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COMPUTING INTERNAL COCKPIT REFLECTIONS OF EXTERNAL POINT LIGHT SOURCES FOR THE MODEL YAH-64 ADVANCED ATTACK HELICOPTER (LOW GLARE CANOPY DESIGN)

Christopher C. Smyth

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U. S. ARMY HUMAN ENGINEERING LABORATORY
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The US Army Human Engineering Laboratoy (HEL) has developed a computer program for computing the internal cockpit reflections on the transparent canopy surfaces of external point light sources. Computations have been completed for the Model YAH-64 Advanced Attack Helicopter (low glare canopy design). The results show that primary reflections as seen from the pilot's position are possible on (1) the upper rear corners of the forward side canopy surfaces, (2) the upper edges of the rear sides, and (3) the sides of the top surface. Computations have also been completed for the copilot's position and show possible reflections on the front and side surfaces. A computer graphics output is used to show reflection points on canopy layouts and perspectives of the cockpit.

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COMPUTING INTERNAL COCKPIT REFLECTIONS OF EXTERNAL POINT LIGHT SOURCES FOR THE MODEL YAH-64 ADVANCED ATTACK HELICOPTER (LOW GLARE CANOPY DESIGN)

INTRODUCTION

The US Army Human Engineering Laboratory (HEL) has developed a computer program for computing internal cockpit reflections on the transparent canopy surfaces of external point light sources. This work is part of a three-stage effort to determine optimum canopy designs for the Model 209 AH-1S Cobra Helicopter and the Model YAH-64 Advanced Attack Helicopter (AAH). This work was undertaken at the request of the Project Manager's Office, USA Aircraft Survivability Equipment. The low glare canopy design presently used on both models consists of flat, transparent panels on the front surfaces and simple cylindrical panels on the sides and top. The design is a reasonable choice for reducing both solar glint to outside observers during daytime operations and internal reflections of outside light sources during nighttime operations.

A flat plate canopy (FPC) design was originally developed for the Cobra and AAH to reduce daytime solar glint to a momentary flash at certain observer-aircraft-sun angles. A moving aircraft no longer produced the continual solar glint which was present on the earlier compound-shaped canopy designs. The continual presence of solar glint had increased the range of visual detection by ground observers.

However, in certain lighting situations during nighttime operations, the internal surfaces of the FPC performed as mirrors reflecting virtual images of external light sources that were visible to the pilot. HEL has shown by computer analysis that these reflections are possible on most of the transparent surfaces and for a wide range of source locations (5). These virtual images of ground-level lights were disorienting to the pilot and he could not easily discriminate between the light sources on the ground and their reflections from the canopy surfaces. This problem was a potential safety hazard during flight.

The present low glare canopy design was developed to reduce these two conflicting problems to manageable levels. The design incorporates front planar transparent surfaces and simple cylindrical surfaces for the sides and top. HEL recommended a similar design with, however, novel features (6). The present work effort is directed toward a closer study of the two problems of glint and reflections, and developing an optimum design for the canopy's transparent surfaces.

METHOD

A ray-tracing program was written to trace in three dimensions the straight-line rays from the nominal position of the pilot's eye backwards to visible points on the internal surfaces of the cockpit. Each ray is traced between transparent surface points until a nontransparent surface is reached. These surfaces are assumed to be diffusive without specular reflectances and the ray is considered absorbed. At each reflection point on a transparent surface, the reflectance and transmittance are computed along with the directional cosines of the corresponding transmitted and reflected rays. In this way, a reflected ray reaching the pilot's eye is traced backwards to all possible external sources that can generate that ray.

The transparent surfaces of the low glare canopy design are specified as a set of planar and cylindrical surfaces and their corresponding edge vertices. Each planar surface is specified by the coordinates of its edge vertices and the consecutive order in which adjacent vertices are listed. A cylindrical surface is specified by cylindrical parameters and the consecutive sequence of the edge vertices and their coordinates. The cylindrical parameters are (1) origin point on the cylindrical axis, (2) directional cosines of the axis, and (3) the radius of the cylinder. The edges of the cylindrical surface are assumed for simplicity to be curvilinear lines which become straightened when the cylinder is transformed into a flat plane.

Given directional cosines and an origin point of a straight-line ray, the program computes in turn, the intersection point of the ray with each surface. The program tests the intersection point against the surface edges. The reflection point for the ray is that intersection point which is contained within the edges of the corresponding surface segment. The angle of incidence between the surface normal and the ray at this point is computed along with the corresponding values of reflectance and transmittance and the directional cosines of the transmitted and reflected rays. Tracing backwards, the reflected ray becomes the incident ray for the next set of computations. (See Appendix A for derivation of equations used in ray tracing on cylindrical surfaces and Appendix A of reference 5 for ray tracing on planar surfaces and computation of transmittance and reflectance values.)

The program includes internal and external obstructing surfaces and the internal blast barrier of the YAH-64 between the pilot and copilot, as well as the transparent surfaces of the canopy in the computation. The obstructing surfaces are those that either obstruct the pilot's vision or block incident rays from external sources. The internal surfaces are (1) the pilot's seat, display panel and side armor, (2) the copilot's seat, gunner-sight and side armor, and (3) the sides and floor of the cockpit. The external surfaces are (1) aircraft nose section, (2) gun pods and wheel wells, (3) wing stubs, (4) rocket pods, (5) engine intakes, and (6) rotary housing These surfaces are specified as planar segments in the same manner as are the canopy surfaces. The intersection computations are performed first for all obstructing surfaces and computation of a reflection point for a ray on an obstructing surface renders the computation complete since the backwards traced ray is considered absorbed.

The transparent blast barrier which separates the copilot and pilot, is treated first as a reflecting surface and then as a transmitting surface for reflection points on surfaces beyond it.

This computation process is repeated for pilot-viewing directions indexed at equal increments over a quarter sector. The sector is bounded by vision directly to the front, to the side, top and bottom. In this way, a table is constructed which lists at discrete intervals all possible internal reflection points and the corresponding external light directions. This approach generates a large amount of data and a computer-graphics routine is included for output. The primary reflection points and the corresponding incident ray entry points are shown on side, top and front views of the canopy and on perspective drawings of the cockpit as seen from the pilot's position. Similar comments apply to computations for the copilot's position. (See Appendix B of reference 5 for a discussion of perspective drawings.)

DISCUSSION

The results of this application are shown in Figures 1 through 19. These figures are hard copies of the computer graphics output. Figure 1 shows side, top and front views of the canopy frame, blast barrier and obstructing surfaces. The pilot's nominal eye position is shown in each view. The blast barrier and obstructing surfaces are sketched in with broken lines. The aircraft fuselage and tail assembly are not included in this sketch.

Figure 2 shows side, top and front views of the canopy frame and blast barrier, sketched with broken lines, separated from the obstructing surfaces. Figure 3 is a perspective drawing of the cockpit as seen from the pilot's position. The pilot's nominal viewing direction is shown by the small cross near the top center of the upper front canopy surface. The drawing covers a 60-degree field of view and shows that the lower portions of the front and forward side canopy surfaces are blocked from view by the pilot's instrument panel.

The frame edges for the canopy sides are drawn as straight lines connecting adjacent corner vertices. This is done for convenience in the computer graphics routines. The computations assume that the frame edges for the cylindrical surfaces are curvilinear lines (see Method, page 3).

Figures 4 through 13 show "dots" for the entry positions of external rays generating primary reflections on the right-hand side of the canopy for the pilot's position. Also shown are the corresponding primary reflections spaced at two degrees by two degrees increments. The number shown at each reflection point is equal to the negative value of the logarithm (base 10) of the light reflectance. The numbers are truncated to their integer values by dropping the fractional parts. The numerical "zero" corresponds to those reflectances which are greater than 0.1 in value. The numerical "one" corresponds to those values equal to or less than 0.1 but greater than 0.01.

Figure 4 shows that entry points are possible over much of the lower front panel and the side surfaces. Figure 5 shows that primary reflection points can occur on (1) the upper rear corner of the front side panels, (2) the upper edge of the rear side panels, and (3) the side edges of the top panel. The front side panel reflections have reflectance values in the 0.1 to 1.0 range, while those on the rear sides and top are in the 0.01 to 0.1 range.

Figures 6 and 7 are perspective drawings of the cockpit as seen from the pilot's nominal viewing position and direction. Figure 6 shows entry points on the lower front and front side surfaces. Figure 7 shows primary reflections on the right-hand side of the canopy. Figure 8 shows reflection points where the pilot has shifted his viewing direction 20 degrees to the right. (Note that some reflection points are shown on the canopy frame. This is because the structure outline is drawn as straight line members between the corner vertices instead of the curvilinear members used in the computations. See Methods.)

Figures 9 through 13 show reflection points generated on one canopy surface by external rays entering another surface. Figure 9 shows reflection points on the top surface generated by entry points on the right rear side surface. Figure 10 shows reflections on the top surface generated by entry points on the right forward side surface. Figure 11 shows reflections on the right rear side due to entry points on the left rear side. Figure 12 shows reflections on the right forward side due to entry points on the lower front surface. Finally, Figure 13 shows reflections on the right rear side due to entry points on the left forward side.

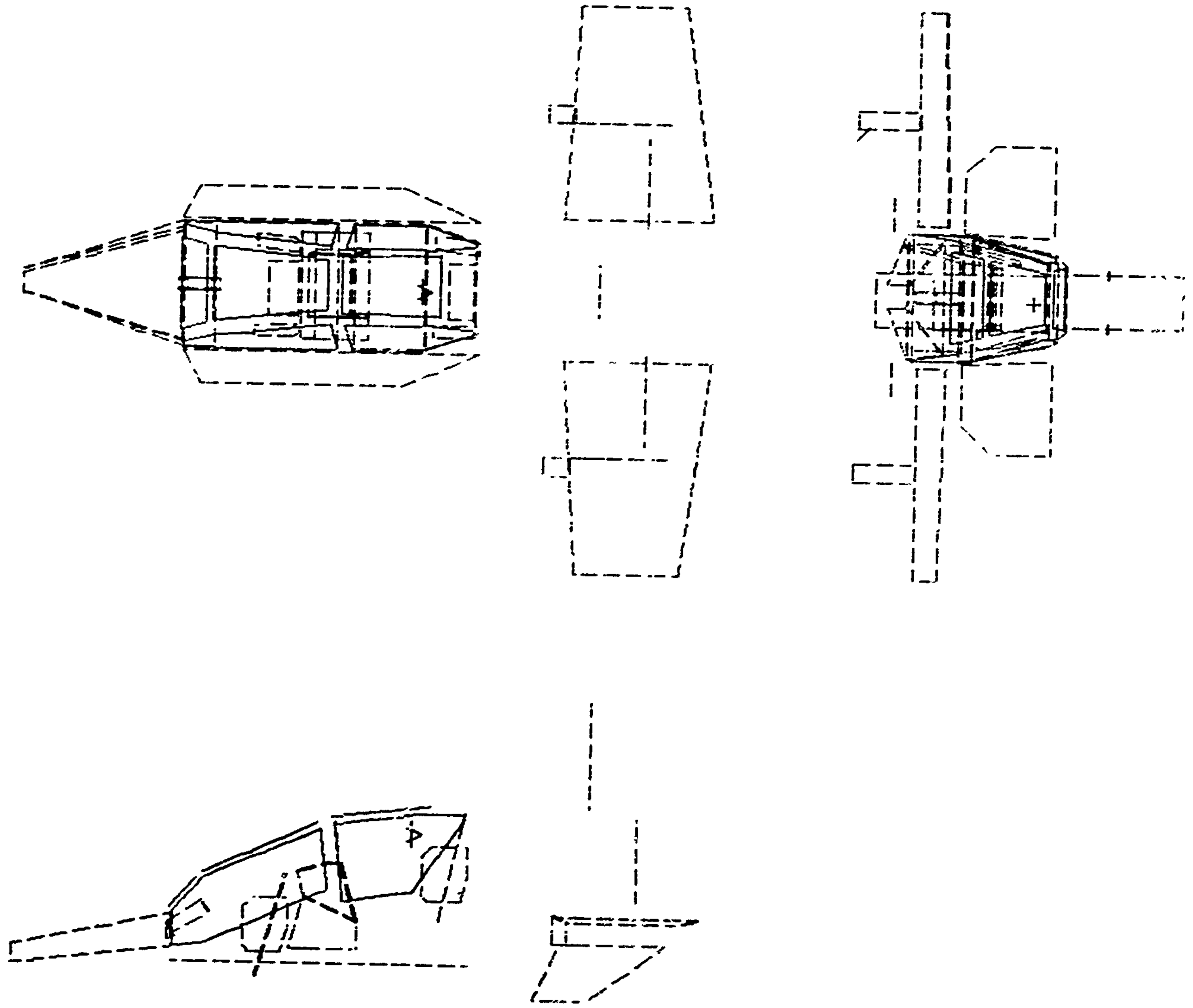

Figure 1. Top, side and front views of canopy frame and obstructing surfaces.

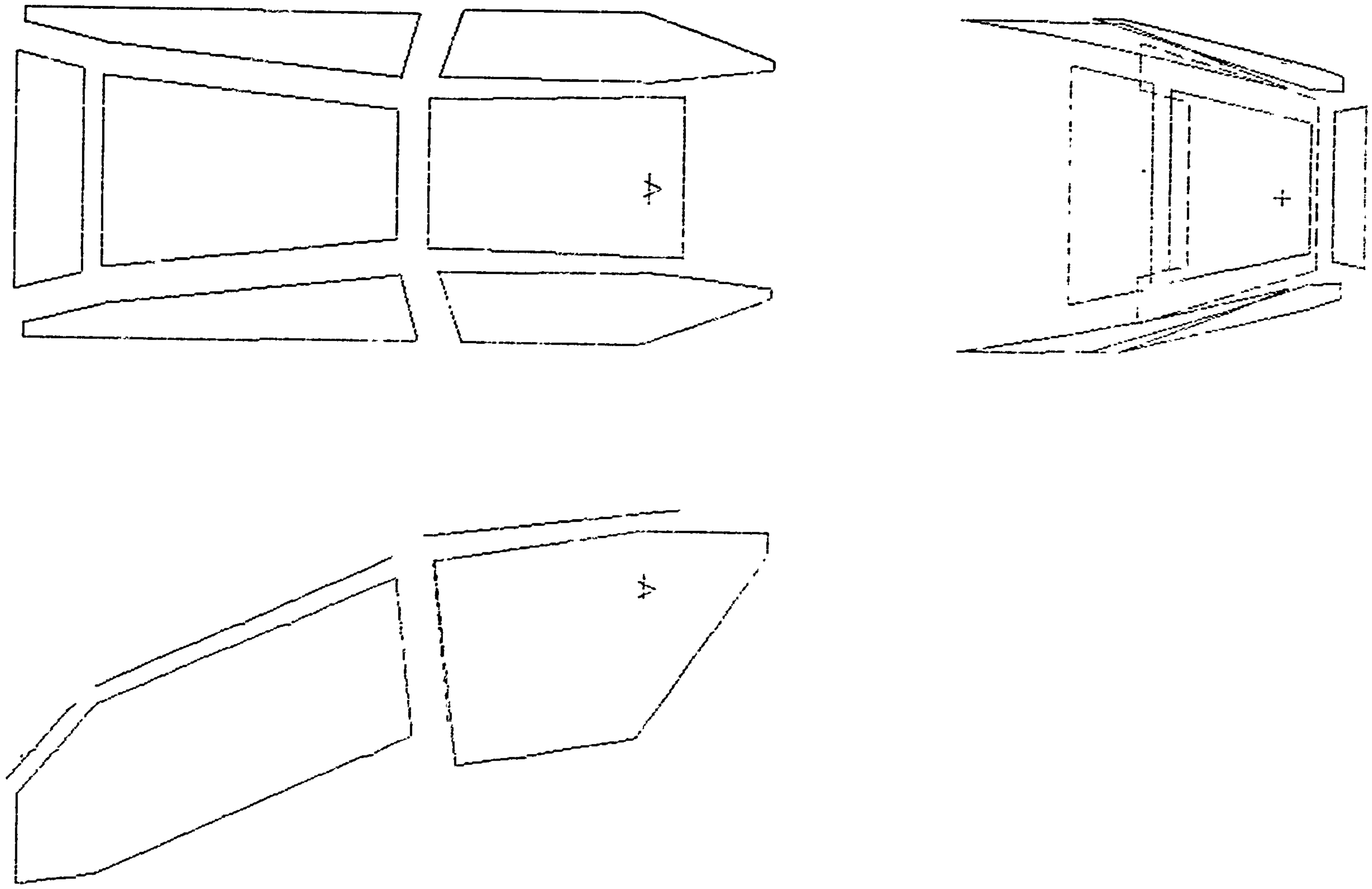

Figure 2. Top, side and front views of canopy frame.

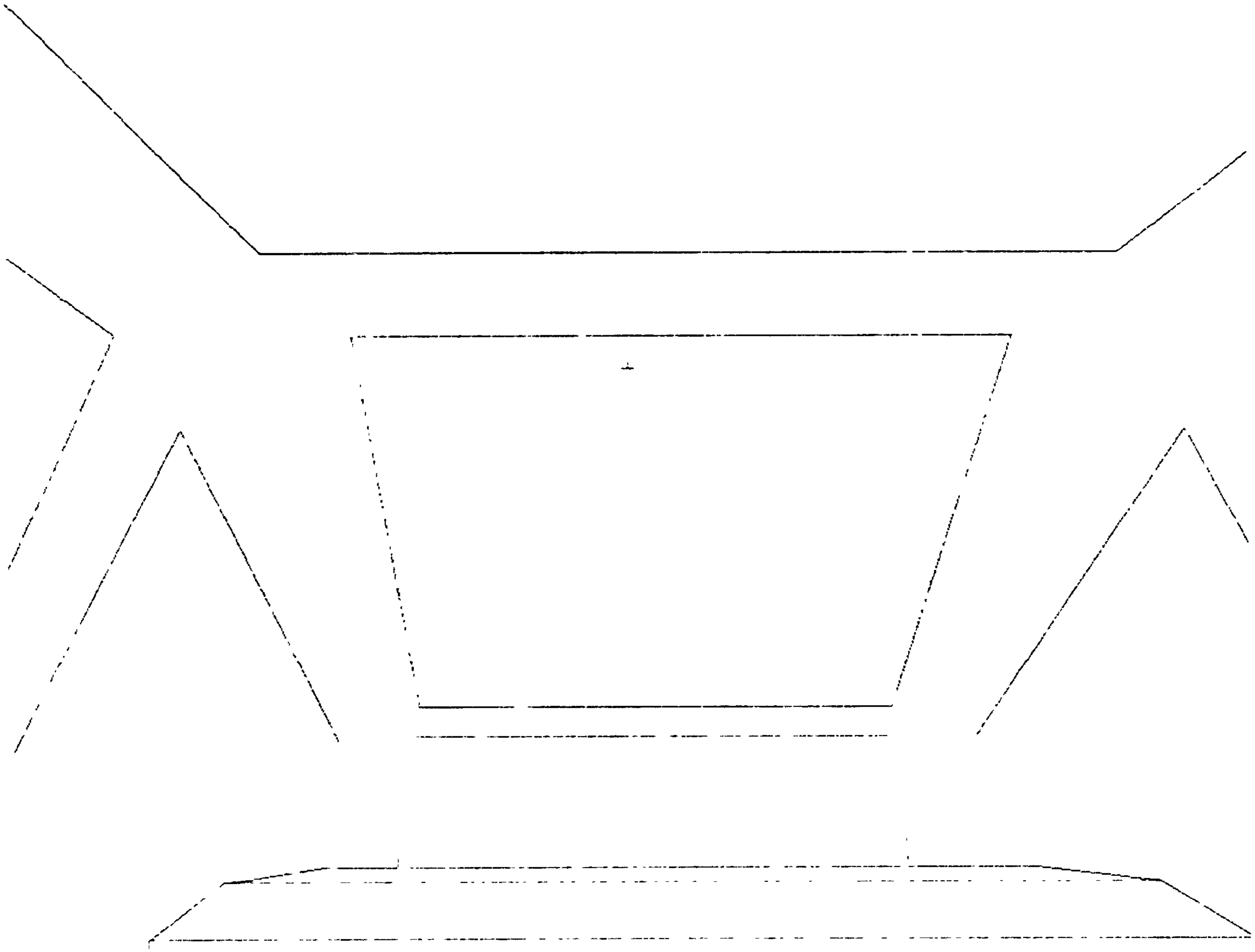

Figure 3. Perspective view of the cockpit interior from the pilot's nominal viewing position and direction.

