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USER'S MANUAL

TEST DESCRIPTION AND REPORT FOR MOMJET/AIMJET CODES

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TEST DESCRIPTION
TEST REPORT

FOR THE

MOMJET/AIMJET CODES

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1 Scope

1.1 Identification

Momjet is based on a free space Moment Method code written by Pamela Haddad at the Radiation Laboratory in 1991.

Momjet code version 1.0, was written at the end of 1996 begining 1997 by H.T. Anasatssiu, modified in summer 1997 by D.S. Filipovic (added some output calculations and I/O features).

List of abbreviatons:

MoM- Method of Moments;

RCS- Radar Cross Section;

CPU- Central Processing Unit;

DBOR- Dicrete Body of Revolution;

FEM- Finite Element Method;

PEC- Perfect Electric Conductor;

EL- Elevation;

AZ- Azimuth;

VV- Vertical/Vertical polarization;

HH- Horizontal/Horizontal polarization.

1.2 System overview

Momjet is a FORTRAN77 code which uses the Moment Method (MoM) to model electromagnetic scattering from perfectly conducting jet engine models, at both, far-field and near-field of the engine.

1.3 Document overview

Section 3.1 describes the execution procedure and code operation. Section 4.5 of this manual gives a brief description of MoM applied to the engine problem, and section 5 presents a few examples of Radar Cross Section and modulation calculations.

2 References

References

[1] H.T. Anastassiu, *Electromagnetic Scattering from Jet Engine Inlets Using Analytical and Fast Integral Equation Methods*, Ph. D. Thesis, University of Michigan, 1997.

[2] D. C. Ross, J. L. Volakis and H. T. Anastassiu, "Hybrid Finite Element-Modal analysis of jet engine inlet scattering" *IEEE Trans. Antennas and Propagation*, vol. 43, no. 3, pp. 277-285, March 1995.

[3] D. C. Ross, J. L. Volakis and H. T. Anastassiu, "Overlapping modal and geometric symmetries for computing jet engine inlet scattering" *IEEE Trans. Antennas and Propagation*, vol. 43, no. 10, pp. 1159-1163, Oct. 1995.

[4] H. T. Anastassiu, J. L. Volakis and D. C. Ross, "The Mode Matching Technique for electromagnetic scattering by cylindrical waveguides with canonical terminations" *Journal of Electromagnetic Waves and Applications*, vol. 9, no. 11/12, pp. 1363-1391, Nov./Dec. 1995.

[5] C. Ross, J. L. Volakis and H. T. Anastassiu, "Efficient Computation of Radar Scattering Modulation from Jet Engines"*Radio Science*, vol. 31, no. 4, pp. 991-997, July-Aug., 1996.

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3 Execution procedures

3.1 Code structure

Momjet models the scattering from metallic cylindrical jet engine inlets terminated by an arbitrary, PEC, cylindrically periodic structure. A simplified geometry is illustrated in Fig. 1, where the termination is a cylindrical hub. A plane wave is assumed to illuminate the open end and couple to waveguide modes in Region 1, propagating towards the termination (Region 2). Each of these modes is used as an excitation for the MoM applied to one periodic sector of the termination (see Figs. 2, 3). Solving the MoM linear system yields the equivalent currents on the termination, and in turn the scattered field within the inlet. To extract the coefficients of the scattered modes propagating towards the open end an integration [1, 2] is performe d at a hand-off plane, which is perpendicular to the inlet axis and lies at a fraction of a wavelength in front of the termination (see Fig. 4). Each of the scattered modes propagates to the open end and radiates in free space. The overall modal contribution yields the Radar Cross Section (RCS) of the engine.

To exploit the inherent periodicity of the engine, the waveguide modes must have exponential, and not trigonometric dependence on ϕ. Immediate consequence of this is that the modal orders may be negative, positive or zero, and there is no distinction between "odd" and "even" behavior, as opposed to the Mode Matching code that has been developed in the past [4].

Additionally, this representation enables calculation of RCS modulation (caused by blades rotation) in a simple manner as a postprocessing job [5].

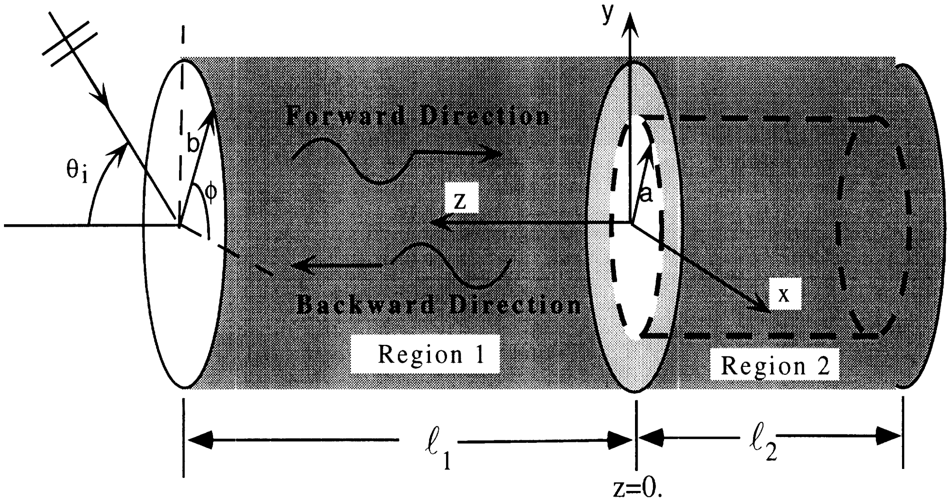

Figure 1: Cylindrical inlet terminated by a cylindrical hub

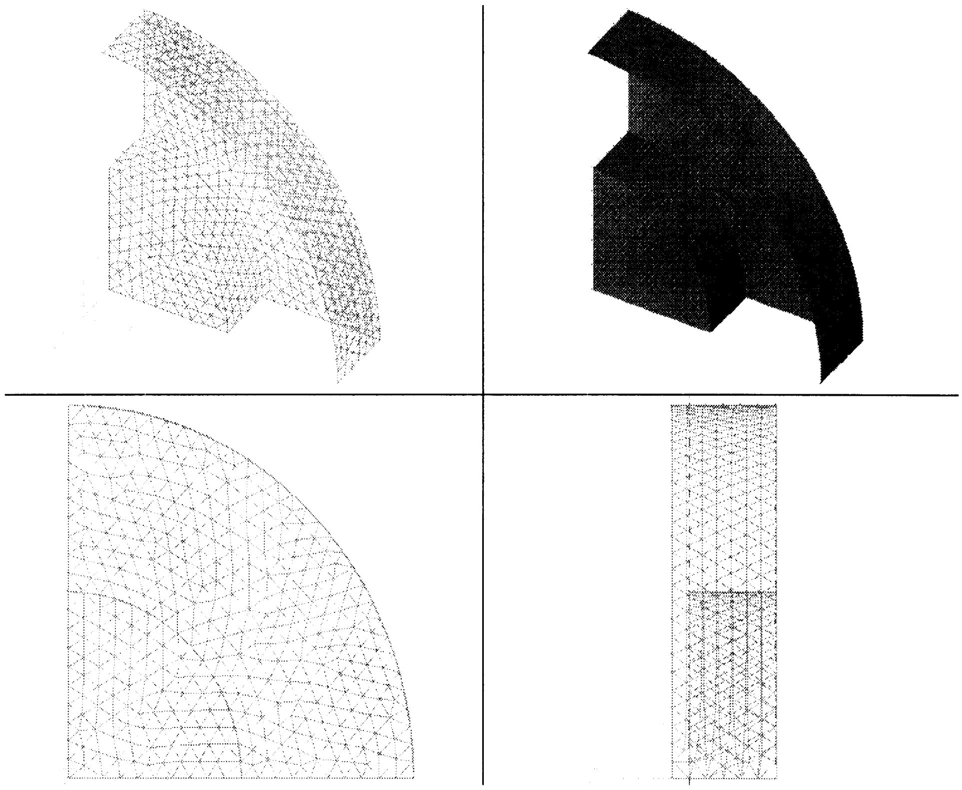

Figure 2: A quarter of a hub geometry.

