NASA CONTRACTOR REPORT 177340

STUDY FOR PREDICTION OF ROTOR/ WAKE/FUSELAGE INTERFERENCE PART II: PROGRAM USERS GUIDE

(NASA-CR-177340-Vol-2) STUDY FOR PREDICTION OF ROTOR/WAKE/FUSELAGE INTERFERENCE. PART 2: PROGRAM USERS GUIDE Final Report, 1 Jun. 1980 - 1 Nov. 1983 (Analytical Methods, Inc., Redmond, Wash.) 94 p HC A05/MF A01 G3/01

N85-22347

Unclas 20170

D. R. Clark
B. Maskew

CONTRACT NAS2- 10620
November 1983

NASA CONTRACTOR REPORT 177340

STUDY FOR PREDICTION OF ROTOR/WAKE FUSELAGE INTERFERENCE
PART II: PROGRAM USERS GUIDE

D. R. Clark
B. Maskew

Analytical Methods, Inc.
2047 - 152nd Avenue, N.E.
Redmond, WA 98052

Prepared for
Ames Research Center
under Contract NAS2-10620

National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California 94035

TABLE OF CONTENTS

TABLE OF CONTENTS (CONCLUDED)

LIST OF FIGURES

3 Conventional Body Input

4 Typical Wing Panelling

5 Sample--Body of Revolution--Nacelle

6 Simple Elliptical Fairing

7 Sample Lifting Surfaces

8 Main Rotor Modelling

9 Tail Rotor Modelling

10 Wake-Grid-Plane Definition

LIST OF FIGURES (CONCLUDED)

1.0 INTRODUCTION

Because the body/rotor program is a direct development of Program VSAERO (Ref. 1), no attempt will be made here to describe in detail the set-up and operation of these features of the present analysis which are in common with the original program. For the description of the non-rotor components, the development of the panelling schemes and the discussion of the underlying theory, the reader is referred to the original reports. The discussion here will place the rotor elements in the basic framework provided by VSAERO and will concentrate on a description of how rotary wing aircraft may be built up and placed in space using the flexibility inherent in the program geometry routines.

The body/rotor code outlined here is directly related to the 1000-panel version of Program VSAERO delivered to the NASA Ames Research Center and installed on the CRAY computer. The computation times are consistent with those published in the original Program User's Guide for cases with complicated wakes if allowance is made for the rotor calculation by multiplying by a factor of roughly 1.3.

2.0 GENERAL PROGRAM ARRANGEMENT

The rotor analysis is contained in a subroutine of program VSAERO and is called whenever a component is identified as belonging to a type 4-patch. Since the rotor blade element analysis responds to changes in inflow velocity, the rotor calculation is placed within the wake relaxation loop structure. This is highlighted in the solution block diagram in Figure 1. A typical solution would proceed as follows.

A. From input data, program assembles body and rotor panel model.

B. Program forms surface panel influence coefficients.

C. Initial wake shape is constructed.

D. On first pass, program sets up blade element model, and assuming uniform inflow, calculates rotor loads and moments and (if requested) trims rotor. On subsequent iterations, inflow calculated on previous cycle is used. From calculated loadings, program evaluates rotor disc flow through velocities (local momentum balance) and doublet strength (to feed the rotor wake) and passes these back to the panel model.

E. Solve for body panel singularity strengths.

F. Calculate new wake shape and determine new inflow velocities at rotor panel centers.

G. Return to D to complete wake relaxation cycle.

H. If requested, carry out viscous/potential flow iteration re-entering at D.

I. Termination.

Embedded within the rotor performance module are nested loops which control the blade flapping, rotor thrust (with collective pitch change) and rotor moments (with cyclic pitch change). These are outlined in the rotor calculation block diagram in Figure 2. At each azimuth location, the section loads are calculated for every station out along the blade. These are integrated radially to form the azimuthal totals. The blade is then moved to the next azimuthal location with flapping motions in response to any out of balance at the first position added. The blade is cycled around the azimuth until blade flapping has stabilised. The thrust is checked against the desired level and the collective pitch adjusted. Once the required thrust has been achieved, rotor moment trim is checked and adjusted if required.

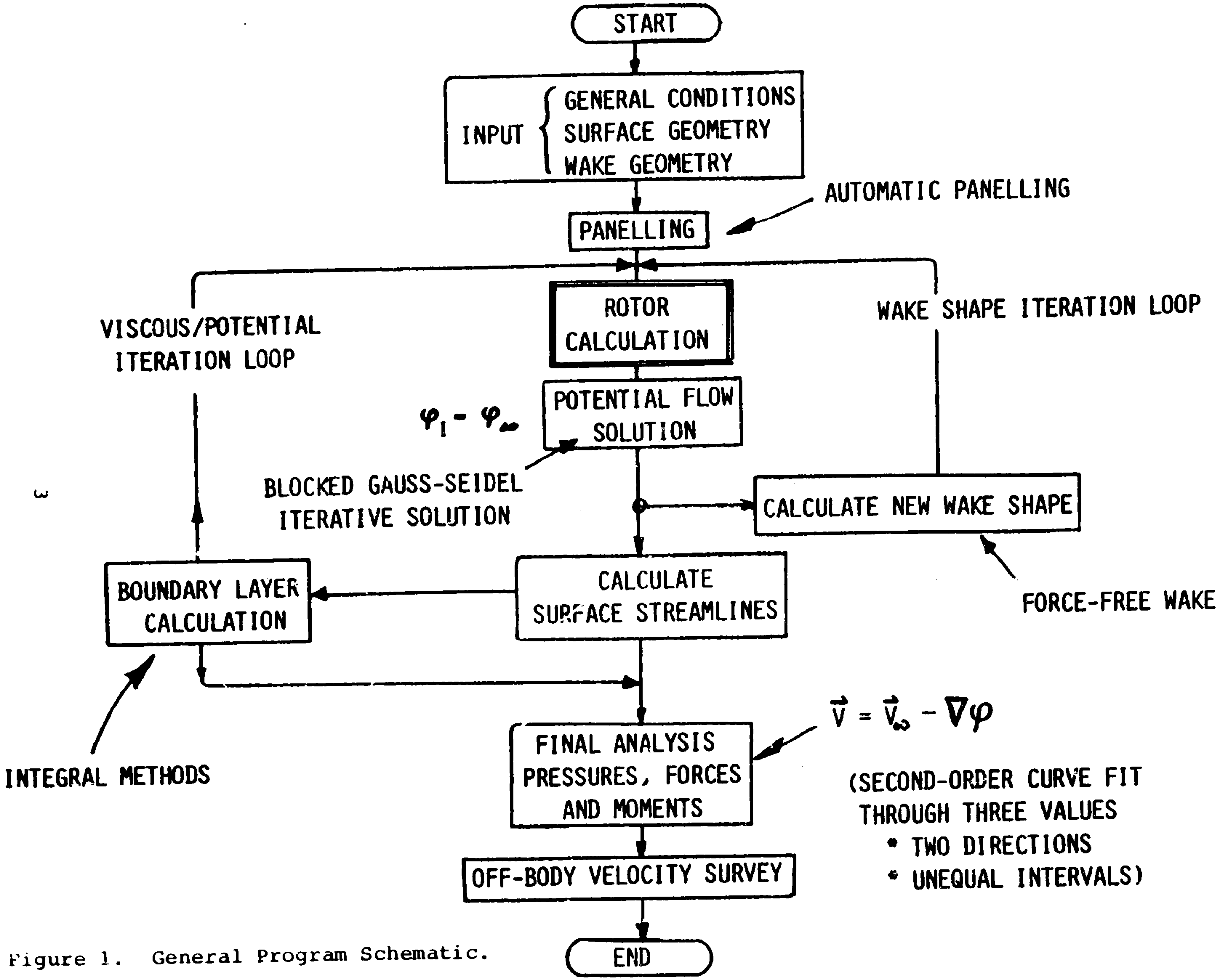


Figure 1. General Program Schematic.

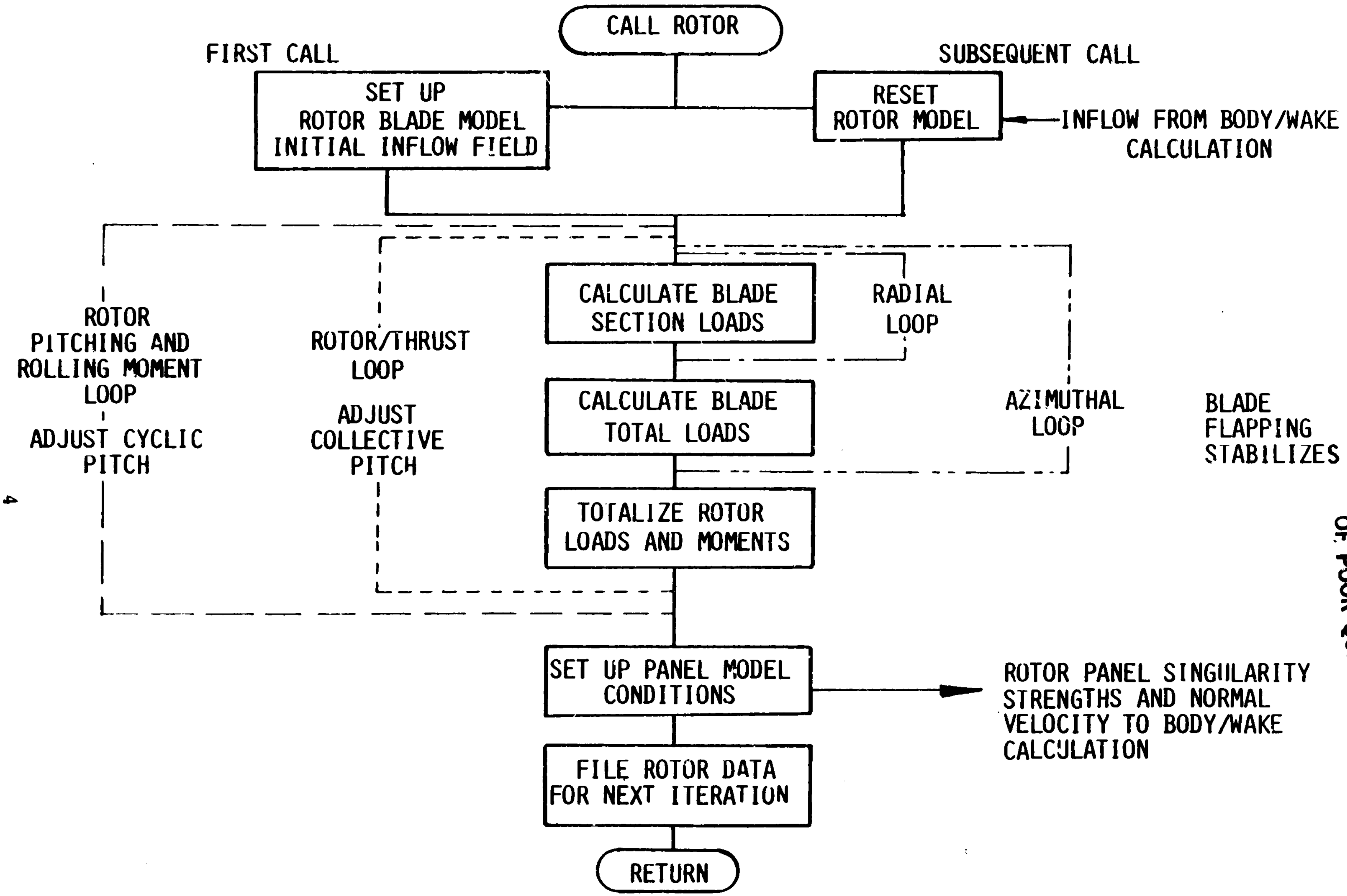


Figure 2. Rotor Calculation Schematic.

3.0 PANEL MODEL DEFINITION (Card Sets 9 through 16)

3.1 Body Panelling

3.1.1 Conventional Input

Body panelling, including any lifting components when present, follows exactly the format set down in the Program VSAERO User's Guide, Ref. 1. As a result, the body can be made up of any convenient combination of panels, patches and components. In the VSAERO hierarchy, the panel is the smallest element controllable by the user. A patch is a collection of panels in a regular array and a component is an identified group of patches taken together for the evaluation of force and moment totals. Components may be further grouped into assemblies.

The body shape may be entered in several ways, depending on its complexity and on the way in which the shape data is available. Conventionally, the body is defined with a set of loft lines which are generally cut at constant body locations, station (x), buttline (y) and waterline (z). Figure 3 illustrates how a typical body may be first broken into patches,Figure 3 (a), and then input, Figure 3(b). The patch allocation is made so that the different regions of the body may be represented by panelling of the appropriate density, high in regions of particular interest, low in other areas bearing in mind that within a patch, the panels form a regular array with the same number of panels in each row and column. Consequently, patch boundaries almost always occur where large changes in body cross section are present and in regions where, away from areas of interest, panel densities are being reduced for reasons of economy.

In the case of the body used in this illustration, the shape was defined with a series of station (constant x) cuts. following the VSAERO User Document, Ref. 1, each section is defined by a series of points located in a local axis system in the global coordinate system. The data set defining each section contains a header card which contains the origin of the local axis system in the global coordinate system, the scale and orientation of the section (section may be scaled and/or rotated to ease input), and indicator cards which alert the computer to the way in which the data is being input and which indicate whether the section is internal to or closes a patch and provide information on how the patch is to be divided up. The header card is then followed by the string of points defining the section, together with node cards which alert the computer to the way in which the surface is subdivided, to any changes in surface curvature at junctions, and to the termination of the string.

Program VSAERO offers the user great flexibility in the ways in which the shape may be input. Individual defining sections may be input in either the x (with y and z), y (with x and z), or z (with x and y) planes or in generalized x, y and z coordinates. Any other previously defined section may be automatically copied

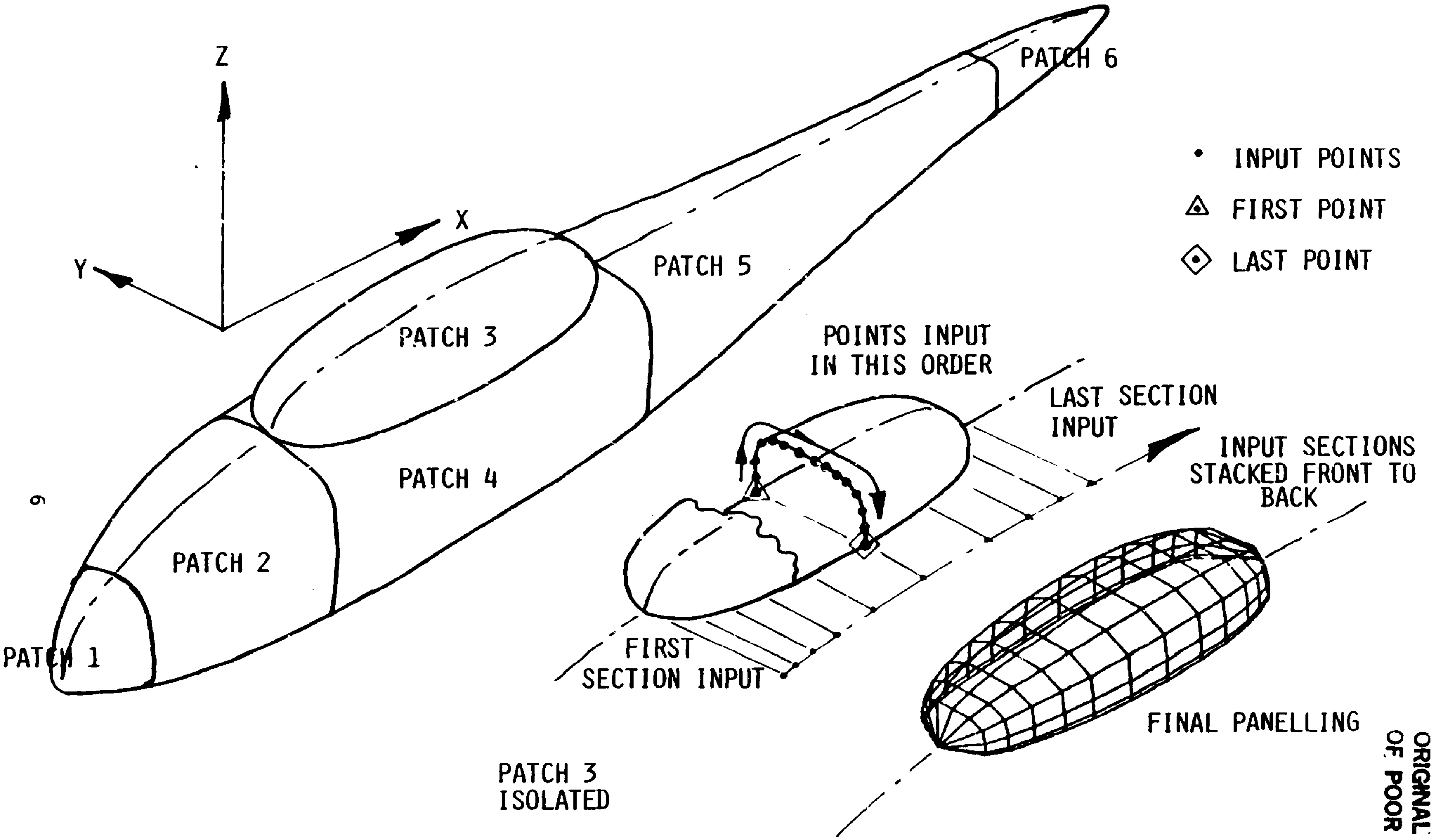


Figure 3. Conventional Body Input

(a) Patch-Section-Point Breakdown.

(TYPICAL BODY PATCH CARD)

```
(IDENT   MAKE   KOMP  KLASS)        ********************
   2       0      0      0                 PYLON                                        (NPATCH=    4 )
                                    ********************
```

(TYPICAL BODY SECTION SET)

(SECTION CARD FOLLOWED BY SECTION POINTS AND TERMINAL NODE CARD)

```
  (STX        STY         STZ        SCALE       ALF        THETA  INMODE NODES NPS  INTS)
 0.00000    0.00000    0.00000    1.00000    0.00000    0.00000     4     1     0     0         (NDSEC=  29)

   (BX         BY          BZ        (  NBP  )
12.00000    1.91290    2.32060      (    1  )
12.00000    1.91280    2.74320      (    2  )
12.00000    1.91000    3.06080      (    3  )
12.00000    1.88610    3.40120      (    4  )
12.00000    1.73070    3.73390      (    5  )
12.00000    1.52290    3.96310      (    6  )
12.00000    1.17360    4.05550      (    7  )
12.00000    0.83550    4.07990      (    8  )
12.00000    0.53430    4.08460      (    9  )
12.00000    0.26050    4.08510      (   10  )
12.00000    0.00000    4.08510      (   11  )
12.00000   -0.26050    4.08510      (   12  )
12.00000   -0.53430    4.08460      (   13  )
12.00000   -0.83550    4.07990      (   14  )
12.00000   -1.17360    4.05550      (   15  )
12.00000   -1.52290    3.96310      (   16  )
12.00000   -1.78070    3.73390      (   17  )
12.00000   -1.88610    3.40120      (   18  )
12.00000   -1.91000    3.06080      (   19  )
12.00000   -1.91280    2.74320      (   20  )
12.00000   -1.91290    2.32070      (   21  )
                                 (NODEC     NPC    INTC)
                                     3      10       0
                                                  (END OF CHORDWISE REGION   33 )
```

TITLES IN PARENTHESIS ARE FOR ILLUSTRATION ONLY AND DO NOT APPEAR IN INPUT DATA SET

NOTE: INMODE=4, SO FULL X, Y, Z DESCRIPTION OF SECTION POINTS USED.

Figure 3. Concluded.

(b) Typical Input Data Set.

and a whole family of automatically defined airfoil, elliptical or polar coordinate sections are available.

The data sets for successive sections are stacked to form the input data set for a patch and the way in which they are stacked is of particular importance. Sections should be stacked in order and in a direction consistent with the way in which the points are input along each section. In the example shown in Figure 3, the points on each section were input up along the profile on the starboard (positive y) side toward the top centerline and although the input points do not necessarily dictate panelling directly, the direction of input determines the order of the panel, with the first section input making up side 1 of a patch, and the panels numbered in the direction of the input points. Since program VSAERO requires that panels and patches have an anticlockwise corner point order when viewed from outside with the bottom to top input scheme used in Figure 3, the sections must be stacked from front to rear. If the <u>points</u> had been entered from top to bottom, then the <u>section</u> input order would have been reversed and the patch would have been defined with sections input first at the rearmost edge of the patch and working forward.

Input sections need not have the same number of defining points. However, when instructing the program on how the section should be subdivided, it should be remembered that a patch is a regular array and all columns must have the same number of panels. This is determined by the user properly setting the appropriate dividing instructions (the node cards) in the section input string.

Wing sections are conventionally input as shown in Figure 4. Using the same format as outlined for bodies above and starting with the lower trailing-edge point, the surface is input point by point working forward toward the leading edge, around the leading edge and aft over the upper surface. As with the body input described above, node cards are inserted to delineate regions of differing panel density or changes in surface curvature. For instance, in the example shown, the panelling is required to be more dense close to the leading edge. This is achieved by inserting a node card with a value of NODEC=1 at the leading edge (indicating the end of a region but maintaining surface curvature) and using values of the distribution controls, INTC=2, at the end of the lower surface and INTC=1 at the end of the upper surface. Following this procedure, sections should be stacked from root to tip if only the starboard (positive y) side of the vehicle is being modelled.

Although a panel is the basic element in modellng the surface and the solution proceeds with the strength of the singularity used to represent the panel as the unknown, the patch is the most conveniently manipulated unit. Patches may be constructed and moved into place to represent the configuration in any way convenient to the user. They may be ordered in any way

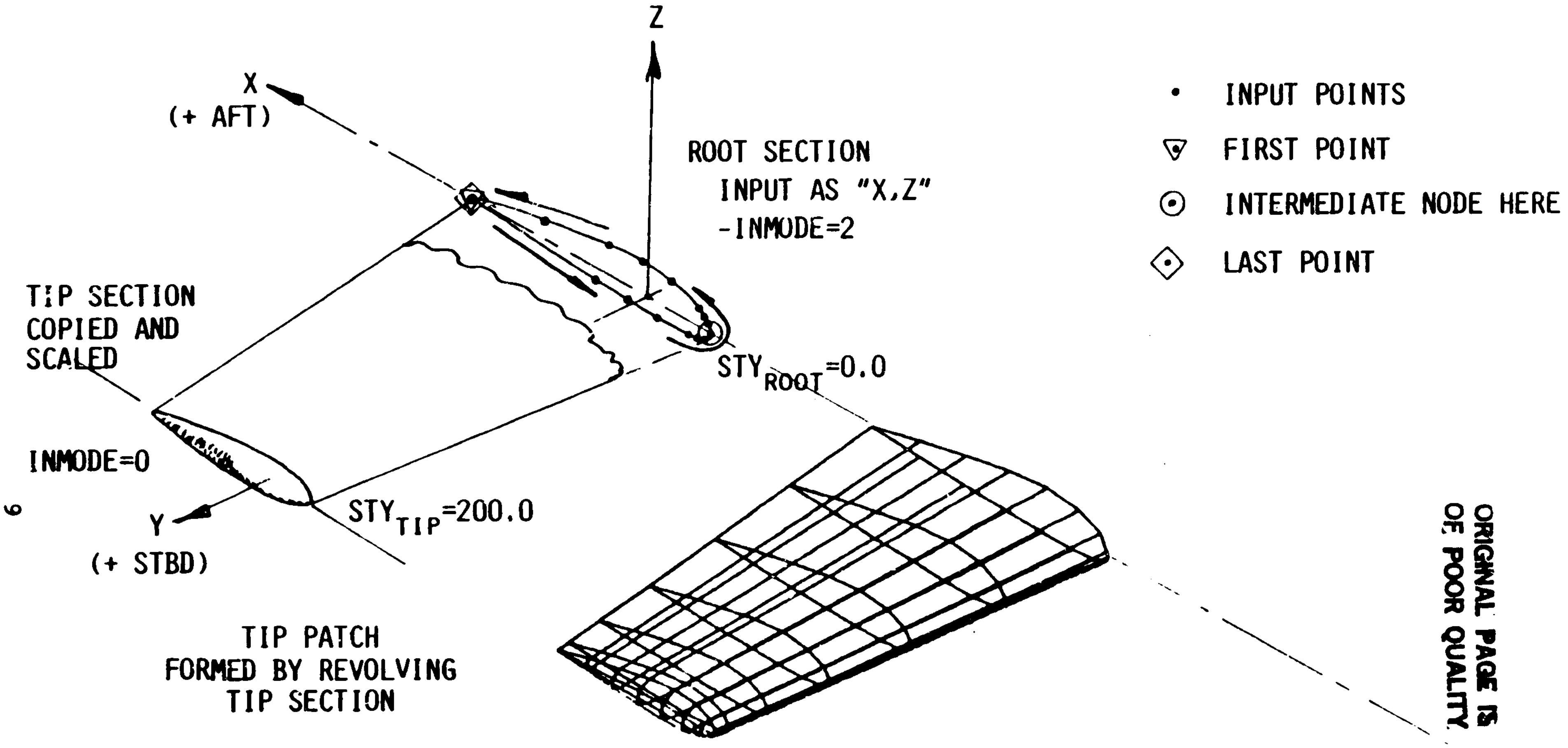


Figure 4. Typical Wing Panelling.

