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NASA Technical Memorandum 108786

IN-02
203580
p-76

LinAir: A Multi-Element Discrete Vortex Weissinger Aerodynamic Prediction Method

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(NASA-TM-108786) LinAir: A MULTI-ELEMENT DISCRETE VORTEX WEISSINGER AERODYNAMIC PREDICTION METHOD (NASA) 76 p

N94-23557

Unclas

G3/02 0203580

October 1993

National Aeronautics and Space Administration

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TABLE OF CONTENTS

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SUMMARY

LinAir is a vortex lattice aerodynamic prediction method similar to Weissinger's extended lifting-line theory (refs. 1 and 2), except that the circulation around a wing is represented by discrete horseshoe vortices, not a continuous distribution of vorticity. The program calculates subsonic longitudinal and lateral/directional aerodynamic forces and moments for arbitrary aircraft geometries. It was originally written by Dr. Ilan Kroo of Stanford University, and subsequently modified by the author to simplify modeling of complex configurations.* The Polhamus leading-edge suction analogy was added by the author to extend the range of applicability of *LinAir* to low aspect ratio (i.e., fighter-type) configurations.

A brief discussion of the theory of *LinAir* is presented, and details on how to run the program are given along with some comparisons with experimental data to validate the code. Example input and output files are given in the appendices to aid in understanding the program and its use. This version of *LinAir* runs in the VAX/VMS, Cray UNICOS and Silicon Graphics Iris workstation environments at the time of this writing.

AERODYNAMIC THEORY

This vortex lattice method solves the Prandtl-Glauert equations for arbitrary aircraft geometries. Lifting surfaces are modeled by discrete, skewed, horseshoe vortices. Each horseshoe vortex makes up one panel, where multiple panels distributed spanwise make up an element. An aircraft geometry is comprised of a number of elements grouped together to form wings, tail surfaces, fuselages, or any other surface desired. High-aspect ratio wings are easily modeled with one element, while multiple chordwise elements are used to model lower aspect ratio wings (such as on fighter-type configurations) or wings with camber. All geometries are represented as mean surfaces, as the method does not model surface thickness. Figure 1 illustrates the modeling of a simple airplane with various elements and panels.

An element is defined by a bound vortex along its quarter-chord line, from which multiple trailing vortices, forming the sides of the panels, extend a large distance (100 reference spans) downstream (fig. 2(a)). Each pair of trailing vortices, connected with the segment of bound vortex in between, forms a skewed horseshoe vortex. The trailing vortices have two segments: the first lies in the plane of the panel from the bound vortex to the panel trailing edge, then the other extends from the panel trailing edge in a user-specified direction between the body X-axis and the freestream direction. Note that if two elements are stacked chordwise (to model a low aspect ratio wing with camber, for example), the trailing vortices from the forward element do not extend onto the plane of the rearward element before extending in the user-specified direction (fig. 2(b)).

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*A part of the Ames version of *LinAir* was written by Dr. Kroo in the private sector. This part of the program, therefore, is not in the public domain and prevents the whole program from being freely distributed by the government. *LinAir* is available commercially from Desktop Aeronautics, P.O. Box 9937, Stanford, CA 94305.

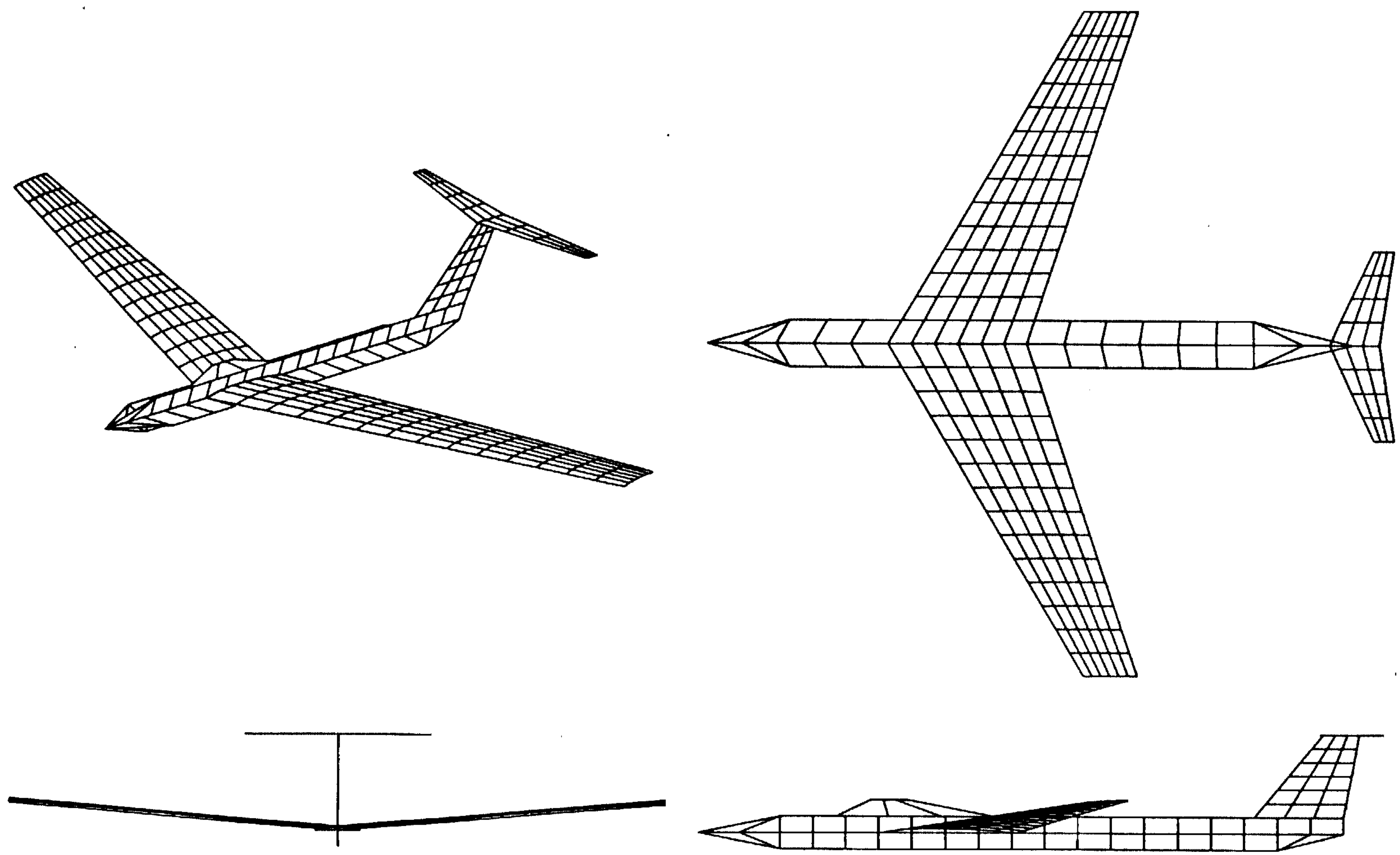
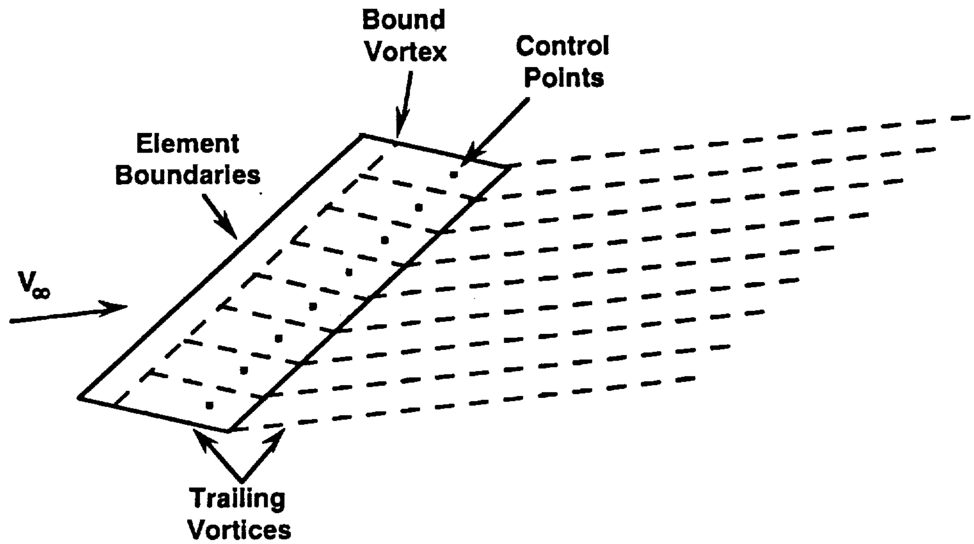
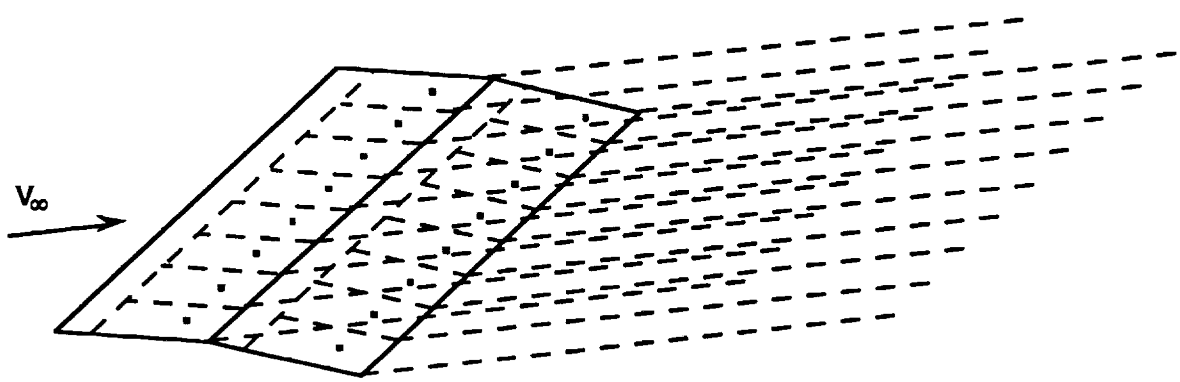


Figure 1. Typical aircraft geometry modeling in *LinAir* (panel edges shown).



a) Single element.



b) Two elements arranged chordwise with different incidence angles.

Figure 2. Element modeling with bound and trailing vortices and control points.

Velocities induced on each bound and trailing vortex segment by all the others in the system are computed by the Biot-Savart Law, then the circulation strengths $(\vec{\Gamma})$ of each horseshoe vortex are determined by enforcing a flow tangency condition at the three-quarter-chord, mid-span point (known as the "control point") of each panel. These circulation strengths are used to calculate the forces on each bound vortex by the Kutta-Joukowsky Theorem, $\vec{F} = \rho\vec{V} \times \vec{\Gamma}$, where $\vec{V}$ is the local velocity. The total inviscid forces and moments on the configuration are finally determined by summing the computed forces over all the panels. The user is referred to Ilan Kroo's *LinAirPro* user's guide (ref. 3) for a more detailed discussion of the theory and implementation of *LinAir*. The *LinAirPro* guide also contains some comparisons of *LinAir* results with exact solutions from various theories, which is helpful for the user in understanding the capabilities and limitations of *LinAir*.

An option is added in this version of *LinAir* to approximate a vortex lift component due to leading-edge separation around sharp, highly-swept surfaces. This is done by application of the Polhamus suction analogy (ref. 4) wherein the chord (axial) forces and side forces calculated in the potential flow solution for a panel are reduced (by a user-specified amount), and this reduced amount is added to the panel normal force. The application of the suction analogy on a single element is illustrated in figure 3. Note that the lower part of the figure shows the entire chord/side force converted to additional normal force. This shows the maximum application of vortex lift; in the program the user has control of the percentage of chord and side force to be converted. The suction analogy is only applied to panels which have a negative chord force (i.e., in the thrust direction).

All longitudinal aerodynamic coefficients calculated by *LinAir* are presented in wind axes (coincident with stability axes at zero sideslip angle), and all lateral/directional aerodynamic coefficients are presented in body axes.

INPUT AND OUTPUT FILES

Input Data File

LinAir uses one input file to control the operation of the program and provide the input conditions and geometry for which the calculations are to be done. The structure of an input file consists of a title line, several namelists, and the geometry data. Multiple input cases may be stacked in one file to expedite the running of several sets of flow conditions (e.g., Mach numbers, series of angles of attack and sideslip, rotation rates) and/or geometries. An example input file is shown first to give the reader a quick look at a relatively simple file, then the complete input file format is presented and explained.

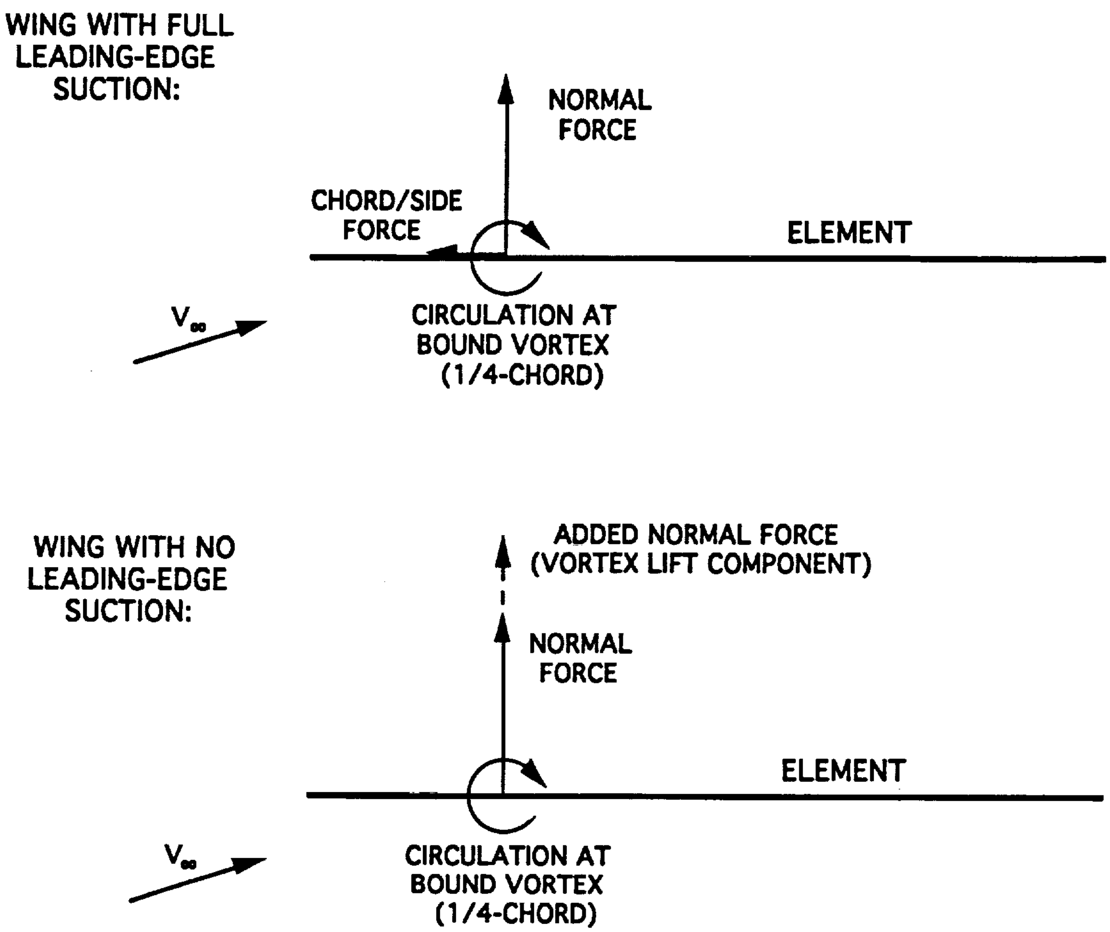


Figure 3. Conversion of leading-edge suction (chord force and side force) to vortex lift.

Example input file

A *LinAir* input file for a simple wing-canard-horizontal tail configuration is given below, and a picture of this geometry is shown in figure 4.

```
 $RUNNUM
 $
EXAMPLE LINAIR INPUT FILE:  WING, CANARD, & HORIZONTAL TAIL
 $OPTION     NET= 'Y'      PIC= '1'       LST= 'IES'     LOD= 'Y'
             PFS= 'Y'      PFL= 'Y'       PFD= 'Y'       PFN= 'Y'       GCHANGE= 'N'
 $
 $REF        Sref= 3.24    Xref= 3.483    Conf= 1        NEPOne= 0
             cref= 0.582   Yref= 0        Isym= 1
             bref= 6.00    Zref= 0        RWAKE= 1
 $
 $FLOCDN     Nseq=  3      Alpha= 0 5 10  Mach= 0.4
 $

'D'  'Linear'   3  15   'Wing'
|<-------- All 3 -------->| |<----- Both sweeps+2, or one sweep+3 (others=999)------->| |<---- Any 2 --->| |<--- Both --- >|
XRLES YRLES ZRLES SweepLE SweepTE Span  CR   CT   Taper  AR   Area  Rooti Tipi Twist Dihed XCTDref
  3     0     0     15      999     3   .8   999   .35   999  999    0    999   0     0     0

      Suctn0   Suctn1   Suctn2   Suctn3      CD0      CD1      CD2    Camber?
        1        0        0        0          0        0        0       'n'

'S'  'Linear'  1  5   'Canard'
 XRLE  YRLE  ZRLE  XRTE  YRTE  ZRTE  XTLE  YTLE  ZTLE  XTTE  YTTE  ZTTE XCTDref
  0     0     0    0.250   0     0   0.577   1     0   0.640   1     0     0

      Suctn0   Suctn1   Suctn2   Suctn3      CD0      CD1      CD2    Camber?
        1        0        0        0          0        0        0       'n'

'C'   2    'Horizontal Tail'
 Npan  XRLE   YRLE   ZRLE   XRTE   YRTE   ZRTE   XTLE   YTLE   ZTLE   XTTE   YTTE   ZTTE
       Suctn0 Suctn1 Suctn2 Suctn3 CD0    CD1    CD2
  4     6      0      0      6.2    0      0      6      0.8    0      6.2    0.8    0
        1      0      0      0      0      0      0
  4     6.2    0      0      6.4    0      0      6.2    0.8    0      6.4    0.8    0
        1      0      0      0      0      0      0
```

The file shows the typical structure of a *LinAir* input file, with lifting surfaces defined by the three different types of input ("D," "S," or "C"; explained in the next section) available in *LinAir*. The wing and horizontal tail are modeled as multiple-element surfaces, which may be desirable for better resolution of the force distributions over the chord lengths. Horizontal surfaces are shown; other surfaces are modeled by specifying non-zero incidence or dihedral angles or non-zero Z-coordinate values. Surface camber is easily modeled in the "D"- and "S"-type inputs by listing any number of X-Z pairs defining the camber line, or by displacing the corner-point Z-values in the "C"-type input. These features and all the others available in *LinAir* are discussed in detail in the next section.

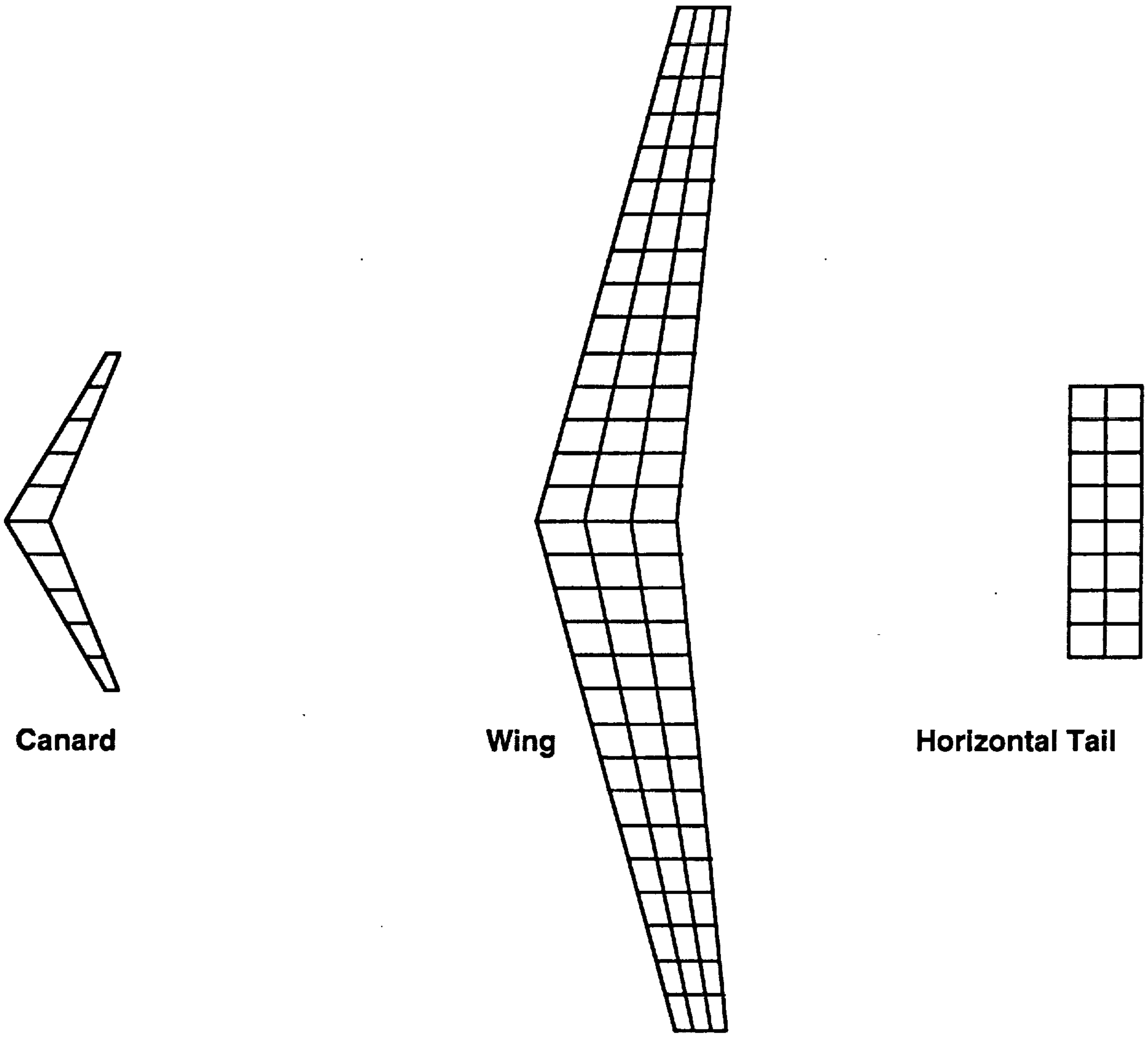


Figure 4. Example *LinAir* geometry.

File structure

The overall structure of an input file is given below. This is followed by a general comments section and a detailed explanation section. Real variables are indicated by "**x.y**" and integers are indicated by "**n**". Variable definitions are given in appendix 1. *Italic text* is informational only (not part of the file), and **bold** text indicates a substitution, or user input. All plain text is intended to be part of the input file, but in the non-namelist, non-data lines the program does not actually read the text, it merely skips over the number of plain text lines shown.

A complete input file is shown, but many of the namelist variables and geometry data can be left out for the simpler cases (additional examples are shown in appendix 2). Blank lines are permitted before, after, and within any namelist, before and after the title line, and where indicated below within the blocks of geometry data.

Start of input file ....

```
$RUNNUM                RUNINI= x.y
$
Title line
 $OPTION NET= 'Y'        PIC= '3'     LST= 'IES'    LOD= 'Y'
         PFS= 'Y'        PFL= 'Y'     PFD= 'Y'      PFN= 'Y'     GCHANGE= 'N'
$
$REF     Sref= x.y       Xref= x.y    Conf= n       NEPOne= n
         bref= x.y       Yref= x.y    Isym= n
         Cref= x.y       Zref= x.y    RWAKE= x.y
         VHDBndy= x.y    XoCbarXr= x.y
$
$FLOCDN  Nseq= n         Alpha= x.y   Beta= x.y
         phat= x.y       qhat= x.y    rhat= x.y
         Mach= x.y
$
```

Geometry is specified by any combination of the following types of input ("D", "S", or "C"), in any order, as long as at least one element of any kind is given.

(blank lines permitted here)

"D" (design parameters) type input:
(Note: Both header lines must be included between the next "surface type" line and the data "x.y" line)

```
'D' 'spacing'  #elements  #panels/element  'name of surface'
|<--------- All 3 -------->| |<------ Both sweeps+2, or one sweep+3 (others=999)------->| |<---- Any 2 --->| |<--- Both --- >|
XRLES YRLES ZRLES SweepLE SweepTE Span CR  CT  Taper AR  Area Rooti Tipi Twist Dihed XCTDref
 x.y   x.y   x.y    x.y     x.y   x.y  x.y x.y  x.y  x.y x.y  x.y   x.y  x.y   x.y   x.y
```
(blank lines permitted here)

```
   Suctn0  Suctn1  Suctn2  Suctn3     CD0   CD1   CD2   Camber?
    x.y     x.y     x.y     x.y       x.y   x.y   x.y   'Y' or 'N'
```
(blank lines permitted here)

```
   Root Camber: # points   Rotate to level?
                   n          'Y' or 'N'
```
n pair of X, Z points representing camber, 1 pair per line, or no points if n = 0

```
   x.y  x.y
   x.y  x.y
   .
   .
   .
```
(blank lines permitted here)

```
   Tip Camber:  # points   Rotate to level?
                   n          'Y' or 'N'
```
n pair of X, Z points representing camber, 1 pair per line, or no points if n = 0

```
   x.y  x.y
   x.y  x.y
   .
   .
   .
```
(blank lines permitted here)

"S" (surface corner points) type input:

```
'S' 'spacing'  #elements  #panels/element  'name of surface'
 XRLE YRLE ZRLE XRTE YRTE ZRTE XTLE YTLE ZTLE XTTE YTTE ZTTE XCTDref
 x.y  x.y  x.y  x.y  x.y  x.y  x.y  x.y  x.y  x.y  x.y  x.y  x.y

   Suctn0  Suctn1  Suctn2  Suctn3     CD0   CD1   CD2   Camber?
    x.y     x.y     x.y     x.y       x.y   x.y   x.y   'Y' or 'N'
```

(blank lines permitted here)

Root Camber: # points Rotate to level?
n **'Y'** *or* **'N'**

n pair of X, Z points representing camber, 1 pair per line, or no points if n = 0

x.y x.y
x.y x.y
.
.
.

(blank lines permitted here)

Tip Camber: # points Rotate to level?
n **'Y'** *or* **'N'**

n pair of X, Z points representing camber, 1 pair per line, or no points if n = 0

x.y x.y
x.y x.y
.
.
.

