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Inverse Scattering Code

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Inverse Scattering Code

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Abstract

A methodology for the evaluation of complex electromagnetics problems is presented. The methodology reduces the computational requirements for the analysis of large scale computational electromagnetics problems by hybridizing the method of moments and physical optics techniques. The targe model is based on triangular facets and the incident field source by its system response function. Data which can be obtained from the analysis are radar cross section, power spectral density, and range profiles.

COMPLEX TARGET SCATTERING CODE

ABSTRACT

A methodology for the evaluation of complex electromagnetics problems is presented. The methodology reduces the computational requirements for the analysis of large scale computational electromagnetics problems by hybridizing the method of moments and physical optics techniques. The target model is based on triangular facets and the incident field source by its system response function. Data which can be obtained from the analysis are radar cross section, power spectral density, and range profiles.

INTRODUCTION

The modeling of radar sensors and targets is of enormous significance because of their importance in all types and phases of military scenarios. The ability to predict the return power spectral density and radar cross section of a given target is a necessary part of stealth vehicle and sensor design. Furthermore, designers of modern systems where features such as polarization and statistical characteristics of the fields scattered from targets are exploited for target identification/discrimination and/or performance enhancement require a detailed understanding of sensor-target interaction. Although electromagnetic performance characterization is critical, practical and accurate sensor modeling against targets such as ships, tanks, and aircraft is still in its infancy.

Many methods are available to solve Maxwell's Equations formulations for large scale targets. These methods include the method of moments (MOM), finite differences, finite elements, and asymptotic methods such as the Uniform Theory of Diffraction and physical optics (PO). Each of these methods have their own advantages and disadvantages, but it is well known that no single analysis technique can accurately and efficiently predict the electromagnetic performance parameters of electrically large and complex structures. For instance, consider a target comprised of electrically large structures with small-to-medium sized electrical perturbations such as the helicopter shown in Figure 1. Modeling such a target with MOM alone is intractable because of the overwhelmingly large impedance matrix. The use of asymptotic methods to model the target sacrifices the detail required for the small-to-medium sized electrical perturbations. Accurate yet efficient methods to model targets comprised of electrically small to large regions are obtained by combining two or more solution techniques. These methods are referred to as hybrid techniques.

Hybrid methods have been the subject of prior investigations, but these investigations were limited to simple geometrical shapes due to the limitations of then existing computer programs. The investigations of [1] and [2] are representative. These prior investigations suggested that curent based hybrid methods are more robust than field based hybrid techniques.

This report is confined to current based method, but extends its generality to arbitrary 3-D perfectly conductiong geometries. The current based hybrid described here utilizes the MOM for regions requiring rigorous analysis and PO for less demanding regions.

The report is organized as follows. The technical approach is described in the next section followed by a discussion of the software structure. The report is concluded with a summary.

TECHNICAL APPROACH

The formulation is based on the standard MOM electric field integral equation (EFIE). The MOM procedure involves two phases. The first phase consists of filling a system of equations by computing the reaction of each unknown's (current coefficients) currents and field with one another. The size of the left hand side of the system of equations is therefore N^2 where N is the number of unknown current coefficients. The next phase is to solve the system of equations. Utilizing direct solver technology the solution of the system of equations is quite time consuming. In fact, the direct solver computational requirement is $O(N^3)$ thus limiting the problem size which can be solved. Figure 2 shows the magnitude of the solver limitation for MOM formulations. It shows the amount of time required to solve the system of equations alone (fill time not included) assuming $(8/3)N^3$ operations for solution at a sustained TeraFLOP rate. Clearly, the solve phase must be done faster or the number of unknowns to be solved for must be reduced.

The strategy utilized here is to reduce the size of the system of equations to be solved for by utilizing PO as an Ansatz solution where possible. The formulation begins with the Stratton-Chu integral representation of Maxwell's Equations. For the generic geometry shown in Figure 3a , the integral equation for a perfectly conducting body is

$$E^s|_{tan}=-E^i|_{tan}=-LJ \qquad (1)$$

where the integro-differential operator L is given as

$$LJ=jk\eta\int s(J+\nabla\nabla'\bullet J/k^2)\Phi ds'. \qquad (2)$$

In the above Φ is the free space Green's function, η is the free space impedance, and ∇ is the surface gradient on the body with respect to the unprimed (source) variables, and k is the wavenumber. In the scattering problem, the incident electric field is the known and the induced current is the unknown to be determined.

The original problem of Figure 3a is partitioned into a two region equivalent problem shown in Figure 3b. Region 1 is the MOM region and region 2 is the large PO region. Rewriting equation 1 in a partitioned form yields

$$LJ_1=E^i|_{tan}-LJ_2 \qquad (3)$$

where the subscripts 1 and 2 represent the MOM and PO regions respectively. The MOM part of the body is that part of the surfaces for which no optic-derived forms are available. These include surface and/or material discontinuities, edges, apertures, and penetrable regions. PO is utilized for the remainder of the body.

Numerical Implementation of Formulation

Equation 3 is numerically solved by the following process. Firstly, the currents, both MOM and PO, are expanded in terms of a set of basis functions and tested utilizing Galerkin's method. Next the PO currents are calculated. Finally, the MOM current coefficients are computed by solving the resulting system of equations utilizing LU decomposition.

The MOM and PO currents are expanded utilizing Rao Wilton Glisson basis functions as follows

$$J_1=\sum_m I_{1m} v_{1m}$$

$$J2=\sum_m I_{2m} v_{1m}$$

where v_{1m} is the Rao Wilton Glisson expansion function of the mth unknown [3], I_1 is the MOM expansion coefficients, and I_2 is the PO expansion coefficients. Note that I_2 is known from a simple nxH calculation on the surface of the target while I_1 is determined by solving the final system of equations.

Next Galerkin testing is used yielding

$$w_{1m}=v_{1m}$$
$$V_1-\langle w_1,L_2J_2\rangle=Z_{11}I_1 \qquad (6)$$

where w_{1m} is the weighting function, Z_{11} represents the MOM impedance matrix, and V_1 represents the field incident on the MOM surface.

Finally the system of equations given by equation 6 is solved using LU decomposition techniques. Note that the system of equations is reduced in size relative to a MOM only formulation. Figure 4 summarizes the procedure.

After the currents have been determined by solving equation 6, the fields at the sensor are computed. A convolution between the fields at the sensor and the sensor's system response is peformed. This is shown in Figure 5. The range of sensor's which can be modeled is determined by the ability to determine the system response of the sensor and the computation and memory requirements necessary to perform the convolution. Typical sensors which could be considered include synthetic aperture radars, real aperture radars,

and linear frequency modulated radars. A typical radar cross section result is shown in Figure 6.

SOFTWARE STRUCTURE

The software is written in a series of independent modules based upon the McDonnell Douglas CARLOS code. CARLOS was rewritten to implement the hybrid solution and for speed. The rewritten version only implements the electric field integral form of Maxwell's equations. The individual modules allow for expansion of the code to include additional solution techniques such as finite differences and finite elements. The current modules are the input geometry model, input system module, MOM module, PO module, sensor module, and output module.

The input geometry module accepts various forms of geometry representation including PATRAN and ACAD. Sensor information is also processed by the input module. Sensor input includes center frequency, bandwidth, beamwidth, polarization, position relative to target, and trajectory.

The MOM module consists of two submodules: matrix fill and matrix solve. The matrix fill submodule calculates the interaction matrix while the solve module determines the MOM currents. The matrix fill module utilizes Gaussian integration of various quadratures depending on the distance between reacting facets to fill the impedance matrix. The solve module utilized is the LAPACK dense symmetric solver.

The PO module calculates the PO currents on the large smooth surfaces of the target. This module simply implements the cross product of the incident field with the outwardly directed surface normal from each PO region facet.

The sensor module combines the fields generated by the MOM and PO modules as well as perturbates them to account for the MOM/PO interactions. In addition, the sensor module peforms the convolution between the returned fields to the sensor and the sensor system response. This can be a very computationally intensive operation due to the large sizes of the fast Fourier transforms required for many sensors.

The last module is the output module which organizes and presents the sensor performance parameters to the user.

A listing of the software is provided in Appendix A.

SUMMARY

A description of a hybrid electromagnetic formulation has been presented. The field presented tot he sensor from the target are determined using MOM and PO. These fields

are convolved with the sensor system response to determine the performance parameters of the sensor.

REFERENCES

[1] L.N. Medgyesi-Mitschang and D.S. Wang, " Hybrid solutions for scattering from perfectly conducting bodies of revolution," IEEE Trans. Antennas Propagat., vol. AP-31, pp. 570-583, 1983.

[2] L.N. Medgyesi-Mitschang and D.S. Wang, " Hybrid solutions for scattering from large bodies of revolution with material discontinuities and coatings," IEEE Trans. Antennas Propagat., vol. AP-32, pp. 717-723, 1984.

[3] S.M. Rao, D.R. Wilton, and A.W. Glisson, "Electromagnetic scattering by surfaces of any shape," IEEE Trans. Antennas Propagat., vol. AP-30, pp. 409-418, May 1982.

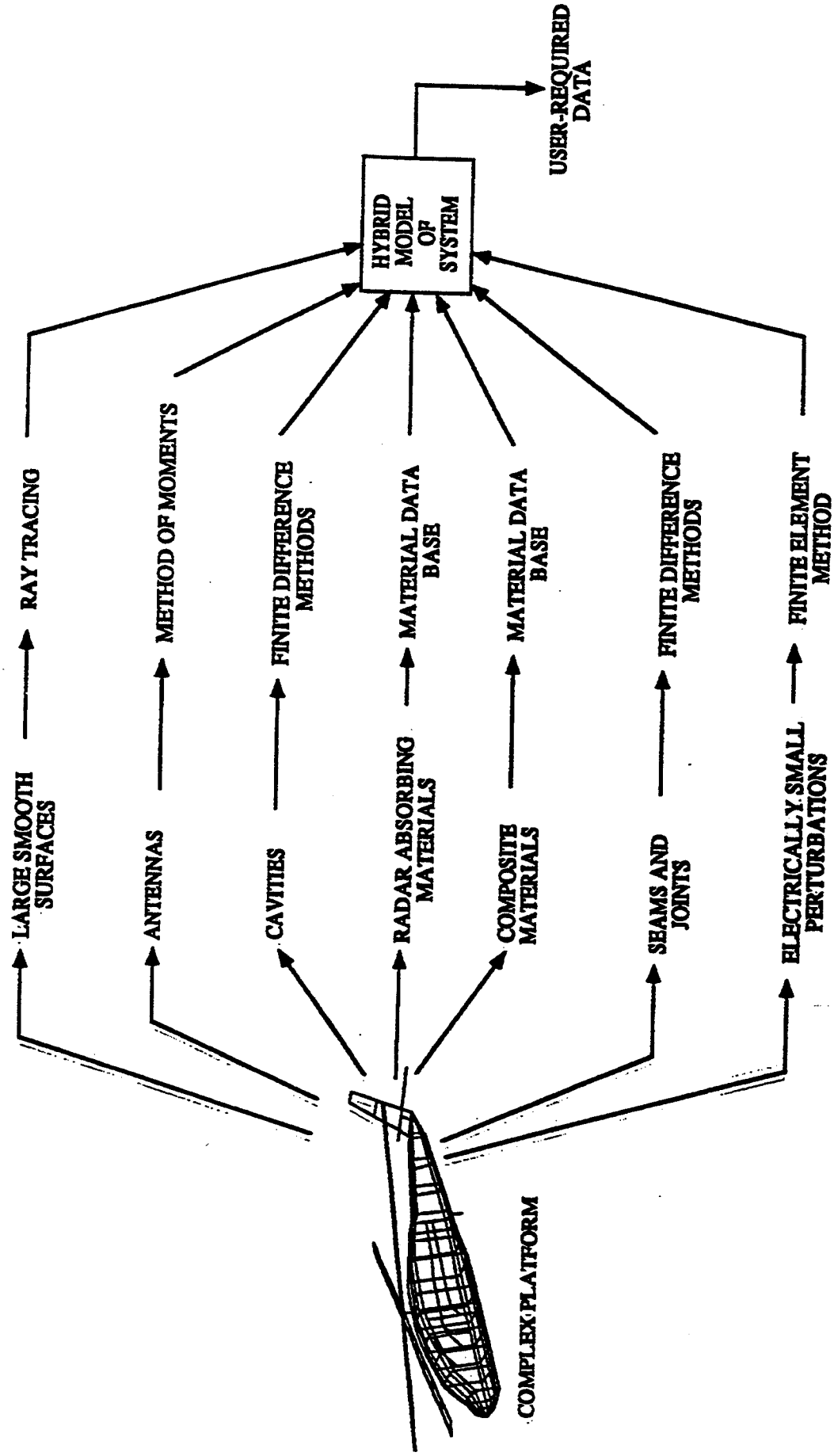


Figure 1. Hybrid Decomposition of a Helicopter

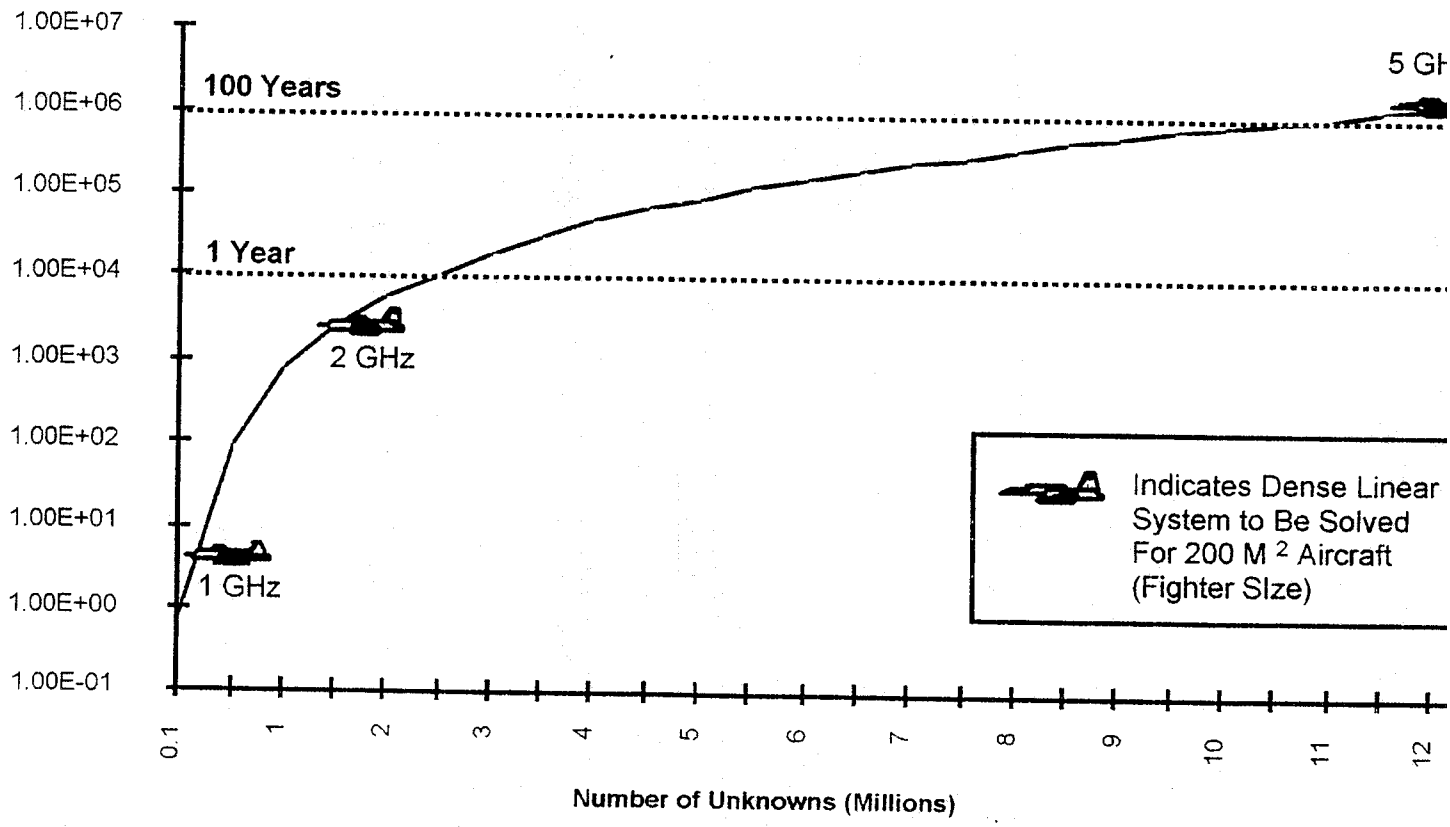
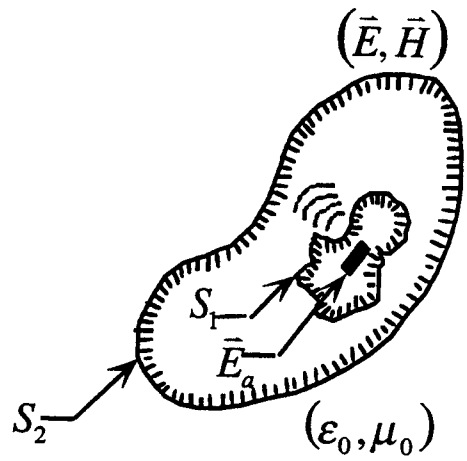
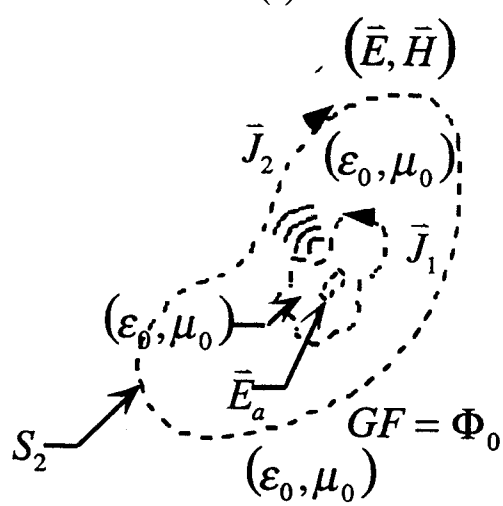


Figure 2. Amount of Time to Solution (Hours) Versus Number of Unknowns for Direct Solver Assuming Sustained TeraFLOP Rate

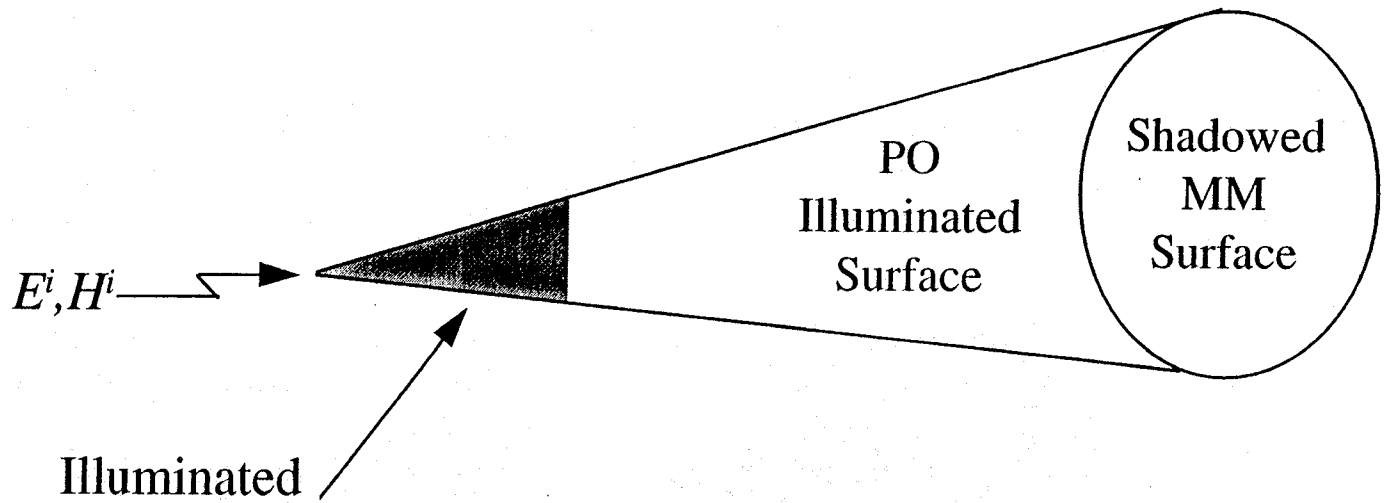


3(a)



3(b)

Figure 3. Example Hybrid Decomposition (a) Original Problem; (b) Equivalent Problem



I_1, I_2 = MM and PO Current Coefficients Respectively
Z_{11} = MM Interaction Matrix
Z_{12} = MM/PO Interaction Matrix
E_1, E_2 = MM and PO Excitation Matricies

Original Exact System: $\begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} E_1 \\ E_2 \end{bmatrix}$