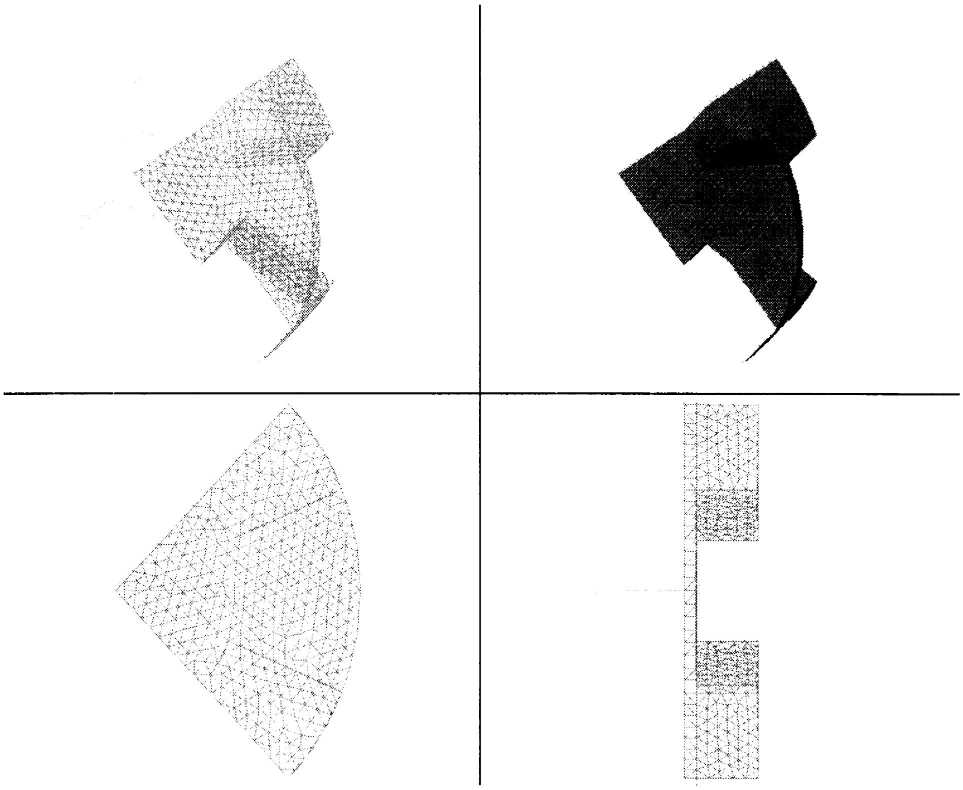

Figure 3: A quarter of a blade geometry.

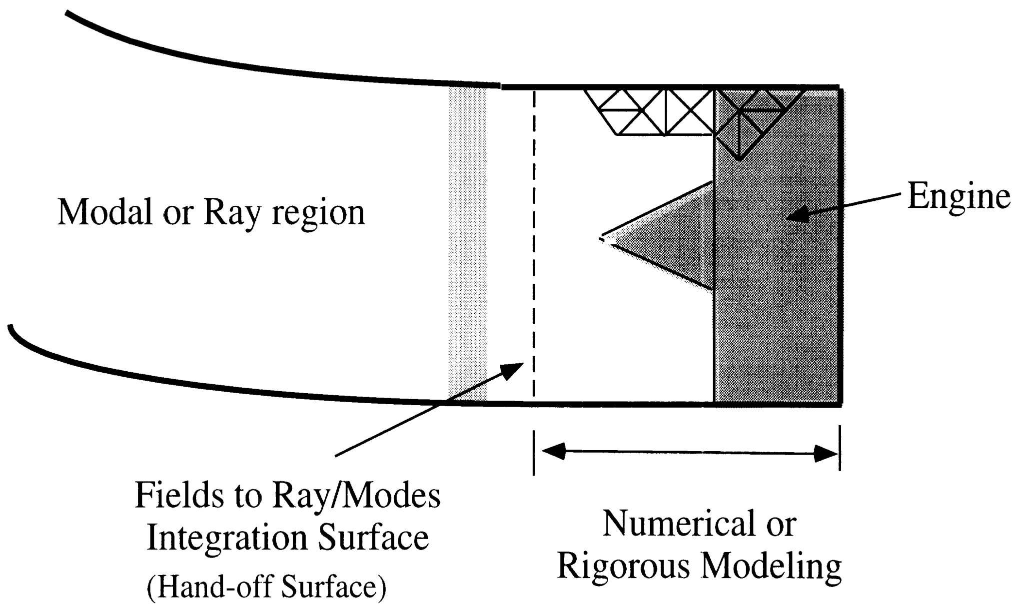

Figure 4: Decomposition of the computational domain.

3.2 User inputs

The input file comprises of a discretized sector of the termination, including the waveguide wall up to the hand-off plane.

Typical input geometries are illustrated in Figs. 2, 3. The current version of Momjet requires an edge-based format of the geometry file (interior nodes and corresponding edges are listed first). To illustrate the file format we consider a $0.2\lambda \times 0.2\lambda$ flat plate (see Fig. 5), lying on the xy plane and centered at the origin. This geometry is not typical for the code, but its simplicity is exploited to clarify the meshing format of the input file. The geometry file has the form

9 8	($N_{nodes} = 9$, $N_{triangles} = 8$)
.1 .1 .0	(the next N_{nodes} entries are
.1 -.1 .0	the Cartesian coordinates of the nodes-
-.1 .1 .0	inner nodes first followed by outer
-.1 -.1 .0	
.1 .0 .0	
.0 .1 .0	
-.1 .0 .0	
.0 -.1 .0	
.0 .0 .0	
16	(total number of edges N_{edges})
8	(number of exterior edges N_{ext})
7 8	(next $N_{edges} - N_{ext}$ entries
5 6	give the pair of nodes defining the edges)
5 9	
6 9	
3 9	
7 9	
8 9	
2 9	
4 8	
4 7	
1 6	
1 5	
3 7	
3 6	
2 8	
2 5	
1 9 10	(the remaining entries give the
2 11 12	triangle connectivity. Each line
2 3 4	entry contains 3 numbers corresponding
5 6 13	to the edge numbers forming the triangle
4 5 14	in a clockwise order)
1 6 7	
8 15 7	
16 8 3	