(blank lines permitted here)

"C" (element corner points) type input:

'C' #elements 'name of surface'

Npan	XRLE	YRLE	ZRLE Suctn0	XRTE Suctn1	YRTE Suctn2	ZRTE Suctn3	XTLE	YTLE CD0	ZTLE CD1	XTTE CD2	YTTE	ZTTE
n	**x.y**	**x.y**	**x.y**	**x.y**	**x.y**	**x.y**	**x.y**	**x.y**	**x.y**	**x.y**	**x.y**	**x.y**
			x.y	**x.y**	**x.y**	**x.y**		**x.y**	**x.y**	**x.y**		
n	**x.y**	**x.y**	**x.y**	**x.y**	**x.y**	**x.y**	**x.y**	**x.y**	**x.y**	**x.y**	**x.y**	**x.y**
			x.y	**x.y**	**x.y**	**x.y**		**x.y**	**x.y**	**x.y**		
n	**x.y**	**x.y**	**x.y**	**x.y**	**x.y**	**x.y**	**x.y**	**x.y**	**x.y**	**x.y**	**x.y**	**x.y**
			x.y	**x.y**	**x.y**	**x.y**		**x.y**	**x.y**	**x.y**		

The above data lines are repeated according to the number of elements (3 shown in this example) specified in the 'C' line.

If additional cases are not desired, no further input is required after last geometry definition.

If additional cases are desired, repeat the title line, the three following namelists (in the order shown), and new geometry, if any (set GCHANGE = 'Y' in OPTION *namelist for new geometry in new case). The* RUNNUM *namelist is not specified for a new case since it contains only the initial run number for all cases within the input file.*

Title line for case #2. (Run number = RUNINI + 1.) This case does not have new geometry.
$OPTION $ }
$REF $ } *Specify changed variables (variables not specified here carry over from*
$FLOCDN $ } *previous case)*
All of the previous geometry carries over without change.

Title line for case #3. (Run number = RUNINI + 2.) This case does have new geometry.
$OPTION GCHANGE= 'Y' $ }
$REF $ } *Specify changed variables (variables not specified here*
$FLOCDN $ } *carry over from previous case)*

New geometry here — use "D", "S", and/or "C" type inputs. None of the previous geometry carries over, so a complete geometry definition must be provided even if changes are minor from previous case.

....*End of input file*

General comments

Data format– All input data are read in free format, and can be entered as integer or real numbers (real numbers read into integer variables are truncated). Alignment of numbers in specific columns is not necessary, as all non-namelist input lines are list-directed inputs. Header lines (shown in plain text in the input file structure above), or at least blank lines in their places, must be present where indicated.

Units– Any system of units may be used, as long as they are consistent for all geometric parameters in any one input file (e.g., feet and square feet, or meters and square meters, etc.).

Coordinate system– *LinAir* geometry and forces use a right-hand rule, body-axis coordinate system. The X-axis extends downstream parallel to the body centerline; Y extends to the right looking upstream, and Z extends upward (in the plane of symmetry). The incidence angles defined in the geometry are the angles of attack of each component when the system is at an angle of attack of zero degrees (i.e., when X is parallel to the freestream). The aerodynamic moments not consistent with the right-hand rule: the pitching, yawing, and rolling moments are defined as positive nose up, nose right, and right wing down, respectively. Figure 5 illustrates the axis system and sign conventions used in *LinAir*.

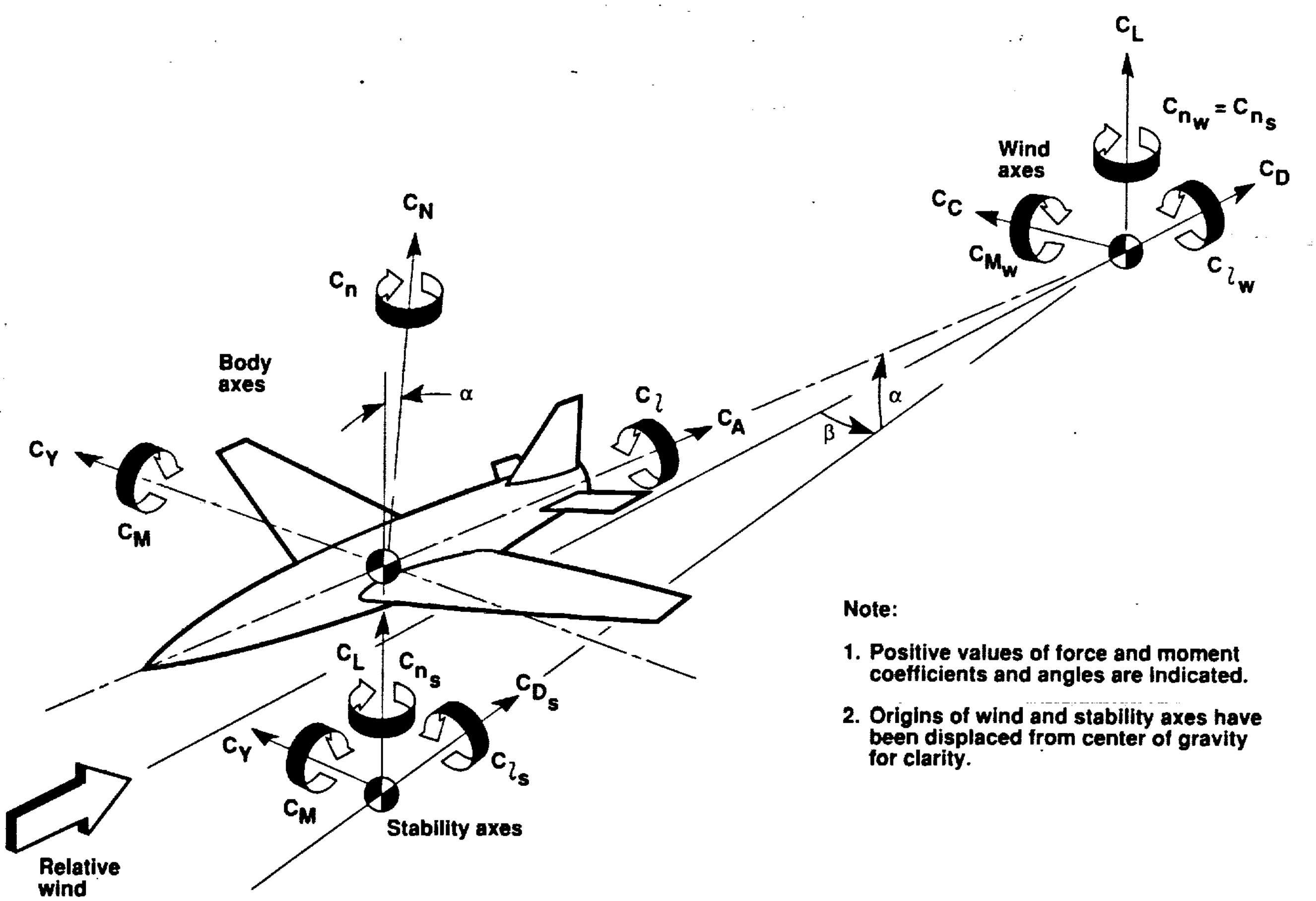


Figure 5. Axis system and sign conventions.

Namelist conventions– The four namelists, RUNNUM, OPTION, REF, and FLOCDN, must be included in every input file in the order shown in the example. The namelist is opened by "$NAME," and terminated by a "$" (or "$END" if you prefer) after the last value specified. The dollar signs may be located in any column other than the first one. If the terminating dollar sign immediately follows the name of the namelist (where no variables are specified within the namelist, as in an additional input case in the file), there must be at least one space between the name of the namelist and the terminating dollar sign.

Variables within the namelist may be separated by any delimiter (including spaces), and may be specified in any order. The variable names are not case-sensitive. Numerical variables not listed are read as zeroes by the program (with the exception of ISYM and RWAKE, whose default values are one). This is in contrast to the other variables in the list-directed inputs, where intentional zeroes must be specified.

Detailed Explanation of Input Data File

RUNNUM namelist– The single variable in this namelist, RUNINI, specifies the initial run number for all runs (cases) within the input file. The run number is used for reference to a given set of data generated by *LinAir* when the user wants to keep a record of the cases run. It is printed in several of the output files, including the database loading file, which is used with the CDDMS** database and plotting system of the Ames Aerodynamics Division.

RUNINI can be input as integer or real (having up to two decimal places). Run numbers for each case following the first case within the same input file are incremented by one (decimal values retained).

Title line– A title of up to 132 characters may be input. This title is printed in the main listing file and in the forces summary file (see *Output File* section for descriptions of these files). Any ASCII character may be used in the title except single quotes (single quotes distinguish the title line from data header lines).

OPTION namelist– This namelist contains only character variables which control the creation of the output files and tell the program whether new geometry is expected in a following case. The *Output File* section describes the function of these variables in detail.

REF namelist–

Geometric reference parameters: The parameters Sref, Cref, and bref are normally specified in the $REF namelist, assuming the user knows them before the program is run. However, the program can calculate these parameters if a "wing" surface definition (which must have the word "wing" in

**CDDMS is the CAPAIR Deliverables Dataset Management System, CAPAIR being a Comprehensive Aerodynamic Prediction method for AIRcraft—a set of empirically-based routines for estimating the aerodynamics of arbitrary aircraft. CDDMS was developed under contract to the Ames Aerodynamics Division for easy storage, retrieval, and plotting of wind tunnel and other data. The heart of CDDMS is the CDD (CAPAIR Deliverables Dataset), a database which will be referred to throughout this report. Information about CDDMS software may be obtained from the author of this report.

the name of the surface; see *Geometry Data* section below) of type "D" or "S" is included in the input file. (Surface geometry parameters are not calculated for type "C" surfaces as the program knows only the *element* corner points of these surfaces.) The program will calculate the reference parameters if they are set equal to zero. If no surface definition having a name containing the word "wing" is input, the program will stop and print an appropriate error message to the screen. If more than one "wing" surface definition is input, the program will use the geometry from the last "wing" to calculate the reference values.

The airplane moment reference center location is the point about which all forces and moments are resolved, and is specified by Xref, Yref, and Zref. The latter two, Yref and Zref, must be specified if not intended to be equal to zero, but XoCbarXr may be substituted for Xref if preferred, provided a "wing" surface of type "D" or "S" is input. XoCbarXr is an abbreviation for $(X/Cbar)_{Xref}$, which is the longitudinal distance from the leading edge of the surface mean aerodynamic chord (MAC) to the moment reference center, expressed as a fraction of the MAC. Note that if using a "wing" surface to calculate Xref from XoCbarXr, the wing must be a simple wing defined by one surface (i.e., no groups of elements forming breaks or nonlinearities in the planform). If the wing planform is not simple, then XoCbarXr would be applied to only part of the wing, and would yield an incorrect Xref.

To have the program calculate Xref from XoCbarXr and the calculated wing geometry, Xref should be set equal to zero or 999 with XoCbarXr not equal to zero or 999. If both parameters are specified, Xref takes precedence. In the output listing, the "REFERENCE VALUES" section shows which of the two values was used to define the C.G. location. If Xref is non-zero, then XoCbarXr was calculated from Xref, and vice-versa.

In additional input cases, if the geometry is changed and the user wants any of the above reference parameters calculated for the new geometry, the parameters of interest must be set equal to zero in the namelist for the new case.

The output force and moment coefficients are based on the input or calculated reference values. If the reference values are calculated, they are shown in the surface parameters section of the main listing output file.

Configuration number: This is an arbitrary number the user assigns to the current geometry for record-keeping purposes. This number is written to the database loading file only for use as the configuration number in a CDD database if the user creates one for storage of the *LinAir* data.

Symmetry: Both symmetric and asymmetric geometries (about the X-Z plane) may be input to *LinAir*. Symmetric configurations are created by defining elements on the right-hand side, as well as the elements on the plane of symmetry, and then reflecting the geometry (ISYM = 1). This is the usual case (and the default value for ISYM), wherein the area and span for half of the wing are entered. In this way winglets, twin vertical tails, and wings with dihedral are each input as single elements. If the geometry is symmetric but the flow condition is not, *LinAir* will create new elements automatically and solve the asymmetrical problem without additional input. For asymmetric geometries (such as an oblique wing), the left-hand side may be input by specifying a negative span for type "D" inputs (described below), or negative "Y" values for type "S" or "C" inputs (input types described later).

Wake orientation: The trailing vortex wakes emanate from the element trailing edges in a user-specified orientation between the body X-axis and the freestream direction. The parameter which controls this is RWAKE, which may vary between 1 and –1 (fig. 6). Note that positive values constrain the wakes to remain parallel to the X-Z plane, floating only with angle of attack. Negative values allow the wakes to float with angle of sideslip as well.

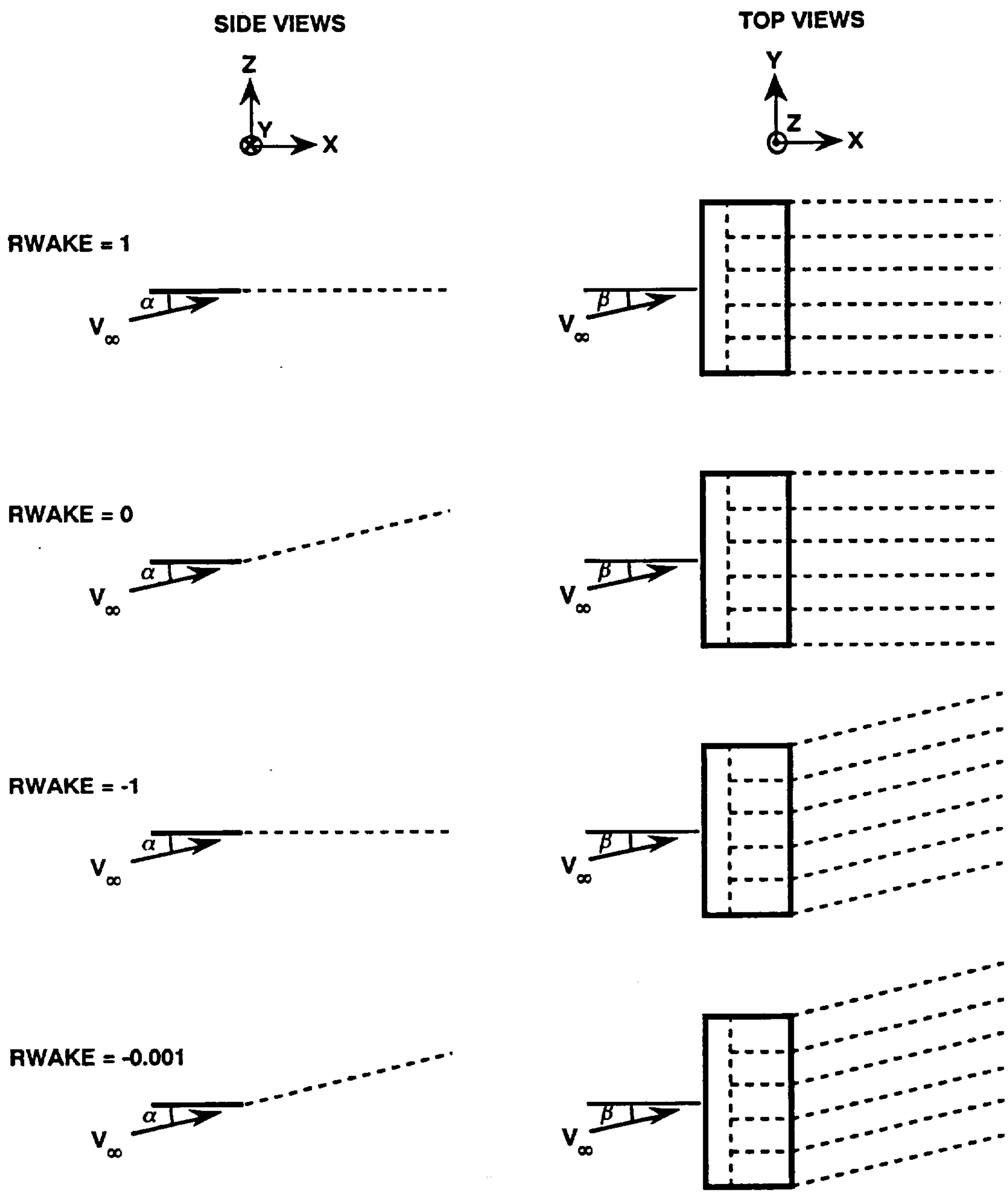


Figure 6. Use of RWAKE parameter for controlling orientation of trailing vortices.

The user should use caution in orienting the wakes away from the body X-axis direction because of the possibility of interference with control points on downstream panels. This would cause abnormally high induced velocities and unrealistic forces for the panels involved. Therefore, it is generally safest to use RWAKE = 1 in most cases. Other values of RWAKE can be used only if the user ensures that no interference will result from any of the angles of attack and sideslip to be run.

Dihedral boundary: The variable "VHDBndy" (Vertical/Horizontal Dihedral Boundary) in the REF namelist applies only to the panel forces written to the panel forces files (see Output Files section), and affects the signs of these forces for consistent data presentation when displaying or reviewing the force results. The use of this variable is discussed in the Panel Forces Summary and Display Files section.

Number of elements and panels per surface: The variable "NEPOne" provides a way for the user to override the number of elements and panels specified for each surface and set them equal to one (NEPOne = 1). This is helpful when setting up the initial geometry if some of the surfaces have more than one element or panel specified, and the user just wants to view or check the geometry calculations of the surfaces without subdividing the surfaces. Setting NEPOne equal to zero restores the numbers of elements and panels to the numbers specified in the surface definitions.

FLOCDN namelist– The FLOCDN namelist contains the flow conditions (angles, rotation rates, and freestream Mach number) for the current run, or case. A run is defined within *LinAir* as a series of data points in which one flow angle or rotation rate varies while the others are held constant (Mach number is always constant within a run). Each one of these data points is referred to as a "sequence number" within the run. If a run contains more than one sequence number (NSEQ > 1; the limit is 30), all angle and rate variables which have non-zero values, other than the one being varied, must have the non-zero values repeated for all sequence numbers. For example, the following run is a "pitch run" (angle of attack varying) with a constant angle of sideslip of 5 degrees, and contains five sequence numbers (1–5):

```
$FLOCDN        Nseq= 5
               Alpha= 0 2 4 6 8
               Beta= 5 5 5 5 5
               (phat, qhat, and rhat need not be specified if zero)
               Mach= 0.6
$
```

LinAir checks the first two values of beta, phat, and rhat for asymmetric flow conditions. If any of these values are not zero, the run is taken as a asymmetric flow condition run, and the geometry is reflected about the X-Z plane if symmetric geometry was input (ISYM = 1).

The angles are input in degrees; roll, yaw, and pitch rates are input as nondimensional values (as defined in Etkin (ref. 5); p, q, r in rad/sec):

$$\hat{p} = \frac{pb_{ref}}{2V_\infty} \qquad \hat{q} = \frac{q\bar{c}}{2V_\infty} \qquad \hat{r} = \frac{rb_{ref}}{2V_\infty}$$

Geometry data– *LinAir* is capable of handling geometries of up to 500 elements, consisting of up to 100 panels per element (2000 total panels maximum, so not all elements can have 100 panels). Detailed explanations of the geometric input parameters follow.

Surface type line: type of input (e.g., 'D' 'Linear' 3 15 'Wing'): As previously shown in the input file structure, three different types of geometry input are available ("D," "S," and "C"), allowing the user to use that which is most convenient depending on the form of the input information. The most basic type of input is the type "C" (element Corner points), which requires four corner points for every element to define a surface. The type "S" (Surface corner points) input is similar to type "C," except that only the outside four corner points of a surface (defined as a group of elements with abutting leading and trailing edges, such as a multi-element wing) and the number of elements and panels/element for the surface need be specified. Camber may be applied to a type "S," as well as to a type "D," surface by providing a camber line definition (described below). This eliminates the need to calculate the displaced height of the boundary of each element due to the camber. The type "D" (Design parameters) input uses typical wing design parameters to build the element geometry. This is the easiest way to input wing, tail and canard geometry, as only the minimum number of parameters necessary to fully describe the surface are required by the program. Multiple-element wings with camber, twist and dihedral are defined by specifying the respective properties without having to know the boundary points of individual elements.

The case of the type-of-input letter ("D," "S," or "C") determines whether the surface is to be included (upper case) or ignored (lower case) in the overall geometry within the input file. This allows a user to leave a particular geometry definition in the input file and have the program ignore it, such as when trying a new geometry before being ready to delete the old one.

Surface type line: element spacing (type "D" and "S" inputs only) (e.g., 'D' 'Linear' 3 15 'Wing'): Multiple elements defining a type "D" or "S" surface are not constrained to be evenly spaced chordwise even though the computer defines the individual element geometries. The user may select full cosine spacing, or cosine spacing biased toward the leading or trailing edge. The default option is linear spacing, selected by 'LINEAR,' or '' (pair of single quotes) for short, following the 'D' or 'S'. The other options are selected by 'COSFULL,' 'COSLE,' or 'COSTE'. Upper or lower case letters may be used indiscriminately for these options.

Surface type line: number of elements (e.g., 'D' 'Linear' 3 15 'Wing'): This is the number of chordwise elements into which to divide the surface for type "D" or "S" inputs, or the number of elements to follow for type "C" inputs (two lines per element).

Surface type line: number of panels per element (type "D" and "S" inputs only) (e.g., 'D' 'Linear' 3 15 'Wing'): This is the number of spanwise panels into which to divide each element for type "D" or "S" inputs. The number of panels per element for type "C" inputs is specified in the geometry data line (see below).

Surface type line: surface name (e.g., 'D' 'Linear' 3 15 'Wing'): The name of the surface to follow is used for reference purposes in the input and output files. The name is arbitrary for any surface, but, as discussed in the REF Namelist section above, if the airplane reference parameters are to be calculated from the current surface, the name of the surface must include the word "wing" (not case-sensitive) anywhere between the single quotes.

If the names of two or more surfaces include the word "wing" (or even the sequence of letters w-i-n-g within a word, as in the word "following," for example) and the reference parameters are to be calculated from a "wing" surface, the program will use the values calculated from the last "wing" surface defined in the input file for the current run. To avoid confusion in cases where w-i-n-g must appear in the names of more than one surface, the user is advised to rename the surface(s) **not** to be used in the reference parameters calculations, then run the program for geometry calculations only (LST= T' in the OPTION namelist, explained in later section), manually type in the calculated reference parameters (Sref, bref, and Cref) from the output file into the input file, change the names of the renamed surfaces back to their desired names, and finally run the program for aerodynamic results. The program will not calculate these four reference parameters from any surface geometry when the four parameters are input in the REF namelist with nonzero values.

Geometry data: design parameters, type "D": Surface input in *LinAir* consists of a set of parameters defining the planform and another set specifying certain aerodynamic options and the camber of the surface airfoil.

Planform definition: The user has as much flexibility as possible in the type "D" input in defining the surface. After specifying the X, Y and Z of the root leading-edge of the surface, the planform can be defined by specifying either or both of the leading- and trailing-edge sweep angles and two or three of the remaining six planform parameters. If both of the sweep angles are specified, only two of the six parameters—span, root chord, tip chord, taper ratio, aspect ratio, and area—are required. If only one of the sweep angles is specified, three of the remaining parameters are required. Parameters set equal to 999 will be ignored by the program in the geometry calculations.

There are, of course, certain combinations of these planform parameters (in pairs or triplets) which do not sufficiently define a wing surface. If both sweep angles are given, then two remaining planform parameters must be specified in any combination **except** the following:

- Span & Aspect ratio
- Span & Area
- Root chord & Aspect ratio
- Root chord & Area
- Tip chord & Aspect ratio
- Taper ratio & Aspect ratio
- Aspect ratio & Area

If one sweep angle is specified (either one), then three remaining planform parameters must be specified in any combination **except** the following:

- Span & Aspect ratio & Area
- Root chord & Tip chord & Taper ratio

The program will stop and print an appropriate error message to the screen if any illegal combination of these parameters is specified.

In either case above (one or both sweep angles specified), if more than the required two or three parameters are specified, priority will be given to the first two or three non-"999" parameters in the list. That is, if for example, all 6 parameters are specified, then the span, root chord, and tip chord will be used to calculate the taper ratio, aspect ratio, and area.

This input flexibility allows the user to define a wing or other surface quickly with very little or no hand calculations required. This also permits one to compare a family of wings with, for example, varying aspect ratio and all other parameters constant within one input file by stacking cases and changing only the aspect ratio from case to case.

The user is warned that it is possible to input some combinations of numbers which will yield negative values for the calculated parameters. There are probably many such combinations, but one example of this occurs when one sweep angle and the span, root chord, and area are given, but the area is too small for the given span and root chord (or, conversely, the span and/or root chord are too large for the given area). In this case, the tip chord and taper ratio would be negative, indicating an unrealistic solution. To correct this problem, the user should select a different combination of parameters to specify, or change the values of the selected parameters to accommodate a realistic wing geometry. Other unrealistic solutions have not been sought out in testing, but the presence of negative numbers among the planform parameters in the output listing file will alert the user of the problem.

The next three parameters in the input list define the incidence and twist of the surface. Any two of the three parameters, rooti, tipi, and twist, are required. The one not specified should be set equal to 999, unless it is the twist, in which case any value would be ignored since the twist is last in the list and would be calculated from the root and tip incidence angles.

