPE $\neq$ 0.0. (Use FISEPE = 1.0). Near convergence, FISEPE must be equal to 0.0.
		FISEPE(2).	-	Same as FISEPE(1) except for the lower surface.

TABLE 4.- INVISCID ITERATION AND GLOBAL INTERACTION CONTROL INPUT DESCRIPTION (UNIT 6)--Concluded

Read Order	Number of Cards		Description and Comments

Read Orders 1-14 define a single global iteration. Repeated global iterations are peformed by repetition of blocks of Read Orders 1-14. The program terminates by reading the first three Read Orders with FNX < 1.0; that is, the last three cards should be:

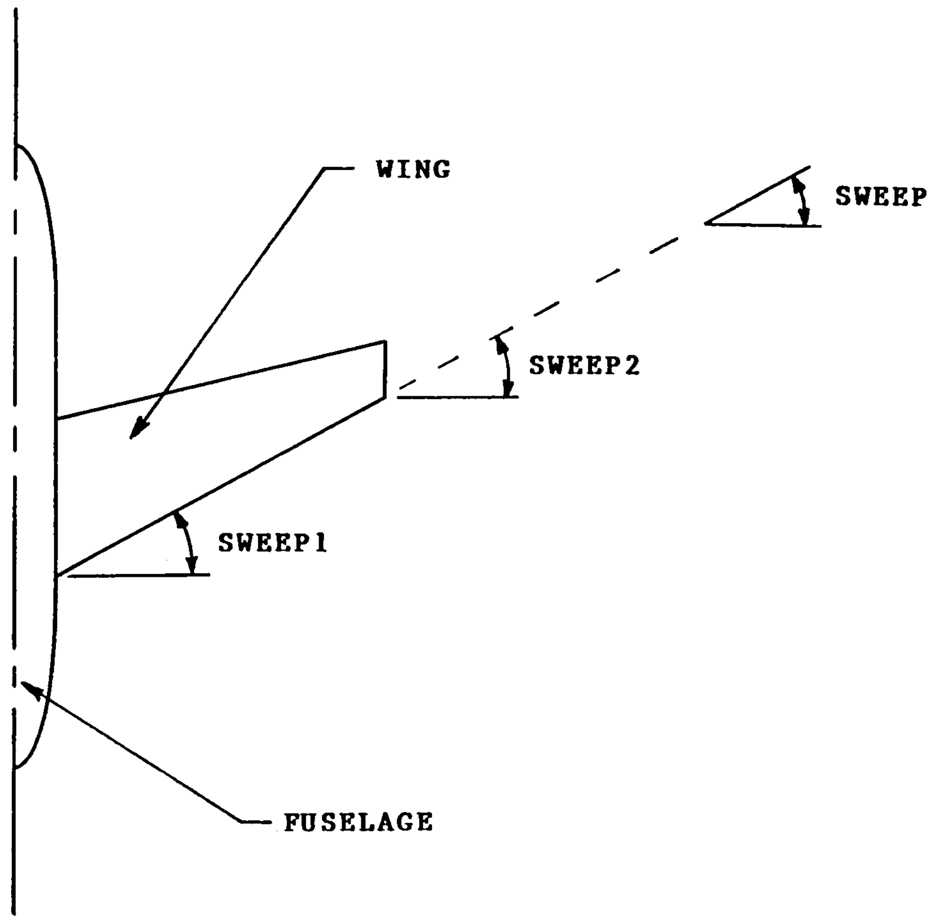
Read Order	Number of Cards		Description and Comments
1	1	TITLE.	- End of calculation.
2	1	DESC.	- Description for card in Read Order 3.
3	1		0.0 . . . . .

