NASA CR-141406

AIRCRAFT COCKPIT VISION

MATH MODEL

(NASA-CR-141406) AIRCRAFT COCKPIT VISION: MATH MODEL (Computer Sciences Corp., Wallops Island, Va.) 37 p HC $4.00 CSCL 05E

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ABSTRACT

A mathematical model has been developed to describe the field of vision of a pilot seated in an aircraft. Given the position and orientation of the aircraft, along with the geometrical configuration of its windows, and the location of an object, the model determines whether the object would be within the pilot's external vision envelope provided by the aircraft's windows. The computer program using this model has already been implemented and is described herein.

1. INTRODUCTION

The National Aeronautics and Space Administration, Wallops Flight Center, Wallops Island, Virginia, is conducting studies of the existing air traffic patterns at uncontrolled airports. Data acquired are being used to evaluate new air-traffic pattern concepts which may reduce the potential for mid-air collision hazard near such airports. The Air Traffic Group of Computer Sciences Corporation, Wallops Island, Virginia, is providing support to the project by developing computer programs for data reduction, developing a data base, and providing statistical and mathematical modeling of the data. Approximately three thousand radar tracks were acquired at three uncontrolled and three controlled airports. A data base called Integrated Data Store (IDS) has been developed to store position-velocity time histories of the tracks, type of aircraft, airport, runway used, wind speed and direction, cloud ceiling, visibility, barometric pressure and other operator comments.

This report describes the math model developed for analyzing the pilot's field of vision from the cockpit of his aircraft. It has been noted that the pilot has a very limited field of vision available to him because he cannot see straight up, straight back, or straight down; and also his ability to detect other aircraft in his vicinity depends upon the orientation of his own aircraft. Most mid-air collisions in the vicinity of airports occur because either the pilot fails to look or cannot see due to his visual restrictions. This math model has been developed to determine whether or not some exterior point is potentially visible to a pilot seated in an aircraft. It should be mentioned that L. S. Joel,

W. A. Steele, J. J. Filliben and G. B. Hare have used similar ideas regarding the geometry of the vision envelope in their math model.*

The computer program simulating the model is initialized by calling Subroutine INIT, which loads the common data areas with the window outlines for the chosen aircraft. Window outlines were obtained from binocular photographs supplied by Mr. P. M. Rich of the Federal Aviation Administration's National Flight Evaluation Center at Atlantic City, New Jersey. The Subroutine VISION is then called to test the visibility of a particular target from a viewing aircraft. The program presently contains the window outlines for the following types of aircraft.

AIRCRAFT	TYPE
MOONEY-21	1
CHEROKEE-140	2
CESSNA-172	3
CESSNA-210	4
PIPER AZTEC	5
PIPER 140B	6
BEECH BARON	7
AERO-COMMANDER 680E	8
BOEING 707	9
DOUGLAS DC8	10

Space has been reserved in the common area for ten more aircraft types.

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*National Bureau of Standards Report 1052, entitled "Approaches to Evaluating the Effects of VFR Towers on Flow and Safety at Airports."

2. MODEL FORMULATION

Since it is the pilot who is at the control, the model equations are written in the coordinate system fixed with the aircraft (A). In essence, the problem is to locate the point of intersection (I) of the line joining the pilot's eyes (P) to the object (O) and the plane of the window. If this point lies in front of the pilot's eyes and falls within the boundary of the window, the object should be visible through that particular window; otherwise not.

2.1 COORDINATE SYSTEMS

Two distinct coordinate systems are used. Figure 1 illustrates the system fixed to the ground (G-System) with the origin at any suitable point. Figure 2 shows the system fixed to the viewing aircraft (A-Syste) with the origin at any suitable point.

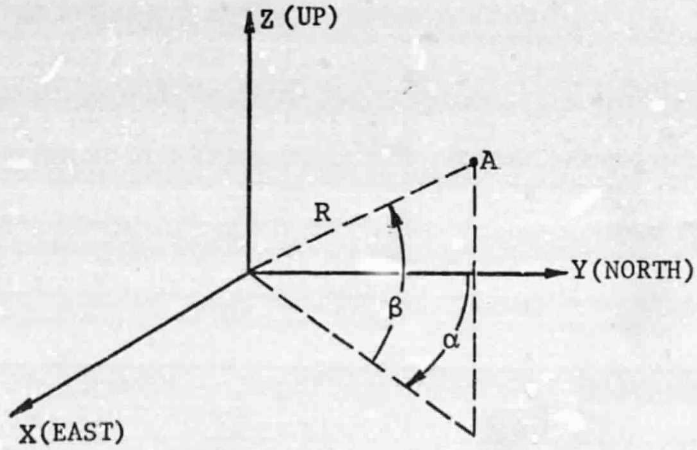

Figure 1. GROUND COORDINATE SYSTEM (G-SYSTEM)

R, β, and α are range, elevation, and azimuth of the aircraft. The cartesian components are:

$$
\begin{aligned}
x &= R \cos\beta \sin\alpha \\
y &= R \cos\beta \cos\alpha \qquad (1) \\
z &= R \sin\beta,
\end{aligned}
$$

where $-90° \leq \beta \leq 90°,$

$-180° \ (0°) \leq \alpha \leq 180° \ (360°).$

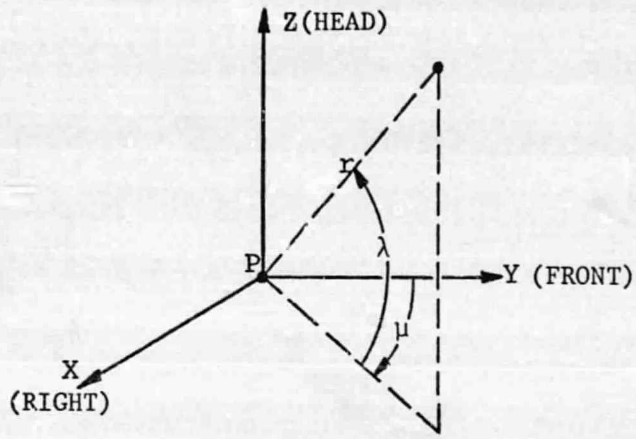

Figure 2. AIRCRAFT COORDINATE SYSTEM (A-SYSTEM)

r, λ, and μ are spherical-polar coordinates of a point in A-System. The cartesian components of which are written as in (1) with (R, β, α) replaced by (r, λ, μ), respectively.

Since the locations of both the pilot and the object are 'read' by the same device on the ground, a coordinate transformation is required to locate the object in the A-System. Figure 3 illustrates the trajectories of the aircraft and the object. It may be pointed out that the object is treated as a point mass and may be another aircraft or a fixed structure, such as a building or a mountain peak.

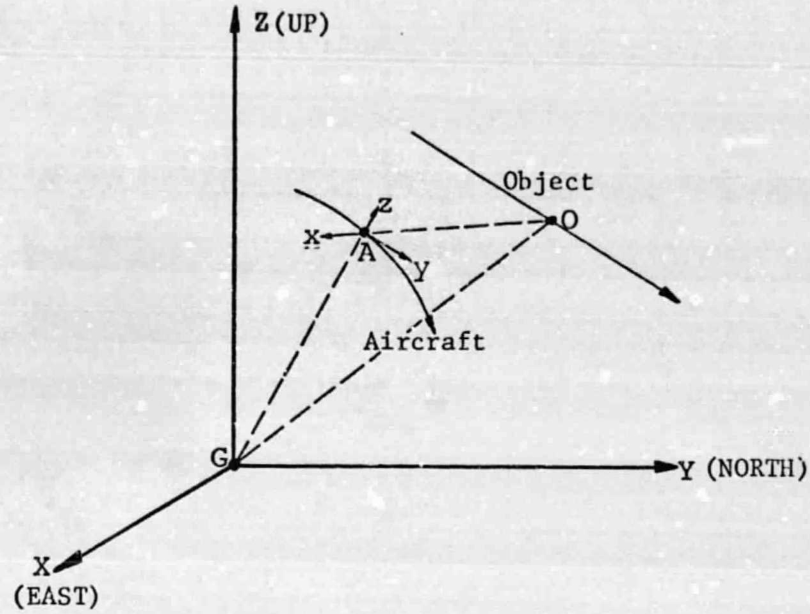

Figure 3

Let (x_o, y_o, z_o) are the coordinates of A and (x_g, y_g, z_g) of O in G-System. Also, assume that (x_a, y_a, z_a) are coordinates of O in A-System. The three vectors are related by a coordinate transformation at any given time:

$$\begin{bmatrix} x_a \\ y_a \\ z_a \end{bmatrix} = T \begin{bmatrix} x_g - x_o \\ y_g - y_o \\ z_g - z_o \end{bmatrix}, \qquad (3)$$

where

$$T = \begin{bmatrix} \cos\phi & 0 & -\sin\phi \\ 0 & 1 & 0 \\ \sin\phi & 0 & \cos\phi \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & \sin\theta \\ 0 & -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} \cos\Psi & -\sin\Psi & 0 \\ \sin\Psi & \cos\Psi & 0 \\ 0 & 0 & 1 \end{bmatrix}. \qquad (4)$$

Above (Ψ, θ, ϕ) are Euler angles between G- and A-Systems defined by three successive rotations: about Z-axis by Ψ (heading), then about new X-axis by θ (pitch), and finally about new Y-axis by ϕ (bank).

