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A COMPUTER PROGRAM FOR BACKSCATTER BY TARGETS COMPOSED OF CONES, CYLINDERS, AND DISKS - 2430-5

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FOREWORD

This report, OSURF report number 2430-5, was prepared by The Ohio State University ElectroScience Laboratory, Department of Electrical Engineering, 1320 Kinnear Road, Columbus, Ohio. Research was conducted under Contract F 19628-67-C-0308. Lt. Nyman was the Electronic Systems Division Program Monitor for this research.

This technical report has been reviewed and is approved.

BERNARD J. FILLIATREAULT
Contracting Officer
Space Defense & Command Systems Program Office

ABSTRACT

This report describes a computer program for determining the backscattered fields of a conducting body of revolution composed of sections of cones and cylinders. The target may be closed at one or both ends with circular disks. The target may have as many as 20 sections, and the program can readily be modified to handle a larger number. The backscattered field for E_θ or E_ϕ polarization is computed using wedge diffraction theory and geometrical optics. The computed results are in good agreement with experimental measurements for cones, cylinders, double cones, and conically capped cylinders.

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A COMPUTER PROGRAM FOR BACKSCATTER BY TARGETS COMPOSED OF CONES, CYLINDERS, AND DISKS

INTRODUCTION

A computer program, which computes the backscattered field of a body of revolution composed of cones, frustums, cylinders, and disks is given in Appendix I. This program is coded in Fortran IV and the cards are numbered consecutively in columns 76-80. This program has been tested for cones, cylinders, frustums, conically capped cylinders, and double cones, for E_θ polarization of the incident and scattered fields. The results of these tests are presented in Reference 1. The theoretical basis for this program is described in References 1 and 2.

The function of this program is to compute the backscattered field as a function of aspect angle and/or frequency for a given target. This is accomplished by reading and storing the target description, identifying the regions of aspect angle corresponding to axial and specular directions, and applying the appropriate geometrical theory of diffraction solutions to calculate the scattered fields.[1, 2] In the form presented here the angular pattern for a given target and frequency is computed. Modification of the program to compute a frequency curve for a given target and aspect angle is straightforward.

TARGET DESCRIPTION

The target shape is described in cylindrical coordinates by the second degree equation

$$(1) \qquad F(\rho, z) = A_1\rho^2 + A_2z^2 + A_3\rho z + A_4z + A_5\rho + A_6 = 0 \quad .$$

As this program is written to handle only targets composed of cones, frustums, cylinders and disks, the description of the profile of the target is that of a straight line segment, and may be expressed as

$$(2) \qquad F(\rho, z) = A_4z + A_5\rho + A_6 = 0$$

where $A_1 = A_2 = A_3 = 0$. In addition to Eq. (2) the boundaries of each section of the target must be specified. That is, within each section of the target the profile is specified by a set of constants A_4, A_5, A_6. The next section is described by a new set of constants and so forth. As an example consider the target shown in Fig. 2. This target is composed of a cone, a cylinder, and a disk, and is a three section target. Thus a set of constants must be specified for each section and the angular boundaries of the sections specified. Figure 1 gives the relations by which the constants may be determined for each surface. The computer format for this input data will be discussed below.

If Eq. (1) is used to describe the target, i.e., any of the constants A_1, A_2 A_3 non-zero, this program will compute the scattered field due to the wedge type discontinuities on the target but will not calculate the correct total scattered field. This is because there is no provision in this program to calculate the geometrical optics field of a doubly curved surface. A calculation of this geometrical optics field is included in the creeping wave computer program.[3]

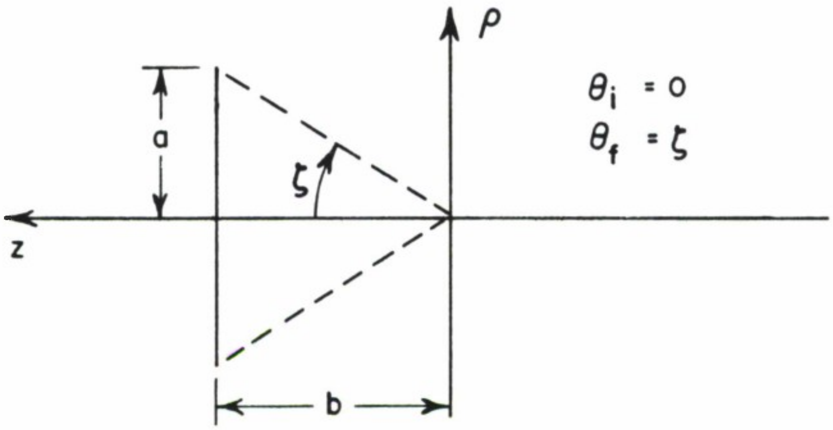
WEDGE DIFFRACTION COMPUTER PROGRAM

Referring to the computer program listing shown in Appendix I, the function of the significant sections of the program will be discussed. The card numbers associated with each section will be specified. This discussion, together with the comment cards included in the program listing, is intended to give sufficient information about the program to enable a qualified programmer to both use and modify the program. Statements which are in common use in Fortran IV such as DIMENSION, COMPLEX, and FORMAT statements will not be discussed as it is assumed that the reader has a knowledge of Fortran IV.

The COMMON declaration (0006) is used to store the constants required in Eq. (2) in the common block labelled /DATA/. This common block is used in conjunction with the unlabelled common block to transfer a particular set of constants A1(I) to A6(I) into the unlabelled common regions shared by the subroutines. This provision reduces the number of calling variables required by each subroutine.

The READ (0030-0040) statements in this block of statements read the required data and provision is also made to write out this data for the purpose of identification.

The statements 0041-0045 initialize constants which are required in the calculations.

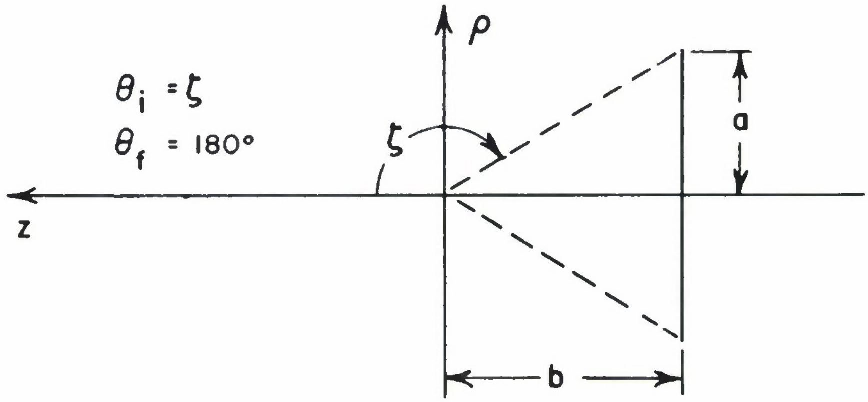


$$\zeta = \mathrm{TAN}^{-1}\left(\frac{a}{b}\right)$$

$$A_4 = 1$$

$$A_5 = 0$$

$$A_6 = -b$$



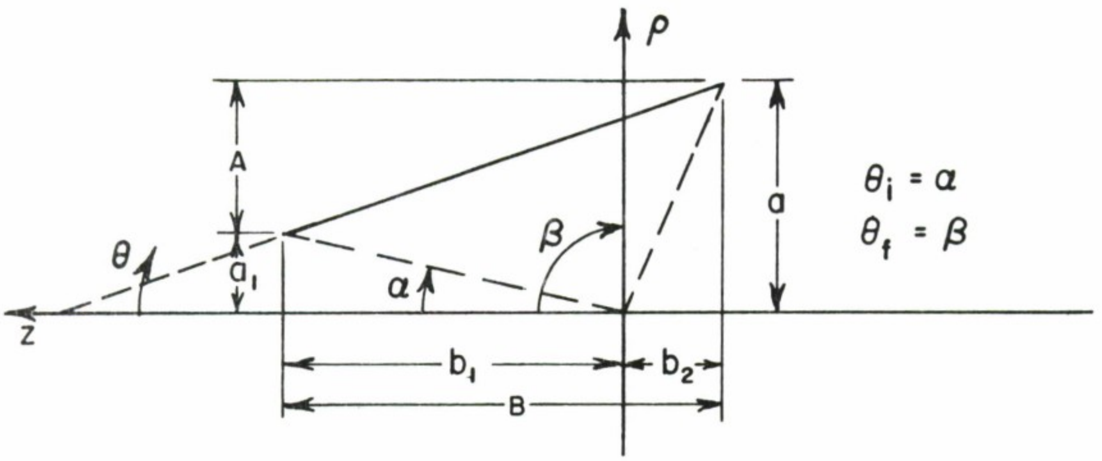
$$\zeta = 180° - \mathrm{TAN}^{-1}\left(\frac{a}{b}\right)$$

$$A_4 = -1$$

$$A_5 = 0$$

$$A_6 = -b$$

Fig. 1(a). Straight line segments and their corresponding analytic description.

