MULTIWALL RADOME ANALYSIS PROGRAM

Air-to-Ground Analysis Group
Reconnaissance and Weapon Delivery Division

February 1976

TECHNICAL REPORT AFAL-TR-75-183

Final Report for Period June 1974 to June 1975

Approved for public release; distribution unlimited.
This report describes a computer analysis tool for calculating the electrical transmission and reflection properties of a multiwall radome. The radome program may be used with a suitable antenna program to estimate the effects of the radome on the antenna pattern.

The analysis tool is comprised of two programs, a radome-geometry program, RADOME, and a flat-panel analysis program, WAVES2. The geometry program calculates the incidence angle for each ray (a ray represents the radiated RF power from each antenna element) at the radome wall. The output data
Abstract continued:

from the geometry program, RADOME, serves as input to the flat-panel program. The flat-panel program then calculates the electrical transmission and reflection parameters of the radome for each ray. These parameters may then be used with a suitable free-space antenna pattern simulation program, and the resultant antenna pattern in the presence of the radome can be computed.
FOREWORD

The computer program in this report was written for the Air Force Avionics Laboratory's Electronically Agile Radar (EAR) program. The work was performed by personnel from the Air-to-Ground Analysis Group, Mr. Richard M. Reeves, Group Leader, Analysis and Evaluation Branch, Reconnaissance and Weapon Delivery Division. Mr. Robert M. Blumgold was the principal investigator. Special acknowledgment is due Dr. James McDougal of the Air-to-Air Analysis Group, Mrs. Georgeanne Chitwood of the Air-to-Ground Analysis Group, and to Mr. Clyde Hoots of the Brunswick Corp., Marion, Va., for their valuable assistance during this study.

Publication of this report does not constitute Air Force approval of the report findings or conclusions. It is published only for the exchange and stimulation of ideas.
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\( X_{mn}, Y_{mn}, Z_{mn} \) Coordinates of array elements

\( m, n \) Antenna array element row and column numbers respectively

\( \alpha, \beta, \gamma \) Direction cosines for the point of interest relative to the antenna phase center

\( \alpha_{ij}, \beta_{ij}, \gamma_{ij} \) Direction cosines of the ray from each element to the illuminated area of the radome

\( B_i - B_n \) Least squares fit coefficients for radome contour

\( n_R \) Unit normal to radome surface (radome coordinates)

\( n_A \) Unit normal to radome surface (antenna coordinates)
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SECTION I
INTRODUCTION

1. GENERAL

This technical report describes a digital computer analysis program which will calculate the electrical transmission and reflection properties of a multiwall radome. The radome program may be used with a suitable antenna program to estimate the effects of the radome on the antenna pattern.

The analysis program is comprised of two programs, a radome-geometry program, RADOME, and a flat-panel analysis program, WAVES2. The radome-geometry program calculates the incidence angle for each ray (a ray represents the radiated RF power from each antenna element) at the radome wall. The output from the geometry program serves as an input to the flat-panel program. The flat-panel program, WAVES2, calculates the electrical transmission and reflection parameters of the radome for each ray, using the input from RADOME. These parameters may then be used with a suitable free-space antenna pattern simulation program, and the resultant antenna pattern in the presence of the radome can then be computed.

This technical report documents the radome-geometry program, RADOME, and the necessary modifications to the flat-panel program, WAVES2. A complete description of the flat-panel program may be found in AFAL-TR-67-191.
2. DEFINITION OF THE PROBLEM

The specific problem which generated the radome analysis program involved position fixing accuracy using an aircraft forward-looking multimode radar. For example, a position fix is to be made of a ground target at location "A" (Figure 1). The antenna electrical boresight is steered to the estimated azimuth, \( \theta_a \), and elevation, \( \theta_e \), of the target. Then by using the antenna's monopulse patterns, an accurate measurement of the target's location relative to the antenna electrical boresight may be determined. However, due to the distortion of the antenna's free-space pattern in the presence of the radome, an error exists in determining the azimuth and elevation location of the target relative to the steered direction of the antenna electrical boresight. Therefore, to minimize the measurement inaccuracies it is desirable to estimate the antenna pattern in the presence of the radome and use this information to correct the measurement of target location.

A table of correction terms may be generated by using the radome analysis program and a suitable antenna pattern simulation program. A set of azimuth and elevation scan angles can be used as inputs to the geometry program, RADOME, to generate the incidence angles for the ray from each element in the antenna array and the information stored on magnetic tape. The magnetic tape storage is required because of the large number of rays involved and the computation time required. The incidence angle information from RADOME on the magnetic tape is then input to the flat-panel program, WAVES2. In the WAVES2 program the transmission and reflection parameters are calculated for each element in the antenna array for given antenna electrical boresight azimuth and elevation angles. Transmission and reflection parameters calculated by
the WAVES2 program can then serve as inputs to a suitable antenna pattern simulation program, and a table of correction terms (i.e., boresight shift) can be generated and subsequently used to correct the measurement of the target's azimuth and elevation location.

3. REPORT ORGANIZATION

This technical report is divided into eight sections. Section two describes items included in the documentation, method of analysis, equations involved, geometry, input and output parameters. Section three gives the variables, common, labeled common, dimension, and data statements for the main program and all subroutines. Section four outlines the input deck structure, defines the required data, and establishes the format of the input data cards. Section five presents a sample problem with a typical set of data describing the radome, gives the user's output requirements, lists the printout, and describes the data stored on magnetic tape for later use. Flowcharts and program listings have been included. Section six describes the Flat-Panel Program and Section seven offers recommendations for best utilization of the routine.
SECTION II
DEVELOPMENT OF THE RADOME-GEOMETRY PROGRAM (RADOME)

1. METHOD

The RADOME program applies the techniques of ray tracing to an antenna array and a multiwall radome, and calculates the incidence angles of antenna radiation at the radome inner surface. The incidence angles are needed to compute reflection and transmission parameters which were accomplished by program WAVES2.

