Mercury Method of Moments: AFRL Quick Start Guide

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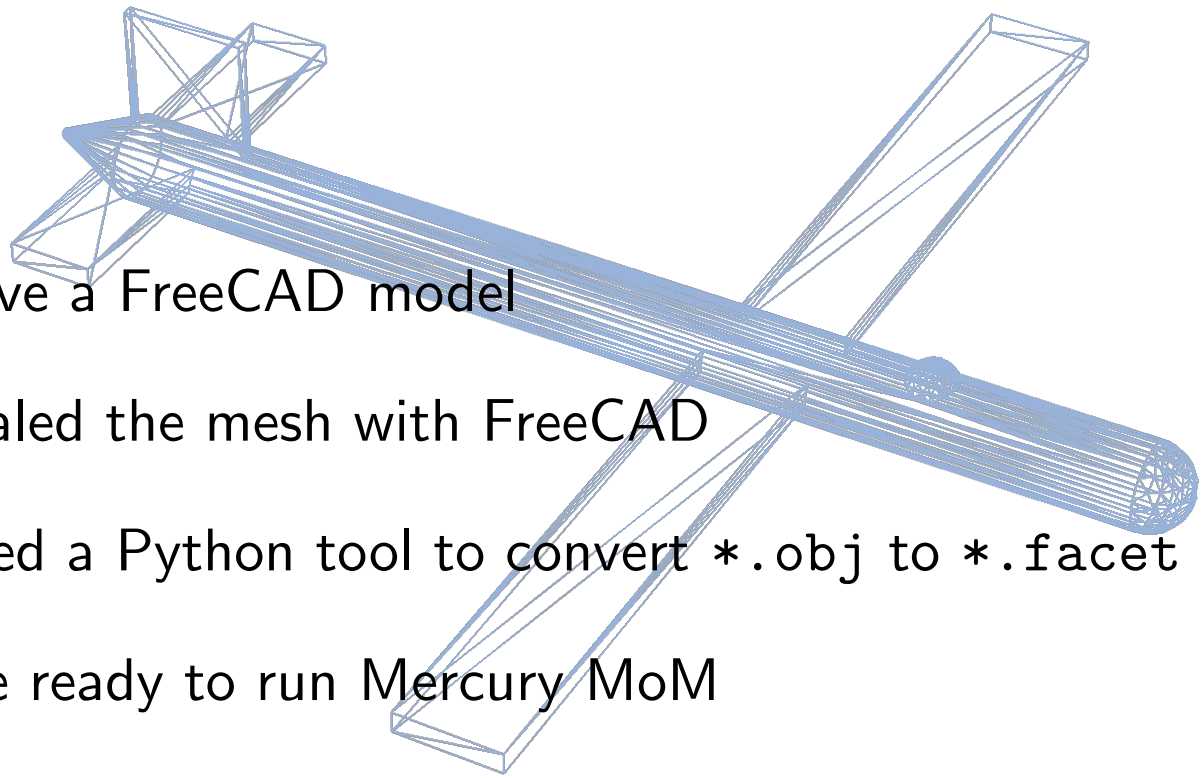
Scope: A Snapshot of Progress

