

Mercury Method of Moments: AFRL Quick Start Guide

Daniel Topa

ERT Inc.

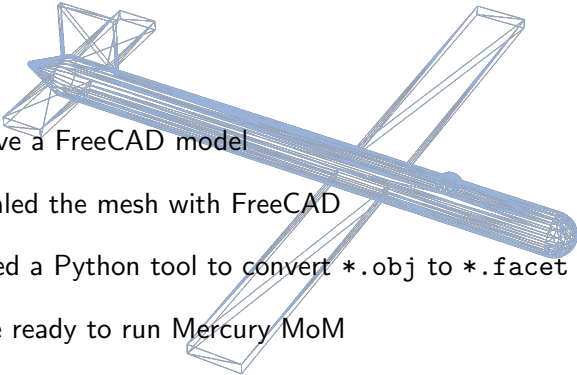
daniel.topa@ertcorp.com

July 7, 2020

Scope: A Snapshot of Progress

1. AFRL Use
2. Configuration
3. Execution
4. Inputs
5. Outputs

Starting Points

- 
- ▶ We have a FreeCAD model
 - ▶ We sealed the mesh with FreeCAD
 - ▶ We used a Python tool to convert *.obj to *.facet
 - ▶ We are ready to run Mercury MoM

What Mercury MoM is

Mercury Method of Moments (MoM) is an electromagnetic simulation package

- ▶ Highly-capable
- ▶ Efficient
- ▶ Versatile

What Mercury MoM Does

Mercury Method of Moments (MoM) in a nutshell

- ▶ Uses Maxwell's Equations in Integral Form
- ▶ Solves Discretized Equations using the Method of Moments
- ▶ Solves for Polarization States of Scattered Electric Field
- ▶ Reduces Integral Equation to Linear System

Using Mercury MoM at AFRL

AFRL use case is very restricted...

- ▶ Far field
- ▶ Monostatic radar
- ▶ Target = Perfect electrical conductor
- ▶ Behavior driven by surface excitations

Using Mercury MoM at AFRL

- ▶ Mercury MoM is well documented...
- ▶ But focus on AFRL special cases

Using Mercury MoM at AFRL

Focus on AFRL application...

- ▶ How to configure
- ▶ How to execute
- ▶ How to create input files
- ▶ How to harvest output files

Using Mercury MoM at AFRL

Demonstration tarball [Hg-MoM-4.1.12.tar.gz](#) runs simple cases

1. Untar
2. Run bash script

Sequence of Minimum Working Examples

Using Mercury MoM at AFRL

Tarball + Executable + 10 minutes = results for 3 CAD models

On Your DREN Box



What Files Go Where?

1. Executable
2. Configuration
3. CAD models

MMoM.4.1.12 is Portable

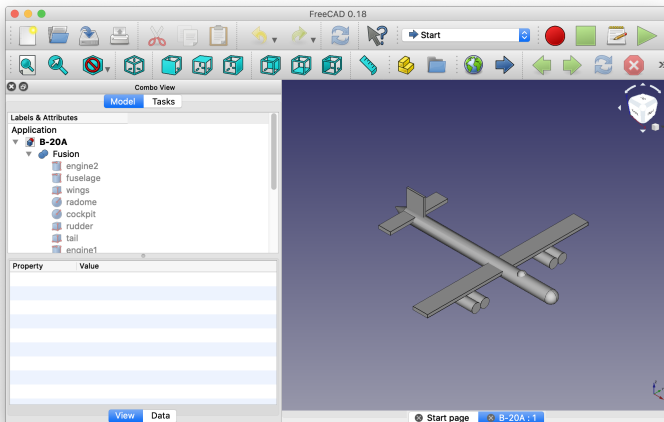
1. Mercury MoM is a [standalone executable](#)
 - 1.1 NO QT
 - 1.2 NO Intel MKL
 - 1.3 NO Intel Fortran
 - 1.4 NO Intel Math Library
2. MMViz requires extensive libraries– Not MoM
3. System requirements for MMoM.4.1.12 follow...