For the sake of generality, let (x_p, y_p, z_p) be the coordinates of the pilot's eyes (P) in the A-System. In the A-System the windows have fixed positions. Therefore, the coordinates of each corner of a window are known.

2.2 SOME GEOMETRICAL FORMULAE

The coordinates of the point of intersection (I), of the line from P to O and the plane of the window, will be determined.

As it may be found in any textbook on solid geometry, the equation of a (straight) line passing through two points (x_1, y_1, z_1) and (x_2, y_2, z_2) is

$$\frac{x-x_1}{x_2-x_1} = \frac{y-y_1}{y_2-y_1} = \frac{z-z_1}{z_2-z_1} = Q, \tag{5}$$

where Q is a constant.

The distance (D) between two points (x_1, y_1, z_1) and (x_2, y_2, z_2) is given by

$$D = \sqrt{(x_2-x_1)^2 + (y_2-y_1)^2 + (z_2-z_1)^2}. \tag{6}$$

Any linear equation in (x, y, z) defines a plane. The equation of a plane, whose three non-collinear points are (x_1, y_1, z_1), (x_2, y_2, z_2) and (x_3, y_3, z_3), is given by determinant equation:

$$\begin{vmatrix} x & y & z & 1 \\ x_1 & y_1 & z_1 & 1 \\ x_2 & y_2 & z_2 & 1 \\ x_3 & y_3 & z_3 & 1 \end{vmatrix} = 0. \tag{7}$$

The intersection point (x_I, y_I, z_I) of the line defined by (5) and the plane defined by (7) is given by

$$\begin{aligned} x_I &= Q(x_a - x_p) + x_p, \\ y_I &= Q(y_a - y_p) + y_p, \\ z_I &= Q(z_a - z_p) + z_p, \end{aligned} \tag{8}$$

where

$$Q = \frac{d - ax_p - by_p - cz_p}{a(x-x_p) + b(y-y_p) + c(z-z_p)},$$

with

$$\begin{aligned} a &= y_1(z_2-z_3) - z_1(y_2-y_3) + (y_2z_3-z_2y_3), \\ b &= -x_1(z_2-z_3) + z_1(x_2-x_3) - (x_2z_3-z_2x_3), \\ c &= x_1(y_2-y_3) - y_1(x_2-x_3) + (x_2y_3-y_2x_3), \\ d &= x_1(y_2z_3-z_2y_3) - y_1(x_2z_3-z_2x_3) + z_1(x_2y_3-y_2x_3). \end{aligned}$$

The area (Δ) of a triangle, whose corners are located at (x_1, y_1, z_1), (x_2, y_2, z_2) and (x_3, y_3, z_3), is given by

$$\Delta_{123} = 1/2 \sqrt{A_1^2 + A_2^2 + A_3^2}, \tag{9}$$

where

$$\begin{aligned} A_1 &= x_1(y_2-y_3) - y_1(x_2-x_3) + (x_2y_3-y_2x_3), \\ A_2 &= x_1(z_2-z_3) - z_1(x_2-x_3) + (x_2z_3-z_2x_3), \\ A_3 &= y_1(z_2-z_3) - z_1(y_2-y_3) + (y_2z_3-z_2y_3). \end{aligned}$$

2.3 GEOMETRY OF VISION

To find out whether the intersection point (I) lies within the boundary of a window the procedure is described as follows:

Figure 4 shows a typical window for the sake of illustration.

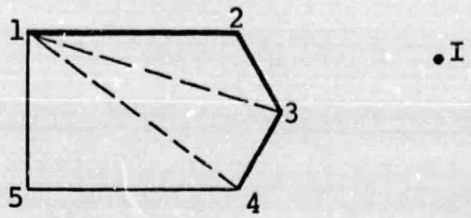

Figure 4

Numerals (1, 2, 3, 4, 5) index corners and I is the point of intersection. The window and the point I lie in one plane. We form all possible combinations out of corners taking two adjacent ones at a time, i.e., (1,2), (2,3), (3,4), (4,5), and (5,1). We pick up one pair at a time and the point I each time to form as many triangles as there are pairs, i.e., (1,2,I), (2,3,I), (3,4,I), (4,5,I) and (5,1,I). We sum the areas (say, Δ^I) of the triangles above. Then we calculate the true area (say, Δ^T) of the window, which is the sum of the areas of triangles whose vertices are at (1,2,3), (1,3,4), and (1,4,5). It may be noted that, by definition, the innter angle between any two adjacent sides of a window may not exceed 180°. Next we evaluate the distance (say, D^{PO}) between the pilot's eyes (P) and the object (O), and also the distance (say, D^{IO}) between the point of intersection (I) and the object (O). Quantities Δ^I and Δ^T are calculated using expression (9), while D^{PO} and D^{IO} are evaluated using (6).

2.4 VISIBILITY CRITERIA

Define a small arbitrary number (say, ε) which will provide the model a certain tolerance in the accuracy of the input data and the computer. Then, the table in Figure 5 establishes the criteria that the object (O) would be visible to the pilot (P) through the particular window whose plane has the point of intersection (I).

	$\left\| \Delta^I - \Delta^T \right\| \leq \varepsilon$	$\left\| \Delta^I - \Delta^T \right\| > \varepsilon$
$D^{IO} < D^{PO}$	VISIBLE	NOT VISIBLE
$D^{IO} \geq D^{PO}$	NOT VISIBLE	NOT VISIBLE

Figure 5. VISIBILITY TABLE

3. NUMERICAL EXAMPLE

For the purpose of illustration, we have chosen a CESSNA-172, the vision envelope of which, as seen by the pilot, is depicted in Figure 6. As it may be noted, the windows have shapes complicated enough to be described by simple geometry. Therefore, the windows are approximated to simple geometric shapes for mathematical convenience, as shown in Figure 7.

We will assume that the origin of the A-System is located at the pilot's eyes; therefore,

$$x_p = y_p = z_p = 0. \tag{10}$$

The position coordinates of the aircraft and the object are given in a coordinate system fixed to the runway, which we will choose to be our ground-based G-System. The orientation of the aircraft (i.e., pitch, heading, and bank angles) are given in the radar-relative coordinate system. Since X-Y planes of both the ground and radar are the same, only the heading is transformed to the G-System.

We will now show, using our model, whether an object is visible through the segment of the front window, marked (X) in Figure 7. The coordinates of the vertices of this window are calculated using (1) in the A-System, and are listed in Figure 8. r is of unit length, which seems to be a valid assumption.