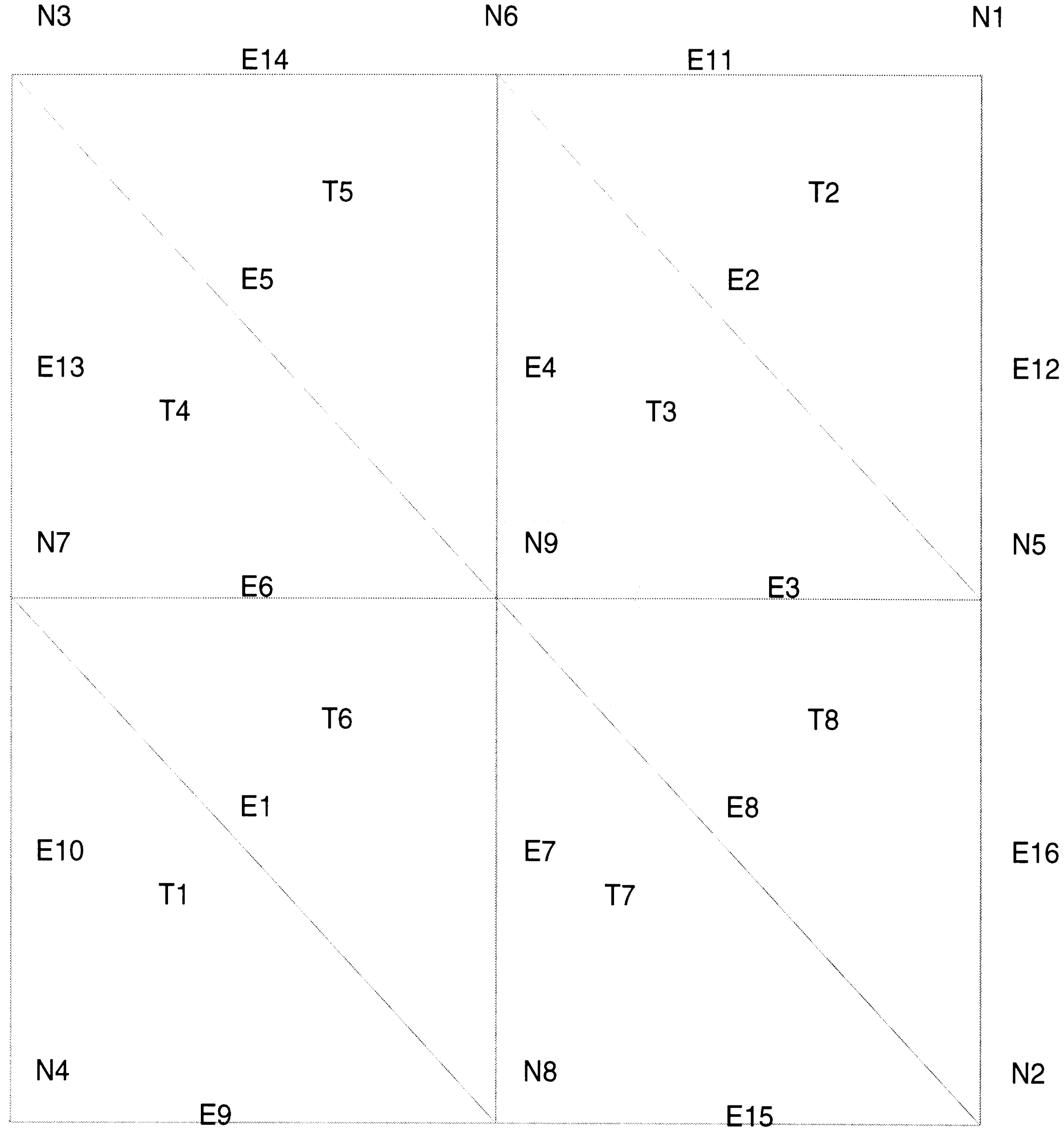

Figure 5: Mesh with node, edge and triangle numbering.

To obtain this format:

• Create the mesh geometry using a meshing package such as IDEAS and export it to a universal file called, for instance, geo-file.unv.

• Convert geo-file.unv to a converter file, called cnv, by running program u2c-new2.f.

• Convert cnv to the desired format geo-file by running program c2p-fas t.f. Both u2c-new2.f and c2p-fast.f are available in the same directory with the main code . Momjet also prompts user for outer radius (in terms of λ), inlet length up to the hand-off plane (in terms of λ), measurement frequency (choose $0.3d0$ if want RCS in $dB/(\lambda^2)$). Inclusion of Ufimtsef currents and evanescent modes is optional. All input parameters may be specified in the input file.

3.3 Initalization

Prior to running the code, several parameters must be set appropriately:

• In module dim.inc set maxnod greater or equal to the number of nodes in geo-file.

• In module param.inc set

* in=number of *nonnegative* modal orders in hollow section (Region 1).

* ii=number of modes per order. Chosen to include at least all propagating modes.

* ngas=number of points per subinterval for hand-off plane integration.

* nsym=number of periodic sectors (slices) of engine termination.

* nangle=number of different incidence angles (θ_{inc}).

* bgas=Gaussian integration tolerance (at the hand-off plane).

* exrho=2^{intrho}=number of integration subintervals along the ρ directi on.

* exphi=2^{intphi}=number of integration subintervals along the ϕ directi on.

* zhandoff=z location of the hand-off plane (the tip of the termination is assumed at $z = 0$.

*irotmax=max rotational angle ϕ (sugested integer value).

*irotst=rotation step (suggested integer value).

*irott=number of rotation steps.

*kstepp=θ step for RCS calculation.

*kfica=number of sampling points on the hand-off plane for unique engine ID repr esentation.

*dejo=1: near-field on the hand-off plane; 2: near-field on the inlet mouth. If one wants field somewhere between, put $1 < dejo < 2$, and make it real.

In order to define accurate number of propagating modes (in and ii), two runs of the code have to be done, according to following steps:

1) initialize in and ii sufficiently high.

2) uncomment line in the Makefile for compilation without optimization, and comm ent the line with optimization included.

3) compile and run the code.

4) check max in and ii when modes are propagating, stop execution, and change parameters in the param.inc file.

5) uncomment line with included optimization and comment line without optimization.

6) compile and run the code.

3.4 Compilation and running

• Compile the code by typing **make** (there is only one Makefile in the directory).

• Run the code by typing **momj**. The interaction is self-explanatory. See section 5 for further details. If you want to use input parameter redirection, then type **momj** < **input.dat**.

4 List of subroutines

4.1 Initialization codes:

u2c-new2.f: converts geo-file.unv to a converter file, called cnv.

c2p-fast.f: converts cnv to the desired format geo-file.

meshpr.f: generates some data for auxiliary files (dim.inc, param.inc...).

4.2 Subroutines in makefile:

Momjet.f: main code.

ac-intcyl2.f: performs a double surface integration over two triangles of a function in local area coordinates.

an-int1.f: performs an analytical double surface integration over the singular part of the integrand.

back-subst.f: solves the MoM linear system using LU decomposition.

edge-len.f: updates the edge length table given the edge numbers of the source and observation triangles.

excitcyl.f: computes elements of excitation vector (right hand side of linear system).

fillzcyl2.f: calculates elements of impedance matrix Z corresponding to incident modal order ninc .

get-R.f: reads in triangle resistivity values from file specified by user. Accor ding to Pamela Haddad, author of the basic MoM code, the algorithm has not been validate d for non-metallic scatterers.

get-mesh1.f: reads in mesh data from file specified by user.

get-verts.f: returns the vertices of a triangle.

normal.f: constructs normal vector to a triangle.

ops.f: various small functions and subroutines performing auxiliary mathematical calculations.

pot-ints-ss.f: computes the potential integrals for uniform and linearly varying surface sources distributed on a planar polygon S. Dependent subroutine in the same module: i-params.

pwcyl5.f: returns the value of $(\mathbf{r} - \mathbf{r}_m) \cdot \mathbf{E}_i$, where $\mathbf{E}_i$ is the incident cylindrical mode and $\mathbf{r}_m$ is the position vector to the

m^{th} vertex of the observation triangle. Dependent subroutines in the same m odule: integration, discreteap, fieldap, vectintcyl, ffargcyl, dyadfree, cGs1dx, GAULEGX, cGs1dy, GAULEGY. See code listing for more information on the function of each subroutine.

resfnc.f: returns the value of the integrand of the resistive term $(\mathbf{r} - \mathbf{r}_m) \cdot (\mathbf{r} - \mathbf{r}_n)$, where $\mathbf{r}_m, \mathbf{r}_n$ are the position vectors to the m^{th}/n^{th} vertices of the given observatio n triangle.

xsintcyl.f: performs a single surface integration of a function over a triangle

in local area coordinates.

solve2.f: linear system solvers.

update-signs.f: updates the triangle sign and edge use tables for an input observation interior edge and an input source interior edge.

usr-datacyl.f: prompts user for, and reads in, data pertaining to file names, incident field, rcs observation cut via standard I/O.

vectint.f: performs a single surface integration of vector function over a trian gle.

cylinsubr2.f: includes several subroutines and functions related to the modal analysis of the hollow section (duct). Subroutines included: excitvec, radcrosec, vemult, modes1. See code listing for more information on th e function of each subroutine.

blockdata.f: initializes common block which contains the local area coordinate integration points and weights used in all integration routines.