2. DERIVATION OF EQUATIONS

The rectangular coordinates of the point of interest (a point at which the antenna boresight is directed) are computed from the given scan angles of the antenna's electrical boresight. The antenna coordinate system is defined by a unit vector, $\mathbf{y}_a$, normal to the face of the antenna array, a unit vector $\mathbf{x}_a$, which is parallel to the face of the array and at a right angle to $\mathbf{y}_a$, and a unit vector $\mathbf{z}_a$, parallel to the array face and perpendicular to $\mathbf{x}_a$ and $\mathbf{y}_a$. The azimuth angle, $\theta_a$, is defined in the plane determined by $\mathbf{x}_a$ and $\mathbf{y}_a$. The elevation angle $\theta_e$ is defined in a plane perpendicular to the one formed by $\mathbf{x}_a$ and $\mathbf{y}_a$.

The location of the antenna array elements is computed in antenna coordinates, one quadrant of the array at a time. The central elements of the array are spaced one quarter of a wavelength from the phase center of the array. The antenna aperture is assumed to be circular, with the elements arranged in a rectangular grid out to the aperture's edge. The maximum number of rows and columns is specified as a user
input. The coordinates of those elements that are contained within a given aperture radius are stored for later use (Figure 3).

The antenna coordinate system is a rectangular coordinate system with its origin at the antenna phase center. In antenna coordinates the location of the $(i,j)$-element is denoted by $x_{ij}, y_{ij}, z_{ij}$.
The direction cosines of a ray from array element \((i,j)\) to the point of interest are determined as follows:

\[
\alpha_{ij} = \frac{(x_{at} - x_{ij})}{|R_{ij}|} \quad (4)
\]

\[
\beta_{ij} = \frac{(y_{at} - y_{ij})}{|R_{ij}|} \quad (5)
\]

\[
\gamma_{ij} = \frac{(z_{at} - z_{ij})}{|R_{ij}|} \quad (6)
\]
where

$$\left|R_{ij}\right| = \left( (x_{at} - x_{ij})^2 + (y_{at} - y_{ij})^2 + (z_{at} - z_{ij})^2 \right)^{1/2}$$

(7)

and 

- \(i\) = row number
- \(j\) = column number

The radome is a body of revolution over the complete window area. The radome contour is generated by rotating the curve (Figure 4), representing the outside mold line, about the YR axis. Coordinates of the radome contour \(y_i\) and \(z_i\) are given by the manufacturer in tabular form. Data cards containing the \(y_i\) and \(z_i\) coordinates of points on the radome contour are used as inputs to the computer program. Usually, points are spaced more closely together on the YR axis nearer the front of the radome. The radome axis, YR, and the antenna axis, \(y_a\), are assumed to be parallel. (Due to program storage limitations it is necessary to store only the coordinates of the radome surface that will encompass the projected surface area of the antenna aperture in the given scan direction.)

Figure 4. Radome Outside Mold Line Contour
The angle \( (\alpha') \) between a ray from the central area of the antenna aperture and the YR axis is used to determine the region where this ray passes through the radome's surface (Figure 5). The angle \( (\alpha') \) is determined from the following equations.

\[
x = x_{at} - x_{11} \quad (8)
\]
\[
y = y_{at} - y_{11} \quad (9)
\]
\[
z = z_{at} - z_{11} \quad (10)
\]
\[
| R | = \left[ x^2 + y^2 + z^2 \right]^{1/2} \quad (11)
\]
\[
\alpha' = \cos^{-1} \left[ \frac{y}{| R |} \right] \quad (12)
\]

The interval \( \Delta YR_i \) on the YR axis is obtained by subtracting the YR coordinate of the \( i \)th radome contour point from the antenna's phase center location.

\[
\Delta YR = Y_0 - y_1 \quad (13)
\]

Beginning with the first point of the radome contour near the tip, points are tried until the quantity \( Z = \Delta YR_i \tan(\alpha') \) is less than the \( Z \) coordinate of the \( i \)th radome contour point. Once this point is determined, i.e., \( (Z_i - Z) > 0 \), the sixty radome contour points that are symmetric about this central point are determined and used to encompass
the projected area of the antenna aperture. The value of sixty points was chosen from empirical results. If the points are too close to the tip of the radome, then we choose sixty points beginning with the point closest to the radome tip as we progress toward the rear of the radome. Similarly, if the points are too close to the rear, then sixty points are used beginning with the last point and working forward.

The surface region of the radome encompassing the projected area of the antenna aperture in a given scan direction is determined through the use of the following equations (Figure 6).

$$\theta = \theta_1 + \Delta \theta$$  \hspace{1cm} (14)

where $\theta_1$ is the initial rotation angle about the YR axis, and $\Delta \theta$ is the incremental change in the rotation angle.
The program allows ninety values of $\theta$. The incremental change ($\Delta \theta$) is a user-supplied input, and a suggested value based on empirical results is two degrees. The initial value of the rotation angle ($\theta_1$), also supplied by the user, is chosen on the basis of ($\Delta \theta$) and by program results so that the determined region of the radome encompasses the projected antenna aperture area.

Thus, provision is made for as many as sixty radome surface elements (radially) and by ninety surface elements (rotationally), or 5400 possible surface elements defining the projected aperture area of the antenna on the radome's surface. In general, the projected antenna aperture will occupy less than this number of radome surface elements.
The required surface region of the radome is determined by the following equations:

\[
X(\theta, j) = z_j \sin \theta \tag{15}
\]

\[
Y(\theta, j) = y_j \tag{16}
\]

\[
Z(\theta, j) = z_j \cos \theta \tag{17}
\]

where \(y_j, z_j\) are the coordinates of the \(j\)th point on the radome contour.

The antenna coordinates of the region of interest are determined as follows:

\[
X_\theta j = -(X(\theta, j) - x_0) \tag{18}
\]

\[
Y_\theta j = y_0 - Y(\theta, j) \tag{19}
\]

\[
Z_\theta j = Z(\theta, j) - z_0 \tag{20}
\]

where \(x_0, y_0, z_0\) are the radome coordinates of the antenna phase center.
The direction cosines of the illuminated area of the radome relative to the antenna phase center are:

\[ a_j = \frac{x_{\theta j}}{\text{TMA}G_{\theta j}} \]  
\[ \beta_j = \frac{y_{\theta j}}{\text{TMA}G_{\theta j}} \]  
\[ \gamma_j = \frac{z_{\theta j}}{\text{TMA}G_{\theta j}} \]

\[ \text{TMA}G_{\theta j} = \left[ x_{\theta j}^2 + y_{\theta j}^2 + z_{\theta j}^2 \right]^{1/2} \]

The antenna elements to the illuminated area direction-cosines are:

\[ \alpha_{m,n} = \frac{\Delta x_{m,n}}{|R_{m,n}|} \]  
\[ \beta_{m,n} = \frac{\Delta y_{m,n}}{|R_{m,n}|} \]  
\[ \gamma_{m,n} = \frac{\Delta z_{m,n}}{|R_{m,n}|} \]

where

\[ \Delta x_{m,n} = x_{\theta j} - x_{m,n} \]  
\[ \Delta y_{m,n} = y_{\theta j} - y_{m,n} \]
for which
\[ X_{\theta_j}, Y_{\theta_j}, Z_{\theta_j} \] are the antenna coordinates of a subelement of the illuminated area.

\[ X_{m,n}, Y_{m,n}, Z_{m,n} \] are the antenna coordinates of each element in the antenna array.

and
\[ m,n \] are the row and column number of the antenna elements.