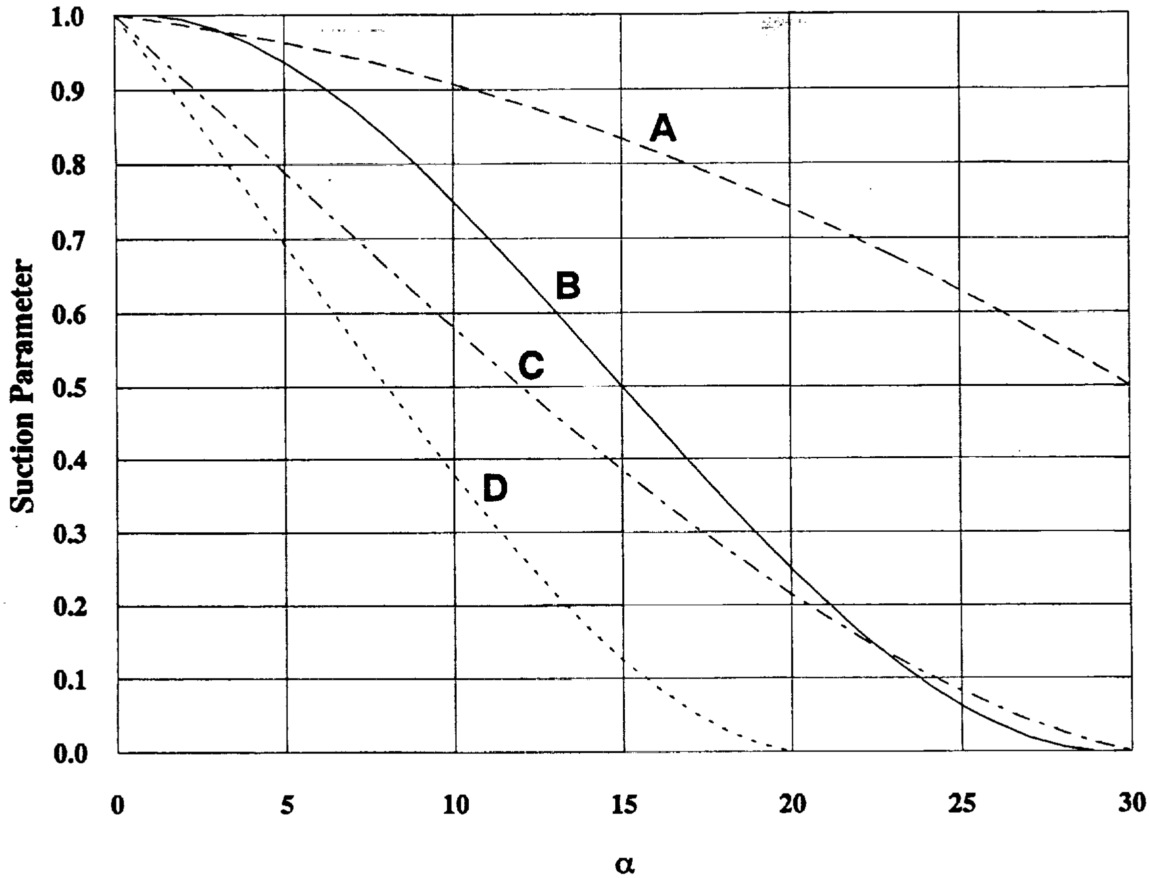
The last two parameters in this first line, the dihedral angle (Dihed) and the fractional-chord location of the twist/dihedral reference line ($XCTD_{rcf}$), are both required. The former parameter is self-explanatory; the latter is the imaginary constant-chord line about which the twist and dihedral angles are defined. Use $XCTD_{ref} = 0$ for rotating about the leading edge, and $XCTD_{ref} = 1$ for rotating about the trailing edge, and intermediate values for rotating about other constant-chord lines.

Aerodynamic options, camber: The line of input data following the planform definition contains the leading-edge suction coefficients to be applied to the element forces, the viscous drag parameters, and a flag for indicating whether a camber line definition follows for the current surface.

The four suction coefficients define a polynomial (up to third-order) defining the variation of a suction parameter with angle of attack, and are applied to all elements which comprise the surface. The suction parameter computed from the suction coefficients is constrained to vary between one and zero: one indicating full leading-edge suction (no vortex lift), and zero indicating no leading-edge suction (full vortex lift). Full suction would be expected on blunt leading edge, thick wings of relatively low sweep (such as on transport aircraft), whereas no suction would be expected on sharp-edged, thin, highly-swept wings (such as on high-speed fighter aircraft). The variation of suction with angle of attack is often desirable for wings that are not highly swept (Λ_{LE} less than ~40° to 50°) or do not have sharp leading edges, that may not generate significant vortex lift until moderate or higher angles of attack. If a wing is expected to have partial vortex lift within the angle of attack range of interest, one might set the suction coefficients for full suction at $\alpha = 0°$ and about half suction at the maximum angle of attack. On the other hand, for a wing with a greater vortex lift component, one might let the suction drop to zero at the maximum angle of attack, or set it to zero or some low value throughout the entire angle of attack range. Figure 7 shows some of the suction variations used by the author for various geometries and the coefficients which define these variations. The polynomial coefficients for these suction variations can be determined by hand for simple cases, or by any polynomial curve fitting routine given an appropriate number of points approximating the suction variation.

The effects of applying the suction analogy on the aerodynamics of a delta wing are shown in figure 8. Experimental and predicted lift and pitching moment characteristics and predicted induced drag characteristics are shown for a flat delta wing of aspect ratio = 2 (Λ_{LE} = 63°). The experimental data and the NASA Langley prediction are from reference 6, and the other three curves are *LinAir* predictions using different amounts of leading-edge suction (full, none, and a variation of suction with angle of attack—from full at $\alpha = 0°$ to none at $\alpha = 30°$). The Langley prediction is from a vortex lattice code which makes use of the Polhamus suction analogy, which overlaps the *LinAir* no-suction prediction in the figure. It is expected that the results of these two predictions would be similar, and they are similar for all three coefficients plotted—lift, moment, and drag. Comparisons with the experimental data, however, show that these no-suction predictions over predict the lift and pitching moment. Turning off the effect of the suction analogy, as shown in the *LinAir* full-suction curves, removes the vortex-lift increment, lowering the lift to levels well below those of the experimental data. (The pitching moment and induced drag are also lowered, though in the case of the former, the *LinAir* curve was not lowered below the level of the experimental data. Experimental drag data were not available for comparison.) Some degree of vortex lift, therefore, is required for the vortex lattice codes to simulate the physical effects. One of the suction variations shown in figure 7 (curve "C") was used for an additional *LinAir* run, labeled "*LinAir*, Varying Suction" in figure 8. This lift curve follows the experimental data fairly well up to the break at approximately 18° angle of attack, and so might be considered a better prediction than the full- or no-suction *LinAir* curves in this case. However, the pitching moment prediction for this suction variation curve is not necessarily any better, and the assessment of the drag prediction cannot be made since experimental drag was not available. It is an exercise in judgment to determine the proper use of the suction analogy for various geometries, and the user is encouraged to make his or her own comparisons of *LinAir* results with experimental data for different geometries to better learn the effects of the suction analogy.

Note that all of the prediction curves in figure 8 are plotted to 30° angle of attack, well above the angle where substantial flow separation over the wing causes a distinct break in the lift and pitching moment curves. *LinAir* is well beyond its range of applicability at these high angles, yet use of the suction analogy does permit better results at higher angles of attack than straight potential flow methods. The portions of the *LinAir* curves in figure 8 above the break in the experimental data are shown to warn the user of the typical errors to be expected when *LinAir* is run at angles beyond its range of applicability.



Curve Coefficients for...

$$\text{Suction parameter} = \text{Suctn0} + \text{Suctn1}\,[\alpha \times \cos(\Gamma) + \beta \times \sin(\Gamma)] + \text{Suctn2}\,[\alpha^2 \times \cos(\Gamma) + \beta^2 \times \sin(\Gamma)] + \text{Suctn3}\,[\alpha^3 \times \cos(\Gamma) + \beta^3 \times \sin(\Gamma)] \quad (\Gamma \equiv \text{Dihedral})$$

Curve	Suctn0	Suctn1	Suctn2	Suctn3
A	1	-5.556×10^{-3}	-3.703×10^{-4}	0
B	1	4.167×10^{-3}	-3.750×10^{-3}	8.333×10^{-5}
C	1	-4.164×10^{-2}	-1.945×10^{-4}	1.570×10^{-5}
D	1	-5.654×10^{-2}	-1.445×10^{-3}	8.856×10^{-5}

Figure 7. Variation of suction with angle of attack.

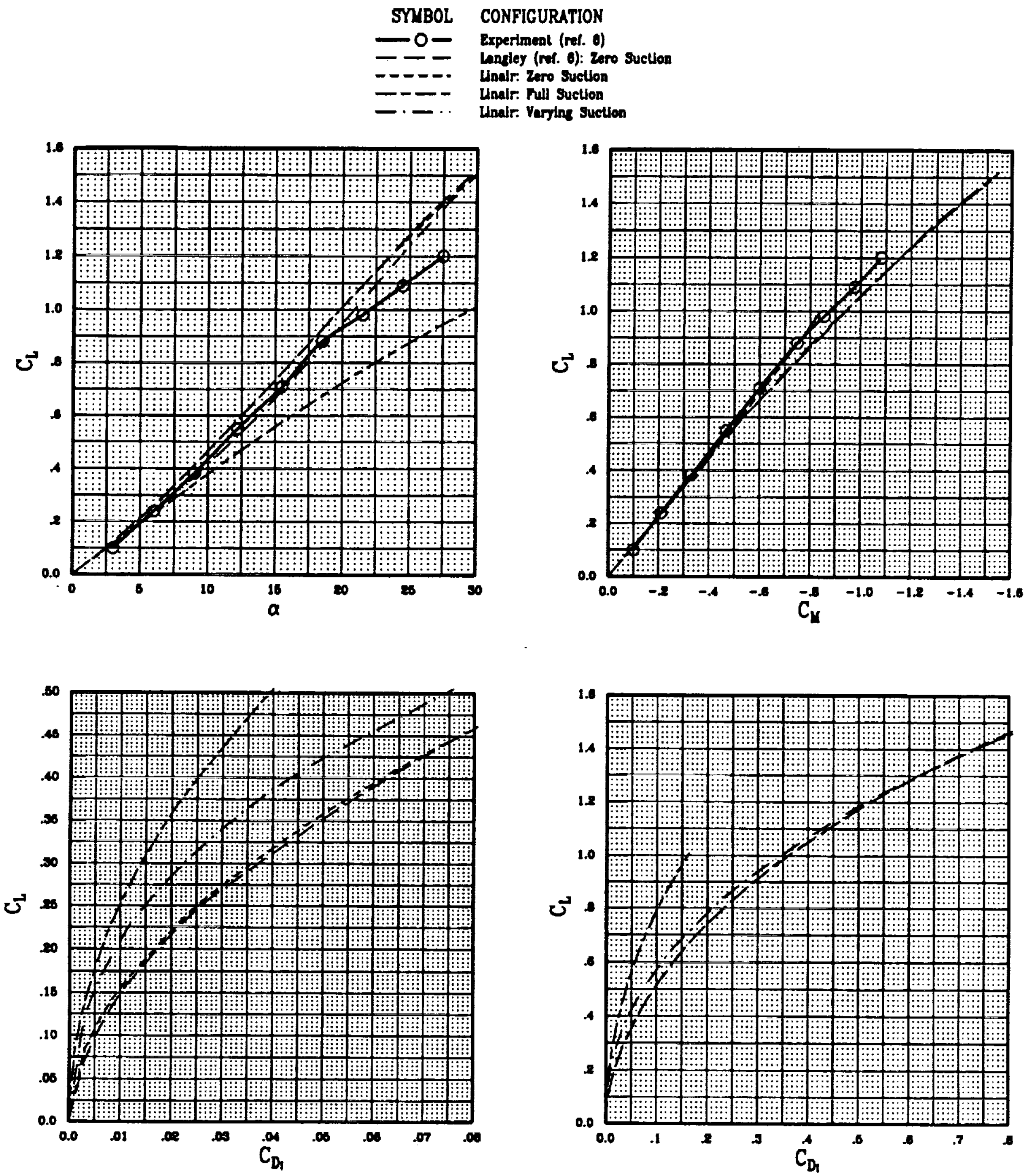


Figure 8. Effect of leading-edge suction on delta wing (AR = 2) aerodynamics.

Provision is made in *LinAir* for adjusting the computed forces and moments to compensate, in part, for the assumption of inviscid flow in the method. Viscous drag effects can be approximated by modeling the two-dimensional profile drag of the sections comprising each element with the following equation:

$$C_d = C_{d_0} + C_{d_1} + C_{d_2} C_l^2$$

The C_{d_0}, C_{d_1}, and C_{d_2} terms are user inputs from known airfoil section data, and are specified for each surface or element in the input file.

A word of caution about the use of the viscous drag parameters: these pertain to airfoil section characteristics, and are best used when the *LinAir* surfaces are modeled with single elements (i.e., not having multiple chordwise elements, such as the canard in the left side of fig. 4). The user must be alert to possible errors if section drag characteristics are applied to a column of panels within multiple chordwise elements.

The camber definition flag follows the viscous drag parameters in the subject input data line. This flag must contain the letter 'Y' (upper or lower case) if a camber definition follows. If there is no camber definition, 'N,' '' (pair of single quotes), or any string without a 'Y' in it will tell the program not to expect a camber definition for the current surface, and the next line in the input file would either be another element header line, a new title line for a new case, or nothing if at the end of the file.

If a camber definition is given, header lines for both the root and tip camber must be included, along with the appropriate X, Z pairs defining the camber. The number n in the header line is the number of pairs of points following (up to 100 points are allowed). The "Rotate to level?" question applies to camber definitions which have a non-level chord line ($Z_{LE} \neq Z_{TE}$); a "yes" input ('Y' or 'y') causes the program to rotate all the points in the camber curve so that $Z_{LE} = Z_{TE}$. A "no" input (anything without a 'Y' or 'y') would be input if the user desires to specify the root or tip incidence angle by the camber definition instead of by the rooti or tipi parameters mentioned above. After the header line, the root camber points are listed, one pair per line. Any number of points from 2 to 100 may be specified (matching the "n" in the header line), or no points if the root is to be flat. The camber points need not be normalized with respect to the wing chord. The program automatically normalizes the points based on the first and last "X" values specified, then scales the definition according to the local chord of the row of panels across all the elements defining the surface.

The tip camber header line and points follow the root camber definition. The tip camber can be made different from the root camber by providing a new set of points, or it can be made the same as the root camber by setting the number of tip camber points to "0" with no points following (provided 2 or more points were given for the root). If the root is to be cambered and the tip flat, leading- and trailing-edge points for the tip should be specified with zero Z-values. The camber definition is scaled linearly from root to tip.

Geometry data: surface corner points, type "S": As the name of this type of input implies, a surface is defined here by specifying the X, Y and Z's of the four corners. This input is handy when a drawing showing the overall dimensions of a geometry is available. Twist and dihedral are defined by the locations of the corner points in space. $XCTD_{ref}$ is required only for calculating the twist and dihedral for display to the user in the main listing file; it does not affect the actual twist and dihedral of the surface. The suction coefficients and camber are handled the same way as in type "D" inputs.

Note that since the two trailing vortices from each panel are always parallel to each other and form the panel sides, the tip chord of a panel (in plan view, i.e., neglecting twist) is always parallel to the root chord. The user, therefore, must ensure that the input corner points of the root and tip chords lie along lines which are parallel to each other, aside from twist. This constraint also dictates that triangular elements be modeled with zero chord at the tip or root, not zero span along the leading or trailing edges.

Geometry data: element corner points, type "C": This input type, being the most basic, requires the most amount of preparation to enter. It allows the user absolute control of the boundaries of each element, with the program doing no interpolation for intermediate points. It is best suited for surfaces consisting of one or a few elements each at the most. In addition to specifying the X, Y and Z's of the four corners of each element, the number of panels for each element is specified at the beginning of each data line (recall that the number of panels in type "D" and "S" inputs is specified in the element type line). The number of data lines for type "C" inputs is dictated by the number of elements specified in the element type line. Camber is defined by specifying appropriate variations in height of the corner points of each element, and the same caution about parallel root and tip chords stated for type "S" surfaces applies here.

Notes on geometry modeling: The vortex lattice method computes only an approximation of the flow qualities based on induced velocities, so exact modeling of the geometry is not necessary. Often, extra time spent matching the element boundaries to the fine details of the geometry does not yield any significant improvement in the results. It is more important that panel edges of all elements in approximately the same plane be carefully aligned in the spanwise direction to minimize abnormally high induced velocities due to trailing vortices passing too close to control points on downstream panels (note the spanwise alignment of the canard, wing and tail panels in fig. 4).

Also, avoid the temptation to try to model the geometry as accurately as possible by using a lot of elements. That is the job of more sophisticated methods, not a vortex lattice method. Modeling a wing with discrete vortex elements is a crude way to approximate the flow over a wing, since the vortex lattice does not represent a solid surface, and velocities and forces are computed only at discrete points. If you are unsatisfied with initial results from a *LinAir* run, refining the geometry may help somewhat, but more realistic answers are usually obtained from more powerful codes. This program is intended to be a "quick-look" preliminary design code.

Output Files

The creation of the output files is controlled by the terms in the OPTION namelist. Each of the terms in the OPTION namelist is a character variable, for which the input is enclosed in single quotes. An example OPTION namelist requesting all of the available output files is as follows:

$OPTION	NET= 'Y'	PIC= '1' (or '3' or 'Y')	LST= 'IES'	LOD= 'Y'		
	PFS= 'Y'	PFL= 'Y'	PFD= 'Y'	PFN= 'Y'	PFA= 'Y'	$

The program searches for the character(s) shown between the single quotes for each variable, and if a match is found, the option is selected. If an option is not desired, the variable name may be left out of the namelist, or left in but followed by two single quotes without the required character(s) in between (e.g., NET = ''). Either upper or lower case letters are valid for any of the options.

The output files which these variables control are listed here, with summary descriptions of the files in succeeding sections. Examples of all of the output files are in appendix 3.

- NET Geometry network file
- PIC Geometry picture file
- LST Main listing file
- LOD Database loading file
- PFS Panel forces summary file
- PFL Panel lift coefficients display file
- PFD Panel drag coefficients display file
- PFN Panel normal force coefficients display file
- PFA Panel axial force coefficients display file

Geometry display files†

The namelist parameters NET and PIC control the output of geometry display files:

- NET = 'Y' creates a **network** file (name.net)
- PIC = '1' creates a **picture** file (name.pic), plan view only
- PIC = '3' or 'Y' creates a **picture** file (name.pic), plan, side and rear views

Network and picture files are used to display *LinAir* geometries on a graphics screen or printer. The network file contains just the geometry information, and is often used within graphics programs, such as *RAID* in the Aerodynamics Division, to display and manipulate the geometry on a workstation, such as an Iris. Display of color force distributions using *RAID* requires the input of the network file (discussed in *Panel Force Display File* section below).

The network file is also used in programs such as *PANSKETCH*, *PLANVIEW* or *THREEVIEW* to create various picture files. *PANSKETCH* is run separately from *LinAir*, and it allows the user to specify a particular viewing orientation and whether the geometry is to be reflected about the plane of symmetry. Multiple viewing frames can be created in one picture file, allowing the user to set up different views of the geometry in one file. *PLANVIEW* and *THREEVIEW* are linked with *LinAir* for the convenience of the user who just wants to view the geometry in either a plan view only (generally sufficient for geometries made for pitch runs only) or in the standard three views. Once a

†The network and picture files created by the NET and PIC options are specifically for use with a number of graphics programs available in the Ames Aerodynamics Division. The program names are shown in *ITALICS*, and may be obtained by contacting the author.

picture file is created, it can be run through *PICDIP22* to create a .DIP file for viewing on a terminal or for printing.

All geometries are displayed as panel outlines; the vortex elements are not shown for clarity. Bound vortices are located at the quarter-chord of the panels, and trailing vortices emanate from the sides of each panel at the trailing edges.

Main listing file

LST controls the creation and contents of the main listing file (name.lst), which may contain any or all of the following sections:

- LST= 'I' Input geometry (more than a raw input dump; contains calculated geometry parameters)
- LST= 'E' Element and total system force coefficients for each sequence number
- LST= 'S' Summary of total system force coefficients for entire run (series of angles of attack or sideslip or rotation rates)

It is recommended that the user select LST= 'I' at first to verify the geometry along with the picture files, then run the aerodynamic calculations with LST= 'E' and/or 'S'. All three of the options may be selected at once (i.e., LST = 'IES') — the output file would then contain both the geometry and the aerodynamic results. The order of the parameters within the quotes is arbitrary. Details of the contents of this file are shown in appendix 3.

Database loading file

LOD controls the creation of the database loading file (name.lod). To write the file, select LOD = 'Y'. This file is designed to be compatible with the CDDMS system of databases and plotting routines. It can be directly loaded into a CDD, which the user can create with the assistance of the CDDMS documentation. When creating the CDD, specify the number of forces as 23, and allow for the maximum number of runs and number of sequences per run you expect to make. In addition to data, a CDD also needs a configuration table (to which the CONF variable in the REF namelist refers) and a names table. Examples of these tables, ready to be loaded into your CDD, are available from the author, as are all other related database and plotting files.

Panel forces summary and display files

Five different panel force output file options are available:

- PFS = 'Y' create panel force coefficients summary file (name.pfs)
- PFL = 'Y' create panel lift coefficients display file (name.pfl)
- PFD = 'Y' create panel drag coefficients display file (name.pfd)
- PFN = 'Y' create panel normal force coefficients display file (name.pfn)
- PFA = 'Y' create panel axial force coefficients display file (name.pfa)

The display files are sequential lists of forces for all panels, written in the order of panels 1 to N for elements 1 to M, and are meant to be used in conjunction with the geometry network file for plotting using the *RAID* graphics program (the sequence of the panel forces matches the sequence of panels in the network file). A separate file is written for each sequence number to permit display of data for different flow conditions from one *LinAir* run.

The forces summary file contains all of the force data contained in the display files, as well as the element and panel numbers, panel location and dimensional data. One file is written for all sequence numbers and runs, the data being separated by run and sequence number headers. This can be thought of as a "diagnostic" file, useful for reviewing characteristics of individual panels and for plotting the panel forces with their X, Y, or Z locations (such as versus fraction of chord or span, for example).

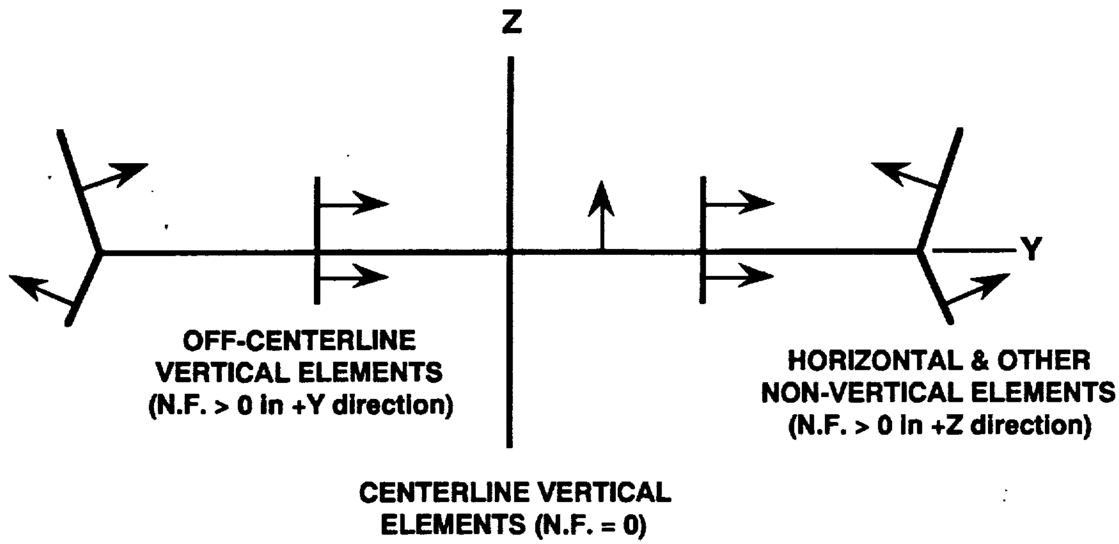
For both types of force data output files, the direction of the unit normals for all panels are checked and the signs of the normal forces reversed if necessary to ensure a consistent data presentation. An inconsistency in the presentation arises when plane-of-symmetry elements (e.g., fuselage and centerline vertical tail elements) are defined without being careful that their dihedral angles all have the same sign (all +90° or all –90°). This can happen when vertical elements are defined above and below a horizontal reference line, say along a centerline of a fuselage, where the element roots are along the reference line. The dihedral angle would be +90° for the elements whose tips lie above the centerline, and –90° for those with the tips below the centerline. The unit normals in the program would in this case point in opposite directions, and similar forces for +90° and –90° elements would have opposite signs since the direction of the forces is determined by the normals. This particular inconsistency is of concern in asymmetric flow condition cases (yaw runs or roll- or yaw-rate runs) only; in symmetric cases, the normal forces for vertical plane-of-symmetry panels are set equal to zero. The program takes care of this inconsistency in asymmetric cases so the user does not have to think about defining all of the elements in a consistent orientation.

There are a few other conditions where such inconsistencies arise. These conditions, along with the condition described above, are shown in figure 9. The unit normal components in the figure point in the direction required for consistent data presentation. If the geometry was input such that the components of the normals do not point in the proper directions for the cases shown, the program reverses the sign on the panel normal and lift forces and puts an indicator ("R" immediately after the "CNP" value) for that panel in the forces summary file.

Program execution time with different output file options

The execution time of *LinAir* depends on the output desired. Geometry calculations alone execute very quickly, since the program makes one pass through the simple geometry equations. Aerodynamic calculations take much longer because of the large matrix operations involved. Asymmetric flow condition runs require more time since geometry on both sides of the plane of symmetry has to be included in the aerodynamic calculations.

SYMMETRIC FLOW CONDITIONS (β = phat = rhat = 0):



ASYMMETRIC FLOW CONDITIONS (β, phat, rhat $\neq$ 0):

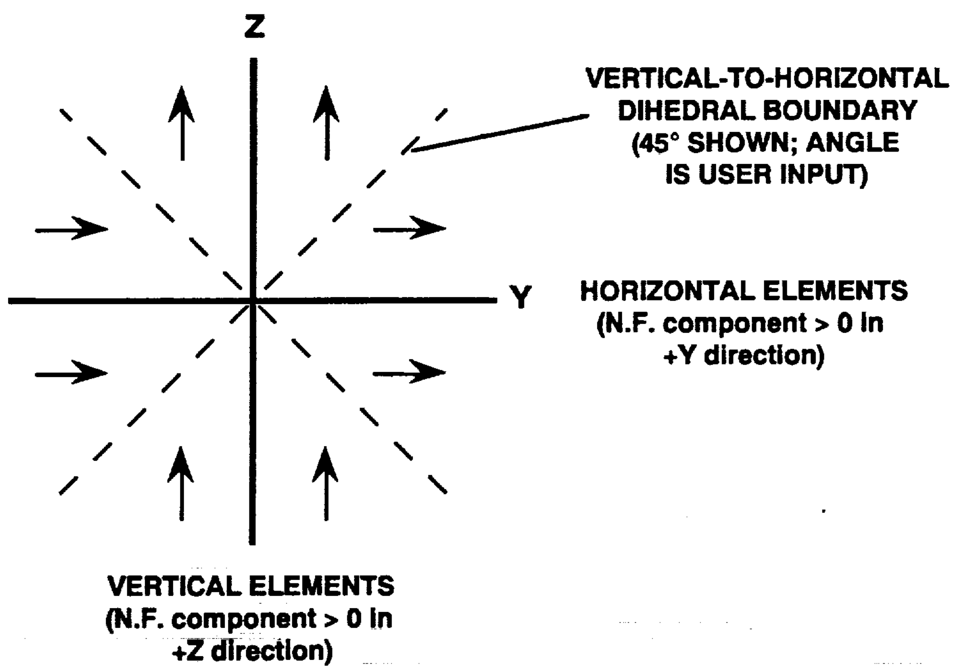


Figure 9. Normal force component orientations for consistent data presentation (rear view of elements shown).