4.3 Auxiliary files:

const.inc: includes various constants.

dim.inc: includes uniform array dimensioning.

param.inc: includes modal and integration parameters.

4.4 Output files:

Program generates different forms of output data, regarding both near field and far field calculation. Some output files are memory consuming (depending on the users specification and configuration under test), so that obtaining all output files upon only one run might be impossible.

rcsphi.txt: $RCS = RCS(\theta_{inc})$ for ϕ incident polarization.

rcsth.txt: $RCS = RCS(\theta_{inc})$ for θ incident polarization.

modul.txt: $RCS = RCS(\phi_{rot})|_{\theta_{inc}=const}$ modulation file.

unwaight.txt: total unweighted scattered electric field on the hand-off plane (I D for every engine termination).

efield.txt: total electric field on the hand-off or inlet mouth plane.

hfield.txt: total magnetic field on the hand-off or inlet mouth plane.

imped.txt: wave impedance on the hand-off or inlet mouth plane.

engine.field: output file in the XPATCH format.

incrot.txt: scattered parameters on the hand-off or inlet mouth plane (for both polarizations and all incident angles).

incrotcomp.txt: complex values of incrot.txt.

firot.txt: scattered parameters with modulation on the hand-off or inlet mouth p lane (for both polarizations and all incident angles).

firotcomp.txt: complex values of firot.txt.

Number and position of sampling points on the hand-off plane is determined by the parameters ngas, exrho and exphi (see param.inc file and Fig. 6).

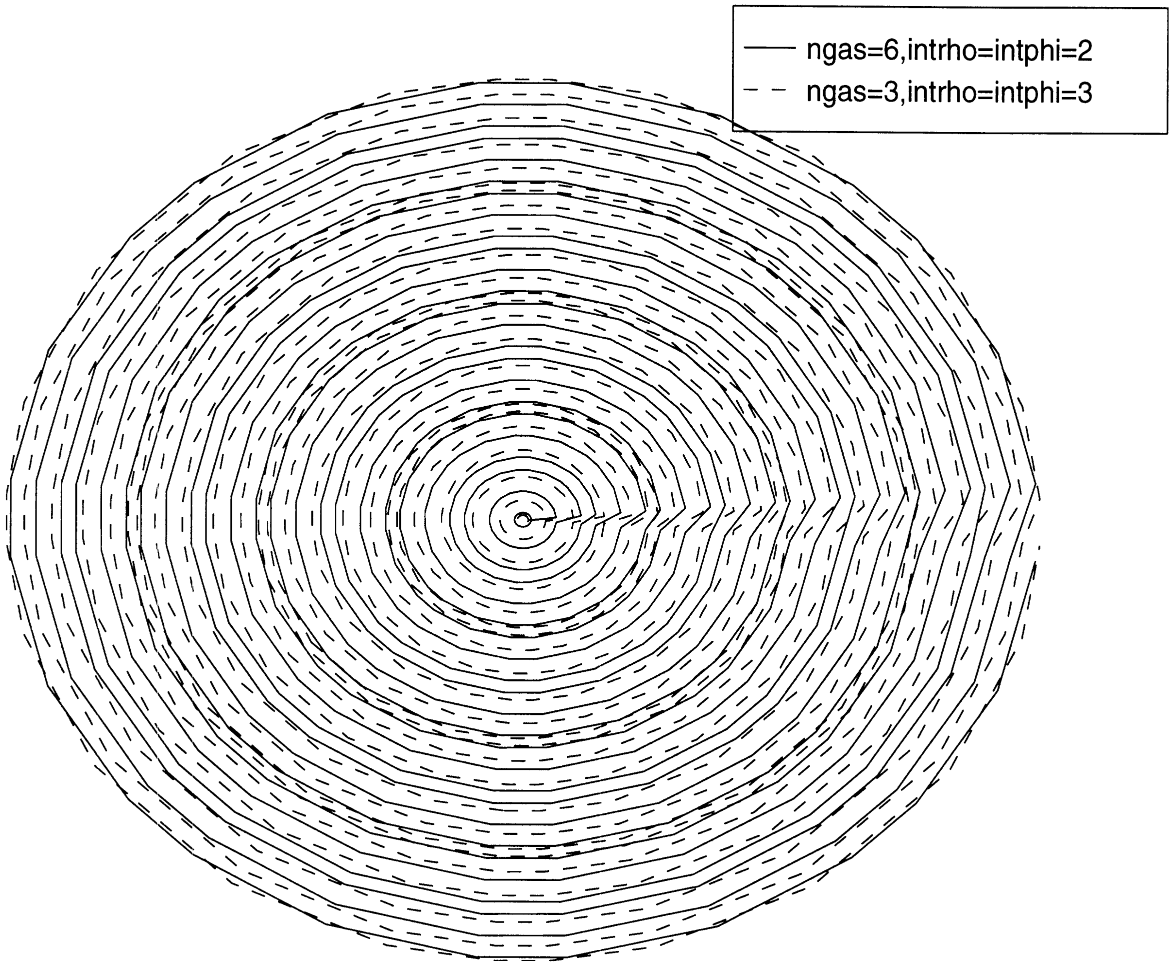

Figure 6: Sampling points on the hand-off plane.

4.5 Notes - theory

A major reason for an emphasis on the EM characterization of jet engines is their critical importance in determining the airplane's reflectivity and for target identification. Even though the engine is a small component of the overall structure, its complexity and visibility in the front sector of the aircraft make its contribution a large component of the overall airframe scattering. Moreover, the rotating engine blades cause unavoidable doppler shifts which are important for target identification purposes. The latter can be an important discriminatory for both civilian and military applications and more reliable than other methods.

As applied to electromagnetic scattering problems, the Moment Method (MoM) has proven to be a very accurate integral equation technique. However, its brute force application to the jet engine problem is not feasible due to excessive electrical size of the structure. To reduce the CPU time and storage requirements down to manageable levels, the inherent blade periodicity of the jet engine was exploited to show that the computational domain can be reduced down to a single blade or engine "slice". This discrete body of revolution (DBOR) approach reduces the number of unknowns and storage requirements by a factor equal to the number of blades. In [1] we applied the DBOR concept in the context of integral equation methods for modeling the complex jet engine configurations. By considering mode by mode excitation [1, 2, 3] it is shown that the analysis over the entire engine can be reduced down to a surface integral equation over a single blade. It is further demonstrated that the resulting modal scattering matrix is sparse, leading to additional storage and CPU time reductions.