TABLE 5.- SAMPLE INVISCID ITERATION AND GLOBAL INTERACTION CONTROL INPUT FILE (UNIT 5)

```
LOCKHEED-GEORGIA WING A ON BODY (1)
       FNX        FNY       FNZ     FPLOT     FCONT      BLCP
       40.         6.        8.        2.        0.        0.
       FIT       COVO       P10       P20       P30     FHALF
       60.    1.E-08       1.6        .8        1.        1.
       30.    1.E-08       1.6        .8        1.        1.
       10.    1.E-08       1.6        .8        1.        0.
     FMACH      ALDEG
      .800      1.200
  LOCKHEED WING ´A´ ON BODY
  ITER 1
      UINF RINF(MIL)      AK(1)     AK(2)     XPROZ    XDRUCK
        1.       0.2        .00       .00      .010      .200
     FFLAG  FFIPRINT
       1.0      -1.0
      RELI FISEPE(1) FISEPE(2)
       -.9       0.0       0.0
LOCKHEED-GEORGIA WING A ON BODY (2)
       FNX        FNY       FNZ     FPLOT     FCONT      BLCP
       40.         6.        8.        2.        1.        2.
       FIT       COVO       P10       P20       P30     FHALF
      100.    1.E-08       1.6        .8        1.        1.
       50.    1.E-08       1.6        .8        1.        1.
       20.    1.E-08       1.6        .8        1.        0.
     FMACH      ALDEG
      .800      1.200
  LOCKHEED WING ´A´ ON BODY
  ITER 2
      UINF RINF(MIL)      AK(1)     AK(2)     XPROZ    XDRUCK
        1.       0.2        .00       .00      .010      .200
     FFLAG  FFIPRINT
       1.0      -1.0
      RELI FISEPE(1) FISEPE(2)
        .6       0.0       0.0
LOCKHEED-GEORGIA WING A ON BODY (3)
       FNX        FNY       FNZ     FPLOT     FCONT      BLCP
      160.        24.       32.        2.        2.        3.
       FIT       COVO       P10       P20       P30     FHALF
       20.    1.E-08       1.6        .8        1.        0.
     FMACH      ALDEG
      .800      1.200
  LOCKHEED WING ´A´ ON BODY
  ITER 3
      UINF RINF(MIL)      AK(1)     AK(2)     XPROZ    XDRUCK
        1.       0.2        .00       .00      .010      .200
     FFLAG  FFIPRINT
       1.0      -1.0
      RELI FISEPE(1) FISEPE(2)
        .8       0.0       0.0
```