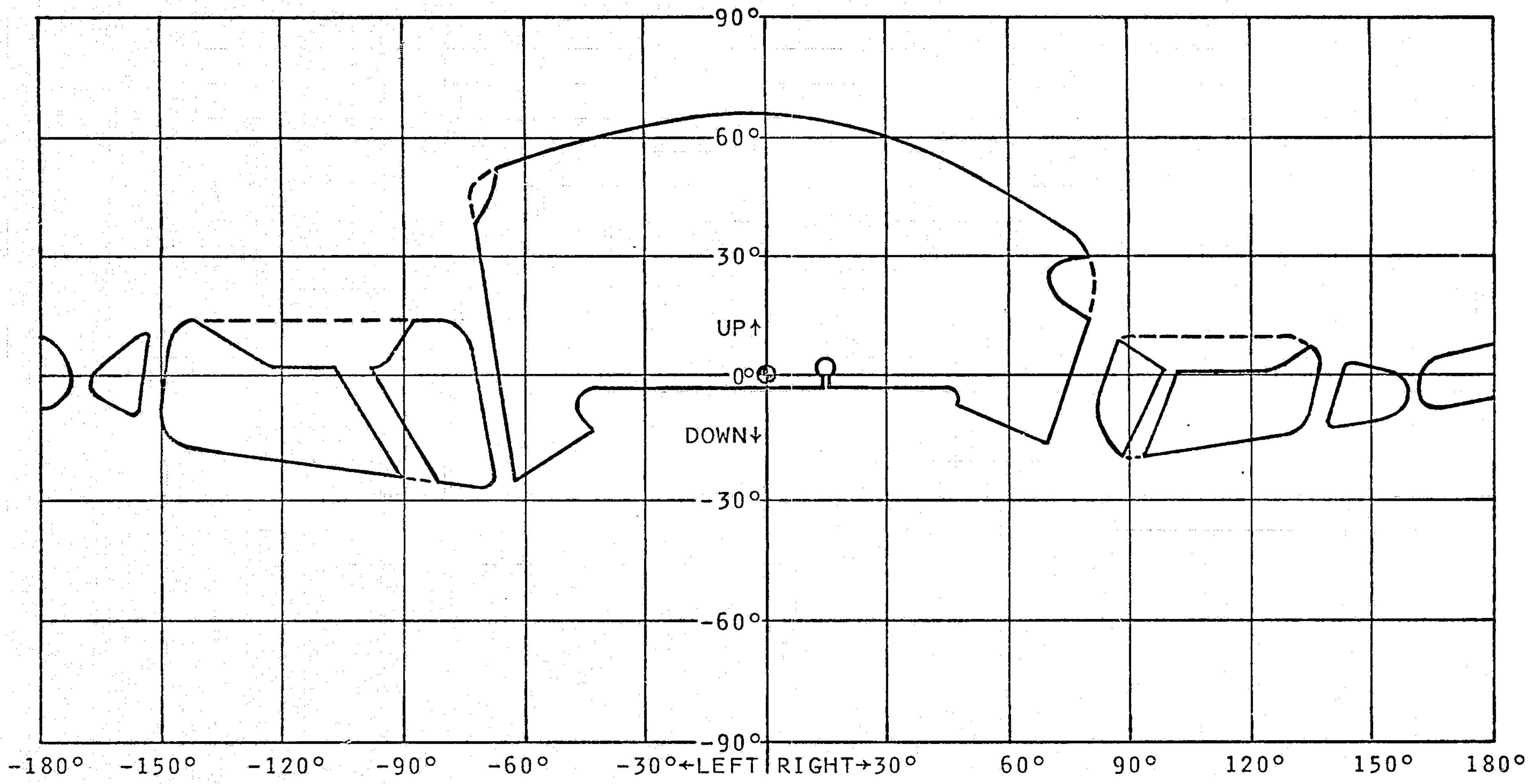

Figure 6. Vision Envelope for Single-Engine, High-Wing
1966 CESSNA 172

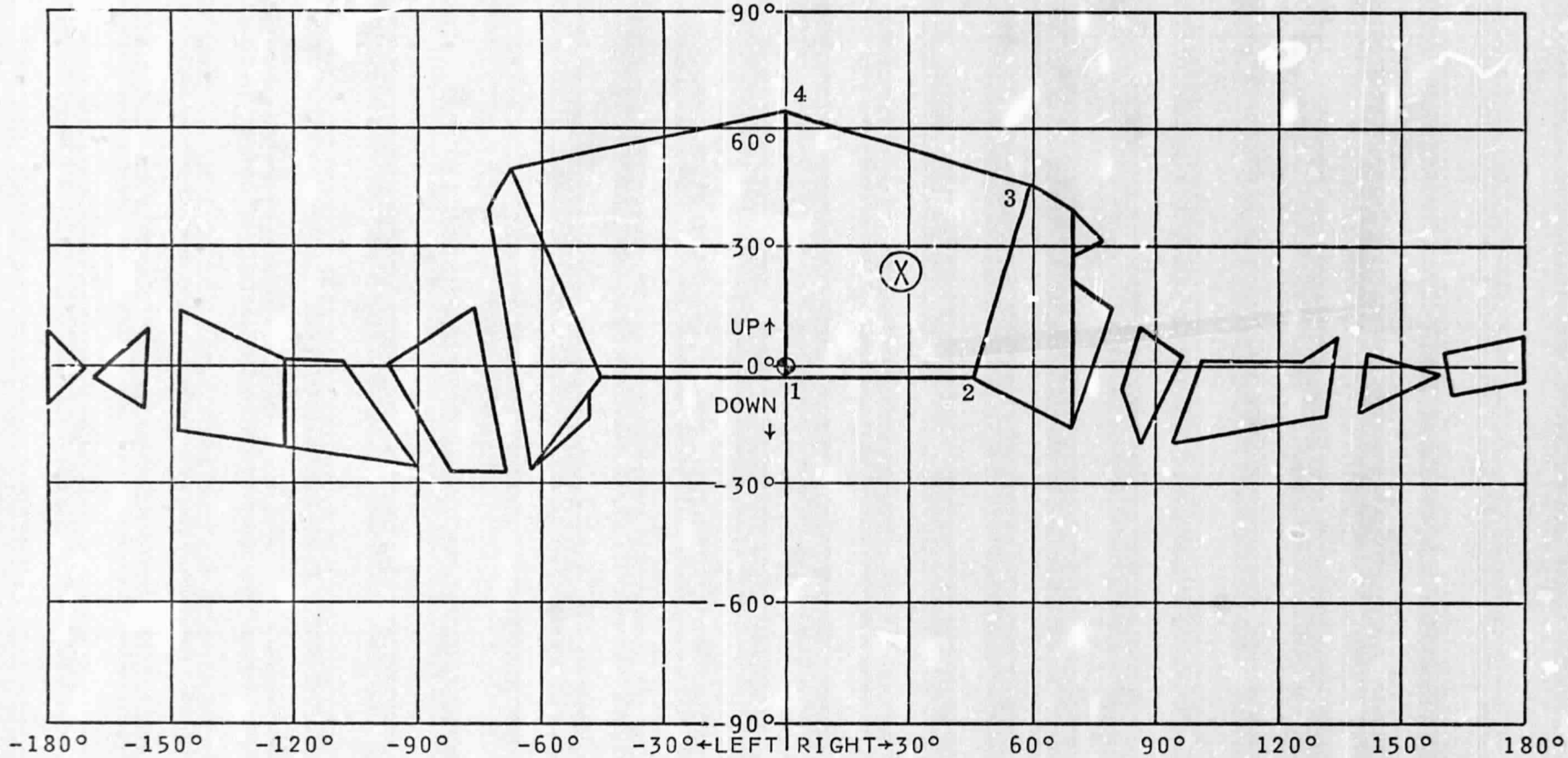

Figure 7. Simple Geometry of the Vision Envelope of CESSNA 172

i Corner No.	λ (in degrees)	μ (in degrees)	x_i	y_i	z_i
1	-2	0	0.000	0.999	-0.0348
2	-2	46	0.718	0.694	-0.034
3	46	60	0.6015	0.347	0.719
4	65	0	0.000	0.422	0.912

Figure 8

The coordinate of the aircraft and the object in G-System are given as

$$(x_o,\ y_o,\ z_o) = (-2142,\ 6498,\ 770)\ \text{ft}, \tag{11}$$

$$(x_g,\ y_g,\ z_g) = (-11050,\ 4000,\ 1200)\ \text{ft} \tag{12}$$

The orientation of the aircraft in radar-relative system is

$$(\Psi,\ \theta,\ \phi) = (-69°,\ -2°,\ -19°), \tag{13}$$

and in the G-System (runway) is

$$\begin{aligned}(\Psi,\ \theta,\ \phi) &= (-69°-46.18°,\ -2°,\ -19°)\\ &= (-115°.18,\ -20°,\ -19°),\end{aligned} \tag{14}$$

where we have corrected for the runway azimuth (46°.18) as measured by radar. The coordinates of the object in the A-System are evaluated using (3) and (4) with values given in (11), (12), and (14). They are

$$\begin{bmatrix} x_a \\ y_a \\ z_a \end{bmatrix} = \begin{bmatrix} -0.4125 & -0.9044 & 0.1683 \\ 0.8507 & -0.4252 & 0.3086 \\ 0.3253 & -0.0349 & 0.9449 \end{bmatrix} \begin{bmatrix} -13192 \\ -10498 \\ 430 \end{bmatrix}$$

$$= \begin{bmatrix} -3979 \\ -15553 \\ -4251 \end{bmatrix}. \tag{15}$$

Since a plane can be fixed by any three non-collinear points, we will choose vertices 1, 2, and 3. Therefore, from the table in Figure 8,

$$
\begin{aligned}
(x_1, y_1, z_1) &= (0, 0.999, -0.0348), \\
(x_2, y_2, z_2) &= (0.718, 0.694, -0.034), \\
(x_3, y_3, z_3) &= (0.6015, 0.347, 0.719). \qquad (16)
\end{aligned}
$$

With the aid of (10), (15), and (16) we have the point of intersection given by (8):

$$(x_I, y_I, z_I) = (-0.2004, -0.7835, -0.2141). \qquad (17)$$

The area enclosed by the window is evaluated using (9):

$$
\begin{aligned}
\Delta^T &= \Delta_{123} + \Delta_{134} = 0.258 + 0.413 \\
&= 0.671 \qquad (18)
\end{aligned}
$$

As described in article 2.3, we will calculate the areas of the triangles whose vertices are (1, 2, I), (2, 3, I), (3, 4, I), and (4, 1, I). They are:

$$
\begin{aligned}
\Delta^I &= \Delta_{12I} + \Delta_{23I} + \Delta_{34I} + \Delta_{41I} \\
&= 0.6725. \qquad (19)
\end{aligned}
$$

With (18) and (19), we have:

$$\Delta^I - \Delta^T = 0.0042. \qquad (20)$$

Also using (6), we find that the distance between the intersection point (I) and the object (O) is less than that between the pilot (P) and the object (O), i.e.,

$$
\begin{aligned}
D^{IO} &= 16606.37, \\
D^{PO} &= 16607.20. \qquad (21)
\end{aligned}
$$

With the tolerance level $\varepsilon = 0.02$ and the table in figure 5, we conclude that the object is visible to the pilot through the window (X).

4. CONCLUSION

We have presented a technique and a computer program to determine whether a pilot can see an exterior (point) object if the position and the orientation of the aircraft, the position of the object, and the geometry of the windows of the aircraft are known. The formulation and calculation are extremely simple and easy to implement. The object is treated as a point mass, and may be another aircraft, the top of a building, or a mountain peak in the range of sight. Pilot look angles to the other references such as runway approach lights etc., can also be evaluated.

Since the speed of the aircraft is finite, and the object most probably has a finite dimension, it may be interesting and useful to know the duration the pilot can see the object. It might be interesting as well to determine the times and durations the pilot can see the particular area at which he expects to land during various traffic patterns.

The model assumes that the probability of the pilot looking through one window is the same as that when looking through another. In practice this is not true. The pilot spends more time looking through front windows and less through farther ones. This observation may be represented by a Gaussian distribution, and included in the calculation of the probability that the pilot can see through a particular window. This can be achieved by a modification of (X_p, Y_p, Z_p) at $t = t$ in Equation (8).

5. ACKNOWLEDGMENT

We wish to express our thanks to Loyd Parker of the NASA Wallops Flight Center for formulating the requirements.

APPENDIX

COMPUTER LISTING AND OUTPUTS

```
CVTEST          THIS IS THE MAIN PROGRAM
C
C       WRITTEN BY J.BASHIR
C       ON MACHINE HONEYWELL625
C
C
C       VISION TEST PROGRAM.
C       THE MAIN PROGRAM CALLS SUBROUTINES INIT AND VISION.
C       SUBROUTINE INIT STORES THE DATA FOR THE TYPE OF A/C
C       CHOSEN AND EVALUATES ITS FIELD OF VISION.
C       SUBROUTINE VISION DETERMINES THE VISIBILITY
C       OF A TARGET FROM AN AIRCRAFT WHOSE WINDOW
C       GEOMETRY IS KNOWN,GIVEN THE POSITION COORDINATES
C       OF THE VIEWING AND TARGET A/C'S AND THE YAW,
C       PITCH AND BANK ANGLES OF THE VIEWING A/C.
C
C       INPUT TO INIT IS 'ITYPE' GIVEN AS AN ARGUMENT.
C
C       INPUT TO SUBROUTINE VISION IS PASSED THROUGH A
C       LABELED COMMON BLOCK 'INPUT',WHOSE VARIABLE
C       LIST IS AS :
C           VRNWAZ - RUNWAY AZIMUTH IS GIVEN IN RADAR
C                    RELATIVE FRAME OF REFERENCES
C                    (ZERO DEGREES AT MAG.NORTH).
C           VXP,VYP,VZP - POSITION COORDINATES OF THE
C                         VIEWING A/C(RUNWAY RELATIVE).
C           VAZ - VIEWING A/C'S AZIMUTH,GIVEN IN DEGREES
C                 IN RADAR RELATIVE COORD.SYSTEM AND IS
C                 MEASURED CLOCKWISE FROM NORTH OR Y-AXIS.
C           VEL - VIEWING A/C'S ELEVATION ANGLE IN DEGREES.
C           VBA - VIEWING A/C'S BANK ANGLE IN DEGREES.
C           VXT,VYT,VZT - POSITION COORDINATES OF THE
C                         TARGET A/C(RUNWAY RELATIVE).
C
C       OUTPUT IS BROUGHT THROUGH A LABELED COMMON BLOCK
C       'OUTPUT',WHOSE VARIABLE LIST IS AS GIVEN BELOW.
C
C           IVISIBL = 1  MEANS VISIBLE.
C                   = 0  MEANS NOT VISIBLE.
C           IVWINDO = WINDOW NO. AT WHICH TARGET IS LOCATED.
C           VPLAMDA = VERTICAL ANGLE OF THE LOCATION
C                     OF THE TARGET A/C IN THE WINDOW
```

```
C                    (UPWARDS IS +VE,DOWNWARDS -VE)
C          VPMU = HORIZONTAL ANGLE OF THE LOCATION
C                 OF THE TARGET A/C IN THE WINDOW
C                    (RIGHT IS +VE,LEFT -VE)
C
C
      COMMON /INPUT/ VRNWAZ,VXP,VYP,VZP,
     1               VAZ,VEL,VBA,VXT,VYT,VZT
      COMMON /OUTPUT/ IVISIBL,IVWINDO,VPLAMDA,VPMU
C
C     READ TYPE OF AIRCRAFT DESIRED,
C           ITYPE = A CODE NUMBER WHICH INDICATES
C                   WHICH A/C IS DESIRED.
C     CODES FOR DIFFERENT A/C'S ARE LISTED
C     IN SUBROUTINE INIT,
C
      READ,ITYPE
C
C1    CALL SUBROUTINE INIT TO SET THE A/C TYPE AND
C     DETERMINE ITS FIELD OF VISION,
C
      CALL INIT(ITYPE)
C
C     TEST EXAMPLE FOR FIVE CASES,
C
      DO 10 I=1,5
C
         READ,VRNWAZ,VXP,VYP,VZP,VAZ,VEL,VBA,VXT,VYT,VZT
C
C2    CALL SUBROUTINE VISION
C
         CALL VISION
C
         WRITE(6,50)IVISIBL,IVWINDO,VPLAMDA,VPMU
   50    FORMAT(5X,'IVISIBL = ',I1,4X,'IVWINDO = ',
     1          I2,4X,'VPLAMDA = ',F7.2,4X,'VPMU = ',F7.2,//)
   10 CONTINUE
      STOP
      END
```

```
      SUBROUTINE INIT(ITYPE)
C
C       THIS SUBROUTINE STORES THE DATA REQUIRED
C      FOR THE TYPE OF AIRCRAFT CHOSEN FOR VISIB-
C      -ILITY MODEL.
C
C11    EVALUATION OF THE FIELD OF VISION
C      THE FIELD OF VISION UTILIZES ALL AVAILABLE
C      WINDOWS,BUT EXCLUDES ALL OBSTRUCTIONS.
C      THE AVAILABLE FIELD OF VISION IS SUBDIVIDED
C      INTO NUMBER OF GEOMETRIC CLOSED FIGURES CALLED
C      WINDOWS.
C      THE VERTICES OF THE WINDOWS ARE DETERMINED
C      THROUGH A SET OF RAYS EMANATING FROM THE PILOT'S
C      EYES AND EACH RAY IS SPECIFIED IN A SPHERICAL
C      COORDINATE  SYSTEM WHICH MEASURES ANGULAR
C      DISPLACEMENTS FROM FROM LEVEL REFERENCE AXES
C      PARALLEL TO THE FUSELAGE AND PARALLEL TO THE
C      AIRCRAFT'S WINGS.
C
C
C
C12    DETERMINATION OF THE EQUATION OF THE PLANE OF THE WINDOWS
C
C      ONLY 3 NON COLLINEAR POINTS ARE REQUIRED TO
C      DETERMINE THE EQN. OF THE PLANE.
C      EQN AX+BY+CZ=D DEFINES A PLANE WHERE A,B,C AND D
C      ARE CONSTANTS,THESE CONSTANTS ARE EVALUATED BY EXPANDING
C      THE FOLLOWING DETERMINANT.
C
C                * X  Y  Z  *
C                * X1 Y1 Z1 *  = 0
C                * X2 Y2 Z2 *
C                * X3 Y3 Z3 *
C
C
C13    CALCULATION OF THE AREAS ENCLOSED BY THE WINDOWS.
C
C      EACH WINDOW IS DIVIDED INTO NUMBER OF TRIANGLES AND
C      THE AREA  OF EACH TRIANGLE IS CALCULATED AND THEN
C      ADDED TO EVALUATE THE AREA OF THE WINDOW.
C      INPUT-
```

```
C                   ITYPE  -  A CODE NUMBER WHICH INDICATES
C                             WHICH A/C IS DESIRED.
C
C                             MOONEY=21      = 1        SEL
C                             CHEROKEE-140 = 2        SEL
C                             CESSNA=172     = 3        SEH
C                             CESSNA=210     = 4        SEH
C                             PIPER AZTEC    = 5        SEH
C                             PIPER=140B     = 6        SEH
C                             BEECH BARON    = 7        TE
C                             AERO-COMM680E= 8        TE
C                             BOENG=707      = 9        ME
C                             DOUGLAS DC8    = 10       ME
C
C           OUTPUT-
C                   THE OUTPUT VALUES ARE RETURNED IN COMMON BLOCK,
C                   SINCE THEY ARE REQUIRED BY SUBROUTINES VISION
C                   AND VISIBL.
C
C                    NWINDO  -  NO.OF GEOMETRIC WINDOWS CONSTRUCTED
C                               OUT OF THE AVAILABLE WINDOWS FOR
C                               EACH A/C.
C                    NRAYS   -  NO OF VERTICES OF EACH WINDOW.
C
C                    TLAMDA  -  VERTICAL ANGLE FOR EACH CORNER
C                               OF THE WINDOW,(IN DEGREES)
C                    TMU     -  HORIZONTAL ANGLE FOR EACH CORNER
C                               OF THE WINDOW,(IN DEGREES)
C
C
C           THIS PROGRAM IS WRITTEN WITH ROOM FOR
C           EXPANSION TO 20 AIRCRAFTS.
C
C
            COMMON TLAMDA(25,6),TMU(25,6),NWINDO,XRAY(25,6),
           1       YRAY(25,6),ZRAY(25,6),NRAYS(25),A(4,25),
           2       AREA1(25)
C
            DIMENSION  NW(20),NR(25,20),TL(6,25,20),TM(6,25,20),
           1           V1(150),V2(150),V3(150),V4(150),V5(150),
           2           V6(150),V7(150),V8(150),V9(150),V10(150),
           3           H1(150),H2(150),H3(150),H4(150),H5(150),
```

```
      4          H6(150),H7(150),H8(150),H9(150),H10(150)
C
      EQUIVALENCE (TL(1,1,1),V1(1)),(TL(1,1,2),V2(1)),
     1            (TL(1,1,3),V3(1)),(TL(1,1,4),V4(1)),
     2            (TL(1,1,5),V5(1)),(TL(1,1,6),V6(1)),
     3            (TL(1,1,7),V7(1)),(TL(1,1,8),V8(1)),
     4            (TL(1,1,9),V9(1)),(TL(1,1,10),V10(1))
      EQUIVALENCE (TM(1,1,1),H1(1)),(TM(1,1,2),H2(1)),
     1            (TM(1,1,3),H3(1)),(TM(1,1,4),H4(1)),
     2            (TM(1,1,5),H5(1)),(TM(1,1,6),H6(1)),
     3            (TM(1,1,7),H7(1)),(TM(1,1,8),H8(1)),
     4            (TM(1,1,9),H9(1)),(TM(1,1,10),H10(1))
C
      DATA NW/20,15,16,18,15,18,20,15,20,17,10*0/
      DATA NR/6,4,4,4,5,3,5,4,4,3,4,4,3,4,4,4,4,4,3,5,5*0,              MOONEY21
     1        4,3,3,4,4,4,4,4,4,4,3,4,4,5,4,10*0,                       CHEROKEE
     2        4,3,5,4,3,3,3,4,4,4,3,4,4,4,3,3,9*0,                      CES-172
     3        4,5,5,4,4,5,4,4,4,4,4,4,3,4,5,4,4,4,7*0,                  CES-210
     4        4,5,5,4,4,4,4,4,4,4,5,4,4,4,4,10*0,                       PIPER-AZ
     5        4,3,4,3,4,4,4,3,5,5,3,5,3,3,3,4,4,4,7*0,                  PIPER140
     6        5,4,3,4,5,4,5,4,4,4,5,5,4,4,4,3,5,5,3,6,5*0,              BEECH-BA
     7        4,5,4,4,5,4,4,3,4,5,5,4,4,3,5,10*0,                       AERO-COM
     8        5,4,4,4,4,4,4,3,3,5,3,4,5,4,5,4,4,4,5,5,5*0,              BOENG707
     9        4,4,4,4,5,4,4,5,5,5,5,6,4,3,4,4,4,8*0,                    DC-8
     1        250*0/
      DATA V1/-24.,-22.,-9.,5.,4.,-20.,-15.,6.,7.,-4.,2*0.,                *
     1        -4.,7.,5.,-3.,2*0.,-3.,5.,-22.,-24.,2*0.,-18.,8.,                *
     2        20.,-12.,-19.,0.,-12.,19.,17.,3*0.,-12.,17.,19.,                 *
     3        8.,-7.,0.,25.,46.,60.,30.,2*0.,30.,60.,60.,54.,2*0.,             *
     4        30.,54.,32.,3*0.,-5.,24.,30.,-5.,2*0.,-5.,30.,32.,               *
     5        4.,2*0.,-5.,4.,-25.,3*0.,-56.,-40.,-20.,-30.,2*0.,               M
     6        -20.,24.,-4.,-30.,2*0.,-4.,24.,40.,48.,2*0.,-4.,                 O
     7        48.,47.,37.,2*0.,-4.,37.,11.,-33.,2*0.,0.,4.,-10.,               O
     8        3*0.,-33.,0.,-10.,-26.,-37.,0.,30*0./                            N
      DATA H1/134.,145.,150.,133.,127.,122.,117.,120.,100.,100.,           E
     1        2*0.,100.,100.,85.,92.,2*0.,92.,85.,77.,84.,2*0.,                Y
     2        67.,77.,57.,57.,64.,0.,57.,57.,54.,3*0.,57.,54.,47.,             2
     3        40.,43.,0.,37.,46.,20.,0.,2*0.,0.,20.,0.,-16.,2*0.,              1
     4        0.,-16.,-32.,3*0.,30.,46.,0.,0.,2*0.,0.,0.,-32.,
     5        -37.,2*0.,0.,-37.,-30.,3*0.,-54.,-32.,-40.,-74.,                 *
     6        2*0.,-40.,-45.,-84.,-74.,2*0.,-84.,-45.,-55.,-79.,               *
     7        2*0.,-84.,-79.,-110.,-134.,2*0.,-84.,-134.,-155.,                *
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     8        -143,,2*0,,-152,,-162,,-166,,3*0,,-143,,-152,,-166,,        *
     9        -160,,-151,,0,,30*0,/                                        *
      DATA V2/-9,76,,9,,-13,,2*0,,-17,,10,,18,,73*0,,-4,,18,,              *
     1        -4,73*0,,18,,22,,-11,,-20,,2*0,,-16,,22,,30,,                *
     2        -15,,2*0,,-15,,30,,43,,-8,,2*0,,-8,,43,,59,,-7,,             C
     3        2*0,,-6,,59,,60,,-7,,2*0,,-7,,60,,55,,-8,,2*0,,              H
     4        -16,,55,,27,,-21,,2*0,,10,,35,,35,,3*0,,10,,35,,             E
     5        -37,,-27,,2*0,,35,,27,,-3,,-3,,2*0,,27,,17,,-20,,            R
     6        -26,,-3,,0,,-17,,13,,6,,-7,,2*0,,60*0,/                      O
      DATA H2/168,,172,,150,,144,,2*0,,130,,140,,108,,3*0,,                K
     1        122,,108,,97,,3*0,,108,,92,,82,,90,,2*0,,67,,                E
     2        74,,71,,57,,2*0,,57,,71,,60,,50,,2*0,,50,,60,,               E
     3        25,,15,,2*0,,10,,18,,0,,0,,2*0,,0,,0,,-30,,-28,,             1
     4        2*0,,-28,,-30,,-53,,-36,,2*0,,-55,,-55,,-87,,                4
     5        3*0,,-55,,-87,,-67,,-43,,2*0,,-87,,-120,,-118,,              0
     6        -76,5,2*0,,-120,,-152,,-146,,-138,,-118,,0,,-152,,           *
     7        -157,,-172,,-171,,2*0,,60*0,/                                *
      DATA V3/-8,,-5,,7,,3,,2*0,,-12,,-3,,3,,3*0,,-20,,-13,,7,,1,,         *
     1        1,,8,,7,,-20,,2,,10,,2*0,,28,,31,,40,,3*0,,-16,,15,,          *
     2        22,,73*0,,-2,,-16,,40,,46,,2*0,,-2,,-2,,46,,65,,2*0,,65,,    *
     3        51,,-3,,-2,,2*0,,50,,40,,-26,,-2,,2*0,,-7,,-26,,             C
     4        -13,,3*0,,15,,1,,-26,,-26,,2*0,,2,,2,,-20,,-25,,             E
     5        2*0,,2,,15,,-15,,-20,,2*0,,10,,-2,,-10,,3*0,,                S
     6        -9,,0,,10,,3*0,,54*0,/                                       S
      DATA H3/163,,180,,180,,161,,2*0,,140,,160,,142,,3*0,,94,,132,,       N
     1        135,,126,,102,,0,,82,,87,,97,,87,,2*0,,70,,78,,70,,3*0,,     A
     2        70,,80,,70,,3*0,,46,,70,,70,,60,,2*0,,0,,46,,60,,0,,         -
     3        3*0,,-67,,-46,,0,,2*0,,-67,,-72,,-62,,-45,,2*0,,             1
     4        -48,,-62,,-48,,3*0,,-76,,-97,,-82,,-68,,2*0,,                7
     5        -108,,-122,,-122,,-90,,2*0,,-122,,-147,,-146,,               2
     6        -122,,2*0,,-155,,-168,,-156,,3*0,,-180,,-171,,-180,,         *
     7        3*0,,54*0,/                                                  *
      DATA V4/-11,,-6,,-6,,-11,,2*0,,-17,,-14,,-6,,-6,,-17,,               *
     1        0,,-17,,-5,,-7,,-23,,-24,,0,,-24,,-7,,-4,,-26,,              *
     2        2*0,,-25,,-6,,-5,,-22,,2*0,,-21,,1,,7,,-8,,-18,,             *
     3        0,,7,,15,,28,,27,,2*0,,-8,,7,,27,,-6,,2*0,,-6,,              C
     4        33,,41,,38,,2*0,,-6,,38,,38,,-12,,2*0,,-12,,40,,             E
     5        27,,-20,,2*0,,-20,,13,,4,,-35,,2*0,,-32,,4,,                 S
     6        -37,,3*0,,-50,,-42,,-10,,-10,,2*0,,-50,,-12,,                S
     7        -14,,-52,,-56,,0,,-52,,-14,,-11,,-38,,2*0,,-32,,             N
     8        -20,,-8,,-27,,2*0,,-18,,-16,,-10,,-13,,2*0,,42*0,/           A
      DATA H4/166,,167,,164,,164,,2*0,,155,,160,,157,,152,,                -
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          1     150.,0.,148.,148.,131.,129.,133.,0.,127.,127.,                2
          2     87.,82.,2*0.,77.,85.,77.,74.,2*0.,67.,74.,64.,                1
          3     54.,58.,0.,64.,72.,50.,37.,2*0.,54.,64.,37.,20.,              0
          4     2*0.,20.,40.,59.,17.,2*0.,20.,17.,-38.,-10.,
          5     2*0.,-10.,-39.,-40.,-23.,2*0.,-23.,-35.,-45.,-31.,            *
          6     2*0.,-32,5,-45.,-38.,3*0.,-53.,-47.,-53.,-75.,                *
          7     2*0.,-58.,-77.,-110.,-120.,-80.,0.,-120.,-110.,               *
          8      147.,-144.,2*0.,-154.,-150.,-158.,-156.,2*0.,
          9     -166.,-164.,-166.,-168.,2*0.,42*0./
      DATA V5/-3.,3.,3.,-3.,2*0.,-12.,-4.,4.,5.,-13.,0.,-13.,                 *
          1     -5.,5.,6.,-16.,0.,-16.,7.,7.,-12.,2*0.,-12.,7.,6.,
          2     -12.,2*0.,-12.,4.,22.,-7.,2*0.,-7.,22.,25.,-8.,               P
          3     2*0.,-8.,25.,16.,-20.,2*0.,-22.,-18.,-32.,-33.,               I
          4     2*0.,-18.,10.,-11.,-21.,2*0.,-13.,21.,26.,-4.,                P
          5     -17.,0.,-4.,26.,26.,-7.,2*0.,-7.,26.,10.,-18.,                E
          6     2*0.,-18.,10.,-22.,-30.,2*0.,-10.,6.,4.,-7.,                  R
          7     2*0.,60*0./
      DATA H5/156.,153.,145.,143.,2*0.,138.,142.,140.,135.,131.,0.,           A
          1     131.,133.,132.,124.,123.,0.,113.,115.,95.,82.,                Z
          2     2*0.,82.,95.,80.,77.,2*0.,72.,73.,30.,30.,2*0.,               T
          3     30.,30.,0.,0.,2*0.,0.,0.,-45.,-30.,2*0.,-30.,                 E
          4     -34.,-37.,-33.,2*0.,-34.,-47.,-49.,-35.,2*0.,                 C
          5     -53.,-55.,-90.,-90.,-85.,0.,-90.,-90.,-100.,-104.,            *
          6     2*0.,-104.,-100.,-157.,-120.,2*0.,-120.,-157.,                *
          7     -154.,-142.,2*0.,-158.,-162.,-171.,-167.,2*0.,
          8     60*0./
      DATA V6/-17.,-8.,-4.,-19.,2*0.,-16.,-6.,-6.,3*0.,-6.,6.,9.,
          1     -4.,2*0.,-4.,9.,4.,3*0.,-20.,-4.,4.,-16.,2*0.,                *
          2     -24.,14.,30.,-8.,2*0.,-8.,30.,45.,-6.,2*0.,-6.,               *
          3     45.,53.,3*0.,-6.,48.,60.,53.,-10.,0.,-10.,53.,                *
          4     39.,-10.,-20.,0.,-20.,-10.,-30.,3*0.,-33.,-10.,               P
          5     -6.,-40.,-46.,0.,-6.,-10.,45.,3*0.,-6.,45.,48.,               I
          6     3*0.,-6.,48.,48.,3*0.,-6.,48.,38.,-7.,2*0.,-7.,               P
          7     38.,34.,-34.,2*0.,-25.,-1.,-10.,-19.,2*0.,42*0./              E
      DATA H6/145.,146.,126.,124.,2*0.,121.,119.,109.,3*0.,                   R
          1     109.,119.,85.,91.,2*0.,91.,85.,78.,3*0.,86.,91.,              1
          2     78.,77.,2*0.,64.,77.,70.,56.,2*0.,56.,70.,56.,                4
          3     30.,2*0.,30.,56.,25.,3*0.,17.,56.,13.,-11.,-9.,               0
          4     0.,-9.,-11.,-35.,-35.,-25.,0.,-25.,-35.,-30.,                 B
          5     3*0.,-33.,-40.,-87.,-71.,-52.,0.,-87.,-40.,-40.,              *
          6     3*0.,-87.,-40.,-54.,3*0.,-87.,-54.,-94.,3*0.,                 *
          7     -87.,-94.,-120.,-113.,2*0.,-113.,-120.,-160.,                 *
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      8     -147.,2*0.,-158.,-162.,-167.,-165.,2*0.,42*0./
       DATA V7/-10.,-3.,3.,1.,-14.,0.,-26.,7.,12.,-18.,2*0.,          •
      1     -14.,17.,-3.,3*0.,-3.,17.,18.,-3.,2*0.,-3.,18.,           •
      2     14.,-5.,-9.,0.,-5.,22.,30.,-3.,2*0.,-3.,30.,42.,          *
      3     51.,47.,0.,-3.,47.,63.,-5.,2*0.,49.,56.,64.,63.,          B
      4     2*0.,-5.,63.,50.,-12.,2*0.,-8.,3.,58.,78.5,-6.,           E
      5     0.,-6.,78.5,94.,-4.,-14.,0.,-4.,94.,93.,-4.,2*0.,         E
      6     -4.,93.,83.,55.,2*0.,-4.,55.,29.,6.,2*0.,-4.,6.,          C
      7     -34.,3*0.,-32.,13.,20.,-21.,-33.,0.,-4.,20.,20.,          H
      8     8.,-4.,0.,-21.,-4.,-4.,3*0.,-16.,-4.,3.,2.,-4.,           -
      9     -15.,30*0./                                               B
       DATA H7/162.,164.,156.,148.,145.,0.,143.,148.,121.,117.,       A
      1     2*0.,112.,116.,98.,3*0.,98.,116.,82.,91.,2*0.,            R
      2     91.,82.,74.,62.,86.,0.,56.,71.,67.,43.,2*0.,43.,          O
      3     67.,66.,57.,50.,0.,43.,50.,-7.,0.,2*0.,44.,50.,           N
      4     33.,-7.,2*0.,0.,-7.,-16.,-19.,2*0.,-32.,-20.,-17.,        -
      5     -31.,-46.,0.,-46.,-31.,-54.,-82.,-74.,0.,-82.,            B
      6     -54.,-110.,-88.,2*0.,-88.,-110.,-136.,-156.,2*0.,         5
      7     -88.,-156.,-152.,-140.,2*0.,-88.,-140.,-132.,3*0.,        5
      8     -134.,-144.,-151.,-159.,-145.,0.,-156.,-151.,             •
      9     -164.,-168.,-162.,0.,-159.,-156.,-162.,3*0.,              •
      •     -161.,-163.,-167.,-170.,-172.,-178.,30*0./
       DATA V8/-18.,-10.,-9.,-17.,2*0.,-24.,-7.,4.,3.,-24.,0.,        •
      1     -18.,7.,-15.,-18.,2*0.,-15.,7.,23.,-14.,2*0.,             A
      2     -14.,23.,21.,-2.,-15.,0.,-15.,-13.,-12.,-17.,             E
      3     2*0.,-15.,26.5,17.,-19.,2*0.,26.,36.,46.,3*0.,            R
      4     26.,46.,48.,16.,2*0.,-23.,-19.,48.,40.,-26.,0.,           O
      5     -26.,40.,10.,-42.,-42.,0.,-50.,0.,0.,-58.,2*0.,
      6     0.,6.,5.,0.,2*0.,-58.,0.,-10.,3*0.,-58.,-10.,             C
      7     -27.,-44.,-58.,0.,60*0./                                  O
       DATA H8/139.,144.,134.,134.,2*0.,114.,116.,103.,86.,77.,       M
      1     0.,78.,86.,65.,69.,2*0.,65.,86.,62.,54.,2*0.,54.,         6
      2     62.,49.,36.,38.,0.,38.,37.,30.,26.,2*0.,25.,48.,          8
      3     -5.,70.,2*0.,44.,43.,20.,3*0.,44.,20.,-10.,-5.,           0
      4     2*0.,-2.,0.,-10.,-36.,-10.,0.,-10.,-36.,-65.,-48.,        E
      5     -38.,0.,-50.,-65.,-98.,-67.,2*0.,-65.,-73.,-105.,         •
      6     -98.,2*0.,-67.,-98.,-108.,3*0.,-67.,-108.,-132.,          •
      7     -139.,-107.,0.,60*0./
       DATA V9/-4.,5.,5.,-10.,-15.,0.,17.,17.,16.,13.,2*0.,15.,
      1     19.,15.,13.,2*0.,-6.,6.,9.,-8.,2*0.,-8.5,12.,18.,         •
      2     -11.5,2*0.,-11.5,18.,19.,-19.,2*0.,-24.,22.,27.,          •
      3     -41.,2*0.,-41.,27.,25.,3*0.,-34.,20.,18.,3*0.,            •
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     4        -34.,20.,12.,-12.,-36.,0.,65.,79.,80.,3*0.,76.,                B
     5        80.,80.,74.,2*0.,57.,66.,59.,46.,49.,0.,46.,59.,               O
     6        74.,54.,2*0.,74.,80.,89.,89.,67.,0.,54.,74.,67.,               E
     7        53.,2*0.,66.,82.,81.,68.,2*0.,64.,81.,80.,68.,                 N
     8        2*0.,68.,80.,83.,65.,60.,0.,61.,65.,83.,75.,66.,0.,            G
     9        30*0./                                                         -
C
      DATA H9/110.,110.,76.,67.,87.,0.,96.,100.,88.,84.,2*0.,83.,            7
     1        84.,72.,77.,2*0.,68.,75.,37.,29.,2*0.,27.,36.,0.,              0
     2        0.,2*0.,0.,0.,-32.,-26.,2*0.,-31.,-37.,-70.,-75.,              7
     3        2*0.,-75.,-70.,-103.,3*0.,-80.,-103.,-111.,3*0.,               *
     4        -80.,-113.,-137.,-131.,-89.,0.,38.,53.,37.,3*0.,               *
     5        37.,37.,30.,17.,2*0.,34.,34.,20.,15.,27.,0.,15.,               *
     6        20.,17.,-9.,2*0.,17.,30.,10.,-50.,-39.,0.,-9.,17.,
     7        -39.,-37.,2*0.,-50.,-64.,-72.,-65.,2*0.,-63.,-72.,
     8        -81.,-86.,2*0.,-86.,-81.,-89.,-111.,-127.,0.,
     9        -119.,-111.,-89.,-116.,-124.,0.,30*0./
      DATA V10/-5.,5.,6.,-12.,2*0.,13.,26.,25.,13.5,2*0.,-11.5,              *
     1        7.,6.5,-6.,2*0.,-6.5,8.5,10.5,-6.5,2*0.,-7.,10.,               *
     2        15.,-7.,-9.,0.,-7.,15.,14.,-12.,2*0.,14.,17.,27.,              D
     3        22.,2*0.,-12.,14.,22.,20.,-17.,0.,-15.,10.,25.,                O
     4        29.,27.,0.,-15.,27.,32.,28.,-28.,0.,-28.,32.,26.,              U
     5        16.,-26.,0.,-27.,-25.,8.5,17.,8.,-12.5,58.,78.,                G
     6        98.,108.,2*0.,56.,58.,108.,3*0.,56.,108.,52.,47.,              L
     7        2*0.,52.,108.,64.,48.,2*0.,64.,108.,97.,74.,2*0.,              A
     8        48*0./                                                         S
      DATA H10/103.,104.,94.,88.,2*0.,91.,97.,85.,78.,2*0.,85.,              D
     1        91.5,75.,69.,2*0.,67.,74.,50.,38.5,2*0.,37.,48.,               C
     2        28.,17.,18.,0.,17.,28.,19.,9.5,2*0.,19.,19.5,-11.,             8
     3        -12.,2*0.,9.5,19.,-12.,-30.,-30.,0.,-35.,-35.5,                *
     4        -38.,-47.,-48.5,0.,-35.,-48.5,-56.,-78.,-64.,0.,               *
     5        -78.,-56.,-90.,-95.,-85.,0.,-99.,-97.,-108.5,-115.,            *
     6        -131.,-123.,-40.,-26.,-21.,-117.,2*0.,-77.,-40.,
     7        -117.,3*0.,-77.,-117.,-101.,-97.,2*0.,-101.,-117.,
     8        -121.,-109.,2*0.,-121.,-117.,-139.,-140.,2*0.,
     9        48*0./
C
C     STORE THE DATA FOR THE A/C CHOSEN.
C
      NWINDO=NW(ITYPE)
      DO 1  I=1,NWINDO
         NRAYS(I) = NR(I,ITYPE)
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            DO 1  J=1,NRAYS(I)
      C
      C11   TLAMDA AND TMU ARE THE VERTICAL AND HORIZONTAL
      C     ANGLES OF THE VERTICES OF THE WINDOWS.
               TLAMDA(I,J) = TL(J,I,ITYPE)
       1       TMU(I,J)    = TM(J,I,ITYPE)
      C
      C     XRAY,YRAY,ZRAY ARE THE COORD. OF THE CORNERS OF THE
      C     WINDOWS.
      C
            DO 15 I=1,NWINDO
            K=NRAYS(I)
            DO 15 J=1,K
            IF(TLAMDA(I,J).GT.90.0) TLAMDA(I,J) = 180.0-TLAMDA(I,J)
            IF(TLAMDA(I,J).GT.90.0) TMU(I,J) = 180.0+TMU(I,J)
            TMU(I,J)=TMU(I,J)/57.29853
            TLAMDA(I,J)=TLAMDA(I,J)/57.29853
            XRAY(I,J)=+COS(TLAMDA(I,J))*SIN(TMU(I,J))
            YRAY(I,J)=+COS(TLAMDA(I,J))*COS(TMU(I,J))
            ZRAY(I,J)=+SIN(TLAMDA(I,J))
       15   CONTINUE
      C
      C12   EQUATION OF THE PLANE OF THE WINDOW  IS DETERMINED HERE.
      C     A(1,I),A(2,I),A(3,I),A(4,I) ARE THE A,B,C,D CONSTANTS
      C     OF THE EQN OF TH PLANE OF THE WINDOW.
      C
            DO 30 I=1,NWINDO
                  A(1,I)  =YRAY(I,1)*(ZRAY(I,2)-ZRAY(I,3))
           1              -ZRAY(I,1)*(YRAY(I,2)-YRAY(I,3))
           2              +(YRAY(I,2)*ZRAY(I,3)-YRAY(I,3)
           3              *ZRAY(I,2))
                  A(2,I)  =-XRAY(I,1)*(ZRAY(I,2)-ZRAY(I,3))
           1              +ZRAY(I,1)*(XRAY(I,2)-XRAY(I,3))
           2              -(XRAY(I,2)*ZRAY(I,3)-ZRAY(I,2)
           3              *XRAY(I,3))
                  A(3,I)  = XRAY(I,1)*(YRAY(I,2)-YRAY(I,3))
           1              -YRAY(I,1)*(XRAY(I,2)-XRAY(I,3))
           2              +(XRAY(I,2)*YRAY(I,3)-YRAY(I,2)
           3              *XRAY(I,3))
                  A(4,I)  = XRAY(I,1)*(YRAY(I,2)*ZRAY(I,3)
           1              -ZRAY(I,2)*YRAY(I,3))-YRAY(I,1)
           2              *(XRAY(I,2)*ZRAY(I,3)-ZRAY(I,2)
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         3              *XRAY(I,3))+ZRAY(I,1)*(XRAY(I,2)
         4              *YRAY(I,3)-XRAY(I,3)*YRAY(I,2))
   30    CONTINUE
C
C13      THIS LOOP CALCULATES THE AREAS OF THE
C        WINDOWS.
C
         DO 40   I=1,NWINDO
                 J2=1
                 SUM=0
           DO 35 JJ=1,(NRAYS(I)-2)
                 J2=J2+1
                 J3=J2+1
               A1 = XRAY(I,1)*(YRAY(I,J2)-YRAY(I,J3))
         1           -YRAY(I,1)*(XRAY(I,J2)-XRAY(I,J3))
         2           +(XRAY(I,J2)*YRAY(I,J3)-YRAY(I,J2)
         3           *XRAY(I,J3))
               A2 = XRAY(I,1)*(ZRAY(I,J2)-ZRAY(I,J3))
         1           -ZRAY(I,1)*(XRAY(I,J2)-XRAY(I,J3))
         2           +(XRAY(I,J2)*ZRAY(I,J3)-ZRAY(I,J2)
         3           *XRAY(I,J3))
               A3 = YRAY(I,1)*(ZRAY(I,J2)-ZRAY(I,J3))
         1           -ZRAY(I,1)*(YRAY(I,J2)-YRAY(I,J3))
         2           +(YRAY(I,J2)*ZRAY(I,J3)-ZRAY(I,J2)
         3           *YRAY(I,J3))
               AREA=0.5*SQRT(A1**2+A2**2+A3**2)
         SUM=SUM+AREA
   35     CONTINUE
         AREA1(I)=SUM
   40    CONTINUE
         RETURN
         END
```

```
      SUBROUTINE VISION
C
C     THIS SUBROUTINE TESTS WHETHER TARGET AIRCRAFT LIES
C     IN THE VIEWING AIRCRAFT'S PILOT'S FIELD OF VISION,
C     THE LOCATION OF THE TARGET  A/C  IN THE PLANE OF THE WINDOW
C     AT WHICH IT WAS LOCATED IS CALCULATED AND PASSED
C     TO THE LABELED COMMON BLOCK 'OUTPUT';
C
C
C21   DEFINITION OF THE TRANSFORMATION MATRICES TO BRING
C     TARGET A/C IN VIEWING A/C'S COORDINATE SYSTEM,
C
C
C22   DETERMINE THE EQN.OF THE LINE JOINING PILOT'S EYES AND
C     THE TARGET A/C,ALSO INTERSECTION POINT
C     OF THIS LINE WITH PLANE OF THE WINDOW,
C     EQN OF THE LINE JOINING (X1,Y1,Z1)AND(X2,Y2,Z2) IS
C     (X-X1)/X2-X1)=(Y-Y1)/Y2-Y1)=(Z-Z1)/Z2-Z1)=Q
C
C
C     DETERMINE INTERSECTION POINT OF THE LINE OF SIGHT WITH
C     THE PLANE OF THE WINDOW,
C     INTERSECTING POINT IS GIVEN BY
C             XI=Q(XO-XE)+XE
C             YI=Q(YO-YE)+YE
C             ZI=Q(ZO-ZE)+ZE
C     WHERE
C         XO,YO,ZO ARE THE COORDINATES OF THE TARGET A/C
C     IN VIEWING PLAN'S SYSTEM, XE,YE,ZE IS A/C'S EYES COORD.
C     AND
C     Q=(D-A*XE-B*YE-C*ZE)/(A(XO-XE)+B(YO-YE)+C(ZO-ZE))
C
C
C23   CALCULATION OF DISTANCES JOINING XI,YI,ZI AND XO,YO,ZO
C
C     DISTANCE JOINING(XI,YI,ZI)AND(XP,YP,ZP)MUST BE SMALLER
C     THAN DISTANCE JOINING(XP,YP,ZP)AND(XE,YE,ZE),THIS TEST
C     IS PERFORMED TO ENSURE THAT INTERSECTION POINT LIES IN
C     FRONT OF PILOT'S EYES AND NOT BEHIND HIS BACK,
C
C
C24   CALCULATE THE AREAS FORMED WITH JOINING XI,YI,ZI
```