To demonstrate the reduction of the computational domain we consider a cylindrically periodic scatterer (Fig. 7). We define the current column vector $\{\mathbf{J}\}^{(m_s)}$ of the m_s^{th} slice by

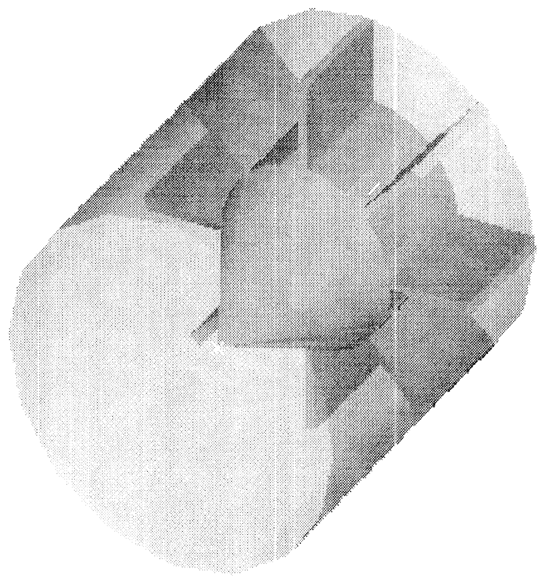

Figure 7: Simplified model of a jet engine.

$$\{\mathbf{J}\}^{(m_s)} \equiv \left[I_1^{(m_s)}, I_2^{(m_s)}, ..., I_Q^{(m_s)}\right]^T \tag{1}$$

where $I_p^{(m_s)}$ are the elementary currents on the m_s^{th} slice. Brute force MoM yields the linear system

$$\begin{aligned}
&[\mathbf{A}]^{(00)}\{\mathbf{J}\}^{(0)} + [\mathbf{A}]^{(01)}\{\mathbf{J}\}^{(1)} + ... + [\mathbf{A}]^{(0,N_s-1)}\{\mathbf{J}\}^{(N_s-1)} = \{\mathbf{b}\}^{(0)} \\
&[\mathbf{A}]^{(10)}\{\mathbf{J}\}^{(0)} + [\mathbf{A}]^{(11)}\{\mathbf{J}\}^{(1)} + ... + [\mathbf{A}]^{(1,N_s-1)}\{\mathbf{J}\}^{(N_s-1)} = \{\mathbf{b}\}^{(1)} \\
&... \\
&[\mathbf{A}]^{(N_s-1,0)}\{\mathbf{J}\}^{(0)} + ... + [\mathbf{A}]^{(N_s-1,N_s-1)}\{\mathbf{J}\}^{(N_s-1)} = \{\mathbf{b}\}^{(N_s-1)}
\end{aligned} \tag{2}$$

where

$$A_{pq}^{(n_s m_s)} \equiv jkZ \int_{\Sigma_0}\int_{\Sigma_0} \mathbf{f}_p(\mathbf{r}) \cdot \bar{\bar{\mathbf{R}}}^{-n_s} \cdot \bar{\bar{\mathbf{G}}}(\bar{\bar{\mathbf{R}}}^{n_s} \cdot \mathbf{r}, \bar{\bar{\mathbf{R}}}^{m_s} \cdot \mathbf{r}') \cdot \bar{\bar{\mathbf{R}}}^{m_s} \cdot \mathbf{f}_q(\mathbf{r}') d^2S d^2S' \tag{3}$$

are the entries of the submatrices $[\mathbf{A}]^{(n_s m_s)}$ representing the interactions between the $\mathbf{f}_p$ and $\mathbf{f}_q$ elementary currents located on the m_s^{th} and the n_s^{th} slices, $\bar{\bar{\mathbf{G}}}$ is the cylindrical waveguide dyadic Green's function and $\bar{\bar{\mathbf{R}}}$ is the rotation dyadic [1]. Also, $\{\mathbf{b}\}^{(n_s)}$ is the excitation column vector of the n_s^{th} slice defined by

$$\{\mathbf{b}\}^{(n_s)} \equiv \left[V_1^{(n_s)}, V_2^{(n_s)}, ..., V_Q^{(n_s)}\right]^T \tag{4}$$

where

$$V_p^{(n_s)} = \int_{\Sigma_0} \mathbf{E}^i \left(\bar{\bar{\mathbf{R}}}^{n_s} \cdot \mathbf{r}\right) \cdot \bar{\bar{\mathbf{R}}}^{n_s} \cdot \mathbf{f}_p(\mathbf{r})\, d^2S \tag{5}$$

In the latter equation, $\mathbf{E}^i$ is the incident field, Σ_0 is the *outer* surface of the slice within the volume V_0. Clearly, the index m_s indicates the slice where the source point is located, whereas n_s is the index representing the slice containing the observation point. Both indices run from 0 to $N_s - 1$.

Following the analysis in [1] it can be shown that it is sufficient to determine only the currents on the basic slice by solving

$$\left[[\mathbf{A}]^{(00)} + [\mathbf{A}]^{(01)}e^{jn_i\phi_s} + ... + [\mathbf{A}]^{0,(N_s-1)}e^{j(N_s-1)n_i\phi_s}\right]\{\mathbf{J}\}^{(0)} = \{\mathbf{b}\}^{(0)} \tag{6}$$

If the cylindrical waveguide dyadic Green's function is to be used, (6) can be further simplified, but that procedure is mainly of theoretical importance; the cylindrical waveguide dyadic Green's function is very difficult to handle computationally, and therefore the free space Green's function is used throughout the code. Additional elementary currents are placed on the waveguide walls to account for the appropriate boundary conditions. An additional result of [1] is that for a given order of the incident mode, only a limited set of scattered modes is excited. Namely, only the scattered modes with orders n that satisfy $n = n_i + \nu N_s \quad , \quad \nu \in \mathbf{Z}$ are reflected back, and this is in agreement with the result given by the FEM analysis of a similar problem [3].

The importance of the periodicity analysis cannot be exaggerated. Since the problem essentially reduces to modeling only one slice of the scatterer, the number of equations or unknowns is reduced by a factor of N_s. For a typical $N_s = 40$, this implies a CPU time and memory reduction each by a factor of 1600. For large scatterers with large periodicity numbers N_s, such as jet engines, the problem can thus be scaled to a tractable size. Moreover, the limited coupling among the scattered modes results in sparse modal scattering matrices which are much easier to store and handle.

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5 Test example and initialization

5.1 Test example

This example is of the 4 blade termination described in Fig. 3. The outer radius is 2λ, the hub radius is λ, the termination is 0.5λ deep, the length of the hollow region is 3λ and the hand-off plane is located 0.1λ in front of the termination. The number of nodes for this geometry is 656.

5.2 Initalization files

the dim.inc file should read

```
Integer nmax,maxnod,maxedg,maxtri,maxz,maxrcs
Parameter (nmax=4)
Parameter (maxnod=657)
Parameter (maxtri=2*maxnod)
Parameter (maxedg=3*maxnod)
c Parameter (maxz=3*maxnod)
Parameter (maxz=1777)
Parameter (maxrcs=200)
```

and the param.inc file should read

```
integer ii,in,iis,ii2,ii4
integer ngas,nsym,nangle,kfica,irott,irotmax,itotst
integer intrho,intphi,exrho,exphi,kstepp
real*8 bgas,zhandoff
parameter(in=11,ii=4)
```

```
parameter(iis=in*ii)
parameter(ii2=2*iis)
parameter(ii4=2*ii2)
parameter(ngas=3)
parameter (nsym=4)
parameter (nangle=121)
parameter(bgas=1.0d-2)
parameter(intrho=2)
parameter(intphi=2)
parameter(exrho=2**intrho)
parameter(exphi=2**intphi)
parameter(zhandoff=0.1d0)
parameter(irotmax=91)
parameter(irotst=1) (irotst=10 for firot.txt and incrot.txt)
parameter(irott=irotmax/irotst + 1)
parameter(kstepp=1) (kstepp=2 for firot.txt and incrot.txt)
parameter(kfica=exrho*exphi*ngas*ngas)
parameter(dejo=1)
```

We emphasize that in and ii are chosen so that all propagating modes are included. The code output yields the propagation characteristics of each mode, hence running the code itself for a few test cases eventually provide s the correct values of in and ii.

6 Software input

6.1 Interactive input

For this geometry the input reads:

Enter inlet radius in wavelengths

2.0d0

Enter mesh file name:

blade_2w_4

Enter length of hollow section in wavelengths

3.0d0

Enter 1 for inclusion of rim

contribution and 2 for non-inclusion

2 !(not including Ufimtsef currents on the rim)

Enter 1 for inclusion of evanescent modes

and 2 for exclusion

2

Enter measurement frequency in GHz

0.3d0 !(to obtain RCS in dB/λ^2)

6.2 Input file

For running the code by using redirection, the input file is:

2.0d0

blade_2w_4

3.0d0

2

2

0.3d0

7 Software output

7.1 Screen output

The output reads:

TM modes (n,m,krho,prop./evan.)