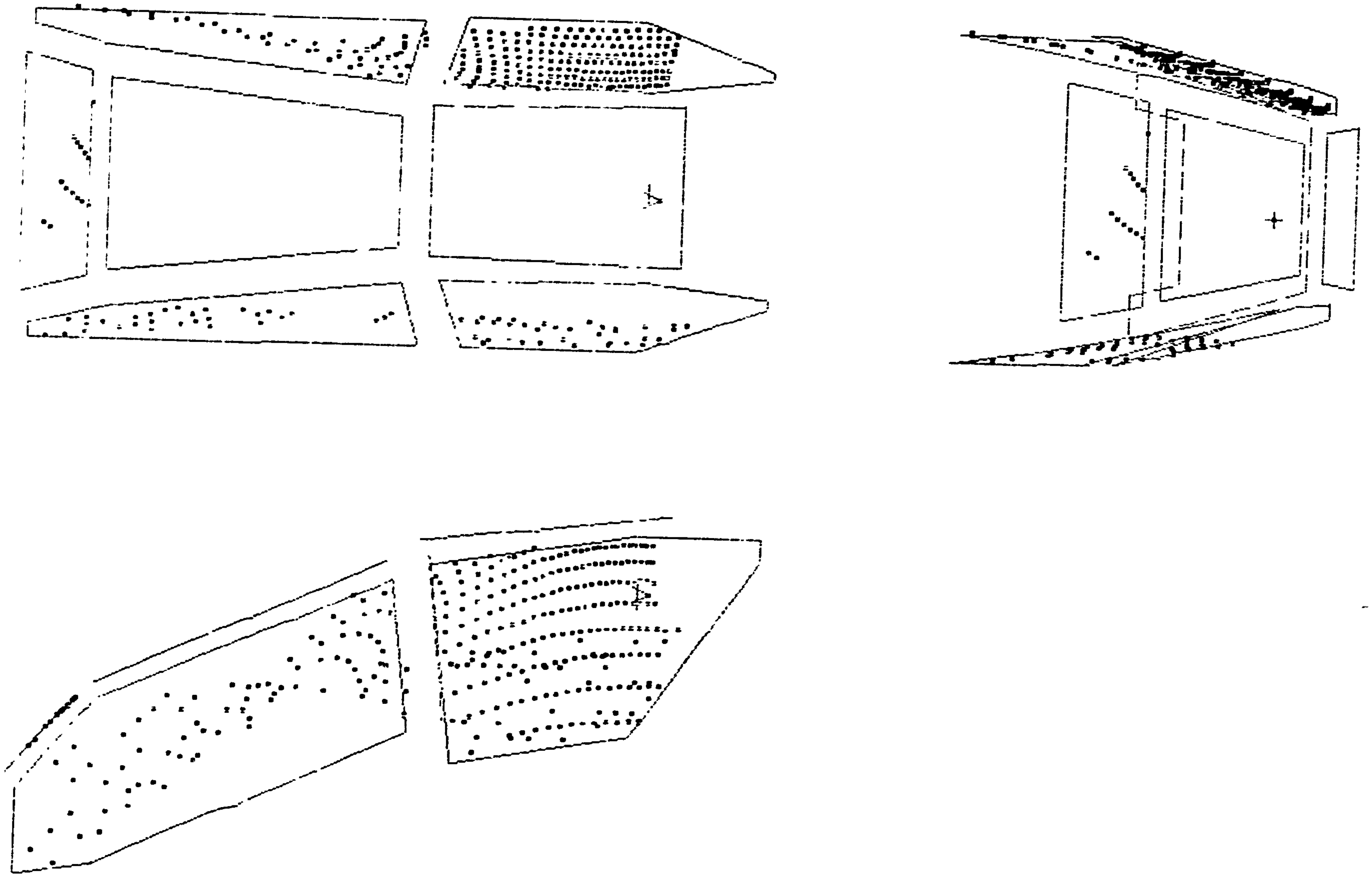

Figure 4. Entry ray positions generating primary reflections on the right-hand side side of the canopy as seen from the pilot's position.

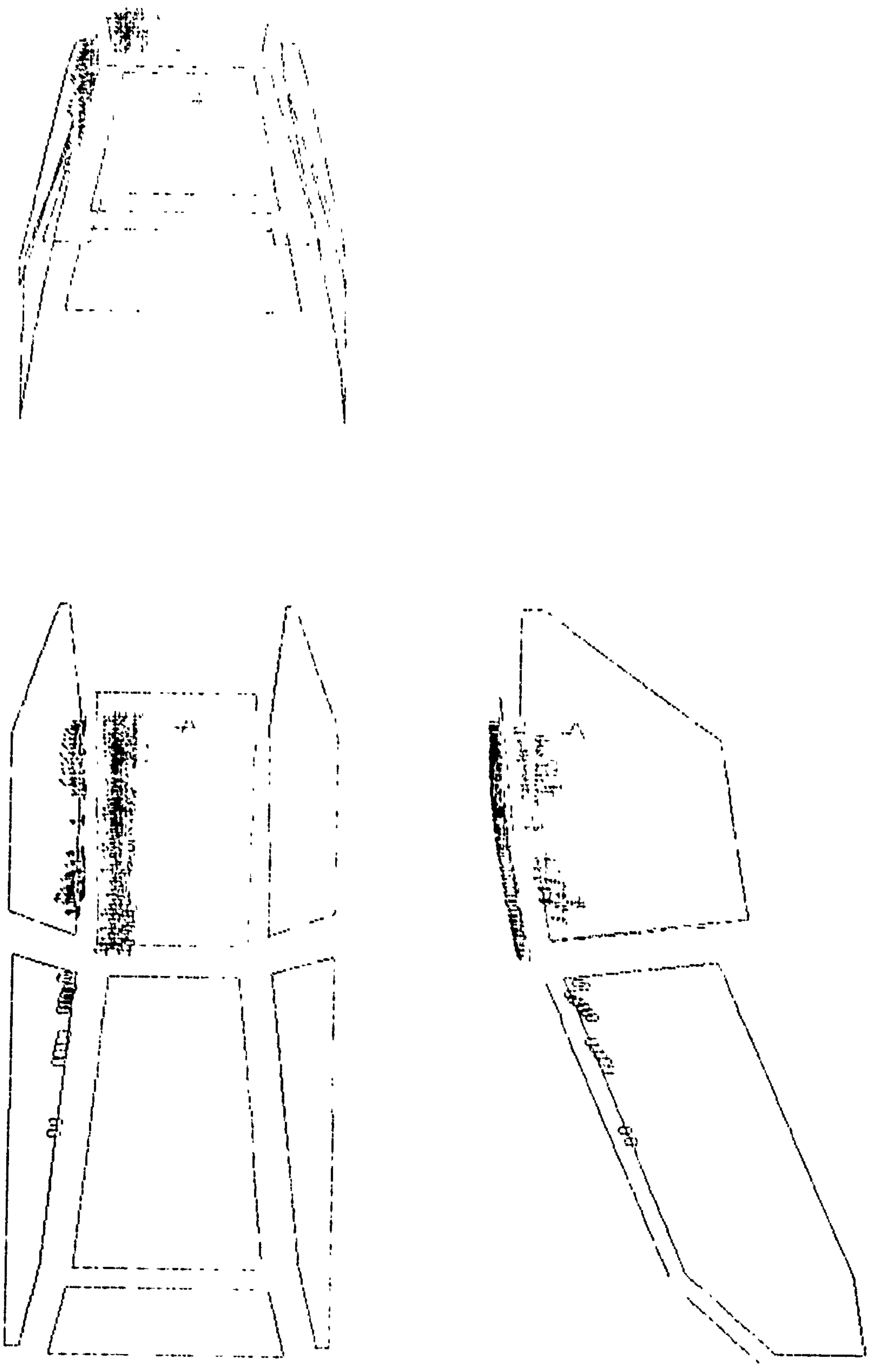

Figure 5. Primary reflection points on the right-hand side of the canopy and their associated reflectance values for the pilot's positicn.

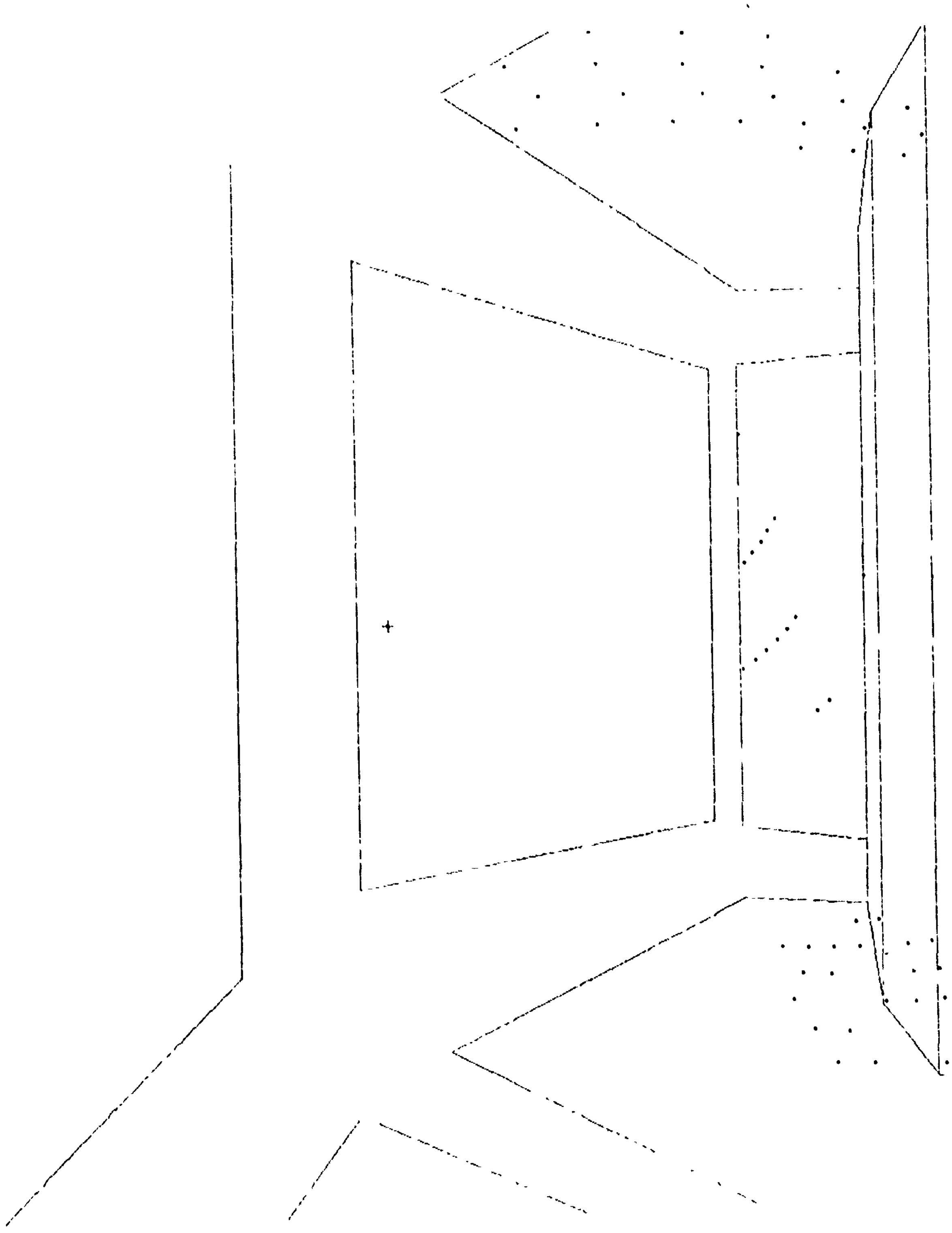

Figure 6. Perspective view of entry ray positions for the pilot's nominal viewing direction and position.

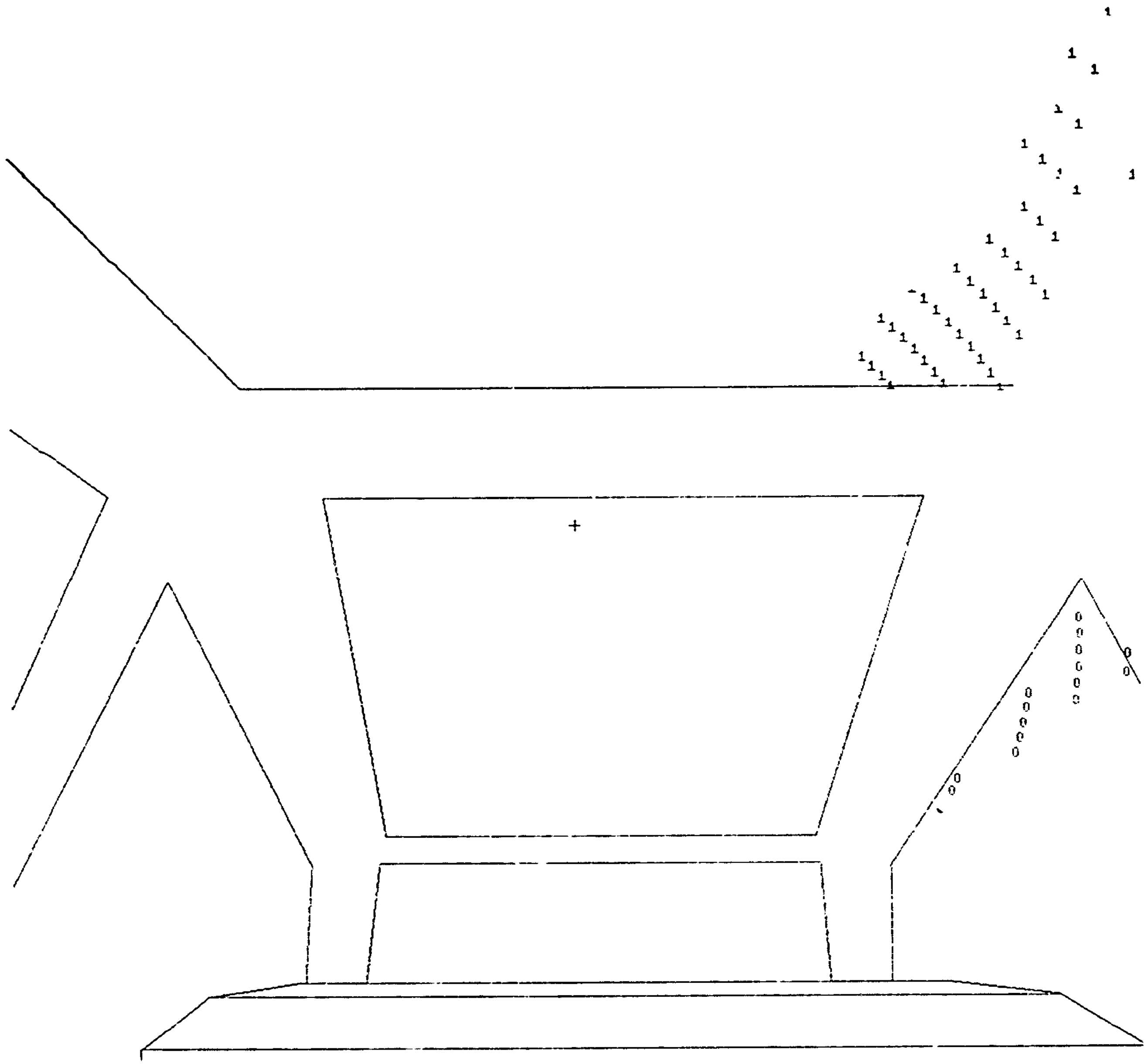

Figure 7. Perspective view of primary reflection points for the pilot's nominal viewing direction and position.

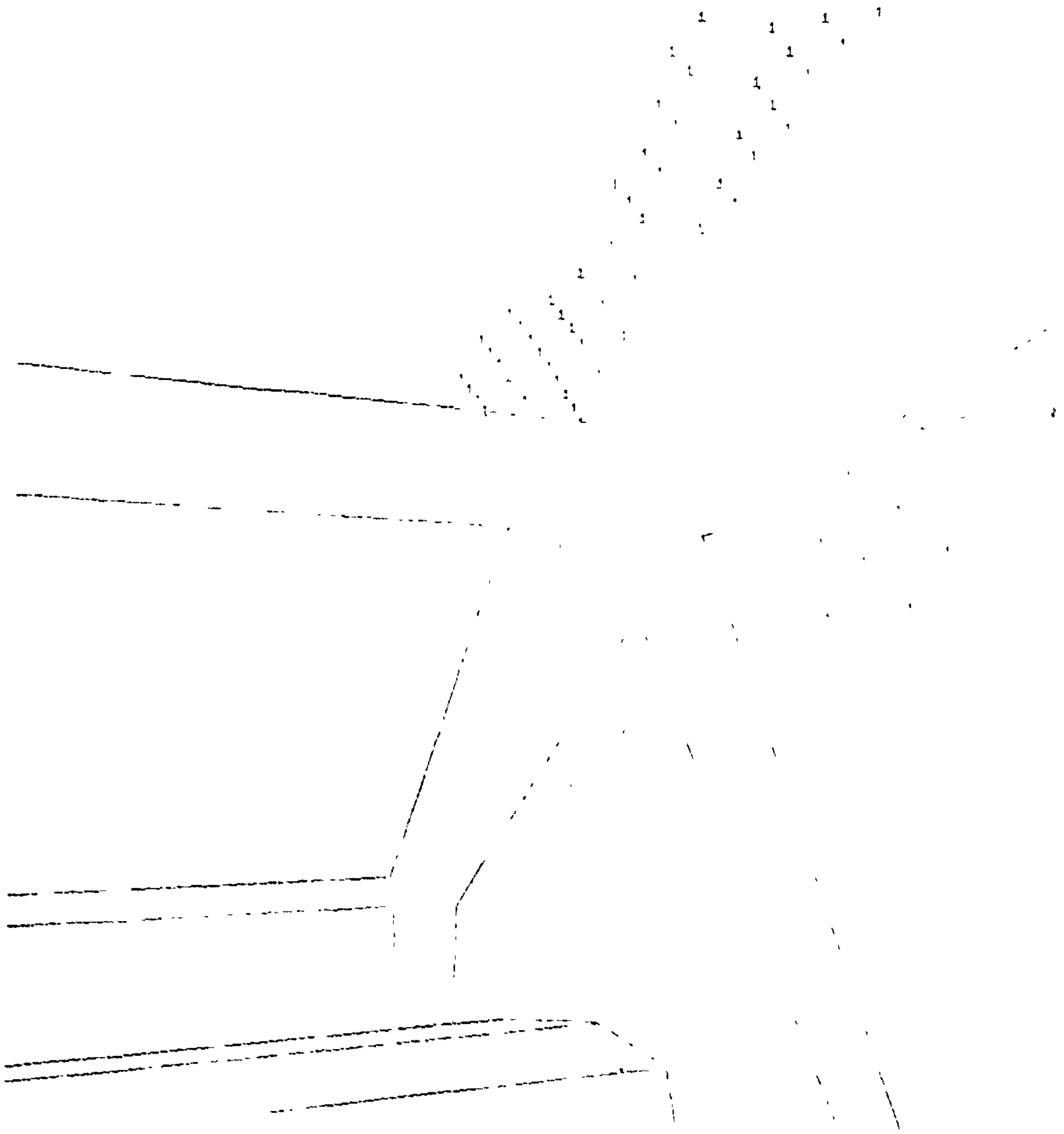

Figure 8. Perspective view of primary reflection points for the pilot viewing 20-degrees to the right side.