Mercury MoM 4.1.12 Dependencies

```
$ ldd MMoM_4.1.12
```

Dependency		Location
libpthread.so.0	=>	/lib/x86_64-linux-gnu/libpthread.so.0
libm.so.6	=>	/lib/x86_64-linux-gnu/libm.so.6
libdl.so.2	=>	/lib/x86_64-linux-gnu/libdl.so.2
libc.so.6	=>	/lib/x86_64-linux-gnu/libc.so.6
libgcc_s.so.1	=>	/lib/x86_64-linux-gnu/libgcc_s.so.1
ld-linux-x86-64.so.2	=>	/lib64/ld-linux-x86-64.so.2

B-20A Bomber



B-20A Bomber: From FreeCAD to MoM

- 1 B-52 dimensions
(wingspan, fuselage)
- 2 Created in **FreeCAD** `B-20A.FCStd`
- 3 Mesh created in **FreeCAD**
- 4 Mesh repaired in **FreeCAD** (frmly MMViz)
- 5 Mesh exported `B-20A.obj`
- 6 Mesh converted (**Python**) `B-20A.facet` (MATLAB/ALPINE)
- 7 Create geometry file (vim) `B-20A.geo`
- 8 Create materials library (vim) `Materials.lib`

Input files

1. B-20A.geo
2. B-20A.facet
3. Materials.lib

Input files

- 1 B-20A.geo: points to CAD model, materials
- 2 B-20A.facet: CAD model from *.obj file
- 3 Materials.lib: empty file

*.geo Purpose

1. Geometry file *.geo controls simulation
2. Points to CAD model, materials library
3. Describes radar configuration
4. Establishes perspectives for azimuth and elevation
5. Determines integral domain (Volume or Surface)
6. Establishes boundary conditions
7. Specifies length units

*.geo Structure

1. B-20A.geo
 - 1.1 Points to facet file
 - 1.2 Configure linear algebra solver
 - 1.3 Radar frequency range
 - 1.4 Angular sampling ranges
 - 1.5 Boundary conditions
 - 1.6 Mono- or Bistatic
 - 1.7 Surface or Volume integral elements
 - 1.8 Length units
2. B-20A.facet
 - 2.1 Vertex list
 - 2.2 Face list
3. Materials.lib
 - 3.1 Permeability
 - 3.2 Permittivity



*.geo Example

```
B-20                                ! stem for output file names
!Mercury MoM input file, VIE/SIE Version 4.x compatible (VIE/Dual Sided SIE)
FREQUENCY                            ! AFRL special case 3-30 MHz
  ghz
  0.003000 0.030000 28              ! Freq Start, Freq Stop, Num Frequencies
Excitation
  MONOSTATIC                        ! AFRL special case
Angle Cut                            ! yaw angle
  1
  0.000000 359.000000 360
  AZIMUTH
  90.000000
Boundary Conditions
Materials.lib                         ! AFRL special case: empty file
4
V_FREE_SPACE => Free_Space           ! AFRL special case
V_PEC => PEC                         ! AFRL special case
V_PMC => PMC
V_NULL => NULL
1
0 BC_PEC V_FREE_SPACE               ! AFRL special case
SIE                                 ! AFRL special case
B-20A.facet                         ! CAD model
m                                   ! units: meters
Geometry_End
```