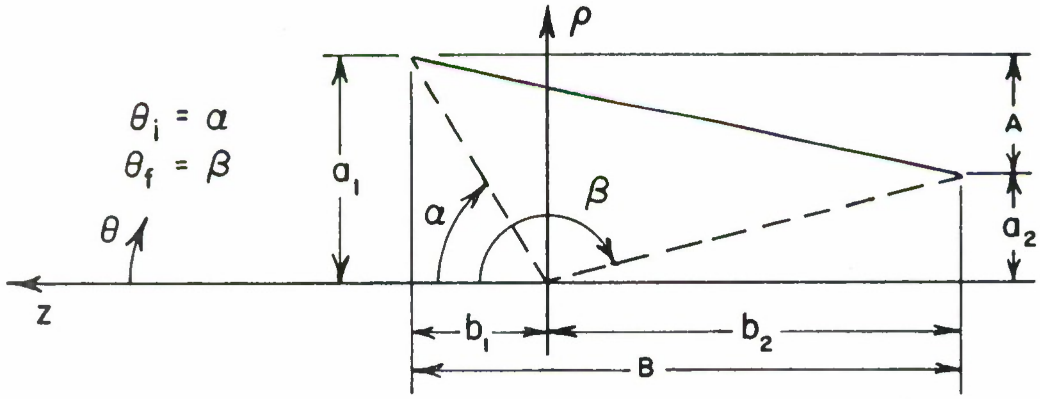


$$\alpha = \mathrm{TAN}^{-1}\left(\frac{a_1}{b_1}\right) \qquad \beta = 180° - \mathrm{TAN}^{-1}\left(\frac{a_2}{b_2}\right)$$

$$A_4 = \frac{A}{B}$$

$$A_5 = 1$$

$$A_6 = -\left[b\left(\frac{A}{B}\right) + a_1\right]$$



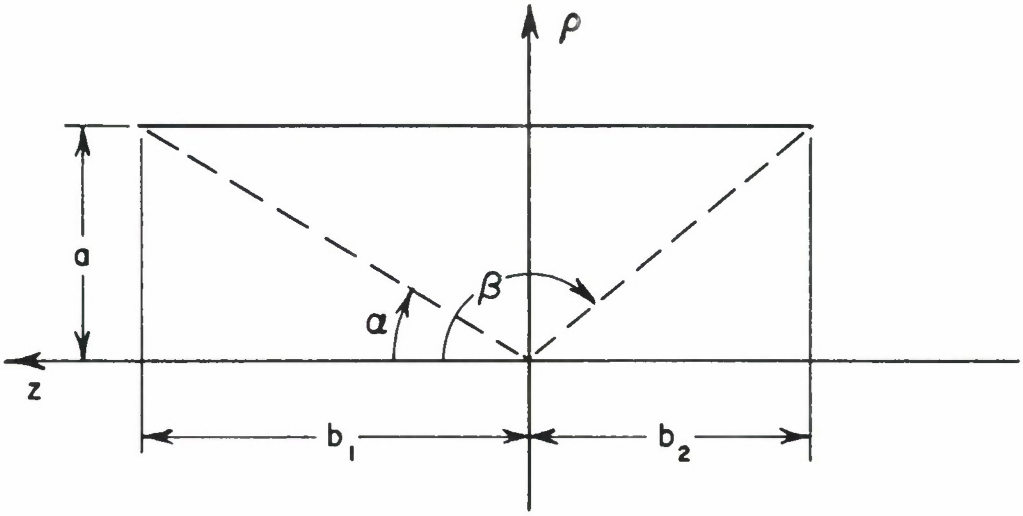
$$\alpha = \mathrm{TAN}^{-1}\left(\frac{a_1}{b_1}\right) \qquad \beta = 180° - \mathrm{TAN}^{-1}\left(\frac{a_2}{b_2}\right)$$

$$A_4 = -\frac{A}{B}$$

$$A_5 = 1$$

$$A_6 = -\left[b_2\left(\frac{A}{B}\right) + a_2\right]$$

Fig. 1(b). Straight line segments and their corresponding analytic description.



$$\theta_i = \alpha \qquad \theta_f = \beta$$

$$\alpha = \mathrm{TAN}^{-1}\left(\frac{a}{b_1}\right) \qquad \beta = 180° - \mathrm{TAN}^{-1}\left(\frac{a}{b_2}\right)$$

$$A_4 = 0$$

$$A_5 = 1$$

$$A_6 = -a$$

Fig. 1(c). Straight line segments and their corresponding analytic description.

The next block of statements (0046 - 0108) identifies the geometrical properties of the target. The function of this section may be described by consideration of a particular target. Figure 2 shows a particular target composed of a cone-cylinder-disk. The geometrical properties of interest are the locations of the wedges, the wedge angles WA(IW), the specular directions THSX(IW), and the length of the specular line FLSX(IW). This task is accomplished by examining the normal vectors (VNX, VNY, VNZ) of the adjoining surfaces at the junction between two sections. The wedge angle is then obtained from the scalar product of the normal vectors, the specular direction is determined by checking for parallel normals at the ends of each section, and the length of the specular line is obtained using the law of cosines.

The next block of statements (0109 - 0110) remove the redundancy in specular angle which can occur when the z-axis is a specular direction. For example, in the case of a closed cylinder the directions $\theta = 0°$, 180° are specular directions. In a subsequent test for a specular region in (0190 - 0196) the sine of the specular angle is taken. As the sine is periodic in 180° care must be taken that the shadowed specular region

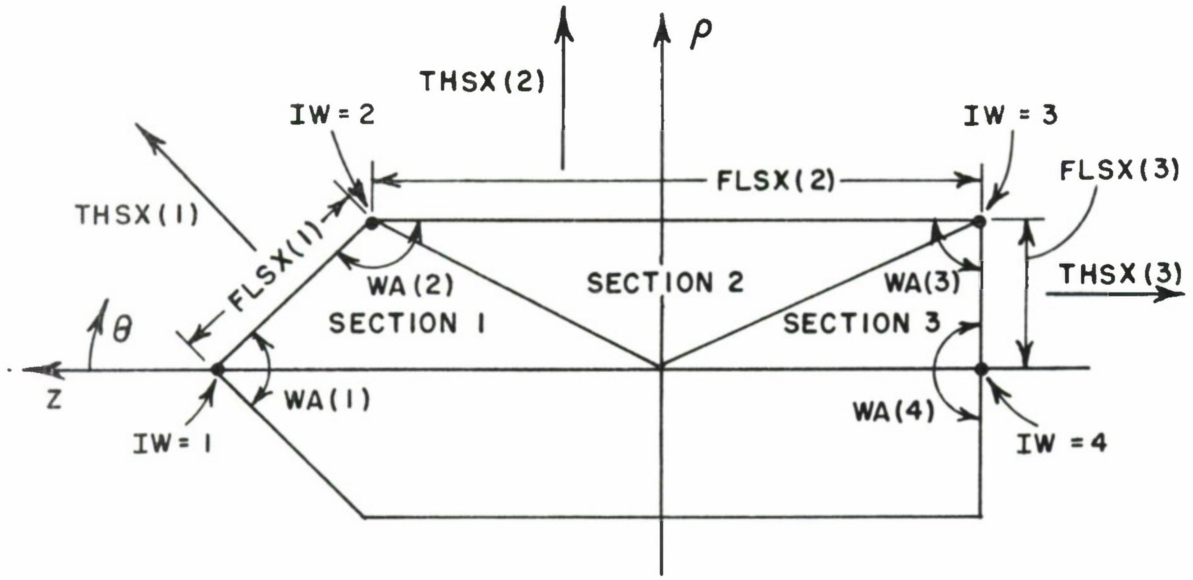


Fig. 2. A three section target-the cone-cylinder-disk.

is not included in evaluating the scattered field. This is accomplished by setting the specular angles 0° and 180° equal to 360°. These specular directions on the axis may then be evaluated using the solution for the axial caustic given in Ref. 1, and located at (0242 - 0266) in this program.

The statements (0111 - 0115) convert the computed wedge angles WA(IWD) to the parameter FN(IWD) required for the wedge diffraction coefficient, where IWD is the number of the particular wedge.

Having identified the required geometrical properties of the target the scattered field must now be computed. Thus the iteration for the incidence angle THT is set up (0116 - 0117) and the DO loop entered (0118). The incidence angle is incremented and the propagation vector of the incident wave is computed (0119 - 0124). Next, the total field is initialized. Then a DO loop is entered (0128) in which the total scattered field is to be obtained by summation of the individual contributions. First the location of the wedge ID is computed (0129 - 0135). Next the test parameter BESAR for the axial solution region is computed. At this point a transfer to the solution for a tip scattered field is made if ID = NWD (0137). A determination is now made whether the points on the wedge ID at $\phi = 0°$, $180°$ are illuminated or shadowed by calling the subroutine WILLY (0138 - 0143). The COMMON block is now reset (0144), having been used in the previous test, and the angle between the incident ray and the "side" of the wedge ID is computed (0145 - 0177). The phase of the backscattered field of the $\phi = 0°$, $180°$ points on the wedge ID is calculated by the subroutine PHASE. Having completed these calculations we now move to the computation of the scattered field due to the "wedge" ID.

The first step in the field calculation is a test (0185 - 0189) to determine if the incident angle THT is in a region for which the axial solution[1] must be used. This region is bounded by the angle corresponding to the first null of the first order Bessel function $J_1(2ka\sin\theta)$. If so a transfer is made to the axial solution. Next (0190 - 0197) a test is made to determine whether the incidence angle is within a region about a specular direction specified by the first null of the sin(x)/x function. If so a transfer to the specular solution[1] is made. It is noted that as this test is made after the test for the axial region the axial solution has precedence. At this point a transfer to the solution for a tip scattered field is made if ID = 1. Locating this provision after the axial and specular region test insures that the specular region THSX(1) indicated in Fig. 2 will be included.

Having tested for regions where a special solution is required, the scattered field due to the wedge discontinuity is now computed (0201 - 0210), and added to obtain the total field. A transfer to the end of the DO loop is then made.

The solution for the specular field using the sin(x)/x formulation given in Ref. 2, is computed in 0211 - 0238. Again this field is added to obtain the total field, and upon completion transfers to the end of the DO loop.

The solution for the axially scattered fields given in Ref. 2 is computed in 0239 - 0272. Again this contribution is added to obtain the total field, and a transfer is made to the end of the DO loop.

The tip scattered fields are computed in 0273 - 0297 using the physical optics solution for the field scattered by an infinite conducting cone.[4] Again this contribution is added to obtain the total scattered field.

Statement 301 (0297) is the end of the range of the DO loop over the number of wedges. Thus at this point the contribution of the wedge (ID) to the total field has been computed and added to the scattered field.

At the termination of the DO loop the total backscattered field EDTOT due to all contributions has been computed. Next the backscattered field and the echo area for the incident angle THT are written (0298 - 0305). After the loop on incidence angle is completed the program is terminated (0306 - 0308).

SUBROUTINES AND FUNCTIONS

Subroutine FNORM(FNVX, FNVY, FNVZ, R, THT, PHI)
0309 - 0331

This subroutine computes the normal vector (FNVX, FNVY, FNVZ) to the surface for the section whose description is in the unlabelled COMMON region. The spherical coordinates of the point at which the normal is computed are R, THT and PHI.

Subroutine FCOMM(I) 0332 - 0343

This subroutine shifts the constants describing the section I from the /DATA/ COMMON into unlabelled COMMON.

Function RAD(THT) 0344 - 0363

This function calculates the distance from the origin to the surface at the angle THT. The constants describing the surface are stored in unlabelled COMMON.

Subroutine WILLY(FWI, THTI, PHI, THIN, PHIN)

This subroutine determines whether the incident wave specified by THIN, PHIN = 0., π illuminates the wedge at location THTI, PHI. If the wedge is illuminated FWI is set equal to 1., if shadowed FWI is set equal to zero.