Asymptomatic Solution: $Z_{11} I_1 = E_1 - Z_{12} I_2$

Note: Hybrid Solution Has Reduced Size Linear System

Figure 4. Simplified Hybrid Formulation

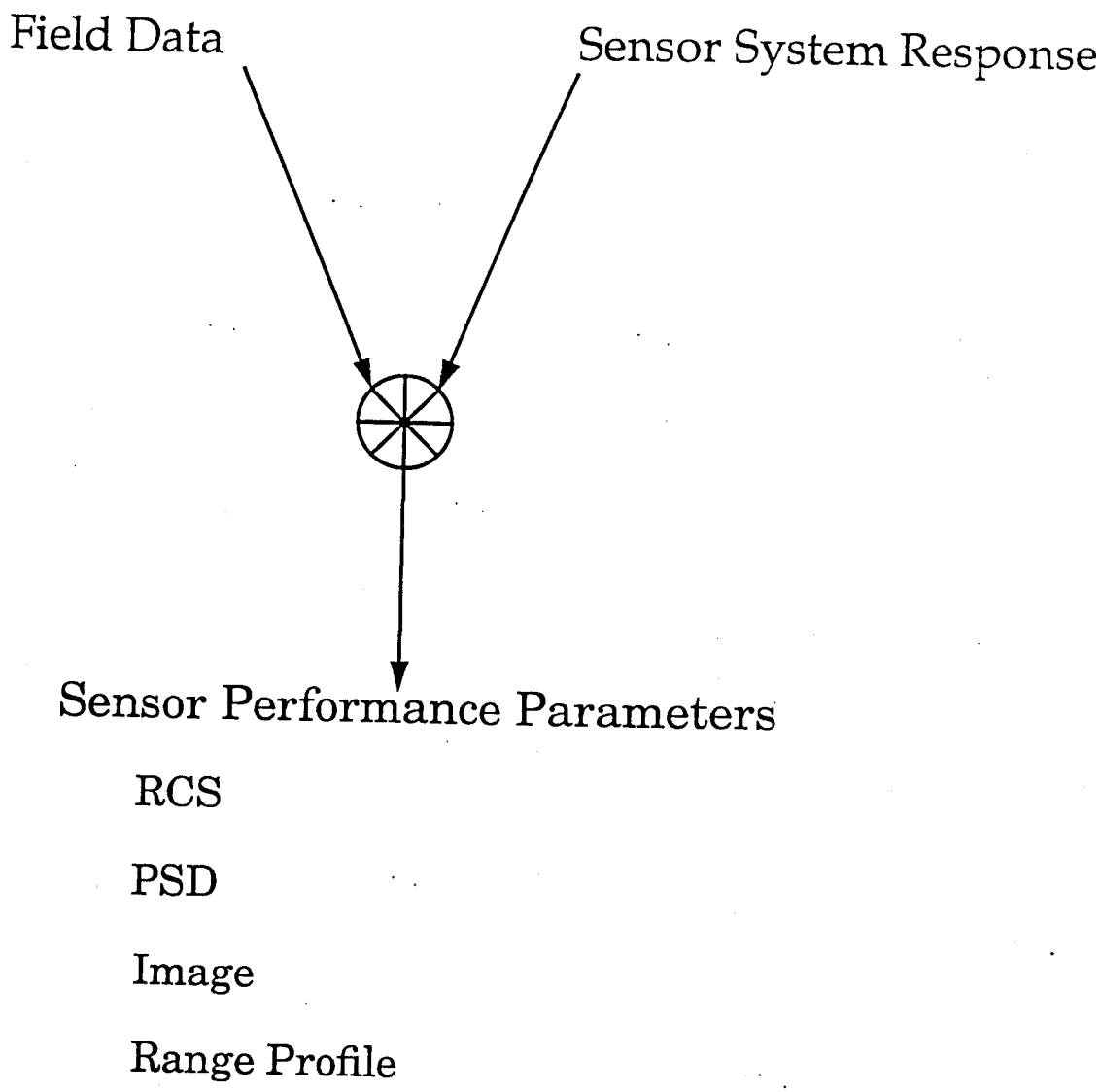


Figure 5. Convolution Stage

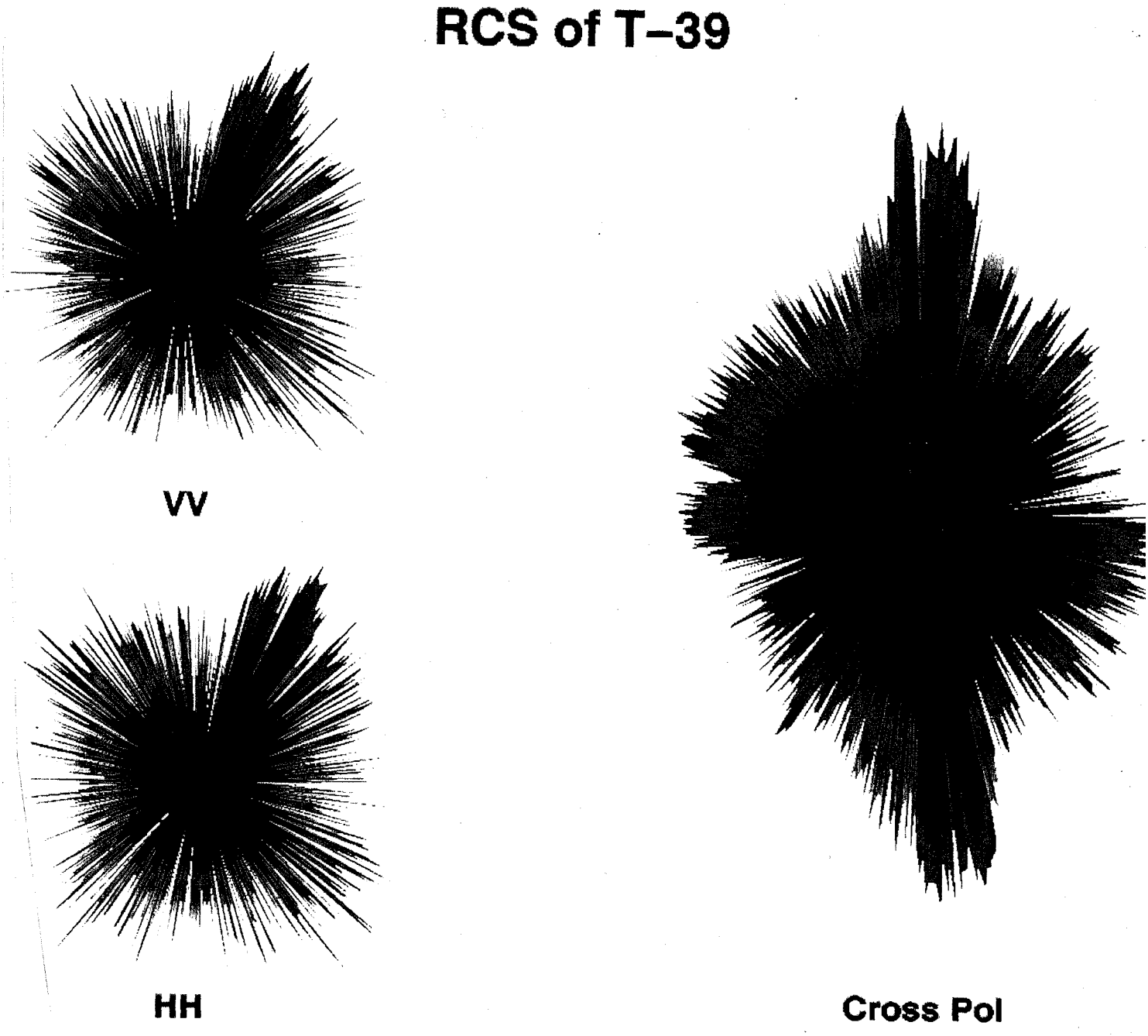


Figure 6. Sample RCS Calculation

Appendix A

Source Code Listing

```
      subroutine agm(nunit,numpat,nface,nedge,xvert,yvert,zvert,idxvf)
c
c read agm file
c
      implicit none
      real xvert(*),yvert(*),zvert(*),x1,y1,z1,x2,y2,z2,x3,y3,z3
      integer idxvf(3,*),nvrt,nfct,nunit,i,numpat,nface,nedge
      nvrt=0
      nfct=0
c
c read vertices forming facets
c
 100  read(nunit,*,end=300)
      read(nunit,10)x1,y1,z1
      read(nunit,10)x2,y2,z2
      read(nunit,10)x3,y3,z3
 10   format(3g10.5)
      nfct=nfct+1
      do 110 i=1,nvrt
        if(x1.eq.xvert(i).and.y1.eq.yvert(i).and.z1.eq.zvert(i))then
          idxvf(1,nfct)=i
          goto 120
        endif
 110  continue
      nvrt=nvrt+1
      xvert(nvrt)=x1
      yvert(nvrt)=y1
      zvert(nvrt)=z1
      idxvf(1,nfct)=nvrt
 120  continue
      do 200 i=1,nvrt
        if(x2.eq.xvert(i).and.y2.eq.yvert(i).and.z2.eq.zvert(i))then
          idxvf(2,nfct)=i
          goto 210
        endif
 200  continue
      nvrt=nvrt+1
      xvert(nvrt)=x2
      yvert(nvrt)=y2
      zvert(nvrt)=z2
      idxvf(2,nfct)=nvrt
 210  continue
      do 220 i=1,nvrt
        if(x3.eq.xvert(i).and.y3.eq.yvert(i).and.z3.eq.zvert(i))then
          idxvf(3,nfct)=i
          goto 230
        endif
 220  continue
      nvrt=nvrt+1
      xvert(nvrt)=x3
      yvert(nvrt)=y3
      zvert(nvrt)=z3
      idxvf(3,nfct)=nvrt
 230  continue
      goto 100
 300  continue
      numpat=nvrt
      nface=nfct
      nedge=0
      return
      end
```

```
      subroutine block(ib,jb)
c
c Determine if any of the unknowns from the test and source surfaces fall
c within the system matrix sub-block being filled.
c Eliminate any unknowns from the index arrays
c which are not in the sub-block. Set nincl=0 if none of the test/source
c unknown combinations will contribute to the sub-block being filled.
c
      implicit none
      include 'arraydim.inc'
      include 'edges.inc'
      include 'index.inc'
      include 'block.inc'
      integer ni,ib,nj,jb,itype,i,indii,jtype,j,indjj
      ni=numedg(ib)
      nj=numedg(jb)
c
c itype and jtype variables
c 0 - none of the edges are in the sub-block
c 1 - edges are only in the sub-block
c
      itype=0
c
c loop over edges
c
      do 100 i=1,ni
            indii=iabs(indxi(i))
            if((iblck1.le.indii.and.indii.le.iblck2)
     +        .or.(jblck1.le.indii.and.indii.le.jblck2))then
c
c edge is within sub block
c
               itype=1
            else
c
c edge is not within sub block.
c for edge not within sub block set temporary global unknown to 0.
c
               indxi(i)=0
            endif
 100  continue
c
c if no unknowns within subn block, quit on this surface
c
      if(itype.eq.0)then
         nincl=0
         return
      endif
      jtype=0
c
c loop over edges
c
      do 200 j=1,nj
            indjj=iabs(indxj(j))
            if((jblck1.le.indjj.and.indjj.le.jblck2)
     +        .or.(iblck1.le.indjj.and.indjj.le.iblck2))then
c
c edge is within sub block
c
               jtype=1
            else
c
c edge is not within sub block.
c for edge not within sub block set temporary global unknown to 0.
c
               indxj(j)=0
```

```
            endif
 200  continue
c
c if no unknowns within sub block, quit on this surface
c
      if(jtype.eq.0)then
         nincl=0
         return
      endif
      return
      end
```

```
      subroutine block2(ni,indx,nj,jndx,numb)
c
c are test and source unknowns in sub-block?
c
      integer indx(*),jndx(*)
      include 'arraydim.inc'
      include 'index.inc'
      include 'block.inc'
      numb=1
      do 310 i=1,ni
      it=indx(i)
      do 310 j=1,nj
        jt=jndx(j)
        do 300 kloc=1,nincl
          ib=iabs(indxi(it))
          jb=iabs(indxj(jt))
          if(iblck1.le.ib.and.ib.le.iblck2.and.
     +     jblck1.le.jb.and.jb.le.jblck2)return
          if(jblck1.le.ib.and.ib.le.jblck2.and.
     +     iblck1.le.jb.and.jb.le.iblck2)return
 300    continue
 310  continue
      numb=0
      return
      end
```

```
      subroutine blocki(ni,indx,numb)
c
c are test unknowns in sub-block?
c
      implicit none
      integer indx(*),numb,i,ni,it,kloc
      include 'arraydim.inc'
      include 'index.inc'
      numb=1
      do 110 i=1,ni
        it=indx(i)
        do 100 kloc=1,nincl
          if(indxi(it).ne.0)return
 100    continue
 110  continue
      numb=0
      return
      end
```

```
      subroutine blockj(nj,jindx,numb)
c
c source unknowns in sub-block?
c
      implicit none
      integer jindx(*),numb,j,nj,jt,kloc
      include 'arraydim.inc'
      include 'index.inc'
      numb=1
      do 210 j=1,nj
        jt=jindx(j)
        do 200 kloc=1,nincl
          if(indxj(jt).ne.0)return
 200    continue
 210  continue
      numb=0
      return
      end
```

```
      subroutine build(zxx,it,jt,isym,z1,lz1)
c
c add the element zxx to the system matrix z1 at all locations.
c
      implicit none
      complex*8 zxx,z1(*),sign
c
      include 'arraydim.inc'
c
      include 'index.inc'
      include 'block.inc'
      integer nbi,nbj,kloc,nb,lz1,ib,it,jb,jt,isym,kb,indb
      if(part) then
        nbi=iblck2-iblck1+1
        nbj=jblck2-jblck1+1
      endif
      do 100 kloc=1,nincl
        nb=lz1
        ib=indxi(it)
        jb=indxj(jt)
        if(ib.eq.0 .or. jb.eq.0) go to 100
        sign=curij
        if(ib*jb.lt.0) sign=-sign
        ib=iabs(ib)
        jb=iabs(jb)
c
c build symmetric matrix in packed form.
c
c skip the diagonal elements of a symmetric matrix, if the elements are be:
c the main diagonal of z1.
          if(isym.ne.0 .and. it.eq.jt .and. ib.gt.jb) go to 100
c double the elements of a full matrix, if the elements are on the main
c diagonal of z1.
          if(ib.eq.jb) then
            if(isym.eq.0 .or. it.ne.jt) then
              sign=2.0*sign
            endif
          endif
          if(ib.gt.jb) then
            kb=ib
            ib=jb
            jb=kb
          endif
          indb=(jb-1)*jb/2+ib
c
c check if a sub-block of a partitioned matrix is being filled.
c
        if(part) then
          if(iblck1.le.ib .and. ib.le.iblck2 .and.
     1     jblck1.le.jb .and. jb.le.jblck2) then
c matrix element is in the sub-block
            nb=nbi
            ib=ib-iblck1+1
            jb=jb-jblck1+1
            if(iblck1.eq.jblck1 .and. iblck2.eq.jblck2) then
              indb=(jb-1)*jb/2+ib
            else
              indb=(jb-1)*nb+ib
            endif
          elseif(jblck1.le.ib.and.ib.le.jblck2.and.
     +           iblck1.le.jb.and.jb.le.iblck2)then
c
c matrix element is in transpose of sub-block
c
          nb=nbj
          ib=ib-jblck1+1
```

```
          jb=jb-iblck1+1
          indb=nbi*nbj+(jb-1)*nb+ib
          else
c matrix element is not in either sub-block
            go to 100
          endif
        endif
        z1(indb)=sign*zxx+z1(indb)
 100  continue
      return
      end
```

```
      function db(x)
c
c express x in decibels
c
      implicit none
      real*4 db,x
      db=-1000.
      if(x.eq.0.)return
      db=10.*log10(x)
      return
      end
```

```
      subroutine dot(a,b,x,n)
c
c x=x+c*(a dot b)
c
      implicit none
      integer i,n
      complex a(*),b(*),x,temp
      temp=(0.,0.)
      do 10 i=1,n
        temp=temp+a(i)*b(i)
 10   continue
      x=x+temp
      return
      end
```

```
      subroutine edges(ifacvrt,nface,iedvrt,nedge)
c
c determine patch edges
c
c ifacvrt=indices of vertices forming faces
c nface=number of faces
c iedvrt=indices of vertices forming edges
c nedge=number of edges
c
      implicit none
      integer ifacvrt(3,*),iedvrt(2,*)
      integer nedge,iface,nface,iedge,i1,i2,je,j1,j2
c
c initialize number of edges
c
      nedge=0
c
c loop over faces determining the edges of the face iface
c
      do 200 iface=1,nface
        do 190 iedge=1,3
          if(iedge.eq.1)then
            i1=ifacvrt(2,iface)
            i2=ifacvrt(3,iface)
          elseif(iedge.eq.2)then
            i1=ifacvrt(3,iface)
            i2=ifacvrt(1,iface)
          else
            i1=ifacvrt(1,iface)
            i2=ifacvrt(2,iface)
          endif
c
c does edge exist?
c
c if edge has already been found: common to a previously
c analyzed face goto next edge
c
          do 170 je=1,nedge
            j1=iedvrt(1,je)
            j2=iedvrt(2,je)
c
c new edge?
c
            if((i1.eq.j1.and.i2.eq.j2).or.
     &          (i1.eq.j2.and.i2.eq.j1))goto 190
 170      continue
c update edge count
c
          nedge=nedge+1
c
c store newly found edge
c
          iedvrt(1,nedge)=i1
          iedvrt(2,nedge)=i2
 190    continue
 200  continue
      return
      end
```

```
      subroutine eindex(i2,indi)
c
c determine the global unknown numbers corresponding to the edges
c of surface i2
c
      implicit none
      integer indi(*),ni,i2,ie,k,kz
      include 'arraydim.inc'
      include 'edges.inc'
      include 'indx2.inc'
      include 'ecurind.inc'
c
c assign # edges on surface i2 to ni
c
      ni=numedg(i2)
c
c assign the first edge of surface i2 to ie.
c used to calculate offset for global unknown # assignment.
c inde=index of first edge of surface i2
c
      ie=inde(i2)
c
c loop over the edges of surface i2
c
      do 30 k=1,ni
c
c calculate the index of iedind that contains the unknown
c # of edge k
c
        kz=ie+k-1
c
c indi=global unknown # of the kth edge of surface i2
c
        indi(k)=iedind(kz)
 30   continue
      return
      end
```

```
      subroutine eleqind(newind,noldind,jcur,nedge)
c
c newind <-- noldind (edge indices or unknowns)
c jcur=jcur-1 (decrement edge/unknown count)
c
      implicit none
      include 'arraydim.inc'
      include 'ecurind.inc'
      integer indnew,newind,indold,noldind,iabold,jcur,
     +iedge,nedge,indz
      indnew=newind
      indold=noldind
      if(indold.eq.0)return
      if(iabs(indnew).eq.iabs(indold))return
      iabold=iabs(indold)
      jcur=jcur-1
      do 10 iedge=1,nedge
        indz=iedind(iedge)
        if(indz.eq.indold)then
          indz=indnew
        elseif(indz.eq.-indold)then
          indz=-indnew
        endif
        if(indz.gt.iabold)then
          indz=indz-1
        elseif(indz.lt.-iabold)then
          indz=indz+1
        endif
        iedind(iedge)=indz
 10   continue
      return
      end
```

```
      subroutine faces(ivrt,nedge,itype,nvf,nfaces)
c
c determine face information
c
c
c ivrt=indices of vertices forming edges
c nedge=number of edges
c itype=work array that contains edge numbers with vertices common to iedge
c nvf=indices of vertices forming faces
c nfaces = number of faces
c ntype=# of other edges that have common vertices of edge iedge
c
      implicit none
      integer ivrt(2,*),nvf(3,*),itype(*)
      integer nfaces,iedge,nedge,ntype,jedge,i,j,kedge,k
c
c initialize face count
c
      nfaces=0
c
c loop over edges which may form faces
c
      do 500 iedge=1,nedge-2  ! nedge-2 because 3 edges comprise face
c
c initialize count of edges with vertices common to iedge
c
        ntype=0
c
c loop over edges other than iedge that have yet to be checked for common
c vertices
c
        do 200 jedge=iedge+1,nedge  ! all edges numbered < iedge+1 have
c either been checked or are the current edge being check (iedge)
c
c loop over vertices of both iedge and jedge testing for common vertices
c
          do 190 i=1,2
            do 180 j=1,2
              if(ivrt(i,iedge).eq.ivrt(j,jedge))then
c
c update count of edges with common vertices to iedge
c
                ntype=ntype+1
c
c store edge numbers with vertices common to iedge
c
                itype(ntype)=jedge
                goto 200
              endif
 180        continue
 190      continue
 200    continue
c
c loop over edges with common vertices to iedge testing for closed perimeter
c
        do 400 jedge=1,ntype-1  ! ntype-1 because it takes 2 edges+iedge to
c form a face
c
          do 390 kedge=jedge+1,ntype  ! all itype arguments < jedge+1 have
c been checked to see if they form a perimeter with iedge already already
c or are the current itype argument being checked (jedge)
c
c loop over vertices of both jedge and iedge edges
c
            do 380 j=1,2  ! jedge vertices
              do 370 k=1,2  ! kedge vertices
```

```
c
c face formed when two edges with same common vertiex to either vertex of
c edge iedge and edges are not common to the same vertex of iedge
c
                 if((ivrt(j,itype(jedge)).eq.ivrt(k,itype(kedge))).and.
     &(ivrt(j,itype(jedge)).ne.ivrt(1,iedge).and.ivrt(j,itype(jedge))
     &.ne.ivrt(2,iedge)))then
c
c update face count (nfaces)
c
                   nfaces=nfaces+1
                   nvf(1,nfaces)=ivrt(1,iedge)
                   nvf(2,nfaces)=ivrt(2,iedge)
                   nvf(3,nfaces)=ivrt(j,itype(jedge))
                   goto 400
                 endif
 370           continue
 380         continue
 390       continue
 400     continue
 500   continue
       return
       end
```

```
      subroutine acad(nunit,nvrt,nface,xvert,yvert,zvert,idxvf)
c
c read acad geometry files
c
      implicit none
      integer idxvf(3,*),nvrt,nfct,nunit,nsolids,i,nvrtemp,j,numpoly
     +,nfacet,k,idx1,idx2,idx3,nface
      real xvert(*),yvert(*),zvert(*)
      nvrt=0
      nfct=0
c
c title line must be skipped
c
      read(nunit,*)
      read(nunit,*)nsolids
c
c loop over solids defining geometry
c
      do 500 i=1,nsolids
        read(nunit,*)
        read(nunit,*)
        read(nunit,*)nvrtemp
c
c read vertices
c
        do 100 j=nvrt+1,nvrt+nvrtemp
          read(nunit,*)xvert(j),yvert(j),zvert(j)
 100    continue
        read(nunit,*)numpoly
c
c loop over polygons
c
        do 300 j=1,numpoly
          read(nunit,*)
          read(nunit,*)nfacet
          do 200 k=nfct+1,nfct+nfacet
c
c read and set facet indices
c
            read(nunit,*)idx1,idx2,idx3
            idxvf(1,k)=idx1+nvrt
            idxvf(2,k)=idx2+nvrt
            idxvf(3,k)=idx3+nvrt
            if(idxvf(1,k).lt.nvrt+1.or.idxvf(1,k).gt.nvrt+nvrtemp.or.
     &        idxvf(2,k).lt.nvrt+1.or.idxvf(2,k).gt.nvrt+nvrtemp.or.
     &        idxvf(3,k).lt.nvrt+1.or.idxvf(3,k).gt.nvrt+nvrtemp)then
             write(6,*)'   error: Face vertex index out of range'
             stop
            endif
 200      continue
c
c increment facet idex counter
c
          nfct=nfct+nfacet
 300    continue
c
c increment vertex index counter
c
        nvrt=nvrt+nvrtemp
 500  continue
c
c total facets and edges
c
      nface=nfct
      return
      end
```

```
      subroutine fldrcs(ifreq,nfreq,fr,freq)
c
c print out far fields.
c
      implicit none
      logical freq
      include 'arraydim.inc'
      include 'problem.inc'
      include 'wavenumber.inc'
      include 'threat.inc'
      include 'order.inc'
      include 'dbsm.inc'
      include 'scatter.inc'
      include 'const.inc'
      complex*8 a1
      real*4 dtor,fr,p0,s,db,s1,s2,s3,s4
      integer k,numb,k1,ifreq,nfreq
      dtor=pi/180.
      write(6,4) title,fk,fr,2.*pi/fk
 4    format(1h1,'problem: ',a80,//,' fk = ',g12.4,/,' fr = ',f9.3,/,
     & ' lambda = ',g12.4,/)
      write(6,*)
      if(numzel.ne.0) then
        write(6,*) '    3d-patch'
      endif
          p0=(fk*fk*eta/2./pi)**2/(4.*pi)
          s=2.*db(0.2997925/fr)
        a1=(0.,-1.)
      if(monbi.gt.0) then
        write(6,16) 'mono-static rcs'
        write(6,18) 2,2
      elseif(monbi.eq.0) then
        write(6,16) 'bi-static rcs'
        write(6,*) '            phi = ',phi,'   thet = ',thet
        write(6,18) 2,2
      endif
 16   format(//,5x,a,/)
 18   format(34x,'sigma/lambda**',i1,' (db)',36x,'sigma/m**',i1,' (db)',
     1 /,20x,45(1h-),7x,45(1h-),/,
     2 5x,'phis',5x,'thes',2(9x,'00',10x,'00',10x,'00',10x,'00',5x),/,
     3 1h+,15x,2(9x,'--',10x,'//',10x,'-/',10x,'/-',5x))
      do 119 k=1,nang
        ttscat(k)=a1*ttscat(k)
        s1=abs(ttscat(k))
        s1=db(p0*s1*s1)
        ppscat(k)=a1*ppscat(k)
        s2=abs(ppscat(k))
        s2=db(p0*s2*s2)
        tpscat(k)=a1*tpscat(k)
        s3=abs(tpscat(k))
        s3=db(p0*s3*s3)
        ptscat(k)=a1*ptscat(k)
        s4=abs(ptscat(k))
        s4=db(p0*s4*s4)
          write(6,23) phis(k),thes(k),s1,s2,s3,s4,s1+s,s2+s,s3+s,s4+s
 23       format(1x,2f8.1,4f12.2,4x,4f12.2)
        if(dbsm) then
          s1=s1+s
          s2=s2+s
        endif
c plot file
        if(iangle(k).lt.0) then
          numb=1
          do 110 k1=k+1,nang
            if(iangle(k1).gt.0) then
              numb=numb+1
```

```
            else
              go to 111
            endif
110       continue
111       continue
            if(nang.gt.1) then
              write(31,*) numb,'  dbsm = ',dbsm
            elseif(ifreq.eq.1) then
              write(31,*) nfreq,'  dbsm = ',dbsm
            endif
        endif
        if(nang.gt.1) then
          if(abs(iangle(k)).eq.1) then
              write(31,1) thes(k),s1,s2
          else
              write(31,1) phis(k),s1,s2
          endif
        else
          if(freq) then
              write(31,1) fr,s1,s2
          else
              write(31,1) fk,s1,s2
          endif
        endif
1     format(1x,f8.2,2f10.2,i5)
119   continue
      return
      end
```

```
      subroutine gauss
c
c determine gaussian abscissas and weights
c
c
      implicit none
      include 'intord.inc'
      include 'triint.inc'
      real*4 qcoef(28),eta(28),x(28)
      real*4 etai,xi,etamxi
      integer numpnt(8),np(8),mp(8),mlt(28)