(a) Point Input and Tip Closure Schematic.

```
   (CTX        CTY        CTZ        SCAL        THET)
100 00000  30 00000  10 00000    1 00000    0 00000  (COMPONENT CARD--CARD 9)                  (NCOMP=  2

 (IDENT    MAKE    KOMP   KLASS)         ********************
     1       0       0       0              SIMPLE WING          (PATCH CARD--CARD 10)        (NPATCH=   2 )
                                         ********************

   (STX        STY        STZ       SCALE        ALF         THETA  INMODE NODES NPS INTS)
  0 00000    0 00000    0 00000  15 00000    0 00000    0 00000       2     0    0    0         (NDSEC=   3)  (ROOT SECTION CARD--
                                                                                                               CARD 11)
   (BX         BZ         DELY         (  NBP  )
  6 00000    0 00000    0 00000        (    1  )
  3 00000   -0 32000    0 00000        (    2  )
  0 70000   -0 50000    0 00000        (    3  )
 -0 60000   -0 60000    0 00000        (    4  )
 -1 52000   -0 55000    0 00000        (    5  )
 -1 88000   -0 43000    0 00000        (    6  )
 -1 98000   -0 35000    0 00000        (    7  )
 -2 00000   -0 25000    0 00000        (    8  )

                                 (NODEC     NPC    INTC)                                    ROOT SECTION INPUT
                                     1        8       2                                     WITH NODEC AT LEADING
                                                        (END OF CHORDWISE REGION     3 )    EDGE AND TRAILING EDGE

   (BX         BZ         DELY         (  NBP  )
 -1 98000   -0 10000    0 00000        (    9  )
 -1 88000    0 20000    0 00000        (   10  )
 -1 55000    0 48000    0 00000        (   11  )
 -0 66000    0 82000    0 00000        (   12  )
  0 40000    0 90000    0 00000        (   13  )
  2 00000    0 72000    0 00000        (   14  )
  4 00000    0 40000    0 00000        (   15  )
  6 00000    0 00000    0 00000        (   16  )

                                 (NODEC     NPC    INTC)
                                     3        8       1
                                                        (END OF CHORDWISE REGION     4 )

   (STX        STY        STZ       SCALE        ALF         THETA  INMODE NODES NPS INTS)
  0 00000  200 00000   20 00000  10 00000    0 00000    0 00000       0     3    6    2         (NDSEC=   4)  (TIP SECTION CARD)

 (IDENT    MAKE    KOMP   KLASS)         ********************
     2       2       0       0              TIP PATCH                    (TIP PATCH CARDS)      (NPATCH=   3 )
                                         ********************

                                     (NPC INTC KURV NPTIP               NODES NPS INTS          AUTOMATIC TIP PATCH)
                                       3    3    1    0                   5    0    0

(END OF INPUT LIST FOR PATCH GEOMETRY)

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

Figure 4. Concluded.

(b) Typical Wing Input.

without significantly affecting the solution and allow changes to a configuration to be made by removing a feature and simply plugging in one or more replacement patches to remodel the vehicle.

Summarising, the input list for a typical surface patch would be as outlined below. The names used for the data items are those employed in the Program VSAERO User's Manual. The terms "chordwise" and "spanwise" can be considered to represent directions along the input section and along the patch length respectively. For completeness, they are also defined here.

Patch Card:- CARD 10.

IDENT	Patch type	1-Wing 2-Body 3-Lifting Surface (Neumann) 4-Rotor
KOMP KASS	Defines component and assembly to which patch belongs	
PNAME	Patch title	

Section Cards:- (Stacked in spanwise direction) CARD 11

STX, STY, STZ	Location of origin of section input points
SCALE, ALPHA, BETA	Scaling factor and rotation angles
INMODE	Type of section input
NODES	Nodes to signal changes in spanwise panel distribution, surface curvature, end of patch, etc.
NPS	Number of spanwise panels in the interval
INTS	Way in which spanwise section is divided

Defining Input Points:- CARD SET 12.

BX, BY, BZ	Coordinates of section points. Form depends on INMODE used.

Chordwise Nodes:- CARD 14

NODEC	Nodes to signal changes in chordwise distribution, surface curvature, end of section, etc.
NPC	Number of chordwise panels to be generated in in the interval
INTC	Way in which chordwise section is to be divided

The values of the nodes used to delineate changes in either chordwise (NODEC) or spanwise (NODES) directions are the same. In both cases, values of 1 and 2 represent the end of a region within a patch where in the first case, surface curvature is continuous into the next region and in the second case is discontinuous. A value of 3 indicates the end of a section, chordwise, or a patch, spanwise, while values of 4 and 5, used only on the last sections of patches indicate, respectively, the final sections of components and of the whole configuration.

A similar arrangement with matching values is used to indicate the way in which the surface is to be divided in the chordwise and spanwise directions. The parameters, INTC and INTS, may be values of 0 through 3 depending on whether the points are to be:

	Value
Closely spaced at the beginning and end of the region	0
Closely spaced at the beginning of the region	1
Closely spaced at the end of the region	2
Equally spaced	3

When an unequal distribution is called for, the distance along the surface across the interval is broken up using a cosine form. A detailed description of the procedure is given in the Program VSAERO Manual, Ref. 1.

Of course, the panelling could be built directly upon the input points and sections with no subdivision or interpolation. In this case, the input points on successive sections are simply connected together to form the panelling. This option is selectable by setting NPS or NPC equal to zero. Any values other than zero determine the number of panels within the particular spanwise or chordwise interval.

In the discussion above, the standard method of inputting configurations has been outlined. Program VSAERO offers many other options. Two of them, which are particularly useful in entering helicopter shapes, are outlined below.

3.1.2 Bodies of Revolution

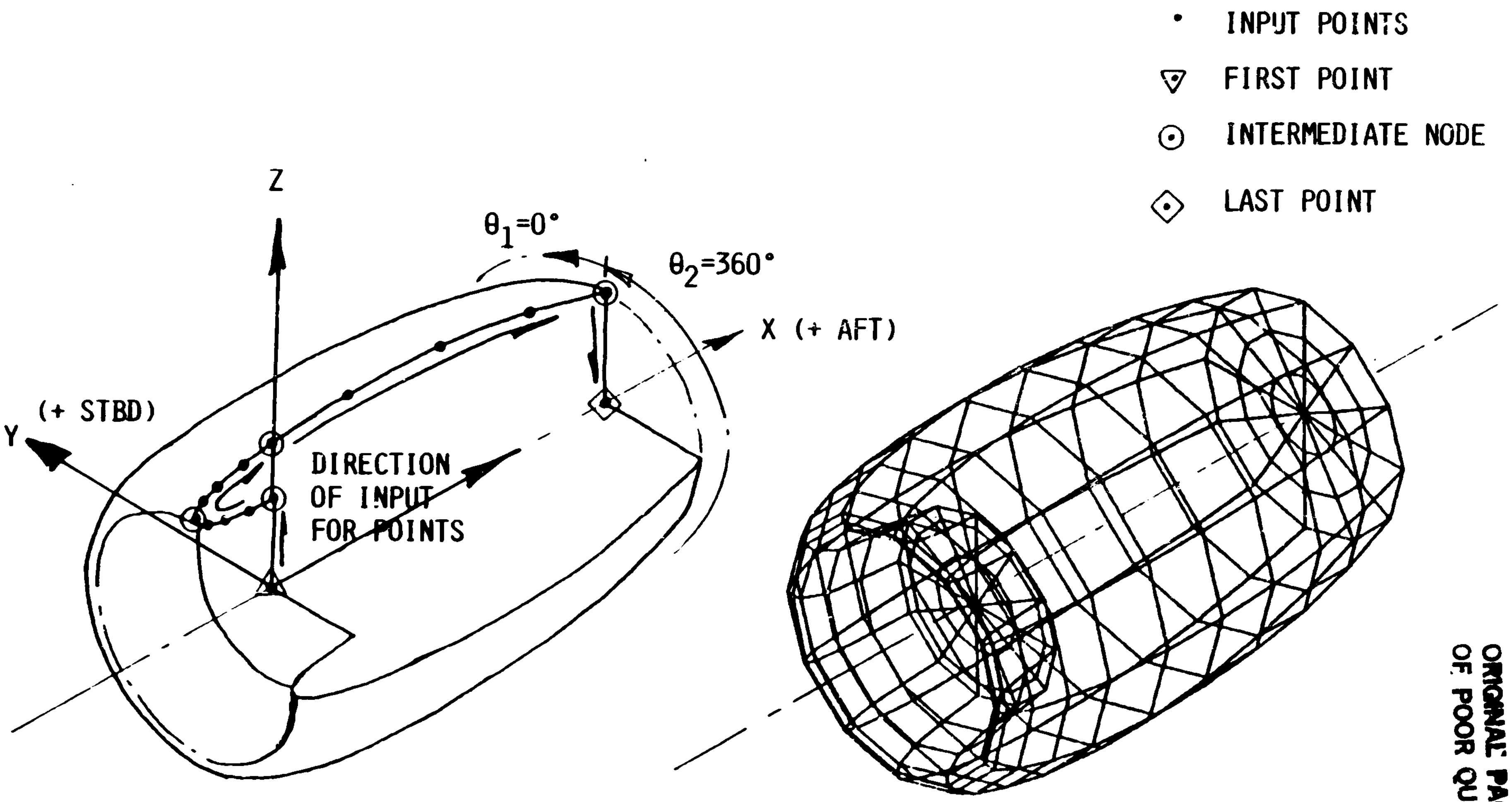
There are many applications in the modelling of typical helicopter shapes that do not require the detail provided by section by section input. Many configuration elements, in fact, may be simply defined as bodies of revolution. Examples are engine nacelles, tail boom sections, rotor head fairings and external stores. Figures 5 and 6 illustrate how two of these, a simple engine nacelle and a rotor head fairing (or radome) may be generated.

For the first example, Figure 5, the engine nacelle, the unit is made up of one section defined in the y = 0 plane by inputting values of x and z to outline the profile and then rotated through 360° to form the nacelle. It can be modelled as one patch with four separate regions. They are: the inlet face, the inner surface of the inlet, the outside surface of the nacelle, and, finally, the exhaust plane.

As with normal input, the card set describing the nacelle is preceded by a patch card. Generally, only one section card is required. This locates the input section in the global coordinate system and specifies its orientation and scale relative to that frame. The parameter, INMODE, describes how the section points are to be input; INMODE=2, for both the examples in Figures 5 and 6 signifies points being entered in the y = 0 plane. If a flow-through nacelle were being modelled, INMODE=5 could have been used to specify a standard NACA 4-digit cross section.

The body of rotation option is selected by setting the spanwise node card, NODES, to a negative value. For the examples, simple polar symmetric bodies are used so NODES is -3 in both cases. However, more complex bodies may be built up by combining sections to vary panel density, and in that case, values of -1 or -2 would be appropriate at the intermediate spanwise sections depending on whether the surface curvature was continuous or discontinuous across the node. The final section, completing the rotation, would, of course, have NODES=-3 signifying the closing of the patch (or -4 or -5 if this were the last patch on the component on the body).

Definition of the cross-section points (defining the local chordal shape) follows the same rules for defining conventional cross sections outlined above.



SECTION DEFINING POINTS
INPUT IN Y=0 PLANE AND
ROTATED (DEFAULT)
ABOUT X-AXIS

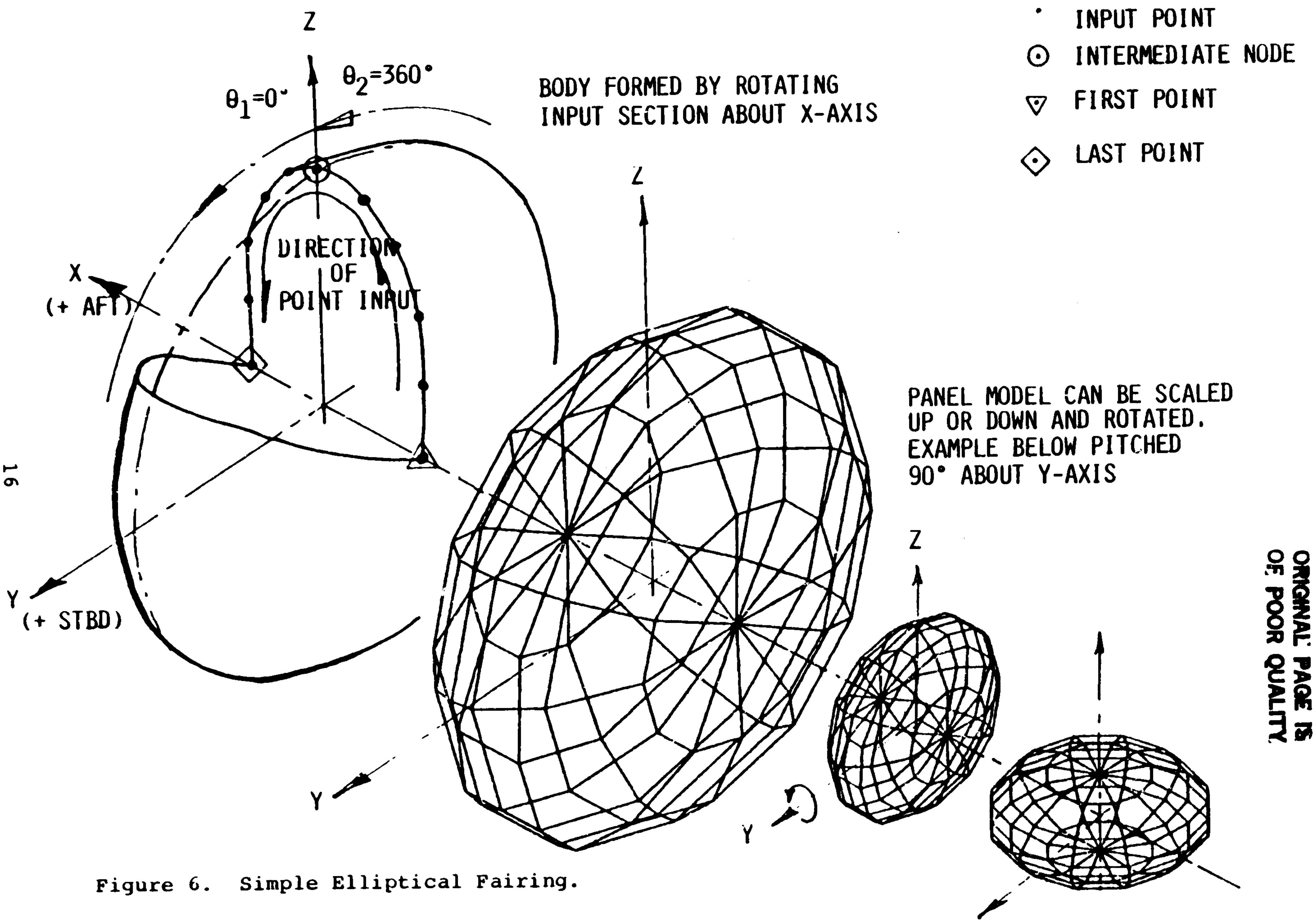
Figure 5. Sample--Body of Revolution--Nacelle.

(a) Patch Section Points Schematic.

```
  (CTX      CTY      CTZ      SCAL     THET)     (COMPONENT CARD PLACES NACELLE IN GLOBAL FRAME)  (NCOMP=
100 00000  60 00000  80 00000  1 00000  0 00000

 (IDENT   MAKE   KOMP   KLASS)      ********************
    2       0      0      0          SIMPLE NACELLE          (PATCH CARD)                      (NPATCH=   2 )
                                    ********************

   STX      STY      STZ      SCALE     ALF      THETA  INMODE NODES NPS INTS)
 0 00000  0 00000  0 00000  30 00000  0 00000  0 00000     2    -5    12   3        (NDSEC=   3) (SECTION CARD)

   (BX      BZ      DELY      (  NBP  )
 0 00000  0 00000  0 00000    (   1   )    (INLET FACE)
 0 00000  0 95000  0 00000    (   2   )

                           (NODEC    NPC    INTC)
                              2       3      2
                                                  (END OF CHORDWISE REGION    3 )

    (BX      BZ      DELY      (  NBP  )
 -0 40000  1 00000  0 00000    (   3   )
 -0 75000  1 06000  0 00000    (   4   )
 -0 90000  1 12000  0 00000    (   5   )    (INNER FRONT COWL)
 -0 95000  1 15000  0 00000    (   6   )
 -1 00000  1. 25000  0 00000   (   7   )

                           (NODEC    NPC    INTC)
                              1       4      2
                                                  (END OF CHORDWISE REGION    4 )

    (BX      BZ      DELY      (  NBP  )
 -0 95000  1 35000  0 00000    (   8   )
 -0 90000  1 38000  0 00000    (   9   )    (OUTER FRONT COWL)
 -0 75000  1 44000  0 00000    (  10   )
  0 00000  1 50000  0 00000    (  11   )

                           (NODEC    NPC    INTC)
                              1       4      1
                                                  (END OF CHORDWISE REGION    5 )

    (BX      BZ      DELY      (  NBP  )
  1 00000  1 65000  0 00000    (  12   )    (AFT COWL)
  4 00000  1 20000  0 00000    (  13   )

                           (NODEC    NPC    INTC)
                              2       6      3
                                                  (END OF CHORDWISE REGION    6 )

    (BX      BZ      DELY      (  NBP  )    (EXHAUST FACE)
  4 00000  0 00000  0 00000    (  14   )

                           (NODEC    NPC    INTC)
                              3       3      3
                                                  (END OF CHORDWISE REGION    7 )

  (THETA2     THETA1        BODY OF REVOLUTION)
 360 00000   0 00000

 (END OF INPUT LIST FOR PATCH GEOMETRY)
```

Figure 5. Concluded.

(b) Sample Body of Revolution--Nacelle Input List.



ORIGINAL PAGE IS
OF POOR QUALITY

Figure 6. Simple Elliptical Fairing.

(a) Basic Set-up.

```
   (CTX       CTY       CTZ       SCAL      THET)       (COMPONENT CARD)                              (NCOMP=  2
100 00000   0 00000 100 00000   1 00000   0 00000

(IDENT    MAKE    KOMP   XLASS)        ********************
   2        0       0       0           SIMPLE FAIRING         (PATCH CARD)               (NPATCH=   2 )
                                       ********************

   (STX       STY       STZ       SCALE     ALF       THETA  INMODE NODES NPS INTS)
 0 00000   0 00000   0 00000   0.30000   0 00000   0 00000      2    -5   12    3     (NDSEC=   3)   (SECTION CARD)

   (BX        BZ        DELY        (  NBP  )
 -1 00000   0 00000   0 00000       (    1  )
 -0 75000   1 85000   0 00000       (    2  )
 -0 25000   2 40000   0 00000       (    3  )
  0 00000   2 45000   0 00000       (    4  )
                                 (NODEC     NPC      INTC)
                                     1        4        2
                                                           (END OF CHORDWISE REGION    3 )          (SECTION INPUT)

   (BX        BZ        DELY        (  NBP  )
  0 25000   2 40000   0 00000       (    5  )
  0 75000   1 85000   0 00000       (    6  )
  1 00000   0 00000   0 00000       (    7  )
                                 (NODEC     NPC      INTC)
                                     3        4        1
                                                           (END OF CHORDWISE REGION    4 )

  (THETA2     THETA1        BODY OF REVOLUTION)
360 00000   0 00000

(END OF INPUT LIST FOR PATCH GEOMETRY)

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

Figure 6. Concluded.

(b) Input Data Listing.

The input set is completed by specifying the final and initial angles, θ, to define the rotation arc on CARD 15. For a body such as the nacelle, remote from the system plane of symmetry, a full 360° of rotation is used. However, in the same applications where the flow is symmetrical, where no yawing is involved and where the body is on the plane of symmetry, then only the positive side of the body of revolution is defined and is 180°.

The second example used, the ellipsoidal fairing of Figure 6, illustrates another feature of Program VSAERO; that is, the ability to construct elements of the configuration as separate components in the most convenient orientation and then rotate them or move them to the required location. The positioning and rotation are controlled by entries on a special component card which must precede a patch or a group of patches identified as belonging to a separate component. This card precedes the first patch identifying card.

In the simple example given the component is made up of only one patch. As with the nacelle, it is defined in the y = 0 plane by inputting the values of x and z outlining the cross section. This outline is then rotated about the section 'X' axis to form the body of revolution.

Once the shape is formed in the section coordinate system, three further processes are available at the component level before the final shape is set in the global frame. At this level, all the patches within the component may be scaled, either increased or reduced in size, rotated or translated. The changes are applied in that order. Two rotations are available; a simple one, where the body is rotated about the component 'Y' axis and rotation about a general axis that is defined by two input points. The simple rotation is the default mode. The user-defined axis rotation is entered by specifying a negative value for the scale parameter and then inserting an extra data card which contains the rotation axis defining points. For the simple fairing case shown in Figure 6 the default is used and the body is pitched up 90° to lie with its long axis in the horizontal plane.

3.1.3 Lifting Surfaces--Type-3 Patches

A further option offered by Program VSAERO which is useful in modelling components remote from a region of interest is the ability to use a lifting-surface representation rather than a full surface singularity model, and enforcing the Neumann rather than the Dirichlet boundary condition. A typical application of this feature would be in modelling wings or other lifting or control surfaces that do not have a direct effect on the components that were the focus of the study or in regions where no aerodynamic rigor is sacrificed by not including the effects of the thickness of the components. Figure 7 shows examples of this where simple type-3 patches are used to model typical vertical/horizontal tail assemblies.

Depending on the level of detail required, this assembly could be created by as few as two defining points on each of three sections if simple, flat surfaces are desired. The example in Figure 7(a) and (b) shows this input. The group of input cards required is preceded by a patch card (and a component card if a separate component is called for) calling out a type-3 patch. Input continues with the section card defining the lower root and then two cards defining the trailing- and leading-edge points followed by a chordwise node card. Note that on the chordwise node card the program is instructed to break the chord down into five panels, NPC=5, distributed so that they are denser at the leading edge, INTC=2.

The second section card, at the joint between vertical and horizontal planes, with a spanwise node value, NODES, of two signifying a discontinuity in surface curvature, contains the information to divide the vertical section in the spanwise direction into four rows of panels, NPS=4, spaced equally, INTS=3. Input is complete with the section defining the horizontal plane. In this case there are five panels spanwise, NPS=5, divided so that they are spaced densely at root and tip, INTS=0. Since this is the last section to be input on this patch, the spanwise node, NODES is set equal to three. The panelling in the chordwise direction is the same on the horizontal plane as in the vertical.

In the second example, Figure 7(c) and (d), cambered sections are used on both the vertical and horizontal sections and, consequently, a small transition piece is required to go from the vertical to horizontal planes. This is formed quite simply by allowing the program to correct the sections defining the top of the vertical panel and the root of the horizontal panel and generate a row of panels to fill the gap. To do this, four sections are required. The first section, as before, defines the root of the vertical panel this time using INMODE=1, points input as X and Y values, to define the section camber line. The section was defined relative to the quarter chord point; the values of STX, STY, and STZ locate the section in the global frame. In the example, the camber line distribution is assumed constant up the panel and as a consequence, the top section is input by simply relocating the root section with the appropriate values of INMODE=0, with the SCALE factor set to give the correct taper.