---

0 1 1.20241288350811 1

0 2 2.760039056538 1

0 3 4.32686395109136 1

0 4 5.89576721702858 1

1 1 1.91585298512173 1

1 2 3.50779348764358 1

1 3 5.08673402355608 1

1 4 6.66184574789692 -1 mode indices, eigenvalues in λ^{-1},

2 1 2.56781132204712 1 1 for propagation and -1 for evanescence

...

TE modes (n,m,krho,prop./evan.)

---

0 1 1.91585298512173 1

0 2 3.50779348764358 1

...

Incident mode order= -10 !(working with mode order=-10)

Order of system = 1777

No. of triangular elements = 1216

Slice 0 !(working with slice 0)

...

7.2 Output files

Output file rcsphi.txt is:

Phi-phi Polarization

Incident angle,phi-phi,phi-theta

1.000000000000000E-02 29.63130309987938 -33.7006615992966

.51 29.61263172062007 -33.6934223356198

1.01 29.55830862102566 -33.671398471112

1.51 29.4690832676185 -33.6322516048832

2.01 29.34619755314773 -33.5727299658859

2.51 29.19138128112484 -33.4894831967613

3.01 29.00683892922878 -33.3799718084723

3.51 28.7952212610019 -33.2432625945877

...

Output file rcsth.txt is:

Theta-theta Polarization

Incident angle,theta-theta,theta-phi

1.000000000000000E-02 29.63128937395119 -33.7006771055563

.51 29.57655924653133 -33.7333963422247

1.01 29.41605365137127 -33.8246024976252

1.51 29.14821273587283 -33.9607797097266

2.01 28.77040147133607 -34.1182654337324

2.51 28.27883999812705 -34.2625784532682

3.01 27.66851579327062 -34.3501517110011

3.51 26.93309717096325 -34.3348619021295

...

Output file modul.txt (rotation angle,RCS) is:

Phi-phi Polarization

theta= 1.000000000000000E-02

1 29.63130309269709

2 29.6313030730663

3 29.63130304108263

4 29.63130299690191

5 29.63130294073939

...

Theta-theta Polarization

theta= 1.000000000000000E-02

1 29.631289381133347

2 29.63128940076427

3 29.63128943274794

4 29.63128947692864

5 29.63128953309115

...

Output file unweight.txt is:

X,Y,Z,Unwaited E-Field at the Handoff Plane

5.641662856629827E-02 1.015140670462751E-02 .1 81.08614154147517

4.049268616987463E-02 4.057375264402420E-02 .1 80.9713012643719

1.003855320833504E-02 5.643681853501174E-02 .1 80.26172131340697

-1.015140671619875E-02 5.641662856421617E-02 .1 79.68034874500992

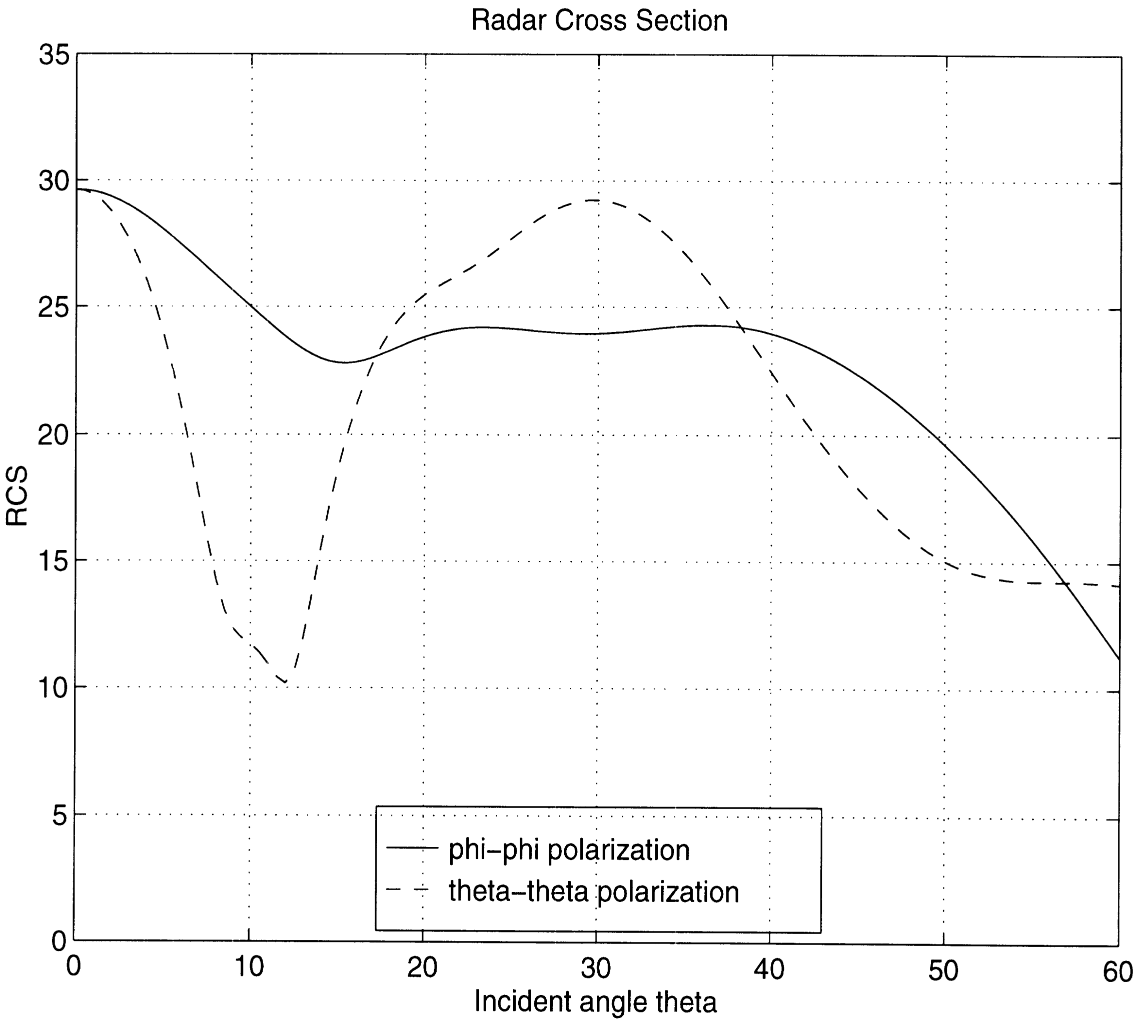

Figure 8: RCS for both polarizations.