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

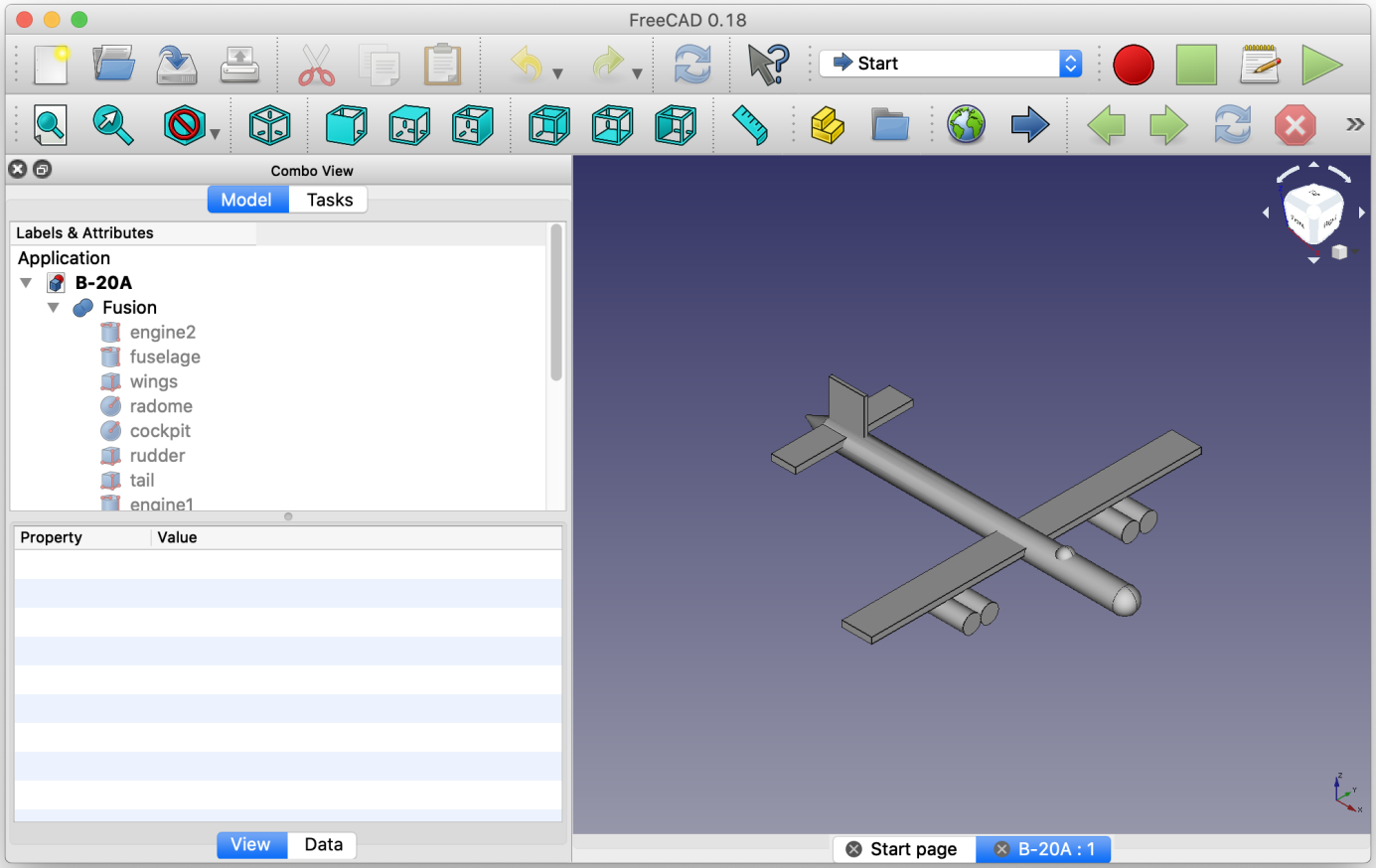
1. Mercury MoM is a standalone executable
   - 1.1 NO QT
   - 1.2 NO Intel MKL
   - 1.3 NO Intel Fortran
   - 1.4 NO Intel Math Library
2. MMViz requires extensive libraries– Not MoM
3. System requirements for MMoM.4.1.12 follow...

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


FreeCAD 0.18
Start
Combo View
Model
Tasks
Labels & Attributes
Application
B-20A
Fusion
engine2
fuselage
wings
radome
cockpit
rudder
tail
engine1
Property
Value
View
Data
Start page
B-20A : 1