The root section of the horizontal plane is again defined with input points, this time values of X and Z in a constant Y plane, INMODE=2, taking care to place it in the correct position relative to the earlier input sections using the appropriate STX, STY, and STZ local origin values. Again the tip section (the camber is assumed constant) is input simply by copying and

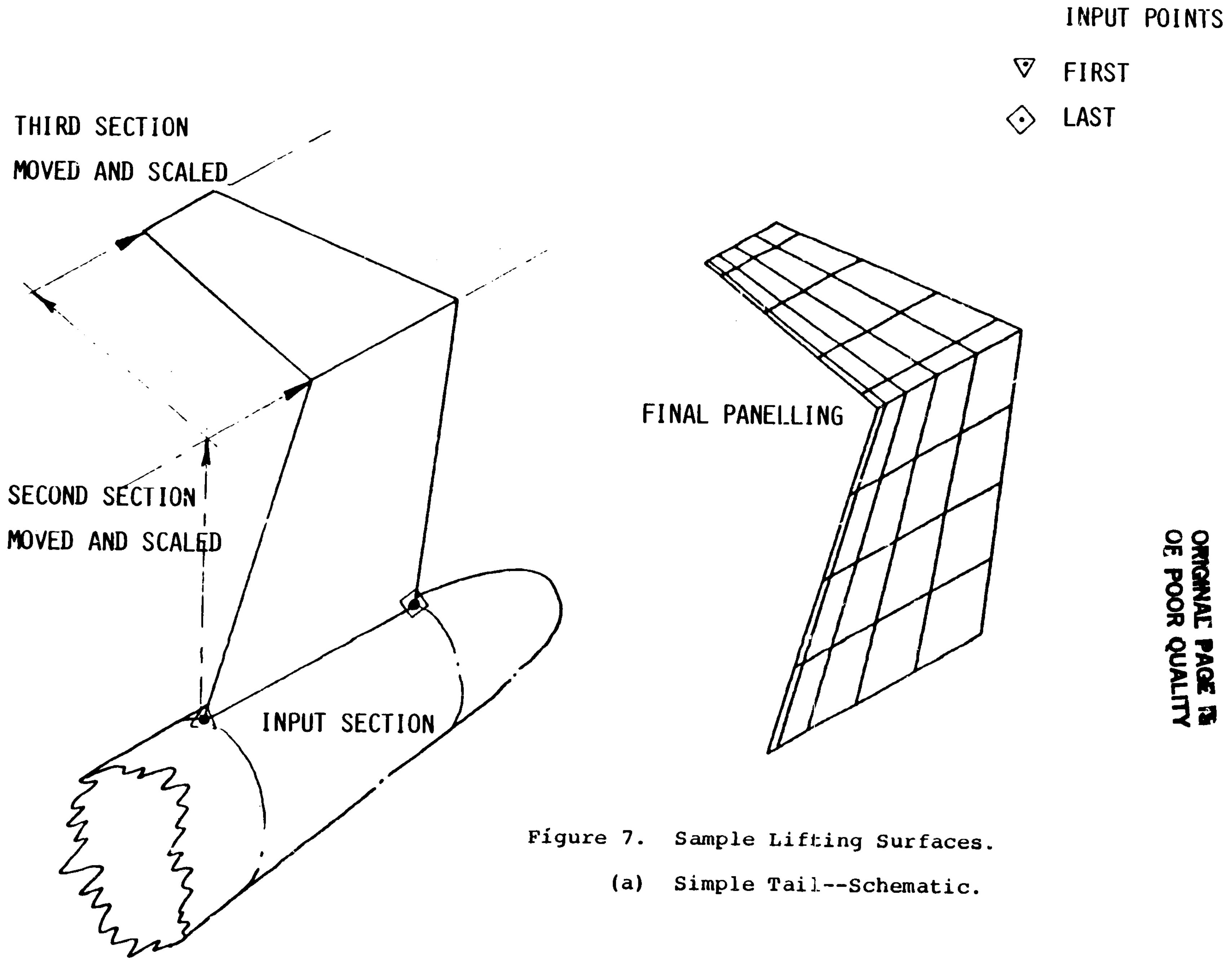


Figure 7. Sample Lifting Surfaces.

(a) Simple Tail--Schematic.

```
    (CTX        CTY        CTZ        SCAL       THET)
500 00000    0 00000    0 00000    1 00000    0 00000          (COMPONENT CARD)                     (NCOMP=  2

 (IDENT    MAKE    KOMP   KLASS)          ********************
     3       0       0       0              SAMPLE SIMPLE TAIL      (PATCH CARD)                (NPATCH=   2 )
                                          ********************

    (STX        STY        STZ        SCALE       ALF        THETA INMODE NODES NPS INTS)
  0 00000    0 00000   10 00000   30 00000    0 00000    0 00000     2      0    0    0          (NDSEC=   3)     (SECTION 1)

    (BX         BZ         DELY        (  NBP  )
  0 00000    0 00000    0 00000        (    1  )
  1 00000    0 00000    0 00000        (    2  )

                                  (NODEC     NPC     INTC)
                                       3       5        1
                                                        (END OF CHORDWISE REGION    3 )

    (STX        STY        STZ        SCALE       ALF          .TA INMODE NODES NPS INTS)
 15 00000    0 00000   45 00000   20 00000    0 00000    0 00000     0      2    4    3          (NDSEC=   4)     (SECTION 1 COPIED)

    (STX        STY        STZ        SCALE       ALF        THETA INMODE NODES NPS INTS)
 20 00000   30 00000   45 00000   10 00000    0 00000    0 00000     0      5    5    0          (NDSEC=   5)     (SECTION 1 COPIED)

(END OF INPUT LIST FOR PATCH GEOMETRY)

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

Figure 7. Continued.

(b) Simple Tail--Input Details.

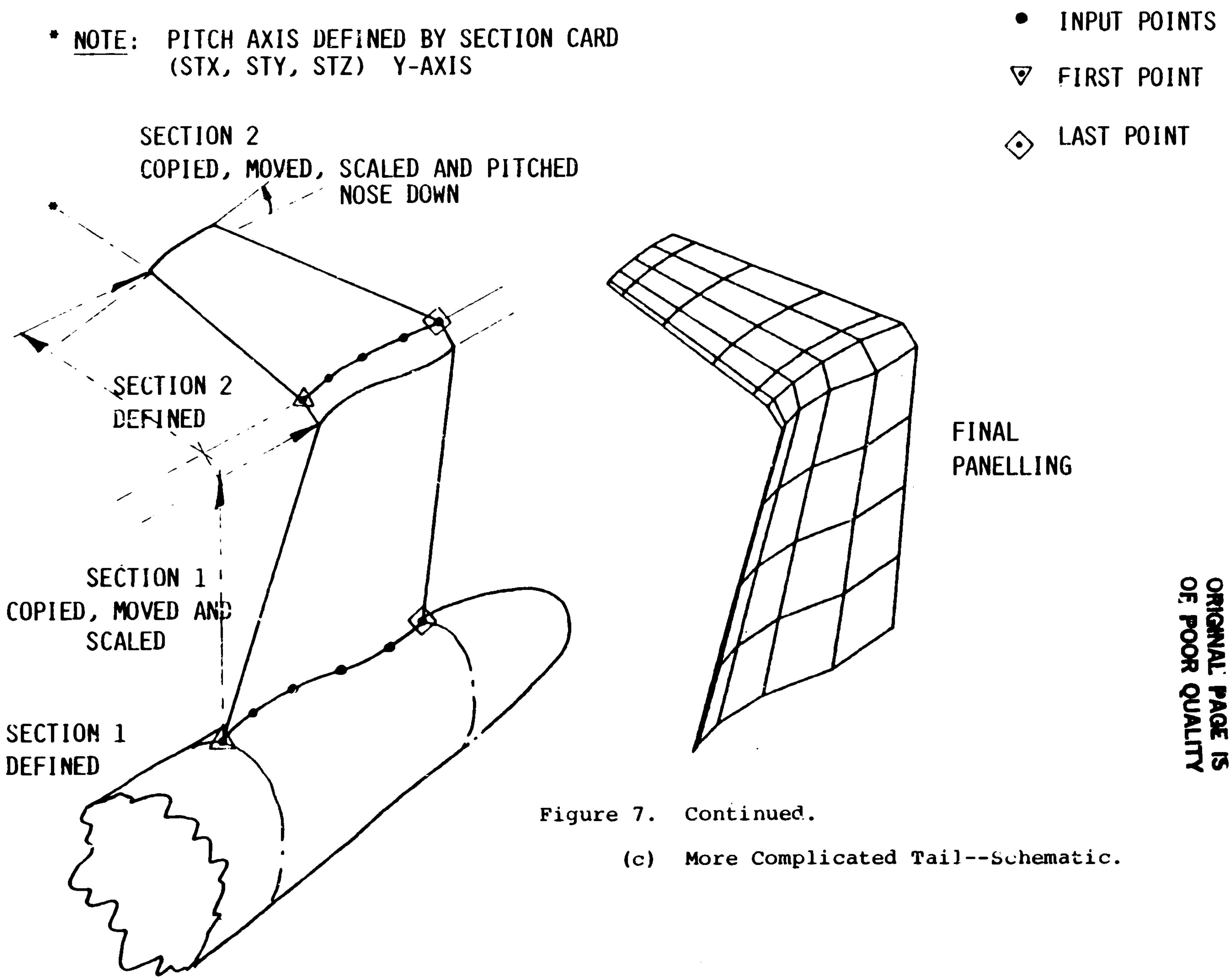


Figure 7. Continued.

(c) More Complicated Tail--Schematic.

```
     (CTX        CTY         CTZ        SCAL        THET)                (COMPONENT CARD)                                (NCOMP=  2
 500.00000   0.00000     0.00000    1.00000     0.00000

(IDENT   MAKE   KOMP   KLASS)           ********************       (PATCH CARD)                        (NPATCH=   2 )
    3      0      0      0               SAMPLE  TAIL
                                        ********************

     (STX        STY         STZ        SCALE        ALF         THETA INMODE NODES NPS INTS)
   0.00000    0.00000    10.00000   30.00000     0.00000     0.00000     3     0    0    0      (NDSEC=   3)   (SECTION 1)

     (BX         BY         DELZ          (  NBP )
   0.00000    0.00000    0.00000          (    1 )
   0.20000    0.06000    0.00000          (    2 )
   0.40000    0.06000    0.00000          (    3 )
   0.60000    0.01000    0.00000          (    4 )
   0.80000   -0.03000    0.00000          (    5 )
   1.00000    0.00000    0.00000          (    6 )

                                         (NODEC     NPC     INTC)
                                            3         5        1
                                                                (END OF CHORDWISE REGION     3 )
     (STX        STY         STZ        SCALE        ALF         THETA INMODE NODES NPS INTS)
  15.00000    0.00000    43.00000   20.00000     0.00000     0.00000     0     2    4    3      (NDSEC=   4)   (COPY SECTION 1)
     (STX        STY         STZ        SCALE        ALF         THETA INMODE NODES NPS INTS)
  15.00000    2.00000    45.00000   20.00000     0.00000     0.00000     2     2    0    0      (NDSEC=   5)   (SECTION 2)

     (BX         BZ         DELY          (  NBP )
   0.00000    0.00000    0.00000          (    1 )
   0.20000    0.03500    0.00000          (    2 )
   0.40000    0.06500    0.00000          (    3 )
   0.60000    0.06000    0.00000          (    4 )
   0.80000    0.03500    0.00000          (    5 )
   1.00000    0.00000    0.00000          (    6 )

                                         (NODEC     NPC     INTC)
                                            3         5        1
                                                                (END OF CHORDWISE REGION     5 )

     (STX        STY         STZ        SCALE        ALF         THETA INMODE NODES NPS INTS)
  20.00000   30.00000    45.00000   10.00000    -5.00000     0.00000     0     5    5    0      (NDSEC=   6)   (COPY AND TWIST
                                                                                                                  SECTION 2)
(END OF INPUT LIST FOR PATCH GEOMETRY)   (FOR TIP TWIST)

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

Figure 7. Concluded.

(c) More Complicated Tail Input Details.

scaling the root section. Here, however, the section is pitched down using the pitch angle control, ALF, to model an appropriate value of section twist. Since both surfaces and the connecting fairing are being modelled as one patch, the chordwise distribution of subdivided panels must be conserved. This does not require, as in this example, that the same number of points be input provided that the chordwise node cards for each section have a non-zero value for NPC, the number of panels chordwise, and that this is repeated at each spanwise station.

3.1.4 Rotors--Type-4 Patches

In the body/rotor analysis, two models of the rotor are constructed. They are the detailed blade element model which is to be discussed later and the panel model which provides the coupling between the rotor and fuselage flow fields. The panel model of the rotor is constructed in much the same way as the bodies of rotation discussed above with the added fact that the chordwise and spanwise (in the rotor framework radial and azimuthal) panel breakdown forms the basis for the radial spacing of blade stations and the azimuthal increments in the blade element calculation.

The rotor is modelled using a disc-like array of panels generated in exactly the same way as the bodies of revolution. The panels are represented, as are all panels in program VSAERO, by a combination of source and doublet singularities. In a type-4 patch both source and doublet elements of the singularity are specified (known as a result of the blade element calculation) and are passed over, within the program, from the blade element to the panel calculation. Part I of this report contains an explanation of the form of the singularities. Each rotor disc must form a separate patch preceded by the appropriate patch card and it is recommended that they also be identified as a separate component for ease of manipulation and the separate accumulation of loads. Figure 8(a) and (b) shows how a typical main rotor may be generated.

The input for this example, Figure 8(b), begins with a patch card with IDENT set to four (4) to signify a rotor. This is followed by the section card, placing the rotor center in the global frame with the appropriate values of STX, STY and STZ and announcing that a body of revolution is to be generated with NODES=-3, -4 or -5. Using this approach, INMODE is most commonly two (2) and the line defining the rotor disc is input in the y = 0.0 plane with values of x and z and rotated about the x-axis (default). It is at this stage that blade coning can be introduced, as in the example. With this simple form only two points are required, but, of course, any higher-order description may be used to generate curved rotor disc surfaces. In the example, the point closest to the axis forms the innermost defining station for the aerodynamic parts of the blade and the outer point the tip radius. Normally the blade radius is broken down

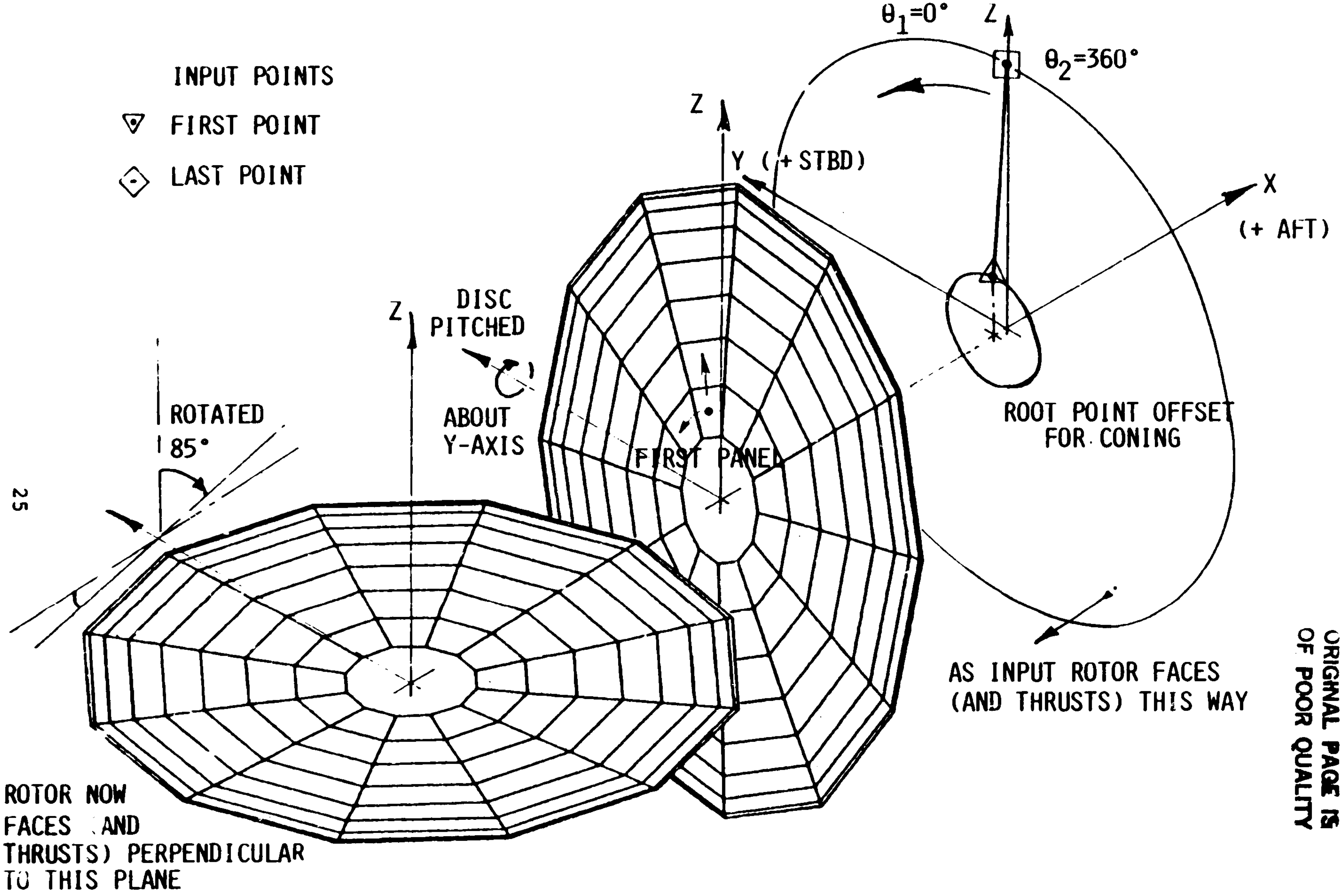


Figure 8. Main Rotor Modelling.

(a) Schematic.

* NOTE: TYPE 4 PATCH FOR ROTOR

```
    (CTX        CTY        CTZ        SCAL       THET)        (COMPONENT CARD)
100.00000    0.00000  100.00000  400.00000    85.00000                                                 (NCOMP=  2

 *(IDENT    MAKE    KOMP    KLASS)          ********************
     4        0       0       0              SIMPLE MAIN  ROTOR     (PATCH CARD)                    (NPATCH=   2 )
                                            ********************

    (STX        STY        STZ        SCALE      ALF        THETA  INMODE NODES NPS  INTS)
  0.00000    0.00000    0.00000    1.00000    0.00000    0.00000      2    -4    12    3          (NDSEC=   3)  (SECTION CARD)
    (BX         BZ        DELY          (  NBP  )
 -0.01000    0.20000    0.00000         (    1  )
 -0.05000    1.00000    0.00000         (    2  )
                                 (NODEC     NPC     INTC)
                                     3        8        2
                                                      (END OF CHORDWISE REGION    3 )

   (THETA2     THETA1        BODY OF REVOLUTION)
 360.00000    0.00000
```

ORIGINAL PAGE IS
OF POOR QUALITY

Figure 8. Concluded.

(b) Input Details.

automatically specifying, as in the example, the inner and outer points and the number and distribution of panels to be formed on the chordwise (radial) node card. INTC=2 is recommended for the radial breakdown since this concentrates the panels at the outer end of the radius. The number of panels is dictated by the detail required. Cases have been successfully executed with as few and 3 panels radially and the maximum set by program capacity is 20. Experience with conventional rotor performance programs has shown that fifteen segments radially is more than adequate for detailed blade studies.

Since the disc is being formed by the body of revolution feature, the number of azimuth stations is set by the NPS parameter on the section card and the distribution should be uniform with INTS set equal to three (3). The input is completed by including the rotation angle range of 360o.

With the disc panelled in the input location about the x-axis, all that remains is to pitch it into the appropriate attitude. This is accomplished using the rotations available on the component card. The default rotation is about the component y-axis with a positive rotation being nose-up. In the example, it was determined that the tip path plane should be 5° nose-down so the rotation required on the component card to place the disc in the correction orientation was +85o. The values of the component origin, CTX, etc. then locate the rotor relative to the rest of the configuration

If a more involved rotation was required, say to apply some lateral tilt to a main rotor or to position a tail rotor, this can be done by activating the option to specify the axis of rotation. This is done by setting the scale parameter on the component card to a negative value and inserting on the following card two points specifying the rotation axis. The details for applying this technique are discussed in full in the VSAERO program guide and are summarised in Figure 9(a) and (b) for the case of a tail rotor. Here, as a further example of the program flexibility, the rotor is input with unit radius and the scale parameter on the component card is used to bring the radius up to the full scale value. A further point to note in the tail rotor model is that the rotation angle range has been changed to: $\theta_2 = 450.0$, $\theta_1 = 90.0$. This is required to line up the first panel in the panel model of the rotor with the zero azimuth location in the blade element model. Since this is conventionally over the tail for the main rotor and along the aft pointing horizontal radial for a tail rotor, the tail rotor panel model before rotation must start in the horizontal position. The same effect could, of course, be achieved by using INMODE=3 or 4, carrying out the original line definition in the z = 0 plane and by returning to the $\theta_2 = 360.0$, $\theta_1 = 0.0$ degrees rotation range.

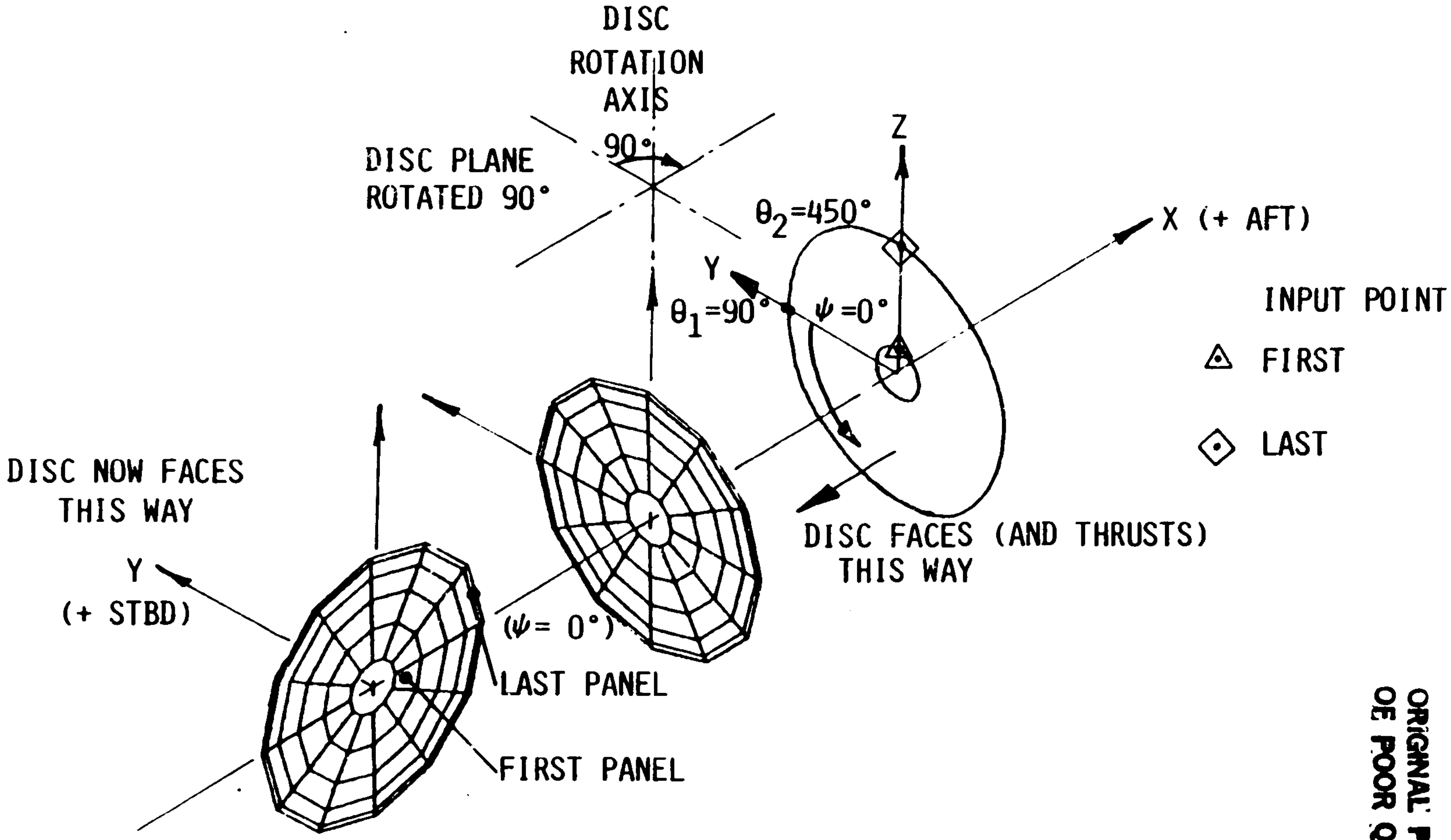


Figure 9. Tail Rotor Modelling.