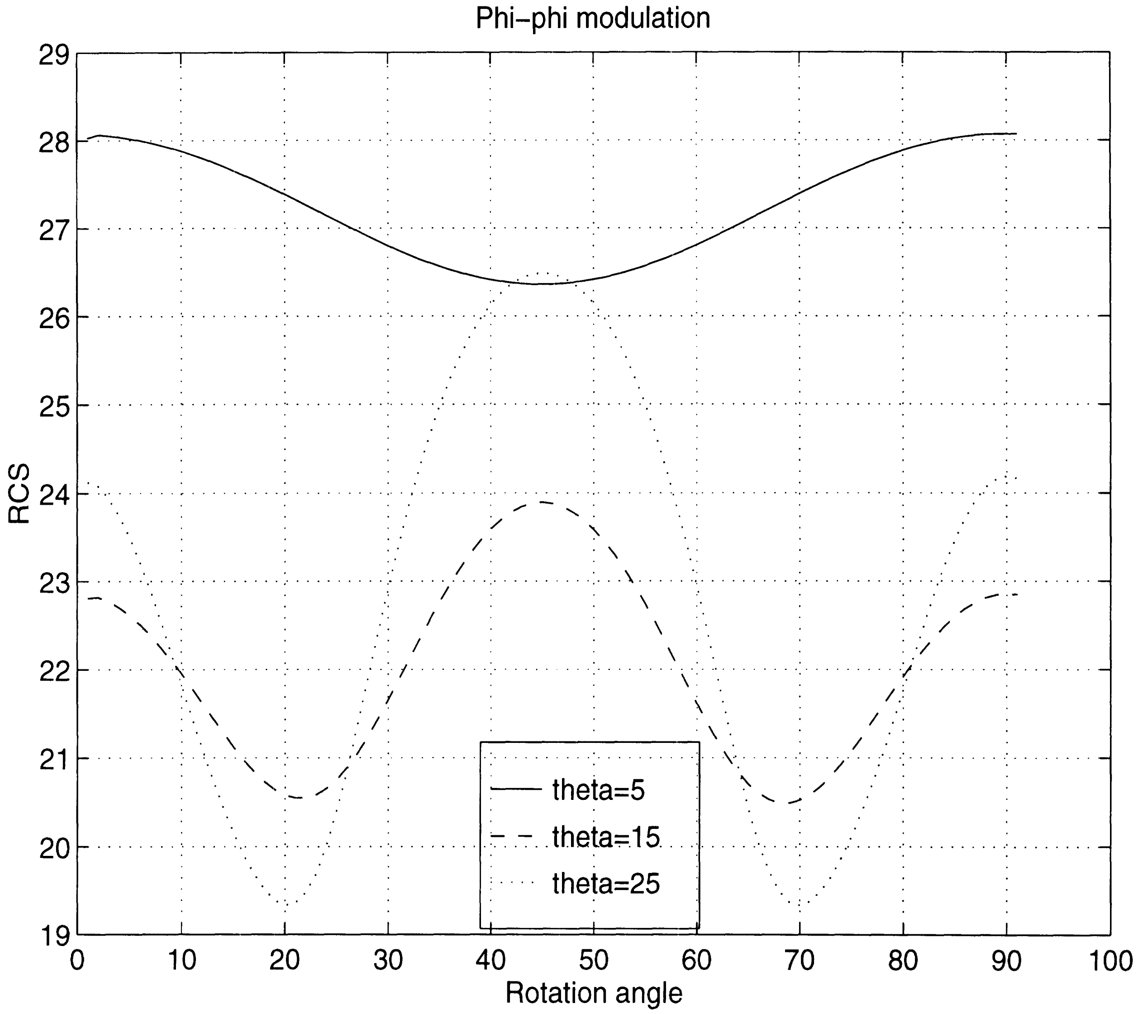

Figure 9: Modulation pattern for rotating blades-phi polarization.

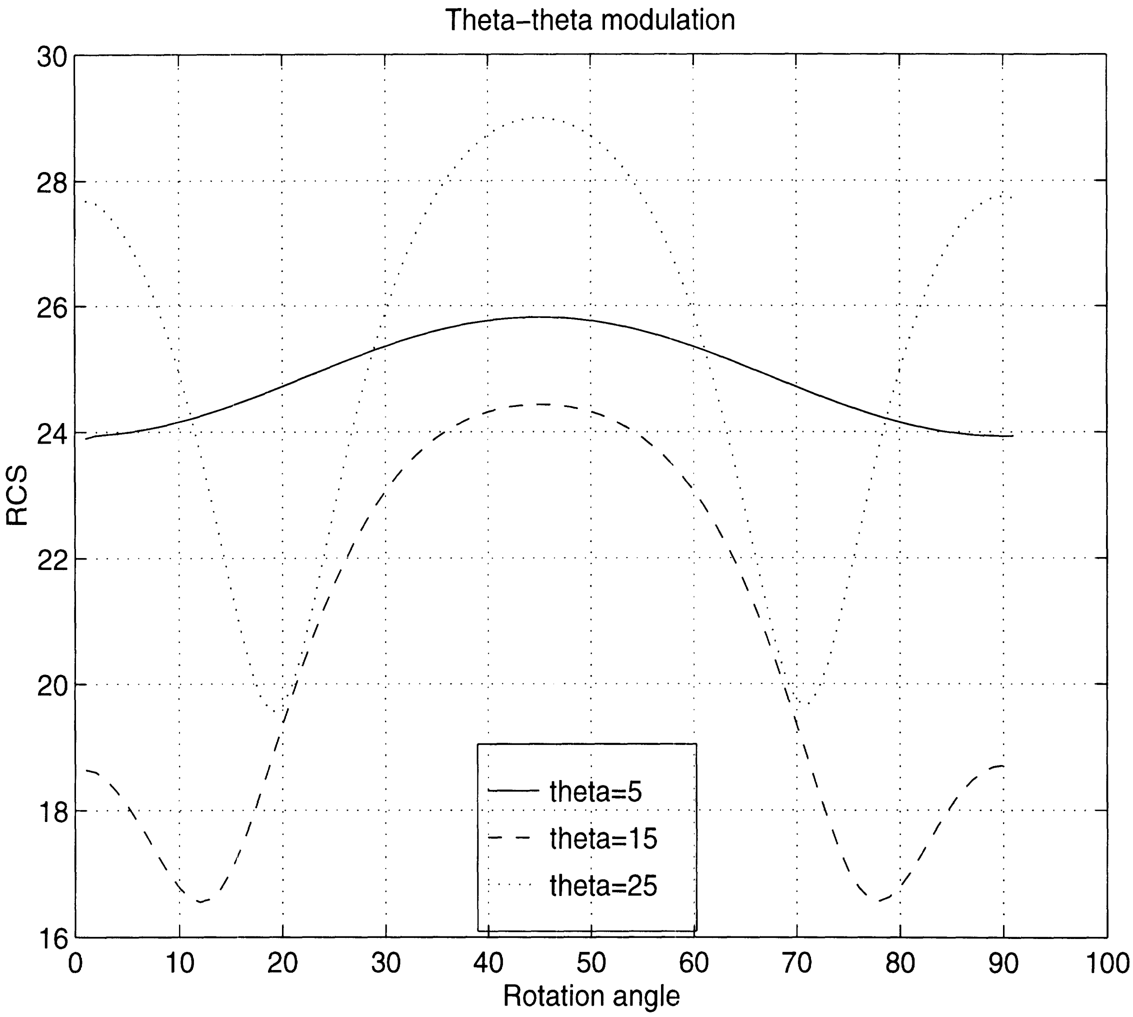

Figure 10: Modulation pattern for rotating blades-theta polarization.

-4.057375265232938E-02 4.049268616155283E-02 .1 78.92981225914005

...

Output file efield.txt (X, Y, E[dB]) is:

Phi polarization

Incident angle theta is .0

5.641662856629827E-02 1.015140670462750E-02 -25.6136436860384

4.049268616987463E-02 4.057375264402420E-02 -25.6263851407603

1.003855320833505E-02 5.643681853501173E-02 -25.5845661159781

-1.015140671619874E-02 5.641662856421617E-02 -25.6136436882361

-4.057375265232938E-02 4.049268616155282E-02 -25.6263851430904

...

Theta polarization

Incident angle theta is .0

5.641662856629827E-02 1.015140670462750E-02 12.26351927746214

4.049268616987463E-02 4.057375264402420E-02 12.25082615166598

1.003855320833505E-02 5.643681853501173E-02 12.26903042801212

-1.015140671619874E-02 5.641662856421617E-02 12.26351927652879

-4.057375265232938E-02 4.049268616155282E-02 12.25082615094696

...

Output file hfield.txt (X, Y, H[dB]) is:

Phi polarization

Incident angle theta is .0

5.641662856629827E-02 1.015140670462750E-02 -135.934187068036

4.049268616987463E-02 4.057375264402420E-02 -135.987570212459

1.003855320833505E-02 5.643681853501173E-02 -135.99616979836

-1.015140671619874E-02 5.641662856421617E-02 -135.934187071225

-4.057375265232938E-02 4.049268616155282E-02 -135.98757021614

...