      integer i,npnt,k,nfrmula,imult
c 1 point
      data numpnt(1),np(1),mp(1) /1,1,1/
      data mlt(1) /1/
      data qcoef(1) /1.0/
      data eta(1) /.3333333/
      data x(1) /.3333333/
c 3 point
      data numpnt(2),np(2),mp(2) /3,2,1/
      data mlt(2) /3/
      data qcoef(2) /.3333333/
      data eta(2) /.166666/
      data x(2) /.6666667/
c 7 point
      data numpnt(3),np(3),mp(3) /7,3,3/
      data (mlt(i),i=3,5) /1,3,3/
      data (qcoef(i),i=3,5) /.225,.1259392,.1323941/
      data (eta(i),i=3,5) /.3333333,.1012865,.4701421/
      data (x(i),i=3,5) /.3333333,.7974270,.0597159/
c 12 point
      data numpnt(4),np(4),mp(4) /12,6,3/
      data (mlt(i),i=6,8) /3,3,6/
      data (qcoef(i),i=6,8) /.0508449,.1167863,.0828511/
      data (eta(i),i=6,8) /.0630890,.2492867,.3103524/
      data (x(i),i=6,8) /.873822,.5014265,.6365025/
c 15 point
      data numpnt(5),np(5),mp(5) /15,9,3/
      data (mlt(i),i=9,11) /3,6,6/
      data (qcoef(i),i=9,11) /.0530778,.0708531,.0692747/
      data (eta(i),i=9,11) /.0649305,.5170399,.0438635/
      data (x(i),i=9,11) /.870139,.2845756,.3135592/
c 16 point
      data numpnt(6),np(6),mp(6) /16,12,5/
      data (mlt(i),i=12,16) /1,3,3,3,6/
      data (qcoef(i),i=12,16) /.1443156,.1032174,.0324585,
     +.0950916,.0272303/
      data (eta(i),i=12,16) /.3333333,.1705693,.0505472,
     +.4592926,.2631128/
      data (x(i),i=12,16) /.3333333,.6588614,.8989055,
     +.0814148,.0083948/
c 19 point
      data numpnt(7),np(7),mp(7) /19,17,6/
      data (mlt(i),i=17,22) /1,3,3,3,3,6/
      data (qcoef(i),i=17,22) /.0971358,.0313347,.0778275,
     +.0796477,.0255777,.0432835/
      data (eta(i),i=17,22) /.3333333,.4896825,.4370896,
     +.1882035,.0447295,.221963/
      data (x(i),i=17,22) /.3333333,.020635,.1258208,
     +.6235929,.910541,.0368384/
c 25 point
      data numpnt(8),np(8),mp(8) /25,23,6/
      data (mlt(i),i=23,28) /1,3,3,6,6,6/
      data (qcoef(i),i=23,28) /.0798945,.0711238,.0082238,
     +.0454306,.0373598,.0308867/
      data (eta(i),i=23,28) /.3333333,.4250862,.0233089,
```

```
     +.223767,.3587401,.1432954/
      data (x(i),i=23,28) /.3333333,.1498276,.9533823,
     +.1479256,.029946,.0356326/
      do 100 npnt=1,25
        nmpont(npnt)=0
 100  continue
      k=0
c
c loop over the 8 data sets(1,3,7,12,15,16,19,25)
c
      do 200 nfrmula=1,8
        npnt=numpnt(nfrmula)
        nmpont(npnt)=k+1
c
c loop over eta and x indices for each data set
c (i.e., 19 data set: loop over 17-22)
c
        do 150 i=np(nfrmula),np(nfrmula)+mp(nfrmula)-1
           etai=eta(i)
           xi=x(i)
           etamxi=1.-etai-xi
           do 150 imult=1,mlt(i)
             k=k+1
             if(k.gt.108) then
               write(6,*) ' error: subroutine gauss'
               stop
             endif
             weight(k)=0.5*qcoef(i)
             if(imult.eq.1) then
               alfa(k)=etai
               beta(k)=xi
             elseif(imult.eq.2) then
               alfa(k)=etai
               beta(k)=etamxi
             elseif(imult.eq.3) then
               alfa(k)=xi
               beta(k)=etai
             elseif(imult.eq.4) then
               alfa(k)=xi
               beta(k)=etamxi
             elseif(imult.eq.5) then
               alfa(k)=etamxi
               beta(k)=etai
             elseif(imult.eq.6) then
               alfa(k)=etamxi
               beta(k)=xi
             endif
 150     continue
 200  continue
      if(nmpont(nself).eq.0) then
        write(6,*) ' error: nself integration formula not available'
        stop
      endif
      if(nmpont(nnear).eq.0) then
        write(6,*) ' error: nnear integration formula not available'
        stop
      endif
      if(nmpont(nmid).eq.0) then
        write(6,*) ' error: nmid integration formula not available'
        stop
      endif
      if(nmpont(nfar).eq.0) then
        write(6,*) ' error: nfar integration formula not available'
        stop
      endif
      return
```

```
end
```

```
      subroutine geoin(level,iunord)
      implicit none
      include 'arraydim.inc'
      include 'const.inc'
      include 'wavenumber.inc'
      include 'numbers.inc'
      include 'surcord.inc'
      include 'faces.inc'
      include 'indx1.inc'
      include 'edges.inc'
      include 'indx2.inc'
      include 'ecurind.inc'
      include 'unit.inc'
      include 'patchtol.inc'
      include 'numj.inc'
      include 'order.inc'
      integer mompo(nbndmax),indx(2)
      integer level(*),iunord(*)
      integer nint(nbndmax),next(nbndmax),nje(nbndmax),nren(nbndmax),
     & nrpls(nbndmax),nrmin(nbndmax)
      integer npts,numface,numedge,inptyp,iunit,nptsp1,numfcp1,nedgp1
     +,nfact,nedg,nummove,idx1,idx2,istart,iend,i1,i2,i3,ibnd,nside,
     +jstart,jend,jedge,jdx1,jdx2,ijunc,nedint,nedext,nedjun,jbnd,
     +j1,j2,ijnctyp,kedge,iside,nunknon,loc,new,iold,idx,ind2,nhy,
     +i,j,id2,ii,ioffset,jj,kk,iofsete,if1,nlev,neuler
      real*4 dstance,x21,y21,z21,x31,y31,z31,deltax,deltay,deltaz,
     +delta,delinv,del,xx,yy,zz
      character*80 geofil
      write(6,10)
 10   format(//'    geometry input ',//)
c
c initialize number of surfaces , vertices, faces, and edges
c
      nub=0
      npts=0
      numface=0
      numedge=0
c
c loop to read geometry surfaces
c
 20   continue
c
c inptyp > 0: mdac carlos file(standard input)
c inptyp = -1: mdac carlos file(external)
c inptyp = -2: acad facet file
c inptyp = -3: agm file
c inptyp = -4: patran-iges file
c
      read(5,*)inptyp
c
c check for last surface read
c
      if(inptyp.eq.0)goto 100   ! terminate geometry files to be read in
c
c count surfaces
c
      nub=nub+1
      write(6,30)nub
 30   format(///,'  surface number ',i2)
      if(nub.gt.nbndmax)then
        write(6,*)' insufficient dimension: nbndmax = ',nbndmax
        write(6,*) '                              nub = ',nub
        stop
      endif
c
c mompo=mom or po solution type for surface nub
```

```
c mompo=2 (po solution)
c mompo=1 (mm solution)
c
      read(5,*)mompo(nub)
      write(6,*)
      if(mompo(nub).eq.2)then
        write(6,*)'  PO surface'
      elseif(mompo(nub).eq.1)then
        write(6,*)'  MM surface'
      endif
c
c read geometry files
c
      iunit=5
c
c prepare to read external files/devices
c
      if(inptyp.lt.0)then
        read(5,40)geofil
 40     format(a80)
        write(6,50)geofil
 50     format(1x,'geometry file name: ',a80)
        iunit=1
        open(unit=1,file=geofil,status='old')
      endif
c
c increment total vertices, faces, and edges by 1. Principally
c used as pointers.
c
      nptsp1=npts+1
      numfcp1=numface+1
      nedgp1=numedge+1
c
c call to different file types
c
c
c iunit = device number to be read
c inptyp=number of vertices (for mdac format)
c nfact=number of faces
c nedg=number of edges
c xv, yv, and zv are vertices
c idxvf are indices of vertices comprising faces
c idxve are indices of vertices comprising edges
c
      if(inptyp.ge.-1)then
        if(inptyp.lt.0)write(6,*) '  mdac carlos file'
        call mdacin(iunit,inptyp,nfact,nedg,xv(nptsp1),yv(nptsp1),
     &   zv(nptsp1),idxvf(1,numfcp1),idxve(1,nedgp1))
      elseif(inptyp.eq.-2)then
        write(6,*)'   acad file'
        call acad(iunit,inptyp,nfact,xv(nptsp1),yv(nptsp1),
     &   zv(nptsp1),idxvf(1,numfcp1))
        nedg=0
      elseif(inptyp.eq.-3)then
        write(6,*) '   agm file'
        call agm(iunit,inptyp,nfact,nedg,xv(nptsp1),yv(nptsp1),
     &   zv(nptsp1),idxvf(1,numfcp1))
      elseif(inptyp.eq.-4)then
        write(6,*) '   patran file'
        call patran(iunit,inptyp,nfact,nedg,xv(nptsp1),yv(nptsp1),
     &   zv(nptsp1),idxvf(1,numfcp1))
      endif
c
c close external file
c
      if(iunit.ne.5)close(unit=iunit)
```

```
c
c number of vertices of surface nub (nup)
c note: inptyp is modified in routine that reads geometry file
c (e.g. mdacin,acad,etc.)
c
      nup(nub)=inptyp
c
c start index of global vertices of surface nub
c
      indp(nub)=nptsp1
c
c rolling count of total vertices
c previous total (npts) plus number of vertices of surface nub= new total (
c
      npts=npts+inptyp
      if(npts.gt.nptsmax)then
        write(6,*)' insufficient dimension : nptsmax = ',nptsmax
        write(6,*)'                          npts = ',npts
        stop
      endif
      write(6,*)
      write(6,*)'number of vertex points input= ',inptyp
      write(6,*)'number of faces input = ',nfact
      write(6,*)'number of edges input = ',nedg
c
c edge and face information determined
c if we have edges calculate faces, if we have faces calculate edges
c
      if(nfact.ne.0)then
        call edges(idxvf(1,numfcp1),nfact,idxve(1,nedgp1),nedg)
      else
c
c edtype used only to conserve memory
c
        call faces(idxve(1,nedgp1),nedg,edtype(nedgp1),idxvf(1,numfcp1),
     &   nfact)
      endif
c
c write face and edge information
c
      write(6,*)
      write(6,*) 'number of faces analyzed = ',nfact
      write(6,*) 'number of edges analyzed = ',nedg
      write(6,*)
c
c orient other faces relative to face 1: all faces oriented for
c outwardly directed surface normal
c
c
c idxef is used as work array only here (saves memory)
c
c
c nfact=number of faces, idxef=indices of edges comprising faces
c
      call reorint(nfact,idxvf(1,numfcp1),idxef(1,numfcp1))
      write(6,*)'face 1 vertex indices: ',idxvf(1,numfcp1),
     & idxvf(2,numfcp1),idxvf(3,numfcp1)
      write(6,*)'edge 1 vertex indices: ',idxve(1,nedgp1),
     & idxve(2,nedgp1)
c
c numfac(nub)=number of faces comprising surface nub
c indf=index of first face of surface nub (numface is the number
c of faces through surface nub-1)
c
      numfac(nub)=nfact
      indf(nub)=numface+1
```

```
c
c update face count through surface nub
c
      numface=numface+nfact
      if(numface.gt.nfacmax)then
        write(6,*)' insufficient dimension: nfacmax = ',nfacmax
        write(6,*) '                        numface = ',numface
        stop
      endif
c
c numedg(nub)=number of edges comprising surface nub
c inde=index of first edge of surface nub (numedge is the number
c of edges through surface nub-1)
c
      numedg(nub)=nedg
      inde(nub)=numedge+1
c
c update edge count through surface nub
c
      numedge=numedge+nedg
      if(numedge.gt.nedgmax)then
        write(6,*) ' insufficient dimension: nedgmax = ',nedgmax
        write(6,*) '                        numedge = ',numedge
        stop
      endif
c
c end of surface read in and processed
c
      goto 20
c
c go to here (100) if all surfaces read in
c
 100  continue
c
c npoynt=total # vertices
c nfaces = total # faces
c nedges = total # edges
c
      npoynt=npts
      nfaces=numface
      nedges=numedge
      write(6,*)
c
c collapse vertices
c
c
c if 2 vertices are separated by a distance < pattol
c they are collapsed to be a single vertex
c
      if(pattol.ne.0.)then
c
c initialize count of collapsed vertices
c
        nummove=0
c
c loop over vertices
c
        do 120 idx1=1,npts
c
c loop over vertices yet to be checked
c
          do 110 idx2=idx1+1,npts
c
c calculate separation distance between vertices idx1 and idx2
c
            dstance=sqrt((xv(idx1)-xv(idx2))**2+(yv(idx1)-yv(idx2))**2+
```

```
     &                  (zv(idx1)-zv(idx2))**2)
c
c if not the same coordinates and separated by < pattol then collapse vert
c
            if(dstance.ne.0..and.dstance.lt.pattol)then
c
c update collapsed vertex count
c
              nummove=nummove+1
c
c collapse vertices: make higher indexed vertex equal to lower:
c this allows the vertex to be checked against distance between it
c and other vertices
c
              xv(idx2)=xv(idx1)
              yv(idx2)=yv(idx1)
              zv(idx2)=zv(idx1)
              goto 120
            endif
 110      continue
 120    continue
        write(6,*)' Number of vertex points collapsed (pattol):'
        write(6,*)'   Vertex points changed - ',nummove
      endif
c
c calculate face center coordinates
c
c
c loop over surfaces
c
      do 140 idx1=1,nub
        istart=indf(idx1)
        iend=indf(idx1)+numfac(idx1)-1
c
c loop over faces of surface idx1
c istart and iend represent range of indices of faces of surface idx1
c
        do 130 numfcp1=istart,iend
c
c calculate global indices of vertices forming faces:
c add offset indp(idx1) to index numbers provided by individual surfaces
c i1,i2,i3=global vertex indices
c
          i1=indp(idx1)+idxvf(1,numfcp1)-1
          i2=indp(idx1)+idxvf(2,numfcp1)-1
          i3=indp(idx1)+idxvf(3,numfcp1)-1
c
c calculate center coordinates
c
          xc(numfcp1)=(xv(i1)+xv(i2)+xv(i3))*.33333333
          yc(numfcp1)=(yv(i1)+yv(i2)+yv(i3))*.33333333
          zc(numfcp1)=(zv(i1)+zv(i2)+zv(i3))*.33333333
 130    continue
 140  continue
c
c calculate edge lengths
c
c
c loop over surfaces
c
      do 160 idx1=1,nub
c
c loop over edges of surface idx1
c istart and iend represent range of indices of edges of surface idx1
c
        istart=inde(idx1)
```

```
          iend=inde(idx1)+numedg(idx1)-1
          do 150 nedgp1=istart,iend
c
c initialize edtype (will be used later to determine the type (interior
c /exterior,etc.) of edge
c
            edtype(nedgp1)=-2
c
c calculate global indices of vertices forming edges:
c add offset indp(idx1) to index numbers provided by individual surfaces
c i1,i2=global vertex indices
c
            i1=indp(idx1)+idxve(1,nedgp1)-1
            i2=indp(idx1)+idxve(2,nedgp1)-1
c
c calculate edge length
c
            edlen(nedgp1)=sqrt((xv(i1)-xv(i2))**2+(yv(i1)-yv(i2))**2+
     &       (zv(i1)-zv(i2))**2)

            if ((idx1 .eq. 1) .and. (nedgp1 .eq. 1)) then
               write(6,*)"edge 1 v1 cords =", xv(i1), yv(i1), zv(i1)
               write(6,*)"edge 1 v2 cords =", xv(i2), yv(i2), zv(i2)
               write(6,*)"edge length =", edlen(nedgp1)
            endif
c
c edge length cannot = 0
c
            if(edlen(nedgp1).eq.0.)then
              write(6,*) ' error: zero edge length'
              write(6,*) '    surface number= ',idx1
              write(6,*) '            edge = ',nedgp1-istart+1
              write(6,*) '            point (1) = ',idxve(1,nedgp1)
              write(6,*) '                  (2) = ',idxve(2,nedgp1)
              write(6,*) '            x,y,z (1) = ',xv(i1),yv(i1),zv(i1)
              write(6,*) '                  (2) = ',xv(i2),yv(i2),zv(i2)
              stop
            endif
 150      continue
 160    continue
c
c determine edges which form faces (create idxef)
c this also reorients edge array idxve to be
c consistent with idxvf
c
c loop over surfaces
c
        do 190 ibnd=1,nub
          istart=indf(ibnd)
          iend=indf(ibnd)+numfac(ibnd)-1
c
c loop over beginning and ending indices of
c faces of surface ibnd
c
          do 180 numfcp1=istart,iend
c
c loop over the sides of faces
c
            do 170 nside=1,3
c
c calculate global indices of vertices forming faces:
c add ofset indp(ibnd) to index numbers provided by
c individual surfaces
c i1 and i2=vertices forming edge opposite vertex nside
c
              if(nside.eq.1)then
```

```
              i1=indp(ibnd)+idxvf(2,numfcp1)-1
              i2=indp(ibnd)+idxvf(3,numfcp1)-1
            elseif(nside.eq.2)then
              i1=indp(ibnd)+idxvf(3,numfcp1)-1
              i2=indp(ibnd)+idxvf(1,numfcp1)-1
            else
              i1=indp(ibnd)+idxvf(1,numfcp1)-1
              i2=indp(ibnd)+idxvf(2,numfcp1)-1
            endif
c
c calculate starting and ending indices of
c edges of surface ibnd
c
            jstart=inde(ibnd)
            jend=inde(ibnd)+numedg(ibnd)-1
c
c loop over edges
c
            do 165 jedge=jstart,jend
c
c calculate global indices of vertices forming edges:
c add offset indp(ibnd) to index numbers provided by individual surfaces
c jdx1,jdx2=global vertex indices
c
              jdx1=indp(ibnd)+idxve(1,jedge)-1
              jdx2=indp(ibnd)+idxve(2,jedge)-1
c
c ijunc=0:not common edges
c ijunc=1:common edge oriented correctly
c ijunc=-1:common edge oriented incorrectly
c
              ijunc=0
              if(i1.eq.jdx1.and.i2.eq.jdx2)then
                ijunc=1
              elseif(i1.eq.jdx2.and.i2.eq.jdx1)then
                ijunc=-1
              endif
              if(ijunc.ne.0)then
                if(edtype(jedge).eq.-2)then
c
c assign indices creating edge/face array
c
                  idxef(nside,numfcp1)=jedge-jstart+1
                  if(ijunc.eq.-1)then
c
c reorient edge jedge
c
                    jdx1=idxve(1,jedge)
                    idxve(1,jedge)=idxve(2,jedge)
                    idxve(2,jedge)=jdx1
                  endif
                else
c
c assign indices creating edge/face array
c
                  idxef(nside,numfcp1)=-(jedge-jstart+1)
                endif
c
c increment count of edges common to jedge with
c count starting at -2
c
                edtype(jedge)=edtype(jedge)+1
                goto 170
              endif
 165        continue
c
```

```
c dangling edge
c
            write(6,*) 'error finding edges: ibnd = ',ibnd
            write(6,*) '                     numfcp1 = ',numfcp1
            write(6,*) '                          nside = ',nside
            stop
 170      continue
 180    continue
 190  continue
c
c edtype = 0 - interior
c         -1 - exterior
c         -3 - interior common to more than two faces
c         >0 - exterior connected to edge on another surface
c
c initialize count of edge types
c nedint=# interior edges
c nedext=# exterior edges
c nedjun=# junction edges
c
      nedint=0
      nedext=0
      nedjun=0
      do 230 ibnd=1,nub
        istart=inde(ibnd)
        iend=inde(ibnd)+numedg(ibnd)-1
        do 220 nedgp1=istart,iend
          i1=indp(ibnd)+idxve(1,nedgp1)-1