(a) Schematic.

```
   (CTX       CTY       CTZ        SCAL      THET)       (COMPONENT CARD)
600 00000 -10 00000 100.00000 -80 00000  90.00000                                                    (NCOMP=  3

   (CPX       CPY       CPZ       CHX       CHY       CHZ)    (MODIFIED COMPONENT ROTATION AXIS
 0 00000   0 00000   0.00000   0 00000   0.00000  10 00000     --SELECTED BY NEGATIVE ON SCALE)

 (IDENT   MAKE   KOMP   KLASS)          ********************
     4      0      0      0               SIMPLE TAIL ROTOR     (PATCH CARD)              (NPATCH=   3 )
                                        ********************

   (STX       STY       STZ       SCALE      ALF       THETA INMODE NODES NPS INTS)
 0 00000   0.00000   0 00000   1 00000   0.00000   0 00000     2    -5   12    3        (NDSEC=  16)     (SECTION CARD)

   (BX        BZ        DELY        (  NBP  )
 0 00000   0 20000   0 00000       (    1  )
 0 00000   1 00000   0 00000       (    2  )

                                   (NODEC    NPC    INTC)
                                       3       5       2
                                                         (END OF CHORDWISE REGION   17 )

  (THETA2    THETA1       BODY OF REVOLUTION)
 450 00000  90 00000

(END OF INPUT LIST FOR PATCH GEOMETRY)      (ROTATION TO ψ = 0° FOR ROTOR ALONG X-AXIS)

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

ORIGINAL PAGE IS
OF POOR QUALITY

Figure 9. Concluded.

(b) Input Details.

4.0 WAKE INPUT

4.1 Wake Grid Planes:- CARD SETS 17 and 18

In program VSAERO the development of the wakes after they are shed is calculated in a series of planes perpendicular to the onset flow starting upstream of the first shedding location. The way in which these planes are set up is described in full in the VSAERO program guide and the recommendations made there for fixed wing aircraft and general shapes apply equally well to rotor/body problems.

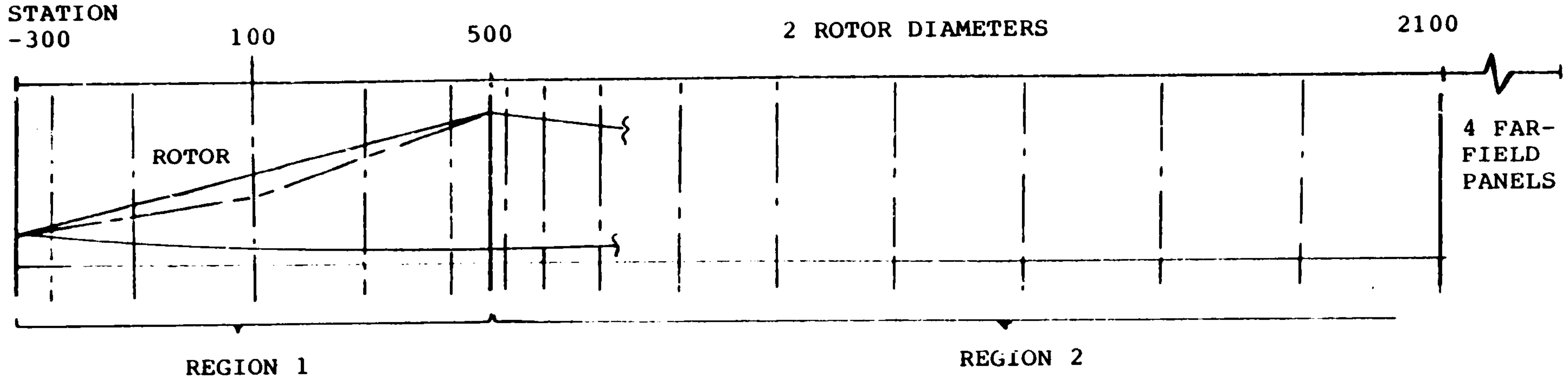
Figure 10(a) illustrates how the defining grid planes would be set up for a typical helicopter study. Note that the first grid plane corresponds to the leading edge of the disc. As a general guide for isolated rotors, the grid planes should be distributed over the disc to correspond to the azimuthal breakdown of panels using a full cosine distribution (dense at leading- and trailing-edges, open in the center) with steps equal to half of the total rotor azimuthal increments. Downstream of the trailing edge of the disc, the first two disc diameters of distance could be broken into ten segments with half cosine spacing and then a further six diameters with four large segments to fill in the far-field effects.

In regions where substantial flow distortion is expected, say around the front of a fuselage or if details of the passage of a wake over a wing leading edge are required, then regions of more closely set grid planes are required. Figure 10(b) is an example of how this may be achieved.

As with the input of body sections, the wake stations are specified by inputting a series of values separated with node cards which indicate how intervals are to be divided up. The number of divisions may be specified using NPC; the distribution is specified as with body input using the parameter, INTC, and as before, individual stations may be input and used without further subdivision by setting NPC equal to zero. The last wake grid plane should be followed by a node card with NODE set equal to three (3) to terminate wake grid plane input.

4.2 Separation Line Specification:- CARD SETS 19 through 23

In the version of program VSAERO described in this report, two types of wake are available. These are the type-1 wakes, springing from lifting bodies, and the type-4 wakes, enclosing regions of flow with energy states higher or lower than the surroundings. The way in which these wakes are described are generally similar, the attachment process is identical and they only differ in that for the type-4 wakes the velocity jump across the jet sheet must be identified in order that the program may assign the correct vortex strength to the sheet elements.



```
INPUT LIST FOR WAKE DATA IN SUBROUTINE WAKGOM/
*********************************************************************

(VARIABLES ARE IDENTIFIED IN PARENTHESES FOR CONVENIENCE)

   (DX        ( NBP ))
 -300.0000    (   1 )
  500.0000    (   2 )

 2100.0000    (   3 )

 6900.0000    (   4 )
```

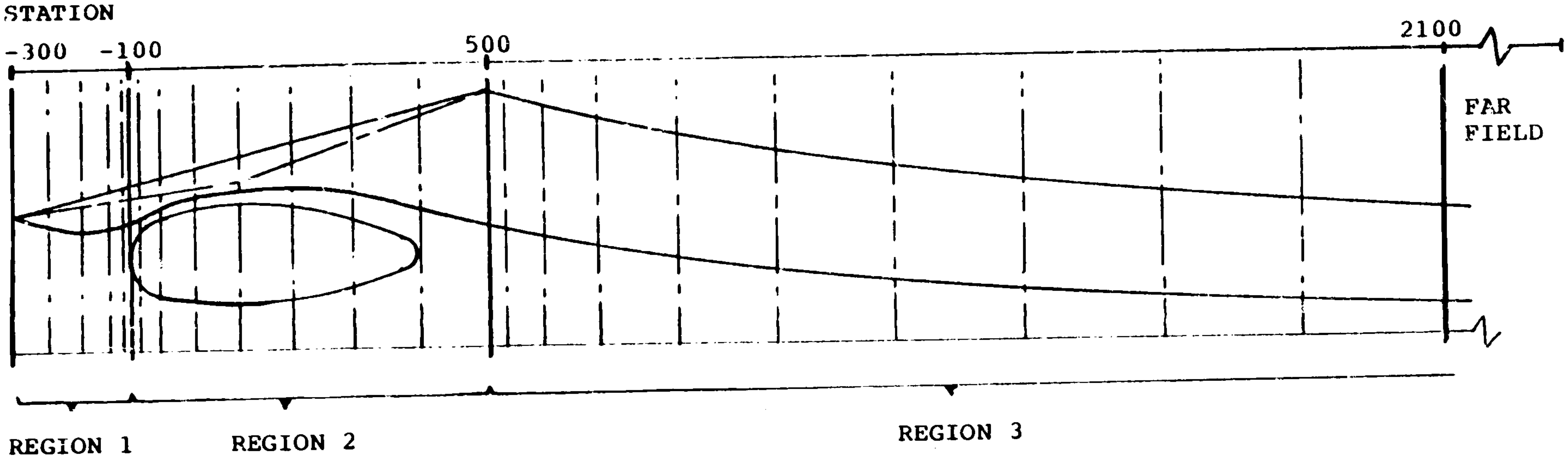
* NOTE: FIRST GRID PLANE MUST BE AT OR UPSTREAM OF FIRST SHEDDING EDGE.

```
(BASIC POINTS FOR WAKE-GRID-PLANE STATIONS IN SUBROUTINE WGRID)

(NODE   NPC  INTC)
    1     6     0

(NODE   NPC  INTC)
    1    10     1

(NODE   NPC  INTC)
    3     4     1
```

(NODE NPC INTC) 1 6 0	REGION 1
(NODE NPC INTC) 1 10 1	REGION 2
(NODE NPC INTC) 3 4 1	FAR FIELD

Figure 10. Wake-Grid-Plane Definition.

(a) Simple Isolated Rotor.



(BASIC POINTS FOR WAKE-GRID-PLANE STATIONS IN SUBROUTINE WGRID)

```
   (DX         ( NBP ))
-300.0000      (   1 )
-100.0000      (   2 )

                           (NODE  NPC  INTC)
                              1    5     2

 500.0000      (   3 )

                           (NODE  NPC  INTC)
                              1    8     1

2100.0000      (   4 )

                           (NODE  NPC  INTC)
                              1   10     1

6900.0000      (   5 )

                           (NODE  NPC  INTC)
                              3    4     1
```

REGION 1 PLANES CLOSER TOGETHER AS BODY IS APPROACHED

REGION 2 PLANES OPEN OUT AWAY FROM NOSE

REGION 3

Figure 10. Concluded.

(b) Embedded Body.

While the uses of the type-1 wakes are clear cut, on wing and other lifting-surface trailing edges, the use of type-4 wakes requires some additional explanation for the helicopter application. Several elements of helicopter configurations shed wakes where changes in energy level are involved. Most obvious is the efflux from the powerplant. Less clear, but nonetheless important, is the wake from the rotor head assembly. Since, in this case, the shape is normally not modelled in detail and the drag coefficient of the assembly is generally known, it is possible to model the overall effect of the component by constructing a bulk model and attaching a type-4 wake along its aft facing edges. The rotor model also uses a type-4 wake.

Each individually identified wake is treated in much the same way as a patch is handled in the body input and, as in the case of the patch, it must be preceded by a wake (patch) card, CARD 19. This card contains the information which identifies the wake type, IDENTW=1 for a regular wake or =4 for a jet model/separated base/rotor wake; indicates whether the wake is held fixed or is relaxed, IFLEXW=1 or 0, respectively; and a descriptive title.

4.2.1 <u>Wake Definition for Type-1 Wakes</u>

The method of attaching the wake along the separation line is explained in detail in the VSAERO Program User's Guide. The following notes should be considered a supplement to the original, more detailed presentation.

The separation line is applied to the surface in such a way that the local attached flow comes from the <u>left</u>. In the example shown in Figure 11 the separation is parallel to side 2 of the patch. The string of panels to which the wake sheet is attached is identified on Card 20 as follows.

(KWPACH)	(KWSIDE)	(KWLINE)	(KWPAN1)	(KWPAN2)	(INPUT)	(NODEWS)
1	2	0	1 (or 0)	6 (or 0)	2	0

Default for the set of panels alongside KWSIDE

Using the default, 0, for KWPAN1, KWPAN2 in cases where the string of panels is the complete set parallel to side KWSIDE is recommended

KWPACH is the patch to which the wake is attached and KWSIDE the patch side parallel to and in the same direction as the shedding line. If the sheet is attached along the patch edge, KWLINE takes the default value of zero. However, if the sheet were attached along an internal panel edge, this would be identified by counting, in this case along side 1, until the shedding panel

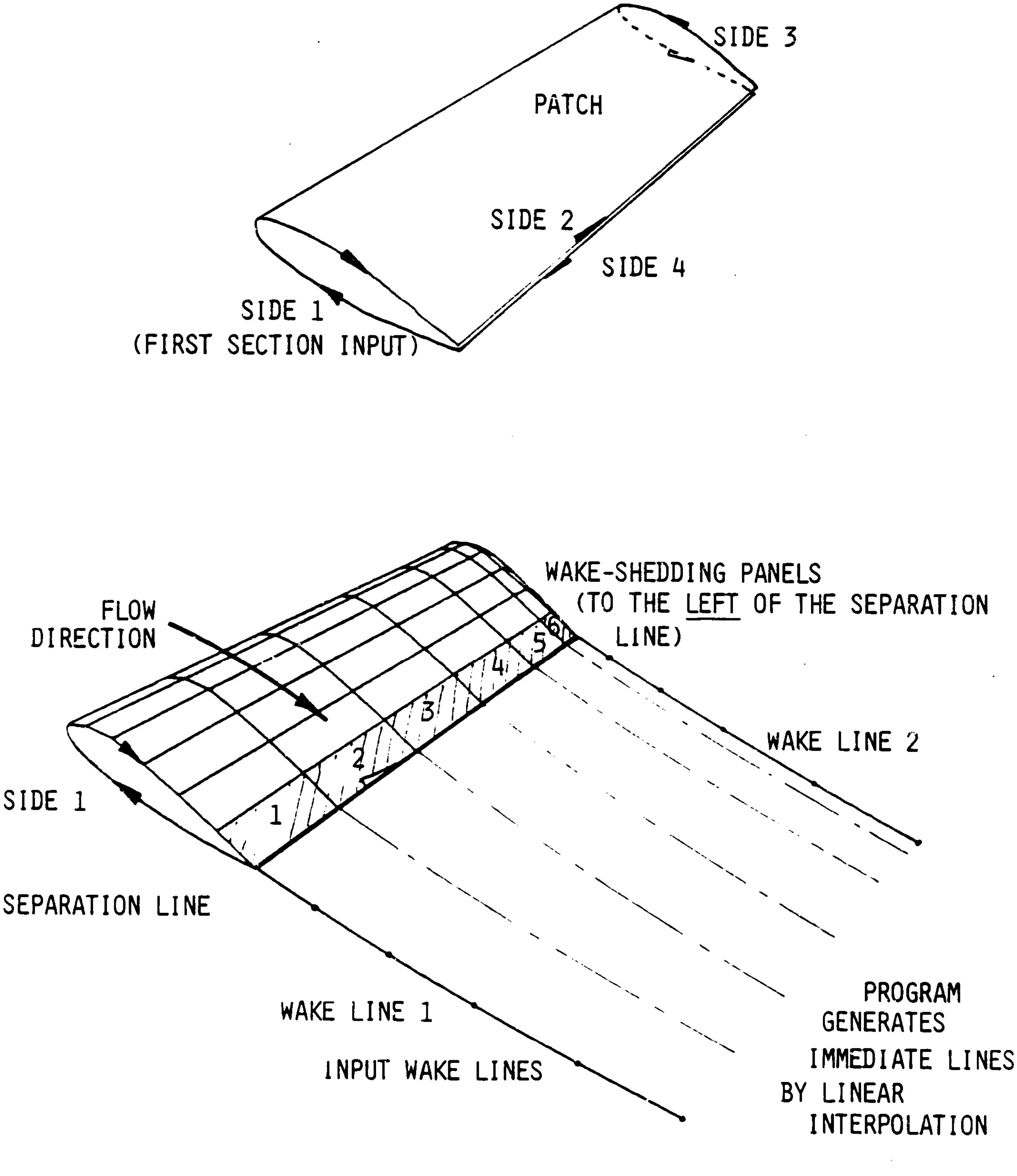


Figure 11. Type-1 Wake-Wing Separation Lines.

was reached. This number, then, defines KWLINE. KWPAN1 and 2 define the spanwise extent of the shedding; again the default values of zero give full span, and numbering proceeds across the patch in the direction of the shedding line where only part-span shedding is present. Card 20 is equivalent to the section card, Card 11, of the body input.

Because INPUT is 2 on card 20 above, this card must be followed by CARD SET 21/22 defining the geometry of streamwise wake-line, LINE 1. As with the input of body section data, the wakes may be prescribed in a number of ways. For the current example, INPUT=2 indicates that the program expects data to be entered in X and Z coordinates with a local origin at the shedding point. As with the body input, wake filaments may be described with any level of detail desired and the wake segmented with node cards separating the different elements. For the simple case used here, if an initially rectilinear wake was required, it should be enough to prescribe a point in the far field downstream and a node card. If the wake had to pass an obstruction, say another body or a flap, a more detailed path may be prescribed. Both examples are outlined in Figure 12 below. In both cases the X and Z coordinates are relative to an origin at the trailing edge. CARD SET 21/22 is equivalent to CARD SET 12/14 of the body input.

When the input is complete the wake is terminated with another CARD 20:

					(INPUT)	(NODEWS)
0	0	0	0	0	0	3

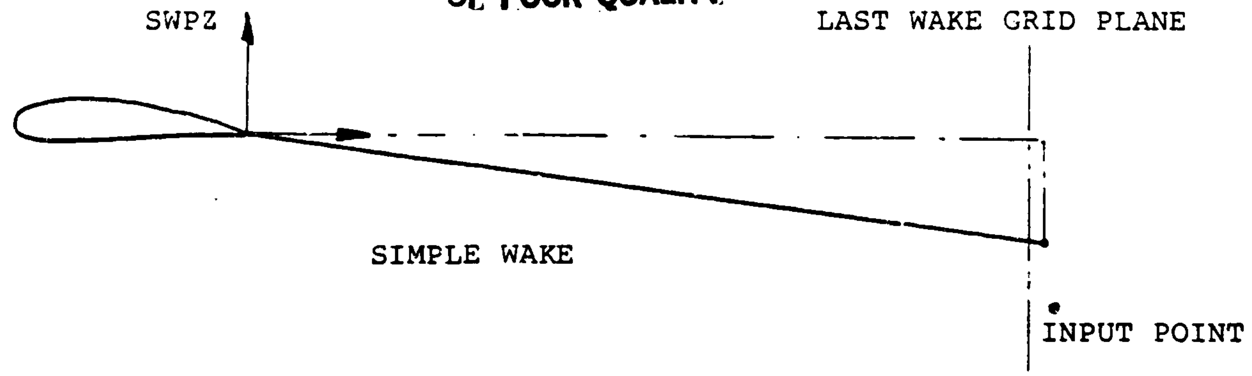
The string of wake-shedding panels has already been defined

End of this wake but another wake must follow. The final wake <u>must</u> have a 5 here

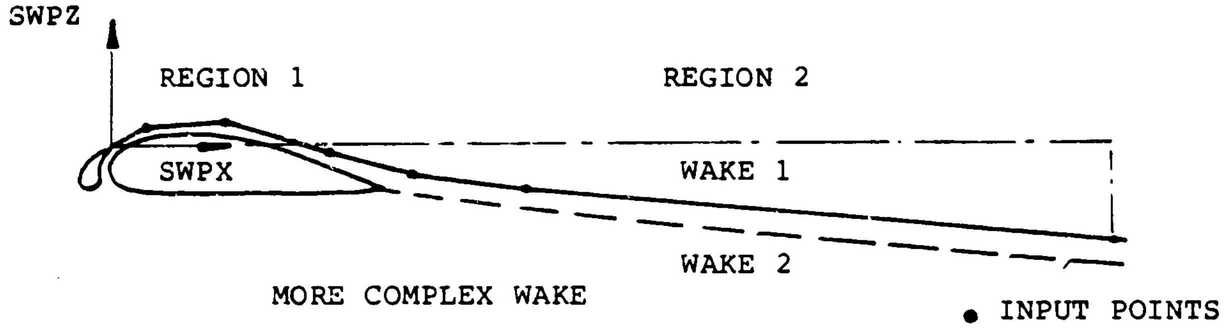
This copies LINE 1 to LINE 2 to complete the wake geometry description. (Note that INPUT>0 can be used here if a different wake line geometry is required, in which case CARD SET 21/22 must follow for LINE 2)

<u>Note</u>: In the case of type-1 wakes (IDENTW=1 on CARD 19) it is possible to turn the wake over and attach it along side 4 of the patch--in this case it would start at the tip and move inboard. CARD 20 would then be:

ORIGINAL PAGE IS
OF POOR QUALITY



```
(SWPX     SWPZ
4000.00   200.00
                                (NUMBER  NPC  INTC)
                                     3    10     1
```



```
(SWPX      SWPZ                       (NUMBER  NPC  INTC)
200.00     100.00
600.00     125.00
1200.00    -50.0                                              REGION 1
1600.00    -200.00
                                  [illegible]    12  [illegible]
2200.00    -300.00
3000.00    -800.00                                            REGION 2
                                  [illegible]    10  [illegible]
```

(WAKE 2 NOT SHOWN FOR CLARITY)

Figure 12. Wake Trajectory Definition.

(KWPACH)	(KWSIDE)	(KWLINE)	(KWPAN1)	(KWPAN2)	(INPUT)	(NODEWS)
1	4	0	1 (or 0)	7 (or 0)	2	0

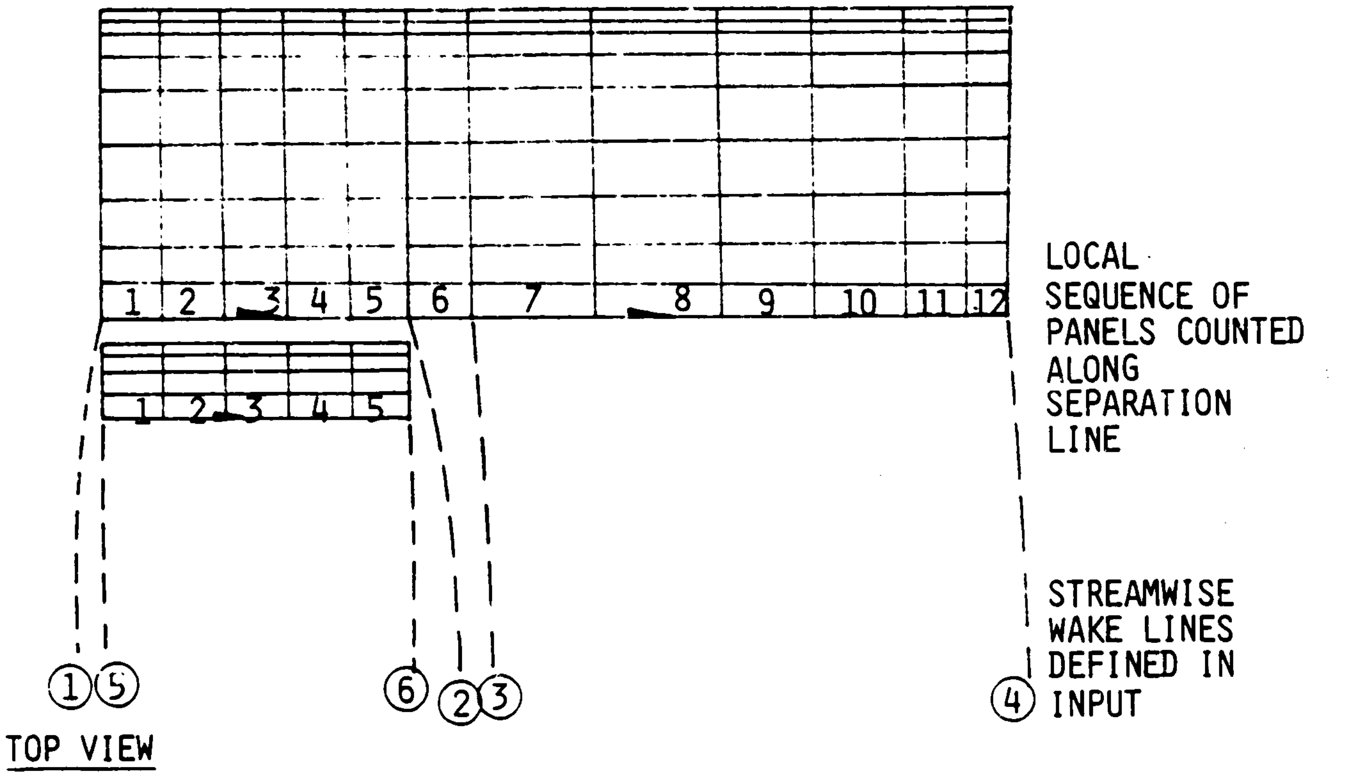
No change

In the initial example, the wake input at the first section was simply copied across the span, but in many cases this would be inappropriate. A more involved example is given below.

Changing the wake line geomtry in the middle of a patch is achieved by simply breaking the string of wake shedding panels into sets. This is possible since there is an opportunity to define a streamwise wake line at the beginning of each string of wake-shedding panels and at the end of the last string. This is explained by Figure 13. The input for these wakes would be as follows

```
                     IDENTW
CARD 19                1        0        0       Wing Wake

CARD 20                1        2        0        1        5        2       0



CARD SET 21/22       SWPX(1), SWPZ(1)
for Line 1                                     INPUT=2 Format
                     SPWX(2), SWPZ(2)
                        .          .
                        .          .
                        .          .
                                                 (NODEWS)  (NWP)  (INTC)
                                                     3      10      3


CARD 20                1        2        0        6        6        0       0

                                             KWPAN1, KWPAN2  INPUT =0
                                                             Copies Line 1
                                                             into Line 2

CARD 20                1        2        0        7       12        2
                                                                INPUT for
                                                                Line 3
```

ORIGINAL PAGE IS
OF POOR QUALITY



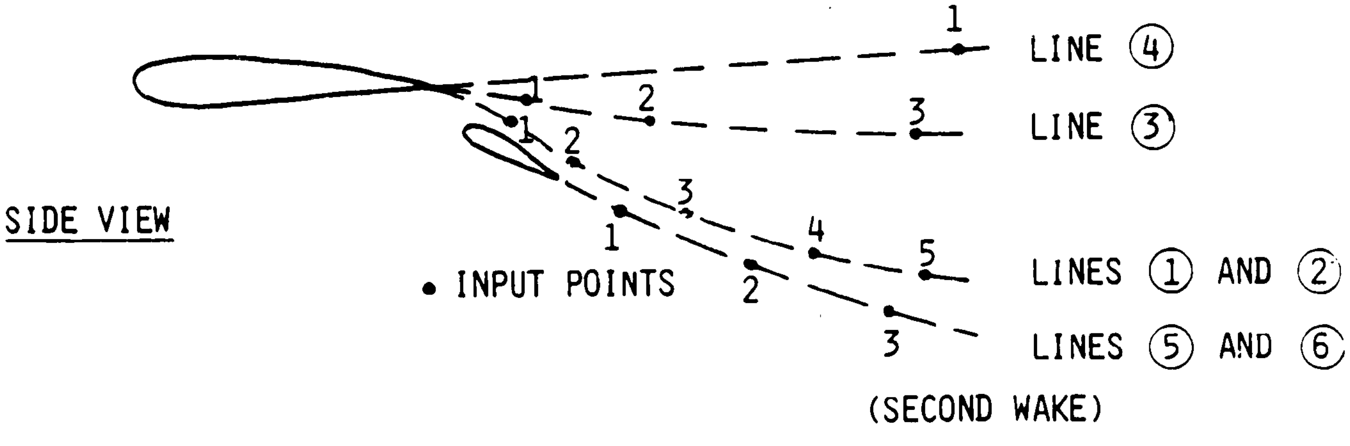


Figure 13. Wake Shedding Schematic--Multi-line Input.

```
CARD SET 21/22    SWPX(1), SWPZ(1)
For Line 3        SWPX(2), SWPZ(2)
                     .        .
                     .        .
                     .        .
                                         (NODEWC) (NWP) (INTC)
                                             3     10     3

CARD 20             0     0     0     0     0     2     3
                                                  NODEWS=3
                                                  terminates
                                                  this wake


CARD SET 21/22    SWPX(1), SWPZ(1)
for Line 4        SWPX(2), SWPZ(2)
                     .        .
                     .        .
                     .        .
                                         (NODEWC) (NWP) (INTC)
                                             3     10     3

CARD 19             1     0     0     Flap Wake

CARD 20             2     2     0     0     0     2     0


CARD SET 21/22    SWPX(1), SWPZ(1)
for Line 5        SWPX(2), SWPZ(2)
                     .        .
                     .        .
                     .        .
                                         (NODEWC) (NWP) (INTC)
                                             3     10     3

CARD 20             0     0     0     0     0     0     5

                         INPUT=0 Copies Line      NODEWS=5
                         5 (i.e., the previous    for final
                         line) into Line 6        wake
```

If the wake separation line passes over a number of patches then a separate string of wake-shedding panels must be specified for each patch. (Multiple strings of wake-shedding panels may still be specified within a patch as shown above). This is illustrated with the example shown in Figure 14. Following the sketch, the multipatch input for this wake becomes:

	KWPACH	KWSIDE	KWLINE	KWPAN1	KWPAN2	INPUT	NODEWS
CARD 20	1	2	0	0	0	2	0
CARD SET 21/22 FOR WAKE LINE 1							
CARD 20	2	2	0	0	0	0	0
				(Copies wake line 1 into wake line 2)			
CARD 20	3	1	0	5	6	2	0
CARD SET 21/22 FOR WAKE LINE 3							
CARD 20	3	2	0	0	0	2	0
CARD SET 21/22 FOR WAKE LINE 4							
CARD 20	0	0	0	0	0	2	5
						End of Wake Input	
CARD SET 21/22 FOR WAKE LINE 5							

__WARNING__: Before leaving the discussion of type-1 wakes, it is important to note that the panelling on the upper and lower sides of the wake __must__ match. This is required so that the correct doublet jump across the wake may be properly evaluated and shed into the wake columns.

ORIGINAL PAGE IS
OF POOR QUALITY

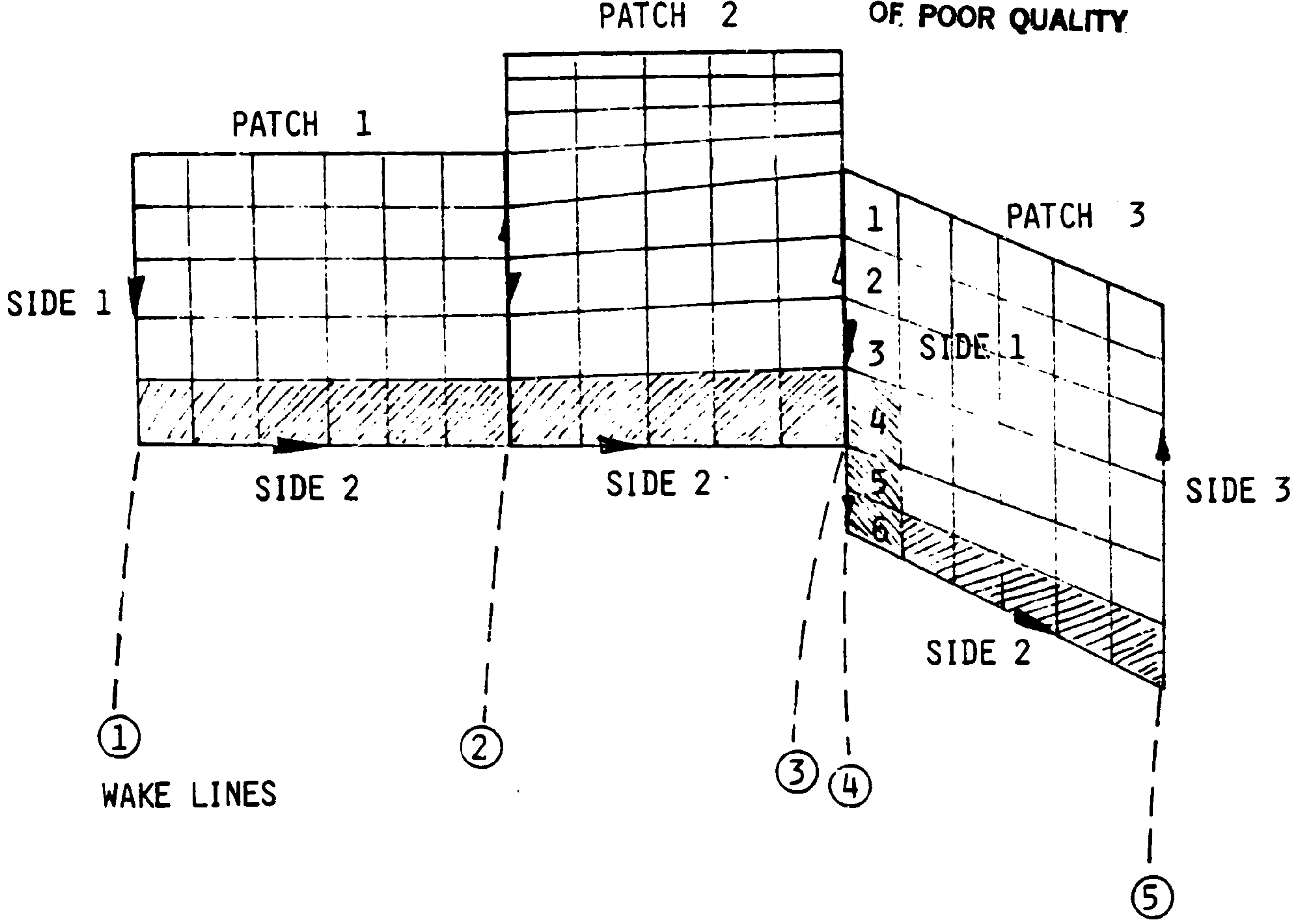


Figure 14. Multiple Patch Wakes.

4.2.2 Wake Definition for Type-4 Wakes on Bodies

Type-4 wakes are specified in the same manner as type-1 wakes, and are fed by flow from the left when looking along the direction of the separation line. Figure 15 shows two examples of this type of wake.

In the jet efflux case, Figure 15(a), the nacelle and base are all part of the same patch and the wake is attached along the aft-facing edge. This is parallel to side 2 of the patch on the 17th row of panels along side 1 (see Figure 5 for details of nacelle panelling). Consequently, KWPATCH takes the nacelle patch number, KWSIDE=2 and KWLINE=17. Since the wake is attached across the full width of the patch, KWPAN1 and KWPAN2 are set to zero.

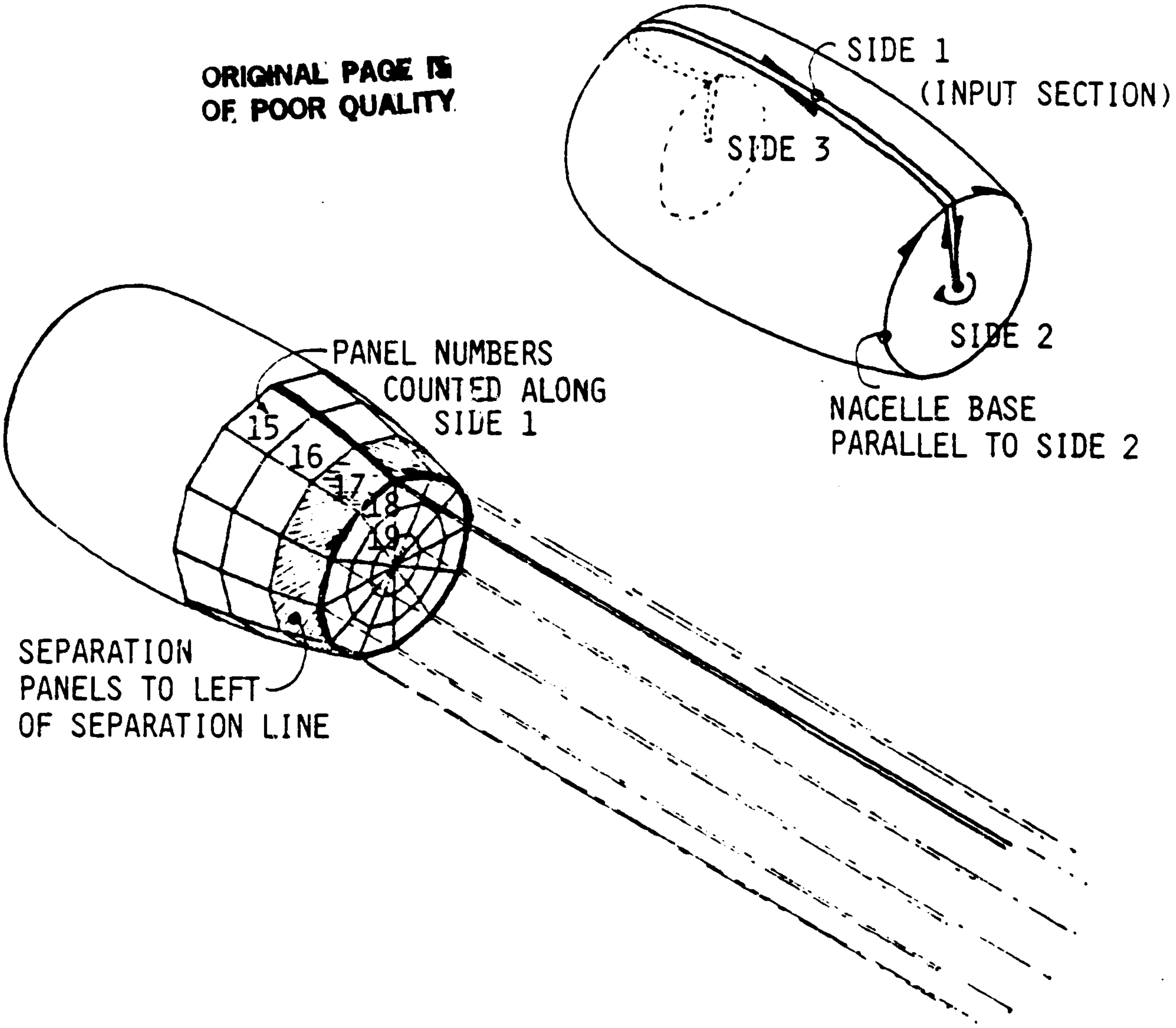
In the case of the rotor head block model, Figure 15(b), the block is in three parts with separate patches for the front and rear faces, patches 1 and 3, and the main surface as patch 2. Here, the wake is attached along the edge, side 3, of patch 2. Consequently, KWSIDE=3, KWLINE=0 (the default for the edge) and KWPAN1 and KWPAN2 are again zero, since the wake goes all around the edge of the patch.

The wake geometry for type-4 wakes is defined in a manner identical to that required for type-1 patches on CARD SETS 21/22.

Since type-4 patches involve regions of higher or lower energy and the wake strength is set to produce the appropriate internal flow, the inner and outer velocities (normalized with respect to a unit onset flow) must be specified. This is done on CARD SET 23 immediately following the wake definition.

Input for normal type-4 wakes (i.e., those attached to normal wing or body patches) is completed by ensuring that the flow into the wake cavity, from the area of panels enclosed by the wake, matches the flow down the inside of the wake column. This is done by using the option available within the program to suspend the usual assumption of zero flow through the boundary and by replacing it with appropriate normal velocity. This would be positive for an outflow. The special options available with CARD SET 8 provide this capability.

The first entry on Card 8, NORSET, sets the number of regions in which the transpiration velocity is to be changed. If this is non-zero, the program then expects to read a Card 8A for each region. Explained in detail in the VSAERO manual, Card 8A, identifies the patch and the rows and columns involved, and specifies the velocity value. Examples are given of typical CARD SET 8/8A input for the two cases in Figure 15.



KWSIDE=2; KWLINE=17

KWPAN1 AND KWPAN2 = 0

CARD 8

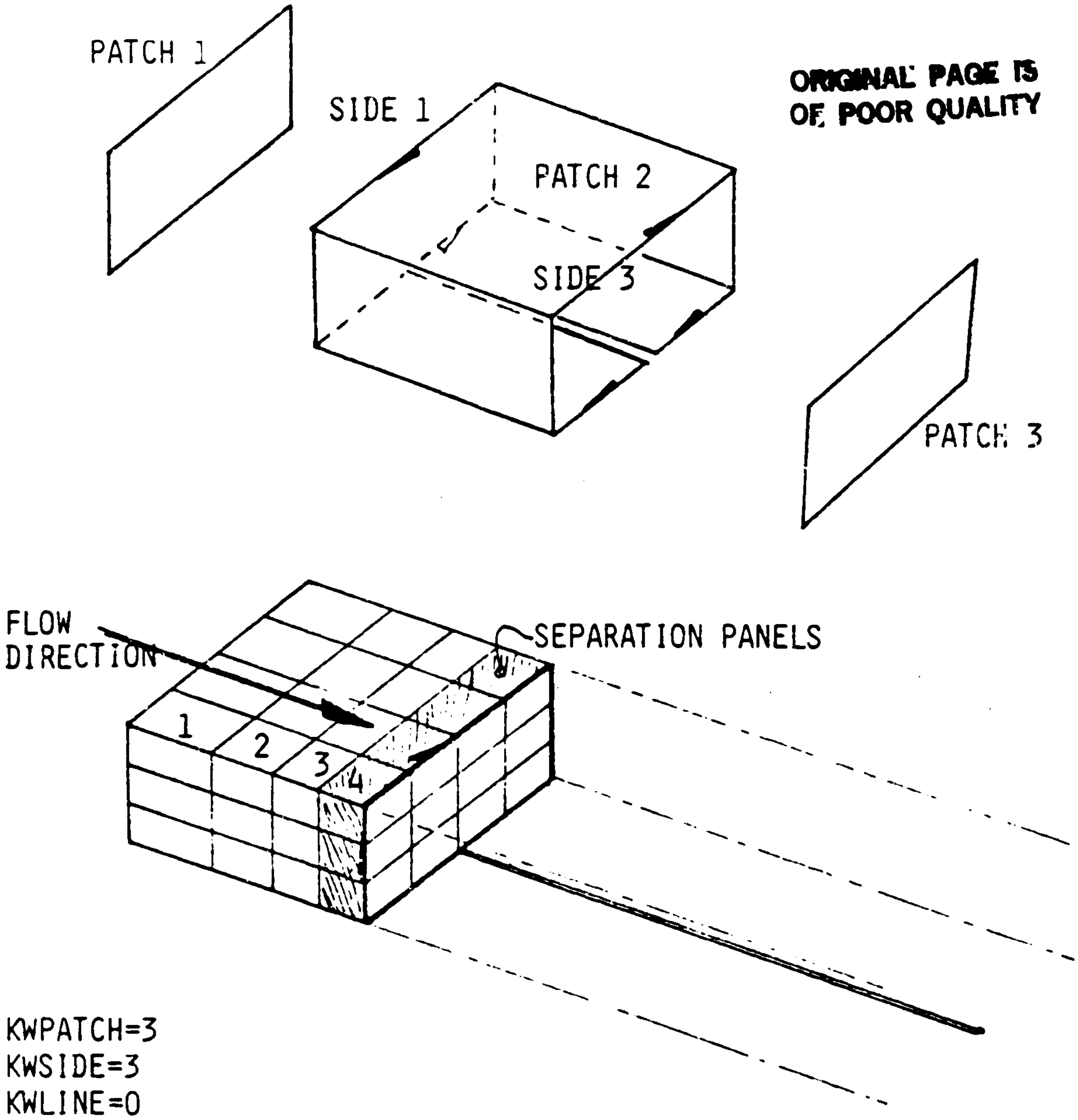
(NORSET	NVORT	NPSOM	JETPAN)
1	0	0	0

CARD 8A

(NORPCH	NORF	NORL	NOCF	NOCL	VNORM)
1	18	1	0	0	2.5

DEFAULT FULL WIDTH (TYPICAL)

Figure 15(a). Type-4 Wake on Nacelle.



KWPATCH=3
KWSIDE=3
KWLINE=0
KWPAN1 AND KWPAN2 = 0

CARD 8:

(NORSET	NVORT	ETC.)
1	0	

CARD 8A:

(NORPCH	NORF	NORL	NOCF	NOCL	VNORM)
3	0	0	0	0	0.0
	DEFAULT FULL PATCH				TYPICAL

Figure 15(b). Type-4 Separated Wake on Block Model of Rotor Head.

CARD SET 8/8A is also used to identify sets of panels which are known to fall inside regions of higher/lower energy level. This is required if correction of the calculated values of the pressure coefficients to account for the altered dynamic head of the region is desired. As with the outflow option above, the number of sets of panels to be modified are identified with JETPAN on CARD 8 and the patch row and column information supplied on CARD 8A for each set. The incremental dynamic head is calculated with the wake sheet values of VIN and VOUT input on CARD 23.

4.2.3 Wake Definition for Type-4 Wakes on Rotors

The wakes used in the rotor calculation are a special form of the type-4 wakes discussed above and are invoked by the program automatically when a type-4 wake is attached to a type-4 rotor patch. Wake attachment is similar to that described for other type-4 patches above, but extra care must be taken to completely enclose the wake volume. This is detailed in Figure 16.

Considering how the rotor patch is generated by rotating the input section, the chordwise (in this case radial) direction is side 1 of the patch. The outer edge of the disc becomes the spanwise direction and is side 2 of the patch. Side 3 and side 4 follow naturally to complete the definition. The card set for the wake is as follows.

	(IDENTW)	(IFLEXW)	(IDEFW)	(WNAME)
CARD 19	4	0	0	ROTOR WAKE TIP
	Type-4 Wake	Distorted wake will be calculated	Separation line defined by panel string, Card 20 must follow	

	(KWPATCH)	(KWSIDE)	(KWLINE)	(KWPAN1)	(KWPAN2)	(INPUT)	(NODEWS)
CARD 20	1	2	0	0	0	2	0
		Tip circle	Default attaches wake along patch edge	Default attaches wake along the full length of edge			

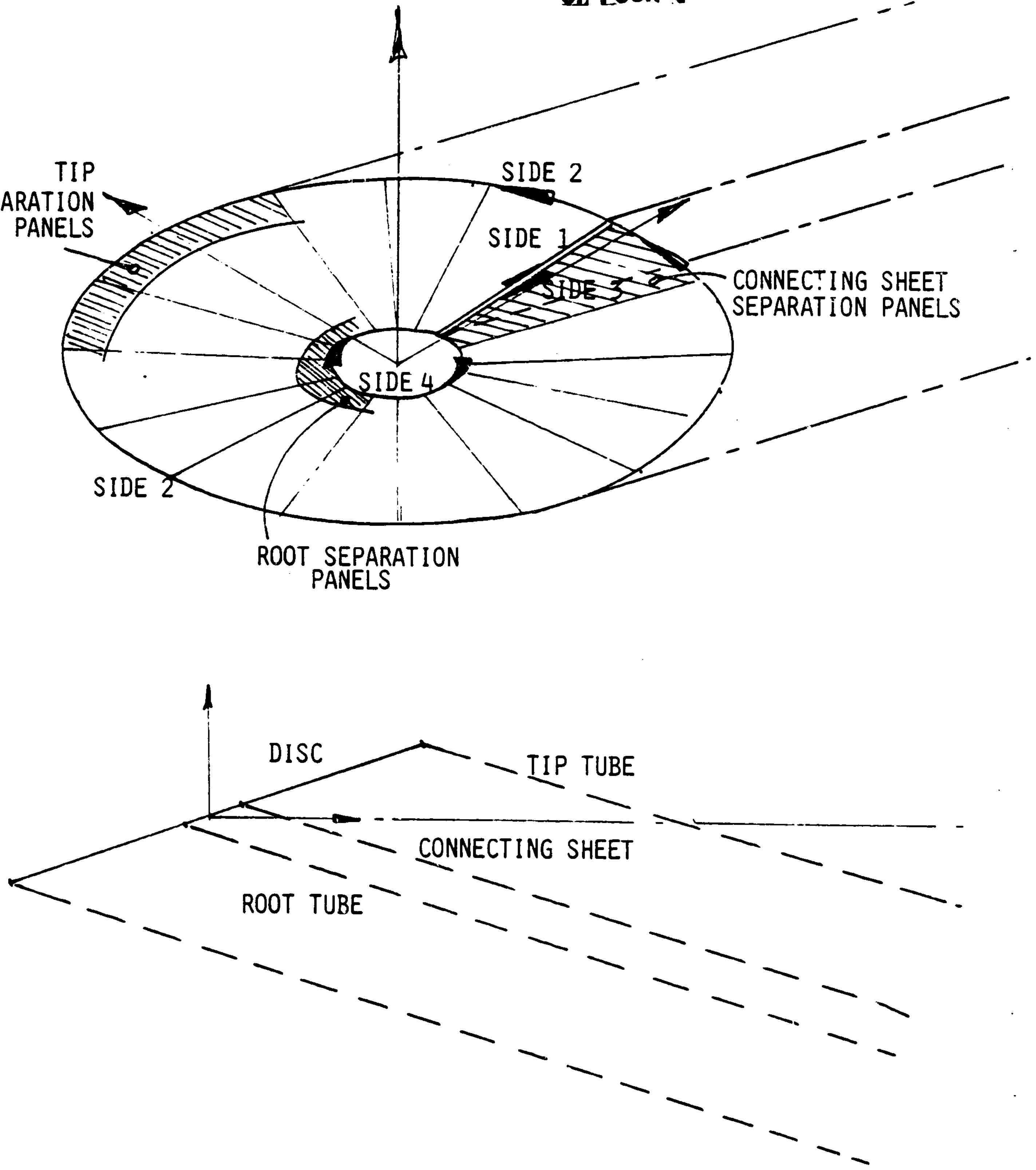


Figure 16. Rotor Wake Specification--Simple Isolated Rotor.

CARD SET 21/22: DEFINING WAKE FILAMENT AS IN TYPE-1 WAKES ABOVE.

	(KWPATCH)	(KWSIDE)	(KWLINE)	(KWPAN1)	(KWPAN2)	(INPUT)	(NODEWS)
CARD 20	0	0	0	0	0	0	3 terminates tip wake

copies filament input
on previous CARD 20 to
close wake column

	(IDENTW	IFLEXW	IDEFW)	(WNAME)
CARD 19	4	0	0	Rotor Wake Root

	(KWPATCH)	(KWSIDE)	(KWLINE)	(KWPAN1)	(KWPAN2)	(INPUT)	(NODEWS)
CARD 20	1	4	0	0	0	2	0

CARD SET 21/22: TO DEFINE WAKE LINES

	(KWPATCH)	(KWSIDE)	(KWLINE)	(KWPAN1)	(KWPAN2)	(INPUT)	(NODEWS)
CARD 20	0	0	0	0	0	0	3 Terminates root vortex

	(IDENTW	IFLEXW	IDEFW)	(WNAME)
CARD 19	1	0	0	Connecting Sheet

Note type-1 wake
for connecting sheet

	(KWPATCH)	(KWSIDE)	(KWLINE)	(KWPAN1)	(KWPAN2)	(INPUT)	(NODEWS)
CARD 20	1	3	0	0	0	2	0

CARD SET 21/22: TO DEFINE WAKE LINES

	(KWPATCH)	(KWSIDE)	(KWLINE)	(KWPAN1)	(KWPAN2)	(INPUT)	(NODEWS)
CARD 20	0	0	0	0	0	0	5 Last Wake Input

This example shows the simplest form of rotor wake input and provides an initially prescribed skewed cylinder form for the wake tube generated by copying the first filament input around the edges of the patch. This is adequate for cases where no body is in close proximity to the rotor. For cases where the fuselage presents substantial interference, a more involved wake specification is required. An example of this is provided in Figure 17 and below. The technique is identical to that illustrated above for type-1 wakes varying in a spanwise direction. For the example, the rotor disc has been divided into 16 azimuthal sections (columns). Although the analysis in program VSAERO can cope with an initially prescribed wake filament passing through a body, it is better from the point of view of numerical stability if all filaments are prescribed so as to pass over the outside. In the situation pictured in Figure 17, the fuselage is narrow relative to the disc panelling and only the three filaments from the front of the disc, from columns 8, 9 and 10, need to be bent to pass around the body. In the illustration, filament 1 is copied around the edge to filament 7. Filaments 8, 9 and 10 are input individually. Filament 11 is a return to the original trajectory and this is copied around until the wake closes at filament 17. The data set for this looks as follows. It should be noted that the filament is associated with the trailing corner of the panel in questions (corner 2 in the example shown).

	(KWPATCH)	(KWSIDE)	(KWLINE)	(KWPAN1)	(KWPAN2)	(INPUT)	(NODEWS)
CARD SET 20	1	2	0	1	6	2	0
				Attachment to columns 1-6		Input as X and Z	
CARD SET 21/22:	WAKE FILAMENT INPUT AS X AND Z RELATIVE TO SHEDDING POINT FOR FILAMENTS 1 TO 6 AND TO BE COPIED TO 7.						
CARD SET 20	1	2	0	7	7	0	0
				Last section of "constant" wake		Copies previous section	
CARD SET 20	1	2	0	8	8	2,3 or 4	0
				Filament 8		Input as required	
CARD SET 21/22:	WAKE FILAMENT INPUT AS X,Z OR X,Y OR X,Z AS NEEDED FOR FILAMENT 8.						

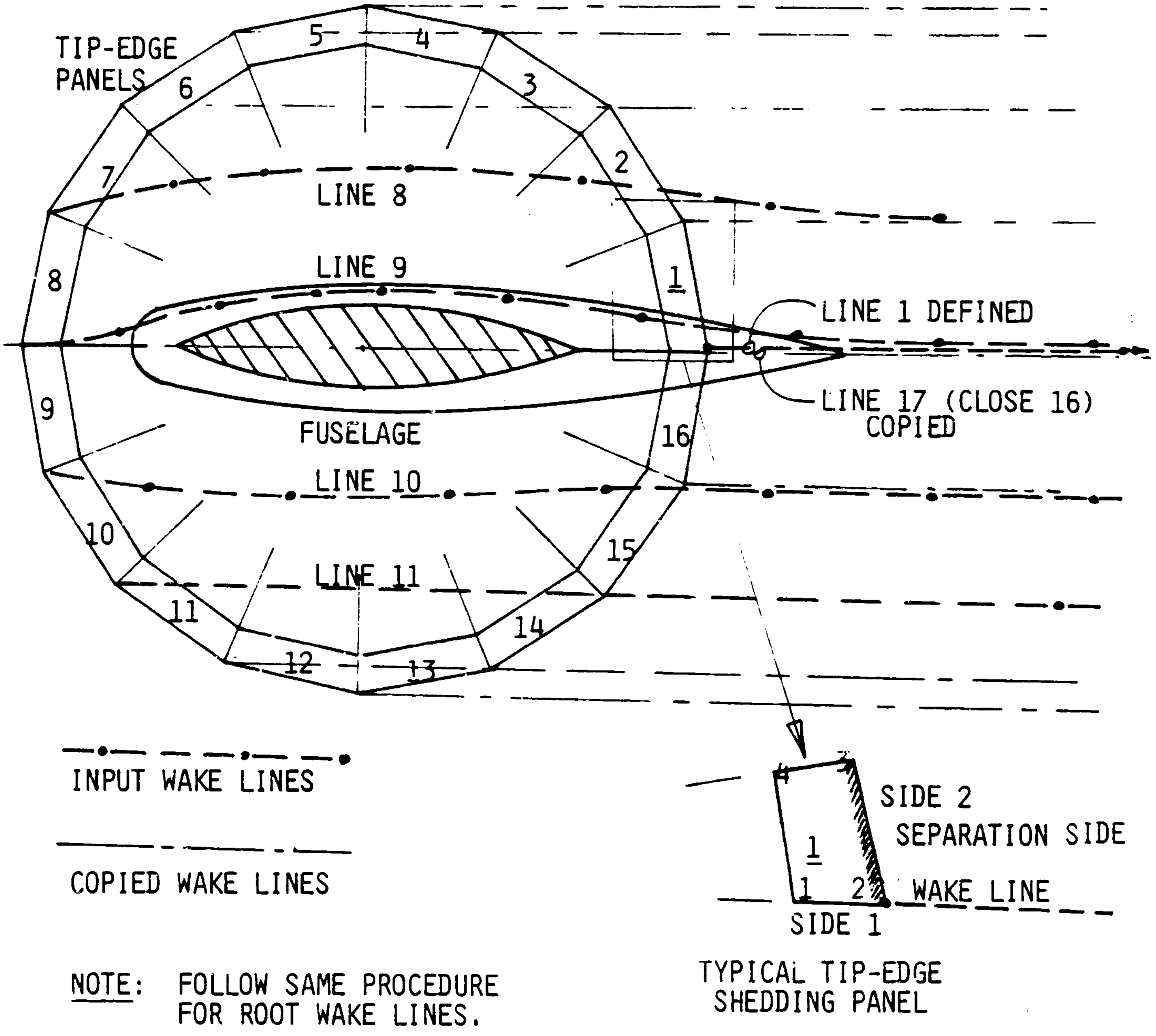


Figure 17. Rotor Wake Input Schematic with Fuselage Present.

CARD SET 29 1 2 0 9 9 2,3 or 4 0

CARD SET 21/22: FOR FILAMENT 9

CARD SET 20 1 2 0 10 10 2,3 or 4 0

CARD SET 21/22: FOR FILAMENT 10.

CARD SET 20 1 2 0 11 16 2 0

CARD SET 21/22: FOR FILAMENTS 11 THROUGH 16. SHOULD MATCH FILAMENTS 1 THROUGH 7.

CARD SET 20 0 0 0 0 0 0 0

Copies 16 to 17
and closes outside
of wake

Wake definition continues with the input along sides 3 and 4 of the patch displacing the wake filament as appropriate to pass around obstructions.

Since rotor wakes are type-4 wakes, the initial wake strength must be defined with CARD SET 23, specifying V_{INNER} and V_{OUTER}. This is updated internally as the calculation proceeds. Unlike conventional type-4 wake situations, there is no need to use NORVEL (on CARD 8) for rotor patches since the disc panel boundary conditions are set internally using local loadings supplied by the rotor blade element calculation.

In a conventional VSAERO data deck, the wake data completes the input string required for the aerodynamics calculation. However, if any type-4 rotor patches have been called, the program expects to read the input data set for the rotor blade elmement calculation. This is described in the next section.

5.0 ROTOR BLADE ELEMENT MODEL INPUT DESCRIPTION

When the presence of a rotor is signalled by the insertion of a type-4 patch, the program requires that the data be loaded to construct the blade element model. This data set identifies the body patch involved; contains the controls which limit print volume and iteration cycles; provides the description of the blade geometry and mass properties including twist, planform and airfoil section; and defines the flight conditions.

5.1 Rotor Patch Identifiers (Cards R1 and R2)

Since the blade element model is built on the framework provided by the panel model, with disc panels and blade segments being matched, the first data items identify the rotor patch. CARD SET R1 provides the patch number and orients the disc for the blade element velocity components. The parameter roll is the relative angle of rotor, zero degrees for a main rotor and ninety degrees for a tail rotor. The roll angle is used simply to resolve the induced velocity components generated in the body axis system into the correct relation for the blade element analysis. Card R2 provides a general title for the rotor calculation.

5.2 Output Print Controls (Card R3)

As an aid in rotor performance diagnosis, different levels of printout are available. At the most detailed level, all of the blade section geometric onset flow and loading data are available at each radial and azimuthal station for every step in the iteration cycle. This includes in the first group, available at every radius and azimuth:

> blade section radius, span, chord, geometric pitch, angle of attack, yaw angle, inflow angle, Mach number, velocity components in rotor control axis system, induced velocity components in body axis system, section lift coefficient, and section drag coefficient.

The second group includes the loading data available every radius and azimuth. These are:

> blade loading (lift/unit span), H-force loading, total torque loading, drag torque loading, lift torque loading, segment lift, segment H-force, segment total torque, lift torque, and drag torque.

The third group includes integrated blade data available at each azimuth location. This is made up of principally blade lift, H-force and torques and includes the blade flapping parameters, the flapping angle and the first and second flapping derivatives.

Rotor totals are printed for each iteration and are not selectable.

The output data selection is completed with an option to print the airfoil data as input and as interpolated at intermediate stations. It is recommended that restraint be exercised in switching on the print options since large volumes of output are generated. Irrespective of the print option chosen, the plot file contains all of the data for the final iteration cycle. The printout default values are all OFF and a particular group of output must be selected by inputting a value of one for the parameter. Card R3 is arranged in columns of 10 as outlined below.

	ISPNT1	ISPNT2	IBPNT1	IPT1	IPT2
Card 3	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1
	Group 1	Group 2	Group 3	Airfoil Data	
	Blade section data at every radius and azimuth		Blade totals at each azimuth		

5.3 Iteration Controls. (Card R4)

The rotor model used in the delivered verison of the program is for a fully articulated rotor and the performance calculation may proceed in either of two modes. In the first, direct mode, the blade control angles are preset and the calculation goes one cycle. In the second mode the rotor forces and moments are requested and the controls adjusted through three embedded iteration loops to produce the desired levels. The parameters entered on Card R4 control this process. These parameters, with MCOUNT controlling rotor moments, LCOUNT controlling rotor lift, and NFLAP controlling blade flapping, and hence control axis orientation, may be set individually or together using default values.

5.3.1 Blade Flapping

The innermost iteration is the blade flapping cycle which steps the blade around the azimuth calculating the loads based on the local conditions and the blade response to conditions at the previous step. The blade is assumed to be fully articulated. The default value of the controlling parameter is 4 (four full azimuthal cycles allowed to stabilize flapping). If the blade flapping cycle is inhibited, by setting NFLAP=1 the blade flapping parameters, the control axis angle and the fore, aft and lateral flapping inputs must be included on Card R11. Even if the default flapping cycle is selected, NFLAP=0 (set to 4 internally), it speeds convergence if values of control and flapping angles are set on Card R11.

5.3.2 Rotor Lift

The rotor lift is modulated using the collective pitch control. A total of six iterations are permitted if the default, LCOUNT=0 (set to 6 internally) are used. A starting value of collective pitch must be entered on CARd R11. The search for a converged value of collective pitch uses a quadratic fit through the successively updated calculated thrust values, comparing at each step with the target value. Blade flapping equilibrium is re-established after each change in collective pitch.

5.3.3 Rotor Moments

The rotor pitching and rolling moment loop entered on Card R4 produces the default, three iterations. If a search is ordered, target values of pitching and rolling moment must be loaded on Card R13 or zeroes will be assumed. If MCOUNT is set equal to 1, values of lateral and fore and aft cyclic pitch must be input on Card R12.

5.4 The Blade Element Model Geometry (CARD SETS R6, R7, R8, R9, R10)

In the program the basis for the blade geometry and breakdown into radial sections comes from the panel model. Having identified the appropriate patch, the panel corner points on the first column of the patch are studied (by the program). At the same time the number of rows (blade segments) is set, NR, and the number and size of the azimuthal increments determined, NC, from the number of columns on the patch. The panel geometry is available at this stage as coordinates in the global axis system. To convert these into blade radii requires the input of the rotor center of rotation and this is supplied on Card R5. The panel edges become the radial boundaries between the blade sections and the disc panelling and blade segmentation correspond. These radii form the basis for the rest of the geometry input data. Figure 18 illustrates how this procedure is carried out. The first radial station, defined by the innermost panel edge, is assumed to be coincident with the flapping hinge for the articulated rotors modelled here. The rest of the blade geometry information is input at the blade radial stations corresponding to the panel edges.

Blade geometry is defined with three parameters entered on CARD SETS R6, R7 and R8. These, respectively, are the chord, the twist and the leading-edge sweep. Each card set contains two

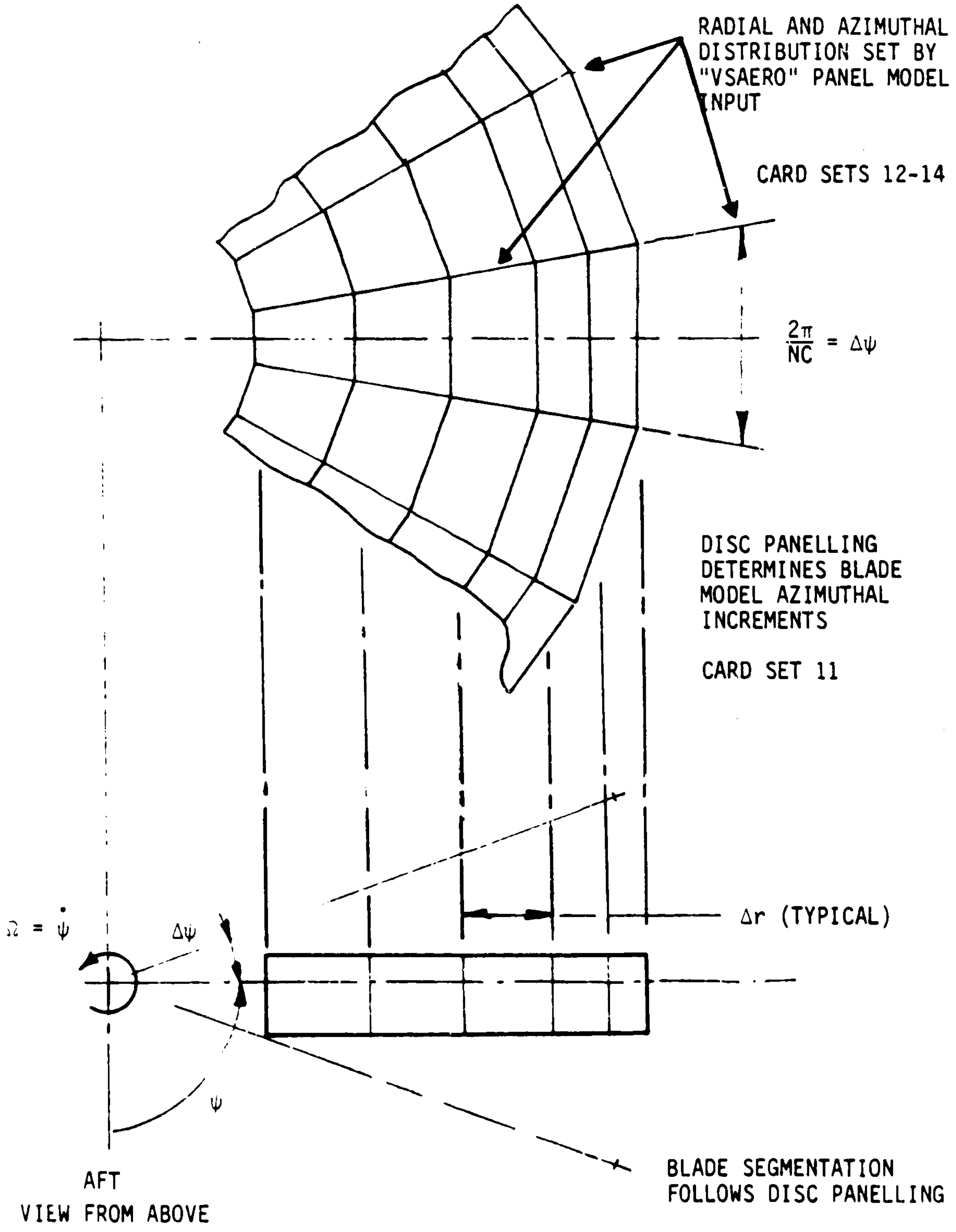


Figure 18. Schematic Relationship between Blade and Panel Models.

basic parts. They are: first, a card containing an indicator, INSET, which signals if a constant value is to be read (INSET=1) or if values are to be read at the NR+1 defining radial stations (INSET=0). If a constant twist is selected, the total twist should be loaded defined in the conventional sense relative to the 0.75 radius.

The rotor description is completed by entering the blade mass distribution, required by the flapping calculation on Card R9 and the number of blades on R10.

5.5 Rotor Performance and Control.(Cards R11, R12, R13, R14)

Cards R11 through R14 provide the input which set up and control the rotor performance.

5.5.1 Rotor Speed and Flapping. (Card R11)

Card R11 provides the information which orients the control axis system in space, sets up the initial flapping, applies a starting value of collective pitch and sets up the correct onset flow and rotor rotational speed.

If the default, zero, value for the control axis angle, ALPHAC, is used here, the program requires that system drag (the negative of the rotor propulsive force required) be loaded in Card R13. Since the program calculates the blade coning from the input mass properties, entry of the blade flapping values, A1 and B1, completes the rotor orientation input. If the flapping is constrained, NFLAP=1 on Card R4, appropriate values of ALPHAC, A1 and B1, must be input. Otherwise, the calculation may be started assuming zero flapping, but supplying realistic starting values speeds the flapping convergence. Input of unrealistic values of ALPHAC, A1 and B1 can lead to failure to close the flapping loop and a subsequent crash.

Blade speeds are set with the input of the advance ratio, the rotor rotation rate, OMEGA, and the hover tip Mach number.

5.5.2 Rotor Blade Cyclic Control. (Card R12)

As was noted above in Section 5.3.3 in the discussion of Card R4, the user has the option, with the parameter, MCOUNT, of trimming the rotor to target moments (MCOUNT=0, default) or of setting cyclic controls and taking whatever moments result (MCOUNT=1). If MCOUNT is set equal to 1, values of a and b must be entered on Card R12 or values of zero will be assumed.

5.5.3 Rotor Loads and Moments. (Cards R13 and R14)

Rotor lift and moment targets and the aircraft drag are entered on Card R13. If either LCOUNT or MCOUNT on Card R4 are left to the default value or if any value other than 1 is input, then target values of lift or moment must be loaded on Card R13.

The value of drag entered here is the drag area formed by dividing the actual drag by the dynamic pressure and is used as a guide in setting up the control axis angle if this is not input above on Card R11.

Card R13 is completed with the entry of V_{CLIMB} in areas where it is derived.

The air density used in the reduction of the loads and moments to coefficient form is entered on Card 14. If desired, a rotor tip loss factor may be used in the calculation. This is also entered on Card R14. When a tip loss is used, the lift outboard of the radius ratio, r/r_{TIP} entered on Card R14 is varied linearly to zero at the tip. The calculated drag is not affected.

5.5.4 Airfoil Data Sets. (Card R15, CARD SETS R16)

Airfoil data is used by the program in the conventional manner with table look-up and interpolation for C_L and C_D as a function of local aerodynamic angle of attack and Mach number. The airfoil sets are keyed to a particular radius, specified at input, and during execution the program interpolates between the data sets appropriate to the nearest radial stations on either side of the blade segment radius.

At input the parameter, NDSEC, on Card R15 indicates how many data sets are to be loaded. Data sets may be loaded or copied from sets loaded earlier in the input string. This is indicated by a parameter on the first card of set R16. With the parameter, ICOPY=1, a data set is read. With ICOPY=0 the data set is copied form the previously read set. The radius (absolute) at which the data applies is also entered on Card R16.1. The data set follows using the "standard" C81 format, Ref. 2. In this format data is read as a function of blade section angle of attack for a range of Mach number. Each set of coefficients is entered separately. The program interpolates to the local coefficient value at the required value of Mach number and angle of attack and then between data sets, loaded as a function of span location, to the correct value.

6.0 INPUT DATA DECK BLOCKING AND VARIABLE LIST

The VSAERO data deck assembly was described in great detail in the user's document and will not be repeated here since the only change in set-up from the operational point of view is the addition of the rotor data block. This enters the run stream after the wake information has been loaded.

6.1 Input Summary

The input is divided into the following parts:

(i) BASIC INPUT
General information, operating mode, onset flow, reference conditions, special options

(ii) PATCH GEOMETRY
Description of configuration surface in components, patches, sections, basic points, etc., for panel generation

(iii) WAKE INPUT
Wake-grid-planes, type of wake, wake separation line, initial streamwise geometry

(r) ROTOR INPUT
Geometry, iteration and print controls, control settings, force and moment targets, and airfoil data

(iv) SURFACE STREAMLINE INPUT
Location of starting point for each surface streamline

(v) BOUNDARY LAYER INPUT
Reynold's number, etc.

(iv) OFF-BODY STREAMLINE INPUT
Location of starting point and required upstream/downstream distances for each off-body streamline

In the following description, the input variables are first listed in 6.2 for each of the above parts. Then, 6.3 gives a detailed description of the function of each input variable. This is followed in 6.4 by an input flow chart to help with the assembly of the input data file. Section numbering has been left common with the original VSAERO document. In the detailed description and flow chart sections, only the rotor input is described. The user is referred to the Program VSAERO User's Guide for the other sections.

6.2 Input Variable List

Basic Input Summary

Card No.	Variables	Format
1	Text	20A4
2	IPRI, IPRLEV, IPRESS, MSTOP, MSTART, MODIFY	6I5
2A	IPRGOM, IPRNAB, IPRWAK, IPRCPV, IPRPPI (only if IPRLEV=5 on CARD 2)	5I5
3	MODE, NPNMAX, NRBMAX, ITGSMX, IMERGE, NSUB, NSPMAX, NPCMAX	8I5
3A	NROWB(I), I=1, |NRBMAX| (only if NRBMAX<0 on CARD 3)	16I5
4(a)	NWIT, NVPI, IBLTYP (if MODE=1 on CARD 3)	3I5
or		
4(b)	NT, NHC (if MODE=2 on CARD 3)	2I5
4A	(only if NVPI>0 and IBLTYP=0 on CARD 4(a)	
(i)	NPSETS	I5
(ii)	NPCHBL, NBCOL, (KOL(I), I=1, NBCOL) (Number of 4A(ii) cards = NPSETS)	16I5
	If MSTART>0 and MODIFY=0; this is the end of the basic data on a restart run.	
5	RSYM, RGPR, RNF, RFF, RCORE, SOLRES, TOL	7F10.0
6	ALDEG, YAWDEG, RMACH, VMOD, COMFAC	5F10.0
6A	ALBAR, RFREQU, HX, HY, HZ (only if MODE=2 on CARD 3)	5F10.0
7	CBAR, SREF, SSPAN, RMPX, RMPY, RMPZ	6F10.0
8	NORSET, NVORT, NPASUM, JETPAN, NBCHGE	5I5

Card No.	Variables	Format
8A	(NORPCH(I), NORF(I), NORL(I), NOCF(I), NOCL(I), VNORM(I), ADUB(I), I=1, NORSET) (only if NORSET>0 on CARD 8)	5I5, 2F10.0
8B(i)	VORT (only if NVORT>0 on CARD 8)	F10.0
(ii)	(RXV(I), RYV(I), RZV(I), I=1, NVORT+1)	3F10.0
8C	(NPSPCH(I), NPSRF(I), NPSRL(I), NPSCF(I), NPSCL(I), I=1, NPASUM) (only if NPASUM>0 on CARD 8)	5I5
8D	(JETPCH(I), JETRF(I), JETRL(I), JETCF(I), JETCL(I), VIN(I), VOUT(I), I=1, JETPAN) (only if JETPAN>0 ON CARD 8)	5I5 2F10.0
8E	(KPAN(I), KSIDE(I), NEWNAB(I), NEWSID(I), I=1, NBCHGE) (only if NBCHGE>0 on CARD 8)	4I5

Patch Geometry Input Summary

Card No.	Variable	Format
9	CTX, CTY, CTZ, SCAL, THET (component card)	5F10.0
9A	CPX, CPY, CPZ, CHX, CHY, CHZ (only if SCAL<0 on CARD 9)	6F10.0
10	IDENT, MAKE, KOMP, KLASS, PNAME (patch card) (Note: If MAKE=0, go directly to CARD 16)	4I5, 6A4
11	STX, STY, STZ, SCALE, ALF, THETA, INMODE, NODES, NPS, INTS (section card)	

Card No.	Variable	Format
12(a)	BY, BZ, X (INMODE=1)	3F10.0
(b)	BX, BZ, Y (INMODE=2)	
(c)	BX, BY Z (INMODE=3)	
(d)	BX, BY, BZ (INMODE=4)	
(e)	TC, INPUT (INMODE=5 or 7)	F10.0, I5
(f)	H, INPUT (INMODE=6 or 8)	
(g)	BX, RAD, THET (INMODE=12)	3F10.0
13	XRB, NINT (after options 12(e) and 12(f)	F10.0, I5
14	NODEC, NPC, INTC, MOVE (use with CARD 12 and and 13)	30X, 4I5
14A	NPCH, NSEC, IB, LB (if NODEC<0 on CARD 14)	4I5
14B	XPIV, YPIV, ZPIV, HX, HY, HZ, ROT (if MCVE=1 on CARD 14)	7F10.0
15	THETA2, THETA1 (only if NODES<0 on CARD 11)	2F10.0
16	NPC, INTC, KURV, NPTIP, NODES, NPS, NTS (special tip patch) (only if MAKE=0 on CARD 10)	35X, 3I5, 10X, 3I5
16A	(S(I), Y(I), Z(I), 1=1, NPTIP (only if KURV>1 on CARD 16)	3F10.0

Wake Input Summary

Card No.	Variables	Format
17	X (wake grid plane stations)	F10.0
18	NODE, NPC, INTC, MARK	30X, 4I5
19	IDENTW, IFLEXW, IDEFW, WNAME (wake card)	3I5,5X 6A4
20	KWPACH, KWSIDE, KWLINE, KWPAN1, KWPAN2, INPUT, NODEWS, IDWC, IFLXL, DTHET	9I5, F10.0

Card No.	Variables	Format
21(a)	SWPY, SWPZ, X (if INPUT=1 on CARD 20)	3F10.0
21(b)	SWPX, SWPZ, Y (if INPUT=2 ON CARD 20)	
21(c)	SWPX, SWPY, Z (if INPUT=3 on CARD 20)	
21(d)	SWPX, SWPY, SWPZ (if INPUT=4 on CARD 20)	
22	NODEWC, NPC, INTC	30X, 3I5
23	VIN, VOUT ... (if IDENTW=4 on CARD 19)	8F10.0

Rotor Input Summary

Card No.	Variable	Format
R1	IPRCH, ROLL	I10, F10.0
R2	TITLE	80A1
R3	ISPNT1, ISPNT2, IBPNT1, IPT1 IPT2	8I10
R4	MCOUNT, LCOUNT, NFLAP	3I10
R5	XO, YO, ZO	3F10.0
R6.1	INSET	I10
R6.2	CHORD(I), I=1 for INSET=-1 I=NR+1 for INSET=0	8F10.0
R7.1	INSET	I10
R7.2	TWRATE, for INSET=-1 TWIST(I), I=NR+1 for INSET=0	F10.0 8F10.0
R8.1	INSET	I10
R8.2	SWEEP(I), I=1 for INSET=-1 I=NR+1 for INSET=0	F10.0 8F10.0
R9	BMASS	F10.0
R10	NB	I10

Card No.	Variable	Format
R11	MU, ALPHAC, OMEGA, MTIP, COLL, A1, B1	8F10.0
R12	ALPHAS (Not used), A1S, B1S	8F10.0
R13	BW, DRAG, PM, RM, VCLIMB	8F10.0
R14	RHO, TIPLOS	8F10.0
R15	NDSEC	I10
R16.1	ICOPY, YR	I10, F10.0
R16.2	TITLE, (NMACH(I), NALPHA(I), I=1,2)	
R16.3	MACH(J), J=1, NMACH	8F10.0
R16.4	ALPHAI, (COI(I,J), J=1,9)	8F10.0
R16.5	(COI(J), J=10, NALPHA)	8F10.0
	Repeat R16.4 AND R16.5 NMACH times	
	Repeat to R16.3 twice COI(I,J)=C_L, I=1, C_D, I=2	
	Repeat to R16.1 NDSEC times	

Repeat Rotor Card Set R1 - R16 for each type-4 patch.

Surface Streamline Input Summary

Card No.	Variables	Format
24	F, KP, NS (compulsory input if IBLTYP=1) (Place one card no. 24 for each streamline)	F10.4, 2I5
25	F, KP, NS (end of surface streamline data)	2F10.4, 2I5

Boundary Layer Input Summary

Card No.	Variables	Format
26	RNB, TRIPUP, TRIPOP, XPRINT, XSKIP (CARD 26 only present if NVPI>0 on CARD 4(a))	5F10.0

Off-Body Velocity Scan Input Summary

Card No.	Variables	Format
27	MOLD, MEET, NEAR, INCPRI, INCPRJ, INCPRK (Start of each scan box. Finish the set with a blank card)	6I5
28	XO, YO, ZO, NP (if MOLD=1 on CARD 27)	3F10.0, I5
29	X1, Y1, Z1, NP1 (if NP>1 on CARD 28)	
29A	(AL1(I), I=1, |NP1|)(only if NP1<0 on CARD 29)	8F10.0
30	X2, Y2, Z2, NP2 (if NP>2 on CARD 28)	3F10.0, I5
30A	(AL2(I), I=1, |NP2|)(only if NP2<0 on CARD 30)	8F10.0,
31	X3, Y3, Z3, NP3 (if NP=4 on CARD 28)	3F10.0, I5
31A	(AL3(I), I-1, |NP3|)(only if NP3<0 on CARD 31)	8F10.0
32	X1, Y1, Z1, RO1, RI1, THETA1, THETA2 (if MOLD=2 on CARD 27)	7F10.0
33	X2, Y2, Z2, RO2, RI2 (if MOLD=2 on CARD 27)	5F10.0
34	NAL, NTHETA, NRAD (if MOLD=2 on CARD 27)	3I5
34A	(AL1(I), I=1, |NAL|)(if NAL<0 on CARD 34)	8F10.0
34B	(ALTHET(I), I=1, |NTHETA|)(if NTHETA<0 on CARD 34)	8F10.0
34C	(ALRAD(I), I=1, |NRAD|)(if NRAD<0 on CARD 34)	8F10.0

Off-Body Streamline Input Summary

Card No.	Variables	Format
35	RSX, RSY, RSZ, SU, SD, DELS, NEAR (one card per streamline; finish with a blank card)	6F10.0, I5

6.3 Rotor Input Data Deck Description

Note: All integers are right justified.

Card	Columns	Variable	Format
R1	1-10	IPATCH Rotor patch number	I10
	11-20	ROLL Rotor roll attitude =0.0 for main rotor = 90.0 for tail rotor	F10.0
R2	1-80	TITLE	80A1
R3	1-10	ISPNT1 =1, prints blade radial variation of blade section data =0, suppresses print	I10
	11-20	ISPNT2 =1, prints blade radial variation of blade loads, etc. =0, suppresses print	I10
	21-30	IBPNT1 =1, Prints rotor forces and moment summary at each azimuth =0, suppresses print	I10
	31-40	IPT1 =1, prints input airfoil data =0, suppresses print	I10

Card	Columns	Variable	Format
	41-50	IPT2 =1, prints interpolated airfoil at each blade section =0, suppresses print	I10
R4	1-10	MCOUNT Controls cyclic pitch/rotor moment loop =0, sets default =3 =1, runs to set values of A1s and B1s	I10
	11-20	LCOUNT Controls collective pitch/rotor lift loop =0, sets default =6; recommend default or ≥3	I10
	21-30	NFLAP Controls blade flapping/tip path plane loop =0, sets default =4; recommend =4 for main rotors, =1 for tail rotors	I10
R5	1-30	XO, YO, ZO Rotor center in body axis system	3F10.0

Card	Columns	Variable	Format
R6 (SET)		BLADE CHORD	
6.1	1-10	Inset =-1, constant chord; read only 1 value on 6.2 Inset =0, variable chord; read (NR+1) values on 6.2	I10
6.2	1-80	Blade chord values, dimensions in feet	8F10.0
R7 (SET)		BLADE TWIST	
R7.1	1-10	Inset =-1, constant twist rate; read total twist from 7.2 Inset =0, variable twist; read (NR+1) values on 7.2	I10
R7.2	1-80	Blade twist values Inset =-1, total twist in Col. 1-10 Inset=0, section twist relative to 0.75 radius, in degrees	8F10.0
R8 (SET)		BLADE LEADING-EDGE SWEEP	
R8.1	1-10	Inset =-1, constant sweep; 8.2 blank (sweep = 0.0) Inset =0, variable sweep; read (NR+1) values from 8.2	I10
R8.2	1-80	Sweep values Inset =-1, blank card Inset =0, leading-edge sweep positive aft in degrees	8F10.0
R9	1-10	BLADE MASS Distribution assumed constant; dimensional in slugs/ft.	F10.0
R10	1-10	NUMBER OF BLADES	I10

Card	Columns	Variable	Format
R11		ROTOR PARAMETERS	
	1-10	ADVANCE RATIO	F10.0
	11-20	CONTROL AXIS ORIENTATION	F10.0
		=0 if drag value on Card 14 used	
		= value if tip path tilt entered (degrees positive aft)	
	21-30	OMEGA	
		rotor rotational speed (radians/sec.)	F10.0
	31-40	HOVER TIP MACH NUMBER	F10.0
	41-50	INPUT COLLECTIVE PITCH (degrees)	F10.0
	51-60	A1	
		Input fore and aft flapping (degrees)	F10.0
	61-70	B1	
		Input lateral flapping (A1 and B1 can be input = 0.0)	F10.0
R12		CYCLIC CONTROLS	
	1-10	SHAFT AXIS ANGLE (not used)	
	11-20	A1s	
		Fore and aft cyclic input (deg.)	F10.0
	21-30	B1S	
		Lateral cyclic input (deg.)	F10.0

Card	Columns	Variable	Format
R13		ROTOR LOADS AND MOMENT VALUES	
	1-10	GROSS WEIGHT (lbs.)	F10.0
	11-20	DRAG	
		(D/q) square feet	F10.0
	21-30	ROTOR PITCHING MOMENT TARGET	
		(set MCOUNT=3 on Card 3) (ft.-lbs.)	F10.0
	31-40	ROTOR ROLLING MOMENT TARGET	
		(set MCOUNT=3 on Card 3) (ft.-lbs.)	F10.0
	41-50	V CLIMB (ft./sec.)	
R14		MISCELLANEOUS	
	1-10	AIR DENSITY (slugs/Ft.3)	F10.0
	11-20	TIP LOSS FACTOR	
		Linear tip loss applied outside input value, R/RTip	F10.0
		Default =0.0, no tip loss	
R15	1-10	NDSEC	
		Number of airfoil data sets following	I10
R16		AIRFOIL DATA SETS	
		Repeat ND sec. times	

Note: Repeat R1 through R16 for each rotor, type-4, patch used.

CARD SET R16:- AERODYNAMIC SECTION DATA. These data tables are input in the standard format currently used in the Rotorcraft Flight Simulation Program, C-81, Ref. 2.

Repeat NDSEC times.

CARD 16A:- Copy Control Integer.

Column	Variable	Value	Description
1-5	ICOPY(IDSEC)	0	Complete aerodynamic tables are read in for this section
		ID	Sectional aerodynamic data is copied over from previously defined section ID

Note: If ICOPY(IDSEC)>0, the rest of CARD SET R16 is omitted for this section.

CARD R16B:- Title and Control Card.

Columns	Variable	Value	Description
1-30	TITLE	ANY	Alphanumerical title of sets of tables
31-32	NMACH(1)	3-18	Number of Mach number entries in C_ℓ table
33-34	NALPHA(1)	3-99	Number of angle-of-attack entries in C_ℓ table
35-36	NMACH(2)	3-18	Number of Mach number entries in C_d table
37-38	NALPHA(2)	3-99	Number of angle-of-attack entries in C_d table
39-40	NMACH(3)	3-18	Number of Mach number entries in C_m table. Not used. Set=0
41-42	NALPHA(3)	3-99	Number of angle-of-attack entries in C_m table. Not used. Set=0

Note: CARD SETS R16C through R16E are repeated as a group three times for C_ℓ, C_d and C_m; that is, in the following descriptions

$K = 1$ ----- C_ℓ

$K = 2$ ----- C_d

$K = 3$ ----- C_m Not used in rotor/body performance calculation at this time

CARD 16C:- Mach Number Entries.

Columns	Variable	Value	Description
8-14	MACH(1)	arbitrary	Lowest Mach number
15-21	MACH(2)	"	Next highest Mach number
22-28	MACH(3)	"	Next highest Mach number
⋮	⋮	⋮	
64-70	MACH(9)	"	Next Highest Mach number

Note: Additional card may be required with same format to input NMACH(K) values of Mach numbers.

CARD R16D:- Angle-of-Attack/Coefficient Data.

Columns	Variable	Value	Description
1-7	ALPHA(K)	arbitrary	Angle of attack, degrees
8-14	COI(K,1)	"	Coefficient at MACH(1)
15-20	COI(K,2)	"	Coefficient at MACH(2)
22-28	COI(K,3)	"	Coefficient at MACH(3)
⋮	⋮	⋮	
64-70	COI(K,9)	"	Coefficient at MACH(9)

CARD R16E:- Continued Coefficient Data.

Columns	Variable	Value	Description
8-14	COI(K,10)	arbitrary	Coefficient at MACH(10)
.	.	.	
.	.	.	
.	.	.	
64-70	COI(K,18)	"	Coefficient at MACH(18)

Notes: 1. CARD R16E included only if NMACH(K)>9.

2. CARDS R16D and R16E repeated NALPHA(K) times for each angle of attack.

7.0 REFERENCES

1. Maskew, B., "Program VSAERO User's Guide", <u>NASA CR-166476</u>, Prepared for NASA Ames Research Center under Contract NAS2-8788, 1983.

2. Davis, J.M. et al., "Rotorcraft Flight Simulation with Aeroelastic Rotor and Improved Aerodynamic Representations", Bell Helicopter Textron, <u>USAAMRDL TR-74-10</u> (A, B and C), U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, VA, June 1974.

APPENDIX: SAMPLE CASE

Contains: 1. Sample Input

2. Sample Output

Note: The case has been chosen to be roughly representative of the H-34 rotor as tested on the Ames Rotor Test Module. The test module has been generated as a body of revolution (see Section 3.1.2). The rotor has been run in a requested thrust, fixed cyclic mode with the control axis tilt input. This sets the tip path plane angle and determines the propulsive force. The output has been somewhat truncated but a sample of each section has been retained. Only output specific to the rotor portions of the program is retained. For body output examples the user is referred to Reference 1.

1. SAMPLE INPUT

ORIGINAL PAGE IS
OF POOR QUALITY

```
CARD (SET) #
    1
    2         AMES 40 BY 80 BODY ROTOR MODEL
    3              0      0      0      0
    4              1    999
    5              3      0      0
    6         1.0         0.0
    7         0.00        0.00       0.06
    8         5.826       100.00     5.826     9.843     0.00      0.00    (END OF BASIC DATA)
                   0      0
-------------------------------------------------------------------------------------------
    9         -9.843      0.000      -6.850    1.000     0.00
   10              2      0      0    BODY
   11         0.000       0.000      0.000     33.284    0.00      0.00           2    -4    12    3
 12 (SET)     0.00        0.00
   |          0.00125     0.01589
   |          0.00375     0.02721
   |          0.0075      0.03804
   |          0.0123      0.04852
   |          0.0375      0.08037
   |          0.0625      0.09997
   |          0.0875      0.11419
   |          0.1125      0.12503
   |          0.1375      0.13345
   |          0.1750      0.14265
   |          0.2250      0.15010
   v          0.2950      0.15337
   14                                          1      8      3
12 (CONT'D)   0.3250      0.15339
   |          0.3750      0.15079
   |          0.4250      0.14603
   |          0.4750      0.13948
   |          0.5750      0.12202
   |          0.6250      0.11151
   |          0.6750      0.09997
   |          0.7250      0.08764
   |          0.7750      0.07520
   |          0.8250      0.06276
   |          0.8750      0.05033
   |          0.9250      0.03789
   v          1.0000      0.01923
   14                                          2     12      3
12 (CONT'D)   1.0000      0.00000
   14                                          3      2      3
   15         360.00      0.00                                        (END OF BODY GEOMETRY INPUT)
-------------------------------------------------------------------------------------------
    9         0.0         0.00       0.00      28.00     86.00     0.00
   10              4      0      0   1  ROTOR
   11         0.00        0.00       0.00      1.00      0.00      0.00           2    -5    24    3
 12 (SET)     0.0         0.10
    "         -0.023      1.00
   14                                          3     12      2
   15         360.00      0.00                                        (END OF ROTOR GEOMETRY INPUT)
-------------------------------------------------------------------------------------------
 17 (SET)     -28.00
    "         28.00
   18                                          1     12      0
 17 (CONT'D)  230.0
   18                                          1     10      1
 17 (CONT'D)  560.0
   18                                          3      3      1
-------------------------------------------------------------------------------------------
   19              4      0      0          ROTOR WAKE
   20              3      2      0      0      0      2      0
   21         600.0       0.00
   22                                          3     10      1
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
20                                      0    3         (END OF ROTOR WAKE)
23        1.05      1.00
-----------------------------------------------------------------------------
19           4      0    0          BODY WAKE
20           1      2   20     0     0    2    0
21      600.00      0.00
22                                             3   10     1
20                                        0    5       (END OF BODY BASE WAKE)
23        0.02      1.00
-----------------------------------------------------------------------------
R1                  2
R2         H-34 ROTOR
R3                  1         1        1        0        0
R4                  1         6        1        1
R5      0 00      0.00,     0.00
R6.1               -1
R6.2    1.366
R7.1               -1
R7.2    -8.0
R8.1               -1
R8.2    0.0
P9      0.500
R10                 4
R11     0.25     -10.0     24.86     0.626     10.00     6.00     3.90
R12     0.00      0.00      0.00
R13     21194.0   0.00      0.00     0.00      0.00
R14     0.002378  1.0                                 (END OF ROTOR BLADE INPUT)
-----------------------------------------------------------------------------
R15                 2
R16.1               0 0.1
R16.2     AERODYNAMIC TABLES FOR 0012 11391165 947
R16.3           0.      .20    .30    .40    .50    .60    .70    .75    .80
                .90    1.
R16.4   -180.   0.      0.     0.     0.     0.     0.     0.     0.     0.
                0.      0.
        -172.5  .78     .78    .78    .78    .78    .78    .78    .78    .78
                .78     .78
        -151.   .62     .62    .62    .62    .62    .62    .62    .62
                .62     .62
        -147.   1.      1.     1.     1.     1.     1.     1.
                1.      1.
        -129.   1.      1.     1.     1.     1.
                1.      1.
        -49.    -1.18   -1.18  -1.18                                 1.652
                -1.18   -1.18
        -39.    -1.18   -1.1                             1.042  1.042  1.042
                -1.18
        -21.                                      .302   .302   .302   .302
                               .242   .242   .242   .242   .242   .242
                        .132   .132   .132   .132   .132   .132   .132   .132
                .132    .132
          73.   .062    .062   .062   .062   .062   .062   .062   .062   .062
                .062    .062
        180.    .022    .022   .022   .022   .022   .022   .022   .022   .022
                .022    .022
R16.1             1 90 0                          (END OF ROTOR AIRFOIL DATA)
-----------------------------------------------------------------------------
```

AIRFOIL DATA TRUNCATED

STREAMLINE AND OFF-BODY DATA SETS FOLLOW IS REQUIRED. OTHERWISE TERMINATE DATA SET WITH SEVERAL BLANK LINES.

2. SAMPLE OUTPUT

ORIGINAL PAGE IS
OF POOR QUALITY

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

                                       ANALYTICAL METHODS, INC

                                           PROGRAM VSAERO-1000
                                                                  07 83

                                          FLOW ANALYSIS METHOD

                                        FOR GENERAL CONFIGURATIONS


                                                                 CONTACT  BRIAN MASKEW (206) 643 9090

                         ************************************************************
                        AMES 40 BY 80 BODY ROTOR MODEL
'NPUT LIST FOR BASIC DATA IN SUBROUTINE INDAT/
**********************************************

(VARIABLES ARE IDENTIFIED IN PARENTHESES FOR CONVENIENCE)

  (IPRI IPRLEV IPRESS  MSTOP MSTART MODIFY)
     0      0      0      0      0      0

  (MODE NPNMAX NRBMAX ITGSMX IMERGE  NSUB NBPMAX NPCMAX  IWCUT  ITKEN)
     1    999      0      0      0      0      0      0      0      0

  (NWIT   NVPI IBLTYP)
     3      0      0

   (RSYM      ROPR       RNF        RFF        RCORE      SOLRES     TOL        RELFAC)
  1 00000    0 00000    0 00000    0.00000    0.00000    0.00000    0 00000    0 00000

   (ALDEG     YAWDEG     RMACH      RMINF      VSOUND     RHO        OTHETA     COMPOP)
  0 00000    0 00000    0 06000    0.00000    0.00000    0.00000    0 00000    0 00000

   (CBAR      SREF       SSPAN      RMPX       RMPY       RMPZ)
  5 8260    100 0000    5 8260     9.8430     0 0000     0.0000

(NORSET  NVORT NPASUM JETPAN NBCHGE INTSET)
     0      0      0      0      0      0

(END OF INPUT LIST FOR BASIC DATA)

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