Subroutine CROSS(X, Y, Z, A1, A2, A3, B1, B2, B3)
0384 - 0390

This subroutine computes the cross product $\overline{A}X\overline{B}$ and returns the answer in (X, Y, Z).

Function PHASE(THTI, PHII, THTB, PHIB, RB, FK) 0391 - 0400

This function calculates the phase of the backscattered field for an incident (and scattering) direction given by THTI, PHII = 0., π, for the wedge location RB, THTB, PHIB = 0., π, with a propagation constant FK.

Function SINXX(Y) 0401 - 0408

This function computes sin(y)/y.

Function DIFF1(FN, PHI, FK, BETA) 0409 - 0439

This function calculates the plane wave diffraction coefficient given in Refs. 1 and 2. FN is the wedge parameter, PHI the angular argument, FK the propagation constant, and BETA the half angle of the diffraction cone.

Function BESL0(X) 0440 - 0465

This function computes the zero order Bessel function $J_0(x)$.

Function BESL1(X) 0466 - 0491

This function computes the first order Bessel function $J_1(x)$.

Function BESL2(X) 0492 - 0501

This function computes the second order Bessel function $J_2(x)$.

INPUT DATA

A typical set of data cards is shown in Appendix II. The order of the cards is as follows:

Card #1 This card specifies in format (115) the number of cases to be run.

Card #2 This card specifies the number of sections of the target, in format (1I5).

Card #3 This card specifies, in order, the wavelength of the incident radiation, the starting incidence angle, the final incidence angle, the increment in angle, and the polarization factor. The wavelength is in meters, the angles in degrees, and the polarization factor is (+1.) for E_θ polarization or (-1.) for E_ϕ polarization. The format is (5F10.5).

Next N cards (N=number of target sections). These cards specify in order, the initial and final angular boundaries of the section (in radians), and the constants $A_1 \ldots . A_6$. The format is (8F10.5).

If the number on card number 1 is different from 1, the cards #2 to (#3 + N) are repeated. This is necessary if any of the following options are desired.

1. A change in incidence angle range.
2. A change in wavelength.
3. A change in polarization.
4. A change in target.

It is also possible to re-write the control statements in the program to provide more versatility in the control, that is, to provide for automatic looping over wavelength, or polarization. The form presented here is convenient as most experimental data is taken in the form of an echo area pattern, rather than as echo area versus frequency. A flow diagram of the program is given in Appendix IV.

CONCLUSIONS

This report is not intended to completely specify each detail of the computer program. It is intended to provide information about the program which is necessary to the use or modification of the program. The accuracy of the program has been tested for the case of E_θ (parallel) polarization as reported in Ref. 1. Tests for E_ϕ (perpendicular) polarization have not been completed, but some results are given in Appendix III.