The next step is to find the radome subelement intersected by a ray in the boresight direction from each antenna element. For each element in the antenna array, a search of the illuminated area of the radome surface is made, beginning with the first radome station. The direction cosines from the element to the radome surface are compared to those of the central ray. If the direction cosines are within a given tolerance, i.e., the two rays are pointing in approximately the same direction, then this point on the radome surface is used to indicate where the ray passes through the radome. The direction cosine for the angle between the ray from the element to the surface and the central ray is

\[ DC = a_{ij} + \beta_{ij} + \gamma_{ij} \]
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where \( \alpha, \beta, \gamma \) = direction cosines for the central ray, and
\( \alpha_{ij}, \beta_{ij}, \gamma_{ij} \) = direction cosines of the ray from the element to the window area.

The ray is parallel to the antenna electrical boresight when "DC" is equal to one. The tolerance is set to slightly less than one. And, the coordinate of the radome surface that is used is the point where "DC" is greater than the given tolerance.

Next, the normal to the surface of the illuminated area is determined for each coordinate where a ray intersects the radome surface. A least squares curve fitting routine (CURFIT) is used to fit the radome outside mold contour data to a sixth degree polynomial in radome coordinates (Figure 2). A transformation is then made to antenna coordinates, so that

\[
f(y) = B_n + B_1 y + B_2 y^2 + B_3 y^3 + B_4 y^4 + B_5 y^5 + B_6 y^6 \quad (33)
\]

An equation in \( x, y, z \) can be found for the surface of the illuminated area of the radome, when given that the radome is a body of revolution (Figure 7). Thus,

\[
R = f(y) \quad (34)
\]
\[
x^2 + z^2 = R^2 \quad (35)
\]
\[
x^2 + z^2 = f^2(y) \quad (36)
\]
\[
x^2 + z^2 - f^2(y) = 0 \quad (37)
\]
\[
F = x^2 + z^2 - f^2(y) \quad (38)
\]
Figure 7. Determination of Normal to Radome Surface

The normal to the surface is given by

\[ \mathbf{N} = \nabla F \]

\[ \mathbf{N} = 2 \mathbf{i} + 2z \mathbf{k} - 2y \frac{df(y)}{dy} \mathbf{j} \]  \hspace{1cm} (39)

where

\[ \frac{df(y)}{dy} = B_1 + 2B_2y + 3B_3y^2 + 4B_4y^3 + 5B_5y^4 + 6B_6y^5 \]  \hspace{1cm} (40)
To obtain the unit normal, first define

$$\mathbf{N}^* = \frac{1}{2} \mathbf{N} = x \mathbf{i} + z \mathbf{k} - f(y) \frac{df(y)}{dy} \mathbf{j}$$  \hspace{1cm} (41)$$

$$|N^*| = \left\{ x^2 + z^2 + \left[ f(y) \frac{df(y)}{dy} \right]^2 \right\}^{1/2}$$  \hspace{1cm} (42)$$

Then the unit normal, in radome coordinates, is stated by

$$\mathbf{n}_R = \frac{\mathbf{N}^*}{|N^*|} = \alpha_i R + \beta_j R + \gamma_k R$$  \hspace{1cm} (43)$$

In antenna coordinates, the unit normal is

$$\mathbf{n}_A = \alpha_i A - \beta_j A + \gamma_k A$$  \hspace{1cm} (44)$$

The incidence angle of the ray from each element to the radome surface is determined by taking the dot product of the unit vector from the array element to the surface, and the normal to the surface at the point of intersection. Thus,

$$x_{ij} = \mathbf{r}_{ij} \cdot \mathbf{n}_A$$  \hspace{1cm} (45)$$

$$\theta_{ij} = \cos^{-1}(x_{ij})$$  \hspace{1cm} (46)$$
where \( \vec{r}_{ij} \) is the unit vector of the ray from the \( i, j \) element to the intersection point on the surface

\[ n_a \] is the unit normal curve at the point of intersection

and \( \theta_{ij} \) is the incidence angle for the ray from an array element.

The sequence of events we have described in this section is programmed in RADOME. The end product is the incidence angle of each ray at the radome surface. This is used in program WAVES2 to calculate reflection and transmission properties of the radome for each ray.

3. INPUT

Program I/O (Input/Output) is described in Section III and examples are given in Section V. Briefly, the input consists of the following items:

a. Number of radome stations
b. Initial rotation angle, incremental angle, and total number of angles
c. Antenna elevation and azimuth scan angles
d. Antenna phase center location in radome coordinates
e. Number of computer runs to be made
f. Wavelength
g. Aperture radius
h. Maximum number of rows and columns in the antenna array
i. Radome outside mold station coordinates
4. OUTPUT

Program output is in the form of a tabular printout:

a. Row and column number for each array element whose ray passes through the radome wall
b. Incidence angle for each ray
c. Number of rays passing through the radome wall
d. Elevation and azimuth scan angles
e. Number of radome stations
f. Initial rotation angle, incremental angle, and number of angles
g. Antenna phase center location in radome coordinates
SECTION III
GENERAL ANALYSIS PROGRAM DESCRIPTION

1. THE MAIN PROGRAM

The analysis program is written in FORTRAN IV for a CDC 6600 CYBER 74, operating under SCOPE 3.4.1. The main program is primarily an executive routine which calls a series of subroutines. The subroutines are organized into the following functional groups:

1. Antenna element location, ARRAY
2. Element to point of interest direction cosines, DIRET
3. Window area surface coordinates, SFILE
4. Illuminated radome stations, START
5. Element to radome direction cosines, DIRER
6. Normal to window area, NORM
7. Incidence angles, INCID

The Main Program, PROGRAM RADOME (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE7), is a routine which reads the following input variables:

NSEC, number of radome stations
ANGI, initial rotation angle
ANGD, incremental rotation angle
NANG, number of angular positions
THEL, elevation scan angle
THAZ, azimuth scan angle
COMMON FILE (60,90,3), NSEC, ANGI, ANGD, NANG, AX, AY, AZ
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COMMON/BLK1/TGTX,TGTY,TGTZ
COMMON/BLK3/ABGET(45,45,3)
COMMON/BLK20/SW2

AX,AY,AZ antenna phase center location in radome coordinates

2. SUBROUTINES
a. ARRAY
   COMMON/BLK2/EFILE(45,45,3),NUMM,NUMN
   COMMON/BLK12/RMAX
   COMMON/BLK13/IMAX,JMAX
   COMMON/BLK20/SW2
   DATA XLAMDA/1.2/
   DATA RR/18.0/

   NUMM,NUMN - maximum allowable number of rows and columns in
   the antenna array
   RMAX - radius of antenna aperture
   IMAX,JMAX - actual number of rows and columns in the antenna
   array
   XLAMDA - wavelength (inches)
   RR - aperture radius (inches)
   EFILE - file of element locations

b. DIRET
   COMMON/BLK1/TGTX,TGTY,TGTZ
   COMMON/BLK2/EFILE(45,45,3),NUMM,NUMN
   COMMON/BLK3/ABGET(45,45,3)
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COMMON/BLK12/RMAX

COMMON/BLK13/IMAX,JMAX

TGSTX,TGY,TGZ - antenna coordinates of point of interest

NUMM,NUMN - maximum allowable number of rows and columns
            in the array

ABGET - file of array element to point of interest
direction cosines

RMAX - maximum radius of antenna aperture

IMAX,JMAX - maximum number of rows and columns in the
            array

c. SFILE

COMMON FILE (60,90,3),NSEC,ANGI,ANGD,NANG,AX,AY,AZ

COMMON/BLK4/XY(200),XZ(200)

COMMON/BLK5/NSTART,NFIN

COMMON/BLK20/SW2

DIMENSION FX(90),FY(90),FZ(90)

FILE - file of antenna coordinates of window area

NSEC - number of radome stations

ANGI - initial rotation angle

ANGD - rotation angle increment

NANG - number of incremental angles

AX,AY,AZ - radome coordinates of antenna phase center

XY,XZ - files of radome stations, Y and Z co-
          ordinates
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NSTART,NFIN - beginning and ending window area radome station numbers

SW2 - switch set false after first run

FX,FY,FZ - radome coordinates of window area

d. START

COMMON FILE (60,90,3), NSEC, ANGI, ANGD, NANG, AX, AY, AZ
COMMON/BLK2/EFILE(45,45,3), NUMM, NUMN
COMMON/BLK3/ABGET(45,45,3)
COMMON/BLK4/XY(200), XZ(200)
COMMON/BLK5/NSTART, NFIN

FILE - defined in SFILE

NSEC - 

ANGI - 

ANGD - 

NANG - 

AX, AY, AZ - 

XY, XZ - 

EFILE - defined in ARRAY

NUMM, NUMN - 

ABGET - defined in DIRET

NSTART, NFIN - defined in START

e. DIREK

COMMON FILE (60,90,3), NSEC, ANGI, ANGD, NANG, AX, AY, AZ
COMMON/BLK2/EFILE(45,45,3), NUMM, NUMN
AFAL-TR-75-183

COMMON/BLK3/ABGET(45,45,3)
COMMON/BLK5/NSTART,NFIN
COMMON/BLK6/IFILE(45,45),JFILE(45,45)
COMMON/BLK8/FILEE(45,45,3)
COMMON/BLK12/RMAX
COMMON/BLK13/IMAX,JMAX

DATA TOL/.99939/

FILE - defined in SFILE
EFILE - defined in ARRAY
NUMM,NUMN - defined in ARRAY
ABGET - defined in DIRET
NSTART - defined in START
NFIN - defined in START
IFILE - file of radome stations for ray intersections
JFILE - file of the number of angular increments for a given radome station ray intersection
FILEE - file of direction cosine, for each ray
RMAX - defined in ARPAY
IMAX - defined in ARRAY
JMAX - defined in ARRAY
TOL - if the direction cosine of the difference in the direction of the point of interest and a particular coordinate of the window area is greater than TOL then this coordinate is used to obtain the point where the ray passes through the radome surface
f. NORM

COMMON FILE (60,90,3), NSEC, ANGI, ANGD, NANG, AX, AY, AZ
COMMON/BLK2/FILE(45,45,3), NUMM, NUMN
COMMON/BLK5/NSTART, NFIN
COMMON/BLK6/FILE(45,45), JFILE(45,45)
COMMON/BLK13/IAX, IMAX
DIMENSION FILEN(45,45,3)
EQUIVALENCE (FILE, FILEN)
COMMON/BLK10/LT
DATA BN/ /
DATA BI/ /
.
.
.
DATA B6/ /

FILE - defined in SFILE
NSEC - "
ANGI - "
ANGD - "
NANG - "
AX - "
AY - "
AZ - "
NUMM - defined in ARRAY
NUMN - "
NSTART - defined in START
AFAL-TR-75-183

NFIN - defined in START
IFILE - defined in DIRER
JFILE - 

\[ g. \text{ INCID} \]

COMMON/BLK2/FILE(45,45,3),NUMM,NUMN
COMMON/BLK4/XY(200),XZ(200)
DIMENSION FILEN(45,45,3)
EQUIVALENCE(FILE,FILEN)
COMMON/BLK8/FILEE(45,45,3)
COMMON/BLK9/XINCID(45,45)
COMMON/BLK10/LT
COMMON/BLK13/IMAX,JMAX

FILE,NUMM,NUMN - defined in ARRAY
XY,XZ - defined in SFIL
IFILE,JFILE - defined in DIRER
FINEN - defined in NORM
FILE - defined in ARRAY
FILEE - defined in DIRER
XINCID - file of incidence angles for each ray passing through the radome wall
LT - defined in NORM
IMAX,JMAX - defined in ARRAY
IMAX - defined in ARRAY
JMAX - defined in ARRAY
FILEN - file of normals for ray/radome intersection, for those rays passing through the radome wall (in antenna coordinates)

LT - used to test the value of IFILE in DIRER

EFILE - defined in ARRAY

B1
B2
B3 } coefficients of six-degree polynomial fit of
B4 } radome's outside mold line contour
B5
B6
SECTION IV
MAIN PROGRAM INPUT

The input deck structure is shown in Figure 8.