          i2=indp(ibnd)+idxve(2,nedgp1)-1
c
c edge common to more than 2 faces? edge cannot be common to more
c than two faces
c
          if(edtype(nedgp1).gt.0)then
            edtype(nedgp1)=-3
            write(6,*) '    error: Interior edge is common to more',
     &        ' than two faces'
            write(6,*) '           Surface = ',ibnd
            write(6,*) '           Edge = ',nedgp1-istart+1
            write(6,*) '           Point (1) = ',idxve(1,nedgp1)
            write(6,*) '                 (2) = ',idxve(2,nedgp1)
            write(6,*) '           X,Y,Z (1) = ',xv(i1),yv(i1),zv(i1)
            write(6,*) '                 (2) = ',xv(i2),yv(i2),zv(i2)
            stop
          endif
c
c interior edge?
c
          if(edtype(nedgp1).eq.0)then
c
c increment interior edge count
c
            nedint=nedint+1
            goto 220
          endif
c
c if edge is an exterior edge it is necessary to determine what type
c of exterior edge
c
          do 215 jbnd=1,nub
            jstart=inde(jbnd)
            jend=inde(jbnd)+numedg(jbnd)-1
            do 210 jedge=jstart,jend
c
c if edge is interior or edge is same edge as nedgp1 no need to check:
c only looking for external edge to external edge relationships
```

```
c
                if(edtype(jedge).eq.0)goto 210
                if(nedgp1.eq.jedge)goto 210
                j1=indp(jbnd)+idxve(1,jedge)-1
                j2=indp(jbnd)+idxve(2,jedge)-1
c
c ijnctyp=0 : not a junction edge
c        =1 : junction edge formed by faces with same orientation
c        =-1 : junction edge formed by faces with opposite orientations
c
c same orientation means they both have outwardly
c directed normal vector
c
                ijnctyp=0
c
c vertices numbered same direction (error for PO surfaces)
c
                if(xv(i1).eq.xv(j1).and.yv(i1).eq.yv(j1).and.
     &             zv(i1).eq.zv(j1).and.xv(i2).eq.xv(j2).and.
     &             yv(i2).eq.yv(j2).and.zv(i2).eq.zv(j2))then
                   ijnctyp=-1
c
c vertices ordered properly
c
                elseif(xv(i1).eq.xv(j2).and.yv(i1).eq.yv(j2).and.
     &                 zv(i1).eq.zv(j2).and.xv(i2).eq.xv(j1).and.
     &                 yv(i2).eq.yv(j1).and.zv(i2).eq.zv(j1))then
                   ijnctyp=1
                endif
                if(ijnctyp.eq.-1)then
                  write(6,*) '   error: Inconsistent triangular face ',
     &             'orientation between intersecting surfaces'
                  write(6,*) '            Surfaces ibnd/jbnd = ',ibnd,jbnd
                  stop
                endif
                if(ijnctyp.ne.0)then
                  edtype(nedgp1)=jedge
c
c increment junction edge increment
c
                  nedjun=nedjun+1
                  if(nedgp1.gt.jedge .and. ibnd.eq.jbnd .and.
     &               nedgp1.ne.edtype(jedge))then
                    kedge=edtype(jedge)
                    write(6,*) '    error: Surface contains a re-',
     &               'entrant junction edge which is multiply defined'
                    write(6,*) '            ibnd = jbnd = ',ibnd
                    write(6,*) '        nedgp1 = ',nedgp1-istart+1
                    write(6,*) '            jedge = ',jedge-jstart+1
                    write(6,*) '            kedge = ',kedge-jstart+1
                    stop
                  endif
                  goto 220
                endif
 210          continue
 215        continue
c
c increment exterior edge count
c
            nedext=nedext+1
 220      continue
 230    continue
c
c print geometry information
c
      write(6,240)nub,npts,numface,numedge
```

```
      write(6,250)nedint,nedext,nedjun
 240  format(//,' number of surfaces = ',i3,/,
     & ' number of points = ',i5,/,
     & ' number of faces = ',i5,/,
     & ' number of edges = ',i5)
 250  format(' number of interior edges = ',i5,/,
     & ' number of exterior edges = ',i5,/,
     & ' number of junction edges = ',i5,/)
c
c loop over surfaces
c
      do 254 ibnd=1,nub
        istart=indf(ibnd)
        iend=indf(ibnd)+numfac(ibnd)-1
c
c loop over faces
c
        do 253 numfcp1=istart,iend
c
c loop over face sides
c
          do 252 iside=1,3
            i1=idxef(iside,numfcp1)
            nedgp1=inde(ibnd)+iabs(i1)-1
c
c if interior edge do not evaluate
c
            if(edtype(nedgp1).le.0)goto 252
            jedge=edtype(nedgp1)
            kedge=edtype(jedge)
            if(jedge.lt.nedgp1. and. jedge.lt.kedge)then
              idxef(iside,numfcp1)=-idxef(iside,numfcp1)
            endif
 252      continue
 253    continue
 254  continue
c
c determine number of interior/exterior/junction/reentrant edges by surfaces
c
      do 270 ibnd=1,nub
        nint(ibnd)=0
        next(ibnd)=0
        nje(ibnd)=0
        nren(ibnd)=0
        istart=inde(ibnd)
        iend=inde(ibnd)+numedg(ibnd)-1
        do 260 nedgp1=istart,iend
          if(edtype(nedgp1).eq.0)then
            nint(ibnd)=nint(ibnd)+1
          elseif(edtype(nedgp1).eq.-1)then
            next(ibnd)=next(ibnd)+1
          elseif(edtype(nedgp1).gt.0)then
            nje(ibnd)=nje(ibnd)+1
            if(edtype(nedgp1).ge.istart.and.edtype(nedgp1).le.iend)then
              nren(ibnd)=nren(ibnd)+1
            endif
          endif
 260    continue
 270  continue
c
c determine number of unknowns and locations
c   nunknon - Total number of unknowns.
c
      nunknon=0
c
c loop over surfaces
```

```
c
      do 290 ibnd=1,nub
c
c step over boundary edges
c
        istart=inde(ibnd)
        iend=inde(ibnd)+numedg(ibnd)-1
        do 280 nedgp1=istart,iend
          iedind(nedgp1)=0
c
c increment unknown count
c
          nunknon=nunknon+1
          loc=nunknon
c
c assign unknown location
c iedind stores the global unknown number
c of the edge (nedgp1)
c
          iedind(nedgp1)=loc
 280    continue
 290  continue
c
c eliminate duplicate current indices (edges
c common to surfaces)
c
c loop over surfaces
c
      do 330 ibnd=1,nub
c
c loop over edges
c
        istart=inde(ibnd)
        iend=inde(ibnd)+numedg(ibnd)-1
        do 320 nedgp1=istart,iend
c
c is edge a junction edge?
c if not skip it
c
          if(edtype(nedgp1).le.0)goto 320
          jedge=edtype(nedgp1)
          kedge=edtype(jedge)
          new=iedind(nedgp1)
          iold=iedind(jedge)
c
c get rid of duplicate unknown and
c decrement unknown count
c
          call eleqind(new,iold,nunknon,numedge)
 320    continue
 330  continue
c
c assign new unknown count numzel
c
      numzel=nunknon
c
c count number of edges by surface (nbji=#edges)
c
      do 350 ibnd=1,nub
        nbji(ibnd)=0
        istart=inde(ibnd)
        iend=inde(ibnd)+numedg(ibnd)-1
        do 340 nedgp1=istart,iend
          if(iedind(nedgp1).ne.0)nbji(ibnd)=nbji(ibnd)+1
 340    continue
 350  continue
```

```
          do 360 idx=1,numzel
            level(idx)=0
 360      continue
          do 380 ibnd=1,nub
            istart=inde(ibnd)
            iend=inde(ibnd)+numedg(ibnd)-1
            do 370 nedgp1=istart,iend
              ind2=iabs(iedind(nedgp1))
              if(ind2.ne.0)then
                if(mompo(ibnd).gt.level(ind2))level(ind2)=mompo(ibnd)
              endif
 370        continue
 380      continue
c
c count number of unknowns (mm and po)
c
          do 390 idx=1,2
            nelcur(idx)=0
 390      continue
          do 400 idx=1,numzel
            nhy=level(idx)
            if(nhy.gt.0)then
              nelcur(nhy)=nelcur(nhy)+1
            endif
 400      continue
c
c reorder unknowns
c
          do i=1,2
             do j=1,numzel
                idxuned(j,i)=0
             enddo
          enddo
          do 410 idx=1,numzel
            iunord(idx)=0
 410      continue
          indx(1)=0
          indx(2)=indx(1)+nelcur(1)
          do 430 ibnd=1,nub
            istart=inde(ibnd)
            iend=inde(ibnd)+numedg(ibnd)-1
            do 420 nedgp1=istart,iend
              id2=iedind(nedgp1)
              if(id2.ne.0)then
                if(iunord(id2).eq.0)then
                  nhy=level(id2)
                  indx(nhy)=indx(nhy)+1
                  iunord(id2)=indx(nhy)
                endif
              endif
              iedind(nedgp1)=iunord(id2)
c
c idxuned contains edge number corresponding to unknown #
c
              if(idxuned(iedind(nedgp1),1).eq.0)then
                 idxuned(iedind(nedgp1),1)=nedgp1
              else
                 idxuned(iedind(nedgp1),1)=-idxuned(iedind(nedgp1),1)
                 idxuned(iedind(nedgp1),2)=nedgp1
              endif
 420        continue
 430      continue
c
c idxfe contains faces making edge
c
       do ii=1,nub
```

```
         istart=indf(ii)
         iend=indf(ii)+numfac(ii)-1
         ioffset=inde(ii)-1
         do jj=istart,iend
            do kk=1,3
               if(idxef(kk,jj).gt.0)then
                  idxfep(idxef(kk,jj)+ioffset)=jj
               elseif(idxef(kk,jj).lt.0)then
                  idxfem(-idxef(kk,jj)+ioffset)=jj
               endif
            enddo
         enddo
      enddo
c
c calculate face area and normal unit vector
c
      do ii=1,nub
         istart=indf(ii)
         iend=indf(ii)+numfac(ii)-1
         ioffset=indp(ii)-1
         do numfcp1=istart,iend
        i1=idxvf(1,numfcp1)+ioffset
        i2=idxvf(2,numfcp1)+ioffset
        i3=idxvf(3,numfcp1)+ioffset
        x21=xv(i2)-xv(i1)
        y21=yv(i2)-yv(i1)
        z21=zv(i2)-zv(i1)
        x31=xv(i3)-xv(i1)
        y31=yv(i3)-yv(i1)
        z31=zv(i3)-zv(i1)
        deltax=y21*z31-z21*y31
        deltay=-x21*z31+z21*x31
        deltaz=x21*y31-y21*x31
        delta=sqrt(deltax**2+deltay**2+deltaz**2)
        delinv=1./delta
        area(numfcp1)=.5*delta
        normx(numfcp1)=deltax*delinv
        normy(numfcp1)=deltay*delinv
        normz(numfcp1)=deltaz*delinv
        enddo
      enddo
c
c calculate the unit vectors normal and parallel to edges
c
      do ii=1,nub
         istart=indf(ii)
         iend=indf(ii)+numfac(ii)-1
         ioffset=indp(ii)-1
         iofsete=inde(ii)-1
         do numfcp1=istart,iend
            if1=iabs(idxef(1,numfcp1))+iofsete
            del=edlen(if1)
            delinv=1./del
            i1=idxvf(2,numfcp1)+ioffset
            i2=idxvf(3,numfcp1)+ioffset
            xx=xv(i2)-xv(i1)
            yy=yv(i2)-yv(i1)
            zz=zv(i2)-zv(i1)
            upedx(1,numfcp1)=xx*delinv
            upedy(1,numfcp1)=yy*delinv
            upedz(1,numfcp1)=zz*delinv
            unedx(1,numfcp1)=upedy(1,numfcp1)*normz(numfcp1)-
     +                       upedz(1,numfcp1)*normy(numfcp1)
            unedy(1,numfcp1)=-upedx(1,numfcp1)*normz(numfcp1)+
     +                       upedz(1,numfcp1)*normx(numfcp1)
            unedz(1,numfcp1)=upedx(1,numfcp1)*normy(numfcp1)-
```

```
     +                          upedy(1,numfcp1)*normx(numfcp1)
            if1=iabs(idxef(2,numfcp1))+iofsete
            del=edlen(if1)
            delinv=1./del
            i1=idxvf(3,numfcp1)+ioffset
            i2=idxvf(1,numfcp1)+ioffset
            xx=xv(i2)-xv(i1)
            yy=yv(i2)-yv(i1)
            zz=zv(i2)-zv(i1)
            upedx(2,numfcp1)=xx*delinv
            upedy(2,numfcp1)=yy*delinv
            upedz(2,numfcp1)=zz*delinv
            unedx(2,numfcp1)=upedy(2,numfcp1)*normz(numfcp1)-
     +                        upedz(2,numfcp1)*normy(numfcp1)
            unedy(2,numfcp1)=-upedx(2,numfcp1)*normz(numfcp1)+
     +                        upedz(2,numfcp1)*normx(numfcp1)
            unedz(2,numfcp1)=upedx(2,numfcp1)*normy(numfcp1)-
     +                        upedy(2,numfcp1)*normx(numfcp1)
            if1=iabs(idxef(3,numfcp1))+iofsete
            del=edlen(if1)
            delinv=1./del
            i1=idxvf(1,numfcp1)+ioffset
            i2=idxvf(2,numfcp1)+ioffset
            xx=xv(i2)-xv(i1)
            yy=yv(i2)-yv(i1)
            zz=zv(i2)-zv(i1)
            upedx(3,numfcp1)=xx*delinv
            upedy(3,numfcp1)=yy*delinv
            upedz(3,numfcp1)=zz*delinv
            unedx(3,numfcp1)=upedy(3,numfcp1)*normz(numfcp1)-
     +                        upedz(3,numfcp1)*normy(numfcp1)
            unedy(3,numfcp1)=-upedx(3,numfcp1)*normz(numfcp1)+
     +                        upedz(3,numfcp1)*normx(numfcp1)
            unedz(3,numfcp1)=upedx(3,numfcp1)*normy(numfcp1)-
     +                        upedy(3,numfcp1)*normx(numfcp1)
         enddo
      enddo
c
c print out system information
c
      write(6,*)
      write(6,*) '  Total number of unknowns entered = ',numzel
      write(6,*) '      J (total) = ',nunknon
      write(6,*)
      nlev=0
      do 440 idx=1,2
         nlev=nlev+nelcur(idx)
         write(6,*) '      Solution level = ',idx
         write(6,*) '        J (total) = ',nelcur(idx)
 440    continue
        if(nlev.ne.nunknon)then
          write(6,*) '   error: Incorrect unknown count by level'
          stop
        endif
c
c print out surface information
c
      do 450 ibnd=1,nub
       write(6,*)
       write(6,*) '  Surface number ',ibnd
       write(6,*) '   Number of vertices (nodes) = ',nup(ibnd)
       write(6,*) '   Number of triangular facets = ',numfac(ibnd)
       write(6,*) '   Number of edges = ',numedg(ibnd)
       write(6,*) '   Number of interior edges = ',nint(ibnd)
       write(6,*) '   Number of exterior edges = ',next(ibnd)
       write(6,*) '   Number of junction edges = ',nje(ibnd)
```

```
      write(6,*) '   Number of re-entrant junction edges = ',nren(ibnd)
      write(6,*) '   Number of R(+) junction edges = ',nrpls(ibnd)
      write(6,*) '   Number of R(-) junction edges = ',nrmin(ibnd)
      write(6,*) '   Solution level for exterior = ',mompo(ibnd)
c
c check euler formula
c
      neuler=nup(ibnd)+numfac(ibnd)-numedg(ibnd)
      if(neuler.lt.0.or.neuler.gt.2)then
        write(6,*)
        write(6,*) ' warning: Euler's formula does not hold'
        write(6,*) '    Vertices + Faces - Edges should equal (1,2,0)'
        write(6,*) '                                 1 (disk)'
        write(6,*) '                                 2 (sphere)'
        write(6,*) '                                 0 (cylinder)'
      endif
      if(numedg(ibnd).ne.nint(ibnd)+next(ibnd)+nje(ibnd))then
         write(6,*)
         write(6,*) ' error: incorrect edge total'
         stop
      endif
      write(6,*)
      write(6,*) '    Geometry information (problem input units):'
      numfcp1=indf(ibnd)
       write(6,*) '       Centroid of face 1 - x = ',xc(numfcp1)
       write(6,*) '                            y = ',yc(numfcp1)
       write(6,*) '                            z = ',zc(numfcp1)
       write(6,*) '       Unit normal vector to face 1 -  normx = ',
     &normx(numfcp1)
       write(6,*) '                                       normy = ',
     &normy(numfcp1)
       write(6,*) '                                       normz = ',
     &normz(numfcp1)
       write(6,*)
 450  continue
      return
      end
```

```
      subroutine grnint(xfkr,yfkr,xcii,ycii,zcii,xvii,yvii,zvii,deii,
     1 xcjj,ycjj,zcjj,xvjj,yvjj,zvjj,dejj,
     2 nxj,nyj,nzj,areaj,upx,upy,upz,unx,uny,unz,
     3 g11,g1a,g1b,g1c,ga1,gaa,gab,gac,gb1,gba,gbb,gbc,gc1,gca,gcb,gcc)
c
c compute 3d-patch green's function integrals using triangular surface
c quadrature formulas.
c
      implicit none
      real*4 xvii(3),yvii(3),zvii(3),deii(3)
      real*4 xvjj(3),yvjj(3),zvjj(3),dejj(3)
      real*4 asinh,x,s,a,b,xx,xcii,xcjj,yy,ycii,ycjj,zz,
     +zcii,zcjj,apq,bpq,delta,x13,y13,z13,alp,x23,y23,z23,
     +bet,gam,r,sing,wi,ai,bi,rpq,yfkr,y,xfkr,ww,b2,b3,b11,
     +ba1,baa,bab,bb1,bbb,del1,del2,a11,a21,a12,a22,del,ci
     +,xi,yi,zi,d,rhox,rhoy,rhoz,d2,pm2,rm,pp2,rp,p0,term1,
     +r02,term2,term3,areaj,b1,apj,bpj,cpj,xpj,ypj,zpj,
     +wj,aj,bj,cj,xj,yj,zj
      integer ie,ising,npoint,igaus1,igaus2,jgaus1,jgaus2,
     +i,je,j2,j1,j
      complex*8 g,gsing,zsing
      complex*8 g11,g1a,g1b,g1c,ga1,gaa,gab,gac
      complex*8 gb1,gba,gbb,gbc,gc1,gca,gcb,gcc
      real*4 nxj,nyj,nzj,lp,lm
      real*4 upx(3),upy(3),upz(3),unx(3),uny(3),unz(3)
      include 'intord.inc'
      include 'triint.inc'
      include 'wavenumber.inc'
      include 'const.inc'
      complex*8 sumg,sumag,sumbg
      asinh(x)=log(x+sqrt(x**2+1.))
      s(a,b)=asinh(a+b)+(asinh((a*(a+b)+1.)/b)-asinh(a))*abs(b)/
     & sqrt(a**2+1.)
      g11=0.0
      g1a=0.0
      g1b=0.0
      ga1=0.0
      gaa=0.0
      gab=0.0
      gb1=0.0
      gba=0.0
      gbb=0.0
      xx=xcii-xcjj
      yy=ycii-ycjj
      zz=zcii-zcjj
      apq=sqrt(xx**2+yy**2+zz**2)
      bpq=apq*fk/(2.*pi)
      delta=0.0
      do 50 ie=1,3
        if(abs(deii(ie)).gt.delta) delta=abs(deii(ie))
        if(abs(dejj(ie)).gt.delta) delta=abs(dejj(ie))
50    continue
      ising=0
      if(apq.eq.0.0) then
        npoint=nself
        ising=1
      elseif(bpq.le.rnear .or. apq.le.delta) then
        npoint=nnear
        ising=1
      elseif(bpq.lt.rfar) then
        npoint=nmid
      else
        npoint=nfar
      endif
      igaus1=nmpont(npoint)
      igaus2=igaus1+npoint-1
```

```
      jgaus1=igaus1
      jgaus2=igaus2
      if(apq.eq.0.0) then
c
c self term
c
c   singular part (analytic)
        x13=xvii(1)-xvii(3)
        y13=yvii(1)-yvii(3)
        z13=zvii(1)-zvii(3)
        alp=sqrt(x13**2+y13**2+z13**2)
        x23=xvii(2)-xvii(3)
        y23=yvii(2)-yvii(3)
        z23=zvii(2)-zvii(3)
        bet=sqrt(x23**2+y23**2+z23**2)
        gam=x13*x23+y13*y23+z13*z23
        r=sqrt((alp*bet)**2-gam**2)
        a=gam/r
        b=alp**2/r
        sing=(s(a-b,b)-s(a,-b))/alp
        g11=sing
        ga1=sing
        gaa=sing
        gab=sing
        gb1=sing
        gbb=sing
c   non-singular part (numerical integration)