Radar Frequencies

FREQUENCY ! OTHR

ghz

0.003000 0.030000 28 ! 3, 4, 5, ... 30 MHz

Sampling Aspect View

Angle Cut

1

0.000000 359.000000 360 ! stop at 359

AZIMUTH

90.000000

Monostatic or Bistatic Radar

Excitation ! Radar type
MONOSTATIC

Boundary Conditions

Boundary Conditions

B-20-Materials.lib

4

V_FREE_SPACE => Free_Space

V_PEC => PEC

V_PMC => PMC

V_NULL => NULL

1

0 BC_PEC V_FREE_SPACE

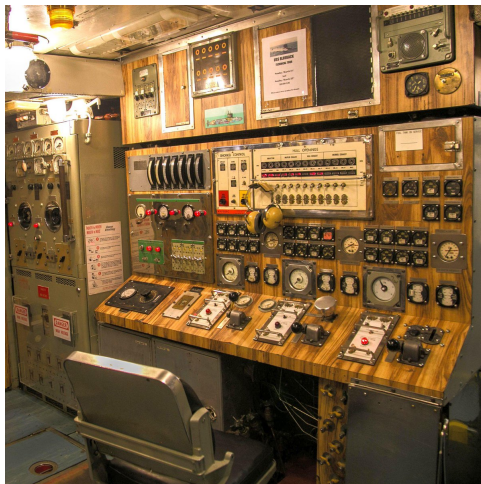
Final settings

SIE	surface integral elements
B-20A.facet	CAD description
m	meters

Configuration Complexity

1. Default configuration is trivial
2. Complicated scenarios may demand complicated adjustments
3. Respond to error messages
4. Adjustments are set in *.geo
5. Survey of settings follows...
 - 5.1 Linear algebra adjustments
 - 5.2 Memory usage
 - 5.3 Quadrature (integration)

Mercury MoM Presents Many Controls



Linear algebra (don't alter)

&MM_MOM

```
bUseACA = .TRUE.,
bSolve_ACA = .TRUE.,
bOutOfCore = .TRUE.,
bNormalizeToWaveLength = .FALSE.,
bNormalize = .FALSE.,
dCloseLambda = 0.100000,
ACA_Factor_Tol = 0.000010,
ACA_RHS_Tol = 0.000100,
Point_Tolerance = 0.001000,
nLargestBlockSize = -1,
MemorySize_GB = -1.000000,
stackSize_GB = -1.000000,

nFillThreads = -1,
nFillMKLThreads = 1,
nLUThreads = -1,
nLUMKLThreads = 1,
nRHSThreads = 1,
nRHSMKLThreads = 1,
bOutputACAGrouping = .FALSE.,
bOutputRankFraction = .FALSE.,
bLimitLUColumns = .FALSE.,
Lop_Admissibility = WEAK,
Kop_Admissibility = CLOSE
```

Memory management (don't alter)

&Scratch_Memory

```
Scratch_RankFraction_Z = 0.300000,  
Scratch_RankFraction_LU = 0.600000,  
Scratch_RankFraction_RHS = 2.000000,  
Scratch_RankFraction_Solve = 1.000000,  
MemoryFraction_Z = 0.950000,  
MemoryFraction_Scratch_LU = 0.500000,  
MemoryFraction_LU = 1.000000,  
MemoryFraction_RHS = 0.500000,  
MemoryFraction_Solve = 0.900000,
```

Quadrature (don't alter)

```
&QUADRATURE
```

```
NTRISELF = 7,  
NTRINEAR = 3,  
NTRIFAR = 3,  
NTETSELF = 11,  
NTETNEAR = 4,  
NTETFAR = 4,  
NQGAUSS = 4
```



Essential Files

Checklist:

1. B-20.geo
2. B-20.facet
3. Materials.lib

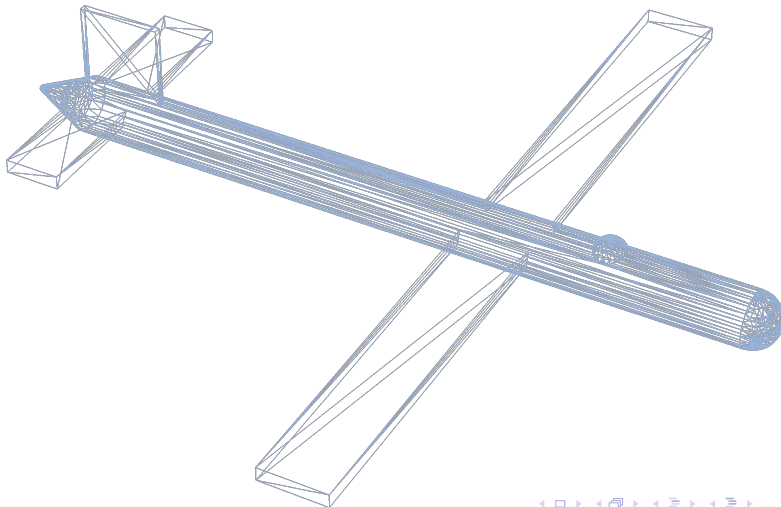
Essential Files

1. `B-20.geo` discussed in previous section
2. `Materials.lib` is an empty file
3. `B-20.facet` discussion follows

CAD Model

1. *.facet contains CAD Model
2. Generated from *.obj
3. Provides vertex locations in \mathbb{R}^3
4. Describes triangular facets in terms of vertex indices
5. Provides census count of faces and vertices
6. See Appendix B of Users Manual
7. Files can be MB size, but...
8. Large files may not work
9. Sample file follows...

Standard Meshing, 50 cm resolution



Structure

1. Vertex header
2. Vertex points: x , y , z
3. Face header
4. Face vertices by index: kx , ky , kz
5. Ensuing sample file
 - 5.1 601 vertices
 - 5.2 1,198 faces
 - 5.3 1,807 lines
6. highest resolution tolerated

Facet File: Beginning

```
facet-maker.f08 2020-04-07 1:13:26
```

```
1
```

```
<B20 MeshModel>
```

```
0
```

```
601
```

6000.000000	-250.000000	1984.313477
0.000000	-250.000000	8000.000000
0.000000	-250.000000	1984.313477
6000.000000	-250.000000	8000.000000
⋮	⋮	⋮

Facet File: Start of Face List

```

      :
      :
      :
35000.000000 28000.000000.000000 0.000000

```

```

1
<B20 MeshModel>

```

```

      3  1198  0  0  0  0  0
      1    2  3  0
      1    4  2  0
      5    6  7  0
      :    :  :  :

```

Checklist

Run directory contains

Ingredient	Example
Executable	<code>\$./MMoM_4.1.12</code>
Geometry file	<code>b20.geo</code>
CAD file	<code>b20.facet</code>
Material library	<code>Materials.lib</code>



Minimal Run Command

```
$/MMoM_4.1.12 b20.geo
```

Better Run Command

Avoid 20,000 lines of screen output...

```
$./MMoM_4.1.12 b20.geo > b20-runtime.txt
```


Output

1. Results are in *.4112.txt
2. 10s of thousands of lines
3. ASCII format
4. Text and numbers
5. **Electric field** results
 - 5.1 For each yaw angle
 - 5.2 For each frequency
6. Complete **configuration settings**
7. **Summary** of CAD model
8. Lots of linear algebra data

Survey of common errors

1. Tarball trivializes runs in different environments
2. Test environments
 - 2.1 Centos
 - 2.2 Fedora
 - 2.3 Ubuntu
 - 2.4 Debian
 - 2.5 Scientific Linux
3. MoM is very portable
4. Specific case follows...

Linux Environment

```
$ lsb_release -a
```

```
Distributor ID: Ubuntu
```

```
Description:    Ubuntu Focal Fossa
```

```
Release:        20.04
```

```
Codename:       focal
```

Hardware

```
$ lscpu
```

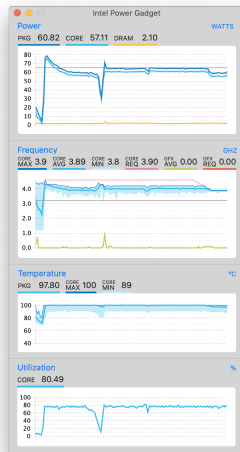
```
Architecture:          x86_64
CPU op-mode(s):        32-bit, 64-bit
Byte Order:            Little Endian
Address sizes:          39 bits physical, 48 bits virtual
CPU(s):                12
Thread(s) per core:    1
Core(s) per socket:    1
Vendor ID:             GenuineIntel
Model name:            Intel(R) Core(TM) i7-8700B CPU @ 3.20GHz
Stepping:              10
CPU MHz:               3200.000
BogoMIPS:              6384.00
L1d cache:             384 KiB
L1i cache:             384 KiB
L2 cache:              3 MiB
L3 cache:              144 MiB
```