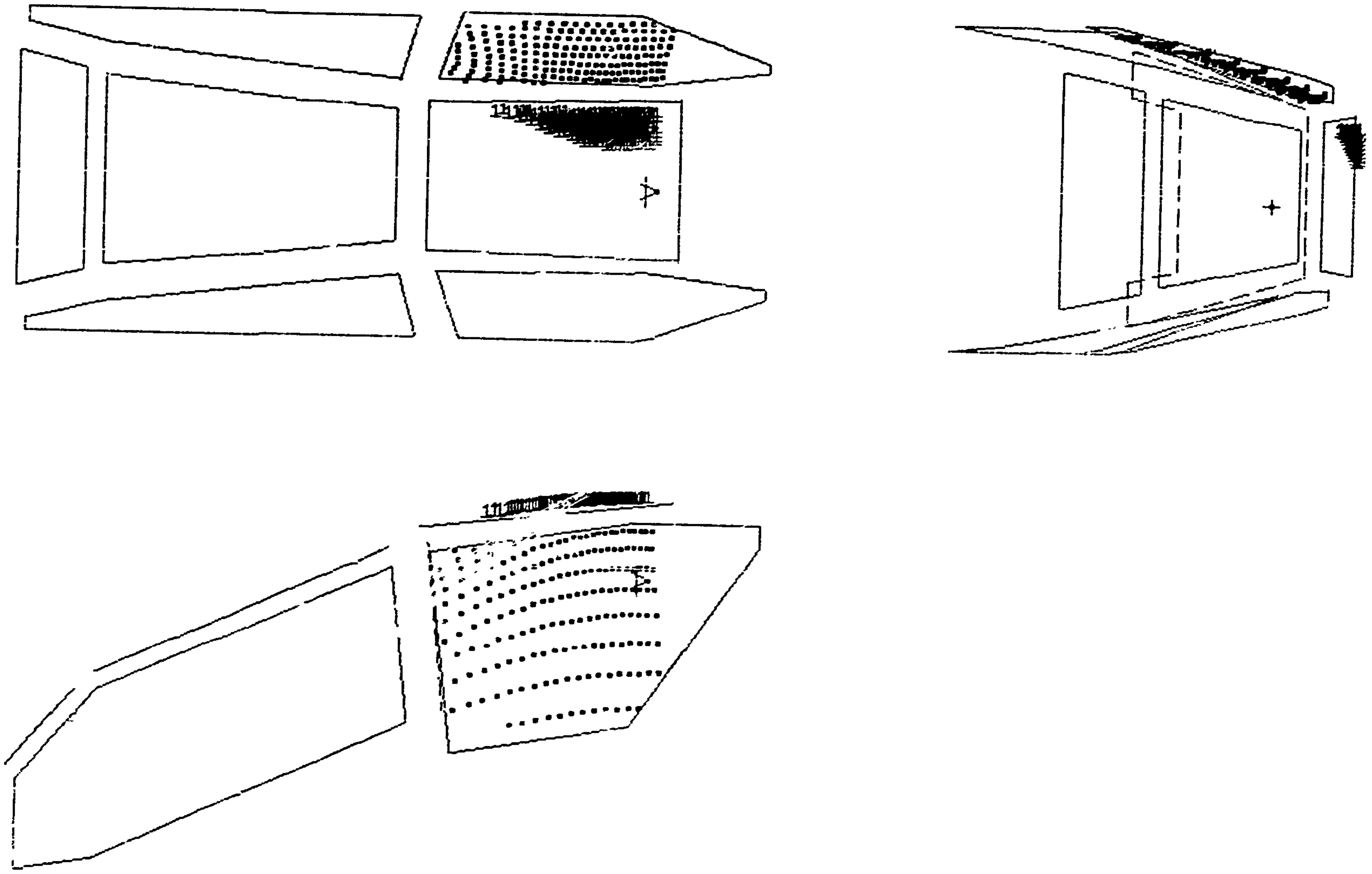

Figure 9. Entry ray positions on the right rear side canopy surface and their corresponding reflection points on the right side of the top surface.

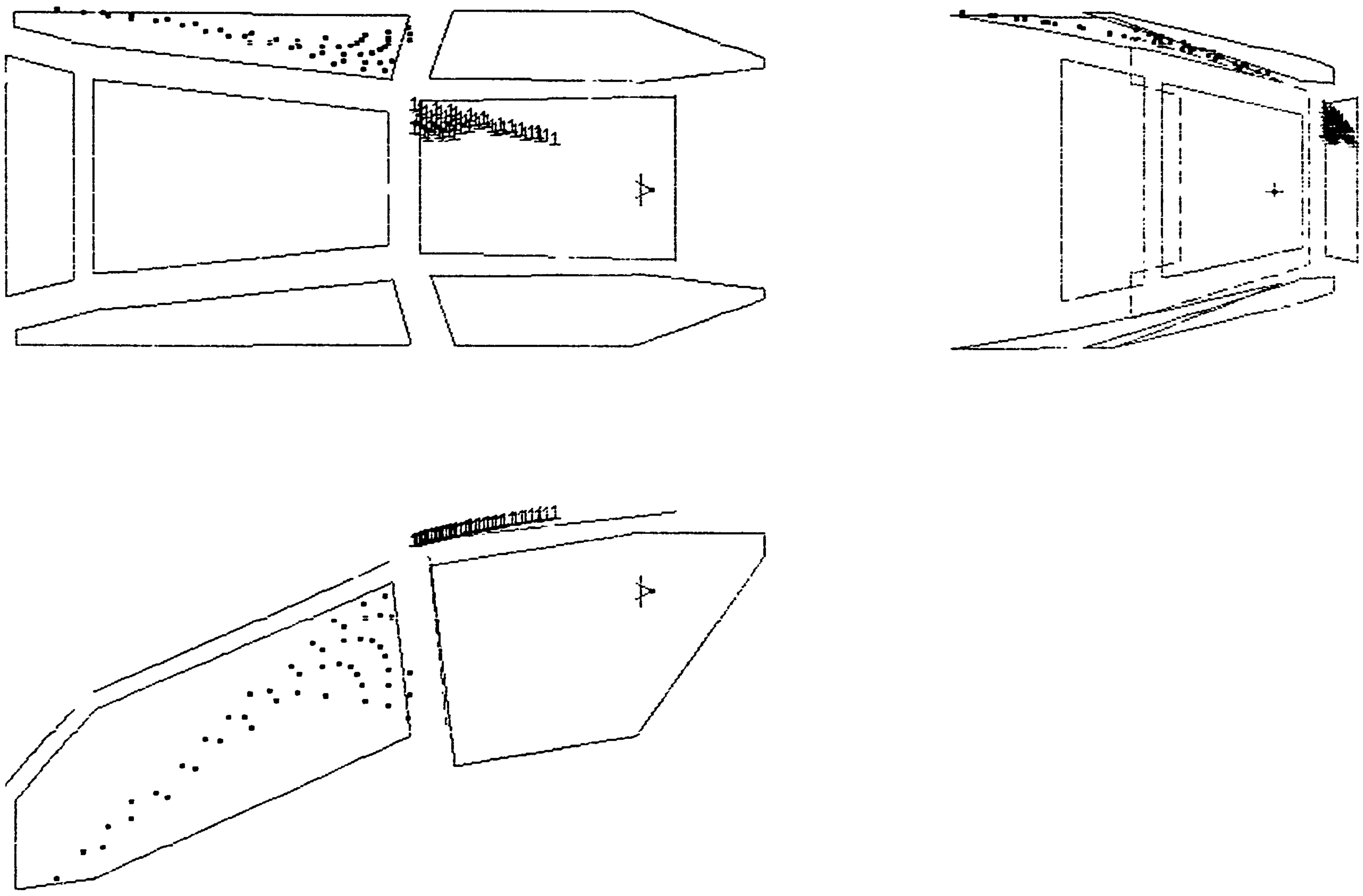

Figure 10. Entry ray positions on the right forward side canopy surface and their corresponding reflection points on the right front of the top surface.

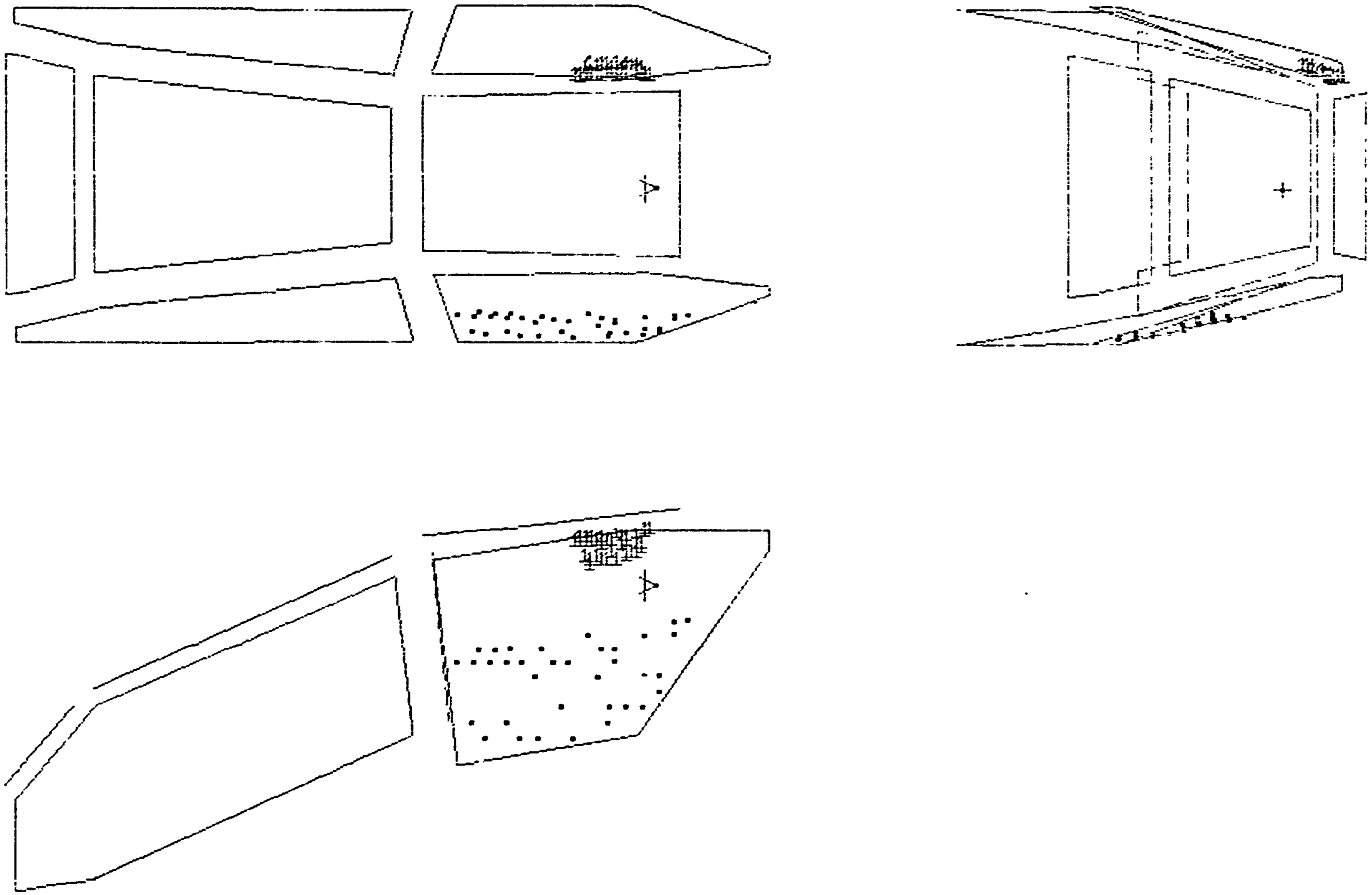

Figure 11. Entry ray positions on the left rear side canopy and their corresponding reflection points on the top edge of the right rear surface.

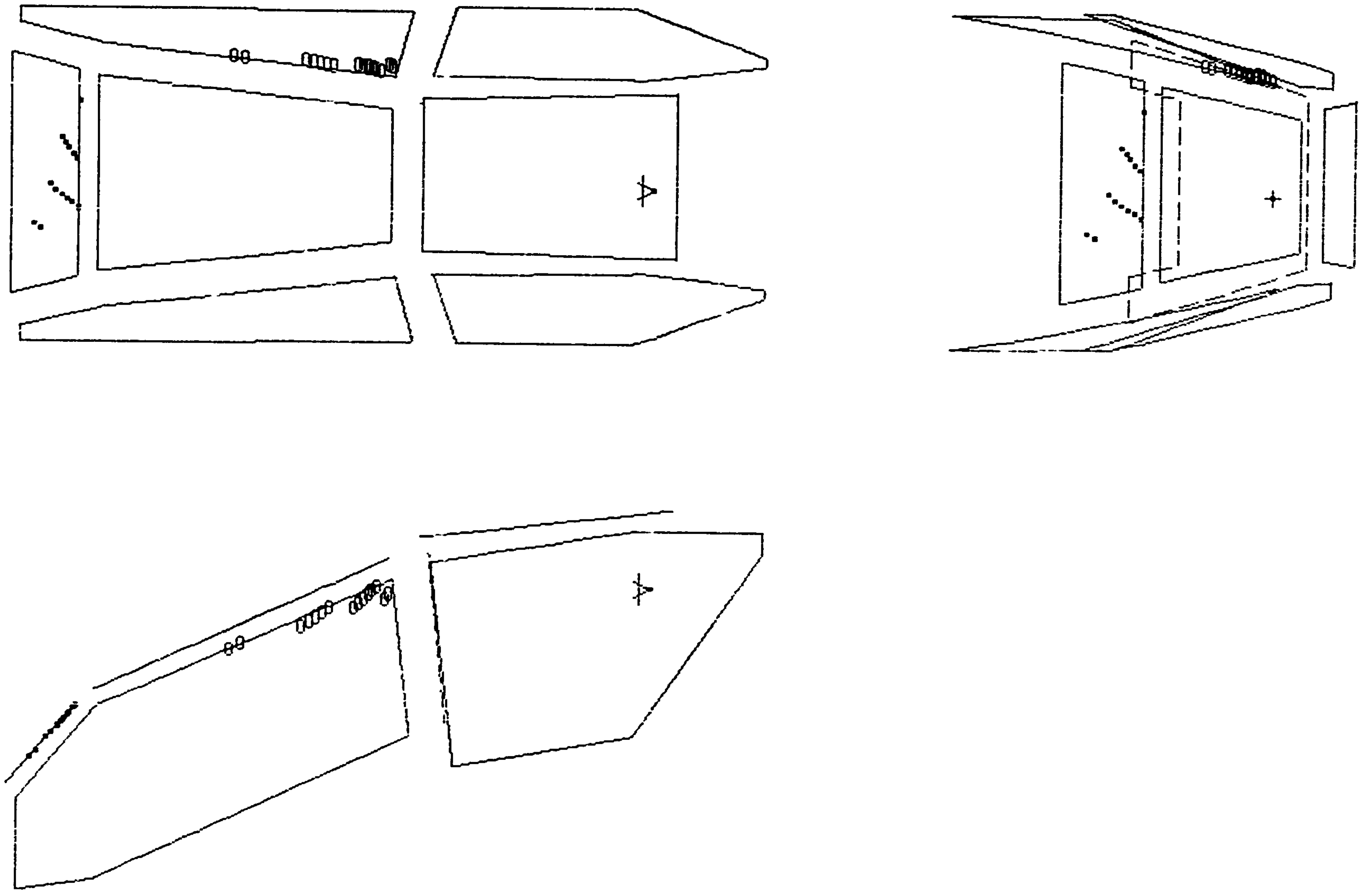

Figure 12. Entry ray positions on the lower front canopy surface and their corresponding reflection points on the upper rear corner of the right forward side surface.

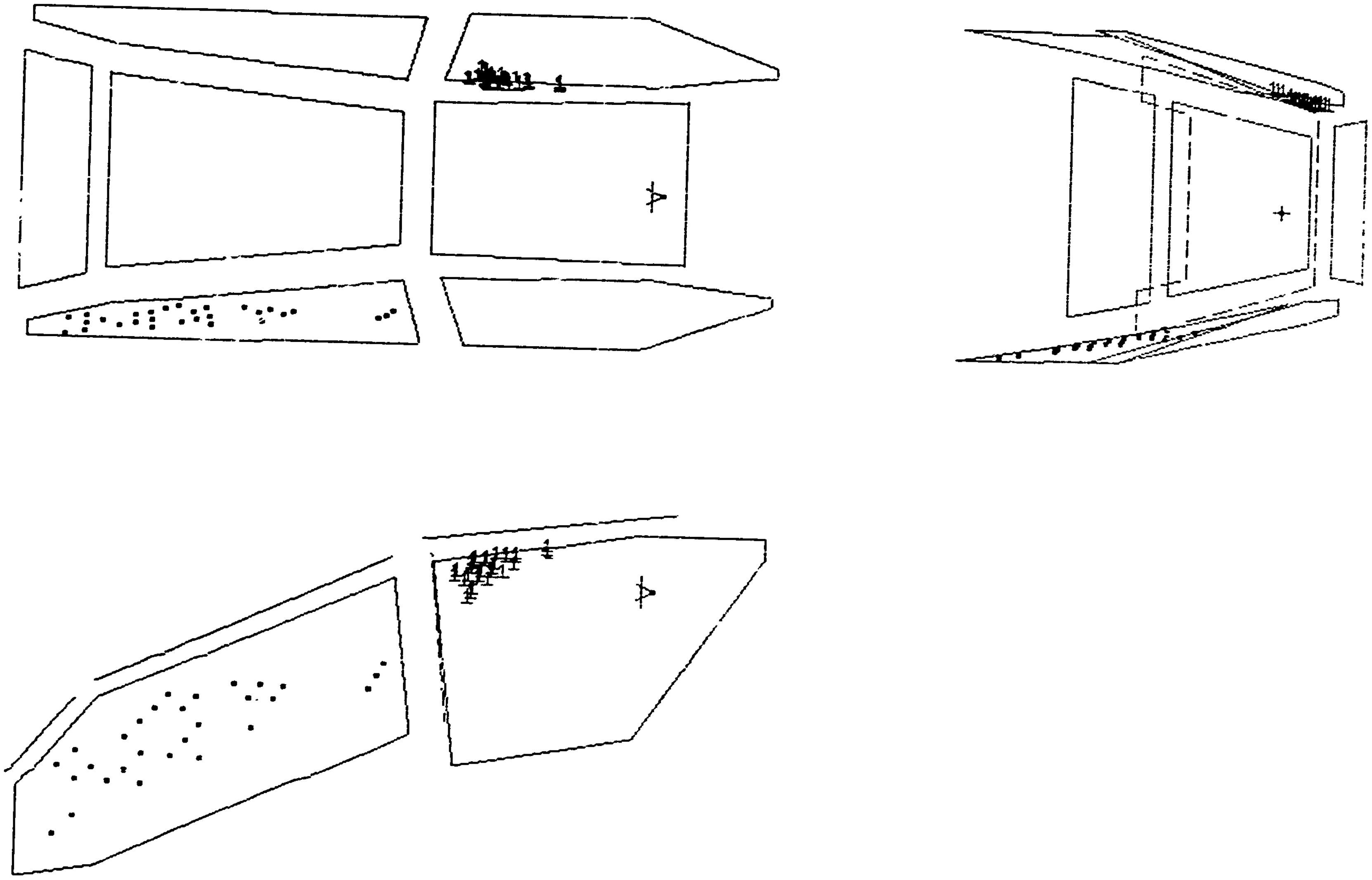

Figure 13. Entry ray positions on the left forward side canopy surface and their corresponding reflection points on the upper front edge of the right rear side surface.

Figures 14 through 19 are similar drawings for the copilot's position. Figure 14 shows "dots" for the entry points of external rays generating primary reflections seen from the copilot's position. The figure shows that entry points occur on the forward side surfaces. Figure 15 shows that the corresponding primary reflections occur on (1) the upper corner of the lower front surface, (2) the upper edge of the forward side surfaces, and (3) the upper front surface. The associated reflectance values range in value from 0.01 to 0.1. Figure 16 is a perspective drawing of the cockpit from the copilot's position. The drawing shows reflection points where the copilot has shifted his viewing direction 45 degrees to the right.

Figures 17 through 19 show pairings between entry points and reflection points by canopy surfaces. Figure 17 shows reflections on the upper front surface generated by entry points on the right forward side surface. Figure 18 shows reflections on the lower front surface due to entry points on the right forward side. Finally, Figure 19 shows reflections on the right forward side due to entry points on the left forward side.

FURTHER RESEARCH

The following additional analyses are to be conducted for further development:

1. Investigate the reflections generated during realistic nighttime lighting situations and approach scenarios.

2. Investigate the solar glint generated as a function of observer-aircraft-sun angles.

3. Investigate the use of optimization techniques to design an optimum configuration for the transparent surfaces of the canopy to minimize both glint and glare reflections.

CONCLUSION

A computer program developed by HEL to show internal cockpit reflections of external point light sources has been applied to the Model YAH-64 Advanced Attack Helicopter (low glare canopy design). The results show that during nighttime operations, ground-light reflections are possible on the transparent surfaces of the canopy. Reflections are possible from the top and side canopy surfaces for the pilot and the front and forward side surfaces for the copilot. The results are an improvement over the flat plate canopy design since reflections are limited to certain portions of these surfaces. Where reflections actually occur depend upon the particular lighting situation and flight scenario.