APPENDIX I
COMPUTER PROGRAM

```
$EXECUTE        I8JOB
$I8JO8          GO,MAP
$I8FTC WEDGD    LIST,NODECK
      COMPLEX EDTOT,PHASE,PHWU,PHWL,WDU,WDL,EDU,EDL,ESX,EBESS,ETIP
       COMPLEX DIFFI,WBS,PBESS
      COMPLEX WBSP,WBSM
      COMMON RAI,RA3,R81,RA9,RAI0,RA11/DATA/ARI(20),AR3(20),BR1(20),AR9(
     C20), AR10(20),ARI1(20)
      DIMENSION THSX(20),FLSX(20),THTI(20),THTF(20)
      DIMENSION VNX(20),VNY(20),VNZ(20)
      DIMENSION WA(2I),FN(21)
 1    FORMAT(I15)
  2   FORMAT(5F10.5)
 3    FORMAT(8F10.5)
 4    FORMAT(3F15.8)
 5    FORMAT(5H RW1=FI5.8,5H RW2=FI5.8)
 6    FORMAT(6H FLSX=F15.8,6H THSX=FI5.8)
 7    FORMAT(5H WDU=2F15.8,5H WDL=2F15.8,5H RDF=FI5.8)
  8   FORMAT(4F15.8)
  9   FORMAT(1F15.8)
  10  FORMAT(6F15.8)
  11  FORMAT(6H THTD=F15.8,5H ESX=2F15.8)
 12   FORMAT(6H THTD=F15.8,7H EBESS=2F15.8)
 I3   FORMAT(6H STTI=F15.8)
 14   FORMAT(6H ARSX=F15.8)
 15   FORMAT(6H PSIU=F15.8,6H PSIL=F15.8)
 16   FORMAT(6H FWIU=F15.8,6H FWIL=FI5.8)
  17  FORMAT(6H THTW=F15.8,4H RW=F15.8,4H AW=F15.8,4H ZW=F15.8)
  18  FORMAT(27H PERPENDICULAR POLARIZATION)
  19  FORMAT(22H PARALLEL POLARIZATION)
      READ(5,1) NCS
      DO 600 NCSI=1,NCS,1
      READ(5,1)N
      READ(5,2)WAVE,THTS,THTE,DTHT,POL
      WRITE(6,2)WAVE,THTS,THTE,DTHT,POL
      IF(POL.LT.0.) WRITE(6,18)
      IF(POL.GT.0.) WRITE(6,19)
      READ(5,3)(THTI(1RD),THTF(IRD),AR1(1RD),AR3(IRD),8RI(IRD),AR9(IRD),
     CARI0(IRD),AR1I(IRD),IRD=1,N)
      WRITE(6,3)(THTI(J),THTF(J),AR1(J),AR3(J),BR1(J),AR9(J),ARI0(J),AR1
     C1(J),J=1,N)
      PI=3.1415927
      TP=2.*PI
      PI2=PI/2.
       FK=TP/WAVE
      DEGRAD=0.01745329
C     WEDGE DETERMINATION
C     NUMBER OF TARGET SECTIONS=N
C     CLOSED TARGET ASSUMED
      NWD=N+I
      DLARGE=0.
      DIA=0.
      TCT=0.90
      DO 201 IW=1,N,I
      THSX(IW)=TP
      FLSX(IW)=0.
      THT1=THTI(IW)
      THT2=THTF(IW)
      CALL FCOMM(IW)
      RW1=RAD(THT1)
      RW2=RAD(THT2)
      CALL FNORM(FXI,FY1,FZ1,RW1,THTI,0.)
      CALL FNORM(FX2,FY2,FZ2,RW2,THT2,0.)
      IF(IW.EQ.1) GO TO 202
```

```
      IW1=IW-1
      THT3=THTF(IW1)
      CALL FCOMM(IW1)
      RW3=RAD(THT3)
      CALL FNORM(FX3,FY3,FZ3,RW3,THT3,0.)
      SPRD=FX1*FX3+FY1*FY3+FZ1*FZ3
      VNX(IW)=FX3
      VNY(IW)=FY3
      VNZ(1W)=FZ3
      DANG=ARCOS(ABS(SPRD))
      IF(SPRD.LT.0.) DANG=PI-DANG
      WA(IW)=PI-DANG
      IF(IW.EQ.N)GO TO 203
  207 CONTINUE
C     CHECK FOR SIN(X)/X REGION
      SPX=FX1*FX2+FY1*FY2+FZ1*FZ2
      SPX=ABS(SPX)
      IF (SPX.GT.TCT)GO TO 204
      GO TO 500
  202 CONTINUE
C     CHECK FOR WEDGE ANGLE ON THE END
      VNX(I)=FX1
      VNY(1)=FY1
      VNZ(1)=FZ1
      WA(1)=PI-2.*ATAN2(FX1,FZ1)
      GO TO 207
  203 CONTINUE
C     CHECK FOR WEDGE ANGLE ON THE END
      FZ2A=ABS(FZ2)
      VNX(NWD)=FX2
      VNY(NWD)=FY2
      VNZ(NWD)=FZ2
      WA(NWD)=PI-2.*ATAN2(FX2,FZ2A)
      GO TO 207
  204 CONTINUE
      THSX(IW)=ATAN2(FX1,FZ1)
      THHX=THSX(1W)
      IF(IW.GT.1 .AND. ABS(THHX).EQ.0.) THSX(IW)=PI
       FLSX(1W)=SQRT(ABS(RW1*RW1+RW2*RW2-2.*RW1*RW2*COS(THT2-THT1)))
      GLSX=FLSX(1W)
      WRITE(6,5) RW1,RW2
      WRITE(6,5) THTI,THT2
      WRITE(6,6) GLSX,THHX
  500 CONTINUE
  201 CONTINUE
      1F(THSX(1).LT.0.1) THSX(1)=TP
      IF(ABS(THSX(N)-PI).LT.0.1) THSX(N)=TP
      DO 208 IWD=1,NWD,1
      FN(IWD)=(TP-WA(1WD))/PI
      FNWR=FN(IWD)
      WRITE(6,9)FNWR
  208 CONTINUE
      FLOOP=ABS((THTS-THTE)/DTHT)
      LOOP=FLOOP+1.
      DO 400 LP=1,LOOP,1
      FLP=LP
      THTD=(FLP-1.)*DTHT
      THT=DEGRAD*THTD
      VX=-SIN(THT)
      VY=0.
      VZ=-COS(THT)
C     PARALLEL POLARIZATION
      EDTOT=(0.,0.)
      IDSX=0
```

```
      DO 301 ID=1,NWD,1
      THTW=THTI(ID)
      CALL FCOMM(ID)
      IF(ID.EQ.NWD) THTW=THTF(N)
      RW=RAD(THTW)
      AW=RW*SIN(THTW)
      ZW=RW*COS(THTW)
      WRITE(6,17) THTW,RW,AW,ZW
      BESAR=2.*FK*AW
      IF(ID.EQ.NWD) GO TO 305
      IF(THT.LT.PI2.AND.ID.GT.1) CALL FCOMM(ID-1)
      CALL WILLY(FW1,THTW,0.,THT,0.)
      FW1U=FW1
      CALL WILLY(FW1,THTW,PI,THT,0.)
      FW1L=FW1
      WRITE(6,16) FW1U,FW1L
      CALL FCOMM(ID)
  306 CONTINUE
C     FIND INCIDENCE ANGLE ON WEDGE
C     INCIDENCE VECTOR VX,VY,VZ
      VXM=-VX
      VYM=-VY
      VZM=-VZ
      IF(THT.GT.PI2) GO TO 309
      SPRD=VXM*VNX(ID)+VZM*VNZ(ID)
      CALL CROSS(BX,BY,BZ,VXM,VYM,VZM,VNX(ID),VNY(ID),VNZ(ID))
      DANG=ARCOS(SPRD)
      SIGN=-1.
      IF(BY.LT.0.) SIGN=1.
      PSIU=PI2+SIGN*DANG
      SPRD=-VXM*VNX(ID)+VZM*VNZ(ID)
      CALL CROSS(BX,BY,BZ,VXM,VYM,VZM,-VNX(ID),VNY(ID),VNZ(ID))
      DANG=ARCOS(SPRD)
      SIGN=1.
      IF(BY.LT.0.) SIGN=-1.
      PSIL=PI2+SIGN*DANG
      GO TO 310
  309 CONTINUE
      CALL FNORM(FTX,FTY,FTZ,RW,THTW,0.)
      SPRD=VXM*FTX+VYM*FTY+VZM*FTZ
      CALL CROSS(BX,BY,BZ,VXM,VYM,VZM,FTX,FTY,FTZ)
      DANG=ARCOS(SPRD)
      SIGN=1.
      IF(BY.LT.0.) SIGN=-1.
      PSIU=PI2+SIGN*DANG
      SPRD=-VXM*FTX+VYM*FTY+VZM*FTZ
      DANG=ARCOS(SPRD)
      PSIL=PI2-DANG
  310 CONTINUE
      WRITE(6,15)PSIU,PSIL
C     DETERMINE PHASE OF WEDGE
      PHWU=PHASE(THT,0.,THTW,0.,RW,FK)
      PHWL=PHASE(THT,0.,THTW,PI,RW,FK)
      PSUP=2.*PSIU
      PSUM=0.
      PSLP=2.*PSIL
      PSLM=0.
C     BESSL0 TEST
      STT0=3.8317/BESAR
      STT1=SIN(THT)
      WRITE(6,13) STT1
      IF (STT1.LT.STT0)GO TO 302
C     SIN(X)/X TEST
      IDX=ID
```

```
      T1=ABS(THSX(IDX)-THT)
      IF(T1.GT.PI2) T1=PI2
      ARSX=2.*FK*FLSX(IDX)*SIN(T1)
      WRITE(6,14)ARSX
      IF(ARSX.LT.PI)GOTO 304
  303 CONTINUE
      NCHECK=303
      WRITE(6,1) NCHECK
      IF(ID.EQ.1) GO TO 305
C     CALCULATE DIFFRACTED FIELDS
      WDU=DIFF1(FN(ID),PSUP,FK,PI2)+POL*DIFF1(FN(ID),PSUM,FK,PI2)
      IF(ID.EQ.IDSX) WDU=(0.,0.)
      WDL=DIFF1(FN(ID),PSLP,FK,PI2)+POL*DIFF1(FN(ID),PSLM,FK,PI2)
      RDF=SQRT(ABS(AW/(2.*SIN(THT))))
      WRITE(6,7) WDU,WDL,RDF
      EDU=RDF*PHWU*WDU*FWIU
      EDL=RDF*PHWL*WDL*FWIL
      EDTOT=EDTOT+EDU+EDL
      GO TO 301
  304 CONTINUE
      NCHECK=304
      WRITE(6,1) NCHECK
C     COMPUTE SIN(X)/X CONTRIBUTION
C     COMPUTE PEAK RETURN USING AVERAGE OF GAUSSIAN CURVATURE
      RW1=RW
      RW2=RAD(THTF(ID))
      AW1=AW
      AW2=RW2*SIN(THTF(ID))
      TAW=ABS(AW1-AW2)
      IF(TAW.LT.0.1) GO TO 307
      RH1=AW1/SIN(THT)
      RH2=AW2/SIN(THT)
      RH1=ABS(RH1)
      RH2=ABS(RH2)
      RSH1=SQRT(RH1)
      RSH2=SQRT(RH2)
      PEAK=ABS(RSH1*RH1-RSH2*RH2)*FLSX(ID)*1.414/(3.*ABS(RH1-RH2))
      PEAK=FK*PEAK
      GO TO 308
  307 PEAK=SQRT(AW1/2.)*FK*FLSX(ID)
  308 CONTINUE
      ESX=-PEAK*SINXX(ARSX)/SQRT(TP*FK)
      ESX=ESX*PHASE(THT,0.,THTW,0.,RW,FK)
      IDSX=ID+1
      WRITE(6,11)THTD,ESX
      EDTOT=EDTOT+ESX
      GO TO 301
  302 CONTINUE
      NCHECK=302
      WRITE(6,1) NCHECK
C     COMPUTE FIELD USING BESSEL FUNCTIONS
      SBSS=0.5
      PKSPC=FK*AW*AW
      PKBSS=AW
      ARGBS=BESAR*SIN(THT)
      IF(ABS(ARGBS).GT.0.05) SBSS=BESL1(ARGBS)/ARGBS
      CALL FNORM(F1X,F1Y,F1Z,RW,THTW,0.)
      PSUB=2.*(PI2-ARCOS(ABS(F1Z)))
      IF(THT.LT.PI2) PSUB=2.*(PI2-ARCOS(VNZ(ID)))
      WBS=DIFF1(FN(ID),PSUB,FK,PI2)
      PBESS=PHASE(THT,0.,0.,0.,ZW,FK)
      SHBDT=CABS(WBS)-0.5
      IF(ABS(SHBDT).LT.0.05) GO TO 321
      WBS=WBS*SQRT(TP*FK)
```

```
      COST=COS(THT)
      WBSP=DIFFI(FN(ID),0.,FK,PI2)+DIFFI(FN(ID),PSUB,FK,PI2)
      WBSM=DIFFI(FN(ID),0.,FK,PI2)-DIFFI(FN(ID),PSUB,FK,PI2)
      WBSP=WBSP*SQRT(FK*TP)
      WBSM=WBSM*SQRT(TP*FK)
      WBS=-COST*COST*WBSM*SBSS+WBSP*(SBSS-BESL2(ARGBS))
      IF(POL.LT.0.) WBS=COST*COST*WBSP*SBSS-WBSM*(SBSS-BESL2(ARGBS))
      EBESS=(0.,-1.)*PKBSS*PBESS*WBS
      IF(FWIU.EQ.0..AND.FWIL.EQ.0.) EBESS=(0.,0.)
      IF(FWIU.GT.0..AND.FWIL.EQ.0.) EBESS=0.5*EBESS
      GO TO 322
  321 CONTINUE
      EBESS=(0.,-1.)*PKSPC*PBESS*SBSS
  322 CONTINUE
      WRITE(6,12) THTD,EBESS
      EDTOT=EDTOT+EBESS
      GO TO 301
 305  CONTINUE
      NCHECK=305
      WRITE(6,1) NCHECK
C     COMPUTE TIP CONTRIBUTION AT ENDS
C     TO FIRST ORDER TIP CONTRIBUTIONS ARE NEGLEGIBLE
      THTCN=THT
      IF(THT.GT.PI2) THTCN=PI-THT
      HFCA=0.5*WA(ID)
      TCNA=PI2-HFCA
      TCNAA=ABS(THTCN-TCNA)
      IF(TCNAA.LT.0.1745) GO TO 312
      IF(ABS(HFCA-PI2).LT.0.1745) GO TO 312
      TANA=TAN(HFCA)
      TANA2=TANA*TANA
      TANTH=TAN(THTCN)
      TANT2=TANTH*TANTH
      COSTH=COS(THCN)
      COSTH3=COSTH*COSTH*COSTH
      ETIP=-WAVE*TANA2/(8.*PI*COSTH3*(1.-TANA2*TANT2))
      ETIP=ETIP*PHASE(THT,0.,0.,0.,ZW,FK)
      IF(POL.LT.0.) ETIP=-ETIP
      GO TO 311
  312 ETIP=(0.,0.)
  311 CONTINUE
      EDTOT=EDTOT+ETIP
 301  CONTINUE
C     OUTPUT SECTION
      WRITE(6,4) THTD,EDTOT
      EMAG=CABS(EDTOT)
      SIGMA=2.*TP*EMAG*EMAG/(WAVE*WAVE)
      SIGMAL=10.*ALOG10(SIGMA)
      WRITE(6,4)SIGMA,SIGMAL
 400  CONTINUE
  600 CONTINUE
      STOP
      END
$IBFTC FFNRM    LIST,NODECK
      SUBROUTINE FNORM(FNVX,FNVY,FNVZ,R,THT,PHI)
C     INPUT R,THT,PHI
      COMMON AR1,AR3,BR1,AR9,AR10,AR11
      ST=SIN(THT)
      CT=COS(THT)
      SP=SIN(PHI)
      CP=COS(PHI)
      U=AR1*ST*ST+AR3*CT*CT+BR1*ST*CT
      V=AR9*CT+AR10*ST
      UTH=2.*(AR1-AR3)*ST*CT+BR1*(CT*CT-ST*ST)
```

```
      VTH=-AR9*ST+AR10*CT
      F1=2.*R*U+V
      F2=R*UTH+VTH
      FX=ST*CP*F1+CT*CP*F2
      FY=ST*SP*F1+CT*SP*F2
      FZ=CT*F1-ST*F2
      FN=SQRT(FX*FX+FY*FY+FZ*FZ)
      FNVX=FX/FN
      FNVY=FY/FN
      FNVZ=FZ/FN
      RETURN
      END
$IBFTC FCOMM.  LIST,NODECK
      SUBROUTINE FCOMM(I)
      COMMON RA1,RA3,RB1,RA9,RA10,RA11/DATA/AR1(20),AR3(20),BR1(20),AR9(
     C20),AR10(20),AR11(20)
      RA1=AR1(I)
      RA3=AR3(I)
      RB1=BR1(I)
      RA9=AR9(I)
      RA10=AR10(I)
      RA11=AR11(I)
      RETURN
      END
$IBFTC RADD    LIST,NODECK
      FUNCTION RAD(THT)
C     CALCULATE R
      COMMON AR1,AR3,BR1,AR9,AR10,AR11
      R=0.
      ST=SIN(THT)
      CT=COS(THT)
      C1=AR1*ST*ST+AR3*CT*CT+BR1*ST*CT
      C2=AR9*CT+AR10*ST
      C3=AR11
      IF(C1.EQ.0.)GO TO 11
      ARG=SQRT(C2*C2-4.*C1*C3)
      R=(-C2+ARG)/(2.*C1)
      R2=(-C2-ARG)/(2.*C1)
      IF(R2.LT.R.AND.R2.GT.0.) R=R2
      GO TO 12
 11   R=-C3/C2
 12   RAD=ABS(R)
      RETURN
      END
$IBFTC WILLY.  LIST,NODECK
      SUBROUTINE WILLY(FWI,THTI,PHI,THIN,PHIN)
C     INPUT THTI,PHI,THIN,PHIN
C     FWI=0.  WEDGE IN SHADOW
C     FWI=1.   WEDGE ILLUMINATED
      COMMON AR1,AR3,BR1,AR9,AR10,AR11
      PI=3.1415927
      PI2=1.5707963
      R=RAD(THTI)
      CALL FNORM(FNX,FNY,FNZ,R,THTI,PHI)
      TH=THIN
      XIN=SIN(TH)*COS(PHIN)
      YIN=0.
      ZIN=COS(TH)
      SPRD=FNX*XIN+FNY*YIN+FNZ*ZIN
      FWI=1.
      IF(SPRD.LT.0.) FWI=0.
      CONTINUE
      RETURN
      END
```

```
$IBFTC CROSS.  LIST,NODECK
       SUBROUTINE CROSS(X,Y,Z,AI,A2,A3,B1,B2,B3)
      X=A2*B3-A3*B2
      Y=A3*B1-AI*B3
      Z=A1*B2-A2*BI
      RETURN
      END
$IBFTC PHAS.   LIST,NODECK
       COMPLEX FUNCTION PHASE(THTI,PHII,THTB,PHIB,RB,FK)
      FS=I.
      TEST=ABS(PHII-PHIB)
      IF(TEST.EQ.0.) FS=-I.
      FL=2.*RB*COS(THTI+FS*THTB)
      FKL=FK*FL
      PHASE=CMPLX(COS(FKL),SIN(FKL))
       RETURN
      END
$IBFTC SINXX.  LIST,NODECK
      FUNCTIONSINXX(Y)
C     SIN(X)/X  FUNCTION
      Z=Y*Y
      SINXX=(I.-(Z/6.)*(I.-(Z/20.)*(I.-(Z/42.)*(I.-(Z/72.)*(I.-(Z/II0.)*
     2(I.-(Z/156.)*(I.-(Z/182.))))))))
      RETURN
      END
$IBFTC DIFCN   LIST,NODECK
      COMPLEX FUNCTION DIFFI(FN,PHI,FK,BETA)
C     SINGLE DIFFRACTION FUNCTION DIFFI
C     FN-WEDGE ANGLE, PHI=ARGUMENT, BETA=CONE ANGLE
      COMPLEX EXPH
      PI=3.I4I5927
      TP=2.*PI
      PI4=PI/4.
      PIF=PI/FN
      PHN=PHI/FN
      PHIA=ABS(PHI)
      EXPH=CEXP((0.,-1.)*PI4)
      SINB=SIN(BETA)
      SINB=ABS(SINB)
      IF(SINB.LT..00I) GO TO 3
      IF(ABS(PHIA-PI).LT.0.I) GO TO I
      T1=COS(PIF)
      T2=COS(PHN)
      T3=SIN(PIF)
      T4=TI-T2
      T4A=ABS(T4)
      IF(T4A.LT..00I) GO TO 3
      DIFFI=EXPH*T3/(FN*SINB*T4)
      DIFFI=DIFFI/SQRT(TP*FK)
      GO TO 2
 I    DIFFI=0.5/SINB
      GO TO 2
 3    DIFFI=I0000.
 2    CONTINUE
      RETURN
      END
$IBFTC BESL0.  LIST,NODECK
      FUNCTION BESL0(X)
C     (X.GT.0.)
      Z=ABS(X)
      Y=X/3.
      Y2=Y*Y
      Y3=Y2*Y
      Y4=Y2*Y2
```

```
      Y5=Y3*Y2
      Y6=Y4*Y2
      Y8=Y6*Y2
      Y10=Y8*Y2
      Y12=Y10*Y2
      IF(Z.GT.3.)GO TO 10
      BESL0=1.-2.2499997*Y2+1.2656208*Y4-.3163866*Y6+.0444479*Y8-.003944
     24*Y10-.00024846*Y12
      GO TO 11
 10   CONTINUE
      F=.79788456-(.00000077/Y)-(.00552740/Y3)-(.00009512/Y3)+(.00137237
     2/Y4)-(.00072805/Y5)+(.00014476/Y6)
      T=X-.78539816-(.04166397/Y)-(.00003954/Y2)+(.00262573/Y3)-(.000541
     225/Y4)-(.00029333/Y5)+(.00013558/Y6)
      BESL0=F*COS(T)/SQRT(X)
 11   CONTINUE
      RETURN
      END
$IBFTC BESL1.  LIST,NODECK
      FUNCTION BESL1(X)
C     POLYNOMIAL APPROXIMATION X.GT.0.
      Y=X/3.
      Y2=Y*Y
      Y3=Y2*Y
      Y4=Y3*Y
      Y5=Y4*Y
      Y6=Y5*Y
      Y8=Y6*Y2
      Y10=Y8*Y2
      Y12=Y10*Y2
      IF(X.GT.3.)GO TO 10
      BESL=0.5-.56249985*Y2+.21093573*Y4-.03954289*Y6+.00443319*Y8-.0003
     21761*Y10+.00001109*Y12
      BESL1=X*BESL
      GO TO 11
 10   CONTINUE
      F=.79788456+(.00000156/Y)+(.01659667/Y2)+(.00017105/Y3)-(.00249511
     2/Y4)+(.00113653/Y5)-(.00020033/Y6)
      T=X-2.35619449+(.12499612/Y)+(.00005650/Y2)-(.00637879/Y3)+(.00074
     2348/Y4)+(.00079824/Y5)-(.00029166/Y6)
      BESL1=F*COS(T)/SQRT(X)
 11   CONTINUE
      RETURN
      END
$IBFTC BESL2.  LIST,NODECK
      FUNCTION BESL2(X)
C     (X.GT.0.)
      IF(X.EQ.0.)GO TO 10
      BESL2=(2.*BESL1(X)/X)-BESL0(X)
      GO TO 11
 10   BESL2=0.
 11   CONTINUE
      RETURN
      END
$DATA
```