Memory

```
$ cat /proc/meminfo
```

```
MemTotal:      57613160    kB
MemFree:       3451612     kB
MemAvailable:  56550388     kB
Buffers:       2078208     kB
Cached:       40111904     kB
SwapCached:    104         kB
Active:       21875712     kB
Inactive:     20779868     kB
```

MoM Efficiently Uses Cores



Common Runtime Errors

1. Triangle area = 0
 - 1.1 Limited by single precision
 - 1.2 Difference between target and smaller triangles
 - 1.3 Mitigation: increase mesh resolution
2. Failure to converge
 - 2.1 Right Hand Side of linear system does not converge
 - 2.2 Observed for Netgen, Mefisto mesh methods
 - 2.3 Mitigation: avoid mesh method

Triangles Too Small

```
-----FATAL ERROR-----FATAL ERROR-----FATAL ERROR-----FATAL ERROR-----  
subroutine Geometry_TRI_Compute( Tris, tol ) :Have Triangles with effective zero area  
nTris_With_Zero_Area = 60
```


Convergence Failure

```
-----FATAL ERROR-----FATAL ERROR-----FATAL ERROR-----FATAL ERROR-----  
subroutine ACA_Sum.Update( A, S, Tol, RefNorm ) : RHS: ACA did not converge  
= 0
```

MoM Produces Copious Output

1. Output *.4112.txt is an admixture of results and diagnostics (slide 41)
2. Cumbersome to work with
3. We want electric field measurements
4. Primary information blocks
 - 4.1 Environment characterization
 - 4.2 Performance description
 - 4.3 Simulation results

MoM Produces Copious Output

1. Slides are admixture of results and diagnostics (slides [41](#))
2. Cumbersome to work with
3. Will show how to harvest [electric field](#) measurements
4. Primary information blocks
 - 4.1 Environment characterization
 - 4.2 Performance description
 - 4.3 Simulation results



Run sequence - launch

```
$/MMoM.4.1.12 b20.geo
```

```
-----  
HOSTNAME = 3dd5a4b0d3c8
```

```
HOSTTYPE =
```

```
CPU =
```

```
OSTYPE =
```

```
MACHTYPE =
```

```
NUMBER_OF_PROCESSORS =
```

```
OMP_NUM_THREADS =
```

```
PROCESSOR_ARCHITECTURE =
```

```
PROCESSOR_IDENTIFIER =
```

```
----- Reporting output in MB from Linux command: vmstat -s -S M -----
```

```
53113 M free memory
```

Run sequence - sample output

```

Freq   = 30.00E+00 MHz
Lambda = 9.99E+00 m
k       = 628.75E-03 m-1
subroutine Solve_SetUp( Surface, bk, pSys, pD, Nodes ) : ...Finished
-----
---| Time : Time total for RHS solve
---| Twall = 0.0004168 ; Tcpu = 0.0002319 ; Ratio = 1.80
-----
---| Out Of Core Times: Diagonal Blocks
---|
---| nWrites.....: 2.
---| GigaBytes Write.....: 0.
---| Write Time (Hr).....: 0.00
---| Average Write Rate (MBytes/sec)..: 19.
---| nReads.....: 5.
---| GigaBytes Read.....: 0.
---| Read Time (Hr).....: 0.0002
---| Average Read Rate (MBytes/sec)..: 48.
---|
-----
Z Column Summary IO 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00

```

*.4112.txt Namelist Data

---| Name List Data |---

```
&MM_MOM
NLARGESTBLOCKSIZE      =      -1,
NSMALLESTREGIONSIZES  =      -1,
BUSEACA                 =      T,
BSOLVE_ACA              =      T,
BOUTOFCORE              =      T,
ACA_FACTOR_TOL          =      9.9999997E-06,
ACA_RHS_TOL             =      9.9999997E-05,
LOP_ADMISSIBILITY       =      WEAK,
DCLOSELAMBDA            =      CLOSE,
BEMCCDATAFILE           =      F,
BNORMALIZE              =      F,
BNORMALIZETOWAVELENGTH =      F,
CMYPLOTPROGRAM          =      junk,
POINT_TOLERANCE         =      1.0000000E-03,
BDIAG                   =      F,
BPRINTHISTOGRAM         =      F,
BCIRPOL                 =      F,
BOUTPUTACAGROUPING      =      F,
BOUTPUTRANKFRACTION     =      F,
BLIMITLUCOLUMNS        =      F,
BOPTIMIZE_LUTHEADS      =      F,
BRESTART                =      F,
```



*.4112.txt Namelist Data

```
NLUTHREADS      =      -1,  
NLUMKLTHREADS   =      1,  
NFILLMKLTHREADS =      1,  
NFILLTHREADS    =     -1,  
NRHSMKLTHREADS  =      1,  
NRHSTHEADS      =      1,  
NMKLTHREADS     =     -1,  
STACKSIZE_GB    =    -1.000000,  
MEMORYSIZE_GB   =    -1.000000,  
/  

```

*.4112.txt Surface Coupling

```
---| Creating Surface coupling |---  
  
---| Using Riverside Research algorithm based character string sort approach.  
    Checking for duplicate Nodes within 0.9993082E-01, tightest is 1E-9  
    Note:  If seg fault here, may be due to single precision.  
        Try loosening the POINT.TOLERANCE from 1E-9.  
    Tolerance is in Integer Powers of 10:  Significant Digits = 1  
    Number of Nodes in File:  601  
    No colocated nodes found.  
---| Finding Common & Free Edges using Riverside Research binarySearch...  
---| Starting Quick CoupleFinding for Surface 1 of 1  
---| Finished Quick CoupleFinding  
  
---| Surface couples created |---  
  
---| Time :  Surface Couples Create Time  
---| Twall = 0.0000103 ; Tcpu = 0.0000047 ; Ratio = 2.21
```




*.4112.txt Global Geometry Information

B20-standard-0.05.geo

```
---| Run Date: April 7, 2020; Time: 21:10:02  
---| MMoM runs on WAVENUMBER in 1/meters : 0.0628754
```

```
---| SURFACE SIE |---:
```

```
---| SIE File :B20-standard-0.05.facet  
---| SIE File Type : ACAD  
---| Input SIE Units : METERS  
---| Number of Triangles : 1198  
---| Area : 1.555E+09  
---| Surface Area in square lambda : 155.714E+03  
---| Edge Length in lambda (average) : 27.31117  
---| RWG Edges per square lambda : 0
```

```
---| Model Size :  
---| vMin (x,y,z) :-0.400E+04-0.280E+05-0.200E+04  
---| vMax (x,y,z) : 0.520E+05 0.280E+05 0.800E+04  
---| vCenter(x,y,z) : 0.240E+05 0.00 0.300E+04  
---| BoxDiagonal : 0.798E+05
```

*.4112.txt Global Geometry Information

```

---| Model Size in Lambda:
---| vMin (x,y,z) :  -40.0 -280.  -20.0
---| vMax (x,y,z) :  520.  280.  80.1
---| BoxDiagonal :  799.

---| SIE Surface Information |---

---| Number of Surfaces      :      1

---| iCoat User Index (from *.geo)      :      0
---| Current Support        :      Jp
---| Boundary Condition Type      :      BC_PEC
---| EM Volumes(INT|EXT)      :      V_NULL V_FREE_SPACE
---| nRWG Edges              :      1797
---| nFree Edges This Surface      :      0
---| nTri This Surface        :      1198
---| Area This Surface        :      1.555E+09