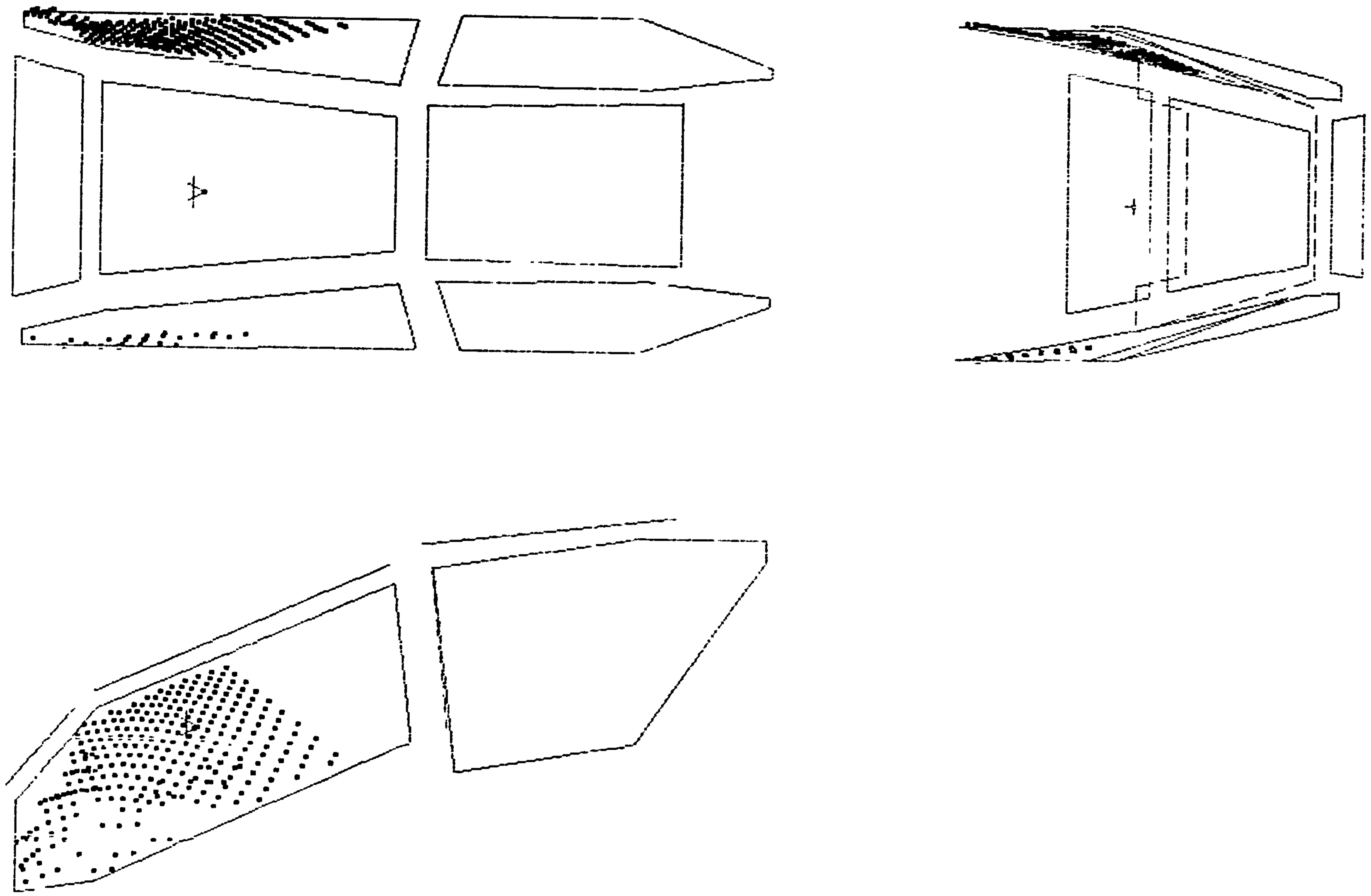

Figure 14. Entry ray positions generating reflections on the right hand side of the canopy as seen from the copilot's nominal position.

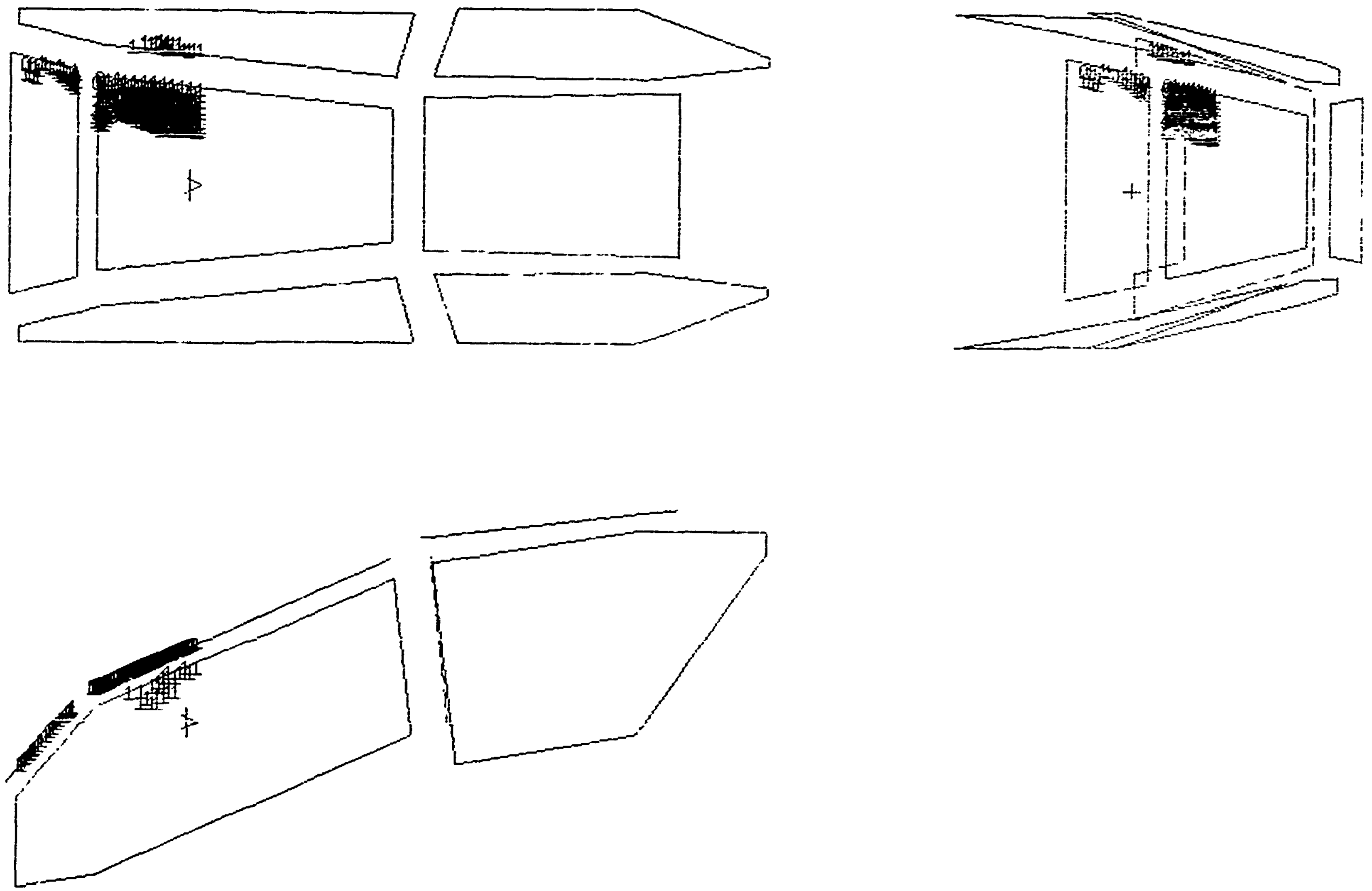

Figure 15. Primary reflection points on the right hand side of the canopy and their associated reflectance values for the copilot's position.

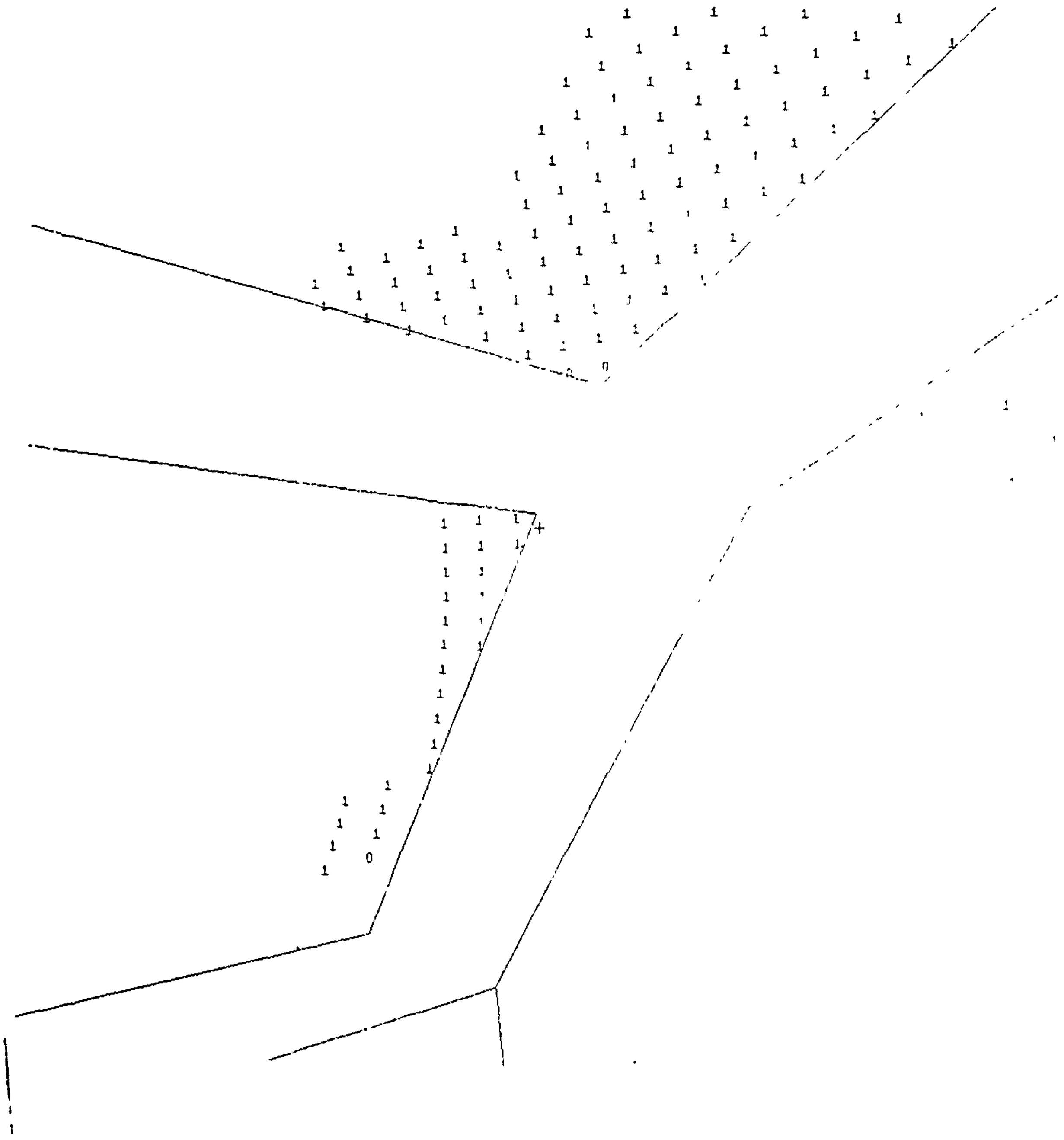

Figure 16. Perspective view of primary reflection points for the copilot's viewing 45-degrees to the right side.

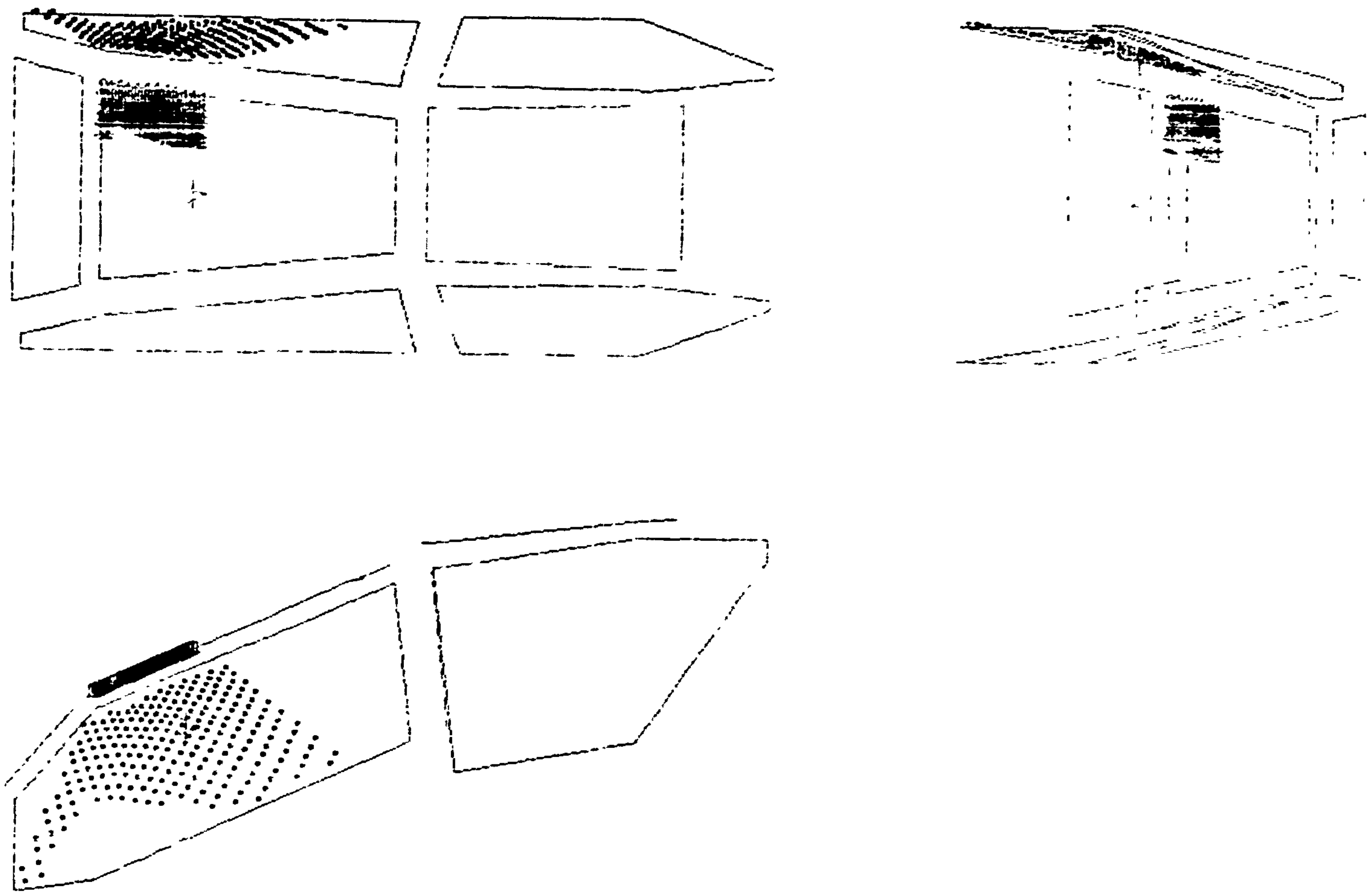

Figure 17. Entry ray positions on the right forward side canopy surface and their corresponding reflection points on the right side of the upper front surface.

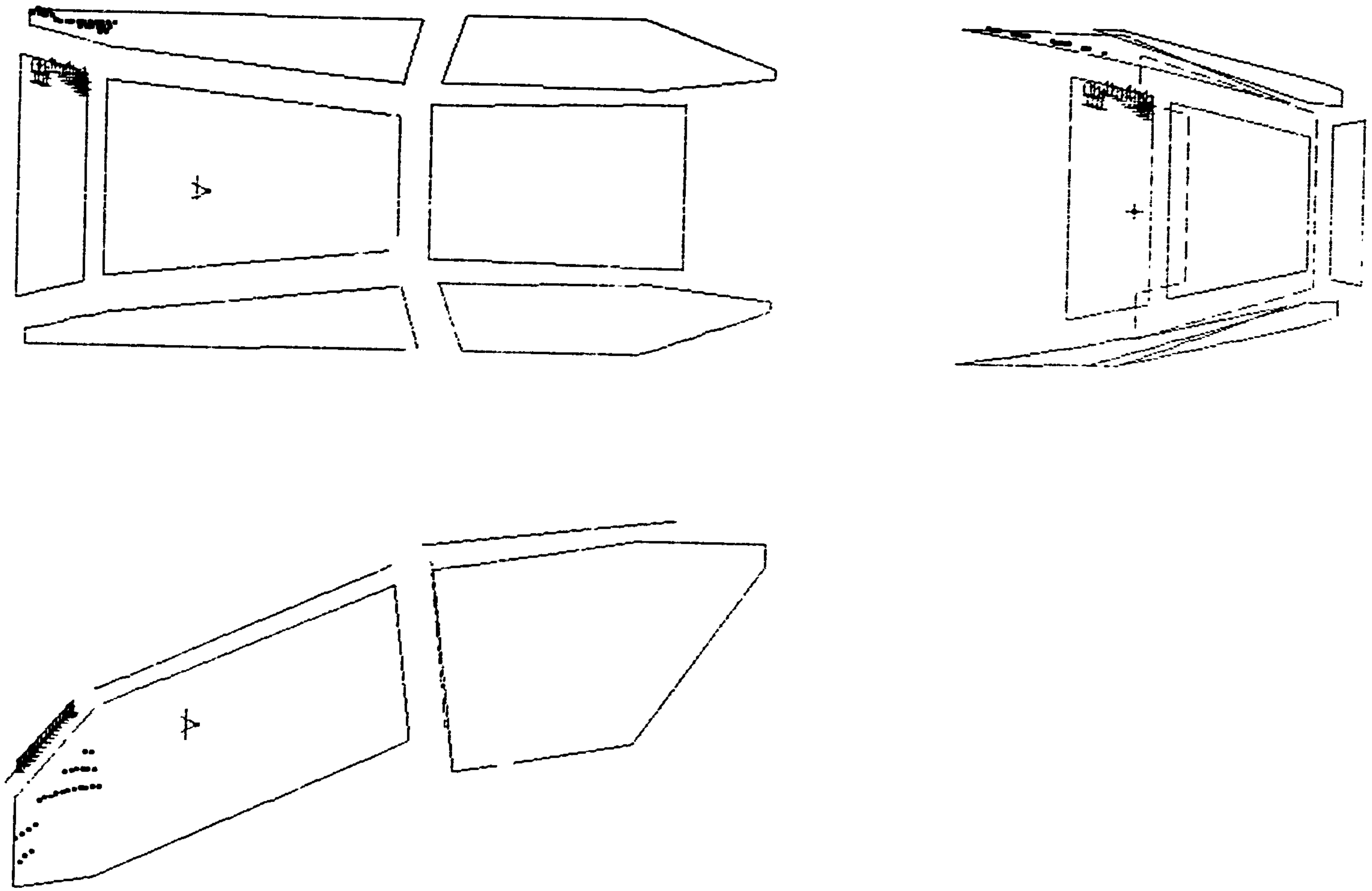

Figure 18. Entry ray positions on the right forward side surface and their corresponding reflection points on the upper right corner of the lower front surface.

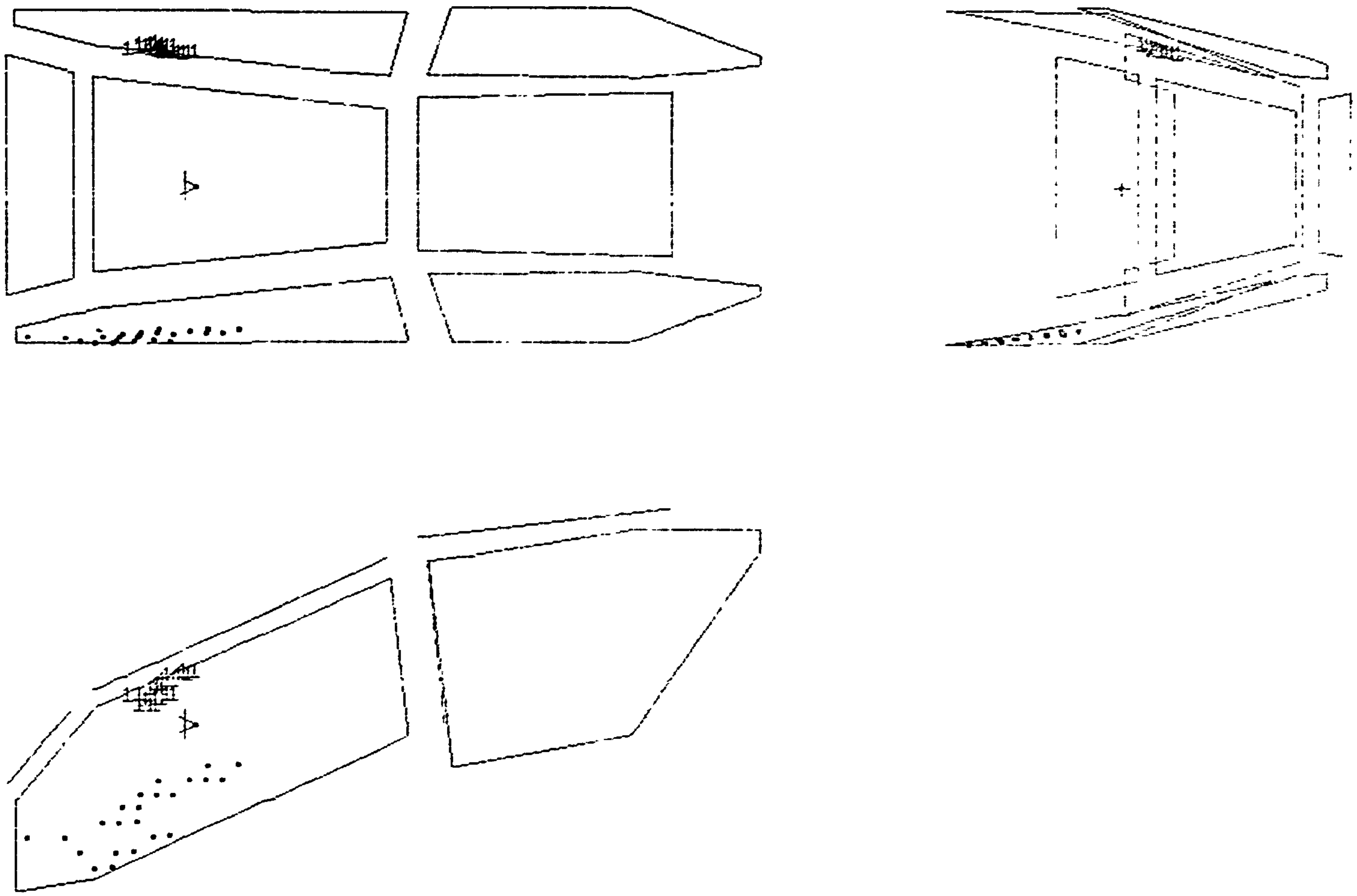

Figure 19. Entry ray positions on the left forward side surface and their corresponding reflection points on the upper edge of the right forward side.