The geometry-alone calculations are run with any or all of the following options selected:

- NET = 'Y'
- PIC = '1,' '3,' or 'Y' ('Y' is equivalent to '3')
- LST = 'I'

Aerodynamic calculations (including geometry calculations) are run with any or all of the following options selected:

- LST = 'E' or 'S'
- LOD = 'Y'
- PFS = 'Y'
- PFA = 'Y'
- PFL = 'Y'
- PFD = 'Y'
- PFN = 'Y'

The following shows relative execution times for the different output options based on a geometry with 70 elements and 307 panels (times in min:sec):

Type of run	**VAX 11/785**	**SGI Iris 4D-25**	**Cray Y-MP 8/864**
Geometry only	0:25	0:01	0:01
Aerodynamics: pitch run, 6 alpha's	23:15	3:13	0:26
Aerodynamics: yaw run, 6 beta's	40:14	5:03	0:32

For most cases, the Iris should be sufficient to give reasonably fast turn-around times. The Cray is probably overkill for all but the largest cases, but the times are shown for comparison purposes anyway.

Interpreting and Using Results

Care must be taken in aligning panel edges among different elements in the stream wise direction to avoid abnormally high induced velocities from trailing vortices passing too close to downstream control points. Unfortunately, there is no specific "tolerance" for acceptable edge alignment, but indications of high induced velocities on particular panels can often be seen in the output in the form of unusually high panel forces and aerodynamic coefficients. The user is advised to check the element coefficients in the main listing file and/or the panel forces in the forces summary file before accepting the results as valid.

The leading-edge suction analogy represents an approximation to the potential flow calculation of panel velocities and forces. One should be aware of its limitations and when it is and is not appropriate to use. It was developed by Edward Polhamus (ref. 4) of NASA Langley Research Center with application to highly-swept, sharp-edged delta wings in mind. Certainly if your configuration is of this type, its use is warranted. But for many fighter aircraft of current interest (sweep angles of 30° to 60°, often with rounded leading edges), the proper degree of its use is not easily determined. Transport aircraft and other high aspect ratio (relatively speaking) aircraft with low sweep angles probably do not need to use the analogy at all to get reasonable results since leading-edge separation and vortical flow effects do not dominate at low to moderate angles of attack.

If in doubt about the application of the suction analogy to your configuration, it is helpful to make a run with full leading-edge suction (Suctn0 = 1, Suctn1 = Suctn2 = Suctn3 = 0) and a run with no suction (Suctn0 = Suctn1 = Suctn2 = Suctn3 = 0) and compare the results. The difference in the shape of the lift curves should be apparent (more so with higher sweep angles). If one is familiar with what to expect in the lift characteristics (or any other parameter which shows a difference due to suction), a reasonable guess for the amount of suction to be applied can be made. Best use of the suction analogy comes with experience, and it is most helpful to compare *LinAir* results with experimental data to "calibrate" your judgments about geometry modeling and the use of the suction analogy.

Keep in mind also that this is a potential flow code, which cannot be expected to provide good results at flow angles where separation occurs over a significant portion of the lifting surfaces. Use of the suction analogy may extend the angle range for reasonable estimates for some configurations, but one must keep in mind that this is only a first approximation of vortical flow effects.

RUNNING *LinAir*

Once the input file is set up, running *LinAir* is simply a matter of executing the program and entering the input file name. The program writes the names of the selected output files to the screen so the user can see what files are being added to the directory, then it runs through the geometry and aerodynamic calculations as requested. If there are errors in the input file structure, one or more of a number of error statements written into the program will generally inform the user of the nature of the problem.

SELECTED RESULTS AND COMPARISONS WITH EXPERIMENT

Experiment/*LinAir* comparisons are shown in this section for two different supersonic STOVL fighter aircraft configurations. It was primarily for these types of configurations (i.e., relatively low aspect ratios, high sweep angles) that Dr. Kroo's original *LinAir* program was modified by the author and made easier to use for particular research applications in the Ames Aerodynamics Division. Dr. Kroo's user's guide (ref. 3) contains a number of comparisons of *LinAir* predictions with experimental data for basic wings, fuselages, flaps, and a complete configuration, and the user may consult this guide for insight on the fundamental evaluations of *LinAir* with experimental data. The fact that this user's guide does not contain experiment/*LinAir* comparisons for transport or other higher-aspect-ratio configurations does not mean that *LinAir* is not suitable for these types of aircraft. On the contrary, *LinAir*, being an extended lifting-line theory code, is best suited for wings of moderate to high aspect ratios, for which the wing can be modeled as a single element.

The first of the STOVL fighters to be used for comparison is the NASA/General Dynamics E-7 configuration. A photograph of a model of this configuration is shown in figure 10, and the *LinAir* modeling of this aircraft is shown in figure 11. It is a simple clipped-delta wing, tailless configuration with camber and twist in the wing. As seen in figure 11, the planform of the fuselage was modeled only in nose and aft sections, with the wing geometry extended to the centerline. This was done only because of the dominance of the wing on the overall aerodynamics. Modeling a center fuselage section with the wing root positioned at the "edges" of the fuselage did not make any appreciable difference in the aerodynamic results. However, such a difference in modeling could have more of an impact on the aerodynamics of other configurations, so the user may want to experiment with various modeling strategies. The wing camber and twist of the E-7 aircraft were easily defined in the *LinAir* model via the design parameters, type "D," input. Note that the side profile of the fuselage was modeled in addition to the vertical tail for running lateral/directional characteristics in *LinAir*.

A small, apparent anomaly is evident in the side view of the geometry in figure 11: at the nose of the airplane, a short horizontal line extends forward of the first row of panels above the point of the nose. This line is the *planform* of the nose section seen on edge; the oblique view of the geometry shows the distinct planform and side projections of the nose. The nose planform elements are not at the same elevation as the point of the nose in the side view in order to be in the same plane as the wing, which was placed at the proper elevation relative to the rest of the side projection of the fuselage and the vertical tail.

One may also notice in figure 11 that, in the front view, the wing appears to be thin at the root and thicker toward the tips. This is a result of the twist modeled in the wing, where with the root incidence being at 0°, the tip incidence is –5.7°, giving the appearance of thickness in the head-on view. As stated previously, however, the wing was also modeled with camber, though the camber is not evident in the figure. The E-7 wing was run with camber for the longitudinal runs ($\beta = 0°$), and without camber for the lateral/directional runs ($\beta \neq 0°$). The reason the camber was left out for the latter runs is that, at the centerline, the cambered wing root panels extend partially up the height of the fuselage side panels just above the wing. The trailing vortices from these wing root panels passed too close to the control points on the fuselage side panels to give reliable results. For the longitudinal runs, the wing camber was acceptable since all the side projection (i.e., fuselage) elements were not needed. The figure shows the configuration as it was run for the lateral/directional cases.

The comparison of the *LinAir*-predicted lift and pitching moment with wind tunnel data is shown in figure 12(a). *LinAir* curves with full leading-edge suction, no suction, and a varying suction distribution with angle of attack are shown to illustrate how the use of the leading-edge suction analogy significantly improves the lift and drag prediction for this aircraft configuration. (The varying suction distribution used in this case is curve B in figure 7, which was found to yield the best overall comparison with the fighter aircraft experimental data in the author's experience to date.) The full-suction *LinAir* lift curve in figure 12(a) falls well below the wind tunnel data at moderate to high angles of attack, while the varying suction curve generally follows the upward bend of the experimental data. The varying suction curve does over predict the lift above 22° angle of attack, but in this angle range much of the wing airflow is probably becoming separated and less dominated by the vortex-lift effects which the Polhamus suction analogy simulates. Note that the no-suction curve over predicts the lift in most of the angle of attack range, which illustrates why it is desirable to let the suction gradually decrease, as in the varying-suction curve.

The agreement in pitching moment between *LinAir* and the wind tunnel data is not as good as in the lift. This is not surprising, however, since this is a potential flow method and no separated flow effects are considered in the basic method (other than by the suction analogy). One could question the sparsity of the wing paneling, as to whether it is dense enough to give a good longitudinal distribution of lift, but a run with paneling twice as dense yielded insignificant differences in the prediction, and even then only at the highest angles of attack.

The drag calculated by *LinAir* is compared to the wind-tunnel-measured drag in figure 12(b). The drag plotted is labeled "C_{D_I}," meaning induced drag, as it is from *LinAir*, but the wind tunnel drag is actually $C_{D_I} - C_{D_{MIN}}$, which includes skin friction and form drag increments which vary with lift but not the induced drag at zero lift due to twist. Thus, one would expect the measured drag to be a little bit higher than the predicted drag. The comparison of the *LinAir* full and varying suction curves with the data points is similar to the lift comparisons: the full-suction prediction agrees with experiment only up to moderate angles of attack, but the varying-suction prediction shows good agreement over a much larger angle-of-attack range.

Lateral/directional aerodynamic comparisons between *LinAir* and the wind tunnel data are shown in figure 12(c). The yawing and rolling moments (in body axes) and side force are plotted vs. angle of sideslip. The prediction of all three coefficients are in reasonably good agreement with the wind tunnel data, though the predicted rolling moment slopes at the two lower angles of attack (–1° and 4°) are low relative to the experimental data. The fact that the wing and fuselage wakes were constrained in the body X-axis direction (RWAKE = 1) to eliminate interference of trailing vortices with downstream control points probably accounts for part of this error, since the non-ideal wakes do not properly simulate the wing, fuselage and tail interactions. A better wake representation would be having the wakes extend from the trailing edges of the complete surfaces, not just from every panel. Body and wing thickness effects probably also play an important role in the lateral/directional aerodynamics, and, as stated before, are not modeled in *LinAir*.

The other aircraft configuration used for comparison purposes is the NASA/McDonnell Douglas 279-3. A photograph of a wind tunnel model of the 279-3 is shown in figure 13, and the *LinAir* modeling is shown in figure 14. This is a more complex configuration than the E-7, having a canard, and anhedral in the wing in addition to camber and twist. As with the E-7, the planform and side projections of the fuselage were modeled to permit prediction of both the longitudinal and lateral/ directional aerodynamic characteristics. The same anomaly of the planform and side projection nose points not lining up on the E-7 geometry is present here, as seen in figure 14.

The *LinAir* predictions for the 279-3 aircraft are compared with experimental data in figure 15. In general, the comparisons are similar to those for the E-7 configuration. The lift curve (fig. 15(a)) with the varying suction distribution agrees very well with experiment up to about 20° angle of attack, then the lack of separated flow effects causes the prediction to be high above this angle. The nonlinearity of the experimental pitching moment curve is probably due to many complex flow interactions among the forebody, inlets, canard, and wing, which are not accounted for in the *LinAir* prediction. The "induced" drag comparison (fig. 15(b)) shows good agreement only at low lift coefficient values (varying suction distribution curve), with the drag being under predicted at higher lift. The variation of the suction with angle of attack is the same here as for the E-7 predictions, but appears to be inadequate for this configuration (not reducing the suction fast enough with angle of attack).

The *LinAir*-predicted lateral/directional characteristics (fig. 15(c)) generally follow the same trends as the experimental data, but the slopes in most cases are about half of the experimental values. Again, better wake modeling, in addition to including the effects of thickness, could improve the predictions.

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5. Etkin, Bernard: Dynamics of Atmospheric Flight. John Wiley & Sons, 1972.

6. Mehrotra, Sudhir Chandra; and Lan, Edward C.: A Theoretical Investigation of the Aerodynamics of Low-Aspect-Ratio Wings with Partial Leading-Edge Separation. NASA CR-145304, January 1978.

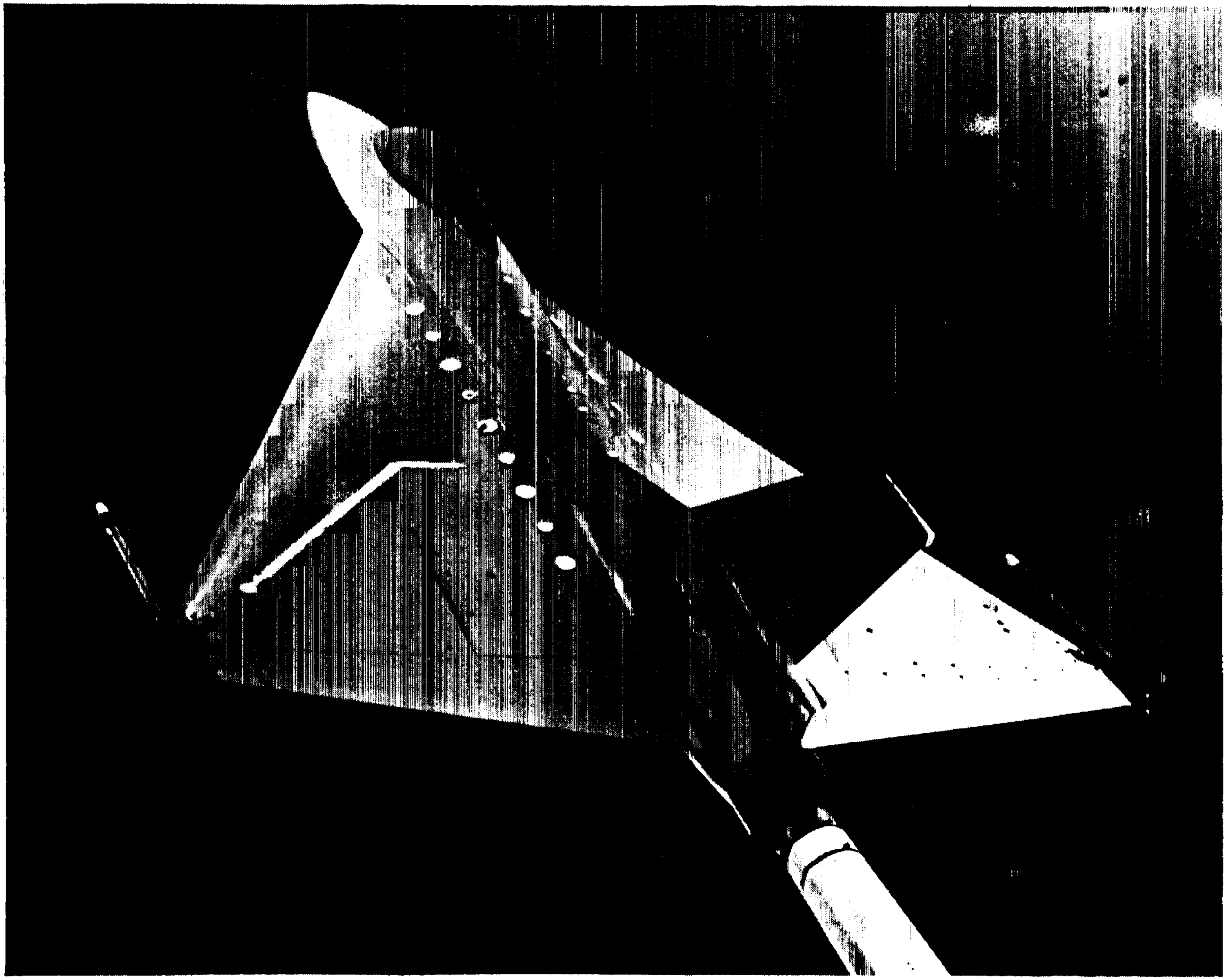


Figure 10. 1/9-Scale E-7 model installed in 12-Foot Pressure Wind Tunnel.

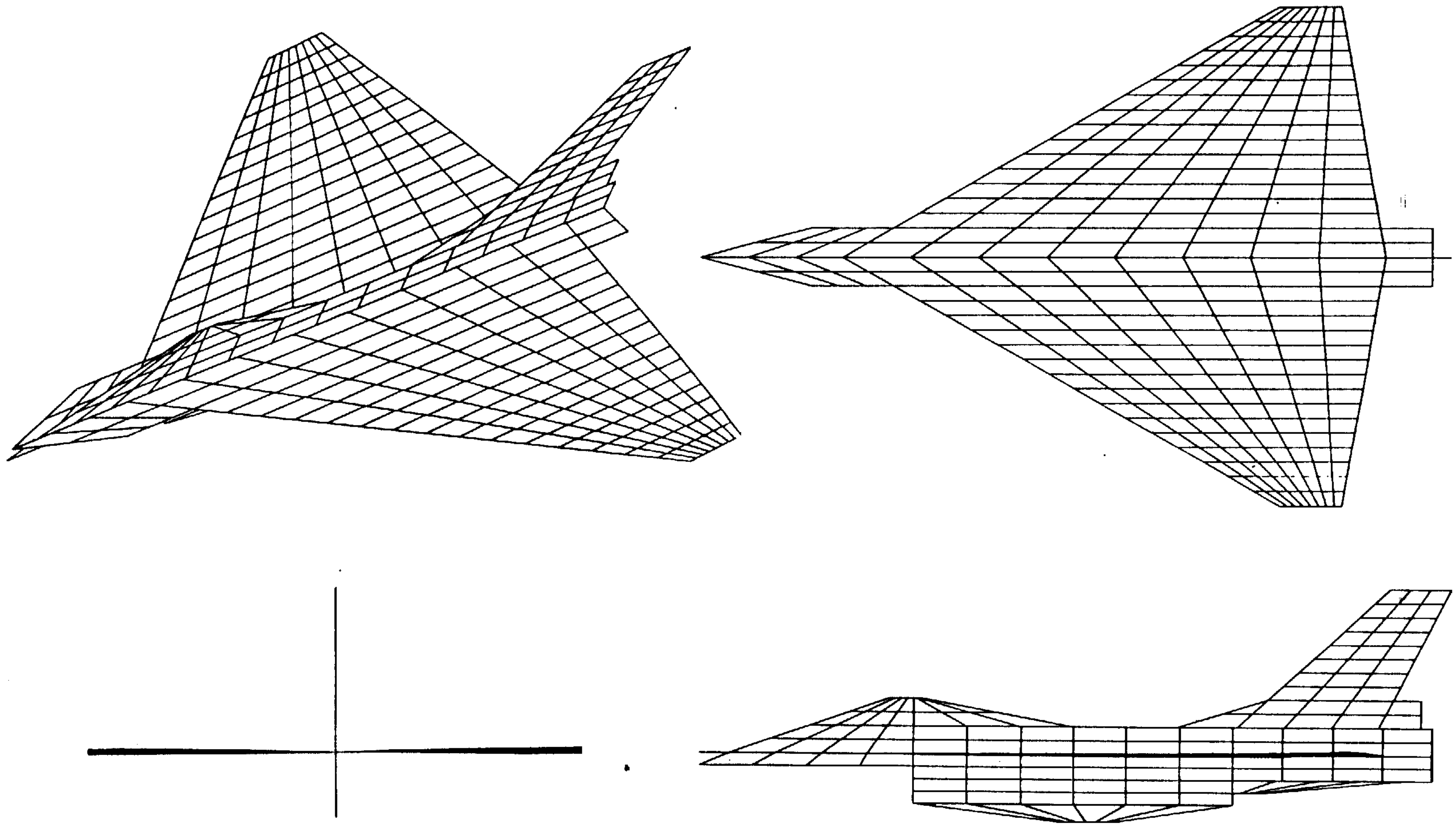
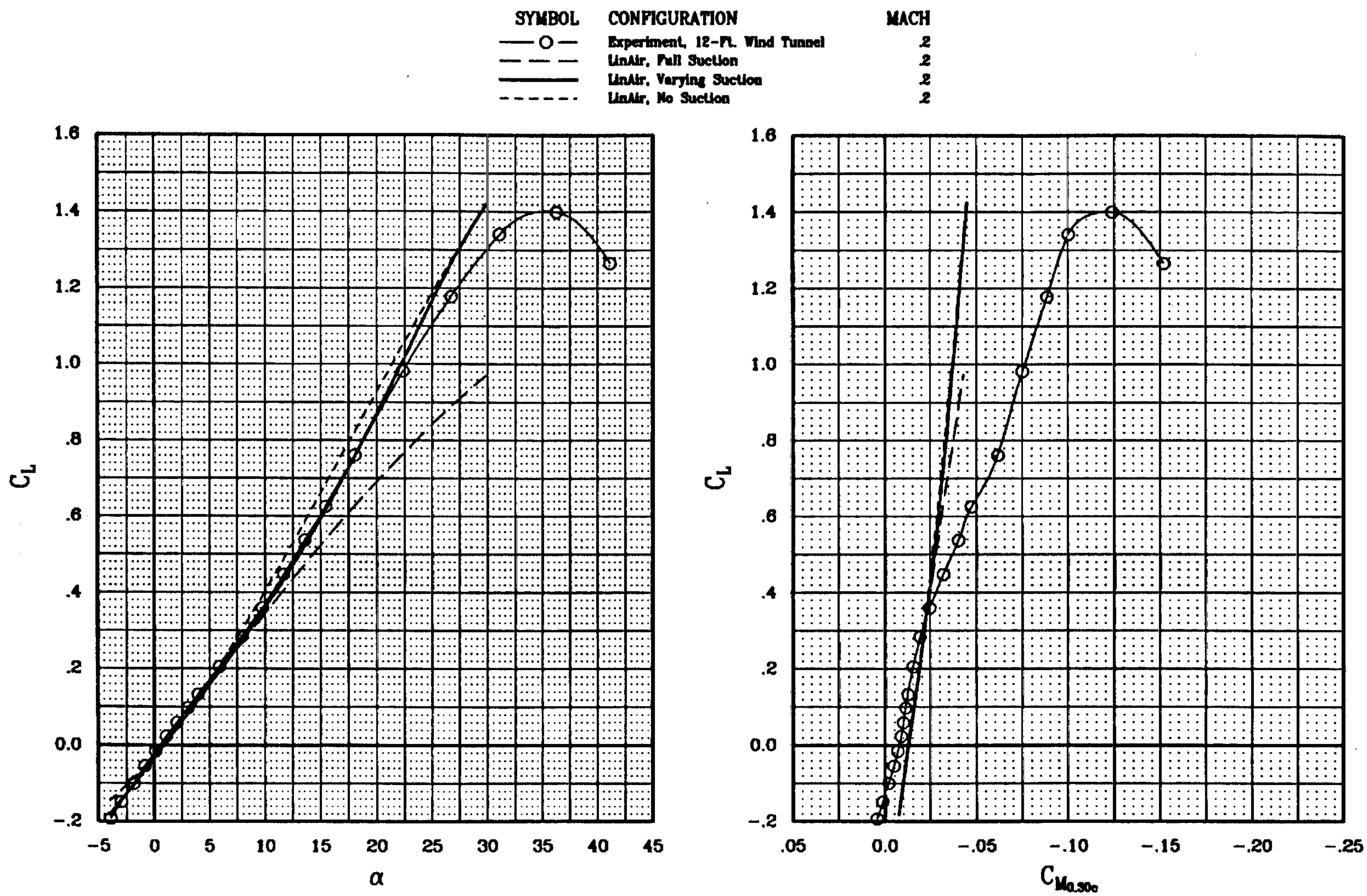
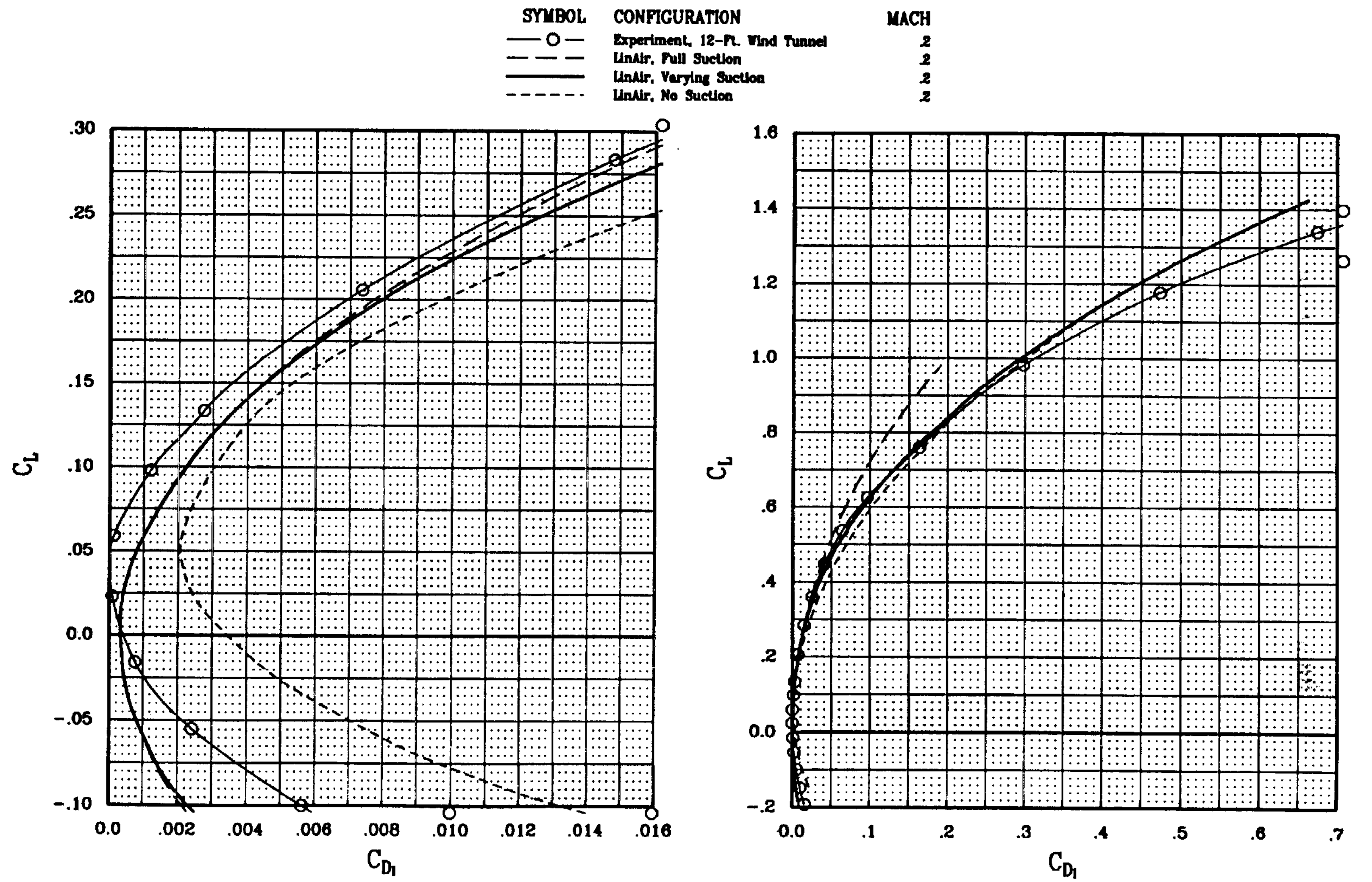


Figure 11. *LinAir* modeling of E-7 configuration.