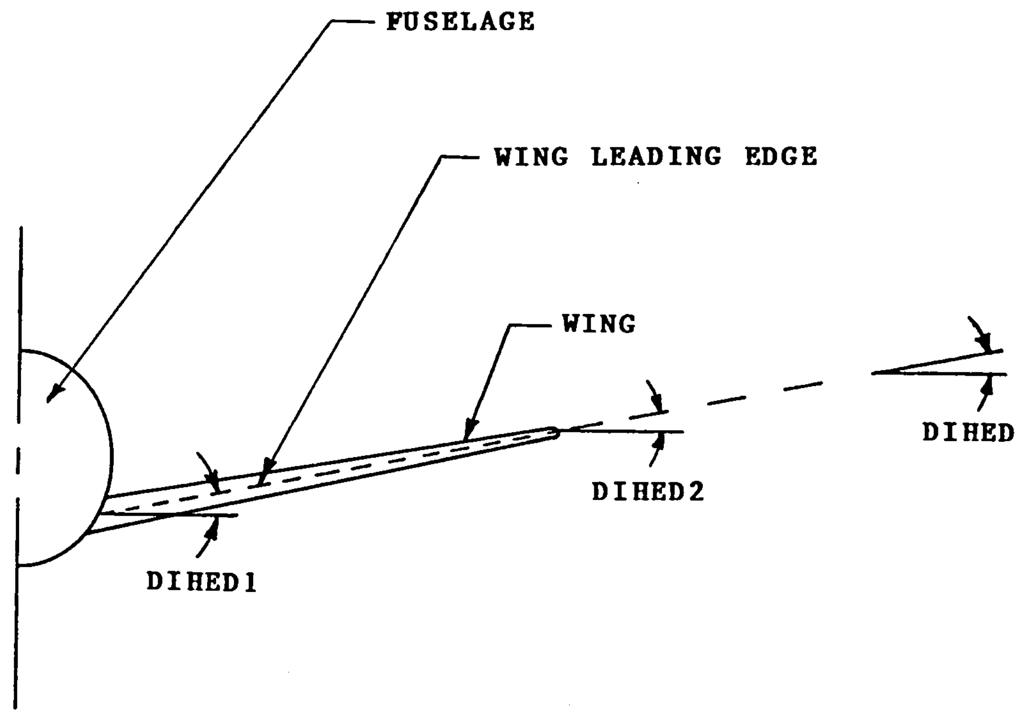
TABLE 5.- SAMPLE INVISCID ITERATION AND GLOBAL INTERACTION CONTROL INPUT FILE (UNIT 5)--Concluded

```
LOCKHEED-GEORGIA WING A ON BODY (4)
      FNX       FNY       FNZ     FPLOT     FCONT      BLCP
       0.       24.       32.        2.        2.        3.
      FIT      COVO       P10       P20       P30     FHALF
      40.   1.E-08       1.6        .8        1.        0.
    FMACH     ALDEG
     .800     1.200
  LOCKHEED WING 'A' ON BODY
  ITER 4
     UINF RINF(MIL)     AK(1)     AK(2)     XPROZ    XDRUCK
       1.       0.2       .10       .10      .010      .200
    FFLAG  FFIPRINT
      1.0      -1.0
     RELI FISEPE(1) FISEPE(2)
       .8       0.0       0.0
LOCKHEED-GEORGIA WING A ON BODY (5)
      FNX       FNY       FNZ     FPLOT     FCONT      BLCP
     160.       24.       32.        2.        2.        3.
      FIT      COVO       P10       P20       P30     FHALF
      40.   1.E-08       1.6        .8        1.        0.
    FMACH     ALDEG
     .800     1.200
  LOCKHEED WING 'A' ON BODY
  ITER 5
     UINF RINF(MIL)     AK(1)     AK(2)     XPROZ    XDRUCK
       1.       0.2       .10       .10      .010      .200
    FFLAG  FFIPRINT
      1.0      -1.0
     RELI FISEPE(1) FISEPE(2)
       .8       0.0       0.0
LOCKHEED-GEORGIA WING A ON BODY (6)
      FNX       FNY       FNZ     FPLOT     FCONT      BLCP
     160.       24.       32.        1.        2.        3.
      FIT      COVO       P10       P20       P30     FHALF
      40.   1.E-08       1.6        .8        1.        0.
    FMACH     ALDEG
     .800     1.200
  LOCKHEED WING 'A' ON BODY
  ITER 6
     UINF RINF(MIL)     AK(1)     AK(2)     XPROZ    XDRUCK
       1.       0.2       .10       .10      .010      .200
    FFLAG  FFIPRINT
      1.0      -1.0
     RELI FISEPE(1) FISEPE(2)
       .8       0.0       0.0
  END OF CALCULATION
      FNX
      0.0
```



(Dimensions and angles exaggerated for clarity.)

Figure 1.- Definition of SWEEP1, SWEEP2, and SWEEP in Read Order 3.



(Dimensions and angles exaggerated for clarity.)

Figure 2.- Definition of DIHED1, DIHED2, and DIHED in Read Order 3.

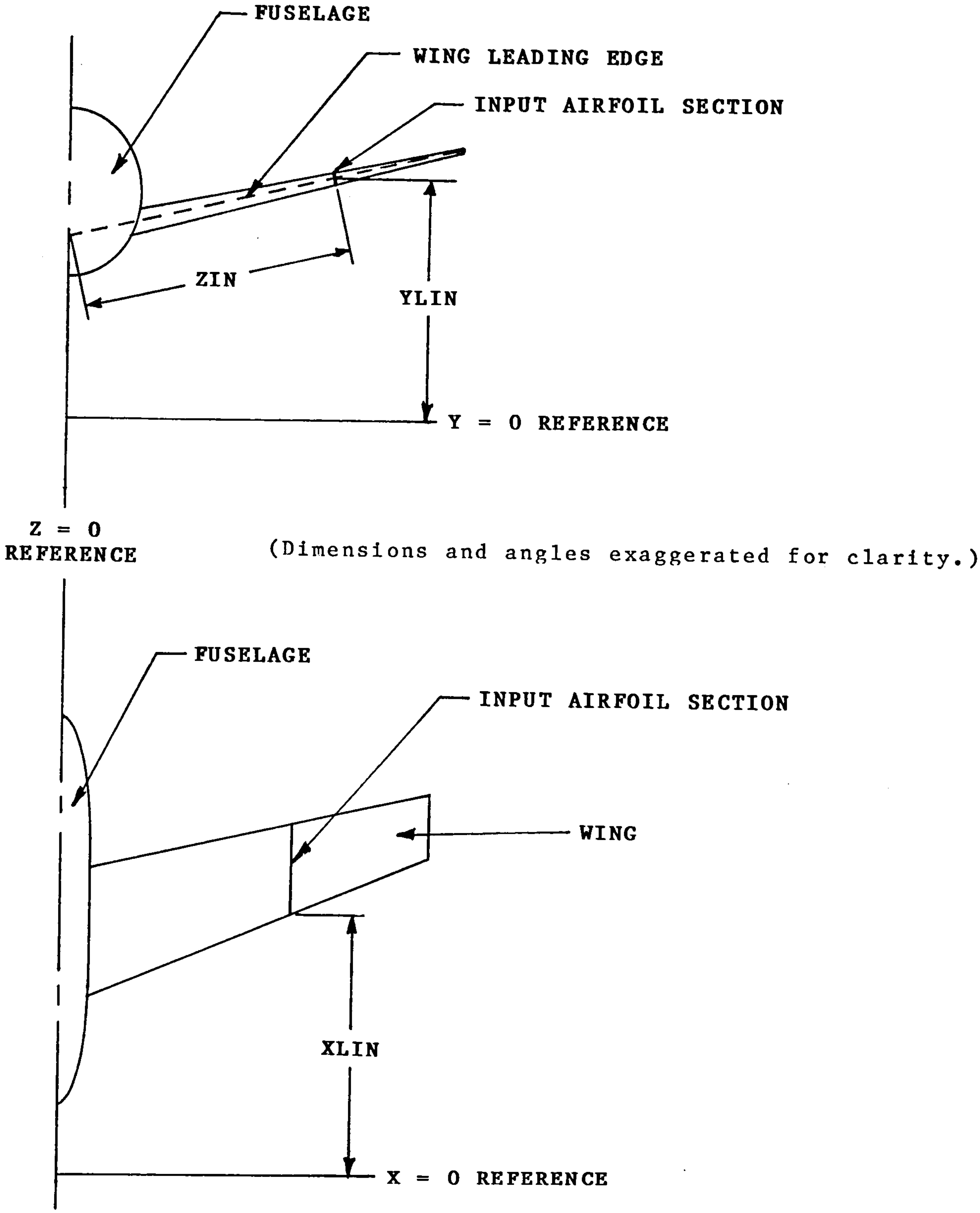


Figure 3.- Definition of ZIN, XLIN, and YLIN in Read Order 5.

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15. Supplementary Notes

16. Abstract

A program for the Transonic Analysis of a Wing and Fuselage with Interacted Viscous Effects (TAWFIVE) has been developed. A finite-volume full-potential method is used to model the outer inviscid flow field. First-order viscous effects are modeled by a three-dimensional integral boundary-layer method. Both turbulent and laminar boundary layers are treated. Wake thickness and curvature effects are modeled using a two-dimensional strip method.

A very brief discussion of the engineering aspects of the program is given. The input and use of the program are covered in great detail.

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