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APPENDIX A

INTERNAL REFLECTIONS FROM CYLINDRICAL SURFACES

The ray-tracing techniques used in the computation are those of Appendix A, reference 5 with appropriate augmentation for computing the intersection of a straight-line ray with a cylindrical surface. As in reference 5, coordinates are measured in a cartesian coordinate system (x,y,z) with the y-axis along the longitudinal axis of the aircraft, the z-axis directed into the canopy top and the x-axis orthogonal to the other two axes.

A straight-line ray is specified by an origin point (x_s,y_s,z_s) and its directional cosines (a_s,b_s,c_s). We wish to compute the intersection point of this ray with a cylinder and determine if the intersection point is enclosed by the edges of a surface on the cylinder. A cylinder is specified by three parameters (1) an origin point, P_o $(x_o y_o,z_o)$ on the cylindrical axis, (2) directional cosines (a_o,b_o,c_o) for the axis, and (3) its radius, r_c. A cylindrical surface, then, is specified by these cylindrical parameters and a consecutive sequence of N adjacent corner vertices (P_j (x_j,y_j,z_j), j = 1,N) on the cylinder and their coordinates in the rectangular space.

(1) Intersection of a straight-line ray with a cylinder

The intersection point of a line with the surface of a cylinder may be computed given the origin (x_s,y_s,z_s) and directional cosines (a_s,b_s,c_s) of the line, and the origin (x_o,y_o,z_o) and directional cosines (a_o,b_o,c_o) of the cylinder's axis and the radius, r_c, of the cylinder. Note that the coordinates of the intersection point, P_i (x_i,y_i,z_i), are given by

$$\begin{aligned} x_i &= x_s + a_s \cdot R_s, \\ y_i &= y_s + b_s \cdot R_s, \\ z_i &= z_s + c_s \cdot R_s, \end{aligned} \tag{1}$$

where R_s is the length along the line between its origin and the intersection point.

Consider now another line from the intersection point, P_i orthrogonal to the cylindrical axis. The dot product of the unit vectors must be equal to zero; i.e.,

$$a_o \cdot (x_i-x_c) + b_o \cdot (y_i-y_c) + c_o \cdot (z_i-z_c) = 0, \tag{2}$$

where the point, P_c (x_c,y_c,z_c) is at the intersection of the axis and this line. Note that the coordinates of this point are given by

$$\begin{aligned} x_c &= x_o + a_o R_o, \\ y_c &= y_o + b_o R_o, \qquad (3) \\ z_c &= z_o + c_o R_o, \end{aligned}$$

where R_o is the distance along the cylindrical axis between the points P_o and P_c.

Substituting equations (1) and (3) into equation (2), we obtain a relationship between the two distances,

$$R_o = \alpha R_s + \beta, \qquad (4)$$

where

$$\alpha = a_o a_s + b_o b_s + c_o c_s, \text{ and}$$

$$\beta = a_o(x_s - x_o) + b_o(y_s - y_o) + c_o(z_s - z_o).$$

Note that the parameter α equals the dot product of the unit vectors for the straight-line ray and the cylindrical axis. The parameter β equals the length of the projection of the line $\overrightarrow{P_sP_o}$ onto the cylindrical axis.

The line $\overrightarrow{P_iP_c}$ connects a point on the surface of the cylinder and one on the axis. Since it is orthogonal to the axis, its length equals the radius of the cylinder and

$$r_c^2 = (x_i - x_c)^2 + (y_i - y_c)^2 + (z_i - z_c)^2 \qquad (5)$$

Substituting equations (1), (3) and (4) into equation (5) produces the quadratic expression

$$a \cdot R_s^2 + 2bR_s + c - r_c^2 = 0, \qquad (6)$$

where $a = a_1^2 + a_2^2 + a_3^2$,

$$b = a_1 b_1 + a_2 b_2 + a_3 b_3,$$

$$c = b_1^2 + b_2^2 + b_3^2,$$

and $a_1 = \alpha a_o - a_s,$

$$b_1 = x_o - x_s + \beta a_o,$$

$$a_2 = \alpha b_o - b_s,$$

$$b_2 = y_o - y_s + \beta b_o,$$

$$a_3 = \alpha c_o - c_s,$$

$$b_3 = z_o - z_s + \beta c_o.$$

Solving equation (6) leads to

$$R_s = \frac{1}{a}\left[-b \pm \sqrt{b^2 + (r_c^2 - c) \cdot a}\,\right] \tag{7}$$

where the sign of the square root is determined by the restriction that R_s be larger or equal to zero, $R_s \geq 0$. Using equation (7) in equation (1) leads to the coordinates of the intersection point P_i.

(2) Determine if the intersection point is enclosed by the edges of a cylindrical surface.

The techniques of section (5), Appendix A, reference 5, can be used to determine if the intersection point of a ray is within a convex planar figure with straight edges. A transformation of the surface of the cylinder into a plane will allow the application of these techniques. We assume that the curvilinear edges are so designed that they transform into straight lines (see Reference 1).

An appropriate transformation is one that will change the cartesian coordinates of a point into coordinates of a cylindrical coordinate system (ζ,ξ,η). A suitable cylindrical system could be defined as follows. The ξ coordinate is the distance along the cylindrical axis measured from the origin point, P_o. Positive values would be in the direction of the axial unit vector. The ζ coordinate is the distance along the cylindrical surface measured in a plane normal to the cylindrical axis. The distance is measured from a reference plane containing the cylindrical axis and a predefined reference vector. Positive values would be counterclockwise displacements as seen facing the axial unit vector for a right-handed coordinate system. The η coordinate is the distance above or below the cylindrical surface measured along a normal to the surface. Positive values are above the surface away from the cylindrical axis.

We may compute the cylindrical coordinates $(\zeta,\xi\eta)$ of a point P from the rectangular coordinates (x,y,z) by first constructing a line from the point P orthogonal to the cylindrical axis. The rectangular coordinates $(x_c,y_c z_c)$ of the point P_c at the intersection of the two lines are given by equation (3) in section (1) above. The dot product of the unit vectors for the two lines is equal to zero and the distance R_o along the axis between the origin, P_o, and the corresponding intersection point is:

$$R_o = a_o(x-x_o) + b_o(y-y_o) + c_o(z-z_o). \tag{8}$$

The distance, R, of the line $\overrightarrow{P_cP}$ is given by

$$R = \left\{(x-x_c)^2 + (y-y_c)^2 + (z-z_c)^2\right\}^{1/2} \tag{9}$$

where equation (8) is substituted in equation (3) for the coordinates (x_c,y_c,z_c). The directional cosines of the line are given by:

$$\begin{aligned} a_c &= (x-x_c)/R, \\ b_c &= (y-y_c)/R, \\ c_c &= (z-z_c)/R, \end{aligned} \tag{10}$$

We next construct a reference vector for the cylindrical coordinate system as follows. Let the vector be normal to the cylindrical axis and in a vertical direction. The z-coordinate of the point P_o is greater than zero, $z_o > 0$, and we consider the truncated point, $P_o^1(x_o,y_o,0)$, from which a line is constructed orthogonal to the cylindrical axis. Let the line and axis intercept at the point P_b (x_b,y_b,z_b). Then the distance along the axis from P_o to P_b is $R_b = -c_o z_o$ as given by equation (8). The coordinates of point P_b are

$$\begin{aligned} x_b &= x_o-a_o c_o z_o, \\ y_b &= y_o-b_o c_o z_o, \\ z_b &= (1-c_o^2)z_o, \end{aligned}$$

as given by equation (3). Also, the length of the line $\overrightarrow{P_o^1P_b}$ is $R = z_o\sqrt{1-c_o^2}$ from equation (9). Use was made of the fact that the sum of the squares of a set of directional cosines is equal to unity; i.e., $a_o^2 + b_o^2 + c_o^2 = 1$. And finally, the directional cosines of the line $\overrightarrow{P_o^1P_b}$ are given by equation (10) as

$$a_R = \frac{a_o c_o}{\sqrt{1-c_o^2}}, \qquad \text{and} \qquad c_R = \sqrt{1-c_o^2}$$

$$b_R = \frac{-b_o c_o,}{\sqrt{1-c_o^2}} \tag{11}$$

These are the directional cosines of the reference vector contained in the reference plane for the cylindrical coordinate, ζ.

We construct a vector with directional cosines (a_p, b_p, c_p) normal to the reference plane from the cross product of the axial unit vector and the reference vector; i.e.,

$$\begin{aligned} a_p &= b_o c_R - b_R c_o, \\ b_p &= -(a_o c_R - a_R c_o). \\ c_p &= a_o b_R - a_R b_o. \end{aligned} \tag{12}$$

This vector at the cylindrical surface is in the direction of decreasing values of the ζ-coordinate.

We let the angle ψ_o be the angular displacement of the line $\overrightarrow{P_cP}$ from the reference plane. The line $\overrightarrow{P_cP}$ is contructed from the point P and is orthogonal to the cylindrical axis. The angle ψ_o is measured in a plane normal to the axis. It is equal to the arccosine of the dot product of the unit vextors of the line $\overrightarrow{P_cP}$ and the reference vector; i.e.

$$\psi_o = \text{arccosine}\,(a_R \cdot a_c + b_R \cdot b_c + c_R \cdot c_c) \tag{13}$$

Note that the dot product of the unit vectors for the line $\overrightarrow{P_cP}$ and the reference plane normal, i.e.,

$$Q = a_c \cdot a_p + b_c \cdot b_p + c_c \cdot c_p \tag{14}$$

has the same sign as does the angle. That is, if $Q \leq 0$, then $\psi_o < 0$, and if $Q > 0$, then $\psi_o > 0$.

The cylindrical coordinates of the point P are determined as follows. The ζ-coordinate is the distance along the cylindrical surface, measured in a plane normal to the cylindrical axis, from the reference plane to the line $\overrightarrow{P_cP}$. The distance is given by

$$\zeta = \psi_o \cdot r_c \tag{15}$$

where ψ_o is the angular separation of the $\overrightarrow{P_cP}$ given by equations (13) and (14). The ξ-coordinate is the distance along the axis from the origin, P_o, to the point, P_c, i.e.,

$$\xi = R_o \tag{16}$$

where R_o is given by equation (8). Finally, the η-coordinate is the distance of the point P above or below the cylindrical surface along the line $\overrightarrow{P_cP}$, i.e.,

$$\eta = R - r_c \tag{17}$$

where R is given by equation (9).

We may use the techniques of section (5), Appendix A, reference 5 by first applying the transformations of equations (15), (16) and (17) to be points of interest. These are (1) the ray origin, P_s, (2) the intersection point, P_i of the ray with the cylinder, and (3) the corner vertices of the cylindrical surface, $(P_j, j=1,N)$.

(3) Computing transmitted and reflected rays

The reflected and transmitted ray components and their associated values of transmittance and reflectance can be computed using the techniques of section (6), Appendix A, reference 5. The transparent surfaces of the canopy are assumed to have infinitesimal thickness. All internally refracted rays leave at the same surface point as does the initially transmitted ray, and this point is the same as that at which the incident ray reaches the surface (see references 2 and 3.)

The angle of incidence, Θ_o, between the incident ray and the surface normal is determined by the dot product of the unit vectors; i.e.,

$$\Theta_o = \text{arccosine}\ (a_s \cdot a_n + b_s \cdot\ b_n + c_s \cdot c_n), \tag{18}$$

where a_s,b_s,c_s are the directional cosines of the incident ray, and a_n,b_n,c_n are those of the surface normal.

The normal to the cylindrical surface is measured at the intersection point, P_i, of the incident ray. The normal is directed into the cockpit volume by convention. It is along the line $\overrightarrow{P_iP_c}$ of section (1), and its directional cosines are given by:

$$\begin{aligned} a_n &= (x_c - x_i)/r_c, \\ b_n &= (y_c - y_i)/\ r_c, \\ c_n &= (z_c - z_i)/r_c. \end{aligned} \tag{19}$$

Note that the coordinates x_c,y_c,z_c of the point P_c are given by equation (3) while those x_i,y_i,z_i of P_i are given by equation (1).

APPENDIX B

COMPUTER PROGRAM

The computer program is programmed for a disk-based batch-operating system in FORTRAN IV language (see references 4 and 7). The program is as listed in Appendix C, reference 5, except for a few additions. A short list of additional subroutines follows. The program is attached.

1. CALC—Controls the computation of the reflection point for an incident ray and stores the calculations on file, if any. Called by CONTL.

2. INTCY—Computes the intersection point of an incident ray with a cylinder and tests the point for enclosure within a cylindrical surface. Called by CALC.

3. TRSCY—Transforms rectangular coordinates into cylindrical coordinates. Called by INTCY.

4. PREC—Draws perspective of cockpit as a function of viewing angles, and shows entry and primary reflection points. Called alone.

5. DRWCT—Draws distribution of points on all surfaces. Called alone.

DRWCP—Draws side, top and front views of canopy and entry and primary reflection points. Draws pairing of entry and reflection points by surface. Called alone.