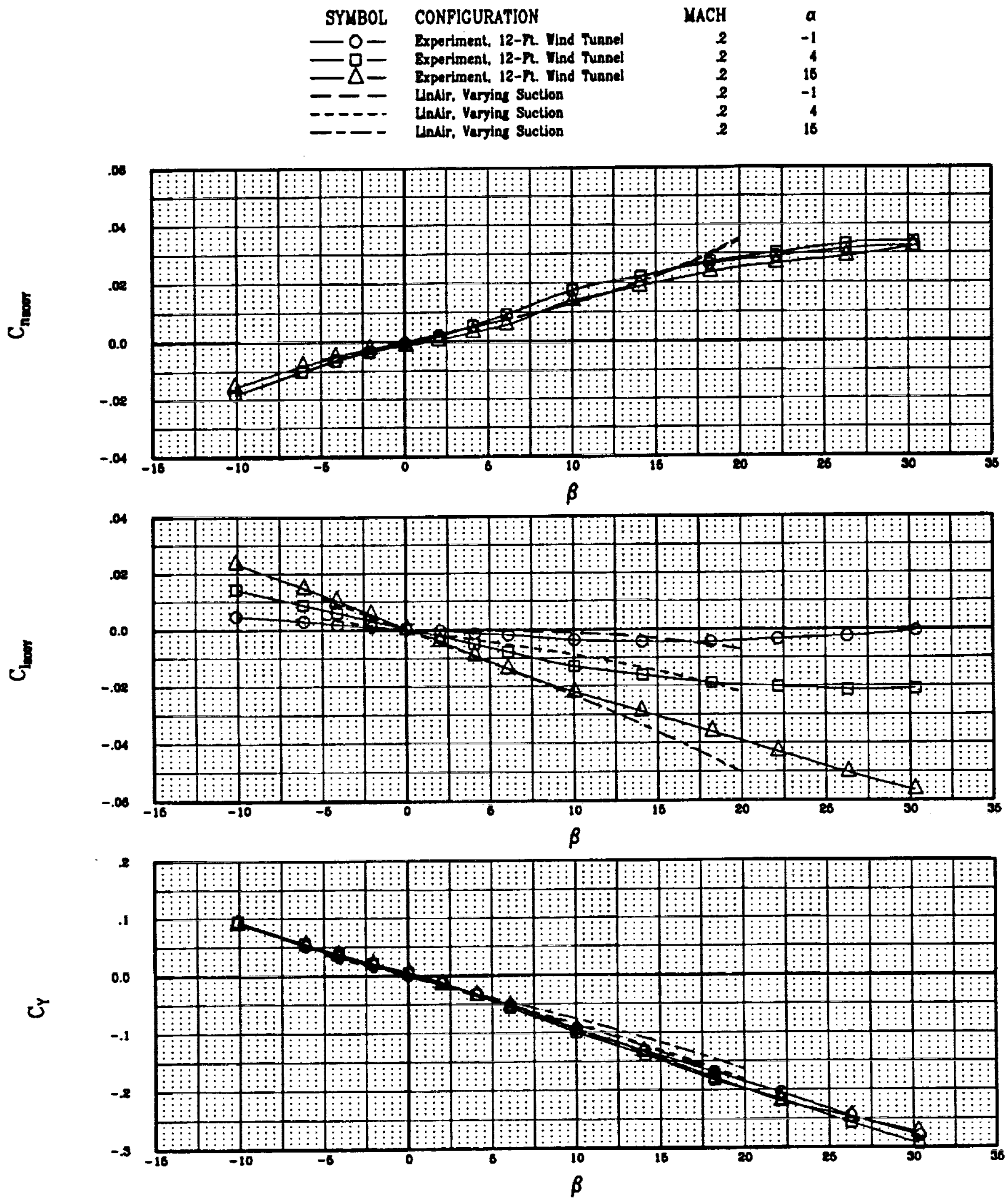
(a) Lift and pitching moment

Figure 12. Comparisons of E-7 *LinAir* predictions with experimental data.



(b) Induced drag

Figure 12. Continued.



(c) Lateral/directional

Figure 12. Concluded.

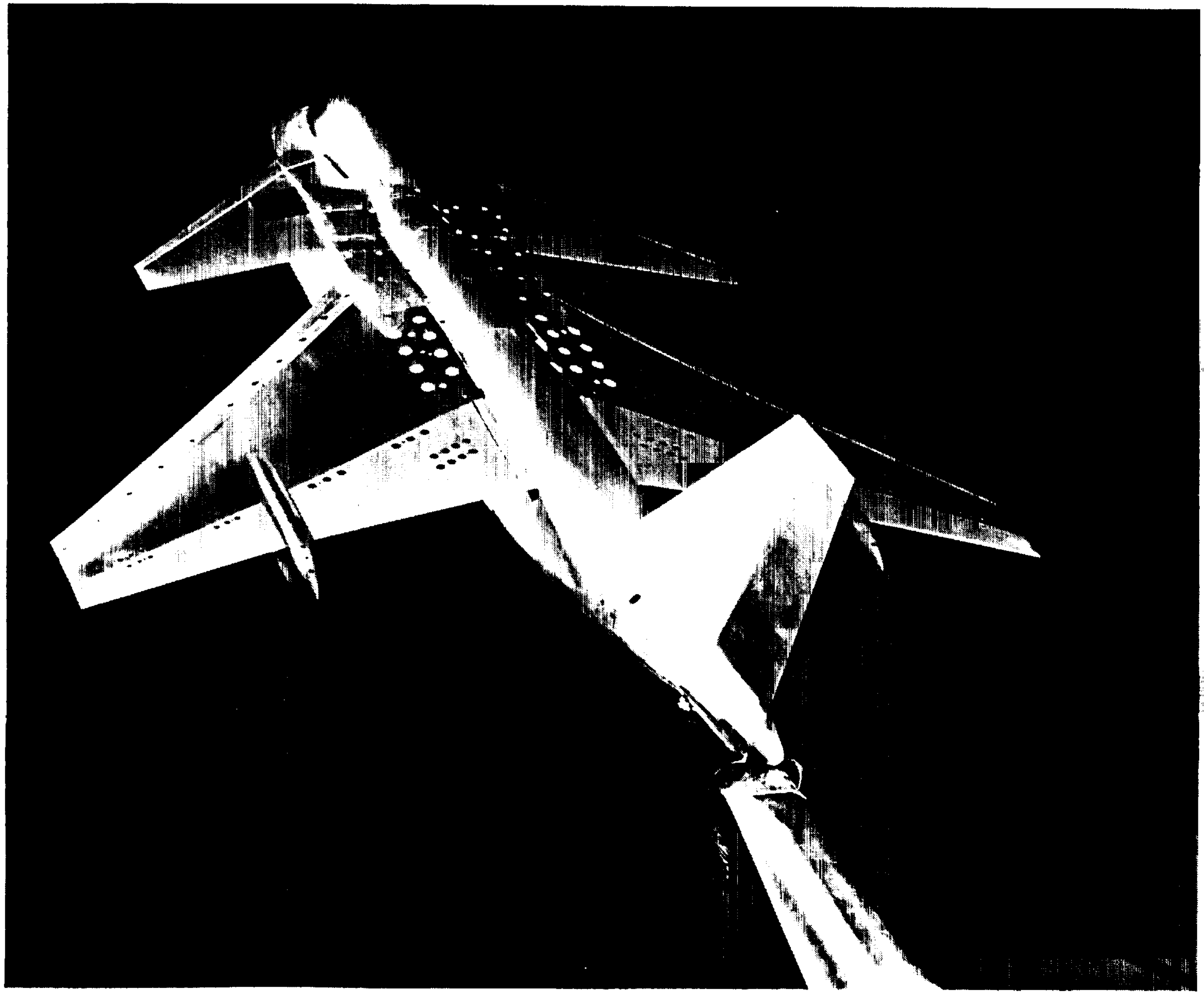


Figure 13. 0.092-Scale 279-3 model installed in 11- by 11-Foot Transonic Wind Tunnel.

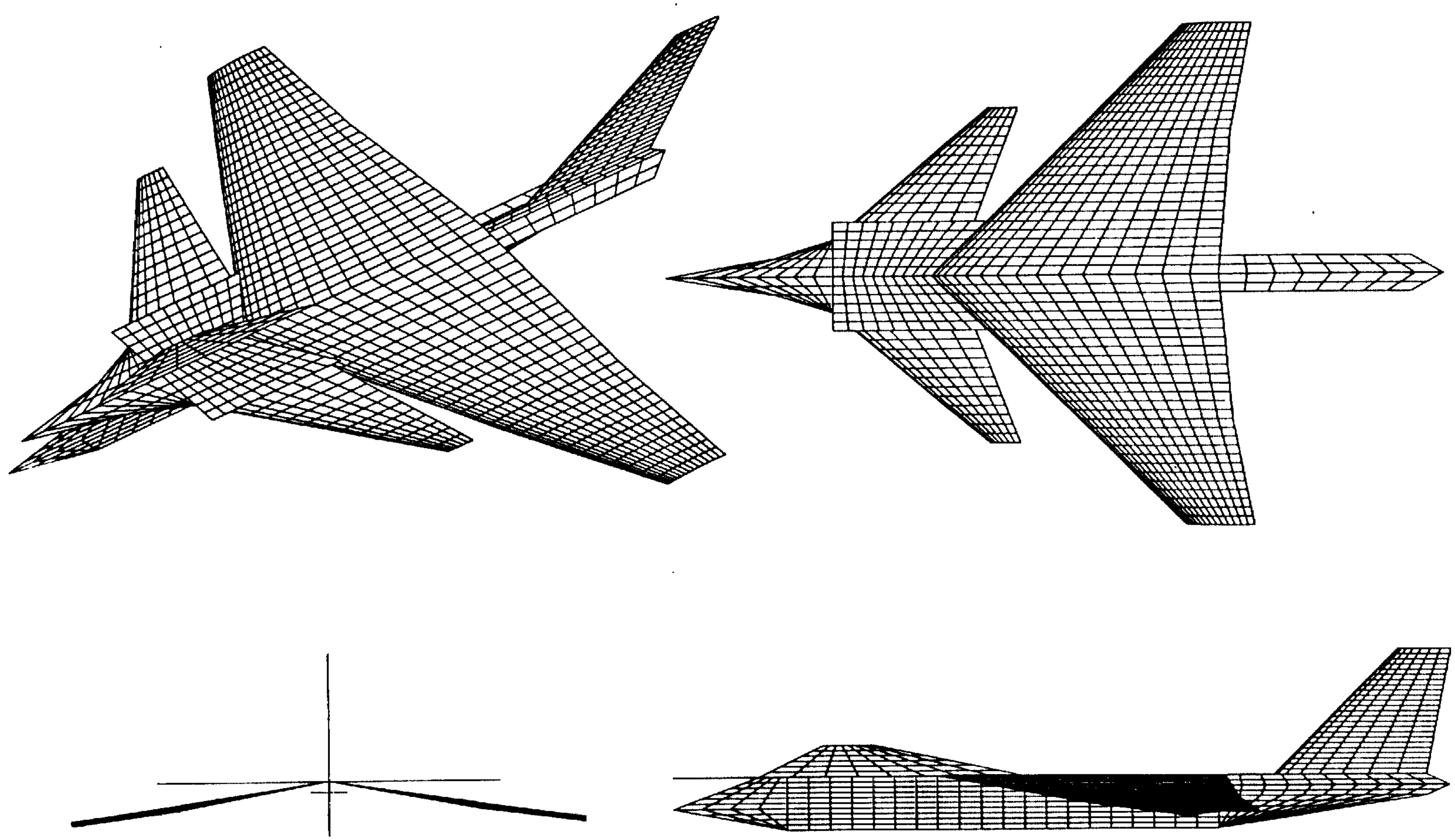
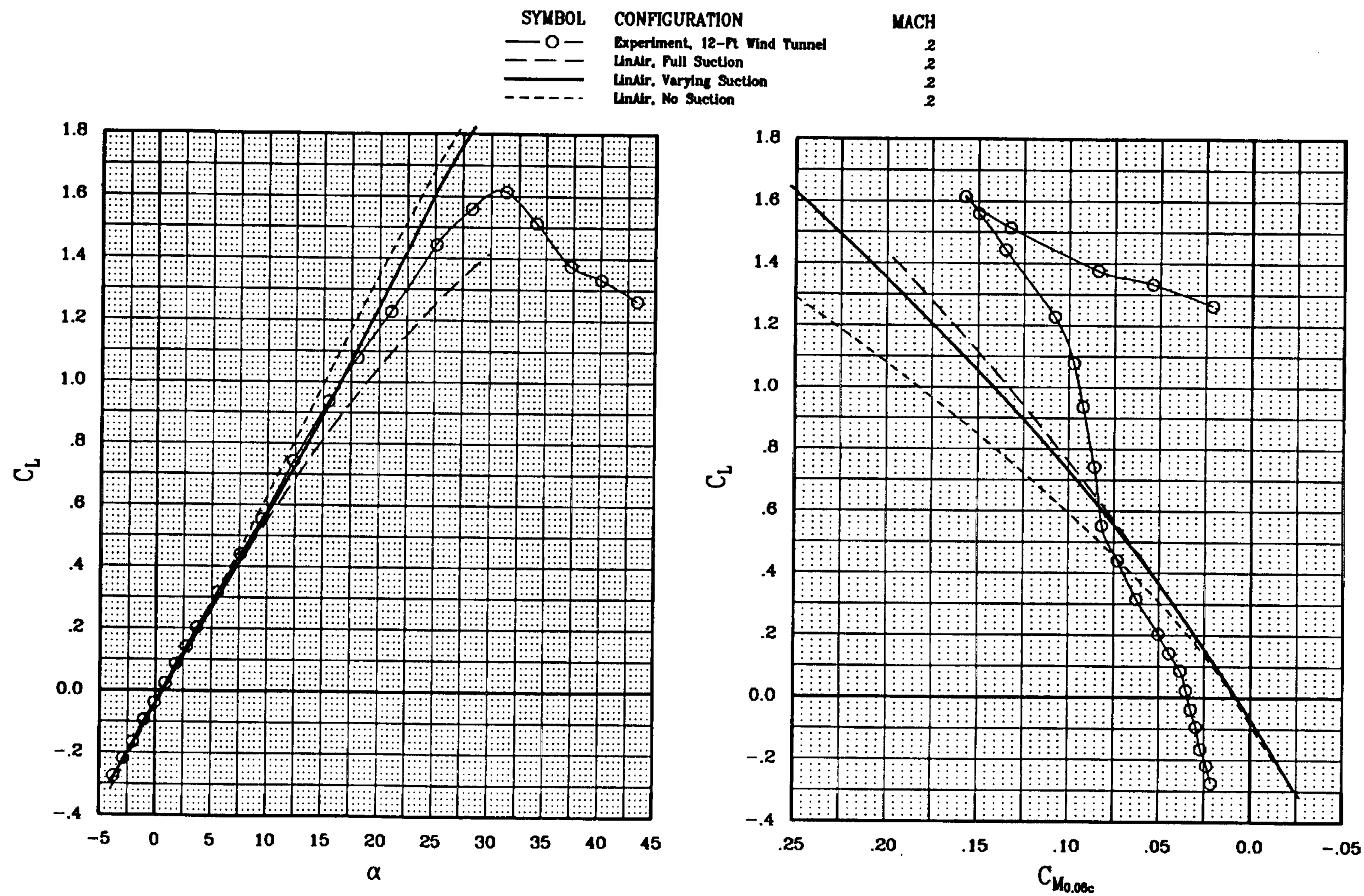
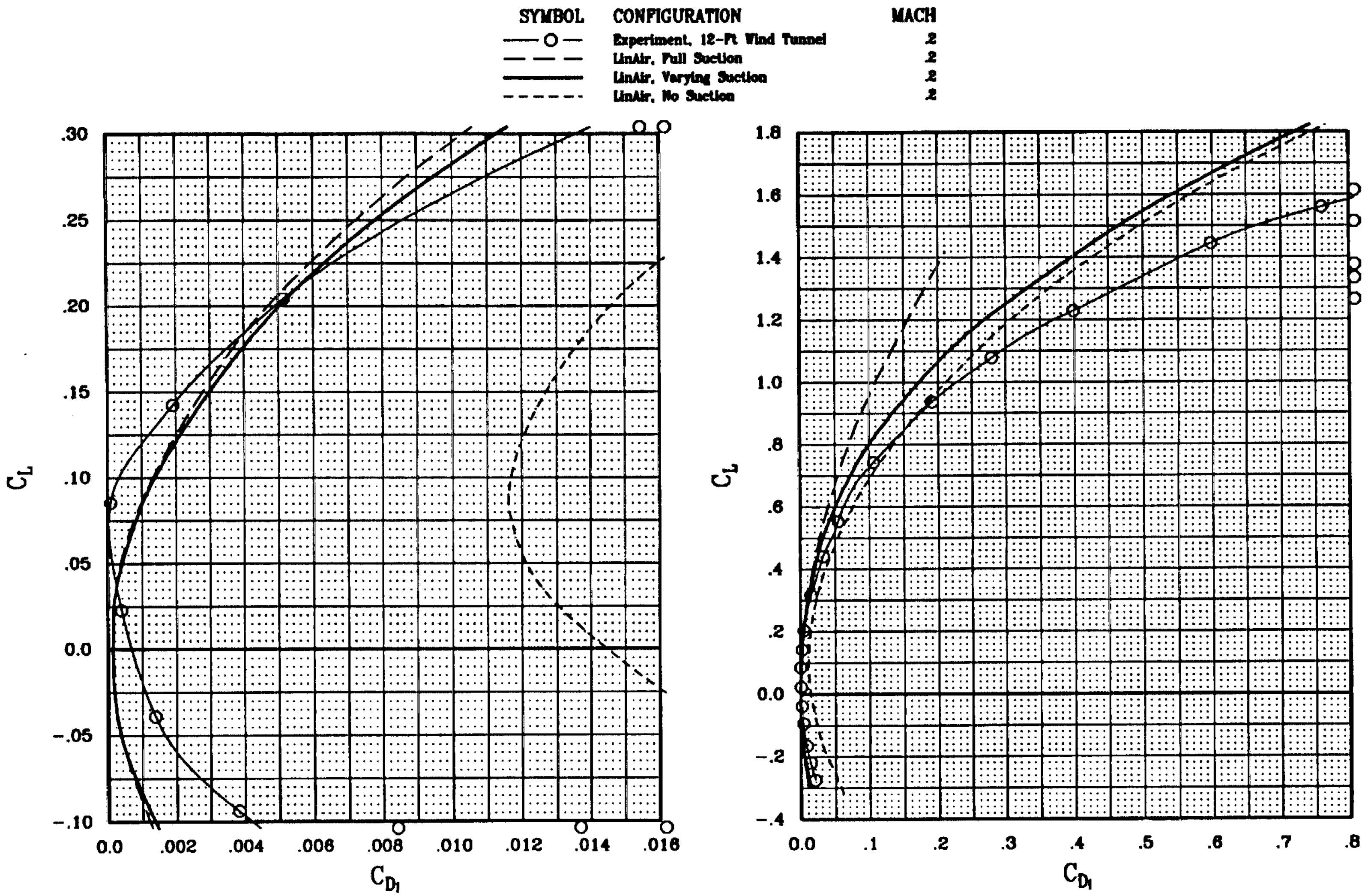


Figure 14. *LinAir* modeling of 279-3 configuration.



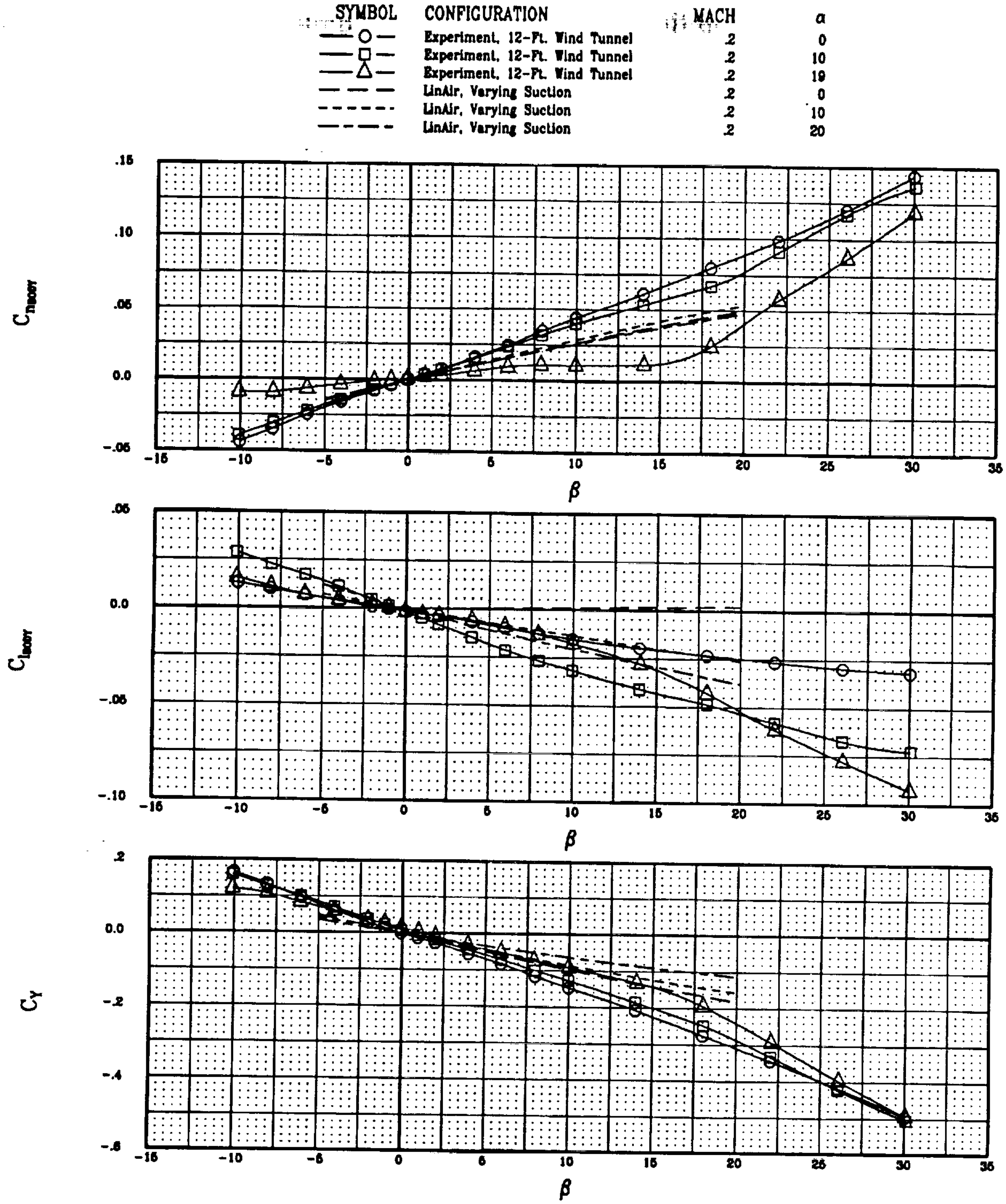
(a) Lift and pitching moment

Figure 15. Comparisons of 279-3 *LinAir* predictions with experimental data.



(b) Induced drag

Figure 15. Continued.



(c) Lateral/directional

Figure 15. Concluded.