![Diagram of Input Deck Structure]

Figure 8. Input Deck Structure

Data Definitions are as follows:

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>DESCRIPTION</th>
<th>FORMAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSEC</td>
<td>number of radome stations</td>
<td>2I5</td>
</tr>
<tr>
<td>NANG</td>
<td>number of circumferential radome divisions</td>
<td>2I5</td>
</tr>
<tr>
<td>ANGI</td>
<td>initial rotation angle in degrees</td>
<td>2F10.5</td>
</tr>
<tr>
<td>ANGD</td>
<td>angular increment</td>
<td></td>
</tr>
<tr>
<td>THEL</td>
<td>antenna elevation scan angle in degrees</td>
<td>2F10.4</td>
</tr>
<tr>
<td>THAZ</td>
<td>antenna azimuth scan angle in degrees</td>
<td></td>
</tr>
<tr>
<td>AX,AY,AZ</td>
<td>radome coordinates of antenna phase center</td>
<td>3F10.4</td>
</tr>
</tbody>
</table>
NUMM - maximum allowable antenna row number 2I2
NUMN - maximum allowable antenna column number
XY, XZ - radome contour coordinates in radome coordinates 2F10.4
SECTION V
USER'S GUIDE

1. PROGRAM CONTROL

To use the radome analysis program for a given problem, the user must set up the input deck and control cards.

A sample problem is presented in this section. Also shown is how specific sections of that problem are related to the sample input. The printed output of the sample program is included.

The following control card deck structure is presented as a guide to the user. The control card structure is applicable to CDC 6600 CYBER 74 SCOPE 3.4.1.

The radome program has been previously stored on a permanent file. The ATTACH card requests the program. A LABEL card is used to make available a magnetic tape for data storage. The data is first written onto a permanent file that has been requested by a REQUEST card. The source decks are transferred to a program library by the UPDATE card. The program is then compiled (FTN), loaded (LGO), and finally cataloged. The cataloged file is rewound and then copied to magnetic tape (Figure 9a).

On subsequent runs there is a difference in the control cards to allow extending the data on the magnetic tape. The radome program is attached along with the permanent file containing the old data. The
tape label is read and the program transferred to the library file by the UPDATE card. The first set of information on the permanent file is skipped, the program compiled, loaded, and executed. The data on the permanent file is extended, the file rewound, and then the entire file copied onto magnetic tape (Figure 9b).
2. SAMPLE PROBLEM

A cut is to be made in the azimuth plane. The first step consists of using the Main Program routine, in which the following variable values are used:

1. Number of radome stations equals 117 (NSEC=117)
2. Initial rotation angle equals 0.0 (ANGI=0.0)
3. Number of angular intervals about radome equals 90 (NANG=90)
4. Angular interval equals -4.0 degrees (ANGD=-4.0)

The number of computer runs, i.e., sets of azimuth and elevation scan angles has been set at 3 (NRUN=3). Elevation, and azimuth-scan angles (THEL,THAZ) are inputs, one set per card, three cards per run.

3. SAMPLE INPUT

Proceeding to the subroutines, we will have inputs as outlined in the following.

a. ARRAY

Wavelength of interest in inches, XLAMDA
DATA XLAMDA/1.2/

Maximum aperture radius in inches, RR
DATA RR/18.0/
Maximum allowable number of rows and columns in the array, respectively (45,45)

NUMM = 45
NUMN = 45

b. SFILE

Coordinates of the radome contour for radome station I=1, 117

\[ \text{XY}(1) = Y_1 \]
\[ \text{XZ}(1) = Z_1 \]
\[ \text{XY}(117) = Y_{117} \]
\[ \text{XZ}(117) = Z_{117} \]

c. Data Input Format

<table>
<thead>
<tr>
<th>Card No.</th>
<th>Variable(s)</th>
<th>Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>NSEC, NANG</td>
<td>2I5</td>
</tr>
<tr>
<td>2</td>
<td>ANGI, ANGD</td>
<td>2F10.5</td>
</tr>
<tr>
<td>3</td>
<td>THEL, THAZ</td>
<td>2F10.5</td>
</tr>
<tr>
<td>4</td>
<td>AX, AY, AZ</td>
<td>3F10.4</td>
</tr>
</tbody>
</table>
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5  NUMM, NUMN  2I2
6-122  XY(I), XZ(I)  2F10.4
123  THEL, THAZ  2F10.5
124  THEL, THAZ  2F10.5

d. The steps given in Section V are shown as flowcharts in Figures 10, 11, and 12. Final printout from our example problem follow the flowcharts.
Figure 10. System Flow Chart.
Call Subroutines

Number of rows and columns in array

Direction cosines to point of interest

Determine where ray passes through radome surface

Normal to radome surface

Incidence angle calculation

Incidence angles for each ray

Figure 11. Radome-Geometry Program Flow Chart
Figure 12. WAVES2 Program Flow Chart
4. SAMPLE OUTPUT

```
LOGICAL SN2

NUM=0
SM2=TUE.
READ (5,100)NSEC,MANG
100 FORMAT (2I5)
CONTINUE
NUN=NUN+1
READ(5,210)THEL,THAZ
210 FORMAT (F10.4)
RE=1.406
WRITE (*4,THEL,THAZ
PPINT(15,NSEC,MANG,ANGL,ANGD,R,THEL,THAZ
C FORMAT(15,NSEC,MANG,ANGL,ANGD,R)
130 FORMAT (15,NSEC,MANG,ANGL,ANGD,R
IF(3.0+ANGD,15.0,0.0)*)E0.2,2*ANGD,F15.2,2*THEL,F15.2,2*THAZ
33 IF(3.0+ANGD,15.0,0.0)*)E0.2,2*ANGD,F15.2,2*THEL,F15.2,2*THAZ
PPINT(15,NSEC,MANG,ANGL,ANGD,R
140 FORMAT (15,NSEC,MANG,ANGL,ANGD,R
CONTINUE
PPINT(15,NSEC,MANG,ANGL,ANGD,R
C PRINT=140
C PRINT=150
C COMPUTE ECT LOCATION IN ANTENNA COORDINATES
THET=THEL+(THEL-THAZ)*SIN(THAZ)
45 GYR=THET*cos(THET)*GTY
tx=TX+GYR
ty=GTY
```