6. DRWCF—Draws sides, top and front views of canopy. Called by DRWCT and DRWCP.

```
/NEWJOB(MCAAH)
/JOB(MCAAH)
/CREATE(FINKAH)
/FORT
C MAINLINE, RAY TRACING FOR PILOT
C 3 DIMENSIONAL FLAT/CYLINDRICAL CANOPY WITH OBSTRUCTIONS
      SUBROUTINE CONTL
      COMMON/FORG/LFG
      COMMON/GAREA/IDFIL(6000)
      COMMON/ANG/ANN,BNN
      DATA ANN,BNN/95.,90./
      CALL GETDEV(LUN,'FINKAH',10)
      CALL GETDEV(LFG,'FORGRA',-1)
      CALL CAND
      CALL CANL(LUN)
      CALL CANT
      CALL DEVT(LUN,0,0)
      RETURN
      END
/FORT
C
C
C CONTROLS INPUT OF DATA
      SUBROUTINE CAND
      DIMENSION AN(2)
      DATA AN/2HYS,2HNO/
      WRITE(1,998)
  998 FORMAT(2X,'CANOPY DATA ON FILE$ (YS OR NO)')
      READ(1,1001)A
      IF(A.EQ.AN(1)) GO TO 1
      CALL READV
      CALL NORML
      GO TO 2
    1 CONTINUE
      CALL READF
    2 CONTINUE
      WRITE(1,1000)
 1000 FORMAT(2X,'PRINTOUT CANOPY DATA$ (YS OR NO)')
      READ(1,1001)A
 1001 FORMAT(1A2)
      IF(A.EQ.AN(1)) CALL TELTY
      WRITE(1,1002)
 1002 FORMAT(2X,'DISPLAY CANOPY CONFIGURATION$ (YS OR NO)')
      READ(1,1001)A
      IF(A.EQ.AN(2)) GO TO 3
      CALL DRWCN
      WRITE(1,1003)
 1003 FORMAT(2X,'HARD COPY$ (YS OR NO)')
      READ(1,1001)A
      IF(A.EQ.AN(2)) GO TO 3
      WRITE(1,1004)
 1004 FORMAT(2X,'PRINTER, TURN ON')
      PAUSE
      CALL GS31(1)
      PAUSE
    3 CONTINUE
      CALL GHLT
      WRITE(1,1005)
 1005 FORMAT(2X,'DISPLAY PERPECTIVE$ (YS OR NO)')
      READ(1,1001)A
```

```
      IF(A.EQ.AN(2)) GO TO 4
      CALL PERP(0)
      WRITE(1,1003)
      READ(1,1001)A
      IF(A.EQ.AN(2))GOTO 4
      CALL GS31(1)
      PAUSE
    4 CONTINUE
      CALL GHLT
      RETURN
      END
/FORT
C
C
C CONTROLS CALCULATION OF REFLECTION POINTS
      SUBROUTINE CANL(LUN)
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     Q,8)
      DIMENSION AN(2)
      DATA AN/2HYS,2HNO/
      DATA AI1,AI2/2.,2./
      CALL SEEK(LUN,0)
      READ(LUN)NVW
      WRITE(1,999)
  999 FORMAT(2X,'COMPLTE PRIMARY REFLECTION POINTS$ (YS OR NO)')
      READ(1,1001)A
 1001 FORMAT(1A2)
      IF(A.EQ.AN(2)) GO TO 300
      NVLL=0
      CALL SEEK(LUN,NVW)
      WRITE(LUN)NVLL
C INDEX PILOT VIEWING DIRECTION
C A1 ELEVATION, ANGLE FROM Z AXIS TOWARD X AXIS IN X Z PLANE
C A2 AZIMUTH, ANGLE FROM X Z PLANE TOWARD Y AXIS .
C Z AXIS TOWARD UPWARD, X AXIS TOWARD LEFT FACING FRONT OF CANOPY AND Y AXIS
C TOWARD BACK OF CANOPY ALONG LONGITUDINAL AXIS OF AIRCRAFT
      A1=0.
   10 A2=AI2
   11 A2=A2-AI2
      IF(A2.GE.-90.) GO TO 15
      A1=A1+AI1
      IF(A1.GT.180.) GO TO 299
      WRITE(1,995)A1
  995 FORMAT(2X,F10.4)
      GO TO 10
   15 CONTINUE
      IS=0
      CALL CALC(A1,A2,IS,LUN,NVLL)
      IF(IS.EQ.NA)CALL CALC(A1,A2,NA,LUN,NVLL)
      GO TO 11
  299 CONTINUE
      CALL SEEK(LUN,NVW)
      WRITE(LUN)NVLL
  300 CONTINUE
      RETURN
      END
/FORT
C
C
C CONTROLS OUTPUT OF CALCULATIONS
```

```
      SUBROUTINE CANT
      DIMENSION AN(2)
      DATA AN/2HYS,2HNO/
      WRITE(1,1006)
 1006 FORMAT(2X,'PERPECTIVE'/2X,'RAY ENTRENCE POINTS'/2X,'RIGHT HAND SIB
     QE COCKPIT (YS OR NO)')
      READ(1,1001)A
 1001 FORMAT(1A2)
      IF(A.EQ.AN(2)) GO TO 40
      CALL PERP(1)
      WRITE(1,1003)
 1003 FORMAT(2X,'HARD COPY+ (YS OR NO)')
      READ(1,1001)A
      IF(A.EQ.AN(2))GOTO 40
      CALL GS31(1)
      PAUSE
   40 CONTINUE
      CALL GHLT
      WRITE(1,1007)
 1007 FORMAT(2X,'PERPECTIVE'/2X,'PRIMARY REFLECTIONS$')
      READ(1,1001)A
      IF(A.EQ.AN(2)) GO TO 41
      CALL PERP(2)
      WRITE(1,1003)
      READ(1,1001)A
      IF(A.EQ.AN(2))GOTO 41
      CALL GS31(1)
      PAUSE
   41 CONTINUE
      CALL GHLT
      RETURN
      END
/FORT
C
C
C PRIMARY REFLECTION ONLY, SURFACE NK TRANSMITTER ONLY
      SUBROUTINE CALC(A1,A2,NK,LLN,NVLL)
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     Q,8)
      COMMON/PILOT/XO,YO,ZO
      COMMON/LINE/AS,BS,CS,XS,YS,ZS,AO,BO,CO
      DATA PI/3.14159/
      A1M=A1*PI/180.
      A2M=A2*PI/180.
      AS=COS(A2M)*SIN(A1M)
      BS=SIN(A2M)
      CS=COS(A2M)*COS(A1M)
      R=1.
      XS=XO
      YS=YO
      ZS=ZO
      IPLN=0
      INK=0
   18 CONTINUE
      DO 20 IS=1,NC
      IF(IS.EQ.INK)GOTO 20
      ISK=0
      IF(IS.LE.NA)CALL INTEC(ISK,IS,XR,YR,ZR)
      IF(IS.GT.NA)CALL INTCY(ISK,IS,XR,YR,ZR)
      IF(ISK.GT.0)GOTO 25
```

```
 20 CONTINUE
    RETURN
 25 CONTINUE
    IF(IS.LE.NC)RETURN
    CALL COMP(ANG,RT,TT)
    T=TT*R
    R=RT*R
    IF(IS.EQ.NK)GOTO 40
    IPUN=IPUN+1
    AI=-AS
    BI=-BS
    CI=-CS
    RX=AS*AC+BS*BC+CS*CC
    AR=-AS+2.*RX*AC
    BR=-BS+2.*RX*BC
    CR=-CS+2.*RX*CC
    IF(IPUN.EQ.2)GOTO 30
    IF(R.LT..00001)RETURN
    IPP=IS
    ASP=AS
    BSP=BS
    CSP=CS
    XP=XR
    YP=YR
    ZP=ZR
    AIP=AI
    BIP=BI
    CIP=CI
    ARP=AR
    BRP=BR
    CRP=CR
    AS=-AR
    BS=-BR
    CS=-CR
    XS=XR
    YS=YR
    ZS=ZR
    GO TO 18
 30 CONTINUE
    IF(T.LT..00001)RETURN
    NVLL=NVLL+1
    WRITE(LUN)A1,A2,ASP,BSP,CSP,IPP,XP,YP,ZP,AIP,BIP,CIP,ARP,BRP,CRP,
   QR,IS,XR,YR,ZR,AI,BI,CI,AR,BR,CR,T
    WRITE(3,1000)A1,A2,ASP,BSP,CSP,IPP,XP,YP,ZP,AIP,BIP,CIP,ARP,BRP,CR
   QP,R,IS,XR,YR,ZR,AI,BI,CI,AR,BR,CR,T
1000 FORMAT(2X,2(F7.2,2X)/2X,3(F7.4,2X)/2((2X,I2,3(2X,F6.2),7(2X,F7.4))
   Q/))
    NK=IPP
    RETURN
 40 CONTINUE
    INK=NK
    GO TO 18
    END
/FORT
C
C
C READ IN SURFACE VERTICES
      SUBROUTINE READV
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     Q,8)
```

```
      COMMON/VERT/XV(200),YV(200),ZV(200),NVR(100,8)
      COMMON/CYL/NCY,NSC(10),NSP(10,10),XC(10),YC(10),ZC(10),AE(10),BE(1
     Q0),CE(10),RC(10)
      COMMON/PILOT/XO,YO,ZO
      READ(2,1000)
 1000 FORMAT()
      READ(2,1001)NT,NB,NC,NP,NA,ND
 1001 FORMAT(/6(2X,I3))
      READ(2,1000)
      READ(2,1002)(NV(I),I=1,ND)
 1002 FORMAT(16(2X,I3))
      READ(2,1000)
      DO 10 J=1,8
      READ(2,1002)(NVR(I,J),I=1,ND)
   10 CONTINUE
      READ(2,1000)
      READ(2,1003)(XV(I),I=1,NT)
 1003 FORMAT(8(2X,F7.4))
      READ(2,1000)
      READ(2,1003)(YV(I),I=1,NT)
      READ(2,1000)
      READ(2,1003)(ZV(I),I=1,NT)
      READ(2,1000)
      READ(2,1002)NCY
      READ(2,1002)(NSC(I),I=1,NCY)
      DO 20 I=1,NCY
      KP=NSC(I)
   20 READ(2,1002)(NSP(I,K),K=1,KP)
      READ(2,1004)(XC(I),YC(I),ZC(I),AE(I),BE(I),CE(I),RC(I),I=1,NCY)
 1004 FORMAT(7(2X,F7.4))
      READ(2,1000)
      READ(2,1003)XO,YO,ZO
      RETURN
      END
/FORT
C
C
C
C ESTABLISH SURFACE NORMAL FOR EACH PLATE SURFACE
C SURFACE NORMALS DIRECTED TOWARD COCKPIT INTERIOR
      SUBROUTINE NORML
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     Q,8)
      COMMON/VERT/XV(200),YV(200),ZV(200),NVR(100,8)
      COMMON/NORM/AXN(100),AYN(100),AZN(100)
      COMMON/CYL/NCY,NSC(10),NSP(10,10),XC(10),YC(10),ZC(10),AE(10),BE(1
     Q0),CE(10),RC(10)
      COMMON/PILOT/XO,YO,ZO
      NVW=0
      CALL GETDEV(LUN,'FINKAH',10)
      CALL SEEK(LUN,0)
      WRITE(LUN)NVW
      WRITE(LUN)NT,NB,NC,NP,NA,ND
      DO 10 I=1,ND
      NK=NV(I)
      WRITE(LUN)NK
      DO 5 K=1,NK
      KV=NVR(I,K)
      PXV(I,K)=XV(KV)
      PYV(I,K)=YV(KV)
```

```
      PZV(I,K)=ZV(KV)
      WRITE(LUN)PXV(I,K),PYV(I,K),PZV(I,K)
    5 CONTINUE
      K=2
    7 A1=PXV(I,K)-PXV(I,1)
      A2=PXV(I,K+1)-PXV(I,1)
      B1=PYV(I,K)-PYV(I,1)
      B2=PYV(I,K+1)-PYV(I,1)
      C1=PZV(I,K)-PZV(I,1)
      C2=PZV(I,K+1)-PZV(I,1)
      P1=SQRT(A1**2+B1**2+C1**2)
      P2=SQRT(A2**2+B2**2+C2**2)
      A=(A1*A2+B1*B2+C1*C2)/(P1*P2)
      IF(ABS(A).LT.1.) GO TO 9
      K=K+1
      IF(K.EQ.NK) GO TO 10
      GO TO 7
    9 AN=ACOS(A)
      R=1./(P1*P2*SIN(AN))
      AXN(I)=+(B1*C2-C1*B2)*R
      AYN(I)=-(A1*C2-C1*A2)*R
      AZN(I)=+(A1*B2-A2*B1)*R
      WRITE(LUN)AXN(I),AYN(I),AZN(I)
   10 CONTINUE
      WRITE(LUN)NCY,(NSC(I),I=1,NCY)
      DO 20 I=1,NCY
      KP=NSC(I)
   20 WRITE(LUN)(NSP(I,K),K=1,KP)
      WRITE(LUN)(XC(I),YC(I),ZC(I),AE(I),BE(I),CE(I),RC(I),I=1,NCY)
      WRITE(LUN)XC,YC,ZC
      NVW=NEXREC(LUN)
      CALL SEEK(LUN,0)
      WRITE(LUN)NVW
      CALL DEVT(LUN,0,0)
      RETURN
      END
/FORT
C
C
C READ FILE FOR CANOPY DATA
      SUBROUTINE READF
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     Q,8)
      COMMON/NORM/AXN(100),AYN(100),AZN(100)
      COMMON/CYL/NCY,NSC(10),NSP(10,10),XC(10),YC(10),ZC(10),AE(10),BE(1
     Q0),CE(10),RC(10)
      COMMON/PILOT/XC,YC,ZC
      CALL GETDEV(LUN,'FINKAH',10)
      CALL SEEK(LUN,0)
      READ(LUN)NVW
      READ(LUN)NT,NB,NC,NP,NA,ND
      DO 10 I=1,ND
      READ(LUN)NK
      NV(I)=NK
      DO 5 K=1,NK
      READ(LUN)PXV(I,K),PYV(I,K),PZV(I,K)
    5 CONTINUE
      READ(LUN)AXN(I),AYN(I),AZN(I)
   10 CONTINUE
      READ(LUN)NCY,(NSC(I),I=1,NCY)
```

```
      DO 20 I=1,NCY
      KP=NSC(I)
   20 READ(LUN)(NSP(I,K),K=1,KP)
      READ(LUN)(XC(I),YC(I),ZC(I),AE(I),BE(I),CE(I),RC(I),I=1,NCY)
      READ(LUN)XO,YO,ZO
      CALL DEVT(LUN,0,0)
      RETURN
      END
/FORT
C
C
C PRINTOUT OF CANOPY DATA FOR REVIEW
      SUBROUTINE TELTY
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     0,8)
      COMMON/VERT/XV(200),YV(200),ZV(200),NVR(100,8)
      COMMON/NORM/AXN(100),AYN(100),AZN(100)
      COMMON/CYL/NCY,NSC(10),NSP(10,10),XC(10),YC(10),ZC(10),AE(10),BE(1
     00),CE(10),RC(10)
      COMMON/PILOT/XO,YO,ZO
      WRITE(1,998)
  998 FORMAT(2X,'PRINTER, TURN ON')
      PAUSE
      WRITE(3,1000)NT,NB,NC,NP,NA,ND
 1000 FORMAT(18(2X,I3))
  996 FORMAT()
      WRITE(3,997)
  997 FORMAT(/2X,'VERTEX POSITION DATA')
      WRITE(3,1001)(XV(I),I=1,NT)
      WRITE(3,996)
      WRITE(3,1001)(YV(I),I=1,NT)
      WRITE(3,996)
      WRITE(3,1001)(ZV(I),I=1,NT)
      WRITE(3,996)
      WRITE(3,1000)((NVR(I,J),I=1,ND),J=1,8)
      WRITE(3,996)
      DO 10 I=1,ND
      KN=NV(I)
      WRITE(3,995)I,KN
  995 FORMAT(/2X,'SURFACE',I3,'NO. VERTICES',I3)
      DO 5 K=1,KN
      WRITE(3,1001)PXV(I,K),PYV(I,K),PZV(I,K)
 1001 FORMAT(2X,3(F7.2,2X))
    5 CONTINUE
      WRITE(3,1002)AXN(I),AYN(I),AZN(I)
 1002 FORMAT(7(2X,F10.4))
   10 CONTINUE
      WRITE(3,994)
  994 FORMAT(/2X,'CYLINDRICAL DATA')
      WRITE(3,1000)NCY
      WRITE(3,1000)(NSC(I),I=1,NCY)
      DO 20 I=1,NCY
      KP=NSC(I)
   20 WRITE(3,1000)(NSP(I,K),K=1,KP)
      WRITE(3,1002)(XC(I),YC(I),ZC(I),AE(I),BE(I),CE(I),RC(I),I=1,NCY)
      WRITE(3,993)
  993 FORMAT(/2X,'PILOT POSITION')
      WRITE(3,1002)XO,YO,ZO
      RETURN
      END
```

```
/FORT
C
C
C DETERMINES IF RAY STRIKES CONVEX SURFACE
      SUBROUTINE INTEC(ISK,IS,XR,YR,ZR)
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     Q,8)
      COMMON/NORM/AXN(100),AYN(100),AZN(100)
      COMMON/LINE/AS,BS,CS,XS,YS,ZS,AC,BC,CC
      CK=AXN(IS)*AS+AYN(IS)*BS+AZN(IS)*CS
      IF(CK.GE.0.) RETURN
C RAY STRIKES SURFACE IN OUTWARD DIRECTION
      I=1
      IF(XS.EQ.PXV(IS,I).AND.YS.EQ.PYV(IS,I).AND.ZS.EQ.PZV(IS,I))I=I+1
      S=(AXN(IS)*(PXV(IS,I)-XS)+AYN(IS)*(PYV(IS,I)-YS)+AZN(IS)*(PZV(IS,I
     C)-ZS))/CK
      XR=AS*S+XS
      YR=BS*S+YS
      ZR=CS*S+ZS
      A1=PXV(IS,1)-XS
      B1=PYV(IS,1)-YS
      C1=PZV(IS,1)-ZS
      P1=XR-XS
      P2=YR-YS
      P3=ZR-ZS
      IN=NV(IS)
      DO 10 I=1,IN
      IC=I+1
      IF(I.EQ.IN) IC=1
      A2=PXV(IS,IC)-XS
      B2=PYV(IS,IC)-YS
      C2=PZV(IS,IC)-ZS
      Q=P1*(B1*C2-B2*C1)-P2*(A1*C2-C1*A2)+P3*(A1*B2-B1*A2)
      IF(Q.GT.0.)RETURN
C RAY STRIKES SURFACE ON ENCLOSED SIDE OF SURFACE EDGE
      A1=A2
      B1=B2
      C1=C2
   10 CONTINUE
C RAY STRIKES ENCLOSED SURFACE
      ISK=1
      AC=AXN(IS)
      BC=AYN(IS)
      CC=AZN(IS)
      RETURN
      END
/FORT
C
C
C COMPUTES INTERSECTION POINT OF LINE WITH CYLINDER
      SUBROUTINE INTCY(ISK,IS,XR,YR,ZR)
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     Q,8)
      COMMON/LINE/AS,BS,CS,XS,YS,ZS,AC,BC,CC
      COMMON/CYL/NCY,NSC(10),NSP(10,10),XC(10),YC(10),ZC(10),AE(10),BE(1
     C0),CE(10),RC(10)
      COMMON/PILOT/XP,YP,ZP
C DETERMINE CYLINDERICAL SURFACE WHICH CONVEX SURFACE IS A PART OF
      DO 2 I=1,NCY
      KP=NSC(I)
```

```
      DO 2 K=1,KP
      IF(NSP(I,K).EQ.IS)GOTO 5
    2 CONTINUE
      RETURN
    5 CONTINUE
C DETERMINE INTERSECTION POINT
      XO=XC(I)
      YO=YC(I)
      ZO=ZC(I)
      RC=RC(I)
      AO=AE(I)
      BO=BE(I)
      CO=CE(I)
      ROS=SQRT((XS-XC)**2+(YS-YO)**2+(ZS-ZO)**2)
      ACC=(XS-XC)/ROS
      BCC=(YS-YC)/ROS
      CCC=(ZS-ZC)/ROS
      A=AO*AS+BC*BS+CO*CS
      B=RCS*(AO*ACC+BC*BOO+CO*CCO)
      A1=AS-A*AC
      A2=BS-A*BC
      A3=CS-A*CC
      B1=ACC*RCS-B*AO
      B2=BOC*ROS-B*BC
      B3=COO*RCS-B*CC
      A=A1**2+A2**2+A3**2
      B=A1*B1+A2*B2+A3*B3
      C=B1**2+B2**2+B3**2
      AB=-B/A
      BB=(SQRT(B**2-A*(C-RO**2)))/A
      RS=AB-BB
      IF(RS.LT.C.)RS=AB+BB
      XR=XS+AS*RS
      YR=YS+BS*RS
      ZR=ZS+CS*RS
      R=RS*(AO*AS+BO*BS+CO*CS)+ROS*(AO*AOO+BO*BOO+CO*CCO)
      X1=XO+AO*R
      Y1=YC+BC*R
      Z1=ZO+CO*R
      AC=(X1-XR)/RC
      BC=(Y1-YR)/RC
      CC=(Z1-ZR)/RC
C DETERMINES WHETHER RAY STRIKES ENCLOSED SURFACE
      XSS=XP
      YSS=YP
      ZSS=ZP
      CALL TRSCY(I,XSS,YSS,ZSS)
      XRR=XR
      YRR=YR
      ZRR=ZR
      CALL TRSCY(I,XRR,YRR,ZRR)
      P1=XRR-XSS
      P2=YRR-YSS
      P3=ZRR-ZSS
      X1=PXV(IS,1)
      Y1=PYV(IS,1)
      Z1=PZV(IS,1)
      CALL TRSCY(I,X1,Y1,Z1)
      A1=X1-XSS
      B1=Y1-YSS
```

```
      C1=Z1-ZSS
      IN=NV(IS)
      DO 10 II=1,IN
      IC=II+1
      IF(II.EQ.IN)IC=1
      X2=PXV(IS,IC)
      Y2=PYV(IS,IC)
      Z2=PZV(IS,IC)
      CALL TRSCY(I,X2,Y2,Z2)
      A2=X2-XSS
      B2=Y2-YSS
      C2=Z2-ZSS
      Q=P1*(B1*C2-B2*C1)-P2*(A1*C2-C1*A2)+P3*(A1*B2-B1*A2)
      IF(Q.GT.0.)RETURN
C RAY STRIKES SURFACE ON ENCLOSED SIDE OF SURFACE EDGE
      A1=A2
      B1=B2
      C1=C2
   10 CONTINUE
C RAY STRIKES ENCLOSED SURFACE
      ISK=1
      RETURN
      END
/FORT
C
C
C CONVERTS COORDINATES IN CLINDRICAL COORDINATES INTO RECTANGULAR SPACE
      SUBROUTINE TRSCY(I,XR,YR,ZR)
      COMMON/CYL/NCY,NSC(10),NSP(10,10),XC(10),YC(10),ZC(10),AE(10),BE(1
     Q0),CE(10),RC(10)
      CN=SQRT(1.-CE(I)**2)
      AN=-AE(I)*CE(I)/CN
      BN=-BE(I)*CE(I)/CN
      AP=BE(I)*CN-BN*CE(I)
      BP=-(AE(I)*CN-AN*CE(I))
      CP=AE(I)*BN-AN*BE(I)
      RO=AE(I)*(XR-XC(I))+BE(I)*(YR-YC(I))+CE(I)*(ZR-ZC(I))
      XX=XC(I)+AE(I)*RO
      YY=YC(I)+BE(I)*RO
      ZZ=ZC(I)+CE(I)*RO
      R=SQRT((XR-XX)**2+(YR-YY)**2+(ZR-ZZ)**2)
      AA=(XR-XX)/R
      BB=(YR-YY)/R
      CC=(ZR-ZZ)/R
      A=AN*AA+BN*BB+CN*CC
      IF(A.GT.1.)A=1.
      IF(A.LT.-1.)A=-1.
      ANG=ACOS(A)
      Q=AP*AA+BP*BB+CP*CC
      IF(Q.LT.0.)ANG=-ANG
      XR=ANG*RC(I)
      YR=RO
      ZR=R-RC(I)
      RETURN
      END
/FORT
C
C
C COMPUTES INCIDENCE ANGLE, REFLECTANCE, AND TRANSMITTANCE
C NATURAL LIGHT, ADDITION OF POLARIZATION COMPONENTS IGNORED