        do 100 i=igaus1,igaus2
          wi=weight(i)
c     region 1
          ai=alfa(i)-1.
          bi=beta(i)
          xx=ai*x13+bi*x23
          yy=ai*y13+bi*y23
          zz=ai*z13+bi*z23
          apq=xx**2+yy**2+zz**2
          rpq=sqrt(apq)
          x=yfkr*rpq
          y=-xfkr*rpq
          ww=wi/rpq
          g=(ww*exp(x))*cmplx(cos(y),sin(y))
          sing=ww
          b2=(1.+ai)**2
          b3=b2*(1.+ai)
          b11=b2
          ba1=b2*(1.-0.5*ai)
          baa=b3*(1.-ai)
          bab=b2*(1.+2.*bi-4.*ai*bi-ai**2)
          bb1=b2*(1.+ai+1.5*bi)
          bbb=b3*(1.+ai+2.*bi)
          g11=(g*b11-sing)+g11
          ga1=(g*ba1-sing)+ga1
          gaa=(g*baa-sing)+gaa
          gab=(g*bab-sing)+gab
          gb1=(g*bb1-sing)+gb1
          gbb=(g*bbb-sing)+gbb
c     region 2
          ai=-alfa(i)
          bi=1.-beta(i)
          xx=ai*x13+bi*x23
          yy=ai*y13+bi*y23
          zz=ai*z13+bi*z23
          apq=xx**2+yy**2+zz**2
          rpq=sqrt(apq)
          x=yfkr*rpq
          y=-xfkr*rpq
```

```
          ww=wi/rpq
          g=(ww*exp(x))*cmplx(cos(y),sin(y))
          sing=ww
          b2=(1.-bi)**2
          b3=b2*(1.-bi)
          b11=b2
          ba1=b2*(1.-bi-1.5*ai)
          baa=b3*(1.-2.*ai-bi)
          bab=b2*(1.-2.*ai-4.*ai*bi-bi**2)
          bb1=b2*(1.+0.5*bi)
          bbb=b3*(1.+bi)
          g11=(g*b11-sing)+g11
          ga1=(g*ba1-sing)+ga1
          gaa=(g*baa-sing)+gaa
          gab=(g*bab-sing)+gab
          gb1=(g*bb1-sing)+gb1
          gbb=(g*bbb-sing)+gbb
c     region 3
          ai=alfa(i)
          bi=beta(i)
          xx=ai*x13+bi*x23
          yy=ai*y13+bi*y23
          zz=ai*z13+bi*z23
          apq=xx**2+yy**2+zz**2
          rpq=sqrt(apq)
          x=yfkr*rpq
          y=-xfkr*rpq
          ww=wi/rpq
          g=(ww*exp(x))*cmplx(cos(y),sin(y))
          sing=ww
          b2=(1.-ai-bi)**2
          b3=b2*(1.-ai-bi)
          b11=b2
          ba1=b2*(1.+0.5*ai-bi)
          baa=b3*(1.+ai-bi)
          bab=b3*(1.+ai+bi)
          bb1=b2*(1.-ai+0.5*bi)
          bbb=b3*(1.-ai+bi)
          g11=(g*b11-sing)+g11
          ga1=(g*ba1-sing)+ga1
          gaa=(g*baa-sing)+gaa
          gab=(g*bab-sing)+gab
          gb1=(g*bb1-sing)+gb1
          gbb=(g*bbb-sing)+gbb
 100    continue
        ga1=ga1/3.
        gaa=gaa/6.
        gab=gab/12.
        gb1=gb1/3.
        gbb=gbb/6.
        g1a=ga1
        g1b=gb1
        gba=gab
      elseif(ising.ne.0) then
c
c near-self term
c
c   the following variables are used in the singularity extraction.
          del1=abs(dejj(1))
          del2=abs(dejj(2))
          x13=xvjj(1)-xvjj(3)
          y13=yvjj(1)-yvjj(3)
          z13=zvjj(1)-zvjj(3)
          x23=xvjj(2)-xvjj(3)
          y23=yvjj(2)-yvjj(3)
          z23=zvjj(2)-zvjj(3)
```

```
c     cramer's rule coefficients
          a11=del2**2
          a21=x23*x13+y23*y13+z23*z13
          a12=a21
          a22=del1**2
          del=a11*a22-a21*a12
          a11=a11/del
          a21=a21/del
          a12=a21
          a22=a22/del
c   test integration loop
        do 200 i=igaus1,igaus2
          wi=weight(i)
          ai=alfa(i)
          bi=beta(i)
          ci=1.-ai-bi
          xi=ai*xvii(1)+bi*xvii(2)+ci*xvii(3)
          yi=ai*yvii(1)+bi*yvii(2)+ci*yvii(3)
          zi=ai*zvii(1)+bi*zvii(2)+ci*zvii(3)
c   distance (+ or -) of test point from source plane
          d=nxj*(xi-xvjj(1))+nyj*(yi-yvjj(1))+nzj*(zi-zvjj(1))
c   projection of test point onto source plane
          rhox=xi-d*nxj
          rhoy=yi-d*nyj
          rhoz=zi-d*nzj
c   singular part
          sing=0.0
          d=abs(d)
          d2=d**2
c   compute l+, r+, l-, r-, and p0 for each side of the source triangle
          do 120 je=1,3
            if(je.eq.1) then
              j2=3
              j1=2
            elseif(je.eq.2) then
              j2=1
              j1=3
            else
              j2=2
              j1=1
            endif
            xx=xvjj(j1)-rhox
            yy=yvjj(j1)-rhoy
            zz=zvjj(j1)-rhoz
            lm=xx*upx(je)+yy*upy(je)+zz*upz(je)
            pm2=xx**2+yy**2+zz**2
            rm=sqrt(pm2+d2)
            xx=xvjj(j2)-rhox
            yy=yvjj(j2)-rhoy
            zz=zvjj(j2)-rhoz
            lp=xx*upx(je)+yy*upy(je)+zz*upz(je)
            pp2=xx**2+yy**2+zz**2
            rp=sqrt(pp2+d2)
            p0=xx*unx(je)+yy*uny(je)+zz*unz(je)
            if(p0.ne.0.0) then
              if(lm.ge.0.0) then
                term1=log((rp+lp)/(rm+lm))
              else
                term1=log((rm-lm)/(rp-lp))
              endif
              sing=p0*term1+sing
            endif
            if(d.ne.0.0) then
              r02=p0**2+d2
              term2=atan(p0*lp/(r02+d*rp))
              term3=atan(p0*lm/(r02+d*rm))
```

```
              sing=-d*(term2-term3)+sing
            endif
 120      continue
          sing=sing/(2.*areaj)
c   compute alpha and beta (apj,bpj) for point rho in the source plane
          xx=rhox-xvjj(3)
          yy=rhoy-yvjj(3)
          zz=rhoz-zvjj(3)
c     cramer's rule
          b1=x13*xx+y13*yy+z13*zz
          b2=x23*xx+y23*yy+z23*zz
          apj=b1*a22-b2*a12
          bpj=a11*b2-a21*b1
c   find nearest point on the source triangle (xpj,ypj,zpj)
          cpj=1.-apj-bpj
          if(apj.lt.0.0) then
            apj=0.0
            if(bpj.lt.0.0) then
              bpj=0.0
            elseif(bpj.gt.1.0) then
              bpj=1.0
            endif
          elseif(bpj.lt.0.0) then
            bpj=0.0
            if(apj.lt.0.0) then
              apj=0.0
            elseif(apj.gt.1.0) then
              apj=1.0
            endif
          elseif(cpj.lt.0.0) then
            if(bpj.ge.apj+1.0) then
              apj=0.0
              bpj=1.0
            elseif(bpj.le.apj-1.0) then
              apj=1.0
              bpj=0.0
            else
              apj=0.5*(1.0+apj-bpj)
              bpj=1.0-apj
            endif
          endif
          cpj=1.-apj-bpj
          xpj=apj*xvjj(1)+bpj*xvjj(2)+cpj*xvjj(3)
          ypj=apj*yvjj(1)+bpj*yvjj(2)+cpj*yvjj(3)
          zpj=apj*zvjj(1)+bpj*zvjj(2)+cpj*zvjj(3)
          xx=xi-xpj
          yy=yi-ypj
          zz=zi-zpj
          rpq=sqrt(xx**2+yy**2+zz**2)
          x=yfkr*rpq
          y=-xfkr*rpq
          zsing=exp(x)*cmplx(cos(y),sin(y))
          g=(wi*sing)*zsing
          g11=g+g11
          g1a=apj*g+g1a
          g1b=bpj*g+g1b
          ga1=ai*g+ga1
          gaa=(ai*apj)*g+gaa
          gab=(ai*bpj)*g+gab
          gb1=bi*g+gb1
          gba=(bi*apj)*g+gba
          gbb=(bi*bpj)*g+gbb
c   non-singular part
          sumg=0.0
          sumag=0.0
          sumbg=0.0
```

```
c   source integration loop
          do 190 j=jgaus1,jgaus2
            wj=weight(j)
            aj=alfa(j)
            bj=beta(j)
            cj=1.-aj-bj
            xj=aj*xvjj(1)+bj*xvjj(2)+cj*xvjj(3)
            yj=aj*yvjj(1)+bj*yvjj(2)+cj*yvjj(3)
            zj=aj*zvjj(1)+bj*zvjj(2)+cj*zvjj(3)
            xx=xi-xj
            yy=yi-yj
            zz=zi-zj
            apq=xx**2+yy**2+zz**2
            rpq=sqrt(apq)
c real and imaginary part of -jkr
            x=yfkr*rpq
            y=-xfkr*rpq
            ww=wj/rpq
            g=(ww*exp(x))*cmplx(cos(y),sin(y))
            gsing=ww*zsing
c the last 3 statements assume that rpq is not zero. the following 3
c statements are required if rpq=0 for self-term integrations.
c...            ww=wj
c...            g=ww*cmplx(yfkr,-xfkr)
c...            gsing=0.0
            sumg=(g-gsing)+sumg
            sumag=(aj*g-apj*gsing)+sumag
            sumbg=(bj*g-bpj*gsing)+sumbg
 190      continue
          sumg=wi*sumg
          sumag=wi*sumag
          sumbg=wi*sumbg
          g11=sumg+g11
          ga1=ai*sumg+ga1
          gb1=bi*sumg+gb1
          g1a=sumag+g1a
          gaa=ai*sumag+gaa
          gba=bi*sumag+gba
          g1b=sumbg+g1b
          gab=ai*sumbg+gab
          gbb=bi*sumbg+gbb
 200    continue
      else
c
c non-self term
c
c   test integration loop
        do 300 i=igaus1,igaus2
          wi=weight(i)
          ai=alfa(i)
          bi=beta(i)
          ci=1.-ai-bi
          xi=ai*xvii(1)+bi*xvii(2)+ci*xvii(3)
          yi=ai*yvii(1)+bi*yvii(2)+ci*yvii(3)
          zi=ai*zvii(1)+bi*zvii(2)+ci*zvii(3)
          sumg=0.0
          sumag=0.0
          sumbg=0.0
c   source integration loop
          do 290 j=jgaus1,jgaus2
            wj=weight(j)
            aj=alfa(j)
            bj=beta(j)
            cj=1.-aj-bj
            xj=aj*xvjj(1)+bj*xvjj(2)+cj*xvjj(3)
            yj=aj*yvjj(1)+bj*yvjj(2)+cj*yvjj(3)
```

```
            zj=aj*zvjj(1)+bj*zvjj(2)+cj*zvjj(3)
            xx=xi-xj
            yy=yi-yj
            zz=zi-zj
            apq=xx**2+yy**2+zz**2
            rpq=sqrt(apq)
c real and imaginary part of -jkr
            x=yfkr*rpq
            y=-xfkr*rpq
            g=(wj*exp(x)/rpq)*cmplx(cos(y),sin(y))
            sumg=g+sumg
            sumag=aj*g+sumag
            sumbg=bj*g+sumbg
 290      continue
          sumg=wi*sumg
          sumag=wi*sumag
          sumbg=wi*sumbg
          g11=sumg+g11
          ga1=ai*sumg+ga1
          gb1=bi*sumg+gb1
          g1a=sumag+g1a
          gaa=ai*sumag+gaa
          gba=bi*sumag+gba
          g1b=sumbg+g1b
          gab=ai*sumbg+gab
          gbb=bi*sumbg+gbb
 300    continue
      endif
      g1c=g11-g1a-g1b
      gac=ga1-gaa-gab
      gbc=gb1-gba-gbb
      gc1=g11-ga1-gb1
      gca=g1a-gaa-gba
      gcb=g1b-gab-gbb
      gcc=g11+gaa+gbb+gab+gba-g1a-ga1-g1b-gb1
      return
      end
```

```
      program hybrid_simple
c
c efie hybrid code (mm/po)
c
      implicit none
      include 'arraydim.inc'
      include 'work.inc'
      include 'const.inc'
      include 'wavenumber.inc'
      include 'order.inc'
      include 'threat.inc'
      include 'numbers.inc'
      include 'surcord.inc'
      include 'scatter.inc'
      include 'unit.inc'
      include 'tilde.inc'
      include 'intord.inc'
      include 'dbsm.inc'
      include 'patchtol.inc'
      include 'numj.inc'
      include 'polar.inc'
      include 'problem.inc'
      character*6 geom
      logical freq
      real*4 lamdl,lamdu,speedl,cvrn,freql,frequ,fk1,fk2,
     +temp1,temp2,ang,angs,ange,anginc,winc,finc,fr
      integer nfreq,ncutfar,nangs,idxc,icut,i,nmm,npo,nwt,
     +ntotw,idxfr
c
c set option array: namelist used to set options in
c input file
c
      namelist /option/monbi,phi,
     +thet,units,freq,nfreq,ncutfar,
     +dbsm,nself,nnear,rnear,nmid,
     +rfar,nfar,pattol,polt,polp,rtilde
c
c calculate constants pi, speed of light, and free space impedance
c
      pi=acos(-1.)
      speedl=2.997925E8
      eta=4.e-7*pi*speedl
c
c read the problem's title
c
      read(5,10)title
 10   format(a)
      write(6,15)title
 15   format(//,15x,' SIMPLE HYBRID CODE',//,
     +10x,'problem: ',a80,//)
c
c set default options (see namelist)
c
c
c monbi=1 (monostatic scattering)
c monbi=0 (bistatic scattering)
c
      monbi=1
c
c thet=bistatic incident theta angle (degrees):monbi=0
c phi=bistatic incident phi angle (degrees):monbi=0
c
      thet=0.
      phi=0.
c
c dbsm=false (write rcs in sigma/lambda**2)
```

```
c dbsm=true (write rcs in sigma/meter**2)
c
      dbsm=.false.
c
c pattol=vertex point tolerance (collapse vertices separated by < pattol)
c
      pattol=0.
c
c number of integration points for self, near, mid, and far terms
c
      nself=7
      nnear=7
      nmid=3
      nfar=3
c
c define near and far regions in wavelengths for integrations
c
      rnear=.25
      rfar=1.
c
c rtilde=true (rtilde is calculated analytically)
c rtilde=false (rtilde is computed numerically)
c
      rtilde=.true.
c
c polt and polp are used to select polarizations analyzed
c =true calculate the polarization, =false do not calculate
c
      polt=.true.
      polp=.true.
c
c units=units used for the problem
c m=meters, cm=centimeters, in=inches, and ft=feet
c
      units='m'
c
c freq=false (wavenumber input)
c freq=true (frequency input in GHz)
c
      freq=.false.
c
c nfreq=number of frequencies to sweep over
c
      nfreq=1
c
c ncutfar=number of farfield pattern cuts
c
      ncutfar=1
c
c set options with namelist
c
      read(5,nml=option)
      write(6,*)
      write(6,*) 'options selected:'
      write(6,*)
c
c print out and check validity of options selected
c
      if(monbi.eq.1)then
        write(6,*) '  monostatic scattering'
      elseif(monbi.eq.0)then
        write(6,*) '  bistatic scattering'
        write(6,*) '        phi = ',phi,'   thet = ',thet
      else
        write(6,*)'error: no scattering type selected'
        write(6,*)'monbi must equal 0 or 1'
```

```
        stop
      endif
      if(monbi.ge.0.and..not.polt)then
        write(6,*) '  phi polarization selected'
      endif
      if(monbi.ge.0.and..not.polp)then
        write(6,*) '  theta polarization selected'
      endif
      if(polt.and.polp)then
        write(6,*)'  theta and phi polarizations selected'
      endif
      if(.not.polt.and..not.polp)then
        write(6,*) ' error: no polarization selected'
        stop
      endif
c
c calculate conversion factor for geometry files
c
c
c cvrn is conversion factor used to convert various units to meters
c
      if(units.eq.'m')then
        units='meters'
        cvrn=1.
      elseif(units.eq.'cm')then
        units='cm'
        cvrn=.01
      elseif(units.eq.'in')then
        units='inches'
        cvrn=2.54*.01
      elseif(units.eq.'ft')then
        units='feet'
        cvrn=12.*2.54*.01
      else
        write(6,*) ' error: units = ',units
        stop
      endif
      write(6,*) '  units are in ',units
      if(freq)then
        write(6,*) '  input is in frequency '
      else
        write(6,*) '  input is in wavenumber'
      endif
      if(.not.dbsm)then
        write(6,*) '  rcs in sigma/lambda**2'
      else
        write(6,*) '  rcs in sigma/meter**2'
      endif
      if(nfreq.gt.1)then
        write(6,*) '  number frequencies: nfreq = ',nfreq
      endif
      write(6,*) '  number of pattern cuts = ',ncutfar
      write(6,*) '  collapsing vertice tolerance = ',pattol
      write(6,*)
      write(6,*) '  integration points and region definitions:'
      write(6,*) '          nself = ',nself
      write(6,*) '          nnear = ',nnear
      write(6,*) '          nmid  = ',nmid
      write(6,*) '          nfar  = ',nfar
      write(6,*) '          rnear  = ',rnear,' lambda'
      write(6,*) '          rfar   = ',rfar,' lambda'
      write(6,*)
      if(rtilde)then
        write(6,*) '  r tilde is calculated analytically'
      endif
c
```

```
c read in frequency or wavenumber input
c
c freql is starting frequency
c fk1 is starting wavenumber
c frequ is the ending frequency
c fk2 is the ending wavenumber
c
      if(nfreq.eq.1)then
        if(freq)then
          read(5,*)freql
          frequ=freql
        else
          read(5,*) fk1
          fk2=fk1
        endif
      else
        if(freq)then
          read(5,*) freql,frequ
        else
          read(5,*) fk1,fk2
        endif
      endif
c
c convert frequency data to wavenumbers or vice versa
c
c frequency calculation gives frequency in GHz
c
      temp1=speedl*1.e-9
      temp2=2.*pi
      if(freq)then
        lamdl=temp1/(freql*cvrn)
        fk1=temp2/lamdl
        lamdu=temp1/(frequ*cvrn)
        fk2=temp2/lamdu
      else
        lamdl=temp2/fk1
        freql=temp1/(lamdl*cvrn)
        lamdu=temp2/fk2
        frequ=temp1/(lamdu*cvrn)
      endif
c
c print out frequency information
c
      write(6,*)
      write(6,*)'     frequency selections:'
      write(6,25)fk1,fk2,units,freql,frequ,lamdl,lamdu,units,
     & nfreq
 25   format(//,' fk = ',g12.4,' - ',g12.4,1x,a5,'**-1'/,
     &' freql = ',f9.3,' - ',f9.3,' GHz',/,
     &' lamdl = ',g12.4,' - ',g12.4,1x,a6,/,
     &' nfreq = ',i3,//)
      fk=max(fk1,fk2)
c
c read geometry files
c
 30   continue
c
c geom selects geometry type (patch, wire, bor, bot, etc)
c here code has been limited to patch
c geom='patch' (3d patches are read in)
c geom='end' (end of geometry file inputs)
c
        read(5,10) geom
        if(geom.eq.'end')then
          goto 40
        elseif(geom.eq.'patch')then
```

```
c
c read geometry
c
          call geoin(work1,work2)
        else
          write(6,*) ' error: invalid geometry type, geom = ',geom
          stop
        endif
      goto 30
 40   continue
c
c read threat parameters and scattered field options
c
c nangs is total numkber of angles analyzed
c
      nangs=0
      do 50 idxc=1,ncutfar
c
c nang=# scattering angles for far field cut idxc
c
        read(5,*) nang
        write(6,*)
        write(6,*) 'number of scattering angles = ',nang
        write(6,*)
        write(6,*) '  monbi = ',monbi
c
c write bistatic angle of incidence
c
        if(monbi.eq.0)then
          write(6,*) '  phi and theta incident = ',phi,thet
        endif
c
c ang=fixed angle
c angs=starting angle
c ange=ending angle
c icut=1 (phi cut)
c icut=2 (theta cut)
c
        read(5,*) ang,icut,angs,ange
        write(6,*) '  icut = ',icut
        if(icut.eq.1)then
          write(6,*) '  phi = ',ang
          write(6,*) '  theta = ',angs,' - ',ange
        elseif(icut.eq.2)then
          write(6,*) '  theta = ',ang
          write(6,*) '  phi = ',angs,' - ',ange
        else
          write(6,*) ' error: icut must equal 1 or 2'
          stop
        endif
c
c scattering angles determined
c
        if(nang.gt.1)then
c
c calculate angular increment (anginc)
c
          anginc=(ange-angs)/(nang-1)
        else
          nang=1
          anginc=0.
        endif
c
c calculate scattering angles (phis,thes)
c
        do 45 i=1,nang
```

```
c
c increment scattering angle count
c
          nangs=nangs+1
          if(i.eq.1)then
            iangle(nangs)=-icut
          else
            iangle(nangs)=icut
          endif
          if(icut.eq.1)then
c
c phi cut
c
            phis(nangs)=ang
            thes(nangs)=angs+anginc*(i-1)
          else
c
c theta cut
c
            phis(nangs)=angs+anginc*(i-1)
            thes(nangs)=ang
          endif
 45     continue
c
c check angular dimensions
c
        if(nangs.gt.namax)then
          write(6,*) ' insufficient dimension: namax = ',namax
          write(6,*) '                          nangs = ',nangs
          stop
        endif
 50   continue
c
c check array sizes
c
      if(numzel.ne.0)then
c
c nmm=#mm unknowns
c npo=#po unknowns
c
         nmm=nelcur(1)
         npo=nelcur(2)
      endif
c
c nwt=# impedance elements required, symmetric mm (upper
c triangle and diagonal stored) + mm/po coupling matrix
c
      nwt=nmm*(nmm+1)/2+nmm*npo
c
c ntotw=total unknowns (mm unknowns + po unknowns)
c
      ntotw=nmm+npo
      write(6,*) ' Total number of Z array elements needed = ',nwt
      write(6,*) ' Total number of work array elements needed = ',ntotw
      if(nwt.gt.nzmax)then
        write(6,*) ' insufficient dimension : nzmax = ',nzmax
        write(6,*) '                          nwt = ',nwt
        stop
      endif
      if(ntotw.gt.nwork)then
        write(6,*) ' insufficient dimension : nwork = ',nwork
        write(6,*) '                        ntotw = ',ntotw
        stop
      endif
      ntotw=numzel
c
```

```
c calculate wave number (winc)
c and frequency (finc) increments
c
      if(ntotw.gt.numax)then
        write(6,*) ' insufficient dimension : numax = ',numax
        write(6,*) '                          ntotw = ',ntotw
        stop
      endif
      if(nfreq.eq.1)then
        winc=0.0
        finc=0.0
      else
        winc=(fk2-fk1)/(nfreq-1)
        finc=(frequ-freql)/(nfreq-1)
      endif
      write(6,60)title,fk1,freql,temp2/fk
 60   format(1h1,'problem: ',a80,//,' fk1 = ',g12.4,/,' freql = ',f9.3,/,
     & ' lambda = ',g12.4,/)
c
c determine gaussian abscissas and weights
c
      call gauss
c
c loop over # frequencies
c
      do 70 idxfr=1,nfreq
c
c calculate wavenumber and frequency (fk,fr)
c
        fk=fk1+(idxfr-1)*winc
        fr=freql+(idxfr-1)*finc
        write(6,*)
        write(6,*) ' Frequency number = ',idxfr
        write(6,*) '    fk = ',fk,'      freq = ',fr
c
c calculate scattered far fields
c
        if(nmm.ne.0.and.npo.ne.0)then
        call solhyb
        elseif(nmm.ne.0.and.npo.eq.0)then
        call solmom
        elseif(nmm.eq.0.and.npo.ne.0)then
        call solpo
        else
        print *,'unknowns do not define problem that can
     & be handled by code'
        stop
        endif
c
c print out rcs based on far fields
c
        call fldrcs(idxfr,nfreq,fr,freq)
 70    continue
      stop
      end
```

```
      subroutine ipatch(th,ph,rbt,rbp,
     1 nface,nedge,indvf,indef,xc,yc,zc,xv,yv,zv,de)
c
c compute 3d-patch physical optics current coefficients for theta and
c phi polarization.
c
      implicit none
      complex*8 rbt(*),rbp(*)
      integer indvf(3,*),indef(3,*),nedge,iface,nface,ie,i1,
     +iv,i2,l1
      real*4 xc(*),yc(*),zc(*),
     1 xv(*),yv(*),zv(*),de(*),dtor,th,cth,sth,cph,ph,sph,fkx,
     2fky,fkz,xx1,yy1,zz1,xx2,yy2,zz2,del,xx,yy,zz,dot,arg
      complex*8 a1,rt1,rp1
      real*4 xvi(3),yvi(3),zvi(3),dei(3)
      real*4 upx(3),upy(3),upz(3)
      real*4 nx,ny,nz
      integer iedge(3)
      include 'wavenumber.inc'
      include 'const.inc'
      dtor=pi/180.
      call vzero(nedge,rbt)
      call vzero(nedge,rbp)
      if(th.eq.90.0) then
        cth=0.0
        sth=1.0
      else
        cth=cos(th*dtor)
        sth=sin(th*dtor)
      endif
      cph=cos(ph*dtor)
      sph=sin(ph*dtor)
      fkx=fk*sth*cph
      fky=fk*sth*sph
      fkz=fk*cth
c step over each 3d-patch face.
      do 200 iface=1,nface
        do 5 ie=1,3
          i1=indef(ie,iface)
          if(i1.gt.0) then
            dei(ie)=de(i1)
          else
            dei(ie)=-de(-i1)
          endif
          iedge(ie)=iabs(i1)
 5      continue
        do 10 iv=1,3
          i1=indvf(iv,iface)
          xvi(iv)=xv(i1)
          yvi(iv)=yv(i1)
          zvi(iv)=zv(i1)
 10     continue
c unit normal vector to triangular face
        xx1=xvi(2)-xvi(1)
        yy1=yvi(2)-yvi(1)
        zz1=zvi(2)-zvi(1)
        xx2=xvi(3)-xvi(1)
        yy2=yvi(3)-yvi(1)
        zz2=zvi(3)-zvi(1)
        nx=yy1*zz2-zz1*yy2
        ny=-xx1*zz2+zz1*xx2
        nz=xx1*yy2-yy1*xx2
        del=sqrt(nx**2+ny**2+nz**2)
        nx=nx/del
        ny=ny/del
        nz=nz/del
```

```
c compute unit vectors parallel to each side of the triangle
c note, the sign for the +- facet is also included
        do 20 ie=1,3
          if(ie.eq.1) then
            i2=3
            i1=2
          elseif(ie.eq.2) then
            i2=1
            i1=3
          else
            i2=2
            i1=1
          endif
          xx=xvi(i2)-xvi(i1)
          yy=yvi(i2)-yvi(i1)
          zz=zvi(i2)-zvi(i1)
c +- sign included here
          del=dei(ie)
          upx(ie)=xx/del
          upy(ie)=yy/del
          upz(ie)=zz/del
 20     continue
c determine if the facet is shadowed.
        dot=fkx*nx+fky*ny+fkz*nz
        if(dot.lt.0.0) go to 200
c step over the 3 edges which bound face i.
        do 100 ie=1,3
c skip the minus facets.
          if(dei(ie).lt.0.0) go to 100
          l1=iedge(ie)
          if(ie.eq.1) then
            i2=3
            i1=2
          elseif(ie.eq.2) then
            i2=1
            i1=3
          else
            i2=2
            i1=1
          endif
c po current coefficients computed.
          xx=0.5*(xvi(i1)+xvi(i2))
          yy=0.5*(yvi(i1)+yvi(i2))
          zz=0.5*(zvi(i1)+zvi(i2))
          arg=fkx*xx+fky*yy+fkz*zz
          a1=(2.0/eta)*cmplx(cos(arg),sin(arg))
          xx=-upx(ie)
          yy=-upy(ie)
          zz=-upz(ie)
c theta polarized h-field.
          rt1=(cth*(xx*cph+yy*sph)-zz*sth)*a1
          rbt(l1)=rt1
c phi polarized h-field.
          rp1=(-xx*sph+yy*cph)*a1
          rbp(l1)=rp1
 100    continue
 200  continue
      return
      end
```

```
      subroutine lop(i,j,z,lz)
c
c call l operator calculation for different situations
c only patch-patch is included
c
      implicit none
      include 'arraydim.inc'
      include 'surcord.inc'
      include 'faces.inc'
      include 'indx1.inc'
      include 'edges.inc'
      include 'indx2.inc'
      integer iv,i,if,ie,nfaci,nedgi,indvrt,j,indfac,indedg,
     +nfacj,nedgj,isym,lz
      real*4 z
      iv=indp(i)
      if=indf(i)
      ie=inde(i)
      nfaci=numfac(i)
      nedgi=numedg(i)
      indvrt=indp(j)
      indfac=indf(j)
      indedg=inde(j)
      nfacj=numfac(j)
      nedgj=numedg(j)
      isym=0
      if(i.eq.j)isym=1
      call patpatl(z,lz,isym,1.,nfaci,nedgi,idxvf(1,if),
     +idxef(1,if),xc(if),yc(if),zc(if),xv(iv),yv(iv),
     +zv(iv),edlen(ie),nfacj,nedgj,idxvf(1,indfac),idxef(1,ind
     +fac),xc(indfac),yc(indfac),zc(indfac),xv(indvrt),
     +yv(indvrt),zv(indvrt),edlen(indedg),normx(indfac)
     +,normy(indfac),normz(indfac),area(indfac)
     +,upedx(1,indfac),upedy(1,indfac),upedz(1,indfac)
     +,unedx(1,indfac),unedy(1,indfac),unedz(1,indfac))
      return
      end
```

```
      subroutine mdacin(nunit,numpat,nface,nedge,xvert
     &                  ,yvert,zvert,ifacvrt,iedvrt)
c
c read vertices and faces or edges (mdac format)
c
c
c iunit=device number of geometry file
c numpat=number of vertices
c xvert,yvert,zvert=vertice coordinates
c ifacvrt=indices of vertices forming faces
c iedvrt=indices of vertices forming edges
c nface=number of faces
c nedge=number of edges
c
      implicit none
      integer ifacvrt(3,*),iedvrt(2,*)
      integer nunit,numpat,k,nface,nedge,idxfac,j,idxed
      real xvert(*),yvert(*),zvert(*)
c
c read number of patches from external mdac carlos file.
c
      if(nunit.ne.5)read(nunit,*)numpat
c
c read vertices
c
      read(nunit,*)(xvert(k),k=1,numpat)
      read(nunit,*)(yvert(k),k=1,numpat)
      read(nunit,*)(zvert(k),k=1,numpat)
c
c read face/edge information
c
      read(nunit,*)nface,nedge
      if(nface.ne.0)then
c
c read face vertices
c
         do 100 idxfac=1,nface
            if(nunit.ne.5)then
              read(nunit,*)(ifacvrt(j,idxfac),j=1,3)
            else
              read(nunit,*) (ifacvrt(j,idxfac),j=1,3)
            endif
c
c vertex indices must be between 1 and numpat.
c
            if(ifacvrt(1,idxfac).lt.1.or.ifacvrt(1,idxfac).gt.numpat.or.
     &       ifacvrt(2,idxfac).lt.1.or.ifacvrt(2,idxfac).gt.numpat.or.
     &       ifacvrt(3,idxfac).lt.1.or.ifacvrt(3,idxfac).gt.numpat)then
              write(6,*)'   error: Face vertex index is out of range.'
              stop
            endif
 100      continue
      else
c
c edges read
c
        do 110 idxed=1,nedge
          read(nunit,*)(iedvrt(j,idxed),j=1,2)
          if(iedvrt(1,idxed).lt.1.or.iedvrt(1,idxed).gt.numpat.or.
     &       iedvrt(2,idxed).lt.1.or.iedvrt(2,idxed).gt.numpat)then
            write(6,*)'   error: Edge vertex index is out of range.'
            stop
          endif
 110    continue
      endif
      return
```

```
end
```

```
      subroutine patpatl(z,lz,isym,c,
     1 nfi,nei,indvfi,indefi,xci,yci,zci,xvi,yvi,zvi,dei,
     2 nfj,nej,indvfj,indefj,xcj,ycj,zcj,xvj,yvj,zvj,dej
     3,nrmx,nrmy,nrmz,areea,upex,upey,upez,unex,uney,unez)
c
c patch-patch 1 operater calculation
c
c isym=0 : entire matrix computed and stored by columns
c isym.ne.0 : upper triangular part calculated and stored
c in packed form by columns
c
      implicit none
      complex*8 z(*)
      dimension xci(*),yci(*),zci(*),indvfi(3,*),xvi(*),yvi(*),zvi(*),
     1 indefi(3,*),dei(*)
      dimension xcj(*),ycj(*),zcj(*),indvfj(3,*),xvj(*),yvj(*),zvj(*),
     1 indefj(3,*),dej(*)
      real nrmx(*),nrmy(*),nrmz(*),areea(*)
      real upex(3,*),upey(3,*),upez(3,*)
      real unex(3,*),uney(3,*),unez(3,*)
      complex*8 zpp
      complex*8 c1,c2,ctemp
      real*4 xvii(3),yvii(3),zvii(3),deii(3)
      real*4 xvjj(3),yvjj(3),zvjj(3),dejj(3)
      real*4 dot(3,3)
      real*4 nxj,nyj,nzj
      real*4 upx(3),upy(3),upz(3),unx(3),uny(3),unz(3)
      real*4 c,dej,xcjj,xcj,ycjj,ycj,zcjj,zcj,xvj,yvj,zvj,
     +areaj,dei,xcii,xci,ycii,yci,zcii,zci,xvi,yvi,zvi,
     +elj,eli
      complex*8 g11,g1a,g1b,g1c,ga1,gaa,gab,gac
      complex*8 gb1,gba,gbb,gbc,gc1,gca,gcb,gcc
      complex*8 zface,zedgei(3),zedgej(3),zedge(3,3)
      integer jface,nfj,je,j1,indefj,numb,jv,indvfj,isym
     +,istop,nfi,iface,ie,i1,indefi,iv,indvfi,j,i,jt
     +,it,lz,nei,nej
      integer iedge(3),jedge(3)
      include 'block.inc'
      include 'const.inc'
      include 'wavenumber.inc'
      c1=c*(0.,1.)*eta*fk/(4.*pi)
      c2=c*(0.,1.)*eta/fk/pi
c
c loop over faces
c
c source loop
c
      do 500 jface=1,nfj
        do 5 je=1,3
          j1=indefj(je,jface)
          if(j1.gt.0) then
            dejj(je)=dej(j1)
          else
            dejj(je)=-dej(-j1)
          endif
          jedge(je)=iabs(j1)
 5      continue
        if(part) then
          call blockj(3,jedge,numb)
          if(numb.eq.0) go to 500
        endif
        xcjj=xcj(jface)
        ycjj=ycj(jface)
        zcjj=zcj(jface)
        do 10 jv=1,3
          j1=indvfj(jv,jface)
```

```
          xvjj(jv)=xvj(j1)
          yvjj(jv)=yvj(j1)
          zvjj(jv)=zvj(j1)
 10     continue
c   normal vector to source triangle
        nxj=nrmx(jface)
        nyj=nrmy(jface)
        nzj=nrmz(jface)
c   area of source triangle
        areaj=areea(jface)
c   unit vectors parallel and normal to each side of source triangle
        do 110 je=1,3
          upx(je)=upex(je,jface)
          upy(je)=upey(je,jface)
          upz(je)=upez(je,jface)
          unx(je)=unex(je,jface)
          uny(je)=uney(je,jface)
          unz(je)=unez(je,jface)
 110    continue
        if(isym.eq.0) then
          istop=nfi
        else
          istop=jface
        endif
c test surface loop
      do 400 iface=1,istop
        do 15 ie=1,3
          i1=indefi(ie,iface)
          if(i1.gt.0) then
            deii(ie)=dei(i1)
          else
            deii(ie)=-dei(-i1)
          endif
          iedge(ie)=iabs(i1)
 15     continue
        if(part) then
          call blocki(3,iedge,numb)
          if(numb.eq.0) go to 400
          call block2(3,iedge,3,jedge,numb)
          if(numb.eq.0) go to 400
        endif

        xcii=xci(iface)
        ycii=yci(iface)
        zcii=zci(iface)
        do 20 iv=1,3
          i1=indvfi(iv,iface)
          xvii(iv)=xvi(i1)
          yvii(iv)=yvi(i1)
          zvii(iv)=zvi(i1)
 20     continue
c calculate vertex dot products.
        do 30 j=1,3
        do 30 i=1,3
          dot(i,j)=xvii(i)*xvjj(j)+yvii(i)*yvjj(j)+zvii(i)*zvjj(j)
 30     continue
c calculate green's function integrals.
        call grnint(fk,0.,xcii,ycii,zcii,xvii,yvii,zvii,deii,
     1   xcjj,ycjj,zcjj,xvjj,yvjj,zvjj,dejj,
     2   nxj,nyj,nzj,areaj,upx,upy,upz,unx,uny,unz,
     3   g11,g1a,g1b,g1c,ga1,gaa,gab,gac,gb1,gba,gbb,gbc,
     4   gc1,gca,gcb,gcc)
        if(isym.ne.0 .and. iface.eq.jface) then
c edge-independant term
           zface=(c1*(gaa*dot(1,1)+gba*dot(2,1)+gca*dot(3,1)+
     1                gab*dot(1,2)+gbb*dot(2,2)+gcb*dot(3,2)+
```

```
     2                  gac*dot(1,3)+gbc*dot(2,3)+gcc*dot(3,3))-c2*g11
     3                  )*.5

c edge-dependant terms
        do 50 j=1,3
           zedgei(j)=-c1*(g1a*dot(j,1)+g1b*dot(j,2)+g1c*dot(j,3))*0.5
           zedgej(j)=-c1*(ga1*dot(1,j)+gb1*dot(2,j)+gc1*dot(3,j))*0.5
           ctemp=c1*g11*.5
           zedge(1,j)=ctemp*dot(1,j)
           zedge(2,j)=ctemp*dot(2,j)
           zedge(3,j)=ctemp*dot(3,j)
 50     continue
        else
c edge-independant term
           zface=c1*(gaa*dot(1,1)+gba*dot(2,1)+gca*dot(3,1)+
     1               gab*dot(1,2)+gbb*dot(2,2)+gcb*dot(3,2)+
     2               gac*dot(1,3)+gbc*dot(2,3)+gcc*dot(3,3))-c2*g11
c edge-dependant terms
           do 51 j=1,3
              zedgei(j)=-c1*(g1a*dot(j,1)+g1b*dot(j,2)+g1c*dot(j,3))
              zedgej(j)=-c1*(ga1*dot(1,j)+gb1*dot(2,j)+gc1*dot(3,j))
              ctemp=c1*g11
              zedge(1,j)=ctemp*dot(1,j)
              zedge(2,j)=ctemp*dot(2,j)
              zedge(3,j)=ctemp*dot(3,j)
 51        continue
        endif
c step over the 3 edges which bound face j.
        do 100 je=1,3
          jt=jedge(je)
          elj=dejj(je)
c step over the 3 edges which bound face i.
        do 100 ie=1,3
          it=iedge(ie)
          eli=deii(ie)
c lpp impedance elements computed.
          zpp=eli*elj*(zface+zedgei(ie)+zedgej(je)+zedge(ie,je))
          if(isym.ne.0) then
            if(it.eq.jt) then
              zpp=2.0*zpp
            else
            endif
          endif
          call build(zpp,it,jt,isym,z,lz)
 100    continue
 400  continue
 500  continue
      return
      end
```

```
      subroutine patran(nunit,numpat,nface,nedge,xvert,yvert,zvert
     +,ifacvrt)
c
c read patran-iges files
c
      implicit none
      integer ifacvrt(3,*)
      integer nunit,nnodes,nel,idx,idx1,idx2,idx3,numpat
     +,nface,nedge
      real*4 xvert(*),yvert(*),zvert(*)
      character*30 name
c
c 4 blank lines skipped
c
      read(nunit,*)
      read(nunit,*)
      read(nunit,*)
      read(nunit,*)
c
c count nodes
c
      nnodes=0
 100  continue
      read(nunit,*)
      read(nunit,10)name
 10   format(56x,a7)
      if(name.eq.'NODE')then
        nnodes=nnodes+1
      else
        backspace(unit=nunit)
        backspace(unit=nunit)
        goto 200
      endif
      goto 100
 200  continue
c
c count elements
c
      nel=0
 300  continue
      read(nunit,*)
      read(nunit,10)name
      if(name.eq.'ELEMENT')then
        nel=nel+1
      elseif(name.eq.'POINT'.or.name.eq.'LINE'
     & .or.name.eq.'SPLSRF'.or. name.eq.'SPLINE')then
      else
        backspace(unit=nunit)
        backspace(unit=nunit)
        goto 400
      endif
      goto 300
 400  continue
c
c read vertices
c
      do 500 idx=1,nnodes
        read(nunit,20)xvert(idx),yvert(idx),zvert(idx)
 20     format(3x,3(1x,g16.7))
 500  continue
c
c read face indices
c
      do 600 idx=1,nel
        read(nunit,30)idx1,idx2,idx3
 30     format(7x,3(1x,i8))
```

```
      idx1=(idx1+1)/2
      idx2=(idx2+1)/2
      idx3=(idx3+1)/2
      ifacvrt(1,idx)=idx1
      ifacvrt(2,idx)=idx2
      ifacvrt(3,idx)=idx3
      if(ifacvrt(1,idx).lt.1.or.ifacvrt(1,idx).gt.nnodes.or.
     &     ifacvrt(1,idx).lt.1.or.ifacvrt(1,idx).gt.nnodes.or.
     &     ifacvrt(1,idx).lt.1.or.ifacvrt(1,idx).gt.nnodes)then
        write(6,*)'   error: face vertex index is out of range'
        stop
      endif
600  continue
     numpat=nnodes
     nface=nel
     nedge=0
     return
     end
```

```
      subroutine pogen(thet,phi,rthet,rphi,work1,work2)
c
c compute physical optics current coefficients for each of the 3d-patch
c surfaces.
c
      implicit none
      complex*8 rthet(*),rphi(*),work1(*),work2(*)
      integer ib,iv,if,ie,nfi,nei
      real*4 signe,thet,phi
c
      include 'arraydim.inc'
c
      include 'surcord.inc'
      include 'faces.inc'
      include 'indx1.inc'
      include 'edges.inc'
      include 'indx2.inc'
      include 'ecurind.inc'
      include 'order.inc'
      complex*8 const
      call vzero(numzel,rthet)
      call vzero(numzel,rphi)
      if(numzel.ne.0)then
c
c step over all exterior surfaces
c
      do 500 ib=1,nub
        iv=indp(ib)
        if=indf(ib)
        ie=inde(ib)
        nfi=numfac(ib)
        nei=numedg(ib)
          signe=1.0
c check if this is a boundary of region nreg.
              call ipatch(thet,phi,work1,work2,
     1         nfi,nei,idxvf(1,if),idxef(1,if),xc(if),yc(if),zc(if),
     2         xv(iv),yv(iv),zv(iv),edlen(ie))
c
c j currents.
c
              const=signe
              call vbuild(0,-const,work2,0,nei,0,iedind(ie),rthet)
              call vbuild(0,const,work1,0,nei,0,iedind(ie),rphi)
 500  continue
      endif
      return
      end
```

```
      subroutine reorint(nface,ifacvrt,icor)
c
c is face orientation consistent with face 1?
c
c faces must be oriented so that normal vectors to faces are directed outwa
c ; it is assumed that face 1 is outwardly directed
c
      implicit none
      integer ifacvrt(3,*),icor(*)
      integer nreor,ncheck,idxf,nface,idxs,isid1f,isid2f,
     +idxf2,idxs1,jsid1f,jsid2f
c
c nreor = number of faces reoriented
c ncheck= number of faces checked for correctness
c icor is a work array used for control only
c ifacvrt= array of vertex numbers comprising faces
c nface is the number of faces
c
      nreor=0
      ncheck=1
      icor(1)=1
      do 100 idxf=2,nface
        icor(idxf)=0
 100  continue
c
c loop over faces (if all faces correct stop else continue)
c
 200  continue
        do 300 idxf=1,nface
c
c is face orientation correct?
c
          if(icor(idxf).eq.1)goto 400
 300    continue
        write(6,*)'consistent patch orientation questionable'
        write(6,*)'                nface = ',nface
        write(6,*)'                ncheck = ',ncheck
        goto 800
 400    continue
        icor(idxf)=2
c
c loop over edges
c
        do 700 idxs=1,3
          if(idxs.eq.1)then
            isid1f=ifacvrt(2,idxf)
            isid2f=ifacvrt(3,idxf)
          elseif(idxs.eq.2)then
            isid1f=ifacvrt(3,idxf)
            isid2f=ifacvrt(1,idxf)
          else
            isid1f=ifacvrt(1,idxf)
            isid2f=ifacvrt(2,idxf)
          endif
c
c are faces adjacent to iface correctly oriented?
c
          do 600 idxf2=1,nface
            if(icor(idxf2).ne.0)goto 600
c
c loop over edges
c
            do 500 idxs1=1,3
              if(idxs1.eq.1)then
                jsid1f=ifacvrt(2,idxf2)
                jsid2f=ifacvrt(3,idxf2)
```

```
                elseif(idxs1.eq.2)then
                  jsid1f=ifacvrt(3,idxf2)
                  jsid2f=ifacvrt(1,idxf2)
                else
                  jsid1f=ifacvrt(1,idxf2)
                  jsid2f=ifacvrt(2,idxf2)
                endif
c
c are edges common to adjacent faces numbere3d in reverse; yes they are ori
c correctly, no flip vertices of idxf2
c
                if(isid1f.eq.jsid2f.and.isid2f.eq.jsid1f)then
                  ncheck=ncheck+1
                  icor(idxf2)=1
                  goto 700
                elseif(isid1f.eq.jsid1f.and.isid2f.eq.jsid2f)then
c
c change orientation
c
                  ncheck=ncheck+1
                  icor(idxf2)=1
                  nreor=nreor+1
                  if(idxs1.eq.1)then
                    ifacvrt(2,idxf2)=jsid2f
                    ifacvrt(3,idxf2)=jsid1f
                  elseif(idxs1.eq.2)then
                    ifacvrt(3,idxf2)=jsid2f
                    ifacvrt(1,idxf2)=jsid1f
                  else
                    ifacvrt(1,idxf2)=jsid2f
                    ifacvrt(2,idxf2)=jsid1f
                  endif
                  goto 700
                endif
 500          continue
 600        continue
 700      continue
      if(ncheck.lt.nface)goto 200
 800  continue
      write(6,*)
      write(6,*)'faces reoriented = ',nreor
      return
      end
```

```
      subroutine rgen(n,th,ph,rbt,rbp,irv,vbt,vbp,wt,wp,xwt,xwp,
     1 nbi)
c
c calculate general cfie r and v matrices for theta and phi polarization.
c either geometric symmetry or imaged fields are included.
c the following inner products are calculated:
c        r = < j , e >
c            < m , h >
c        v = < j , alpha e + (1-alpha) eta n x h >
c            < m , alpha h + (1-alpha) / eta n x e >
c
      implicit none
      complex*8 rbt(*),rbp(*),vbt(*),vbp(*),wt(*),wp(*),xwt(*),xwp(*)
      integer ib,nbi,n,nei,irv,indi,indzj
      real*4 signe,consta,th,ph
c
      include 'arraydim.inc'
c
      complex*8 conij
      common /index/ conij,indi(nwork),
     1 indzj(nwork)
      complex*8 const
c
c step over all exterior surfaces
c
      do 500 ib=1,nbi
          signe=1.0
          consta=1.0
              call rop(ib,n,th,ph,wt,wp,xwt,xwp)
              const=consta
              call vindex(const,ib,nei)
c
c j current testing.
c
c e-field.
              const=signe*conij
              if(irv.eq.1 .or. irv.eq.0) then
                call vbuild(0,const,wt,0,nei,0,indzj,rbt)
                call vbuild(0,const,wp,0,nei,0,indzj,rbp)
              endif
              if(irv.eq.2) then
                call vbuild(0,const,wt,0,nei,0,indzj,vbt)
                call vbuild(0,const,wp,0,nei,0,indzj,vbp)
              endif
 500  continue
      return
      end
```

```
      subroutine rop(ib,n,th,ph,wt,wp,xwt,xwp)
c
c calculate the r matrix operator.
c
      implicit none
      complex*8 wt(*),wp(*),xwt(*),xwp(*)
      real*4 c,th,ph
      integer iv,ib,if,ie,nfi,nei,n
      include 'arraydim.inc'
      include 'surcord.inc'
      include 'faces.inc'
      include 'indx1.inc'
      include 'edges.inc'
      include 'indx2.inc'
      c=1.0
        iv=indp(ib)
        if=indf(ib)
        ie=inde(ib)
        nfi=numfac(ib)
        nei=numedg(ib)
        call rpatch(th,ph,wt,wp,xwt,xwp,
     1   nfi,nei,idxvf(1,if),idxef(1,if),xc(if),yc(if),zc(if),
     2   xv(iv),yv(iv),zv(iv),edlen(ie))
      return
      end
```

```
      subroutine rpatch(th,ph,rbt,rbp,xrbt,xrbp,
     1 nface,nedge,indvf,indef,xc,yc,zc,xv,yv,zv,de)
c
c compute 3d-patch efie r matrices for theta and phi polarization.
c
c analytic expressions.
c
      implicit none
      complex*8 rbt(*),rbp(*),xrbt(*),xrbp(*)
      dimension indvf(3,*),indef(3,*),xc(*),yc(*),zc(*),
     1 xv(*),yv(*),zv(*),de(*)
      complex*8 a1,rt1,rp1,xrt1,xrp1
      real*4 j0,j1,nx,ny,nz
      real*4 kp2,kpx,kpy,kpz,knx,kny,knz
      complex*8 cxx,cyy,czz,dskx,dsky,dskz,sk
      real*4 xvi(3),yvi(3),zvi(3),dei(3)
      real*4 dtor,th,cth,sth,cph,ph,sph,fkx,fky,fkz,fk2
     +,de,xci,xc,yci,yc,zci,zc,xv,yv,zv,xx1,yy1,zz1,xx2,
     +yy2,zz2,del,area,dot,rnx,rny,rnz,x1,y1,z1,x2,y2,z2,
     +crossx,crossy,crossz,trip,dot2,xx,yy,zz,arg,el
      integer nedge,iface,nface,ie,i1,indef,iv,indvf
     +,i2,l1
      integer iedge(3)
      include 'wavenumber.inc'
      include 'tilde.inc'
      include 'const.inc'
      dtor=pi/180.
      call vzero(nedge,rbt)
      call vzero(nedge,rbp)
      call vzero(nedge,xrbt)
      call vzero(nedge,xrbp)
      if(th.eq.90.0) then
        cth=0.0
        sth=1.0
      else
        cth=cos(th*dtor)
        sth=sin(th*dtor)
      endif
      cph=cos(ph*dtor)
      sph=sin(ph*dtor)
      fkx=fk*sth*cph
      fky=fk*sth*sph
      fkz=fk*cth
      fk2=fk**2
c step over each 3d-patch face.
      do 200 iface=1,nface
        do 5 ie=1,3
          i1=indef(ie,iface)
          if(i1.gt.0) then
            dei(ie)=de(i1)
          else
            dei(ie)=-de(-i1)
          endif
          iedge(ie)=iabs(i1)
 5      continue
        xci=xc(iface)
        yci=yc(iface)
        zci=zc(iface)
        do 10 iv=1,3
          i1=indvf(iv,iface)
          xvi(iv)=xv(i1)
          yvi(iv)=yv(i1)
          zvi(iv)=zv(i1)
 10     continue
c unit normal vector to triangular face
        xx1=xvi(2)-xvi(1)
```

```
        yy1=yvi(2)-yvi(1)
        zz1=zvi(2)-zvi(1)
        xx2=xvi(3)-xvi(1)
        yy2=yvi(3)-yvi(1)
        zz2=zvi(3)-zvi(1)
        nx=yy1*zz2-zz1*yy2
        ny=-xx1*zz2+zz1*xx2
        nz=xx1*yy2-yy1*xx2
        del=sqrt(nx**2+ny**2+nz**2)
        nx=nx/del
        ny=ny/del
        nz=nz/del
c area of triangular face
        area=0.5*del
        if(rtilde) then
c analytic integrals
c compute normal and parallel vectors
          dot=xci*nx+yci*ny+zci*nz
          rnx=dot*nx
          rny=dot*ny
          rnz=dot*nz
          dot=fkx*nx+fky*ny+fkz*nz
          knx=dot*nx
          kny=dot*ny
          knz=dot*nz
          kpx=fkx-knx
          kpy=fky-kny
          kpz=fkz-knz
c compute sk and grad(sk) integrals
          kp2=kpx**2+kpy**2+kpz**2
          if(kp2/fk2.ge.0.0001) then
            sk=0.0
            dskx=0.0
            dsky=0.0
            dskz=0.0
c loop over the 3 sides of the face.
            do 50 i1=1,3
              i2=i1+1
              if(i2.gt.3) i2=1
              x1=xvi(i1)
              y1=yvi(i1)
              z1=zvi(i1)
              x2=xvi(i2)
              y2=yvi(i2)
              z2=zvi(i2)
              xx1=x2-x1
              yy1=y2-y1
              zz1=z2-z1
              crossx=ny*zz1-nz*yy1
              crossy=-nx*zz1+nz*xx1
              crossz=nx*yy1-ny*xx1
              trip=kpx*crossx+kpy*crossy+kpz*crossz
              dot=0.5*(kpx*xx1+kpy*yy1+kpz*zz1)
              if(abs(dot).ge.1.e-4) then
                j0=sin(dot)/dot
                j1=0.5*(j0-cos(dot))/dot
              elseif(abs(dot).ge.1.e-8) then
                dot2=dot**2
                j0=1.0-dot2/6.+dot2*dot2/120.
                j1=dot/6.-dot*dot2/60.
              else
                j0=1.0
                j1=0.0
              endif
              xx=0.5*(x2+x1)-rnx
              yy=0.5*(y2+y1)-rny
```

```
              zz=0.5*(z2+z1)-rnz
              arg=kpx*xx+kpy*yy+kpz*zz
              a1=cmplx(cos(arg),sin(arg))
              sk=sk+trip*j0*a1
              dskx=dskx+a1*cmplx((crossx-2.*kpx/kp2*trip)*j0
     &         -xx1*trip*j1,xx*trip*j0)
              dsky=dsky+a1*cmplx((crossy-2.*kpy/kp2*trip)*j0
     &         -yy1*trip*j1,yy*trip*j0)
              dskz=dskz+a1*cmplx((crossz-2.*kpz/kp2*trip)*j0
     &         -zz1*trip*j1,zz*trip*j0)
 50         continue
            sk=(0.,1.)*sk/kp2
            dskx=dskx/kp2
            dsky=dsky/kp2
            dskz=dskz/kp2
          else
c parallel component of k nearly zero
            sk=area
            dskx=area*(xci-rnx)
            dsky=area*(yci-rny)
            dskz=area*(zci-rnz)
          endif
c centroid appoximation
          arg=knx*rnx+kny*rny+knz*rnz
          a1=0.5/area*cmplx(cos(arg),sin(arg))
        else
          arg=fkx*xci+fky*yci+fkz*zci
          a1=0.5*cmplx(cos(arg),sin(arg))
        endif
c step over the 3 edges which bound face i.
        do 100 ie=1,3
          l1=iedge(ie)
          el=dei(ie)
c e-field equation r matrix computed.
          if(rtilde) then
            cxx=dskx+(rnx-xvi(ie))*sk
            cyy=dsky+(rny-yvi(ie))*sk
            czz=dskz+(rnz-zvi(ie))*sk
          else
            cxx=xci-xvi(ie)
            cyy=yci-yvi(ie)
            czz=zci-zvi(ie)
          endif
c theta polarized e-field.
          rt1=(cth*(cxx*cph+cyy*sph)-czz*sth)*a1
          rbt(l1)=el*rt1+rbt(l1)
          xrt1=(-(ny*sth+nz*cth*sph)*cxx+(nx*sth+nz*cth*cph)*cyy+
     &     (nx*cth*sph-ny*cth*cph)*czz)*a1
          xrbt(l1)=el*xrt1+xrbt(l1)
c phi polarized e-field.
          rp1=(-cxx*sph+cyy*cph)*a1
          rbp(l1)=el*rp1+rbp(l1)
          xrp1=(-nz*cph*cxx-nz*sph*cyy+(nx*cph+ny*sph)*czz)*a1
          xrbp(l1)=el*xrp1+xrbp(l1)
 100    continue
 200  continue
      return
      end
```

```
      subroutine vgen(n,th,ph,rt,rp,irv,vt,vp,work1,work2,work3,work4)
c
c compute r matrices for 3d-patch and wire surfaces.
c irv = 0 - both r and v arrays are returned
c       1 - r arrays are returned
c       2 - v arrays are returned
      implicit none
      integer irv,n,lz,i
      real*4 th,ph
      complex*8 rt(*),rp(*),vt(*),vp(*)
      complex*8 work1(*),work2(*),work3(*),work4(*)
      include 'arraydim.inc'
      include 'surcord.inc'
      include 'order.inc'
      if(irv.eq.0 .or. irv.eq.1) then
        call vzero(numzel,rt)
        call vzero(numzel,rp)
      endif
      if(irv.eq.0 .or. irv.eq.2) then
        call vzero(numzel,vt)
        call vzero(numzel,vp)
      endif
      if(numzel.ne.0) then
        call rgen(n,th,ph,rt,rp,irv,vt,vp,work1,work2,work3,work4,
     1   nub)
      endif
      if(irv.eq.0) then
        lz=numzel
        do 100 i=1,lz
          vt(i)=rt(i)
          vp(i)=rp(i)
 100    continue
      endif
      return
      end
```

```
      subroutine solhyb
c
c calculate mm and po currents and fields
c
      implicit none
      include 'arraydim.inc'
      include 'work.inc'
      include 'order.inc'
      include 'threat.inc'
      include 'numj.inc'
      include 'polar.inc'
      include 'scatter.inc'
      include 'const.inc'
      complex zimp(nzmax)
      complex vth(numax),vph(numax),thcur(numax),phcur(numax)
      complex radt(numax),radp(numax)
      complex ttskat,ppskat,tpskat,ptskat
      integer ipvtz(numax)
      integer ntot,nmom,npo,imom,ipomm,idxmm,idxpo,k,i,i2,idx,i1
      real*4 rcond,dumy
      logical solvth,solvph
c
c assign mm, po, and total number of unknowns
c
      ntot=numzel
      nmom=nelcur(1)
      npo=nelcur(2)
c
c print total number of unknowns, mm unknowns, and po unknowns
c
      write(6,*)
      write(6,*) '  total number of unknowns = ',ntot
      write(6,*) '  number of mm unknowns = ',nmom
      write(6,*) '  number of po unknowns = ',npo
c
c calculate mom and po pointers for impedance matrix
c
      imom=1
      ipomm=imom+nmom*(nmom+1)/2
c
c calculate mm and po pointers for excitation vector
c
      idxmm=1
      idxpo=idxmm+nmom
c
c calculate mm impedance matrix
c
      write(6,*)
      write(6,*)'calculating mm coefficient matrix'
c
c zimp is the mm impedance matrix
c
      call zimped(0,0,-1,zimp(imom),work1,ntot,idxmm,idxmm+nmom-1,
     &idxmm,idxmm+nmom-1)
c
c factor mm impedance matrix using symmetric linpack routine
c
      call cspco(zimp(imom),nmom,ipvtz(idxmm),rcond,work1)
      write(6,*)' impedance matrix condition = ',1./(rcond+1.e-30)
c
c calculate po/mm impedance matrix
c zimp is the mm/po impedance matrix
c
      write(6,*)
      write(6,*) 'calculating po/mm interaction matrix'
      call zimped(0,0,-1,zimp(ipomm),work1,ntot,idxmm,idxmm+nmom-1,
```

```
     &idxpo,idxpo+npo-1)
c
c determine polarizations for rcs
c
      solvth=(monbi.ge.0 .and. polt)
      solvph=(monbi.ge.0 .and. polp)
      do 100 k=1,nang
        if(monbi.gt.0)then
          thet=thes(k)
          phi=phis(k)
        endif
c
c calculate excitation vector
c
        if(monbi.eq.0)then
c
c bistatic case
c
          call vgen(-1,thes(k),phis(k),radt,radp,1,dumy,dumy,
     &     work1,work2,work3,work4)
          if(k.eq.1)then
            call vgen(-1,thet,phi,dumy,dumy,2,vth,vph,
     &       work1,work2,work3,work4)
          endif
        else
c
c monostatic case
c
          call vgen(-1,thes(k),phis(k),radt,radp,0,vth,vph,
     &     work1,work2,work3,work4)
        endif
        if(monbi.gt.0.or.(monbi.eq.0.and.k.eq.1))then
          do 139 i=1,ntot
            thcur(i)=0.
            phcur(i)=0.
            if(solvth)thcur(i)=vth(i)
            if(solvph)phcur(i)=vph(i)
 139      continue
c
c calculate po currents
c
          call pogen(thet,phi,work1,work2,work3,work4)
          do 50 i2=idxpo,idxpo+npo-1
            thcur(i2)=work1(i2)
            phcur(i2)=work2(i2)
 50       continue
c
c calculate mm/po right hand side (v-zpomm*ipo)
c
          idx=ipomm-1
          do 70 i2=idxpo,idxpo+npo-1
             do 60 i1=idxmm,idxmm+nmom-1
               idx=idx+1
c
c thcur,phcur=theta/phi polarized rhss
c
               if(solvth)thcur(i1)=thcur(i1)-zimp(idx)*thcur(i2)
               if(solvph)phcur(i1)=phcur(i1)-zimp(idx)*phcur(i2)
 60          continue
 70       continue
c
c solve for mm currents using linpack cspsl
c
         if(solvth)call cspsl(zimp(imom),nmom,ipvtz(idxmm),thcur(idxmm))
         if(solvph)call cspsl(zimp(imom),nmom,ipvtz(idxmm),phcur(idxmm))
       endif
```

```
c
c calculate far fields
c
      ttskat=0.
      tpskat=0.
      ptskat=0.
      ppskat=0.
      if(solvth)then
         call dot(radt,thcur,ttskat,ntot)
         call dot(radp,thcur,ptskat,ntot)
      endif
      if(solvph)then
         call dot(radt,phcur,tpskat,ntot)
         call dot(radp,phcur,ppskat,ntot)
      endif
      ttscat(k)=ttskat
      ppscat(k)=ppskat
      tpscat(k)=tpskat
      ptscat(k)=ptskat
100   continue
      return
      end
```

```
      subroutine solmom
c
c calculate mm currents and fields
c
      implicit none
      include 'arraydim.inc'
      include 'work.inc'
      include 'order.inc'
      include 'threat.inc'
      include 'numj.inc'
      include 'polar.inc'
      include 'scatter.inc'
      include 'const.inc'
      complex zimp(nzmax)
      complex vth(numax),vph(numax),thcur(numax),phcur(numax)
      complex radt(numax),radp(numax)
      complex ttskat,ppskat,tpskat,ptskat
      integer ipvtz(numax)
      integer ntot,nmom,npo,imom,idxmm,k,i
      real*4 rcond,dumy
      logical solvth,solvph
c
c assign mm, po, and total number of unknowns
c
      ntot=numzel
      nmom=nelcur(1)
      npo=nelcur(2)
c
c print total number of unknowns, mm unknowns, and po unknowns
c
      write(6,*)
      write(6,*) '  total number of unknowns = ',ntot
      write(6,*) '  number of mm unknowns = ',nmom
      write(6,*) '  number of po unknowns = ',npo
c
c calculate mom pointers for impedance matrix
c
      imom=1
c
c calculate mm pointers for excitation vector
c
      idxmm=1
c
c calculate mm impedance matrix
c
      write(6,*)
      write(6,*)'calculating mm coefficient matrix'
c
c zimp is the mm impedance matrix
c
      call zimped(0,0,-1,zimp(imom),work1,ntot,idxmm,idxmm+nmom-1,
     &idxmm,idxmm+nmom-1)
c
c factor mm impedance matrix using symmetric linpack routine
c
      call cspco(zimp(imom),nmom,ipvtz(idxmm),rcond,work1)
      write(6,*)' impedance matrix condition = ',1./(rcond+1.e-30)
c
c determine polarizations for rcs
c
      solvth=(monbi.ge.0 .and. polt)
      solvph=(monbi.ge.0 .and. polp)
      do 100 k=1,nang
        if(monbi.gt.0)then
          thet=thes(k)
          phi=phis(k)
```

```
        endif
c
c calculate excitation vector
c
        if(monbi.eq.0)then
c
c bistatic case
c
          call vgen(-1,thes(k),phis(k),radt,radp,1,dumy,dumy,
     &     work1,work2,work3,work4)
          if(k.eq.1)then
            call vgen(-1,thet,phi,dumy,dumy,2,vth,vph,
     &       work1,work2,work3,work4)
          endif
        else
c
c monostatic case
c
          call vgen(-1,thes(k),phis(k),radt,radp,0,vth,vph,
     &     work1,work2,work3,work4)
        endif
        if(monbi.gt.0.or.(monbi.eq.0.and.k.eq.1))then
          do 139 i=1,ntot
            thcur(i)=0.
            phcur(i)=0.
            if(solvth)thcur(i)=vth(i)
            if(solvph)phcur(i)=vph(i)
 139      continue
c
c solve for mm currents using linpack cspsl
c
         if(solvth)call cspsl(zimp(imom),nmom,ipvtz(idxmm),thcur(idxmm))
         if(solvph)call cspsl(zimp(imom),nmom,ipvtz(idxmm),phcur(idxmm))
       endif
c
c calculate far fields
c
       ttskat=0.
       tpskat=0.
       ptskat=0.
       ppskat=0.
       if(solvth)then
          call dot(radt,thcur,ttskat,ntot)
          call dot(radp,thcur,ptskat,ntot)
       endif
       if(solvph)then
          call dot(radt,phcur,tpskat,ntot)
          call dot(radp,phcur,ppskat,ntot)
       endif
       ttscat(k)=ttskat
       ppscat(k)=ppskat
       tpscat(k)=tpskat
       ptscat(k)=ptskat
 100  continue
      return
      end
```

```
      subroutine solpo
c
c calculate po currents and fields
c
      implicit none
      include 'arraydim.inc'
      include 'work.inc'
      include 'order.inc'
      include 'threat.inc'
      include 'numj.inc'
      include 'polar.inc'
      include 'scatter.inc'
      include 'const.inc'
      complex zimp(nzmax)
      complex vth(numax),vph(numax),thcur(numax),phcur(numax)
      complex radt(numax),radp(numax)
      complex ttskat,ppskat,tpskat,ptskat
      integer ipvtz(numax)
      integer ntot,nmom,npo,ipo,idxpo,k,i,i2
      real*4 dumy
      logical solvth,solvph
c
c assign mm, po, and total number of unknowns
c
      ntot=numzel
      nmom=nelcur(1)
      npo=nelcur(2)
c
c print total number of unknowns, mm unknowns, and po unknowns
c
      write(6,*)
      write(6,*) '  total number of unknowns = ',ntot
      write(6,*) '  number of mm unknowns = ',nmom
      write(6,*) '  number of po unknowns = ',npo
c
c calculate po pointers for impedance matrix
c
      ipo=1
c
c calculate po pointers for excitation vector
c
      idxpo=1
c
c determine polarizations for rcs
c
      solvth=(monbi.ge.0 .and. polt)
      solvph=(monbi.ge.0 .and. polp)
      do 100 k=1,nang
        if(monbi.gt.0)then
          thet=thes(k)
          phi=phis(k)
        endif
c
c calculate excitation vector
c
        if(monbi.eq.0)then
c
c bistatic case
c
          call vgen(-1,thes(k),phis(k),radt,radp,1,dumy,dumy,
     &     work1,work2,work3,work4)
          if(k.eq.1)then
            call vgen(-1,thet,phi,dumy,dumy,2,vth,vph,
     &       work1,work2,work3,work4)
          endif
        else
```

```
c
c monostatic case
c
          call vgen(-1,thes(k),phis(k),radt,radp,0,vth,vph,
     &     work1,work2,work3,work4)
        endif
        if(monbi.gt.0.or.(monbi.eq.0.and.k.eq.1))then
          do 139 i=1,ntot
            thcur(i)=0.
            phcur(i)=0.
            if(solvth)thcur(i)=vth(i)
            if(solvph)phcur(i)=vph(i)
 139      continue
c
c calculate po currents
c
          call pogen(thet,phi,work1,work2,work3,work4)
          do 50 i2=idxpo,idxpo+npo-1
            thcur(i2)=work1(i2)
            phcur(i2)=work2(i2)
 50       continue
       endif
c
c calculate far fields
c
       ttskat=0.
       tpskat=0.
       ptskat=0.
       ppskat=0.
       if(solvth)then
          call dot(radt,thcur,ttskat,ntot)
          call dot(radp,thcur,ptskat,ntot)
       endif
       if(solvph)then
          call dot(radt,phcur,tpskat,ntot)
          call dot(radp,phcur,ppskat,ntot)
       endif
       ttscat(k)=ttskat
       ppscat(k)=ppskat
       tpscat(k)=tpskat
       ptscat(k)=ptskat
 100  continue
      return
      end
```

```
      subroutine sysind(ib,jb)
c
c compute system matrix indices for testing and expansion functions
c
      implicit none
      include 'arraydim.inc'
      include 'index.inc'
      integer ib,jb
      nincl=nincl+1
      if(nincl.gt.1)then
        write(6,*)' error subroutine sysind , nincl > 1'
        stop
      endif
c
c given the surface # eindex returns an array containg the global
c unknown indices corresponding to the edges of the surface
c ib and jb are surface numbers
c indxi and indxj are arrays that contain global unknown # of edges
c of surfaces
c
      call eindex(ib,indxi)
      call eindex(jb,indxj)
      return
      end
```

```
      subroutine vbuild(ncomp,const,a,ij1,npi,ij2,indi,b)
c
c add or subtract the subvectors of vector a to vector b.
c
      implicit none
      complex*8 const,sign
      complex*8 a(*),b(*)
      integer indi(*)
      integer li(6)
      integer ncomp,nei,npi,istop,ia,i,ni,ib,inda
     +,indb,ki,ij1,ij2
      if(const.eq.0.0) return
      if(ncomp.eq.0) then
        nei=npi
        istop=nei
      else
        li(1)=1
        li(2)=(npi-3)/2
        li(3)=1
        li(4)=1
        li(5)=(npi-3)/2
        li(6)=1
        istop=ncomp*3
      endif
      ia=1
      do 960 i=1,istop
      if(ncomp.eq.0) then
        ni=1
      else
        ni=li(i)
      endif
      if(ni.eq.0) go to 960
      ib=indi(i)
      if(ib.eq.0) go to 940
c add the (i) subvector of vector a to vector b.
      sign=const
      if(ib.lt.0) sign=-const
      ib=iabs(ib)
      inda=ia-1
      indb=ib-1
      do 110 ki=1,ni
         inda=inda+1
         indb=indb+1
         b(indb)=sign*a(inda)+b(indb)
 110  continue
 940  continue
      ia=ia+ni
 960  continue
      return
      end
```

```
      subroutine vindex(const,ib,nbasis)
c
c compute vector indices for testing functions.
c
      implicit none
      complex*8 const
      integer nbasis,ib,indi,i,indzj
      include 'arraydim.inc'
      complex*8 conij
      common /index/ nloc,conij,indi(nwork),
     1 indzj(nwork)
      include 'edges.inc'
        nbasis=numedg(ib)
      conij=const
      call eindex(ib,indi)
      do 100 i=1,nbasis
        indzj(i)=indi(i)  ! ak
 100  continue
      return
      end
```

```
      subroutine vzero(n,a)
c
c set array a of length n to (0.,0.)
c
      implicit none
      integer i,n
      complex a(*)
      do 10 i=1,n
      a(i)=(0.,0.)
 10   continue
      return
      end
```

```
      subroutine zelcal(ipoctrl,notused,zimpmat,nordimp,work,
     & nbndi,nzji,nbndj,nzjj)
c
c do not use any optimization when compiling this routine on Paragon
c -O3 resulted in wrong answer (compiler error)
c
c calculate <j,e>
c
      implicit none
      complex zimpmat(*),work(*)
      complex const
      integer nzji(*),nzjj(*)
      integer jbnd,nbndj,ibnd,nbndi,njj,nordimp,ipoctrl,notused
      include 'arraydim.inc'
      include 'block.inc'
      include 'index.inc'
      if(part)then
        write(6,*)'  generate the following matrix sub-block:'
        write(6,*)'    rows    ',iblck1,' thru ',iblck2
        write(6,*)'    columns ',jblck1,' thru ',jblck2
        write(6,*)
        if(iblck1.gt.jblck1)then
          write(6,*) '    error: block must be above the main diagonal'
          stop
        endif
      endif
      do 500 jbnd=1,nbndj
      do 500 ibnd=1,nbndi
      if(ibnd.gt.jbnd)goto 500
      write(6,*)
      write(6,*) ' ibnd = ',ibnd,'   jbnd = ',jbnd
c
c e-field and h-field l operator.
c
      nincl=0
      njj=nzji(ibnd)*nzjj(jbnd)
      if(njj.eq.0)goto 500
c e-field , < j , l(j) >.
        curij=1.
        call sysind(ibnd,jbnd)
c
c always true
c
      if(part)call block(ibnd,jbnd)
      if(nincl.ne.0)then
        call lop(ibnd,jbnd,zimpmat,nordimp)
      endif
 500  continue
      return
      end
```

```
      subroutine zimped(izadd,iopctrl,n,zmat,work,lvecmax
     & ,ilowbnd,iupbnd,jlowbnd,jupbnd)
c
c calculate impedance matrix
c
      implicit none
      complex zmat(*),work(*)
      integer ilowbnd,iupbnd,jlowbnd,jupbnd,isize,jsize,
     +lvecmax,nzsize,iopctrl,izadd,n
      include 'arraydim.inc'
      include 'surcord.inc'
      include 'ecurind.inc'
      include 'order.inc'
      include 'block.inc'
c
c set row/column boundaries for block
c
      iblck1=ilowbnd
      iblck2=iupbnd
      jblck1=jlowbnd
      jblck2=jupbnd
c
c calculate the number of rows and columns in block
c
      isize=iblck2-iblck1+1
      jsize=jblck2-jblck1+1
      if(isize.le.0.or.jsize.le.0)then
        write(6,*)'   error: block size <= 0 (zimped)'
        stop
      endif
c
c is this a partitioned solution? for mm/po part=true
c
      if(isize.eq.lvecmax.and.jsize.eq.lvecmax)then
        part=.false.
      else
        part=.true.
      endif
c
c if symmetric block only calculate upper triangle and diagonal
c
      if(iblck1.eq.jblck1.and.iblck2.eq.jblck2)then
          nzsize=isize*(isize+1)/2
      else
          nzsize=isize*jsize
      endif
      call vzero(nzsize,zmat)
      if(numzel.ne.0)then
c
c calculate the elements of the impedance matrix (by block)
c
            call zelcal(iopctrl,0,zmat,isize,work,nub,nbji,
     &       nub,nbji)
      endif
      return
      end
```

```
c
c arraydim.inc
c
c     nptsmax: max number of vertex points
c     namax: max number of scattering angles
c     nzmax: max number Z matrix elements
c     numax: max number of unknowns
c     nbndmax: max number of boundaries
c     nfacmax: max number of faces
c     nedgmax: max number of edges
c     nwork: max number work matrix elements
c
      integer nptsmax,namax,nzmax,numax,nbndmax,nfacmax,
     +nedgmax,nwork
      parameter(nptsmax=3000,namax=722,nzmax=900000
     & ,numax=5000,nbndmax=40,nfacmax=4000,
     & nedgmax=6000,nwork=6000)
```

```
c
c block.inc
c
      integer iblck1,iblck2,jblck1,jblck2
      logical part
      common/blokl/part
      common/bloki/iblck1,iblck2,jblck1,jblck2
```

```
c
c const.inc
c
      real*4 pi,eta
      common/const/pi,eta
```

```
c
c dbsm.inc
c
      logical dbsm
      common/dbsml/dbsm
```

```
c
c ecurind.inc
c
      integer nbji(nbndmax),iedind(nedgmax),idxuned(numax,2)
      common /ecuri/nbji,iedind,idxuned
```

```
c
c edges.inc
c
      integer numedg(nbndmax),edtype(nedgmax)
      real*4 edlen(nedgmax)
      common/edgei/numedg,edtype
      common/edger/edlen
```

```
c
c faces.inc
c
      real*4 normx(nfacmax),normy(nfacmax),normz(nfacmax)
      real*4 area(nfacmax)
      real*4 upedx(3,nfacmax),upedy(3,nfacmax),upedz(3,nfacmax)
      real*4 unedx(3,nfacmax),unedy(3,nfacmax),unedz(3,nfacmax)
      real*4 xc(nfacmax),yc(nfacmax),zc(nfacmax)
      integer numfac(nbndmax)
      common/facesi/numfac
      common/facesr/xc,yc,zc
     +,normx,normy,normz,area
     +,upedx,upedy,upedz,unedx,unedy,unedz
```

```
c
c index.inc
c
      complex*8 curij
      integer nincl,indxi(nwork),indxj(nwork)
      common /indexc/curij
      common /indexi/nincl,indxi,indxj
```

```
c
c indx1.inc
c
      integer idxvf(3,nfacmax),idxef(3,nfacmax),idxve(2,nedgmax)
     +,idxfem(nedgmax),idxfep(nedgmax)
      common/indx1/idxvf,idxef,idxve,idxfem,idxfep
```

```
c
c indx2.inc
c
      integer indp(nbndmax),indf(nbndmax),inde(nbndmax)
      common/indx2/indp,indf,inde
```

```
c
c intord.inc
c
      real*4 rnear,rfar
      integer nself,nnear,nmid,nfar
      common /intdist/ rnear,rfar
      common /intord/ nself,nnear,nmid,nfar
```

```
c
c numbers.inc
c
      integer npoynt,nfaces,nedges
      common/numbers/npoynt,nfaces,nedges
```

```
c
c numj.inc
c
      integer nelcur(2)
      common/numj/nelcur
```

```
c
c order.inc
c
      integer numzel
      common /order/numzel
```

```
c
c patchtol.inc
c
      real*4 pattol
      common/patol/pattol
```

```
c
c polar.inc
c
      logical polt,polp
      common/polar/polt,polp
```

```
c
c problem.inc
c
      character*80 title
      common/problem/title
```

```
c
c scatter.inc
c
      complex*8 ttscat(namax),ppscat(namax),
     +tpscat(namax),ptscat(namax)
      integer nang,iangle(namax)
      real*4 thes(namax),phis(namax)
      common/scatc/ttscat,ppscat,tpscat,ptscat
      common/scati/nang,iangle
      common/scatr/thes,phis
```

```
c
c surcord.inc
c
      integer nub,nup(nbndmax)
      real*4 xv(nptsmax),yv(nptsmax),zv(nptsmax)
      common/surcri/nub,nup
      common/surcrr/xv,yv,zv
```

```
c
c threat.inc
c
      integer monbi
      real*4 thet,phi
      common /threti/monbi
      common /thretr/thet,phi
```

```
c
c tilde.inc
c
      logical rtilde
      common /tilde/rtilde
```

```
c
c triint.inc
c
      real*4 weight(108),alfa(108),beta(108)
      integer nmpont(25)
      common /triint/ weight,alfa,beta
      common /tripnt/ nmpont
```

```
c
c unit.inc
c
      character*5 units
      common/unit/units
```

```
c
c wavenumber.inc
c
      real*4 fk
      common /wavnum/ fk
```

```
c
c work.inc
c
      complex work1(nwork),work2(nwork),work3(nwork),
     +work4(nwork)
      common/work/work1,work2,work3,work4
```

```
CYLINDER (MM/PO SOLUTION)
 $option  $end
  6.2831853
patch
          17  surface 1  endcap at z=0
       1
  0.10000       0.80900E-01  0.30900E-01 -0.30900E-01 -0.80900E-01 -0.10000
 -0.80900E-01 -0.30900E-01  0.30900E-01  0.80900E-01 -0.37300E-01  0.79208E
 -0.45221E-01  0.00000E+00  0.45221E-01 -0.79208E-02  0.37300E-01
  0.00000E+00  0.58780E-01  0.95110E-01  0.95110E-01  0.58780E-01  0.00000E
 -0.58780E-01 -0.95110E-01 -0.95110E-01 -0.58780E-01  0.37876E-01  0.52567E
 -0.14690E-01  0.00000E+00  0.14690E-01 -0.52567E-01 -0.37876E-01
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
          22           0
          13          11          14  (.3,.2) 0.0 0.0 (.68,.24)  0.0  0.0
          12          11          14
          12          14          15
          14          13          16
          14          16          17
          15          14          17
           6          11           5
           6          13          11
           7          13           6
           7          16          13
           8          16           7
           9          16           8
           9          17          16
          10          17           9
           1          17          10
           1          15          17
           2          15           1
           2          12          15
           3          12           2
           4          12           3
           4          11          12
           5          11           4
   90  250   surface 2  cylinder body
       1
  0.1000       0.8090E-01  0.3090E-01 -0.3090E-01 -0.8090E-01 -0.1000
 -0.8090E-01 -0.3090E-01  0.3090E-01  0.8090E-01  0.1000       0.8090E-01
  0.3090E-01 -0.3090E-01 -0.8090E-01 -0.1000      -0.8090E-01 -0.3090E-01
  0.3090E-01  0.8090E-01  0.1000       0.8090E-01  0.3090E-01 -0.3090E-01
 -0.8090E-01 -0.1000      -0.8090E-01 -0.3090E-01  0.3090E-01  0.8090E-01
  0.1000       0.8090E-01  0.3090E-01 -0.3090E-01 -0.8090E-01 -0.1000
 -0.8090E-01 -0.3090E-01  0.3090E-01  0.8090E-01  0.1000       0.8090E-01
  0.3090E-01 -0.3090E-01 -0.8090E-01 -0.1000      -0.8090E-01 -0.3090E-01
  0.3090E-01  0.8090E-01  0.1000       0.8090E-01  0.3090E-01 -0.3090E-01
 -0.8090E-01 -0.1000      -0.8090E-01 -0.3090E-01  0.3090E-01  0.8090E-01
  0.1000       0.8090E-01  0.3090E-01 -0.3090E-01 -0.8090E-01 -0.1000
 -0.8090E-01 -0.3090E-01  0.3090E-01  0.8090E-01  0.1000       0.8090E-01
  0.3090E-01 -0.3090E-01 -0.8090E-01 -0.1000      -0.8090E-01 -0.3090E-01
  0.3090E-01  0.8090E-01  0.1000       0.8090E-01  0.3090E-01 -0.3090E-01
 -0.8090E-01 -0.1000      -0.8090E-01 -0.3090E-01  0.3090E-01  0.8090E-01
  0.0000E+00 -0.5878E-01 -0.9511E-01 -0.9511E-01 -0.5878E-01  0.0000E+00
  0.5878E-01  0.9511E-01  0.9511E-01  0.5878E-01  0.0000E+00 -0.5878E-01
 -0.9511E-01 -0.9511E-01 -0.5878E-01  0.0000E+00  0.5878E-01  0.9511E-01
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          17  surface 3  endcap at z=1
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  0.10000       0.80900E-01  0.30900E-01 -0.30900E-01 -0.80900E-01 -0.10000
 -0.80900E-01 -0.30900E-01  0.30900E-01  0.80900E-01 -0.37300E-01  0.79208E
 -0.45221E-01  0.00000E+00  0.45221E-01 -0.79208E-02  0.37300E-01
  0.00000E+00  0.58780E-01  0.95110E-01  0.95110E-01  0.58780E-01  0.00000E
 -0.58780E-01 -0.95110E-01 -0.95110E-01 -0.58780E-01  0.37876E-01  0.52567E
 -0.14690E-01  0.00000E+00  0.14690E-01 -0.52567E-01 -0.37876E-01
  1.00000E+00  1.00000E+00  1.00000E+00  1.00000E+00  1.00000E+00  1.00000E
  1.00000E+00  1.00000E+00  1.00000E+00  1.00000E+00  1.00000E+00  1.00000E
  1.00000E+00  1.00000E+00  1.00000E+00  1.00000E+00  1.00000E+00
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          11          13          14  (.3,.2) 0.0 0.0 (.68,.24)   0.0  0.0
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          12          14          15
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          15          14          17
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           6          13          11
           7          13           6
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           4          12           3
           4          11          12
           5          11           4
  0
end
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