APPENDIX 1

VARIABLE DEFINITIONS

Variable	Type	I/O	Dim.	Definition (Default values other than 0 enclosed in “< >”)	Used in file
Alpha, α	R	I	30	Angle of attack (degrees)	Input, LST, PFS
AR	R	I/O	–	Aspect ratio, span^2/area	Input, LST
Area	R	I/O	500	True planform area of an element (for one side of geometry if symmetric).	Input, LST, PFS
AR_{ref}	R	I/O	–	Reference aspect ratio. Used for calculation of Oswald’s efficiency factor only. Can be input, or calculated from surface geometry if set equal to zero and if “wing” surface provided (see Geometric Reference Parameters section).	Input, LST
Beta, β	R	I	30	Angle of sideslip (degrees), positive when the nose is to the left relative to the velocity vector.	Input, LST, PFS
b_{ref}	R	I/O	–	Reference span (for yawing and rolling moments, also used in determining trailing vortex lengths). Can be input, or calculated from surface geometry if set equal to zero and if “wing” surface provided.	Input, LST
Camber	C	I	–	Flag for type 'D' or 'S' inputs indicating whether a camber line definition is included for the current surface <‘N' or ''>	Input
CAP	R	O	–	Panel axial force coefficient	PFS
C_{avg}	R	O	–	Average of root and tip chords	LST
$C_{bar}, \bar{c}$, MAC	R	O	–	Mean aerodynamic chord, $\frac{2}{3} C_R \frac{1+\lambda+\lambda^2}{1+\lambda}$	LST
C_D	R	O	–	Total drag coefficient in wind axes, D/qSref	LST
C_{D_I}	R	O	–	Induced drag coefficient in wind axes–drag calculated by *LinAir* without any drag adjustments $(C_{d_0}, C_{d_1}, C_{d_2})$	LST
C_{d_0}	R	I	–	Section profile drag coefficient constant term	Input, LST

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PAGE 42 INTENTIONALLY BLANK

C_{d_1}	R	I	–	Section profile drag coefficient linear term	Input, LST
C_{d_2}	R	I	–	Section profile drag coefficient quadratic term	Input, LST
CDP	R	O	–	Panel drag coefficient	PFS
Chord	R	I/O	–	Chord of a surface, element, or panel	Input, LST, PFS
C_l	R	O	–	Section lift coefficient in wind axes, section lift/q chord	LST
C_L	R	O	–	Lift coefficient in wind axes, L/qS_{ref}	LST
CLP	R	O	–	Panel lift coefficient	PFS
C_M	R	O	–	Pitching moment coefficient in wind axes, $M/qS_{ref}\,c_{ref}$	LST
CNP	R	O	–	Panel normal force coefficient	PFS
Conf	R	I	–	Configuration number, used only for reference in database (.CDD) and in output files	Input, LST, LOD, PFS
COSFULL	–	I	–	Full cosine spacing. Element spacing indicator for type 'D' or 'S' inputs.	Input, LST
COSLE	–	I	–	Cosine spacing, leading-edge dense. Element spacing indicator for type 'D' or 'S' inputs.	Input, LST
COSTE	–	I	–	Cosine spacing, trailing-edge dense. Element spacing indicator for type 'D' or 'S' inputs.	Input, LST
C_R, C_{root}	R	I/O	500	Root chord	Input, LST
C_{ref}	R	I/O	–	Reference chord (for pitching moment coefficient). Can be input, or calculated from surface geometry if set equal to zero and if "wing" surface provided, in which case it is set equal to the mean aerodynamic chord of the wing.	Input, LST
C_{ROLL}	R	O	–	Rolling moment coefficient in body axes, rolling moment/$qS_{ref}b_{ref}$	LST
C_T, C_{tip}	R	I/O	500	Tip chord	Input, LST
C_X, C_A	R	O	–	Axial force coefficient in body axes, X (or A)/qS_{ref}	LST
C_Y	R	O	–	Side force coefficient in body axes, Y/qS_{ref}	LST

C_{YAW}	R	O	–	Yawing moment coefficient in body axes, yawing moment/$qS_{ref}b_{ref}$	LST
C_Z, C_N	R	O	–	Normal force coefficient in body axes, Z (or N)/qS_{ref}	LST
Dihed	R	I/O	500	Dihedral angle (measured in body Y-Z plane). Dihedral is measured from the Y-axis, positive up.	Input, LST, PFS
e	R	O	–	Oswald's span efficiency factor, $\frac{C_L^2}{\pi AR_{ref} C_{D_I}}$	LST
etaCbar, $\eta_{\bar{c}}$	R	O	–	Span station of $\bar{c}$ in percent semi-span	LST
GCHANGE	C	I	3	Control parameter for informing program of changed geometry in new input case	Input
Incd	R	O	–	Panel incidence angle, measured relative to body X-axis	PFS
ISYM	I	I/O	–	Geometry symmetry flag <1> 0 = not symmetric about X-Z plane 1 = symmetric about X-Z plane	Input, LST
LINEAR	–	I	–	Linear spacing (the default). Element spacing indicator for type 'D' or 'S' inputs.	Input, LST
LOD	C	I	3	Database loading file option parameter	Input
LST	C	I	3	Main listing file option parameter	Input
L/D	R	O	–	Lift-to-drag ratio, C_L/C_D	LST
MAC	R	O	–	See C_{bar}	LST
Mach	R	I	–	Freestream Mach number, ratio of freestream velocity to speed of sound (must be < 1)	Input, LST, LOD, PFS
NET	C	I	3	Geometry display file option parameter	Input
N_{seq}	I	I/O	–	Number of sequence numbers (e.g., angles of attack) for current run	Input, LST
$N_{[x,y,z]}$	R	O	500 × 100	Panel unit normals in X, Y and Z directions	PFS
PFA	C	I	3	Panel axial forces display file option parameter	Input
PFD	C	I	3	Panel drag forces display file option parameter	Input

PFL	C	I	3	Panel lift forces display file option parameter	Input
PFN	C	I	3	Panel normal forces display file option parameter	Input
PFS	C	I	3	Panel forces summary file option parameter	Input
PIC	C	I	3	Geometry display file option parameter	Input
phat, $\hat{p}$	R	I/O	30	Nondimensional roll rate, $\hat{p} = \frac{pb_{ref}}{2V_\infty}$	Input, LST
qhat, $\hat{q}$	R	I/O	30	Nondimensional pitch rate, $\hat{q} = \frac{q\bar{c}}{2V_\infty}$	Input, LST
rhat, $\hat{r}$	R	I/O	30	Nondimensional yaw rate, $\hat{r} = \frac{rb_{ref}}{2V_\infty}$	Input, LST
Rooti	R	I/O	500	Root incidence angle (degrees), measured from body X-axis to element chord line at root	Input, LST
RUNINI	R	I	–	Initial run number for all cases within one input file. A run is defined as a series of angles of attack or sideslip or body rotation rates, but does not have to contain more than one flow condition. Run number is incremented by one for each case within the file. RUNINI is required for use in the database loading file, and is use for reference only in the main listing and forces summary files. <1>	Input, LOD, LST, PFS
RWAKE	R	I/O	–	Trailing vortex wake orientation factor, varies from 1 to –1 <1>	Input, LST
Span	R	I/O	500	True unswept span of an element (for one side of geometry if symmetric). The span of the element is the length of its projection in the Y-Z plane (rear view). This is done so that a 20 ft. tall vertical tail has a span of 20 ft. (regardless of its sweep).	Input, LST, PFS
S_{ref}	R	I/O	–	Model reference area (on which aerodynamic coefficients are based). Can be input, or calculated from surface geometry if set equal to zero and if "wing" surface provided.	Input, LST

Suctn	R	I/O	–	Leading-edge suction, varies from 0 to 1 0 = No suction, full vortex lift 1 = Full suction, no vortex lift (use for "pure" vortex lattice calculations)	LST
Suctn[0,1,2,3]	R	I/O	500	Suction coefficients, used for calculating Suctn for each element. The four coefficients allow up to a third-order variation of the suction with angle of attack and/or sideslip: $\text{Suctn} = \text{Suctn0} + \text{Suctn1}\,[\alpha \times \cos(\text{Dihed}) + \beta \times \sin(\text{Dihed})] + \text{Suctn2}\,[\alpha^2 \times \cos(\text{Dihed}) + \beta^2 \times \sin(\text{Dihed})] + \text{Suctn3}\,[\alpha^3 \times \cos(\text{Dihed}) + \beta^3 \times \sin(\text{Dihed})]$	Input, LST
Sweep	R	O	–	Quarter-chord sweep angle (degrees). Sweep is the angle from the element quarter-chord line to its projection in the Y-Z plane; that is, sweep is measured in the plane of the wing, not on the X-Y plane (applies to following sweep angle definitions as well).	LST
SweepLE, Λ_{LE}	R	I/O	–	Leading-edge sweep angle (degrees)	Input, LST
SweepTE	R	I/O	–	Trailing-edge sweep angle (degrees)	Input, LST
Taper, λ	R	I/O	500	Tip-to-root chord ratio	Input, LST
Tipi	R	I/O	500	Tip incidence angle (degrees), measured from body X-axis to element chord line at tip	Input, LST
Twist	R	I/O	500	Difference in incidence angle between tip and root, Tipi - Rooti (degrees)	Input, LST
VHDBndy	R	I/O	–	Vertical-to-horizontal dihedral boundary (degrees) <45>	Input, LST, PFS
$XCTD_{ref}$	R	I/O	–	X/C of the twist/dihedral reference line–the imaginary constant-chord line about which the twist and dihedral angles are defined. Use $XCTD_{ref} = 0$ for rotating about the leading edge, $XCTD_{ref} = 1$ for rotating about the trailing edge, and intermediate values for rotating about other constant-chord lines.	Input, LST

XoCbarXr	R	I/O	–	$(X/Cbar)_{Xref}$ ("X over Cbar of Xref") – the longitudinal distance from the leading edge of the surface MAC to the moment reference center, expressed as a fraction of the MAC; used only when a "wing" surface is input (so that the program knows the spanwise location and length of the wing mean aerodynamic chord).	Input, LST
$[X,Y,Z]_{ref}$	R	I/O	–	Moment reference center location relative to the geometry origin	Input, LST
$[X,Y,Z]_{root}$	R	I/O	500	Element root quarter-chord location	Input, LST
$[X,Y,Z]_{BVC}$	R	O	500 × 100	Panel bound vortex center location	PFS
$[X,Y,Z]_{RLE}$	R	I	500	Element root leading-edge location	Input
$[X,Y,Z]_{RLES}$	R	I/O	–	Surface root leading-edge location (called "[X,Y,Z]rootLE" in main listing file)	Input, LST
$[X,Y,Z]_{RTE}$	R	I	500	Element root trailing-edge location	Input
$[X,Y,Z]_{TLE}$	R	I	500	Element tip leading-edge location	Input
$[X,Y,Z]_{TTE}$	R	I	500	Element tip trailing-edge location	Input

APPENDIX 2

EXAMPLE INPUT FILE

A very simple *LinAir* input geometry is shown in figure 4 of this report, and the corresponding input file is shown in the text. A more complex input file is shown here to illustrate more of the features of *LinAir*. The geometry here is representative of the McDonnell Douglas 279-3 STOVL fighter aircraft, shown in figures 13 and 14. Both the planform and side projections of the aircraft are modeled, making this geometry suitable for both pitch and yaw runs. Type 'D' and 'S' inputs are used in this file, and camber, twist and dihedral are defined for the wing. Note the use of the design parameters inputs for the "lifting" surfaces, for which this type of input was intended, and the use of surface corner point inputs for those surfaces which are generally known more by their boundaries than by their planform properties (such as the fuselage sections).

```
$RUNNUM RUNINI= 1
$
McAir 279-3 -- Canard, Wing (w/ twist & camber), Nose & Aft Fuselage, Fuselage Side & Vertical Tail, Suction = 3rd order variation
$OPTION NET= 'y'  PIC= '3'  LST= ''  LOD= ''  PFS= ''  PFL= ''  PFD= ''  PFN= ''  PFA= ''  GCHANGE= ''
$
$REF    Sref=   428.4    Xref=   27.170    Conf= 124
        Bref=   35.84    Yref=    0.000    Isym=   1
        Cref=   13.38    Zref=    7.92     Rwake=  1
        VHDBndy= 45      XoCbarXr= 999     NEPOne= 0
$
$FLOCDN Nseq= 6
        Alpha=   0  0  0  0  0  0
        Beta =  -5  0  5 10 15 20
        Mach= 0.2
$

'S' 'Linear' 2 2 'Nose 1'
  XRLE     YRLE     ZRLE     XRTE     YRTE     ZRTE     XTLE     YTLE     ZTLE     XTTE     YTTE     ZTTE    XCTDref
  0.       0.       9.53     3.684    0.       9.53     7.670    1.28     9.53     7.670    1.28     9.53      0
                                               Suctn0     Suctn1     Suctn2     Suctn3       CD0      CD1      CD2      Camber?
                                                 1          0          0          0         .0208     0        0         'n'

'S' 'Linear' 6 4 'Nose 2'
  XRLE     YRLE     ZRLE     XRTE     YRTE     ZRTE     XTLE     YTLE     ZTLE     XTTE     YTTE     ZTTE    XCTDref
  3.684    0.000    9.530   11.880    0.000    9.530   11.880    2.560    9.53    11.880    2.560    9.53      0
                                               Suctn0     Suctn1     Suctn2     Suctn3       CD0      CD1      CD2      Camber?
                                                 1          0          0          0         .0208     0        0         'n'

'S' 'Linear' 10 6 'Inlet'
  XRLE     YRLE     ZRLE     XRTE     YRTE     ZRTE     XTLE     YTLE     ZTLE     XTTE     YTTE     ZTTE    XCTDref
 11.880    0.       9.53    18.927    0.       9.53    11.880    3.84     9.53    22.767    3.84     9.53      0
                                               Suctn0     Suctn1     Suctn2     Suctn3       CD0      CD1      CD2      Camber?
                                                 1          0          0          0         .0208     0        0         'n'

'D' 'COSLE' 8 12 'Canard'
  |<------ ALL 3 ------>|   |<---- BOTH SWEEPS + 2, OR ONE SWEEP + 3 (OTHERS = 999) ----->|   |<----- ANY 2 ----->|   |<-- BOTH -->|
 XRLES    YRLES    ZRLES   SweepLE SweepTE   Span      CR       CT     Taper     AR      Area   Rooti    Tipi    Twist    Dihed  XCTDref
 13.42     3.84     9.53     50      999     8.01     8.55     999     0.25     999      999     0        999     0        0      .25

                                               Suctn0     Suctn1     Suctn2     Suctn3       CD0      CD1      CD2      Camber?
                                                 1      4.1667E-3 -3.7500E-3 8.3333E-5      .0208     0        0         'n'

'D' 'COSLE' 16 16 'Wing, inner'
  |<------ ALL 3 ------>|   |<---- BOTH SWEEPS + 2, OR ONE SWEEP + 3 (OTHERS = 999) ----->|   |<----- ANY 2 ----->|   |<-- BOTH -->|
 XRLES    YRLES    ZRLES   SweepLE SweepTE   Span      CR       CT     Taper     AR      Area   Rooti    Tipi    Twist    Dihed  XCTDref
 18.927    0        9.53     45      999    10.367   20.279   10.822   999      999      999     0       -2.2     999      -9      .73

                                               Suctn0     Suctn1     Suctn2     Suctn3       CD0      CD1      CD2      Camber?
                                                 1      4.1667E-3 -3.7500E-3 8.3333E-5      .0208     0        0         'y'

          Root Camber:  # points   Rotate to level?
```


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PAGE 50 INTENTIONALLY BLANK

```
                         16           'N'
0 0
.025 .0015
.05  .0019
.075 .0021
.1   .0023
.15  .0024
.2   .0025
.25  .0026
.3   .0026
.4   .0024
.5   .0020
.6   .0014
.7   .0007
.8   .0003
.9   .0001
1    0
        Tip Camber:  # points   Rotate to level?
                        16           'N'
0 0
.025 .0092
.05  .0115
.075 .0126
.1   .0135
.15  .0144
.2   .0150
.25  .0155
.3   .0154
.4   .0142
.5   .0118
.6   .0084
.7   .0044
.8   .0019
.9   .0005
1    0

'D' 'COSLE' 16 12 'Wing, outer'
 |<------ ALL 3 ------>|  |<---- BOTH SWEEPS + 2, ORONE SWEEP + 3 (OTHERS = 999) ----->|  |<----- ANY 2 ----->|  |<-- BOTH -->|
 XRLES   YRLES   ZRLES  SweepLE SweepTE  Span    CR      CT    Taper   AR    Area   Rooti   Tipi   Twist   Dihed  XCTDref
 29.294  10.239  7.888    45     999    7.553  10.822   4.780   999    999   999    -2.2    -4     999     -9     .73

                                   Suctn0    Suctn1     Suctn2     Suctn3        CD0     CD1     CD2     Camber?
                                     1     4.1667E-3 -3.7500E-3 8.3333E-5      .0208     0       0       'y'

        Root Camber:  # points   Rotate to level?
                        16           'N'
0 0
.025 .0092
.05  .0115
.075 .0126
.1   .0135
```

```
.15  .0144
.2   .0150
.25  .0155
.3   .0154
.4   .0142
.5   .0118
.6   .0084
.7   .0044
.8   .0019
.9   .0005
1   0
           Tip Camber:  # points   Rotate to level?
                           16           'N'
0 0
.025 .0103
.05  .0163
.075 .0201
.1   .0228
.15  .0273
.2   .0302
.25  .0318
.3   .0331
.4   .0350
.5   .0356
.6   .0334
.7   .0271
.8   .0183
.9   .0095
1   0

'S' '' 8 2 'Aft Fuselage'
  XRLE     YRLE     ZRLE     XRTE     YRTE     ZRTE     XTLE     YTLE     ZTLE     XTTE     YTTE     ZTTE     XCTDref
 39.206    0.       8.79    55.220    0.       8.79    39.318    1.28     8.79    52.860    1.28     8.79      0
                                               Suctn0      Suctn1      Suctn2      Suctn3        CD0      CD1      CD2      Camber?
                                                 1           0           0           0          .0208     0        0        'n'


'S' '' 4 6 'Nose, Upper (side projection)'
  XRLE     YRLE     ZRLE     XRTE     YRTE     ZRTE     XTLE     YTLE     ZTLE     XTTE     YTTE     ZTTE     XCTDref
  0.       0.       7.274    8.121    0.       7.274    6.091    0.       9.530    8.121    0.       9.530     0
                                               Suctn0      Suctn1      Suctn2      Suctn3        CD0      CD1      CD2      Camber?
                                                 1           0           0           0          .0208     0        0        'n'

'S' '' 4 4 'Nose, Lower (side projection)'
  XRLE     YRLE     ZRLE     XRTE     YRTE     ZRTE     XTLE     YTLE     ZTLE     XTTE     YTTE     ZTTE     XCTDref
  0.       0.       7.274    8.121    0.       7.274    8.121    0.       5.770    8.121    0.       5.770     0
                                               Suctn0      Suctn1      Suctn2      Suctn3        CD0      CD1      CD2      Camber?
                                                 1           0           0           0          .0208     0        0        'n'
```

```
'S' '' 8 6 'Canopy (side projection)'
  XRLE      YRLE      ZRLE      XRTE      YRTE      ZRTE      XTLE      YTLE      ZTLE      XTTE      YTTE      ZTTE      XCTDref
 6.091      0.        9.530    25.000     0.        9.530    10.677     0.       11.738    14.286     0.       11.738       0
                                                    Suctn0      Suctn1      Suctn2      Suctn3        CD0       CD1       CD2       Camber?
                                                      1           0           0           0          .0208       0         0          'n'

'S' '' 20 10 'Center Fuselage, Main Section (side projection)'
  XRLE      YRLE      ZRLE      XRTE      YRTE      ZRTE      XTLE      YTLE      ZTLE      XTTE      YTTE      ZTTE      XCTDref
 8.121      0.        9.530    38.724     0.        9.530     8.121     0.        5.770    38.724     0.        5.770       0
                                                    Suctn0      Suctn1      Suctn2      Suctn3        CD0       CD1       CD2       Camber?
                                                      1           0           0           0          .0208       0         0          'n'

'S' '' 10 2 'Aft Fuselage, Upper Section (side projection)'
  XRLE      YRLE      ZRLE      XRTE      YRTE      ZRTE      XTLE      YTLE      ZTLE      XTTE      YTTE      ZTTE      XCTDref
38.724      0.        8.778    55.220     0.        8.778    38.724     0.        9.530    53.534     0.        9.530       0
                                                    Suctn0      Suctn1      Suctn2      Suctn3        CD0       CD1       CD2       Camber?
                                                      1           0           0           0          .0208       0         0          'n'

'S' '' 10 2 'Aft Fuselage, Middle Section (side projection)'
  XRLE      YRLE      ZRLE      XRTE      YRTE      ZRTE      XTLE      YTLE      ZTLE      XTTE      YTTE      ZTTE      XCTDref
38.724      0.        8.778    55.220     0.        8.778    38.724     0.        8.026    53.534     0.        8.026       0
                                                    Suctn0      Suctn1      Suctn2      Suctn3        CD0       CD1       CD2       Camber?
                                                      1           0           0           0          .0208       0         0          'n'

'S' '' 10 6 'Aft Fuselage, Lower Section (side projection)'
  XRLE      YRLE      ZRLE      XRTE      YRTE      ZRTE      XTLE      YTLE      ZTLE      XTTE      YTTE      ZTTE      XCTDref
38.724      0.        8.026    53.534     0.        8.026    38.724     0.        5.770    38.724     0.        5.770       0
                                                    Suctn0      Suctn1      Suctn2      Suctn3        CD0       CD1       CD2       Camber?
                                                      1           0           0           0          .0208       0         0          'n'

'D' 'cosle' 8 24  'Vertical Tail'
 |<------- ALL 3 ------>|   |<---- BOTH SWEEPS + 2, OR ONE SWEEP + 3 (OTHERS = 999) ----->|  |<----- ANY 2 ----->|  |<-- BOTH -->|
 XRLES     YRLES     ZRLES   SweepLE SweepTE   Span      CR       CT     Taper    AR      Area    Rooti     Tipi    Twist   Dihed  XCTDref
42.634     0         9.530     45      999     8.83     10.90     3.82    999     999      999      0        999      0       90      0

                                                    Suctn0      Suctn1      Suctn2      Suctn3        CD0       CD1       CD2       Camber?
                                                      1           0           0           0          .0208       0         0          'n'

McAir 279-3 -- Canard, Wing (w/ twist & camber), Nose & Aft Fuselage, Fuselage Side & Vertical Tail, Suction = 3rd order
 $OPTION $
 $REF    $
 $FLOCDN Alpha=  10 10 10 10 10 10
         Beta =  -5  0  5 10 15 20
 $

McAir 279-3 -- Canard, Wing (w/ twist & camber), Nose & Aft Fuselage, Fuselage Side & Vertical Tail, Suction = 3rd order
 $OPTION $
 $REF    $
 $FLOCDN Alpha=  20 20 20 20 20 20
         Beta =  -5  0  5 10 15 20
 $
```

APPENDIX 3

EXAMPLE OUTPUT FILES

Geometry Network and Picture Files

All of the example output files shown in this appendix are from the simple geometry of figure 4 only, as the files for the 279-3 geometry of appendix 2 are quite long. The input file which generated these ouput files is the one shown in the Input Data File section of this report.

Portions of the geometry network and picture files from the simple geometry are shown here. These are shown for information only, as the user need not be concerned with the format of these files if they are used with the graphics programs mentioned in this document. The planform view of this geometry shown in figure 4 was created by selecting the option PIC= '1' in the input file.

GEOMETRY NETWORK FILE: SIMPLE.NET

```
NETWORK = WAKE     2  16
   3.00000     0.00000     0.00000
   3.26667     0.00000     0.00000
   3.05359     0.20000     0.00000
   3.30870     0.20000     0.00000
   3.10718     0.40000     0.00000
   3.35074     0.40000     0.00000
   3.16077     0.60000     0.00000
   3.39277     0.60000     0.00000
   3.21436     0.80000     0.00000
   3.43480     0.80000     0.00000
   3.26795     1.00000     0.00000
   3.47684     1.00000     0.00000
   3.32154     1.20000     0.00000
   3.51887     1.20000     0.00000
   3.37513     1.40000     0.00000
   3.56091     1.40000     0.00000
   3.42872     1.60000     0.00000
   3.60294     1.60000     0.00000
   3.48231     1.80000     0.00000
   3.64498     1.80000     0.00000
   3.53590     2.00000     0.00000
   3.68701     2.00000     0.00000
   3.58949     2.20000     0.00000
   3.72904     2.20000     0.00000
   3.64308     2.40000     0.00000
   3.77108     2.40000     0.00000
   3.69667     2.60000     0.00000
   3.81311     2.60000     0.00000
   3.75026     2.80000     0.00000
   3.85515     2.80000     0.00000
   3.80385     3.00000     0.00000
   3.89718     3.00000     0.00000
BOUNDARY CONDITION = 1 WAKE 1
NETWORK = WAKE     2  16
   3.26667     0.00000     0.00000
   3.53333     0.00000     0.00000
   3.30870     0.20000     0.00000
   3.56381     0.20000     0.00000
   3.35074     0.40000     0.00000
   3.59429     0.40000     0.00000
   3.39277     0.60000     0.00000
   3.62477     0.60000     0.00000
   3.43480     0.80000     0.00000
   3.65525     0.80000     0.00000
   3.47684     1.00000     0.00000
   3.68573     1.00000     0.00000
   3.51887     1.20000     0.00000
   3.71621     1.20000     0.00000
   3.56091     1.40000     0.00000
   3.74668     1.40000     0.00000
   3.60294     1.60000     0.00000
   3.77716     1.60000     0.00000
   3.64498     1.80000     0.00000
   3.80764     1.80000     0.00000
   3.68701     2.00000     0.00000
   3.83812     2.00000     0.00000
   3.72904     2.20000     0.00000
   3.86860     2.20000     0.00000
   3.77108     2.40000     0.00000
   3.89908     2.40000     0.00000
   3.81311     2.60000     0.00000
   3.92956     2.60000     0.00000
   3.85515     2.80000     0.00000
```

...more data lines follow...

GEOMETRY PICTURE FILE: SIMPLE.PIC

```
LANDSCAPE
VIEWPORT  1.0000E-02  9.9000E-01  1.0000E-02  7.0000E-01
SYMBOL 0
WINDOW -1.0609E+00  7.4609E+00 -3.0000E+00  3.0000E+00
FONT 6 25
SCMOVE 0.04 0.72
TEXT PLAN VIEW OF LINAIR NETWORKS
FONT 6 20
SCMOVE 0.07  0.69
TEXT File: simpleuse.net
DATA        2
   3.0000E+00   0.0000E+00
   3.2667E+00   0.0000E+00
DATA        2
   3.0536E+00   2.0000E-01
   3.3087E+00   2.0000E-01
DATA        2
   3.1072E+00   4.0000E-01
   3.3507E+00   4.0000E-01
DATA        2
   3.1608E+00   6.0000E-01
   3.3928E+00   6.0000E-01
DATA        2
   3.2144E+00   8.0000E-01
   3.4348E+00   8.0000E-01
DATA        2
   3.2680E+00   1.0000E+00
   3.4768E+00   1.0000E+00
DATA        2
   3.3215E+00   1.2000E+00
   3.5189E+00   1.2000E+00
DATA        2
   3.3751E+00   1.4000E+00
   3.5609E+00   1.4000E+00
DATA        2
   3.4287E+00   1.6000E+00
   3.6029E+00   1.6000E+00
DATA        2
   3.4823E+00   1.8000E+00
   3.6450E+00   1.8000E+00
DATA        2
   3.5359E+00   2.0000E+00
   3.6870E+00   2.0000E+00
DATA        2
   3.5895E+00   2.2000E+00
   3.7290E+00   2.2000E+00
DATA        2
   3.6431E+00   2.4000E+00
   3.7711E+00   2.4000E+00
DATA        2
   3.6967E+00   2.6000E+00
   3.8131E+00   2.6000E+00
DATA        2
   3.7503E+00   2.8000E+00
   3.8551E+00   2.8000E+00
DATA        2
   3.8038E+00   3.0000E+00
   3.8972E+00   3.0000E+00
DATA       16
   3.0000E+00   0.0000E+00
   3.0536E+00   2.0000E-01
   3.1072E+00   4.0000E-01
   3.1608E+00   6.0000E-01
   3.2144E+00   8.0000E-01
```

...more data lines follow...

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Main Listing File

The main listing file contains the calculated geometrical parameters and the final aerodynamic coefficients. The user will generally want to scan this file to verify the input geometry and check the validity of the final results. If some of the results are suspicious, the forces summary file can help identify possible individual bad panel forces.

There are several features to note about the main listing file:

- It consists of three sections (as dictated by the LST = 'IES' in the OPTION namelist): "Input Data," "Aerodynamic Results: Element and Total Forces per Point," and "Aerodynamic Results: Summary of Total Forces."

- The default values of ISYM (1) and RWAKE (1) were assigned, since they were not specified in the input namelist.