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.,                          nFillThreads = -1,
 bSolve_ACA = .TRUE.,                       nFillMKLThreads = 1,
 bOutOfCore = .TRUE.,                       nLUThreads = -1,
 bNormalizeToWaveLength = .FALSE.,          nLUMKLThreads = 1,
 bNormalize = .FALSE.,                      nRHSThreads = 1,
 dCloseLambda = 0.100000,                   nRHSMKLThreads = 1,
 ACA_Factor_Tol = 0.000010,                 bOutputACAGrouping = .FALSE.,
 ACA_RHS_Tol = 0.000100,                    bOutputRankFraction = .FALSE.,
 Point_Tolerance = 0.001000,                bLimitLUColumns = .FALSE.,
 nLargestBlockSize = -1,                    Lop_Admissibility = WEAK,
 MemorySize_GB = -1.000000,                 Kop_Admissibility = CLOSE
 stackSize_GB = -1.000000,
```

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

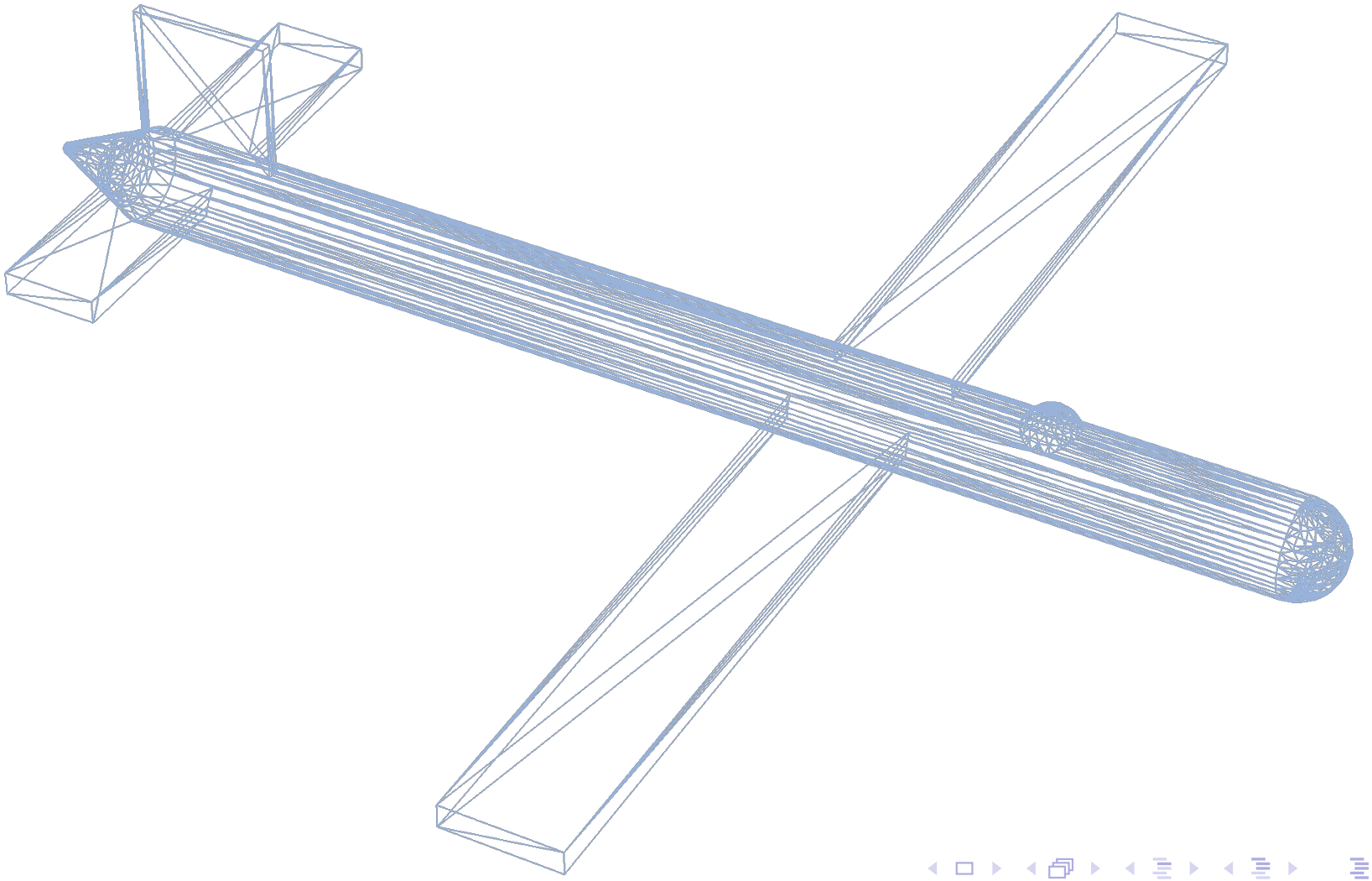
Essential Files

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	`$./MMoM_4.1.12`
Geometry file	`b20.geo`
CAD file	`b20.facet`
Material library	`Materials.lib`

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

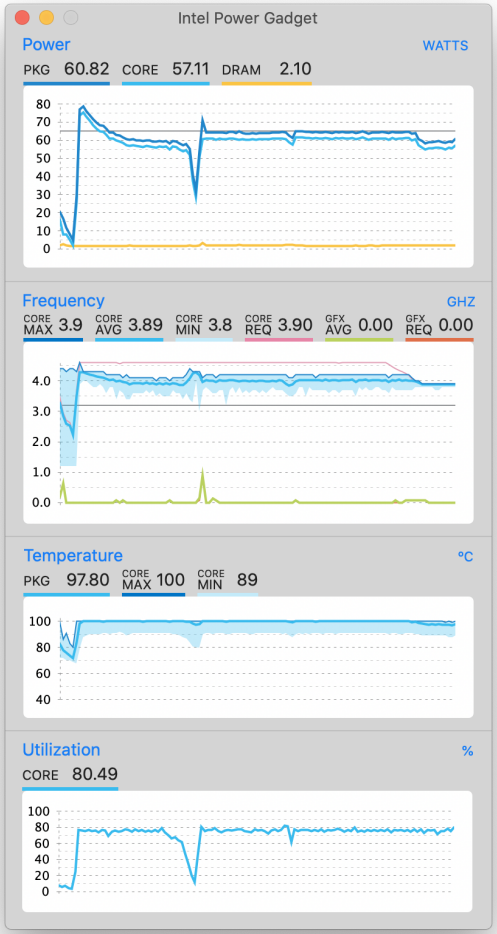
```
$ lscpu
  Architecture:            x86_64
  CPU op-mode(s):          32-bit, 64-bit
  Byte Order:              Little Endian
  Address sizes            39 bits physical, 48 bits virtual
  CPU(s):                  12
  Thread(s) per core:      1
  Core(s) per socket:      1
  Vendor ID:               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,
NSMALLESTREGIONSIZE        =     -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,
BOPTIMIZELUTHREADS         =     F,
BRESTART                   =     F,
```

*.4112.txt Namelist Data

```
NLUTHREADS          =     -1,
NLUMKLTHREADS       =     1,
NFILLMKLTHREADS     =     1,
NFILLTHREADS        =     -1,
NRHSMKLTHREADS      =     1,
NRHSTHREADS         =     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
...Reqested 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.

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