APPENDIX II
INPUT DATA

```
00002
00003
         1.0           0.       180.           1.0           -1.
          0.      .785398         0.            0.            0.         2.0           1.0         -2.0
     .785398        2.617         0.            0.            0.          0.           1.0         -1.0
       2.617    3.1415927         0.            0.            0.        -1.0           0           -2.0
00003
         1.0           0.       180.           1.0           1.0
          0.      .785398         0.            0.            0.         2.0           1.0         -2.0
     .785398        2.617         0.            0.            0.          0.           1.0         -1.0
       2.617    3.1415927         0.            0.            0.        -1.0            0.         -2.0
```

APPENDIX III
COMPUTER TESTS FOR E_ϕ POLARIZATION

A limited amount of data has been obtained for the case of E_ϕ polarization. The computed results are compared with measured data for the cone and double cone in Figs. 3 and 4. The data for the cone is that of Keys and Primich[5] and the double cone data is from Eberle and St. Clair.[6] For the case of the cone the greatest error is in the near forward region where the single diffraction solution is used. The results in this region agree with the single diffraction results of Bechtel.[7] The results in this region could be improved by extending the edge current formulation for the axially scattered fields to this region. In the case of the double cone the calculated echo area is in error in the region about $\theta = 90°$. This is a region where the effect of edge type creeping waves[1] at the junction should be considered. These test results indicate that further extension of the theory and computer program is necessary to remove these sources of error. However, for targets which are large in terms of wavelength the accuracy will improve, as both the edge current and creeping wave effects would diminish.

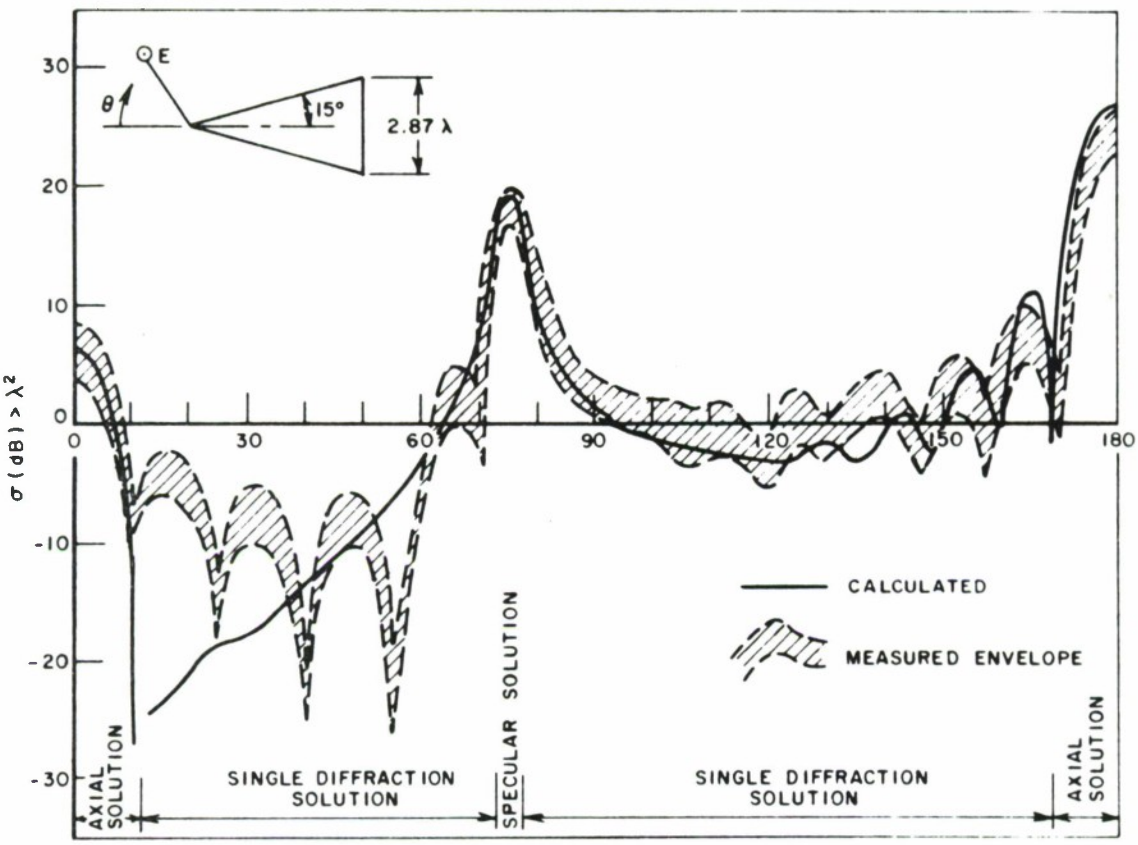


Fig. 3. Echo area of a cone-E_ϕ polarization.

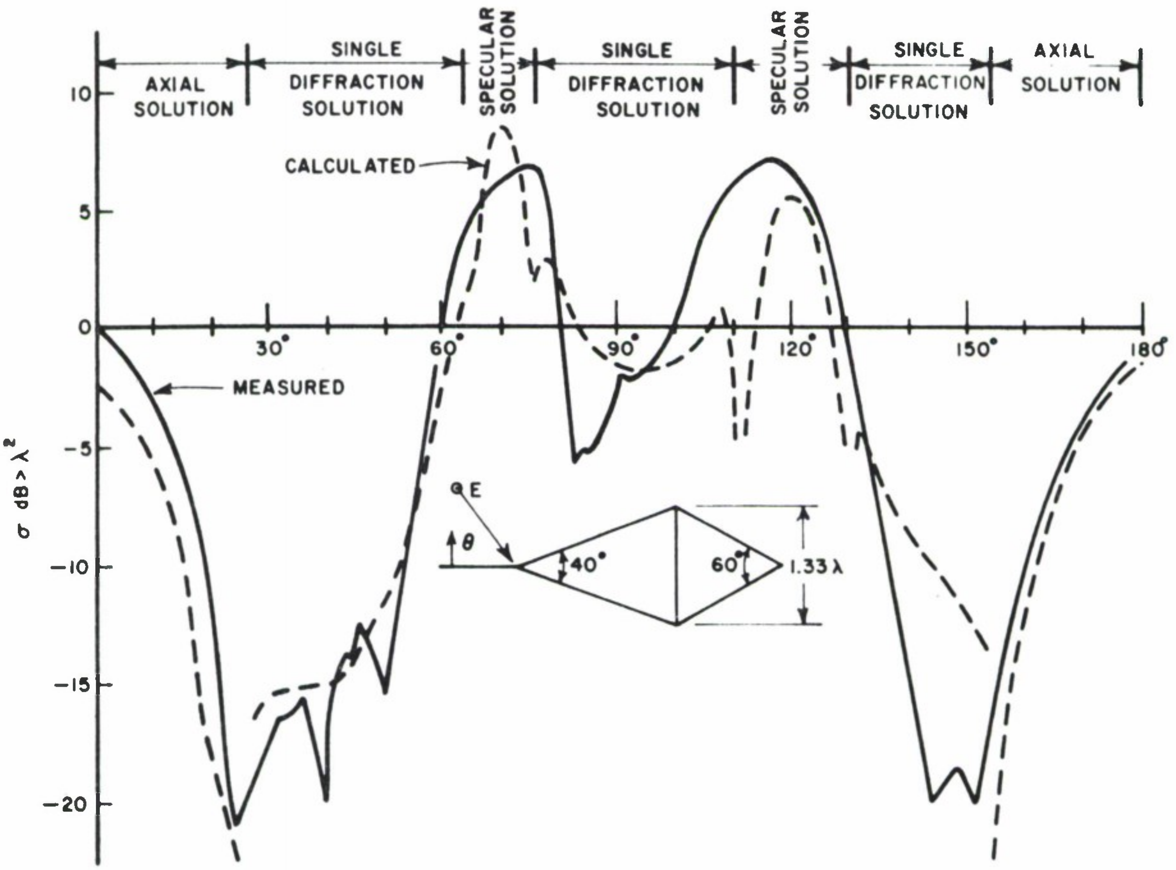
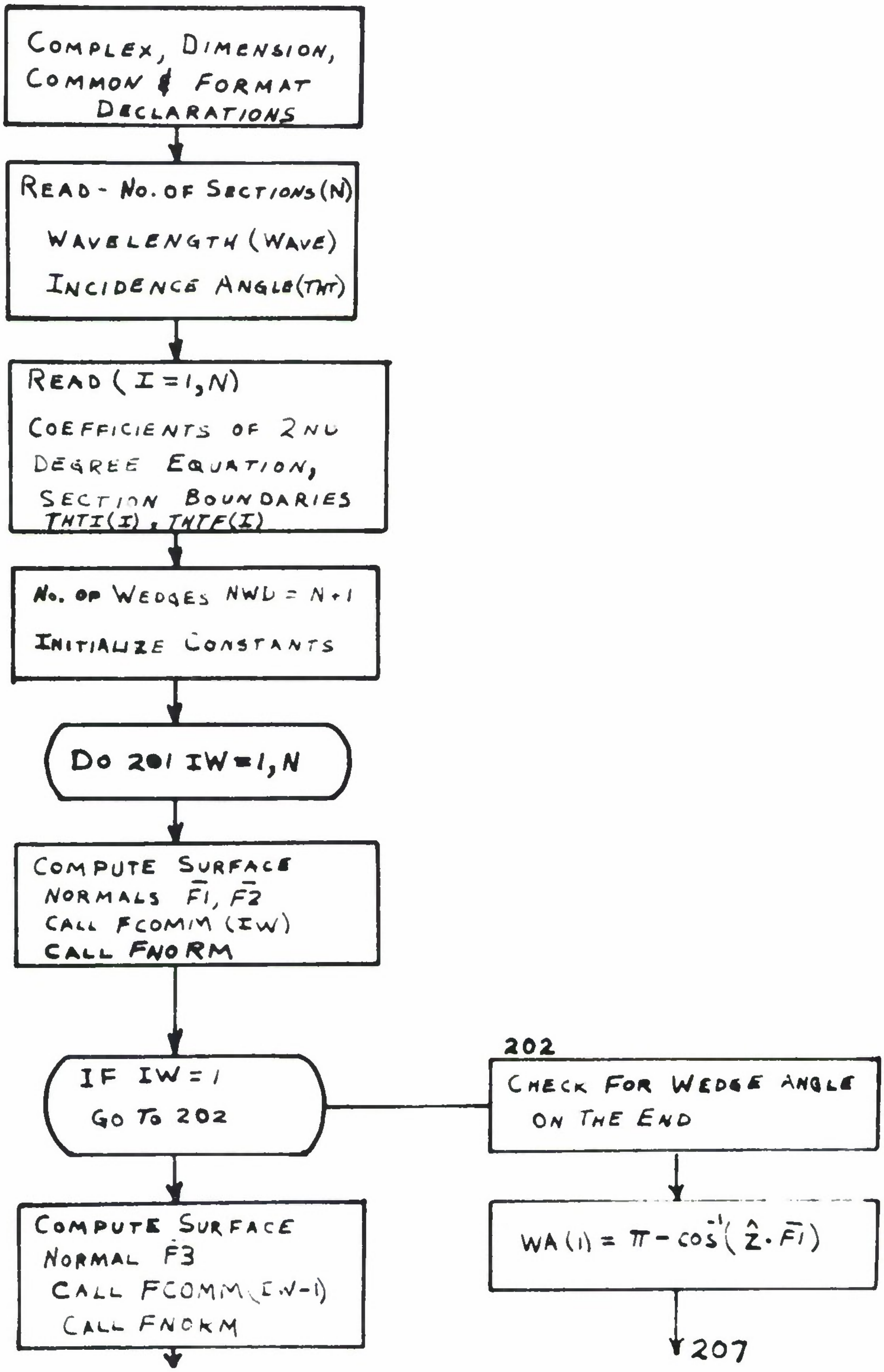


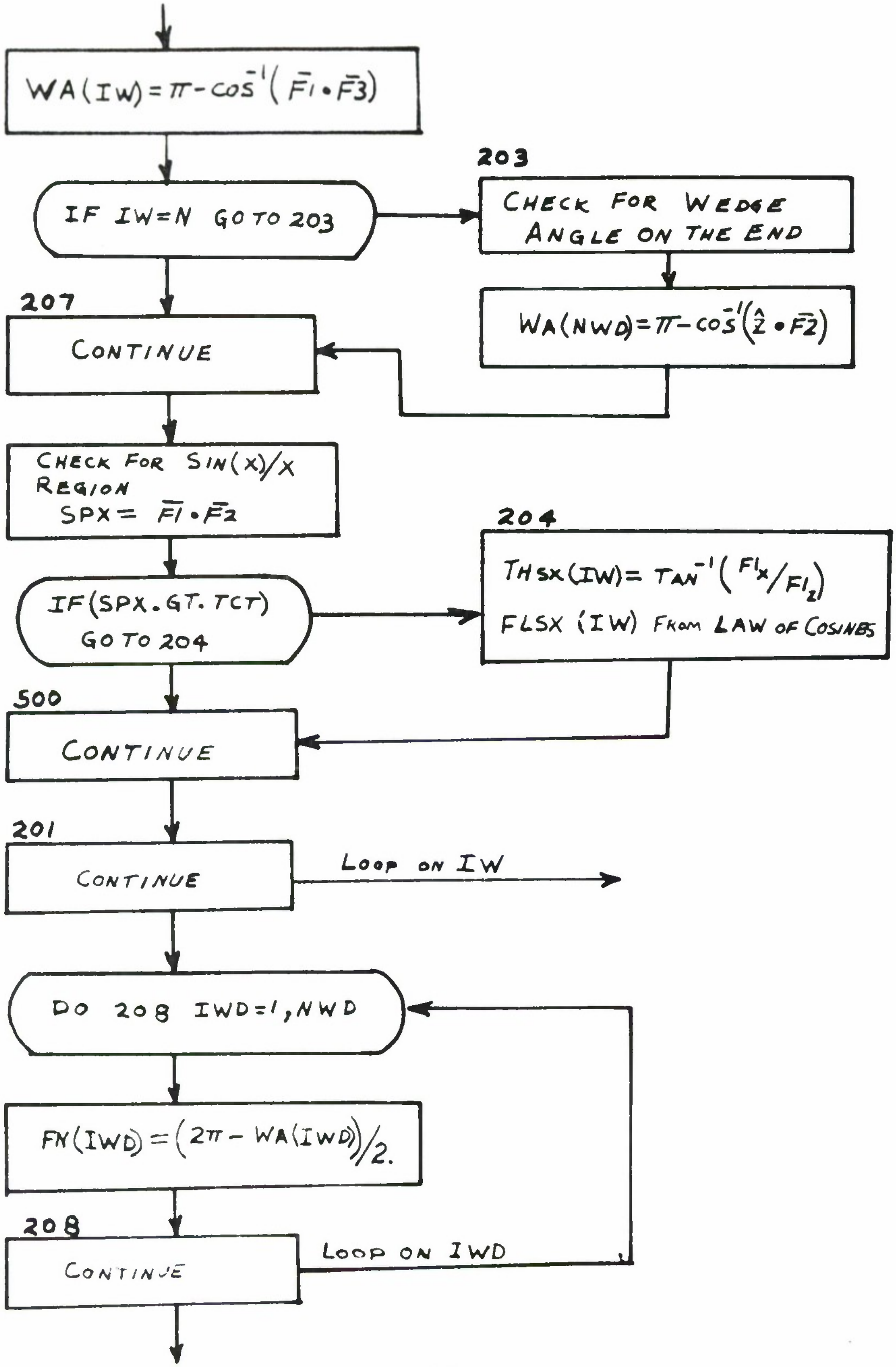
Fig. 4. Echo area of a double cone-E_ϕ polarization.

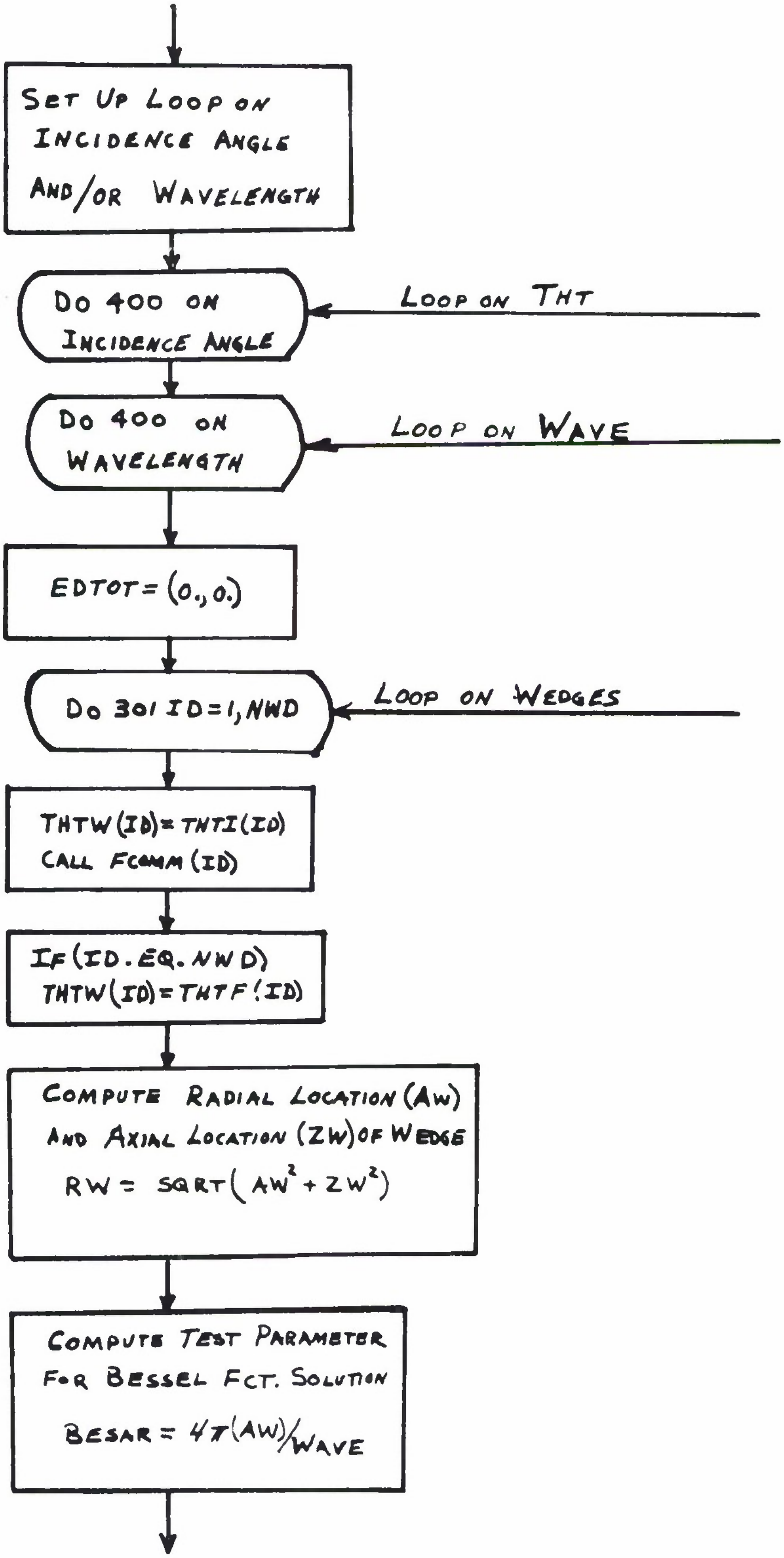
APPENDIX IV
WEDGE DIFFRACTION COMPUTER PROGRAM FLOW DIAGRAM

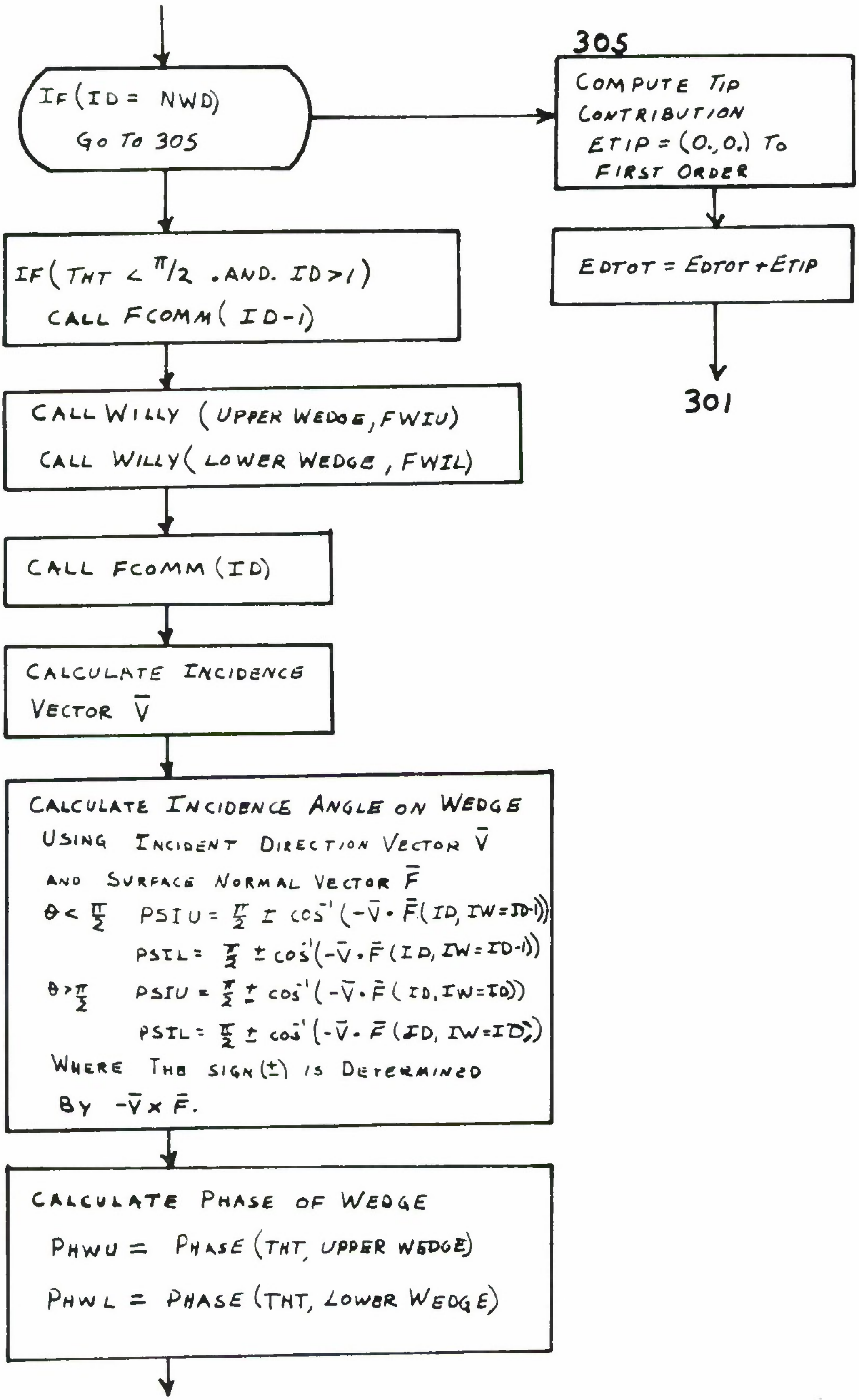
The flow diagram for the wedge diffraction Computer program WEDGD is given in Fig. 5. This flow diagram has also been presented in Ref. 1.