- Of the three surfaces in the input file, only the canard and wing are listed in the "Surface Design Parameters" section. This was made to be consistent with their treatment as elements-grouped-together (i.e., type 'D' and 'S' inputs) in the input file, where a number of elements are specified for a surface as one unit. The calculations for these types of inputs include all the surface geometry calculations before element corner points are determined, as opposed to type 'C' inputs, which skip all the surface-related equations, and thus are not included in the "Surface Design Parameters" section of the output.

- In the summary section, the parameter shown in column two is the angle or rate which varies in the FLOCDN namelist ("alpha" in this case). If more than one parameter is varied (not recommended), only the first one would be included in the summary listing.

- All longitudinal aerodynamic coefficients (C_L, C_D, C_{D_i}, C_M, L/D) are presented in wind axes with the exception of the normal (C_Z) and chord (C_X) force coefficients, which are presented in body axes, and all lateral/directional aerodynamic coefficients (C_{YAW}, C_{ROLL}, C_Y) are presented in body axes. These axis conventions are the same for all *LinAir* output files in which aerodynamic coefficients appear.

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**********************************************************************************************************

                             L I N A I R   ---   V A X / V M S   V E R S I O N   3 . 0

SIMPLE LINAIR INPUT FILE:  WING, CANARD, & HORIZONTAL TAIL

Input data file name is SIMPLE.lin
                                                                                    10-AUG-93  at  10:34:35
**********************************************************************************************************

                                                 I N P U T   D A T A

REFERENCE VALUES:
        Sref =      0.000       (X/Cbar)Xr =   0.250         Configuration number            0.
        Cref =      0.000             Xref =   0.000         Symmetry about X-Z plane        1       (1 = Sym., 0 = None)
        bref =      0.000             Yref =   0.000         Wake orientation                1.00    (1 = Body Axes, 0 = Freestream)
                                      Zref =   0.000
        (See reference values below)

ANGLES AND ROTATION RATES:     SEQUENCE #   ALPHA      BETA      PHAT      QHAT      RHAT
                                    1        0.00      0.00    0.0000    0.0000    0.0000
                                    2        5.00      0.00    0.0000    0.0000    0.0000
                                    3       10.00      0.00    0.0000    0.0000    0.0000

SURFACE DESIGN PARAMETERS (TYPE "D" & "S" INPUTS ONLY):

     ----------------------------------------------------------------------------------------------------
     Wing                                                                     3 elements, 15 panels/element
     Element Spacing:  Linear

            XrootLE    YrootLE    ZrootLE    SweepLE    SweepTE       Span      Croot       Ctip      Taper         AR       Area
             3.0000     0.0000     0.0000    15.0000     5.4050     3.0000     0.8000     0.2800     0.3500    11.1111     1.6200

          Root incd   Tip incd      Twist   Dihedral (X/C)TDref       Cavg       Cbar    etaCbar    XCbarLE (X/Cbar)Xr       Xref
             0.0000     0.0000     0.0000     0.0000     0.0000     0.5400     0.5817     0.4198     3.3374     0.2500     3.4828

            Reference dimensions not specified above:     Sref       Cref       bref
                                                        3.2400     0.5817     6.0000

            No camber for this surface
     ----------------------------------------------------------------------------------------------------
     Canard                                                                    1 element,  5 panels/element
     Element Spacing:  Linear

            XrootLE    YrootLE    ZrootLE    SweepLE    SweepTE       Span      Croot       Ctip      Taper         AR       Area
             0.0000     0.0000     0.0000    29.9849    21.3058     1.0000     0.2500     0.0630     0.2520    12.7796     0.1565

          Root incd   Tip incd      Twist   Dihedral (X/C)TDref       Cavg       Cbar    etaCbar    XCbarLE (X/Cbar)Xr       Xref
             0.0000     0.0000     0.0000     0.0000     0.0000     0.1565     0.1751     0.4004     0.2310    18.5690     3.4828
```


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No camber for this surface

ELEMENT GEOMETRY -- CORNER POINTS:

Element	Root Leading Edge X	Root Leading Edge Y	Root Leading Edge Z	Root Trailing Edge X	Root Trailing Edge Y	Root Trailing Edge Z	Tip Leading Edge X	Tip Leading Edge Y	Tip Leading Edge Z	Tip Trailing Edge X	Tip Trailing Edge Y	Tip Trailing Edge Z
Wing												
1	3.0000	0.0000	0.0000	3.2667	0.0000	0.0000	3.8038	3.0000	0.0000	3.8972	3.0000	0.0000
2	3.2667	0.0000	0.0000	3.5333	0.0000	0.0000	3.8972	3.0000	0.0000	3.9905	3.0000	0.0000
3	3.5333	0.0000	0.0000	3.8000	0.0000	0.0000	3.9905	3.0000	0.0000	4.0838	3.0000	0.0000
Canard												
4	0.0000	0.0000	0.0000	0.2500	0.0000	0.0000	0.5770	1.0000	0.0000	0.6400	1.0000	0.0000
Horizontal Tail												
5	6.0000	0.0000	0.0000	6.2000	0.0000	0.0000	6.0000	0.8000	0.0000	6.2000	0.8000	0.0000
6	6.2000	0.0000	0.0000	6.4000	0.0000	0.0000	6.2000	0.8000	0.0000	6.4000	0.8000	0.0000

ELEMENT GEOMETRY -- QUARTER CHORD PARAMETERS:

Element	Panels	Xroot	Yroot	Zroot	Span	Area	Taper	Sweep	Dihedral	Rooti	Tipi
Wing											
1	15	3.0667	0.0000	0.0000	3.0000	0.5400	0.3500	14.2251	0.0000	0.0000	0.0000
2	15	3.3333	0.0000	0.0000	3.0000	0.5400	0.3500	11.0743	0.0000	0.0000	0.0000
3	15	3.6000	0.0000	0.0000	3.0000	0.5400	0.3500	7.8543	0.0000	0.0000	0.0000
Canard											
4	5	0.0625	0.0000	0.0000	1.0000	0.1565	0.2520	27.9348	0.0000	0.0000	0.0000
Horizontal Tail											
5	4	6.0500	0.0000	0.0000	0.8000	0.1600	1.0000	0.0000	0.0000	0.0000	0.0000
6	4	6.2500	0.0000	0.0000	0.8000	0.1600	1.0000	0.0000	0.0000	0.0000	0.0000

Total number of elements = 6
Total number of panels = 58

ELEMENT GEOMETRY -- LEADING-EDGE SUCTION AND VISCOUS DRAG PARAMETERS:

Element	Suctn 0	Suctn 1	Suctn 2	Suctn 3	Cd0	Cd1	Cd2
Wing							
1	1.000E+00	0.000E+00	0.000E+00	0.000E+00	0.0000	0.0000	0.0000
2	1.000E+00	0.000E+00	0.000E+00	0.000E+00	0.0000	0.0000	0.0000
3	1.000E+00	0.000E+00	0.000E+00	0.000E+00	0.0000	0.0000	0.0000
Canard							
4	1.000E+00	0.000E+00	0.000E+00	0.000E+00	0.0000	0.0000	0.0000
Horizontal Tail							
5	1.000E+00	0.000E+00	0.000E+00	0.000E+00	0.0000	0.0000	0.0000
6	1.000E+00	0.000E+00	0.000E+00	0.000E+00	0.0000	0.0000	0.0000

```
******************************************************************************************************

                        L I N A I R  ---  V A X / V M S   V E R S I O N   3 . 0

SIMPLE LINAIR INPUT FILE:  WING, CANARD, & HORIZONTAL TAIL

Input data file name is SIMPLE.lin
                                                                              10-AUG-93  at  10:34:52
******************************************************************************************************

     A E R O D Y N A M I C   R E S U L T S :   E L E M E N T   A N D   T O T A L   F O R C E S   P E R   P O I N T

   RUN:SEQ     1.00: 1     MACH  =   0.40         PHAT =   0.0000
                           ALPHA =   0.00 Deg.    QHAT =   0.0000
                           BETA  =   0.00 Deg.    RHAT =   0.0000
```

	CL	CDI	CD	L/D	e	CM	CYAW	CROLL	CY	CZ	CX	SUCTN
Wing												
Element 1	0.00000	0.00000	0.00000			0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.000
Element 2	0.00000	0.00000	0.00000			0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.000
Element 3	0.00000	0.00000	0.00000			0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.000
Subtotal	0.00000	0.00000	0.00000			0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	
Canard												
Element 4	0.00000	0.00000	0.00000			0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.000
Subtotal	0.00000	0.00000	0.00000			0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	
Horizontal Tail												
Element 5	0.00000	0.00000	0.00000			0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.000
Element 6	0.00000	0.00000	0.00000			0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.000
Subtotal	0.00000	0.00000	0.00000			0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	
TOTALS FOR ALL ELEMENTS	0.00000	0.00000	0.00000	0.000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	

```
******************************************************************************************************

                         L I N A I R  ---  V A X / V M S  V E R S I O N  3 . 0

SIMPLE LINAIR INPUT FILE:  WING, CANARD, & HORIZONTAL TAIL

Input data file name is SIMPLE.lin
                                                                              10-AUG-93  at  10:35:07
******************************************************************************************************

     A E R O D Y N A M I C   R E S U L T S :   E L E M E N T   A N D   T O T A L   F O R C E S   P E R   P O I N T

    RUN:SEQ     1.00: 2     MACH  =   0.40        PHAT =   0.0000
                            ALPHA =   5.00 Deg.   QHAT =   0.0000
                            BETA  =   0.00 Deg.   RHAT =   0.0000
```

	CL	CDI	CD	CM	CYAW	CROLL	CY	CZ	CX	SUCTN
Wing										
Element 1	0.28877	-0.00570	-0.00570	0.03359	0.00000	0.00000	0.00000	0.28718	-0.03085	1.000
Element 2	0.11438	0.00797	0.00797	-0.02212	0.00000	0.00000	0.00000	0.11464	-0.00203	1.000
Element 3	0.05693	0.00436	0.00436	-0.02924	0.00000	0.00000	0.00000	0.05710	-0.00062	1.000
Subtotal	0.46009	0.00662	0.00662	-0.01778	0.00000	0.00000	0.00000	0.45891	-0.03350	
Canard										
Element 4	0.04514	0.00038	0.00038	0.24685	0.00000	0.00000	0.00000	0.04500	-0.00356	1.000
Subtotal	0.04514	0.00038	0.00038	0.24685	0.00000	0.00000	0.00000	0.04500	-0.00356	
Horizontal Tail										
Element 5	0.03162	0.00138	0.00138	-0.13953	0.00000	0.00000	0.00000	0.03162	-0.00138	1.000
Element 6	0.00919	0.00073	0.00073	-0.04388	0.00000	0.00000	0.00000	0.00922	-0.00007	1.000
Subtotal	0.04081	0.00211	0.00211	-0.18341	0.00000	0.00000	0.00000	0.04084	-0.00145	

TOTALS FOR ALL ELEMENTS

CL	CDI	CD	L/D	e	CM	CYAW	CROLL	CY	CZ	CX
0.54604	0.00911	0.00911	0.000	0.93731	0.04567	0.00000	0.00000	0.00000	0.54476	-0.03851

```
**********************************************************************************************************

                         L I N A I R   ---   V A X / V M S   V E R S I O N   3 . 0

SIMPLE LINAIR INPUT FILE:  WING, CANARD, & HORIZONTAL TAIL

Input data file name is SIMPLE.lin
                                                                                    10-AUG-93  at  10:35:26
**********************************************************************************************************

     A E R O D Y N A M I C   R E S U L T S :   E L E M E N T   A N D   T O T A L   F O R C E S   P E R   P O I N T

    RUN:SEQ     1.00: 3     MACH  =   0.40        PHAT =   0.0000
                            ALPHA =  10.00 Deg.   QHAT =   0.0000
                            BETA  =   0.00 Deg.   RHAT =   0.0000

                    CL        CDI        CD                       CM      CYAW     CROLL       CY        CZ        CX    SUCTN

Wing
    Element  1   0.57830  -0.02238  -0.02238                  0.06615   0.00000   0.00000   0.00000   0.56563  -0.12246  1.000
    Element  2   0.22377   0.03126   0.03126                 -0.04357   0.00000   0.00000   0.00000   0.22580  -0.00807  1.000
    Element  3   0.11118   0.01711   0.01711                 -0.05760   0.00000   0.00000   0.00000   0.11246  -0.00245  1.000
      Subtotal   0.91324   0.02599   0.02599                 -0.03502   0.00000   0.00000   0.00000   0.90388  -0.13299

Canard
    Element  4   0.08974   0.00148   0.00148                  0.48620   0.00000   0.00000   0.00000   0.08863  -0.01412  1.000
      Subtotal   0.08974   0.00148   0.00148                  0.48620   0.00000   0.00000   0.00000   0.08863  -0.01412

Horizontal Tail
    Element  5   0.06228   0.00541   0.00541                 -0.27482   0.00000   0.00000   0.00000   0.06228  -0.00548  1.000
    Element  6   0.01794   0.00287   0.00287                 -0.08642   0.00000   0.00000   0.00000   0.01817  -0.00029  1.000
      Subtotal   0.08022   0.00829   0.00829                 -0.36124   0.00000   0.00000   0.00000   0.08044  -0.00577

TOTALS FOR ALL ELEMENTS
                    CL        CDI        CD       L/D      e        CM      CYAW     CROLL       CY        CZ        CX

                 1.08320   0.03576   0.03576    0.000   0.93995   0.08995   0.00000   0.00000   0.00000   1.07296  -0.15288
```

```
*****************************************************************************************************************

                              L I N A I R   ---   V A X / V M S   V E R S I O N   3 . 0

SIMPLE LINAIR INPUT FILE:  WING, CANARD, & HORIZONTAL TAIL

Input data file name is SIMPLE.lin
                                                                                          10-AUG-93  at  10:35:42
*****************************************************************************************************************

                  A E R O D Y N A M I C   R E S U L T S :   S U M M A R Y   O F   T O T A L   F O R C E S

   RUN      1.00             MACH  =   0.40         PHAT =   0.0000
                             ALPHA =   VARY         QHAT =   0.0000
                             BETA  =   0.00 Deg.    RHAT =   0.0000
```

SEQ	ALPHA	CL	CDI	CD	L/D	e	CM	CYAW	CROLL	CY	CZ	CX
1	0.000	0.00000	0.00000	0.00000	0.000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
2	5.000	0.54604	0.00911	0.00911	0.000	0.93731	0.04567	0.00000	0.00000	0.00000	0.54476	-0.03851
3	10.000	1.08320	0.03576	0.03576	0.000	0.93995	0.08995	0.00000	0.00000	0.00000	1.07296	-0.15288

Database Load File

The file is shown in the proper format for loading into a CDD. No changes need to be made by the user before loading.