```
   M  IDENT   KOMP  KLASS   NROW   NCOL   IPAN   LPAN   NPAN
   1      2      1      1     22     12      1    264    264      BODY
   2      4      2      1     12     24    265    552    288       ROTOR

GEOMIN TIME     6 000

SURPAN TIME    25 000

CONECT TIME    12 000

SURPHI TIME   706 000
```

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

(VARIABLES ARE IDENTIFIED IN PARENTHESES FOR CONVENIENCE)

    (DX       ( NBP ))          (BASIC POINTS FOR WAKE-GRID-PLANE STATIONS IN SUBROUTINE WGRID)
  -28 0000    (   1 )
   28 0000    (   2 )

                                 (NODE  NPC  INTC)
                                    1   12    0
  230 0000    (   3 )

                                 (NODE  NPC  INTC)
                                    1   10    1
  560 0000    (   4 )

                                 (NODE  NPC  INTC)
                                    3    3    1

(IDENTW IFLEXW  IDEFW)                 ********************                                      (NWAKE=   1 )
     4     0      0                      ROTOR WAKE
                                       ********************

(KWPACH KWSIDE KWLINE KWPAN1 KWPAN2  INPUT NODEWS IDWCOL IFLEXL      DTHET)
     2      2      0      0      0      2      0      0      0   0 00000

    (SWPX       SWPZ     DELY)        ( NSWP  )
 600 00000   0 00000   0 00000        (    1  )

                                 (NODEWC     NPC     INTC)
                                        3     10        1

(KWPACH KWSIDE KWLINE KWPAN1 KWPAN2  INPUT NODEWS IDWCOL IFLEXL      DTHET)
     0      0      0      0      0      0      3      0      0   0 00000
                                                             (LAST SECTION ON WAKE    1 )

    (EFFLUX VELOCITIES ON TYPE 4 WAKE       VINNER, VOUTER)
     1 05000    1 00000        0 00000   0. 00000       0 00000    0 00000         0. 00000   0. 00000

(IDENTW IFLEXW  IDEFW)                 ********************                                      (NWAKE=   2 )
     4     0      0                      BODY WAKE
                                       ********************

(KWPACH KWSIDE KWLINE KWPAN1 KWPAN2  INPUT NODEWS IDWCOL IFLEXL      DTHET)
     1      2     20      0      0      2      0      0      0   0 00000

    (SWPX       SWPZ     DELY)        ( NSWP  )
 600 00000   0 00000   0 00000        (    1  )

                                 (NODEWC     NPC     INTC)
                                        3     10        1

(KWPACH KWSIDE KWLINE KWPAN1 KWPAN2  INPUT NODEWS IDWCOL IFLEXL      DTHET)
     0      0      0      0      0      0      5      0      0   0 00000
                                                             (LAST SECTION ON WAKE    2 )

    (EFFLUX VELOCITIES ON TYPE 4 WAKE       VINNER, VOUTER)
     0 02000    1 00000        0. 00000   0 00000       0 00000    0 00000         0. 00000   0 00000
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
COINCIDENT VORTEX LINES HAVE BEEN IDENTIFIED

(DSMIN= 0 49834E-01   SEQAVE=  4 9834       BEGMIN= 0 33132      )

LINKS
     1   1      2   0      3   0      4   0      5   0      6   0      7   0      8   0      9   0     10   0
    11   0     12   0     13   0     14   0     15   0     16   0     17   0     18   0     19   0     20   0
    21   0     22   0     23   0     24   0     25   1     26   4     27   0     28   0     29   0     30   0
    31   0     32   0     33   0     34   0     35   0     36   0     37   0     38   4

LINKV
   -2    1   25   -2   26   38

WAKE-GRID-PLANE STATIONS
     -28 0000   -27 0459    -24 2487    -19.7990    -14 0000     -7 2470     -0 0000      7.2469     14 0000     19 7990
      24 2487    27 0459     28 0000     30 4869     37.8866     50 0166     66 5785     87.1643    111 2672    138.2937
     167.5784   198 4000    229 9998    274.2114    394.9997    557 9994
```

```
  ROTOR INPUT DATA SUMMARY-USES PATCH   2
H-34 ROTOR

  OUTPUT PRINT CONTROLS
  IBPNT1  ISPNT2  IBPNT1  IPT1  IPT2  INTIME
    1       1       1       0     0      0

  ITTERATION LIMITS
  ROTOR MOMENTS  ROTOR LOADS  BLADE FLAP
     MCOUNT         LCOUNT       NFLAP
       1              6            1

  ROTOR CENTER OF ROTATION
  IN BODY AXIS SYSTEM (FT)
        XO         YO        ZO
      0.000      0.000     0.000

  THERE ARE  12 (NR) RADIAL AND  24 (NC) AZIMUTHAL SEGMENTS.

  BLADE DEFINING STATIONS
  RADIUS (FT)
  2.800    6.090    9.324   12.446   15.403   18.145   20.624   22.798   24.630   26.089

  BLADE DEFINING STATIONS
  RADIUS (FT)
 27.148   27.792   28.007

  CHORD
  1.366    1.366    1.366    1.366    1.366    1.366    1.366    1.366    1.366    1.366

  CHORD
  1.366    1.366    1.366

  SWEEP AT L.E. (DEG)
  0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000

  SWEEP AT L.E. (DEG)
  0.000    0.000    0.000

  TOTAL LINEAR TWIST (DEG)
 -8.000

  BLADE MASS/UNIT SPAN (SLUGS/FT)    0.5000
  NUMBER OF BLADES  4

  ADVANCE RATIO   0.25
  CONTROL AXIS ANGLE (DEG)=10.0
  ROTOR ANGULAR VELOCITY (RADS/SEC) 24.86
  TIP MACH NO    0.63

  RATE OF CLIMB (FT/SEC)  0.00

  CONTROL ANGLE SETTINGS (DEG)
  COLLECTIVE  10.00    A1S    0.00 B1S   0.00

  GROSS WEIGHT (LBS)  21194.00      DRAG (SQ FT.)     0.00
  PITCHING MOMENT       0.00     ROLLING MOMENT      0.00 (FT LBS)

  AIR DENSITY (SLUGS/FT3)  0.002378

  LINEAR TIP LOSS APPLIED OUTBOARD OF R/RTIP,
     1.0000
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
 INPUT DATA FOR 2D TABLES
PRINTOUT OF BASIC INPUT FOR DEFINED SECTION   1

ICOPY=   0      YDSEC =   0.10000


  AERODYNAMIC TABLES FOR  012

PRINTOUT OF BASIC INPUT FOR DEFINED SECTION   2

ICOPY=   1      YDSEC =  50.00000

    AZIMUTH ANGLE,STEP  1 PSI=   7.5

SEG    R      DR   R/RT  CHORD  PITCH  ALPHA    PHI    GAMMA   MACH   UI      UP      UR      VX     VY     VZ       CL     CD       SEG
  1   4.44 3.29 0.159   1.37  14.73   1.73 -13.00   51.75   0.19 132.4 -30.55  167.9  -1.99   0.00 -11.28   0.183  0.008     1
  2   7.71 3.23 0.275   1.37  13.80   6.59  -7.21   38.15   0.25 213.4 -27.00  167.6  -2.14   0.00 -12.11   0.708  0.012     2
  3  10.88 3.12 0.389   1.37  12.89   8.29  -4.60   29.79   0.30 292.4 -23.54  167.4  -2.28   0.00 -12.93   0.912  0.014     3
  4  13.92 2.96 0.497   1.37  12.02   8.88  -3.15   24.43   0.36 367.9 -20.23  167.2  -2.42   0.00 -13.71   0.981  0.017     4
  5  16.77 2.74 0.599   1.37  11.21   8.97  -2.24   20.83   0.42 438.7 -17.13  166.9  -2.55   0.00 -14.44   0.983  0.022     5
  6  19.38 2.48 0.692   1.37  10.46   8.84  -1.63   18.32   0.48 503.6 -14.29  166.8  -2.66   0.00 -15.11   0.956  0.030     6
  7  21.71 2.17 0.775   1.37   9.80   8.60  -1.20   16.53   0.53 561.4 -11.75  166.6  -2.77   0.00 -15.71   0.925  0.040     7
  8  23.71 1.83 0.847   1.37   9.23   8.33  -0.90   15.23   0.57 611.2  -9.57  166.4  -2.86   0.00 -16.23   0.894  0.050     8
  9  25.36 1.46 0.905   1.37   3.76   8.07  -0.68   14.31   0.61 652.1  -7.78  166.3  -2.94   0.00 -16.65   0.870  0.057     9
 10  26.62 1.06 0.950   1.37   8.40   7.86  -0.54   13.67   0.63 683.3  -6.41  166.2  -2.99   0.00 -16.97   0.853  0.066    10
 11  27.47 0.64 0.981   1.37   8.15   7.71  -0.45   13.27   0.65 704.5  -5.48  166.1  -3.03   0.00 -17.19   0.841  0.072    11
 12  27.90 0.22 0.996   1.37   8.03   7.63  -0.40   13.08   0.66 715.2  -5.02  166.1  -3.05   0.00 -17.30   0.835  0.075    12

SEG  L/DR      H/DR    QT/DR    QD/DR    QL/DR          L        H      QTOT      QD      QL      SEQ
  1     5.20    0.44      6.2      1.0     -5.2      17.11     1.46     20.5      3.4    -17.1     1
  2    52.41    3.54     57.3      6.6    -50.7     169.47    11.45    185.4     21.4   -163.9     2
  3   126.49    7.78    132.4     21.8   -110.7     395.56    24.31    413.5     68.0   -345.5     3
  4   219.66   12.58    217.7     52.8   -164.9     637.79    37.21    643.8    156.1   -487.6     4
  5   307.40   17.50    317.5    116.3   -201.2     842.79    47.97    870.4    318.9   -551.5     5
  6   393.6    22.28    452.3    235.9   -216.4     975.89    55.25   1121.4    584.9   -536.5     6
  7   473.61   27.10    657.8    442.6   -215.2    1029.67    58.92   1430.2    962.2   -467.9     7
  8   542.10   31.59    925.9    724.6   -201.3     993.09    57.87   1696.2   1327.4   -368.8
  9   600.76   35.45   1182.7   1000.9   -181.8     876.15    51.70   1724.9   1459.7   -26
 10   647.30   38.95   1492.6   1331.0   -161.6     686.08    41.29   1582.1   1410.7
 11   677.84   41.39   1738.6   1593.7   -144.9     436.05    26.62   1118.4   102
 12   693.26   42.64   1873.0   1737.3   -135.7     149.51     9.20    403

    AZIMUTH ANGLE,STEP  2 PSI=  22.5

SEG    R      DR   R/RT  CHORD  PITCH  ALPHA    PHI
  1   4.44 3.29 0.159   1.37  14.73   4.82
  2   7.71 3.23 0.275   1.37  13.80   7
  3  10.88 3.12 0.389   1.37  12
  4  13.92 2.96 0.497   1.37
  5  16.77 2.74 0.599
  6  19.38 2.48 0
  7  21.71 2
  8  23
```

ROTOR BLADE OUTPUT TRUNCATED

ORIGINAL PAGE IS
OF POOR QUALITY

```
                                                                                 039       7
                                                                       788    0 049        8
                                                                     0 956    0 062        9
                                                                -18.93  0 933    0 072       10
                                                     39   0.00 -19.22  0.917    0.078       11
                                               52 5  -3 41   0.00 -19.36  0.909    0 081       12
```

ROTOR BLADE OUTPUT TRUNCATED

```
                                                               QTOT      QD       QL      SEQ
                                                      1 11    -10 8     15 7     26 5      1
                                            9 17     -1 00     20 8      5 3    -15 5      2
                                          158.10     -6.22    206.2     28 1   -178.0      3
                                 -91.5    374.00     -7.22    354 0     83 5   -270.5      4
                        70.8     -85 0    592 11     -5.77    427 2    194 0   -233 2      5
               178 3   143.5     -34.8    761 83     -3.60    442.0    355.7    -86.3      6
      -2 14    266 8   314.9      48 2    828 09     -4 65    580 0    684 7    104 7      7
 444 36  -3.09    376 9   522.4     145 5    814 03     -5.67    690 5    957 0    266 6      8
9  499.68  -5.34    576.7   821.5     244.7    728.73     -7 79    841 1   1198 1    356.9      9
10 542.88  -7.59    781 9  1114.5     332.6    575 41     -8.05    828 7   1181 3    352 6     10
11 572.32  -9.22    937 8  1335.8     397 9    368 17     -5.93    603.3    859.3    256 0     11
12 587.24 -10.06   1021.3  1453.9     432.7    126.65     -2.17    220 3    313.6     93 3     12

    AZIMUTH ANGLE, STEP 24 PSI= 352.5

SEQ   R     DR   R/RT  CHORD  PITCH  ALPHA    PHI   GAMMA  MACH   UI     UP     UR     VX     VY    VZ      CL      CD     SEG
 1  4.44 3.29 0.159   1.37  14.59  -5.61 -20.20  62.07  0.17  88 6 -32.62  167.2  -2 03  0.00 -11.49  -0.592  0 011    1
 2  7.71 3.23 0.275   1 37  13.66   4.63  -9.03  44.51  0 22 169.8 -26.99  166 9  -2.20  0.00 -12.48   0.491  0.010    2
 3 10.88 3.12 0 389   1 37  12.75   7 81  -4 94  33.80  0.27 248 8 -21.51  166 6  -2 37  0 00 -13.44   0.849  0 013    3
 4 13.92 2 96 0.497   1 37  11.83   9 01  -2.87  27 14  0 33 324 4 -16 27  166 3  -2 53  0.00 -14.37   0.993  0 017    4
 5 16 77 2.74 0 599   1 37  11 07   9.42  -1 65  22 78  0 39 395 3 -11 36  166.0  -2 69  0.00 -15.24   1.032  0.021    5
 6 19.38 2.48 0 692   1 37  10 32   9.47  -0 85  19.81  0.44 460 3  -6.86  165 8  -2 83  0 00 -16.03   1.009  0 031    6
 7 21 71 2.17 0 775   1 37   9 66   9.34  -0 31  17.72  0 49 518 1  -2.84  165 6  -2 95  0.00 -16.74   0.971  0 039    7
 8 23 71 1.83 0.847   1 37   9 09   9.15   0 06  16.23  0.53 567 9   0 61  165 4  -3 06  0.00 -17.35   0.937  0.052    8
 9 25 36 1.46 0 905   1 37   8.62   8.94   0 32  15 18  0 57 608 9   3 45  165 2  -3.15  0 00 -17.85   0.909  0 062    9
10 26 62 1.06 0 950   1 37   8 26   8.76   0 50  14.46  0 59 640 2   5 62  165 1  -3 21  0 00 -18 23   0 889  0 069   10
11 27 47 0.64 0 981   1 37   8.01   8.63   0 61  14.01  0.61 661 4   7.09  165 0  -3 26  0.00 -18.49   0.880  0 074   11
12 27.90 0.22 0.996   1 37   7 89   8.56   0.67  13.79  0 62 672.1   7 83  165 0  -3 28  0.00 -18.62   0.876  0 077   12

SEQ  L/DR     H/DR   QT/DR   QD/DR   QL/DR         L       H     QTOT      QD       QL     SEQ
 1    -7 55   0 11   -11 0     0.6    11 6     -24 85    0 36    -36 3      1.9     38 1     1
 2    23 00   0.18    31 3     3.5   -27.8      74 38    0 59    101 2     11 2    -90.0     2
 3    85.34   1.53    94.7    14.7   -80.0     266.46    4.77    295.8     46.0   -249.8     3
 4   169.69   3.82   158.1    39.8  -118.3     501.83   11.29    457 7    117.7   -350.0     4
 5   262.02   6 51   216 0    89.8  -126 2     718.37   17 84    592 2    246.1   -346.0     5
 6   347.08   8.80   304.5   204.3  -100.2     860.43   21.81    754 8    506.4   -248.4     6
 7   423.35  10 70   420 3   369.8   -50.5     920 41   23.27    913 7    804.0   -109 7     7
 8   491.11  11.89   628 3   640.8    12.5     899 67   21 78   1150 9   1173 9     22 9     8
 9   547.57  12.64   859.1   947.7    78.6     798.57   18.43   1267.6   1382.2    114.6     9
10   591.48  13 16  1085 4  1223.5   138.1     626.92   13.95   1150.4   1296.8    146.4    10
11   624 82  13.54  1260 5  1444.4   183.9     401.94    8.71    810.9    929.1    118.3    11
12   642.42  13.71  1360 9  1569.6   208.7     138.55    2.96    293.5    338.5     45.0    12
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
H-34 ROTOR

 BLADE FLAPPING LOOP KFLAP= 1 OUT OF 1

THETA75     A0      A1       B1     ALPHAC   ALPHAS    A1S      B1S
  9.861   3.633   6.000   3.900  -10.000    0.000    0.000    0.000

BLADE TOTALS
PSI      THRUST      H      QTOT       QD        QL        RM        PM          FM          BETA     BETA.      BETA
   7.5   7150.8   418.0  10819.6   7355.4  -3464.2   2613.4  19850.9         0.0          -2.82   -76.66   4408.38
  22.5   7934.8   705.9  14217.6   7379.5  -6838.1   8523.7  20578.0         0.0          -3.40   -32.49   4987.28
  37.5   8338.8   924.3  16838.2   6435.4 -10402.8  14213.8  18523.8         0.0          -3.50    13.88   5111.38
  52.5   8170.2  1007.6  17699.3   4492.7 -13206.6  18149.2  13926.4         0.0          -3.11    59.31   4734.51
  67.5   7388.0   988.3  17570.0   3357.2 -14212.8  19111.6   7916.3         0.0          -2.27   100.70   3849.10
  82.5   6350.5   918.7  16466.7   2889.4 -13577.3  17629.3   2320.9         0.0          -1.02   135.23   2640.72
  97.5   5380.8   833.7  14687.6   2637.1 -12050.6  14937.4  -1966.5         0.0           0.55   160.54   1280.07
 112.5   4803.9   779.0  13268.6   2419.9 -10848.7  12427.1  -5147.5         0.0           2.33   174.91    -33.57
 127.5   4690.3   777.6  12635.7   2203.5 -10432.2  10418.9  -7994.7         0.0           4.19   177.36  -1198.14
 142.5   4886.3   821.6  12400.7   2046.1 -10354.6   8328.8 -10854.3         0.0           6.02   167.72  -2197.05
 157.5   5130.5   872.7  11714.4   1920.6  -9793.7   5497.4 -13272.0         0.0           7.68   146.65  -3060.04
 172.5   5242.3   891.4  10292.2   1925.3  -8366.9   1915.9 -14552.8         0.0           9.07   115.59  -3790.70
 187.5   5096.7   837.7   8115.3   1972.1  -6143.2  -1862.7 -14148.8         0.0          10.09    76.66  -4393.03
 202.5   4730.8   707.6   5761.9   2070.1  -3691.8  -5069.1 -12237.9         0.0          10.67    32.49  -4823.60
 217.5   4289.9   530.8   3732.2   2136.6  -1595.6  -7312.3  -9529.6         0.0          10.77   -13.88  -5009.59
 232.5   3863.8   338.4   2259.9   2182.8    -77.2  -8583.1  -6586.1         0.0          10.38   -59.31  -4907.68
 247.5   3583.4   163.3   1347.4   2253.2    905.8  -9269.7  -3839.7         0.0           9.53  -100.70  -4478.15
 262.5   3436.8    10.2    921.0   2389.4   1468.5  -9540.6  -1256.1         0.0           8.28  -135.23  -3755.33
 277.5   3444.0  -104.8    860.1   2644.6   1784.5  -9560.7   1258.7         0.0           6.72  -160.54  -2778.42
 292.5   3628.6  -178.9   1149.4   3062.5   1913.1  -9386.8   3888.1         0.0           4.94  -174.91  -1603.10
 307.5   3987.0  -200.0   1867.5   3748.7   1881.3  -8856.6   6795.9         0.0           3.08  -177.36   -308.80
 322.5   4564.2  -167.9   3191.6   4720.2   1528.6  -7779.9  10138.8         0.0           1.25  -167.72   1032.58
 337.5   5326.5   -57.0   5203.2   5876.3    673.1  -5707.5  13778.9         0.0          -0.42  -146.66   2327.98
 352.5   6182.7   145.8   7762.4   6853.8   -908.6  -2259.7  17163.4         0.0          -1.81  -115.59   3475.57

  ** BLADE FLAPPING LOOP COMPLETE **
```

```
     H-34 ROTOR

ROTOR TOTALS
                   TOTAL      DRAG      LIFT      ROLL      PITCH
L-FORCE  P-FORCE   TORQUE     TORQUE    TORQUE     MOM.      MOM.    THRUST    H-FORCE
21293.0   1729.9  35130.4   14162.1  -20968.4   8096.3    5792.4   21270.3    1994.0


  CT        CH        CQTOT      CQD       CQL
0.00749  0.00070   0.00044   0.00018  -0.00026


 CT/SIG              CQ/SIG
0.12057             0.00711

   VINF       MU        OMEGAR     VCLIMB
 174.0659   0.2500      696.26      0.00


THETA75      AO        A1        B1      ALPHAC    ALPHAS     A1S       B1S
  9.861     3.633     6.000     3.900   -10.000    0.000     0.000     0.000

  MOMENT LOOP  1 OF 1     COLLECTIVE LOOP 3 OF 6

  ** COLLECTIVE PITCH CONVERGED **

  ** ROTOR MOMENTS CONVERGED **
```

REST OF OUTPUT FOLLOWS

1. Report No.
CR- 177340

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Study for Prediction of Rotor/Wake/Fuselage Interference
Part II: Program Users Guide

5. Report Date
March 1985

6. Performing Organization Code

7. Author(s)
D. R. Clark
B. Maskew

8. Performing Organization Report No.
8304-1

9. Performing Organization Name and Address
Analytical Methods, Inc.
2047 - 152nd Avenue, N.E.
Redmond, WA 98052

10. Work Unit No.

11. Contract or Grant No.
NAS2-10620

12. Sponsoring Agency Name and Address
NASA Ames Research Center
Moffett Field, CA 94035

13. Type of Report and Period Covered
Final, 6/1/80-11/1/83

14. Sponsoring Agency Code
505-42-11

15. Supplementary Notes
Point of Contact: Technical Monitor, Charles A. Smith
M/S 247-1, NASA Ames Research Center
Moffett Field, CA 94035 (415)694-6714

16. Abstract

A method has been developed which allows the fully coupled calculation of fuselage and rotor airloads for typical helicopter configurations in forward flight. To do this, an iterative solution is carried out based on a conventional panel representation of the fuselage and a blade element representation of the rotor where fuselage and rotor singularity strengths are determined simultaneously at each step and the rotor wake is allowed to relax (deform) in response to changes in rotor wake loading and fuselage presence. On completion of the iteration, rotor loading and inflow, fuselage singularity strength (and, hence, pressure and velocity distributions) and rotor wake are all consistent.

The results of a fully coupled calculation of the flow around representative helicopter configurations are presented. The effect of fuselage components on the rotor flow field and the overall wake structure is detailed and the aerodynamic interference between the different parts of the aircraft is discussed. In particular, the flow field developed by the rotor head is followed and the effect of a rotor head cap and pylon modifications in redirecting the rotor head flow are illustrated. Good correlation between measured and calculated fuselage airloads in low-speed flight is achieved and correspondence with observed flow field behavior is demonstrated.

17. Key Words (Suggested by Author(s))

Rotor	Air Loads
Fuselage	Rotor Loads
Helicopter	
Aerodynamic Interference	

18. Distribution Statement
Subject category: 01
Unlimited

19. Security Classif. (of this report)
UNCLASSIFIED

20. Security Classif. (of this page)
UNCLASSIFIED

21. No. of Pages
82

22. Price*

*For sale by the National Technical Information Service, Springfield, Virginia 22161