SUBROUTINE TRAY

COMPOUND K2/FILH.(65,45.71.,NUMM,NUMN
CM1BN=0<12=VMAX
COMPOUND=0<11=MAX
COMPOUND=1:0<7=MAX
LOGICAL SWZ
DATA X,SLAND/4.28/
DATA 99/1.0/
DATA RMAX=R

10
IF (.NOT.SWZ) GO TO 101
READ (6,100) NUMM,NUMN

100 FORMAT (F12)
101 CONTINUE
PRINT (5,110) NUMM,NUMN

110 FORMAT (5,110) NUMM,NUMN
PRINT (6,100) RMAX,X,SLAND
800 FORMAT (10,HNUMM*,F11.3,*,X,SLAND=,*,F11.5)

xx=SLAND/4.
DO 120 IT=2,NUMM,2
IF (XX.GT.RMAX) GO TO 130
XX=XX.X,SLAND/4.

120 CONTINUE
130 IMAX=IT-2
JMAX=IT-2

600 FORMAT (6,H5) RMAX,JMAX
DO 100 IT=1,IMAX
DO 100 J=1,JMAX
EFILE(I,J,1)=0.0005
EFILE(I,J,2)=0.0005
EFILE(I,J,3)=XX
X=EFILE(I,J,1)
Y=EFILE(I,J,2)
Z=EFILE(I,J,3)
IF (XI.GT.RMAX) GO TO 170
XX=XX.X,SLAND/4.

100 CONTINUE

180 CONTINUE
XX=SLAND/4.
XX=SLAND/4.
L=0
DO 140 I=7,IMAX+2
DO 150 J=2,JMAX+2
EFILE(I,J,1)=XX
EFILE(I,J,2)=0.0
EFILE(I,J,3)=XX
X=EFILE(I,J,1)
Y=EFILE(I,J,2)
Z=EFILE(I,J,3)
RSQR(V(X**2+Z**2))
APAY=APAY+47
XX=XX.X,SLAND/2.

150 CONTINUE
170 XX=XX.X,SLAND/2.
XX=SLAND/4.
140 CONTINUE
LI=LI+1
130 CONTINUE
LI=LI+1
130 CONTINUE
55 FORMAT (15,*,TOTAL NUMBER OF FUNCTION CALLS =,14)
GO TO 150
JMAX=JMAX+1
SUBROUTINE DIRET 74/74 OPT=2          FTH 4.2*P300  03/27/77  11:06:15  PAGE

DIRET  7
DIRET  4
DIRET  5
DIRET  6
DIRET  7
DIRET  8
DIRET  9
DIRET 10
DIRET 12
DIRET 13
DIRET 14
DIRET 15
DIRET 16
DIRET 17
DIRET 18
DIRET 19
DIRET 20
DIRET 21
DIRET 22
DIRET 23
DIRET 24
DIRET 25
DIRET 26
DIRET 27
DIRET 28
DIRET 29
DIRET 30
DIRET 31
DIRET 32
DIRET 33
DIRET 34
DIRET 35
DIRET 36
DIRET 37
DIRET 41
DIRET 42

C     THIS SUBROUTINE CALCULATES THE DIRECTION COSINES FROM EACH
C     ELEMENT TO THE TARGET

C     FORMAT(1X,/1X,* DIRECTION COSINES FROM I,J ELEMENT TO TGT */)
C     DO 110 J=1,NMAX
C     X=FILE(I,J,1)
C     Z=FILE(I,J,3)
C     IF(I.GT.NMAX) GO TO 100
C     IF(J.GT.NMAX) GO TO 100
C     X=FILE(I,J,2)
C     XT2=FILE(I,J,3)
C     XMAG=SQRT(X**2+Y**2*Z**2)
C     XAGET(I,J,1) =X/XMAG
C     YAGET(I,J,2) =Y/XMAG
C     ZAGET(I,J,3) =Z/XMAG
C     CONTINUE
C     END

DIRET 110
DIRET 120
DIRET 130
DIRET 140
DIRET 150
DIRET 160
DIRET 170
DIRET 180
DIRET 190
DIRET 200
DIRET 210
DIRET 220
DIRET 230
DIRET 240
DIRET 250
DIRET 260
DIRET 270
DIRET 280
DIRET 290
DIRET 300
DIRET 310
DIRET 320
DIRET 330
DIRET 340
DIRET 350
DIRET 360
DIRET 370
ORG DATA L=1
DO 10 I=1,NSEC
CONV() FILL(0,0,90.1),NSEC,I,ANG1,ANG2,NANG,AX,AY,AZ
CONV2() FILL(0,90,0),NSEC,I,ANG1,ANG2,NANG,AX,AY,AZ
10 CONTINUE
C READ CONTUR LINE X Y Z
LOGICAL SWZ
IF(NOT.SWZ) GO TO 101
DO 100 I=1,NSEC
READ(110)X(I),Z(I)
100 CONTINUE
101 CONTINUE
C CALL START
CALL START
15 CONTINUE
C GENERATE RANDOM COORDINATES SURFACE X Y Z
ANGII=ANG1
L=1
DO 20 I=START,NFIN
DO 120 J=1,NANG
ANGII=ANGII+1
F2(I)=X(I)*COS(ANGII)
F3(I)=X(I)*SIN(ANGII)
FILE(J,1)=F2(I)
FILE(J,2)=F3(I)
ANGII=ANGII+1
20 CONTINUE
25 CONTINUE
ANGII=ANG1
L=L+1
DO 128 I=1,60,10
DO 120 J=1,90,10
PRINT (6,300) FILE(I,J,1),FILE(I,J,2),FILE(I,J,3)
120 CONTINUE
128 CONTINUE
30 CONTINUE
C TRANSFORM THE DATA TO ANTENNA COORDINATES
DO 150 I=1,60
DO 160 J=1,NANG
FILE(I,J,1)=-FILE(I,J,1)*AZ
FILE(I,J,2)=AY*FILE(I,J,2)
FILE(I,J,3)=AZ*FILE(I,J,3)
160 CONTINUE
140 CONTINUE
40 CONTINUE
C PRINT 450
PRINT (450)* XYZ OF SURFACE IN ANTENNA COORDINATES
450 CONTINUE
50 PRINT(6,450) FILE(I,J,1),FILE(I,J,2),FILE(I,J,3),A*B+C
SUBROUTINE START 1/27/75 OPT=2