Theta polarization

Incident angle theta is .0

5.641662856629827E-02 1.015140670462750E-02 -95.2241346546987

4.049268616987463E-02 4.057375264402420E-02 -95.2297448855929

1.003855320833505E-02 5.643681853501173E-02 -95.219767234333

-1.015140671619874E-02 5.641662856421617E-02 -95.2241346556522

-4.057375265232938E-02 4.049268616155282E-02 -95.2297448862359

...

Output file imped.txt (X, Y, modZ) is:

Phi polarization

Incident angle theta is .0

5.641662856629827E-02 1.015140670462750E-02 248.6452468368924

4.049268616987463E-02 4.057375264402420E-02 249.1510287069808

1.003855320833505E-02 5.643681853501173E-02 249.7799134972396

-1.015140671619874E-02 5.641662856421617E-02 248.6452468492195

-4.057375265232938E-02 4.049268616155282E-02 249.1510287238088

...

Theta polarization

Incident angle theta is .0

5.641662856629827E-02 1.015140670462750E-02 215.806613029913

4.049268616987463E-02 4.057375264402420E-02 215.730199783424

1.003855320833505E-02 5.643681853501173E-02 215.8189546096599

-1.015140671619874E-02 5.641662856421617E-02 215.8066130301293

-4.057375265232938E-02 4.049268616155282E-02 215.7301997826038

...

Output file engine.field (incident:EL, AZ; observation:EL, AZ; frequency [GHz]; VV; HV; VH; HH) is:

30.0 .0 30.0 .0 .3 (4.99521787318461,.9731762510585861) (-2.285742277847609E-03,-2.063994260126811E-04) (-1.575715769867148E-03,8.954386064833249E-03) (-1.30286653617953,-3.40646251893064)

30.0 1.0 30.0 1.0 .3 (4.97867761320453,1.07756716164062) (-.234753947300065,.2457638251759209) (-.599056785821603,.2768031011598088) (-1.33348562145874,-3.4231551755766)

30.0 2.0 30.0 2.0 .3 (4.92405101980507,1.37583167577948) (-.459165704963816,.468591104543572) (-1.16817454290087,.5111160198199839) (-1.41684678891507,-3.47068275177345)

...

Output file incrot.txt (X, Y, E, H, modZ) is:

Phi polarization

Incident angle theta is .0 29.63130309987938

.05642 .01015 -25.614 -135.934 248.645

.04049 .04057 -25.626 -135.988 249.151

.01004 .05644 -25.585 -135.996 249.780

-.01015 .05642 -25.614 -135.934 248.645

-.04057 .04049 -25.626 -135.988 249.151

...

Theta polarization

Incident angle theta is .0 29.63128937395119

.05642 .01015 12.264 -95.224 215.807

.04049 .04057 12.251 -95.230 215.730

.01004 .05644 12.269 -95.220 215.819

-.01015 .05642 12.264 -95.224 215.807

-.04057 .04049 12.251 -95.230 215.730

...

Output file firot.txt (X, Y, E, H, modZ) is:

Phi polarization

Incident angle theta is .0

Rotation angle is 1

FField RCS is 29.63130309269709

.05642 .01015 -25.614 -135.931 248.606

.04049 .04057 -25.627 -135.991 249.191

.01004 .05644 -25.584 -135.993 249.747

-.01015 .05642 -25.614 -135.931 248.606

-.04057 .04049 -25.627 -135.991 249.191

...

Theta polarization

Incident angle theta is .0

Rotation angle is 1

FField RCS is 29.63128938113347

.05642 .01015 12.263 -95.224 215.804

.04049 .04057 12.251 -95.230 215.731

.01004 .05644 12.269 -95.220 215.821

-.01015 .05642 12.263 -95.224 215.804

-.04057 .04049 12.251 -95.230 215.731

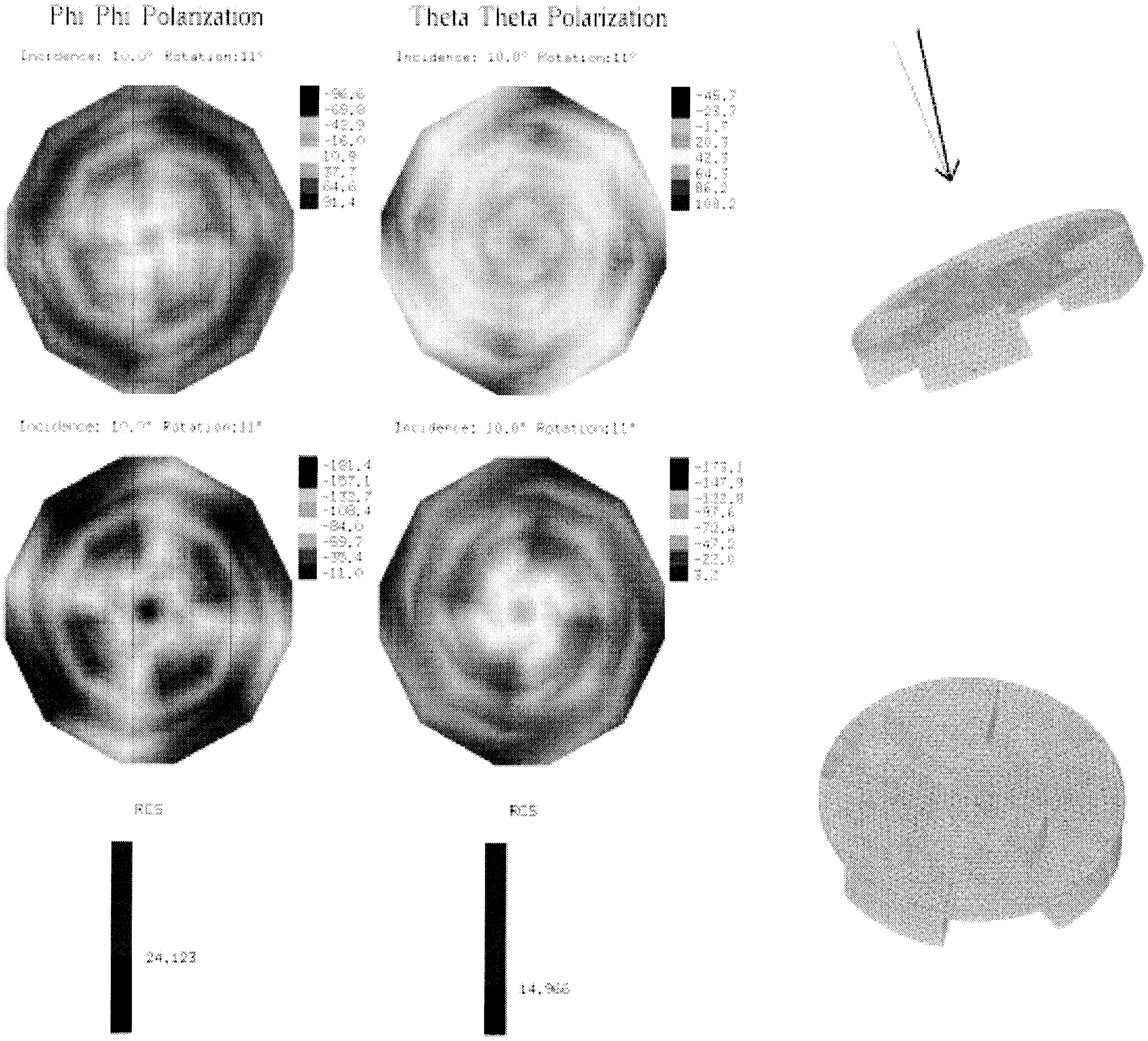

Figure 11: E and H fields on the hand off plane.