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```
C       AND TWO CONSECUTIVE CORNERS OF THE WINDOWS.
C
C       CALCULATION OF THE AREAS IS PERFORMED AS EXPLAINED
C       EARLIER
C
C25     TEST FOR VISIBILITY.
C
C       AREA1 CALCULATED IN SUBROUTINE VISION AND AREA2
C       CALCULATED IN SUBROUTINE VISIBL ARE COMPARED FOR THE
C       VISIBILITY TEST.IF THESE AREAS ARE EQUAL OR WITHIN
C       THE SPECIFIED TOLERANCE(GIVEN IN THE DATA STATEMENT),
C       THEN WE SAY THE TARGET A/C IS VISIBLE OTHERWISE NOT.
C
C26     LOCATION OF THE TARGET A/C IN THE VISIBILITY WINDOW.
C
C       VERTICAL AND HORIZONTAL ANGLES OF THE TARGET
C       A/C ARE CALCULATED.
C
C
        DIMENSION TRNSFM(3,3),AREA2(25)
        DIMENSION XI(25),YI(25),ZI(25)
C
        COMMON TLAMDA(25,6),TMU(25,6),NWINDO,XRAY(25,6),
     1         YRAY(25,6),ZRAY(25,6),NRAYS(25),A(4,25),
     2         AREA1(25)
        COMMON /INPUT/ VRNWAZ,VXP,VYP,VZP,
     1                 VAZ,VEL,VBA,VXT,VYT,VZT
        COMMON /OUTPUT/ IVISIBL,IVWINDO,VPLAMDA,VPMU
C
        DATA XE,YE,ZE/3*0./,TOLR/1.0E-02/
C
C21     DETERMINATION OF THE TRANSFORMATION MATRIX
C
C       TO MAKE ALL DATA CONSISTENT THE A/C'S
C       AZIMUTH IS CORRECTED TO BE RUNWAY RELATIVE.
C
        AZA=(VAZ-VRNWAZ)*3.1416/180.
        ELA=VEL*3.1416/180.
        BAA=VBA*3.1416/180.
        CS=COS(AZA)
        SS=SIN(AZA)
        CT=COS(ELA)
```

```
      ST=SIN(ELA)
      CP=COS(RAA)
      SP=SIN(RAA)
      TRNSFM(1,1)=+CS*CP+SS*ST*SP
      TRNSFM(2,1)=-SS*CP+CS*ST*SP
      TRNSFM(3,1)=-CT*SP
      TRNSFM(1,2)=+SS*CT
      TRNSFM(2,2)=CS*CT
      TRNSFM(3,2)=ST
      TRNSFM(1,3)=+CS*SP-SS*ST*CP
      TRNSFM(2,3)=-SS*SP-CS*ST*CP
      TRNSFM(3,3)=CT*CP
C
C     TARGET A/C IS BROUGHT IN THE VIEWING A/C'S COORD.
C
      XO=(VXT-VXP)*TRNSFM(1,1)+(VYT-VYP)*TRNSFM(2,1)+
     1   (VZT-VZP)*TRNSFM(3,1)
      YO=(VXT-VXP)*TRNSFM(1,2)+(VYT-VYP)*TRNSFM(2,2)+
     1   (VZT-VZP)*TRNSFM(3,2)
      ZO=(VXT-VXP)*TRNSFM(1,3)+(VYT-VYP)*TRNSFM(2,3)+
     1   (VZT-VZP)*TRNSFM(3,3)
C
C22   INTERSECTION POINT OF LINE OF VISIBILITY AND
C     THE PLANE OF THE WINDOW IS DETERMINED.
C
C     XI,YI,ZI ARE THE INTERSECTION POINTS.
C
      DO 70 I=1,NWINDO
         PNOM=A(4,I)-A(1,I)*XE-A(2,I)*YE-A(3,I)*ZE
          DNOM=A(1,I)*(XO-XE)+A(2,I)*(YO-YE)
     1         +A(3,I)*(ZO-ZE)
        RESULT=PNOM/DNOM
      XI(I)=RESULT*(XO-XE)+XE
      YI(I)=RESULT*(YO-YE)+YE
      ZI(I)=RESULT*(ZO-ZE)+ZE
   70 CONTINUE
C
C23   DIST1 AND DIST2 ARE THE DISTANCES JOINING (XI,YI,ZI)
C     WITH (XO,YO,ZO) AND (XE,YE,ZE) WITH  (XO,YO,ZO)
C     RESPECTIVELY.
C
      DO 90 I=1,NWINDO
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         S1=(XO-XI(I))**2
         S2=(YO-YI(I))**2
         S3=(ZO-ZI(I))**2
         DIST1=SQRT(S1+S2+S3)
         S4=(XO-XE)**2
         S5=(YO-YE)**2
         S6=(ZO-ZE)**2
         DIST2=SQRT(S4+S5+S6)
         IF(DIST1.GT.DIST2)GO TO 90
         K=NRAYS(I)
C
C24      THIS LOOP CALCULATES THE AREAS FORMED WITH
C        THE INTERSECTION OF THE SIGHT LINE
C        AND THE WINDOW CORNERS.
C
               SUM=0
         DO 85 J1=1,K
            J2=J1+1
            IF(J1.EQ.K) J2=1
            A1= XRAY(I,J1)*(YRAY(I,J2)-YI(I))
        1       -YRAY(I,J1)*(XRAY(I,J2)-XI(I))
        2       +(XRAY(I,J2)*YI(I)-YRAY(I,J2)*XI(I))
            A2= XRAY(I,J1)*(ZRAY(I,J2)-ZI(I))
        1       -ZRAY(I,J1)*(XRAY(I,J2)-XI(I))
        2      +(XRAY(I,J2)*ZI(I)-ZRAY(I,J2)*XI(I))
            A3= YRAY(I,J1)*(ZRAY(I,J2)-ZI(I))
        1       -ZRAY(I,J1)*(YRAY(I,J2)-YI(I))
        2       +(YRAY(I,J2)*ZI(I)-ZRAY(I,J2)*YI(I))
           AREA=0.5*SQRT(A1**2+A2**2+A3**2)
           SUM=SUM+AREA
   85    CONTINUE
           AREA2(I)=SUM
C
C25      COMPARISON OF AREA1 AND AREA2.
         IF(ABS(AREA2(I)-AREA1(I))-TOLR)500,500,90
C
C26      VPLAMDA AND VPMU ARE VERTICAL AND HORIZONTAL ANGLES.
C        THESE ANGLES ARE CALCULATED FROM (XI,YI,ZI)
C        INCASE IF TARGET IS VISIBLE,OTHERWISE THESE ANGLES
C        ARE CALCULATED FROM (XO,YO,ZO).
C        IVWINDO WILL GIVE WINDOW NO. AT WHICH TARGET
C        BECOME VISIBLE.
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      C
  500 VPLAMDA     =ATAN2(XI(I),YI(I))*180./3.1416
      VPMU        $ATAN2(ZI(I),SQRT(XI(I)**2+YI(I)**2))*180./3.1416
      IVWINDO=I
      IVISIBL=1
      RETURN
   90 CONTINUE
      C
      C   CALCULATE VPLAMDA AND VPMU WHEN TARGET IS NOT VISIBLE
      C
      VPLAMDA     $ATAN2(XO,YO)*180,0/3,1416
      VPMU        $ATAN2(ZO,SQRT(XO**2+YO**2))*180,0/3,1416
      IVWINDO=0
      IVISIBL=0 :
      RETURN
      END
```

OUTPUT

```
IVISIBL = 0    IVWINDO =  0    VPLAMDA =  149.96    VPMU =   65.99
IVISIBL = 1    IVWINDO = 14    VPLAMDA = -131.45    VPMU =    7.84
IVISIBL = 1    IVWINDO =  3    VPLAMDA =  128.51    VPMU =    1.96
IVISIBL = 0    IVWINDO =  0    VPLAMDA =  118.97    VPMU =    3.55
IVISIBL = 1    IVWINDO =  8    VPLAMDA =   10.51    VPMU =    1.30
```

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