COMMON FILE(50,90,3), ESEC, ANGE, ANGA, NANG, AX, AY, AZ
COMMON/BLK1/FILE(45,45,31), HUNM, HUNN
COMMON/BLK2/ANGET(45,45,3)
COMMON/BLK4/XY(Z400, Z2(200))
COMMON/BLK5/NSTART,NFIN
A=ACOS(ANGET(2,2,2))
PRINT(6,200)ANGET(2,2,2)

200 FORMAT(180, "ANGET(*,F11.5)")
DO 100 T=1,NSEC
X=AX+AY*XY(I)
Z=XY*XY*XY(I)
IF(Z. LT.,XZ(I)) GO TO 110
100 CONTINUE
110 NSTART=I
PRINT(6,210)
210 FORMAT(180, "*", "A")
DO 130 J=1,30
NSTART=NSTART+1
IF(NSTART.LT.1) GO TO 110
130 CONTINUE
NFIN=NSTART+59
IF(NFIN.LT.NSEC) GO TO 150
NFIN=NSEC
NSTART=NSTART+59
GO TO 150
140 NSTART=NSTART+1
NFIN=NSTART+59
150 CONTINUE
PRINT(6,120)
PRINT(6,120)
120 FORMAT(1X,1X, NSTART=*, I3, NFIN=*, I3)
RETURN
END
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SUBROUTINE NORM

110 CONTINUE
120 CONTINUE

60 PRINT 140

140 FORMAT(1499,FILE OF DIRECTION COSINES FOR NORMAL OF EL.*H,N*)
   K1=1
   DO 150 P=1,IMAX
   DO 160 N=1,JMAX
   IF(ISIFLM(N,M,GT,LT)) GO TO 160
   K1=K1+1
   K2=MOD(K1,10)
   IF(K2.GT.9) GO TO 160
   WRITE(6,170)M,N,FILEM(N,M,1),FILEM(N,M,2),FILEM(N,M,3)

170 FORMAT(1X,PELEMENT(*,I2,*+,*+I2,*+3E11.5))

160 CONTINUE
150 CONTINUE
RETURN
END
SUBROUTINE INCIDENT  7F77 0*1=2  FNM 4,2+P3B0  03/27/75 11.07.30.  PAGE

SUBROUTINE INCIDENT
COMMON/RLK2/FILE(45,45,11),SUMM,NUMM
COMMON/BLK4/XY(200),XI(200)
COMMON/BLK6/FILE(45,45,45)
COMMON/XCY(45,45,45)
COMMON/FILE(45,45,45)
COMMON/BLK6/FILE(45,45,45)
COMMON/BLK6/INCID(45,45)
COMMON/BLK18/HT
COMMON/BLK13/INMAX,JMAX
C FILE CONTAINS THE DIR COSINES FOR THE NORMAL OF EA. EL.
C FILE CONTAINS THE DIR COSINES FOR THE EL TO RADOME VECTOR
PRINT 360
360 FORMAT (1HE*, INCID ANGLE DIRECTION COSINE AND ANGLE (DEG)*)
      INCID  17
15     KJ=0
      J=1
      DO 110 H=1,JMAX
      IF (FILEH,H,GT,LIT) INCIDH=1000...
      IF (FILEH,H,LT,LIT) GO TO 280
      XINCIDH=FILEJ+FILEH,H,1+FILEH,H,2+FILEH,H,3
      XDEG=ACOS(XINCIDH,H)
      XDEG=XDEG*180./3.14159)
      INCID  25
      K3=K3+1
      IF (L1,GT,1) GO TO 280
      PRINT(5,128)H,N,XINCIDH,N,XDEG
      120 FORMAT (1HE*, INCID*+I2,-*,I2,-*,F11.5,1X,E11.5)
      INCID  35
      CONTINUE
      39     CONTINUE
      100     CONTINUE
      PRINT(6,180)K3
      400 FORMAT (1HE*, NUMBER OF HISTATIC ANGLES =*,I4)
      WRITE(7)INMAX,JMAX,K3,XINCID,FILE,XY
      CONTINUE
      35     RETURN
      FND
SECTION VI
FLAT-PANEL ANALYSIS PROGRAM (WAVES2)

1. ADAPTING THE RADOME PROGRAM

Thus far, the radome analysis program has been one of geometry, i.e., determining the incidence angles for rays passing through the radome wall; there remains the task of determining how the radome wall modifies the electrical parameters of each ray. To accomplish this, first, a flat-panel analysis program (Krueger, AFAL-TR-67-191, Sep 67) is used to calculate the following:

- Power reflection coefficient
- Electrical angle after reflection
- Insertion loss
- Insertion phase delay

Our original flat-panel program required input via data cards containing incidence angles and material thickness. But, due to the increasing number of rays considered, input via data cards became prohibitive, and modification of the flat-panel program was required. The program was modified to read the required input data from magnetic tape. Such inputs consisted of the following:

- Coefficients of the six-degree polynomial fit of the radome
- The radome’s outside mold line contour
- Maximum number of row and column elements in the array
- Incidence angles and their total number
- Radome station number where each ray passes through
- Coordinate of radome surface where each ray passes through the surface

A printout of these inputs follows.
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115 2NJ=K-1.0(1)
     KAN(1)=KE1
     KU(1)=K11
     CONTINUE
     FJJ=F1

29 128 F1=FJ+1.0
     IF(F1.GT.FMIN)CAEXIT=CAEXIT+1
     O2M=29.9776/FJJ
     TEZ=K(N)+1.0
     TNZ=NL+1.0
     TNSG(NL+1.0)=0
     PH(NL+1.0)=0
     DO 1 L=1,NB
     THEA(L)=PI*BIETA(L)/180.
     IF(ER.EQ.0) CALL RLCKA(K(J),KU(J),DIJ+OLAM)
     IF(ER.EQ.0) CALL RLCKA(K(J),KU(J),DIJ+OLAM)

130 139 K(J)=K(J)+1.0
     THZ(J)=CSQRT(K(J)-SIN(TETAZ(J))*SIN(TETA1(J))/KA(J)*COS(TETHA(J))
     TEZ(J)=K(J)*COS(TETHA(J))/CSQRT(K(J)-SIN(TETHA(J))/OLAM
     TNSG(J)=TK(J)
     TNSG(J)=TK(J)
     PH(J)=2.0*PI*(DIJ*CSQRT(K(J)-SIN(TETHA(J))/SIN(TETHA(J)))/OLAM
     IF(DJ,NE.1) GOTO3
     IF(DJ,NE.1) GOTO3
     TE(J)=TE(J)-1.0/TE(J)+1.0
     REM=(TNZ(J)-1.0)/TNSG(J)
     GOTO2

140 144 TNSG(J)=TNSG(J)
     TNSG(J)=TNSG(J)
     GOTO2

150 146 TNSG(J)=TNSG(J)
     TNSG(J)=TNSG(J)
     GOTO2

155 148 TNSG(J)=TNSG(J)

165 150 TNSG(J)=TNSG(J)

170 155 TNSG(J)=TNSG(J)

160 165 TNSG(J)=TNSG(J)

170 170 TNSG(J)=TNSG(J)
SUBROUTINE STRIPS

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GO TO 101
102 ZOSC = CPLX((0.6 - 1.8E-3/FPI2*F*GSC*GPHI))
103 ZL = ZL*ZOSC/(ZL+ZOSC)
104 RFLEC = -(ZL-ZOC)/(ZL+ZOC)
105 STRIPS 173
106 CONTINUE
107 FKLF(L2F) = REAL(REFLC)*SCR
108 NLF(L2F) = IMAG(REFLC)*SCR
109 NL = 1.3/2L
110 YL = NL/1.5
111 STRIPS 174
112 NLF+ = NLF+1
113 F = F+DEL
114 IF(F.LE.FMAX) GO TO 41
115 STRIPS 175
116 CONTINUE
117 RETURN
118 END
119 STRIPS 176
120 STRIPS 177
121 STRIPS 178
122 STRIPS 179
123 STRIPS 180
124 STRIPS 181
125 STRIPS 182
126 STRIPS 183
127 STRIPS 184
128 STRIPS 185
129 STRIPS 186
130 STRIPS 187
131 STRIPS 188
132 STRIPS 189
133 STRIPS 190
134 STRIPS 191
135 STRIPS 192
136 STRIPS 193
137 STRIPS 194
138 STRIPS 195
139 STRIPS 196
140 STRIPS 197
141 STRIPS 198
142 STRIPS 199
3. THE LISTING PROGRAM

The "listing" program will read the magnetic tape containing the flat-panel program outputs, and print out the electrical parameters required for each array element. The program list consists of the following for a given antenna array row or column:

- (I,J) - array row and column numbers, respectively
- - incidence angle in degrees
- RTE - reflection loss in dB for vertical polarization (power)
- ANGLE - electrical angle after reflection
- TTT - transmission loss for vertical polarization in dB (power)
- Angle - insertion phase delay (Deg)
- RTM - reflection loss for horizontal polarization dB (power)
- ANGLE - phase angle in electrical degrees after reflection
- TTM - insertion loss for horizontal polarization in dB (power)
- ANGLE - insertion phase delay in electrical degrees for horizontal polarization

a. WAVES2 INPUTS

The required data cards are:

1. Input magnetic tape from flat-panel program
2. One data card, on which will be entered:
   - In column 5: 1 = row output
   - 2 = column output
   - and in columns 9 and 10: array row or column desired

Final printout of the array element modification parameters follows.
b. WAVES2 OUTPUT

```
PROGRAM MAIN  INPUT, OUTPUT, TAPE5=INPUT, TAPE6=OUTPUT, TAPE7
DIMENSION XINCID(45,45)
C 1,2 IN COL 5 = ROW, COL AND 7 AND 8 ARE ROW OR COL NUM.
READ(15,503) NOT NUM
PRINT(6,510)
-- 90 PEK11(3) IHEL, THA1
    IF (EOF(1)) NE 0) CALL EXIT
    PRINT(6,289) IHEL, THA1
    READ(1) IMAX, JMAX, K1, XINCID
    PRINT(4,578) IMAX, JMAX, K1
    PRINT(4,540)
    PRINT(15,941)
    DO 220 I = 1, IMAX
        DO 220 J = 1, JMAX
            IF (XINCID(I, J) .GT. 900) GO TO 210
            READ(1) FJJ, DUMMY, RE*PHIET, TE*PHIE, RH, PHINT, TH, PHIM
            IF (400 .GT. 10) GO TO 310
            IF (LNE. NUMHIGO TO 300
                GO TO 320
        318 IF (LNE. NUMHIGO TO 300
                CONTINUE
        320 CONTINUE
        PRINT(6, 401) I, J, FJJ, DUMMY, RE*PHIET, TE*PHIE, RH, PHINT, TH, PHIM
        CONTINUE
        30 CONTINUE
        220 CONTINUE
        220 CONTINUE
        220 CONTINUE
        GO TO 90
        400 FORMAT(1X, I2, *, I2, 2X, F7.2, 4X, F8.3, 5X, 8(F7.2, 2X))
        500 FORMAT(3I5)
        510 FORMAT(14I)
        520 FORMAT(18M, *NUM OF ROWS=*, I2, 3X, *NUM OF COLS=*, I2, 3X)
        530 FORMAT(15M, *NUM OF VISIBLE =AYS=*, I6/)
        END
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**AFAL-TR-75-183**

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SECTION VII
RECOMMENDATIONS FOR FURTHER REFINING THE PROGRAM

The following are suggested as subsequent tasks:

1. Verify the radome analysis program by using detailed design and measured data on an existing radome.

2. Obtain a suitable antenna simulation program and interface it with the radome program. Use the radome and antenna simulation programs to estimate the distortion of the antenna pattern due to the radome interference.

3. Verify the results from (2) above using measured data.

4. Perfect the radome simulation program with regard to core storage requirements and central processor time.

5. Document the radome/antenna simulation program as obtained using the foregoing steps.