```



*.4112.txt Unknown Evaluation

```
---| Unknown Evaluation |---  
---| Number of Unknown Blocks Total : 1  
---| SIE : 1  
---| VIE : 0  
  
---| Total Number Unknowns : 1797  
---| SIE : 1797  
---| VIE : 0  
---| ... nJp_Vol : 0  
---| ... nJp : 1797  
---| ... nMp : 0  
---| ... nJm : 0  
---| ... nJunc Jp : 0  
---| ... nJunc Mp : 0
```



*.4112.txt ACA Factorization

```
ACA_FactorMatrix : ...Start
```

```
Start of Diagonal Blocks Computation...
```

```
nOMP_Threads = 1
```

```
nMKL_Threads = 1
```

```
---| Time : Diag Blk Parallel Fill
```

```
---| Twall = 0.0005463 ; Tcpu = 0.0009756 ; Ratio = 0.56
```

*.4112.txt Z Block

Start of Z Block Columns Computation...

```
...kmp_get_stacksize_s = 4194304
```

```
=====
...ACA Scratch Memory ( Z and RHS Fill ).....
...Memory_Available (GB).....= 50.73
...Memory Fraction to Use.....= 0.95
...Memory Available for ACA Scratch (GB).....= 48.19
...Requested nOMP Threads.....= 1
...Actual nOMP Threads.....= 1
...Max:  nRows, nCols, kACA.....= 1797 1797 270
...Max:  Rank Fraction.....= 0.30
...Memory Used for Scratch.....= 0.01
=====
```



*.4112.txt Subroutine Solve

```
subroutine Solve_SetUp( Surface, bk, pSys, pD, Nodes ) : ...Start
```

```
---| EXCITATION is.....:MONOSTATIC
```

```
---| Angle Cut is : AZIMUTH
```

```
---| Fixed Angle is : 90.00000
```

```
---| Number of Pattern points : 360
```

```
---| Var angle (min,max) : 0.00000
```

```
---| MONOSTATIC RHS = nAng * 2 : 720
```

```
---| Memory Available for RHS : 51925. MB
```

```
---| Memory Estimate for ALL RHS : 10. MB
```

```
Computing RHS Block Loop : 1 of 1
```

```
---| nBlockRHS_Ang : 360
```

```
---| from iAng : 1 to iAng = 360
```

```
Solve_System : ... Starting Forward solution
```

```
Solve_System : ... Starting backward solution
```

```
Solve_System : ... Starting Forward solution
```

```
Solve_System : ... Starting backward solution
```



*.4112.txt Electric Fields

```
Freq = 3.00E+00 MHz  
Lambda = 99.93E+00 m  
k = 62.88E-03 m-1
```

```
BACKSCATTER RCS RESULTS .....
```

```
Theta, Phi, Theta-Theta (complex efield), Phi-Theta (complex efield),Theta-Phi (complex  
efield),...
```

```
90.0000, 0.0000,( -0.1238511E+06, -0.5511971E+06),( -0.4439931E+06, -0.3857693E+06),...  
90.0000, 1.0000,( -0.6807091E+05, 0.1494042E+06),( 0.4671754E+05, -0.4308930E+05),...  
90.0000, 2.0000,( 0.9131244E+05, 0.1021946E+06),( -0.5654139E+05, 0.2118485E+06),...  
90.0000, 3.0000,( 0.2310044E+06, -0.7692039E+05),( -0.1079327E+06, 0.3446281E+06),...  
  
90.0000, 359.0000,( 0.6986329E+05, 0.3586468E+05),( -0.1790911E+04, -0.6904529E+05),...
```



Special Thanks to...

Special Thanks to [Capt. Joe Sciacca](#) for blazing the trail forward.

Mercury Method of Moments: AFRL Quick Start Guide

Daniel Topa

ERT Inc.

daniel.topa@ertcorp.com

July 7, 2020