```

```
      SUBROUTINE COMP(ANG,RT,TT)
      COMMON/LINE/AS,BS,CS,XS,YS,ZS,AC,BC,CC
C XN, INDEX OF REFRACTION, TX, INTERNAL TRANSMITTANCE
      DATA XN,TX/1.5,.92/
      A=-AS*AC-BS*BC-CS*CC
      IF(ABS(A).GT.1.)A=1.
      ANG=ACOS(A)
      ANGP= ASIN(SIN(ANG)/XN)
      CA=COS(ANG)
      SA=SIN(ANG)
      S1=SQRT(XN**2-SA**2)
      RO=(((CA-S1)/(CA+S1))**2+((CA*(XN**2)-S1)/(CA*(XN**2)+S1))**2)/2.
      TO=(1.-RO)*CA/COS(ANGP)
      CA=COS(ANGP)
      SA=SIN(ANGP)
      S1=SQRT(XN**2-SA**2)
      RI=(((CA-S1)/(CA+S1))**2+((CA*(XN**2)-S1)/(CA*(XN**2)+S1))**2)/2.
      TI=(1.-RI)*CA/COS(ANG)
      TT=TO*TI*TX/(1.-(RI*TX)**2)
      RT=RO+RI*TT
      RETURN
      END
/FORT
C
C
C COMPUTES ARCSIN
      FUNCTION ASIN(X)
      Y=X
      AX=ABS(Y)
      IF(AX.GE.1.0) GO TO 4
      AC=ATAN(Y/SQRT(1.-Y*Y))
      ASIN=AC
      RETURN
    4 IF(AX.GE.1.0001) GO TO 10
      ASIN=1.57079
      IF(Y.LT.0.)ASIN=-ASIN
      RETURN
   10 WRITE(1,11)X
      STOP
   11 FORMAT(8HERROR * ,23HARCSIN ARGUMENT .GT.1. ,6HARG = ,E16.8)
      END
/FORT
C
C
      FUNCTION ACOS(X)
      Y=X                                                               ARCCOS 2
      AX=ABS(Y)                                                         ARCCOS 3
      IF(AX.GE.1.0)GOTO 4                                               ARCCOS 4
      IF(Y.EQ.0.)GOTO 3                                                 ARCCOS 5
      AC=ATAN(SQRT(1.0-Y*Y)/Y)                                          ARCCOS 6
    1 IF(Y.LT.0.)GOTO 2                                                 ARCCOS 7
      ACOS=AC
      RETURN                                                            ARCCOS 9
    2 ACOS=AC+3.1415926
      RETURN                                                            ARCCOS11
    3 ACOS=1.5707963
      RETURN                                                            ARCCOS13
    4 IF(AX.GE.1.00001)GOTO 10                                          ARCCOS14
      AC=0.                                                             ARCCOS15
      GOTO 1                                                            ARCCOS16
```

```
   10 WRITE(1,11)X
      STOP                                                              ARCCOS18
11    FORMAT(8HERROR * ,23HARCCOS ARGUMENT .GT.1. ,6HANC = ,E16.8)      ARCCOS19
      END
/FORT
C
C
C DRAWS GRAPHIC PICTURE OF CANOPY IN 3 FOLD LAYOUT
      SUBROUTINE DRWCN
      COMMON/GAREA/IDFIL(6000)
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     Q,8)
      COMMON/NORM/AXN(100),AYN(100),AZN(100)
      COMMON/PILOT/XO,YO,ZO
      COMMON/FACT/SX
      SX=2.122
      WRITE(1,998)
  998 FORMAT(2X,'CONSOLE NO 1, TURN ON')
      PAUSE
      CALL GIN(6000)
      IX=(YO-5.5)*SX+100.
      IY=(ZO-111.52)*SX+100.
      CALL GBEG(1,IX,IY)
      CALL EMARK
      IY=(XO+104.)*SX+433.44
      CALL GCPY(2,1,IX,IY)
      IX=(ZO-111.52)*SX+690.42
      CALL GBEG(3,IX,IY)
      CALL ETIC
      NE=3
      DO 10 I=1,ND
C ENTITY IS CANOPY SURFACE--FENCE OR TRANSPARANT
      QS=-AXN(I)
      QF=-AYN(I)
      QT=+AZN(I)
      IX=(PYV(I,1)-5.5)*SX+100.
      IF((I.LE.NC.AND.QS.LT.0.).OR.(I.GT.NC.AND.QS.GT.0.))GOTO 2
C SURFACE FACES VIEWER FROM SIDE VIEW
      IY=(PZV(I,1)-111.52)*SX+100.
      NE=NE+1
      CALL GBEG(NE,IX,IY)
      IF(I.LE.NC)CALL GPUT(3,130,1,2)
      IF(I.EQ.NA)CALL GPUT(3,130,1,2)
      CALL LINS(I)
    2 CONTINUE
      IY=(PXV(I,1)+104.)*SX+433.44
      IF((I.LE.NC.AND.QT.LT.0.).OR.(I.GT.NC.AND.QT.GT.0.))GOTO 3
C SURFACE FACES VIEWER FROM TOP VIEW
      NE=NE+1
      CALL GBEG(NE,IX,IY)
      IF(I.LE.NC)CALL GPUT(3,130,1,2)
      IF(I.EQ.NA)CALL GPUT(3,130,1,2)
      CALL LINT(I)
    3 CONTINUE
      IF((I.LE.NC.AND.QF.LT.0.).OR.(I.GT.NC.AND.QF.GT.0.))GOTO 10
C SURFACE FACES VIEWER FROM FRONT VIEW
      IX=(PZV(I,1)-111.52)*SX+690.42
      NE=NE+1
      CALL GBEG(NE,IX,IY)
      IF(I.LE.NC)CALL GPUT(3,130,1,2)
```

```
      IF(I.EQ.NA)CALL GPUT(3,130,1,2)
      CALL LINF(I)
   10 CONTINUE
      DO 20 I=1,NE
      CALL GEON(I)
   20 CONTINUE
      CALL GSTART
      RETURN
      END
/FORT
C
C
C MARK EYE POSITION IN CANOPY
      SUBROUTINE EMARK
      CALL GPUT(6,50,-10,-5)
      CALL GPUT(7,70,0,10)
      CALL GPUT(8,50,10,-5)
      CALL GPUT(9,70,-7,-10)
      CALL GPUT(10,50,0,20)
      RETURN
      END
/FORT
C
C
      SUBROUTINE ETIC
      CALL GPUT(6,70,0,-5)
      CALL GPUT(7,50,0,10)
      CALL GPUT(8,70,-5,-5)
      CALL GPUT(9,50,10,0)
      RETURN
      END
/FORT
C
C
      SUBROUTINE LINS(I)
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     Q,8)
      COMMON/FACT/SX
      CALL GPUT(3,130,2,0)
      NK=NV(I)
      DO 10 K=1,NK
      K1=K+1
      IF(K.EQ.NK) K1=1
      IX=(PYV(I,K1)-PYV(I,K))*SX
      IY=(PZV(I,K1)-PZV(I,K))*SX
      CALL GPUT(K+5,53,IX,IY)
   10 CONTINUE
      RETURN
      END
/FORT
C
C
      SUBROUTINE LINF(I)
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     Q,8)
      COMMON/FACT/SX
      CALL GPUT(3,130,2,0)
      NK=NV(I)
      DO 10 K=1,NK
      K1=K+1
```

```
      IF(K.EQ.NK) K1=1
      IX=(PZV(I,K1)-PZV(I,K))*SX
      IY=(PXV(I,K1)-PXV(I,K))*SX
      CALL GPUT(K+5,53,IX,IY)
   10 CONTINUE
      RETURN
      END
/FORT
C
C
      SUBROUTINE LINT(I)
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     Q,8)
      COMMON/FACT/SX
      CALL GPUT(3,130,2,0)
      NK=NV(I)
      DO 10 K=1,NK
      K1=K+1
      IF(K.EQ.NK) K1=1
      IX=(PYV(I,K1)-PYV(I,K))*SX
      IY=(PXV(I,K1)-PXV(I,K))*SX
      CALL GPUT(K+5,53,IX,IY)
   10 CONTINUE
      RETURN
      ENC
/FORT
C
C
C DRAWS PERPECTIVE OF CANOPY ANC ENTRY ANC REFLECTION POINTS PILOT EYE
C POSITION
      SUBROUTINE PERP(IES)
      COMMON/GAREA/IDFIL(6000)
      COMMON/PER/ND,NS(50),PXS(50,20),PYS(50,20),PZS(50,20)
      DATA AX,BX,CX/10.,5.,512./
      CALL TRSDC
      CALL GIN(6CCO)
      IXE=CX
      IYE=CX
      CALL GBEG(1,IXE,IYE)
      CALL ETIC
      CALL GEON(1)
      NE=2
      IK=10
      CO 10 I=1,ND
      NK=NS(I)
      IF(IK.GT.6) CALL GBEG(NE,IXE,IYE)
      IK=6
      DO 5 K=1,NK
      K1=K+1
      IF(K.EQ.NK) K1=1
C CHECK EDGES FCR HIDDEN LINES
      CALL CLIPL(IK,I,K,K1)
    5 CONTINUE
      IF(IK.EQ.6) GO TO 10
      CALL GEON(NE)
      NE=NE+1
   10 CONTINUE
      IF(IES.EQ.C) GO TC 21
      CALL GBEG(NE+1,IXE,IYE)
      CALL GPUT(5,176C,C,.FALSE.)
```

```
      IF(IES.EQ.2) CALL GPUT(5,1750,0,0)
      CALL POINT(IES)
      CALL GEON(NE+1)
   21 CALL GSTART
      RETURN
      END
/FORT
C
C
C CONVERTS OBJECT COORDINATES TO DISPLAY COORDINATES , REMOVES LINES BEHIND
C VIEWER, SURFACES OUTSIDE-VIEWING BOX, SURFACES NOT FACING VIEWER
      SUBROUTINE TRSDC
      COMMON/CAN/NT,NB,NC,NP,NA,NDD,NV(100),PXV(100,8),PYV(100,8),PZV(10
     Q0,8)
      COMMON/NORM/AXN(100),AYN(100),AZN(100)
      COMMON/PILOT/X0,Y0,Z0
      COMMON/LINE/X1,Y1,Z1,X2,Y2,Z2,X3,Y3,Z3
      COMMON/PER/ND,NS(50),PXS(50,20),PYS(50,20),PZS(50,20)
      DIMENSION XS(100,8),YS(100,8),ZS(100,8)
      DATA A,B/10.,5./
      ND=1
      NSS=NB+1
      DO 10 I=NSS,NDD
      IF(I.EQ.NA)GOTO 10
      Q=AXN(I)*(PXV(I,1)-X0)+AYN(I)*(PYV(I,1)-Y0)+AZN(I)*(PZV(I,1)-Z0)
      IF(Q.GT.0.)GOTO 10
C SURFACE FACES VIEWER
      KN=NV(I)
      DO 2 K=1,KN
      CALL PLAC(PXV(I,K),PYV(I,K),PZV(I,K),XS(ND,K),YS(ND,K),ZS(ND,K))
C CONVERTED TO VIEWER COORDINATES
    2 CONTINUE
      KD=0
      IXP=0
      IXN=0
      IZP=0
      IZN=0
      DO 5 K=1,KN
      K1=K+1
      IF(K.EQ.KN) K1=1
      IF(YS(ND,K).LT.0..AND.YS(ND,K1).LT.0.) GO TO 5
      IF(YS(ND,K).LT.0..OR.YS(ND,K1).LT.0.) GO TO 3
      X1=XS(ND,K)
      Y1=YS(ND,K)
      Z1=ZS(ND,K)
      Q=1
      GO TO 4
    3 CONTINUE
      CALL INTEP(XS(ND,K),YS(ND,K),ZS(ND,K),XS(ND,K1),YS(ND,K1),ZS(ND,K1
     C),Q)
C SURFACE EDGE EXTENDING BEHIND VIEWER TRIMMED
    4 KD=KD+1
      PXS(ND,KD)=X1*A/(Y1*B)
      PYS(ND,KD)=-1./Y1
      PZS(ND,KD)=Z1*A/(Y1*B)
      CALL TEST(PXS(ND,KD),PZS(ND,KD),IXP,IXN,IZP,IZN)
C POSITIVE POINT OR CROSSING LINE FROM BEHIND
      IF(Q.GT.0.) GO TO 5
      KD=KD+1
      PXS(ND,KD)=X2*A/(Y2*B)
```

```
      PYS(ND,KD)=-1./Y2
      PZS(ND,KD)=Z2*A/(Y2*B)
C LEAD POINT FOR LINE CROSSING FROM IN FRONT
      CALL TEST(PXS(ND,KD),PZS(ND,KD),IXP,IXN,IZP,IZN)
C VERTEX CONVERTED TO DISPLAY VIEWBOX COORDINATES
    5 CONTINUE
      IF(KD.EQ.0) GO TO 10
C SURFACE NOT BEHIND VIEWER
      IF(IXP.GE.KD.OR.IXN.GE.KD.OR.IZP.GE.KD.OR.IZN.GE.KD) GO TO 10
C SURFACE PARTIALLY OR COMPLETELY WITHIN VIEW BOX
      NS(ND)=KD
      ND=ND+1
   10 CONTINUE
      ND=ND-1
      RETURN
      END
/FORT
C
C
      SUBROUTINE POINT(IES)
      DATA AX,BX,CX/10.,5.,512./
      CALL GETDEV(LUN,'FINKAH',10)
      CALL SEEK(LUN,0)
      READ(LUN)NVWC
      CALL SEEK(LUN,NVWC)
      READ(LUN)NVW
      IK=6
      DO 20 I=1,NVW
      READ(LUN)A1V,A2V,ASP,BSP,CSP,IP,XP,YP,ZP,AIP,BIP,CIP,ARP,BRP,CRP,
     QR,IS,XR,YR,ZR,AI,BI,CI,AR,BR,CR,T
      IF(IES.EQ.1) GO TO 30
      GO TO 40
   20 CONTINUE
      CALL DEVT(LUN,0,0)
      RETURN
C ENTRENCE POINTS FOR EXTERNAL RAYS
   30 CONTINUE
      CALL PLAC(XR,YR,ZR,PX,PY,PZ)
      IF(PY.LE.0.) GO TO 20
      XX=PX*AX/(PY*BX)
      ZZ=PZ*AX/(PY*BX)
      IF(ABS(XX).GT.1..OR.ABS(ZZ).GT.1.) GO TO 20
      IX=XX*CX+CX
      IY=ZZ*CX+CX
      CALL GPUT(IK,43,IX,IY)
      IK=IK+1
      GO TO 20
C PRIMARY REFLECTION POINTS
   40 CONTINUE
      CALL PLAC(XP,YP,ZP,PX,PY,PZ)
      IF(PY.LE.0.) GO TO 20
      XX=PX*AX/(PY*BX)
      ZZ=PZ*AX/(PY*BX)
      IF(ABS(XX).GT.1..OR.ABS(ZZ).GT.1.) GO TO 20
      IX=XX*CX+CX
      IY=ZZ*CX+CX
      CALL GPUT(IK,100,IX-4,0)
      CALL GPUT(IK+1,110,IY-4,0)
      IC=-ALOG10(T)
      IC=IC+176
```

```
      CALL GPUT(IK+2,90,IC,0)
      IK=IK+3
      GO TO 20
      END
/FORT
C
C
C DETERMINES VISIBLE PORTION OF EDGE BY REMOVING HIDDEN LINE
C ALL CONSTRAINT SURFACES CONVEX
      SUBROUTINE CLIPL(IK,IV,KV,KV1)
      COMMON/LINE/AV,BV,CV,XV,YV,ZV,AC,BC,CC
      COMMON/PER/ND,NS(50),PXS(50,20),PYS(50,20),PZS(50,20)
      COMMON/DRAW/NSC,RV,ROV(10),RFV(10)
      DATA CX/512./
      XV=PXS(IV,KV)
      YV=PYS(IV,KV)
      ZV=PZS(IV,KV)
      RV=SQRT((PXS(IV,KV1)-XV)**2+(PYS(IV,KV1)-YV)**2+(PZS(IV,KV1)-ZV)**
     Q2)
      AV=(PXS(IV,KV1)-XV)/RV
      BV=(PYS(IV,KV1)-YV)/RV
      CV=(PZS(IV,KV1)-ZV)/RV
      RO=0.
      RF=RV
      CALL CHKS(-1.,0.,0.,RO,RF)
      CALL CHKS(1.,0.,0.,RO,RF)
      CALL CHKS(0.,0.,1.,RO,RF)
      CALL CHKS(0.,0.,-1.,RO,RF)
      IF(RF.LT.RO) RETURN
C EDGE CHECKED AGAINST VIEWBOX
      NSC=1
      ROV(1)=RO
      RFV(1)=RF
      DO 10 I=1,ND
      IF(IV.EQ.I) GO TO 10
C FIND APPARANT INTERSECTION POINT OF EDGES
      ISC=0
      KN=NS(I)
      DO 5 K=1,KN
      K1=K+1
      IF(K.EQ.KN) K1=1
      XE=PXS(I,K)
      YE=PYS(I,K)
      ZE=PZS(I,K)
      RE=SQRT((PXS(I,K1)-XE)**2+(PYS(I,K1)-YE)**2+(PZS(I,K1)-ZE)**2)
      AE=(PXS(I,K1)-XE)/RE
      BE=(PYS(I,K1)-YE)/RE
      CE=(PZS(I,K1)-ZE)/RE
      Q=AE*CV-AV*CE
      IF(Q.EQ.0.) GO TO 5
C EDGES NOT PARALLEL
      RIV=(CE*(XV-XE)-AE*(ZV-ZE))/Q
      IF(AE.EQ.0.) GO TO 2
      RIE=(XV-XE+AV*RIV)/AE
      GO TO 3
    2 CONTINUE
      RIE=(ZV-ZE+CV*RIV)/CE
    3 CONTINUE
      YIE=YE+BE*RIE
      YIV=YV+BV*RIV
```

```
      IF(YIE.GT.YIV)GOTO 5
C CONSTRAINT EDGE IN FRONT OF TEST EDGE
      IF(RIE.GT.0..AND.RIE.LT.RE) GO TO 7
    5 CONTINUE
      IF(ISC.LT.2) GO TO 10
      IF(RO.LT.0..AND.RF.GT.RV) RETURN
C TEST EDGE NOT HIDDEN BEHIND CONSTRAINT SURFACE
      IF(RO.GT.RV.OR.RF.LT.0.) GO TO 10
C TEST EDGE PARTIALLY BLOCKED BY CONSTRAINT SURFACE
      CALL CKLIN(RO,RF)
      IF(NSC.EQ.0) RETURN
      GO TO 10
    7 CONTINUE
C CONSTRAINT EDGE LOCATED
      ISC=ISC+1
      IF(ISC.EQ.1) R1=RIV
      IF(ISC.EQ.2) CALL ORDLN(R1,RIV,RO,RF)
      GO TO 5
   10 CONTINUE
C VISIBLE PORTION OF EDGE REMAINS
      DO 20 I=1,NSC
      RO=ROV(I)
      RF=RFV(I)
      XS=XV+RO*AV
      ZS=ZV+RO*CV
      XF=XV+RF*AV
      ZF=ZV+RF*CV
      IXS=(XS+1.)*CX
      IZS=(ZS+1.)*CX
      IXF=(XF+1.)*CX
      IZF=(ZF+1.)*CX
      CALL GPUT(IK,100,IXS,0)
      CALL GPUT(IK+1,110,IZS,0)
      IDX=IXF-IXS
      IDZ=IZF-IZS
      CALL GPUT(IK+2,53,IDX,IDZ)
      IK=IK+3
   20 CONTINUE
      RETURN
      END
/FORT
C
C
C CONVERTS OBJECT SPACE COORDINATES INTO EYE SPACE COORDINATES
C PILOT EYE DIRECTED IN Y-Z PLANE OF AIRCRAFT COORDINATES AND 5-DEGREES
C ABOVE NEGATIVE Y-AXIS
      SUBROUTINE PLAC(PXV,PYV,PZV,PX,PY,PZ)
      COMMON/PILOT/XO,YO,ZO
      COMMON/ANG/AN,BN
      DATA PI/3.14159/
      AN1=AN*PI/180.
      BN1=BN*PI/180.
      PX=(PXV-XO)*SIN(BN1)-(PYV-YO)*COS(BN1)
      PY=-(PXV-XO)*COS(BN1)*SIN(AN1)-(PYV-YO)*SIN(BN1)*SIN(AN1)-(PZV-ZO)
     Q*COS(AN1)
      PZ=-(PXV-XO)*COS(BN1)*COS(AN1)-(PYV-YO)*SIN(BN1)*COS(AN1)+(PZV-ZO)
     Q*SIN(AN1)
      RETURN
      END
/FORT
```

```
C
C
C TEST SURFACE VERTEX FOR POSITION OUTSIDE VIEWBOX
      SUBROUTINE TEST(X,Z,IXP,IXN,IZP,IZN)
      IF(X.GT.1.) IXP=IXP+1
      IF(X.LT.-1.)IXN=IXN+1
      IF(Z.GT.1.) IZP=IZP+1
      IF(Z.LT.-1.)IZN=IZN+1
      RETURN
      END
/FORT
C
C
C CALCULATES INTERSECTION POINT FOR LINE WITH PLANE NORMAL TO Y-AXIS
      SUBROUTINE INTEP(X1,Y1,Z1,X2,Y2,Z2,B)
      COMMON/LINE/XS,YS,ZS,XF,YF,ZF,XC,YC,ZC
      DATA Y0/1./
      R=SQRT((X1-X2)**2+(Y1-Y2)**2+(Z1-Z2)**2)
      A=(X2-X1)/R
      B=(Y2-Y1)/R
      C=(Z2-Z1)/R
      IF(B.EQ.0.) RETURN
C EDGE NOT PARALLEL TO PLANE
      YI=Y0
      RI=(YI-Y1)/B
      XI=X1+A*RI
      ZI=Z1+C*RI
      IF(B.LT.0.) GO TO 3
C LINE ORIGINATES BEHIND VIEWER
      XS=XI
      YS=YI
      ZS=ZI
      XF=X2
      YF=Y2
      ZF=Z2
      RETURN
    3 CONTINUE
C LINE ORIGINATES IN FRONT OF VIEWER
      XS=X1
      YS=Y1
      ZS=Z1
      XF=XI
      YF=YI
      ZF=ZI
      RETURN
      END
/FORT
C
C
C CHECKS EDGE AGAINST VIEWING BOX SIDE
      SUBROUTINE CHKS(AN,BN,CN,RO,RF)
      COMMON/LINE/AV,BV,CV,XV,YV,ZV,AC,BC,CC
      XN=-AN
      YN=-BN
      ZN=-CN
      Q=AV*AN+BV*BN+CV*CN
      IF(Q.EQ.0.) GO TO 5
      RI=((XN-XV)*AN+(YN-YV)*BN+(ZN-ZV)*CN)/Q
      IF(Q.LE.0.) GO TO 3
C EDGE DIRECTED INTO VIEWBOX FROM OUTSIDE
```

```
      IF(RI.GT.RO) RO=RI
      RETURN
    3 CONTINUE
C EDGE DIRECTED OUT OF VIEWBOX FROM INSIDE
      IF(RI.LT.RF) RF=RI
      RETURN
    5 CONTINUE
C EDGE PARALLEL TO SIDE
      IF(ABS(XV).GT.1..OR.ABS(ZV).GT.1.) RF=RO-1.
      RETURN
      END
/FORT
C
C
C ORDER EDGE INTERSECTION POINTS ACCORDING TO LOW AND HIGH VALUES
      SUBROUTINE ORDLN(R1,R2,RO,RF)
      RO=R1
      RF=R2
      IF(R1.LT.R2) RETURN
      RO=R2
      RF=R1
      RETURN
      END
/FORT
C
C
C CHECKED PARTIALLY BLOCKED LINE FOR VISIBLE SEGMENTS
      SUBROUTINE CKLIN(R1,R2)
      COMMON/DRAW/NSC,RV,ROV(10),RFV(10)
      DIMENSION RO(10),RF(10)
      IF(R1.GT.0..AND.R2.LT.RV) GO TO 20
C VERTEX OF TEST EDGE BEHIND CONSTRAINT SURFACE
      IF(R2.GT.RV) GO TO 5
C LOW END OF EDGE HIDDEN
      RVO=R2
      RVF=RV
      GO TO 10
C HIGH END OF EDGE HIDDEN
    5 CONTINUE
      RVO=0.
      RVF=R1
   10 CONTINUE
      DO 12 I=1,NSC
      RO(I)=ROV(I)
      RF(I)=RFV(I)
      IF(RFV(I).LE.RVO) RF(I)=-1.
      IF(ROV(I).LT.RVO) RO(I)=RVO
      IF(RFV(I).GT.RVF) RF(I)=RVF
      IF(ROV(I).GT.RVF) RF(I)=-1.
   12 CONTINUE
      GO TO 30
C CONSTRAINT SURFACE SEPARATES EDGE INTO TWO VISIBLE ENDS
   20 CONTINUE
      RVO=R1
      RVF=R2
      K=0
      DO 22 I=1,NSC
      K=K+1
      RO(K)=ROV(I)
      RF(K)=RFV(I)
```

```
      IF(RFV(I).GT.RVO.AND.RFV(I).LT.RVF) RF(K)=RVO
      IF(ROV(I).GT.RVO.AND.RFV(I).LT.RVF) RF(K)=-1.
      IF(RFV(I).GT.RVF.AND.ROV(I).LT.RVO) GO TO 27
      IF(RFV(I).GT.RVF.AND.ROV(I).GT.RVO.AND.ROV(I).LT.RVF) RO(K)=RVF
   22 CONTINUE
      NSC=K
      GO TO 30
   27 CONTINUE
      RF(K)=RVO
      K=K+1
      RO(K)=RVF
      RF(K)=RFV(I)
      GO TO 22
C ARRANGE REMAINING VISIBLE SEGMENTS
   30 CONTINUE
      NK=0
      DO 32 I=1,NSC
      IF(RF(I).LE.0.) GO TO 32
      NK=NK+1
      ROV(NK)=RO(I)
      RFV(NK)=RF(I)
   32 CONTINUE
      NSC=NK
      RETURN
      END
/FORT
C
C
      SUBROUTINE PERC(IA,IB)
      COMMON/ANG/AN,BN
      AN=IA
      BN=IB
      CALL READF
      CALL PERP(1)
      PAUSE
      CALL GS31(1)
      PAUSE
      CALL PERP(2)
      PAUSE
      CALL GS31(1)
      PAUSE
      RETURN
      END
/FORT
C
C
C DRAWS GRAPHIC PICTURE OF CANOPY LAYOUT AND ENTRY, PRIMARY REFLECTION POINTS
      SUBROUTINE DRWCP(IE,IR)
      COMMON/FACT/SX
      CALL DRWCF(NE,IX1,IY1,IY2,IX3)
      CALL GBEG(NE+1,IX1,IY1)
      CALL GPUT(5,1760,0,.FALSE.)
      CALL GBEG(NE+2,IX1,IY1)
      CALL GPUT(5,1750,0,0)
      CALL GBEG(NE+3,IX1,IY2)
      CALL GPUT(5,1760,0,.FALSE.)
      CALL GBEG(NE+4,IX1,IY2)
      CALL GPUT(5,1750,0,0)
      CALL GBEG(NE+5,IX3,IY2)
      CALL GPUT(5,1760,0,.FALSE.)
```

```
      CALL GBEG(NE+6,IX3,IY2)
      CALL GPUT(5,1750,0,0)
      IKP=6
      IKR=6
      CALL GETDEV(LUN,'FINKAH',10)
      CALL SEEK(LUN,0)
      READ(LUN)NVWO
      CALL SEEK(LUN,NVWO)
      READ(LUN)NVW
      DO 20 I=1,NVW
      READ(LUN)A1V,A2V,ASP,BSP,CSP,IP,XP,YP,ZP,AIP,BIP,CIP,ARP,BRP,CRP,
     QR,IS,XR,YR,ZR,AI,BI,CI,AR,BR,CR,T
      IF(IS.EQ.IE.AND.IP.EQ.IR)GOTO 30
   20 CONTINUE
      CALL DEVT(LUN,0,0)
      PAUSE
      CALL GS31(1)
      PAUSE
      RETURN
C ENTRENCE POINTS FOR EXTERNAL RAYS AND REFLECTION POINTS TO PILOT'S EYE
   30 CONTINUE
      IC=-ALOG10(T)
      IC=IC+176
      CALL GENT(NE+1)
      IXR=(YR-36.)*SX
      IYR=(ZR-106.48)*SX
      CALL GPUT(IKR,43,IXR,IYR)
      IXP=(YP-36.)*SX
      IYP=(ZP-106.48)*SX
      CALL GENT(NE+2)
      CALL GPUT(IKP,100,IXP-4,0)
      CALL GPUT(IKP+1,110,IYP-4,0)
      CALL GPUT(IKP+2,90,IC,0)
      CALL GENT(NE+3)
      IYR=(XR+121.44)*SX
      CALL GPUT(IKR,43,IXR,IYR)
      IYP=(XP+121.44)*SX
      CALL GENT(NE+4)
      CALL GPUT(IKP,100,IXP-4,0)
      CALL GPUT(IKP+1,110,IYP-4,0)
      CALL GPUT(IKP+2,90,IC,0)
      IXR=(ZR+15.91)*SX
      CALL GENT(NE+5)
      CALL GPUT(IKR,43,IXR,IYR)
      IXP=(ZP+15.91)*SX
      CALL GENT(NE+6)
      CALL GPUT(IKP,100,IXP-4,0)
      CALL GPUT(IKP+1,110,IYP-4,0)
      CALL GPUT(IKP+2,90,IC,0)
      IKR=IKR+1
      IKP=IKP+3
      GO TO 20
      END
/FORT
C
C
C DRAWS GRAPHIC PICTURE OF CANOPY LAYOUT AND ENTRY OR PRIMARY REFLECTION POINTS
C ON ALL SURFACES
      SUBROUTINE DRWCT(IE)
      COMMON/FACT/SX
```

```
      CALL DRWCF(NE,IX1,IY1,IY2,IX3)
      CALL GBEG(NE+1,IX1,IY1)
      CALL GPUT(5,1760,0,.FALSE.)
      IF(IE.EQ.2)CALL GPUT(5,1750,0,0)
      CALL GBEG(NE+2,IX1,IY2)
      CALL GPUT(5,1760,0,.FALSE.)
      IF(IE.EQ.2)CALL GPUT(5,1750,0,0)
      CALL GBEG(NE+3,IX3,IY2)
      CALL GPUT(5,1760,0,.FALSE.)
      IF(IE.EQ.2)CALL GPUT(5,1750,0,0)
      IKP=6
      IKR=6
      CALL GETDEV(LUN,'FINKAH',10)
      CALL SEEK(LUN,0)
      READ(LUN)NVWC
      CALL SEEK(LUN,NVWC)
      READ(LUN)NVW
      DO 20 I=1,NVW
      READ(LUN)A1V,A2V,ASP,BSP,CSP,IP,XP,YP,ZP,AIP,BIP,CIP,ARP,BRP,CRP,
     QR,IS,XR,YR,ZR,AI,BI,CI,AR,BR,CR,T
      IF(IE.EQ.2)GOTO 30
      GO TO 40
   20 CONTINUE
      CALL DEVT(LUN,0,0)
      PAUSE
      CALL GS31(1)
      PAUSE
      RETURN
C PRIMARY REFLECTION POINTS TO PILOT'S EYE
   30 CONTINUE
      IC=-ALOG10(T)
      IC=IC+176
      CALL GENT(NE+1)
      IXP=(YP-36.)*SX
      IYP=(ZP-106.48)*SX
      CALL GPUT(IKP,100,IXP-4,0)
      CALL GPUT(IKP+1,110,IYP-4,0)
      CALL GPUT(IKP+2,90,IC,0)
      CALL GENT(NE+2)
      IYP=(XP+121.44)*SX
      CALL GPUT(IKP,100,IXP-4,0)
      CALL GPUT(IKP+1,110,IYP-4,0)
      CALL GPUT(IKP+2,90,IC,0)
      IXP=(ZP+15.91)*SX
      CALL GENT(NE+3)
      CALL GPUT(IKP,100,IXP-4,0)
      CALL GPUT(IKP+1,110,IYP-4,0)
      CALL GPUT(IKP+2,90,IC,0)
      IKP=IKP+3
      GO TO 20
C ENTRENCE POINTS FOR EXTERNAL RAYS
   40 CONTINUE
      IXR=(YR-36.)*SX
      IYR=(ZR-106.48)*SX
      CALL GENT(NE+1)
      CALL GPUT(IKR,43,IXR,IYR)
      IYR=(XR+121.44)*SX
      CALL GENT(NE+2)
      CALL GPUT(IKR,43,IXR,IYR)
      IXR=(ZR+15.91)*SX
```

```
      CALL GENT(NE+3)
      CALL GPUT(IKR,43,IXR,IYR)
      IKR=IKR+1
      GO TO 20
      END
/FORT
C
C
C DRAWS GRAPHIC PICTURE OF CANOPY FRAME LAYOUT
      SUBROUTINE DRWCF(NE,IX1,IY1,IY2,IX3)
      COMMON/GAREA/IDFIL(8000)
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     Q,8)
      COMMON/NORM/AXN(100),AYN(100),AZN(100)
      COMMON/PILOT/XO,YO,ZO
      COMMON/FACT/SX
      SX=4.66
      CALL READF
      CALL GIN(8000)
      IX1=(YO-36.)*SX
      IY1=(ZO-106.48)*SX
      CALL GBEG(1,IX1,IY1)
      CALL EMARK
      IY2=(XO+121.44)*SX
      CALL GCPY(2,1,IX1,IY2)
      IX3=(ZO+15.91)*SX
      CALL GBEG(3,IX3,IY2)
      CALL ETIC
      NE=3
      NS=NC+1
      DO 10 I=NS,ND
      IF(I.LE.NB)GOTO 10
C ENTITY IS CANOPY SURFACE
      QS=-AXN(I)
      QF=-AYN(I)
      QT=+AZN(I)
      IX=(PYV(I,1)-36.)*SX
      IF(QS.GT.0.)GOTO 2
C SURFACE FACES VIEWER FROM SIDE VIEW
      IY=(PZV(I,1)-106.48)*SX
      NE=NE+1
      CALL GBEG(NE,IX,IY)
      IF(I.EQ.NA)CALL GPUT(3,130,1,2)
      CALL LINS(I)
    2 CONTINUE
      IY=(PXV(I,1)+121.44)*SX
      IF(QT.GT.0.)GOTO 3
C SURFACE FACES VIEWER FROM TOP VIEW
      NE=NE+1
      CALL GBEG(NE,IX,IY)
      IF(I.EQ.NA)CALL GPUT(3,130,1,2)
      CALL LINT(I)
    3 CONTINUE
      IF(QF.GT.0.)GOTO 10
C SURFACE FACES VIEWER FROM FRONT VIEW
      IX=(PZV(I,1)+15.91)*SX
      NE=NE+1
      CALL GBEG(NE,IX,IY)
      IF(I.EQ.NA)CALL GPUT(3,130,1,2)
      CALL LINF(I)
```

```
   10 CONTINUE
      RETURN
      END
C AAH CANOPY DATA
C NUMBER OF VERTICES, SURFACES--CONSTRAINT, FLAT, AND CYLINDRICAL
  166   16   56   58   59   64
C NO. VERTICES PER SURFACE
    4    4    4    4    4    4    4    4    4    4    4    5    5    4    4    4
    4    4    4    4    4    4    4    4    4    7    7    7    7    4    4    6
    4    4    4    4    4    4    4    5    4    4    5    7    7    7    7    4
    4    4    4    4    4    4    4    4    4    4    8    6    6    6    6    4
C VERTICE ASSIGNED TO EACH SURFACE
   89   90   66  121  125  129  133  135  139  143  145  149  153  157  137  145
    1    2    3    4    7    1    5   12   11   21   15   28   22   32   29   33
  110   35   36  111   38   39   38  109   40   41  112   53   47   60   54   61
   61   89   94   93  100   99   98   87   77   81  101   68   71   94  100   85
  117  114  115  122  126  130  134  136  140  144  146  150  154  158  136  148
    2    3    4    5   14    7    4   14   12   20   16   27   23   31   30   34
  109   36   37  112   39   38  111  111   41  110  110   52   48   59   55   64
   62   90   89   94   95  100   99   98   78   82  102   69   72   93   99   86
  114  115  119  123  127  131  130  137  141  140  147  151  166  159  162  163
    9   10   11   12   12    5    3    8    9   19   17   26   24   30   31  109
   35   43   44   44   46   34  109   37   45  112   42   51   49   58   56   63
   63   66   65   70   71   76   75   74   79   83  103   70   73   92   98   87
   90   66   65  124  128  132  129  138  142  139  148  152  155  160  161  164
    8    9   10   11    5    2    2    9   10   18   18   25   25   29   32  110
   42   42   43   37   45   33   34   36   46   45   43   50   50   57   57   62
   64   65   70   69   76   75   74   88   80   84  104   65   74   91   97   88
    0    0    0    0    0    0    0    0    0    0    0  165  156    0    0    0
    0    0    0    0    0    0    0    0    0   17   19   24   26    0    0   41
    0    0    0    0    0    0    0   35    0    0   44   49   51   56   58    0
    0    0    0    0    0    0    0    0    0    0  105   66   75   90   96    0
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0   16   20   23   27    0    0   40
    0    0    0    0    0    0    0    0    0    0    0   48   52   55   59    0
    0    0    0    0    0    0    0    0    0    0  106   67   76   89   95    0
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0   15   21   22   28    0    0    0
    0    0    0    0    0    0    0    0    0    0    0   47   53   54   60    0
    0    0    0    0    0    0    0    0    0    0  107    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0  108    0    0    0    0    0
C VERTICE X-POSITION
      2.00      2.00      2.00      2.00      2.00      2.00      2.00     -2.00
     -2.00     -2.00     -2.00     -2.00     -2.00     -2.00     19.06     18.70
     14.25     12.90     11.20     14.76     17.42    -18.00    -17.60    -13.84
    -13.30    -13.24    -15.96    -17.96      8.50    -11.50    -12.04      9.08
     19.63     19.63     11.46     11.46     11.46     19.63     19.63    -19.63
    -19.63    -11.46    -11.46    -11.46    -19.63    -19.63     19.16     18.84
     14.22     13.10     11.24     14.78     17.50    -17.90    -17.60    -14.00
    -13.30    -13.28    -15.96    -17.96      8.56    -11.48    -12.14      9.16
     23.08     20.92     18.08     13.72     22.72     23.28     23.20     13.60
     13.00     15.16     16.36     22.84     16.72    -16.72    -14.28     14.28
     13.60    -13.60     -9.20      9.20     10.56    -10.56    -11.56     11.56
    -23.08    -20.92    -18.08    -13.72    -22.72    -23.28    -23.20    -13.60
    -13.00    -15.16    -16.36    -22.84     19.63     13.26     11.46    -11.46
    -13.26    -19.63    -12.00     12.00     13.26    -11.46     13.26    -11.46
    -23.75       -4.        4.     23.75       -4.    -23.75        4.     23.75
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```
     24.      36.      36.      24.     -36.     -24.     -24.     -36.
     26.     104.     104.      26.      26.     104.     67.6      61.
     61.     67.6    -104.     -26.     -26.    -104.    -104.     -26.
    -61.    -67.6    -67.6     -61.     -46.     -24.     -22.     -56.
     24.      46.      56.      22.     -10.      10.      10.     -10.
     61.      61.     -61.     -61.     -56.      56.
C VERTICE Y-POSITION
    57.50    57.50    68.37    71.57    58.98    58.98    60.30    57.50
    57.50    68.37    71.57    58.98    58.98    60.30    84.66    82.92
    83.46    86.98    98.18    98.66    96.24    84.66    82.92    83.46
    86.98    98.18    98.66    96.24    87.48    87.48    97.56    97.56
    98.45   103.49   100.92   110.92   115.61   121.40   121.50    98.45
   103.49   100.92   110.92   115.61   121.40   121.50   144.26   142.52
   142.54   146.00   157.52   158.40   156.32   144.26   142.52   142.54
   146.00   157.52   158.40   156.32   148.00   148.00   156.66   156.66
    59.20    59.20    70.14   108.42   110.90    69.78   116.49   113.25
   139.69   156.97   156.97   140.09    58.30    58.30    67.18    67.18
    69.57    69.57   108.01   108.01   112.13   112.13   145.44   145.44
    59.20    59.20    70.14   108.42   110.90    69.78   116.49   113.25
   139.69   156.97   156.97   140.09   115.52   115.52   114.82   114.82
   115.52   115.52   113.01   113.01   103.49   103.49   121.40   121.40
    57.5      5.5      5.5     57.5      5.5     57.5      5.5     57.5
    59.2     65.2    132.61   158.6     65.2     59.2    158.6    132.61
   186.61   191.61   226.61   236.61   186.61   191.61   189.61   189.61
   180.61   180.61   191.61   186.61   236.61   226.61   191.61   186.61
   189.61   189.61   180.61   180.61   214.61   214.61   214.61   214.61
   214.61   214.61   214.61   214.61   198.61   198.61   198.61   198.61
   198.61   224.61   198.6    224.61   214.61   214.61
C VERTICE Z-POSITION
   131.81   138.66   146.27   141.77   133.97   133.97   132.83   131.81
   138.66   146.27   141.77   133.97   133.97   132.83   128.40   130.34
   145.26   148.54   148.08   136.54   127.96   128.40   130.34   145.26
   148.54   148.08   136.54   127.96   118.61   118.61   156.00   156.00
   129.20   148.00   157.58   160.51   160.88   139.20   129.20   129.20
   148.00   157.58   160.51   160.88   139.20   129.20   147.56   149.40
   164.26   167.64   167.68   156.20   147.54   147.56   149.40   164.26
   167.64   167.68   156.20   147.54   137.86   137.86   175.68   175.68
   129.05   141.41   154.80   172.40   150.68   130.85   146.36   174.59
   179.28   179.24   176.40   150.80   143.52   143.52   154.40   154.40
   156.72   156.72   175.15   175.15   177.93   177.93   182.12   182.12
   129.05   141.41   154.80   172.40   150.68   130.85   146.36   174.59
   179.28   179.24   176.00   150.80   152.54   152.54   159.03   159.03
   152.54   152.54   175.79   175.79   148.00   148.00   139.20   139.20
   144.2     129.1    129.1    144.2    122.1    127.05   122.1    127.05
   124.12   124.12   124.12   124.12   124.12   124.12   124.12   124.12
   142.52   140.52   140.52   142.52   132.12   132.92   132.52   132.52
   111.52   111.52   140.52   142.52   142.52   140.52   132.92   132.12
   132.52   132.52   111.52   111.52   147.92   147.92   178.52   178.52
   147.92   147.92   178.52   178.52   181.52   181.52   221.52   221.52
   111.52   132.52   111.52   132.52   157.92   157.92
C CYLINDRICAL DATA
    3
    2    2    1
   60   61
   62   63
   64
   -84.74   135.89   130.93   .0       .9805    .1968    108.98
    84.74   135.89   130.93   .0       .9805    .1968    108.98
     0.     146.86    55.37  1.        .0       .0       127.63
C PILOT EYE POSITION
```

```
    -1.5     142.33   171.2
C CO-PILOT EYE POSITION
    -1.5      83.04   152.14
```