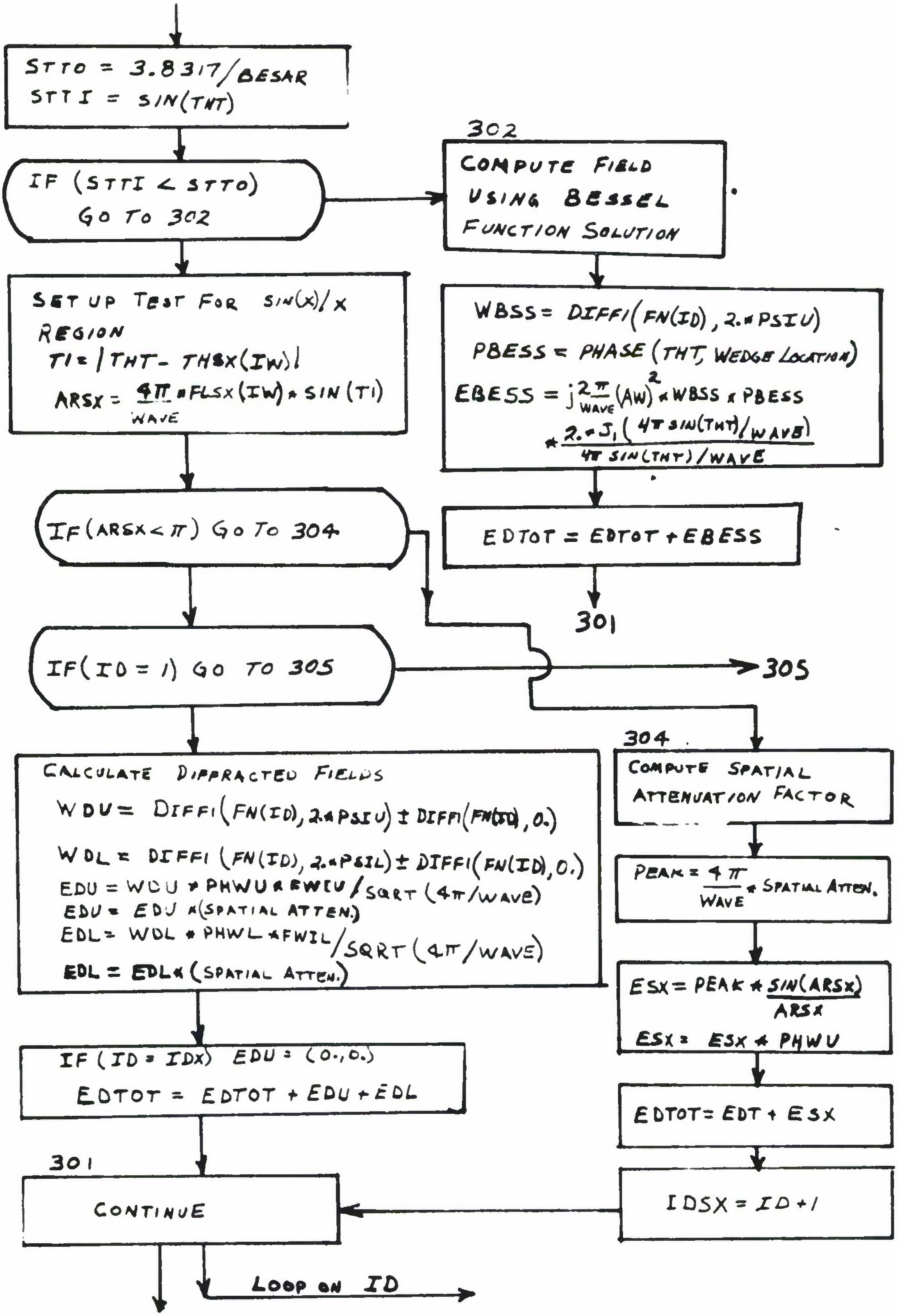
WEDGE DIFFRACTION COMPUTER PROGRAM

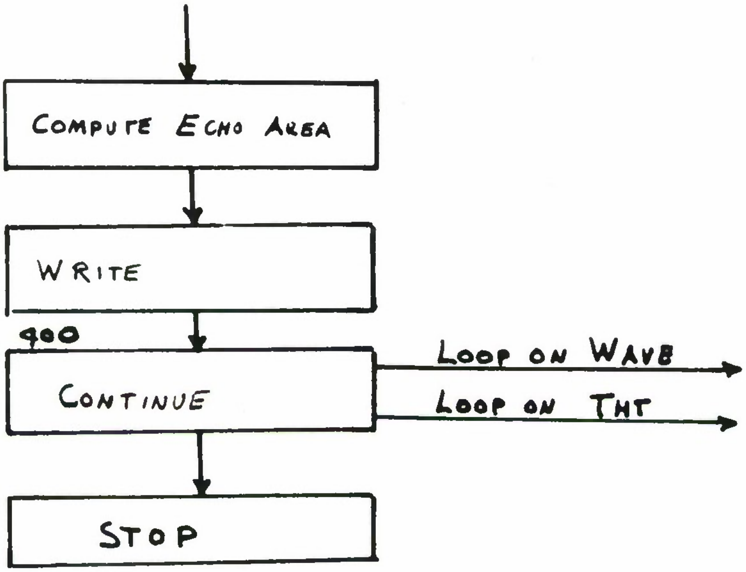



$WA(IW)=\pi-\cos^{-1}(\bar{F1}\bullet\bar{F3})$
IF IW=N GO TO 203
203
CHECK FOR WEDGE ANGLE ON THE END
$WA(NWD)=\pi-\cos^{-1}(\hat{z}\bullet\bar{F2})$
207
CONTINUE
CHECK FOR SIN(X)/X REGION
$SPX=\bar{F1}\bullet\bar{F2}$
IF(SPX.GT.TCT) GO TO 204
204
$THSX(IW)=TAN^{-1}(F1_x/F1_z)$
FLSX (IW) FROM LAW OF COSINES
500
CONTINUE
201
CONTINUE
LOOP ON IW
DO 208 IWD=1,NWD
$FN(IWD)=(2\pi-WA(IWD))/2.$
208
CONTINUE
LOOP ON IWD


Set Up Loop on
Incidence Angle
And/or Wavelength
Do 400 on
Incidence Angle
Loop on THT
Do 400 on
Wavelength
Loop on Wave
EDTOT = (0.,0.)
Do 301 ID=1,NWD
Loop on Wedges
THTW(ID)=THTI(ID)
Call FCOMM(ID)
If(ID.EQ.NWD)
THTW(ID)=THTF(ID)
Compute Radial Location (AW)
And Axial Location (ZW) of Wedge
RW = SQRT(AW² + ZW²)
Compute Test Parameter
For Bessel Fct. Solution
BESAR = 4π(AW)/WAVE


IF (ID = NWD)
GO TO 305
305
COMPUTE TIP CONTRIBUTION ETIP = (0.,0.) TO FIRST ORDER
EDTOT = EDTOT + ETIP
301
IF (THT < π/2 .AND. ID > 1)
CALL FCOMM (ID-1)
CALL WILLY (UPPER WEDGE, FWIU)
CALL WILLY (LOWER WEDGE, FWIL)
CALL FCOMM (ID)
CALCULATE INCIDENCE VECTOR $\bar{V}$
CALCULATE INCIDENCE ANGLE ON WEDGE USING INCIDENT DIRECTION VECTOR $\bar{V}$ AND SURFACE NORMAL VECTOR $\bar{F}$
$\theta < \frac{\pi}{2}$ $PSIU = \frac{\pi}{2} \pm \cos^{-1}(-\bar{V} \cdot \bar{F}(ID, IW = ID-1))$
$PSIL = \frac{\pi}{2} \pm \cos^{-1}(-\bar{V} \cdot \bar{F}(ID, IW = ID-1))$
$\theta > \frac{\pi}{2}$ $PSIU = \frac{\pi}{2} \pm \cos^{-1}(-\bar{V} \cdot \bar{F}(ID, IW = ID))$
$PSIL = \frac{\pi}{2} \pm \cos^{-1}(-\bar{V} \cdot \bar{F}(ID, IW = ID))$
WHERE THE SIGN (±) IS DETERMINED BY $-\bar{V} \times \bar{F}$.
CALCULATE PHASE OF WEDGE
PHWU = PHASE (THT, UPPER WEDGE)
PHWL = PHASE (THT, LOWER WEDGE)


STTO = 3.8317/BESAR
STTI = SIN(THT)
IF (STTI < STTO) GO TO 302
302
COMPUTE FIELD USING BESSEL FUNCTION SOLUTION
WBSS = DIFFI(FN(ID), 2.*PSIU)
PBESS = PHASE (THT, WEDGE LOCATION)
EBESS = j 2π/WAVE (AW)² * WBSS * PBESS * 2.*J1(4π SIN(THT)/WAVE) / 4π SIN(THT)/WAVE
EDTOT = EDTOT + EBESS
301
SET UP TEST FOR SIN(X)/X REGION
TI = |THT - THSX(IW)|
ARSX = 4π/WAVE * FLSX(IW) * SIN(TI)
IF (ARSX < π) GO TO 304
IF (ID = 1) GO TO 305
305
304
COMPUTE SPATIAL ATTENUATION FACTOR
PEAK = 4π/WAVE * SPATIAL ATTEN.
ESX = PEAK * SIN(ARSX)/ARSX
ESX = ESX * PHWU
EDTOT = EDT + ESX
IDSX = ID + 1
CALCULATE DIFFRACTED FIELDS
WDU = DIFFI(FN(ID), 2.*PSIU) ± DIFFI(FN(ID), 0.)
WDL = DIFFI (FN(ID), 2.*PSIL) ± DIFFI(FN(ID), 0.)
EDU = WDU * PHWU * FWIU / SQRT (4π/WAVE)
EDU = EDU * (SPATIAL ATTEN.)
EDL = WDL * PHWL * FWIL / SQRT (4π/WAVE)
EDL = EDL * (SPATIAL ATTEN.)
IF (ID = IDX) EDU = (0.,0.)
EDTOT = EDTOT + EDU + EDL
301
CONTINUE
LOOP ON ID


COMPUTE ECHO AREA
WRITE
900
CONTINUE
LOOP ON WAVE
LOOP ON THT
STOP

REFERENCES

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2. Ryan, C.E., Jr., "Memorandum on Analysis of Echo Area of Targets Using Geometrical Theory of Diffraction and Creeping Wave Theory," Report 2430-1, 22 May 1967, ElectroScience Laboratory, The Ohio State University Research Foundation; prepared under Contract F-19628-67-C-0318 for Department of the Air Force, Electronic Systems Division, L.G. Hanscom Field, Bedford, Massachusetts. (AD 658 469).

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Deputy for Surveillance and Control Systems, Electronic Systems Division L.G. Hanscom Field, Bedford, Mass.

13. ABSTRACT

This report describes a computer program for determining the backscattered fields of a conducting body of revolution composed of sections of cones and cylinders. The target may be closed at one or both ends with circular disks. The target may have as many as 20 sections, and the program can readily be modified to handle a larger number. The backscattered field for E_θ or E_ϕ polarization is computed using wedge diffraction theory and geometrical optics. The computed results are in good agreement with experimental measurements for cones, cylinders, double cones, and conically capped cylinders.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Radar cross section						
Backscatter						
Surface of revolution						
Combination of cones, frustums, and disks						
Geometrical optics						
Diffraction theory						

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