```
23    0    0    0    1    0
    RUN:SEQ
   1.00:   1.00
0.00000E+00  4.00000E-01  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 4.00000E-01  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  6.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  1.00000E+00
 1.00000E+00  3.48285E+00  2.50000E-01
    RUN:SEQ
   1.00:   2.00
0.00000E+00  4.00000E-01  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 4.00000E-01  5.00000E+00  0.00000E+00  5.46039E-01  2.98159E-01  9.11286E-03  9.11286E-03  0.00000E+00  9.37314E-01  4.56687E-02
 0.00000E+00  0.00000E+00  0.00000E+00  5.44755E-01 -3.85122E-02  6.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  1.00000E+00
 1.00000E+00  3.48285E+00  2.50000E-01
    RUN:SEQ
   1.00:   3.00
0.00000E+00  4.00000E-01  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 4.00000E-01  1.00000E+01  0.00000E+00  1.08320E+00  1.17333E+00  3.57610E-02  3.57610E-02  0.00000E+00  9.39948E-01  8.99497E-02
 0.00000E+00  0.00000E+00  0.00000E+00  1.07296E+00 -1.52879E-01  6.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  1.00000E+00
 1.00000E+00  3.48285E+00  2.50000E-01
```


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Forces Summary File

Basic panel information is presented in this file in a straightforward manner to allow the user to quickly survey or plot the detailed *LinAir* results. Some features to note about this file, though not necessarily shown in this example, are:

- The [X, Y, Z]BVC coordinates are of the bound vortex center, which is 1/4-chord back from the leading edge of the panel mid-way between the panel sides. The area, span, and chord are true dimensions, measured in the plane of the panel.

- The panel forces are zero'd out for vertical panels in the plane of symmetry when the flow conditions are symmetric ($\beta = \hat{p} = \hat{r} = 0$).

- The signs of the panel forces are reversed depending on the signs of the unit normals, as explained in the main text of this document. A letter "R" just to the right of the "CNP" value indicates that the sign has been reversed.

- The panel normal and axial forces (CNP and CAP) act in the true normal direction to the panel, and should not be confused with body axis forces. The panel lift and drag (CLP and CDP) are in wind axes.

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LINAIR PANEL FORCES SUMMARY

SIMPLE LINAIR INPUT FILE: WING, CANARD, & HORIZONTAL TAIL

Run	Configuration	Total Elements	Total Panels
1.00	0.	6	58

Vertical/horizontal dihedral boundary = 45.00 deg.
(applies to asymmetric flow condition cases only)

Sequence 1

MACH =	0.40	PHAT =	0.0000
ALPHA =	0.00 Deg.	QHAT =	0.0000
BETA =	0.00 Deg.	RHAT =	0.0000

Element	Panel	XBVC	YBVC	ZBVC	CNP *	CAP	CLP	CDP	True Area	True Chord	Incd.	Dihed.	Nx	Ny	Nz
Wing															
1	1	3.092	0.100	0.000	0.0000	0.0000	0.0000	0.0000	0.052	0.261	0.000	0.000	0.00	0.00	1.00
1	2	3.143	0.300	0.000	0.0000	0.0000	0.0000	0.0000	0.050	0.249	0.000	0.000	0.00	0.00	1.00
1	3	3.193	0.500	0.000	0.0000	0.0000	0.0000	0.0000	0.048	0.238	0.000	0.000	0.00	0.00	1.00
1	4	3.244	0.700	0.000	0.0000	0.0000	0.0000	0.0000	0.045	0.226	0.000	0.000	0.00	0.00	1.00
1	5	3.295	0.900	0.000	0.0000	0.0000	0.0000	0.0000	0.043	0.215	0.000	0.000	0.00	0.00	1.00
1	6	3.346	1.100	0.000	0.0000	0.0000	0.0000	0.0000	0.041	0.203	0.000	0.000	0.00	0.00	1.00
1	7	3.396	1.300	0.000	0.0000	0.0000	0.0000	0.0000	0.038	0.192	0.000	0.000	0.00	0.00	1.00
1	8	3.447	1.500	0.000	0.0000	0.0000	0.0000	0.0000	0.036	0.180	0.000	0.000	0.00	0.00	1.00
1	9	3.498	1.700	0.000	0.0000	0.0000	0.0000	0.0000	0.034	0.168	0.000	0.000	0.00	0.00	1.00
1	10	3.548	1.900	0.000	0.0000	0.0000	0.0000	0.0000	0.031	0.157	0.000	0.000	0.00	0.00	1.00
1	11	3.599	2.100	0.000	0.0000	0.0000	0.0000	0.0000	0.029	0.145	0.000	0.000	0.00	0.00	1.00
1	12	3.650	2.300	0.000	0.0000	0.0000	0.0000	0.0000	0.027	0.134	0.000	0.000	0.00	0.00	1.00
1	13	3.700	2.500	0.000	0.0000	0.0000	0.0000	0.0000	0.024	0.122	0.000	0.000	0.00	0.00	1.00
1	14	3.751	2.700	0.000	0.0000	0.0000	0.0000	0.0000	0.022	0.111	0.000	0.000	0.00	0.00	1.00
1	15	3.802	2.900	0.000	0.0000	0.0000	0.0000	0.0000	0.020	0.099	0.000	0.000	0.00	0.00	1.00
2	1	3.353	0.100	0.000	0.0000	0.0000	0.0000	0.0000	0.052	0.261	0.000	0.000	0.00	0.00	1.00
2	2	3.392	0.300	0.000	0.0000	0.0000	0.0000	0.0000	0.050	0.249	0.000	0.000	0.00	0.00	1.00
2	3	3.431	0.500	0.000	0.0000	0.0000	0.0000	0.0000	0.048	0.238	0.000	0.000	0.00	0.00	1.00
2	4	3.470	0.700	0.000	0.0000	0.0000	0.0000	0.0000	0.045	0.226	0.000	0.000	0.00	0.00	1.00
2	5	3.509	0.900	0.000	0.0000	0.0000	0.0000	0.0000	0.043	0.215	0.000	0.000	0.00	0.00	1.00
2	6	3.549	1.100	0.000	0.0000	0.0000	0.0000	0.0000	0.041	0.203	0.000	0.000	0.00	0.00	1.00
2	7	3.588	1.300	0.000	0.0000	0.0000	0.0000	0.0000	0.038	0.192	0.000	0.000	0.00	0.00	1.00
2	8	3.627	1.500	0.000	0.0000	0.0000	0.0000	0.0000	0.036	0.180	0.000	0.000	0.00	0.00	1.00
2	9	3.666	1.700	0.000	0.0000	0.0000	0.0000	0.0000	0.034	0.168	0.000	0.000	0.00	0.00	1.00
2	10	3.705	1.900	0.000	0.0000	0.0000	0.0000	0.0000	0.031	0.157	0.000	0.000	0.00	0.00	1.00
2	11	3.744	2.100	0.000	0.0000	0.0000	0.0000	0.0000	0.029	0.145	0.000	0.000	0.00	0.00	1.00
2	12	3.784	2.300	0.000	0.0000	0.0000	0.0000	0.0000	0.027	0.134	0.000	0.000	0.00	0.00	1.00
2	13	3.823	2.500	0.000	0.0000	0.0000	0.0000	0.0000	0.024	0.122	0.000	0.000	0.00	0.00	1.00
2	14	3.862	2.700	0.000	0.0000	0.0000	0.0000	0.0000	0.022	0.111	0.000	0.000	0.00	0.00	1.00
2	15	3.901	2.900	0.000	0.0000	0.0000	0.0000	0.0000	0.020	0.099	0.000	0.000	0.00	0.00	1.00
3	1	3.614	0.100	0.000	0.0000	0.0000	0.0000	0.0000	0.052	0.261	0.000	0.000	0.00	0.00	1.00
3	2	3.641	0.300	0.000	0.0000	0.0000	0.0000	0.0000	0.050	0.249	0.000	0.000	0.00	0.00	1.00

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3 3	3.669	0.500	0.000	0.0000	0.0000	0.0000	0.0000	0.048	0.238	0.000	0.000	0.00	0.00	1.00
3 4	3.697	0.700	0.000	0.0000	0.0000	0.0000	0.0000	0.045	0.226	0.000	0.000	0.00	0.00	1.00
3 5	3.724	0.900	0.000	0.0000	0.0000	0.0000	0.0000	0.043	0.215	0.000	0.000	0.00	0.00	1.00
3 6	3.752	1.100	0.000	0.0000	0.0000	0.0000	0.0000	0.041	0.203	0.000	0.000	0.00	0.00	1.00
3 7	3.779	1.300	0.000	0.0000	0.0000	0.0000	0.0000	0.038	0.192	0.000	0.000	0.00	0.00	1.00
3 8	3.807	1.500	0.000	0.0000	0.0000	0.0000	0.0000	0.036	0.180	0.000	0.000	0.00	0.00	1.00
3 9	3.835	1.700	0.000	0.0000	0.0000	0.0000	0.0000	0.034	0.168	0.000	0.000	0.00	0.00	1.00
3 10	3.862	1.900	0.000	0.0000	0.0000	0.0000	0.0000	0.031	0.157	0.000	0.000	0.00	0.00	1.00
3 11	3.890	2.100	0.000	0.0000	0.0000	0.0000	0.0000	0.029	0.145	0.000	0.000	0.00	0.00	1.00
3 12	3.917	2.300	0.000	0.0000	0.0000	0.0000	0.0000	0.027	0.134	0.000	0.000	0.00	0.00	1.00
3 13	3.945	2.500	0.000	0.0000	0.0000	0.0000	0.0000	0.024	0.122	0.000	0.000	0.00	0.00	1.00
3 14	3.972	2.700	0.000	0.0000	0.0000	0.0000	0.0000	0.022	0.111	0.000	0.000	0.00	0.00	1.00
3 15	4.000	2.900	0.000	0.0000	0.0000	0.0000	0.0000	0.020	0.099	0.000	0.000	0.00	0.00	1.00
Canard														
4 1	0.116	0.100	0.000	0.0000	0.0000	0.0000	0.0000	0.046	0.231	0.000	0.000	0.00	0.00	1.00
4 2	0.222	0.300	0.000	0.0000	0.0000	0.0000	0.0000	0.039	0.194	0.000	0.000	0.00	0.00	1.00
4 3	0.328	0.500	0.000	0.0000	0.0000	0.0000	0.0000	0.031	0.157	0.000	0.000	0.00	0.00	1.00
4 4	0.434	0.700	0.000	0.0000	0.0000	0.0000	0.0000	0.024	0.119	0.000	0.000	0.00	0.00	1.00
4 5	0.540	0.900	0.000	0.0000	0.0000	0.0000	0.0000	0.016	0.082	0.000	0.000	0.00	0.00	1.00
Horizontal Tail														
5 1	6.050	0.100	0.000	0.0000	0.0000	0.0000	0.0000	0.040	0.200	0.000	0.000	0.00	0.00	1.00
5 2	6.050	0.300	0.000	0.0000	0.0000	0.0000	0.0000	0.040	0.200	0.000	0.000	0.00	0.00	1.00
5 3	6.050	0.500	0.000	0.0000	0.0000	0.0000	0.0000	0.040	0.200	0.000	0.000	0.00	0.00	1.00
5 4	6.050	0.700	0.000	0.0000	0.0000	0.0000	0.0000	0.040	0.200	0.000	0.000	0.00	0.00	1.00
6 1	6.250	0.100	0.000	0.0000	0.0000	0.0000	0.0000	0.040	0.200	0.000	0.000	0.00	0.00	1.00
6 2	6.250	0.300	0.000	0.0000	0.0000	0.0000	0.0000	0.040	0.200	0.000	0.000	0.00	0.00	1.00
6 3	6.250	0.500	0.000	0.0000	0.0000	0.0000	0.0000	0.040	0.200	0.000	0.000	0.00	0.00	1.00
6 4	6.250	0.700	0.000	0.0000	0.0000	0.0000	0.0000	0.040	0.200	0.000	0.000	0.00	0.00	1.00

* "R" after CNP indicates sign of CNP has been reversed due to negative Ny or Nz for data presentation purposes

---

Sequence 2 MACH = 0.40 PHAT = 0.0000
ALPHA = 5.00 Deg. QHAT = 0.0000
BETA = 0.00 Deg. RHAT = 0.0000

Element								----- True	-----					
Panel	XBVC	YBVC	ZBVC	CNP *	CAP	CLP	CDP	Area	Chord	Incd.	Dihed.	Nx	Ny	Nz
Wing														
1 1	3.092	0.100	0.000	0.6052	-0.0348	0.6060	0.0181	0.052	0.261	0.000	0.000	0.00	0.00	1.00
1 2	3.143	0.300	0.000	0.6539	-0.0493	0.6557	0.0079	0.050	0.249	0.000	0.000	0.00	0.00	1.00
1 3	3.193	0.500	0.000	0.7059	-0.0586	0.7083	0.0032	0.048	0.238	0.000	0.000	0.00	0.00	1.00
1 4	3.244	0.700	0.000	0.7597	-0.0680	0.7628	-0.0015	0.045	0.226	0.000	0.000	0.00	0.00	1.00
1 5	3.295	0.900	0.000	0.8188	-0.0755	0.8223	-0.0038	0.043	0.215	0.000	0.000	0.00	0.00	1.00
1 6	3.346	1.100	0.000	1.0016	-0.1300	1.0091	-0.0422	0.041	0.203	0.000	0.000	0.00	0.00	1.00
1 7	3.396	1.300	0.000	0.9969	-0.1227	1.0038	-0.0353	0.038	0.192	0.000	0.000	0.00	0.00	1.00
1 8	3.447	1.500	0.000	0.9999	-0.1223	1.0068	-0.0347	0.036	0.180	0.000	0.000	0.00	0.00	1.00
1 9	3.498	1.700	0.000	1.0048	-0.1232	1.0117	-0.0351	0.034	0.168	0.000	0.000	0.00	0.00	1.00
1 10	3.548	1.900	0.000	1.0090	-0.1241	1.0160	-0.0356	0.031	0.157	0.000	0.000	0.00	0.00	1.00
1 11	3.599	2.100	0.000	1.0105	-0.1246	1.0175	-0.0360	0.029	0.145	0.000	0.000	0.00	0.00	1.00

1	12	3.650	2.300	0.000	1.0064	-0.1239	1.0133	-0.0358	0.027	0.134	0.000	0.000	0.00	0.00	1.00
1	13	3.700	2.500	0.000	0.9903	-0.1209	0.9970	-0.0341	0.024	0.122	0.000	0.000	0.00	0.00	1.00
1	14	3.751	2.700	0.000	0.9460	-0.1126	0.9522	-0.0297	0.022	0.111	0.000	0.000	0.00	0.00	1.00
1	15	3.802	2.900	0.000	0.8127	-0.0903	0.8175	-0.0192	0.020	0.099	0.000	0.000	0.00	0.00	1.00
2	1	3.353	0.100	0.000	0.2716	-0.0022	0.2707	0.0214	0.052	0.261	0.000	0.000	0.00	0.00	1.00
2	2	3.392	0.300	0.000	0.2784	-0.0035	0.2776	0.0208	0.050	0.249	0.000	0.000	0.00	0.00	1.00
2	3	3.431	0.500	0.000	0.2934	-0.0041	0.2927	0.0215	0.048	0.238	0.000	0.000	0.00	0.00	1.00
2	4	3.470	0.700	0.000	0.3141	-0.0047	0.3133	0.0227	0.045	0.226	0.000	0.000	0.00	0.00	1.00
2	5	3.509	0.900	0.000	0.3417	-0.0057	0.3409	0.0241	0.043	0.215	0.000	0.000	0.00	0.00	1.00
2	6	3.549	1.100	0.000	0.3730	-0.0074	0.3723	0.0251	0.041	0.203	0.000	0.000	0.00	0.00	1.00
2	7	3.588	1.300	0.000	0.3868	-0.0079	0.3860	0.0259	0.038	0.192	0.000	0.000	0.00	0.00	1.00
2	8	3.627	1.500	0.000	0.3933	-0.0081	0.3925	0.0262	0.036	0.180	0.000	0.000	0.00	0.00	1.00
2	9	3.666	1.700	0.000	0.3970	-0.0082	0.3962	0.0265	0.034	0.168	0.000	0.000	0.00	0.00	1.00
2	10	3.705	1.900	0.000	0.3991	-0.0083	0.3983	0.0266	0.031	0.157	0.000	0.000	0.00	0.00	1.00
2	11	3.744	2.100	0.000	0.3990	-0.0083	0.3982	0.0265	0.029	0.145	0.000	0.000	0.00	0.00	1.00
2	12	3.784	2.300	0.000	0.3953	-0.0082	0.3945	0.0262	0.027	0.134	0.000	0.000	0.00	0.00	1.00
2	13	3.823	2.500	0.000	0.3843	-0.0080	0.3835	0.0255	0.024	0.122	0.000	0.000	0.00	0.00	1.00
2	14	3.862	2.700	0.000	0.3553	-0.0073	0.3546	0.0237	0.022	0.111	0.000	0.000	0.00	0.00	1.00
2	15	3.901	2.900	0.000	0.2708	-0.0053	0.2702	0.0184	0.020	0.099	0.000	0.000	0.00	0.00	1.00
3	1	3.614	0.100	0.000	0.1453	-0.0010	0.1448	0.0116	0.052	0.261	0.000	0.000	0.00	0.00	1.00
3	2	3.641	0.300	0.000	0.1459	-0.0013	0.1454	0.0115	0.050	0.249	0.000	0.000	0.00	0.00	1.00
3	3	3.669	0.500	0.000	0.1512	-0.0014	0.1508	0.0118	0.048	0.238	0.000	0.000	0.00	0.00	1.00
3	4	3.697	0.700	0.000	0.1601	-0.0016	0.1596	0.0124	0.045	0.226	0.000	0.000	0.00	0.00	1.00
3	5	3.724	0.900	0.000	0.1711	-0.0018	0.1706	0.0131	0.043	0.215	0.000	0.000	0.00	0.00	1.00
3	6	3.752	1.100	0.000	0.1818	-0.0021	0.1813	0.0138	0.041	0.203	0.000	0.000	0.00	0.00	1.00
3	7	3.779	1.300	0.000	0.1892	-0.0023	0.1886	0.0142	0.038	0.192	0.000	0.000	0.00	0.00	1.00
3	8	3.807	1.500	0.000	0.1934	-0.0024	0.1929	0.0145	0.036	0.180	0.000	0.000	0.00	0.00	1.00
3	9	3.835	1.700	0.000	0.1959	-0.0024	0.1953	0.0147	0.034	0.168	0.000	0.000	0.00	0.00	1.00
3	10	3.862	1.900	0.000	0.1969	-0.0025	0.1964	0.0147	0.031	0.157	0.000	0.000	0.00	0.00	1.00
3	11	3.890	2.100	0.000	0.1965	-0.0025	0.1960	0.0147	0.029	0.145	0.000	0.000	0.00	0.00	1.00
3	12	3.917	2.300	0.000	0.1936	-0.0024	0.1931	0.0145	0.027	0.134	0.000	0.000	0.00	0.00	1.00
3	13	3.945	2.500	0.000	0.1860	-0.0023	0.1855	0.0140	0.024	0.122	0.000	0.000	0.00	0.00	1.00
3	14	3.972	2.700	0.000	0.1670	-0.0019	0.1665	0.0127	0.022	0.111	0.000	0.000	0.00	0.00	1.00
3	15	4.000	2.900	0.000	0.1184	-0.0011	0.1180	0.0092	0.020	0.099	0.000	0.000	0.00	0.00	1.00
Canard															
4	1	0.116	0.100	0.000	0.4010	-0.0231	0.4015	0.0119	0.046	0.231	0.000	0.000	0.00	0.00	1.00
4	2	0.222	0.300	0.000	0.4543	-0.0358	0.4557	0.0039	0.039	0.194	0.000	0.000	0.00	0.00	1.00
4	3	0.328	0.500	0.000	0.4938	-0.0425	0.4956	0.0007	0.031	0.157	0.000	0.000	0.00	0.00	1.00
4	4	0.434	0.700	0.000	0.5245	-0.0479	0.5266	-0.0020	0.024	0.119	0.000	0.000	0.00	0.00	1.00
4	5	0.540	0.900	0.000	0.5377	-0.0510	0.5401	-0.0040	0.016	0.082	0.000	0.000	0.00	0.00	1.00
Horizontal Tail															
5	1	6.050	0.100	0.000	0.3597	-0.0165	0.3598	0.0149	0.040	0.200	0.000	0.000	0.00	0.00	1.00
5	2	6.050	0.300	0.000	0.3467	-0.0155	0.3468	0.0148	0.040	0.200	0.000	0.000	0.00	0.00	1.00
5	3	6.050	0.500	0.000	0.3197	-0.0138	0.3197	0.0141	0.040	0.200	0.000	0.000	0.00	0.00	1.00
5	4	6.050	0.700	0.000	0.2544	-0.0101	0.2543	0.0121	0.040	0.200	0.000	0.000	0.00	0.00	1.00
6	1	6.250	0.100	0.000	0.1121	-0.0010	0.1117	0.0088	0.040	0.200	0.000	0.000	0.00	0.00	1.00
6	2	6.250	0.300	0.000	0.1062	-0.0009	0.1059	0.0084	0.040	0.200	0.000	0.000	0.00	0.00	1.00
6	3	6.250	0.500	0.000	0.0923	-0.0007	0.0920	0.0073	0.040	0.200	0.000	0.000	0.00	0.00	1.00
6	4	6.250	0.700	0.000	0.0630	-0.0003	0.0628	0.0051	0.040	0.200	0.000	0.000	0.00	0.00	1.00

* "R" after CNP indicates sign of CNP has been reversed due to negative Ny or Nz for data presentation purposes

Sequence 3 MACH = 0.40 PHAT = 0.0000
ALPHA = 10.00 Deg. QHAT = 0.0000
BETA = 0.00 Deg. RHAT = 0.0000

Element	Panel	XBVC	YBVC	ZBVC	CNP *	CAP	CLP	CDP	True Area	True Chord	Incd.	Dihed.	Nx	Ny	Nz
Wing															
1	1	3.092	0.100	0.000	1.1921	-0.1381	1.1979	0.0710	0.052	0.261	0.000	0.000	0.00	0.00	1.00
1	2	3.143	0.300	0.000	1.2880	-0.1957	1.3024	0.0309	0.050	0.249	0.000	0.000	0.00	0.00	1.00
1	3	3.193	0.500	0.000	1.3903	-0.2326	1.4096	0.0124	0.048	0.238	0.000	0.000	0.00	0.00	1.00
1	4	3.244	0.700	0.000	1.4964	-0.2699	1.5205	-0.0060	0.045	0.226	0.000	0.000	0.00	0.00	1.00
1	5	3.295	0.900	0.000	1.6127	-0.2995	1.6402	-0.0149	0.043	0.215	0.000	0.000	0.00	0.00	1.00
1	6	3.346	1.100	0.000	1.9727	-0.5161	2.0324	-0.1657	0.041	0.203	0.000	0.000	0.00	0.00	1.00
1	7	3.396	1.300	0.000	1.9635	-0.4871	2.0183	-0.1387	0.038	0.192	0.000	0.000	0.00	0.00	1.00
1	8	3.447	1.500	0.000	1.9694	-0.4855	2.0238	-0.1362	0.036	0.180	0.000	0.000	0.00	0.00	1.00
1	9	3.498	1.700	0.000	1.9791	-0.4889	2.0340	-0.1378	0.034	0.168	0.000	0.000	0.00	0.00	1.00
1	10	3.548	1.900	0.000	1.9874	-0.4925	2.0428	-0.1399	0.031	0.157	0.000	0.000	0.00	0.00	1.00
1	11	3.599	2.100	0.000	1.9904	-0.4945	2.0460	-0.1414	0.029	0.145	0.000	0.000	0.00	0.00	1.00
1	12	3.650	2.300	0.000	1.9822	-0.4920	2.0375	-0.1403	0.027	0.134	0.000	0.000	0.00	0.00	1.00
1	13	3.700	2.500	0.000	1.9505	-0.4799	2.0042	-0.1339	0.024	0.122	0.000	0.000	0.00	0.00	1.00
1	14	3.751	2.700	0.000	1.8633	-0.4470	1.9126	-0.1167	0.022	0.111	0.000	0.000	0.00	0.00	1.00
1	15	3.802	2.900	0.000	1.6007	-0.3586	1.6387	-0.0752	0.020	0.099	0.000	0.000	0.00	0.00	1.00
2	1	3.353	0.100	0.000	0.5349	-0.0089	0.5283	0.0841	0.052	0.261	0.000	0.000	0.00	0.00	1.00
2	2	3.392	0.300	0.000	0.5483	-0.0139	0.5424	0.0815	0.050	0.249	0.000	0.000	0.00	0.00	1.00
2	3	3.431	0.500	0.000	0.5780	-0.0161	0.5720	0.0845	0.048	0.238	0.000	0.000	0.00	0.00	1.00
2	4	3.470	0.700	0.000	0.6186	-0.0186	0.6124	0.0891	0.045	0.226	0.000	0.000	0.00	0.00	1.00
2	5	3.509	0.900	0.000	0.6731	-0.0227	0.6668	0.0946	0.043	0.215	0.000	0.000	0.00	0.00	1.00
2	6	3.549	1.100	0.000	0.7348	-0.0294	0.7287	0.0987	0.041	0.203	0.000	0.000	0.00	0.00	1.00
2	7	3.588	1.300	0.000	0.7618	-0.0313	0.7556	0.1015	0.038	0.192	0.000	0.000	0.00	0.00	1.00
2	8	3.627	1.500	0.000	0.7746	-0.0320	0.7683	0.1030	0.036	0.180	0.000	0.000	0.00	0.00	1.00
2	9	3.666	1.700	0.000	0.7820	-0.0324	0.7757	0.1039	0.034	0.168	0.000	0.000	0.00	0.00	1.00
2	10	3.705	1.900	0.000	0.7860	-0.0328	0.7798	0.1042	0.031	0.157	0.000	0.000	0.00	0.00	1.00
2	11	3.744	2.100	0.000	0.7859	-0.0329	0.7797	0.1041	0.029	0.145	0.000	0.000	0.00	0.00	1.00
2	12	3.784	2.300	0.000	0.7786	-0.0327	0.7724	0.1030	0.027	0.134	0.000	0.000	0.00	0.00	1.00
2	13	3.823	2.500	0.000	0.7569	-0.0318	0.7509	0.1001	0.024	0.122	0.000	0.000	0.00	0.00	1.00
2	14	3.862	2.700	0.000	0.6999	-0.0291	0.6943	0.0929	0.022	0.111	0.000	0.000	0.00	0.00	1.00
2	15	3.901	2.900	0.000	0.5334	-0.0209	0.5289	0.0720	0.020	0.099	0.000	0.000	0.00	0.00	1.00
3	1	3.614	0.100	0.000	0.2862	-0.0041	0.2825	0.0457	0.052	0.261	0.000	0.000	0.00	0.00	1.00
3	2	3.641	0.300	0.000	0.2873	-0.0050	0.2838	0.0450	0.050	0.249	0.000	0.000	0.00	0.00	1.00
3	3	3.669	0.500	0.000	0.2979	-0.0055	0.2943	0.0464	0.048	0.238	0.000	0.000	0.00	0.00	1.00
3	4	3.697	0.700	0.000	0.3154	-0.0062	0.3116	0.0487	0.045	0.226	0.000	0.000	0.00	0.00	1.00
3	5	3.724	0.900	0.000	0.3370	-0.0072	0.3332	0.0514	0.043	0.215	0.000	0.000	0.00	0.00	1.00
3	6	3.752	1.100	0.000	0.3581	-0.0083	0.3541	0.0540	0.041	0.203	0.000	0.000	0.00	0.00	1.00
3	7	3.779	1.300	0.000	0.3726	-0.0090	0.3685	0.0558	0.038	0.192	0.000	0.000	0.00	0.00	1.00
3	8	3.807	1.500	0.000	0.3810	-0.0094	0.3769	0.0569	0.036	0.180	0.000	0.000	0.00	0.00	1.00
3	9	3.835	1.700	0.000	0.3858	-0.0097	0.3816	0.0575	0.034	0.168	0.000	0.000	0.00	0.00	1.00
3	10	3.862	1.900	0.000	0.3879	-0.0098	0.3837	0.0577	0.031	0.157	0.000	0.000	0.00	0.00	1.00
3	11	3.890	2.100	0.000	0.3870	-0.0097	0.3828	0.0576	0.029	0.145	0.000	0.000	0.00	0.00	1.00

3	12	3.917	2.300	0.000	0.3814	-0.0095	0.3773	0.0568	0.027	0.134	0.000	0.000	0.00	0.00	1.00
3	13	3.945	2.500	0.000	0.3663	-0.0090	0.3623	0.0548	0.024	0.122	0.000	0.000	0.00	0.00	1.00
3	14	3.972	2.700	0.000	0.3289	-0.0076	0.3253	0.0497	0.022	0.111	0.000	0.000	0.00	0.00	1.00
3	15	4.000	2.900	0.000	0.2331	-0.0043	0.2303	0.0362	0.020	0.099	0.000	0.000	0.00	0.00	1.00
Canard															
4	1	0.116	0.100	0.000	0.7899	-0.0917	0.7938	0.0468	0.046	0.231	0.000	0.000	0.00	0.00	1.00
4	2	0.222	0.300	0.000	0.8947	-0.1423	0.9059	0.0153	0.039	0.194	0.000	0.000	0.00	0.00	1.00
4	3	0.328	0.500	0.000	0.9725	-0.1687	0.9870	0.0027	0.031	0.157	0.000	0.000	0.00	0.00	1.00
4	4	0.434	0.700	0.000	1.0330	-0.1901	1.0503	-0.0078	0.024	0.119	0.000	0.000	0.00	0.00	1.00
4	5	0.540	0.900	0.000	1.0590	-0.2026	1.0781	-0.0156	0.016	0.082	0.000	0.000	0.00	0.00	1.00
Horizontal Tail															
5	1	6.050	0.100	0.000	0.7085	-0.0657	0.7091	0.0583	0.040	0.200	0.000	0.000	0.00	0.00	1.00
5	2	6.050	0.300	0.000	0.6829	-0.0616	0.6833	0.0579	0.040	0.200	0.000	0.000	0.00	0.00	1.00
5	3	6.050	0.500	0.000	0.6297	-0.0547	0.6297	0.0554	0.040	0.200	0.000	0.000	0.00	0.00	1.00
5	4	6.050	0.700	0.000	0.5010	-0.0401	0.5004	0.0475	0.040	0.200	0.000	0.000	0.00	0.00	1.00
6	1	6.250	0.100	0.000	0.2207	-0.0039	0.2180	0.0345	0.040	0.200	0.000	0.000	0.00	0.00	1.00
6	2	6.250	0.300	0.000	0.2092	-0.0035	0.2067	0.0329	0.040	0.200	0.000	0.000	0.00	0.00	1.00
6	3	6.250	0.500	0.000	0.1818	-0.0028	0.1795	0.0288	0.040	0.200	0.000	0.000	0.00	0.00	1.00
6	4	6.250	0.700	0.000	0.1240	-0.0014	0.1224	0.0202	0.040	0.200	0.000	0.000	0.00	0.00	1.00

* "R" after CNP indicates sign of CNP has been reversed due to negative Ny or Nz for data presentation purposes

Force Display Files and Graphics

The force display files each consist of two numbers in the first row, followed by a column of force coefficients for all the panels. The first number in the first row is the total number of panels for the geometry, and the second number is always a "1" since the *RAID* program expects it (it has nothing to do with the *LinAir* information).

One force display file is shown here, which consists of the lift coefficients in sequence number 3 (Mach = 0.4, alpha = 10°) of the preceding forces summary file. The color graphic following the force display file shows the lift distribution on the 279-3 configuration (*not* corresponding to the preceding forces summary file). The graphic was created by the *RAID* program using the network (.NET) and force display (.PFL) files from *LinAir*. Note that the blue colors along the canard and wing leading edges correspond to high lift, and the yellow and red colors toward the rear of the surfaces indicate low lift.

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58      1
 1.19794
 1.30239
 1.40956
 1.52052
 1.64023
 2.03239
 2.01828
 2.02382
 2.03397
 2.04275
 2.04599
 2.03748
 2.00417
 1.91259
 1.63867
 0.52828
 0.54242
 0.57199
 0.61244
 0.66682
 0.72870
 0.75563
 0.76835
 0.77572
 0.77979
 0.77968
 0.77240
 0.75088
 0.69431
 0.52893
 0.28254
 0.28383
 0.29431
 0.31164
 0.33317
 0.35413
 0.36849
 0.37686
 0.38163
 0.38369
 0.38282
 0.37726
 0.36230
 0.32527
 0.23034
 0.79379
 0.90586
 0.98703
 1.05031
 1.07806
 0.70913
 0.68328
 0.62966
 0.50036
 0.21803
 0.20668
 0.17949
 0.12240
```


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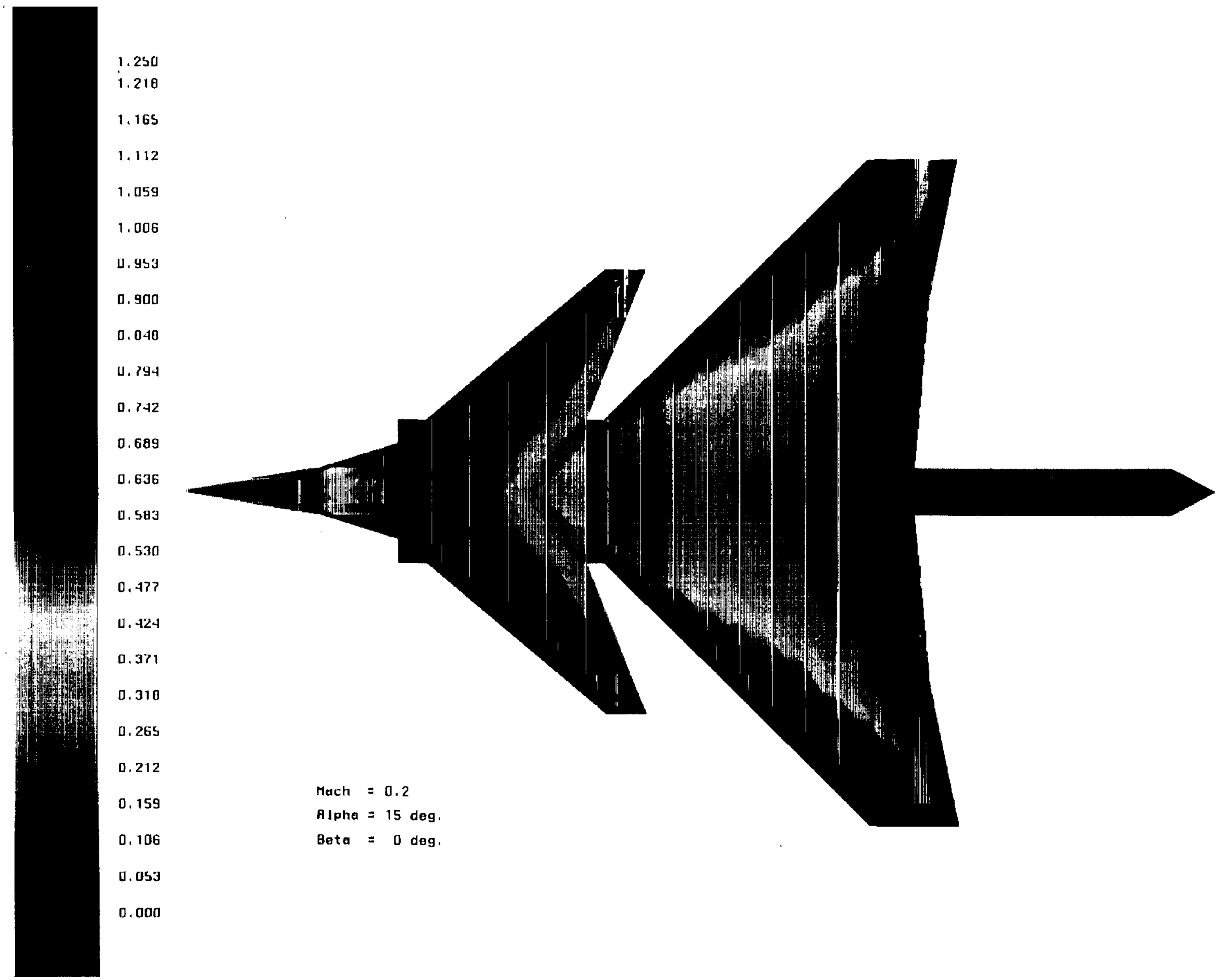

Figure A–3. McDonnell Douglas 279-3 STOVL Fighter *LinAir* lift prediction.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

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1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	October 1993	Technical Memorandum

4. TITLE AND SUBTITLE

LinAir: A Multi-Element Discrete Vortex Weissinger Aerodynamic Aerodynamic Prediction Method

5. FUNDING NUMBERS

505-59-20

6. AUTHOR(S)

Donald A. Durston

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Ames Research Center
Moffett Field, CA 94035-1000

8. PERFORMING ORGANIZATION REPORT NUMBER

A-93111

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NASA TM-108786

11. SUPPLEMENTARY NOTES

Point of Contact: Donald A. Durston, Ames Research Center, MS 227-2, Moffett Field, CA 94035-1000
(415) 604-1515

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified-Unlimited
Subject Category – 02

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

LinAir is a vortex lattice aerodynamic prediction method similar to Weissinger's extended lifting-line theory (refs. 1 and 2), except that the circulation around a wing is represented by discrete horseshoe vortices, not a continuous distribution of vorticity. The program calculates subsonic longitudinal and lateral/directional aerodynamic forces and moments for arbitrary aircraft geometries. It was originally written by Dr. Ilan Kroo of Stanford University, and subsequently modified by the author to simplify modeling of complex configurations. The Polhamus leading-edge suction analogy was added by the author to extend the range of applicability of LinAir to low aspect ratio (i.e., fighter-type) configurations.

A brief discussion of the theory of *LinAir* is presented, and details on how to run the program are given along with some comparisons with experimental data to validate the code. Example input and output files are given in the appendices to aid in understanding the program and its use. This version of *LinAir* runs in the VAX/VMS, Cray UNICOS and Silicon Graphics Iris workstation environments at the time of this writing.

14. SUBJECT TERMS

Vortex lattice, Aerodynamic predictions, Computer program

15. NUMBER OF PAGES

92

16. PRICE CODE

A05

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified		