Radar Cross Section Models for AFCAP Dashboard: A Snapshot

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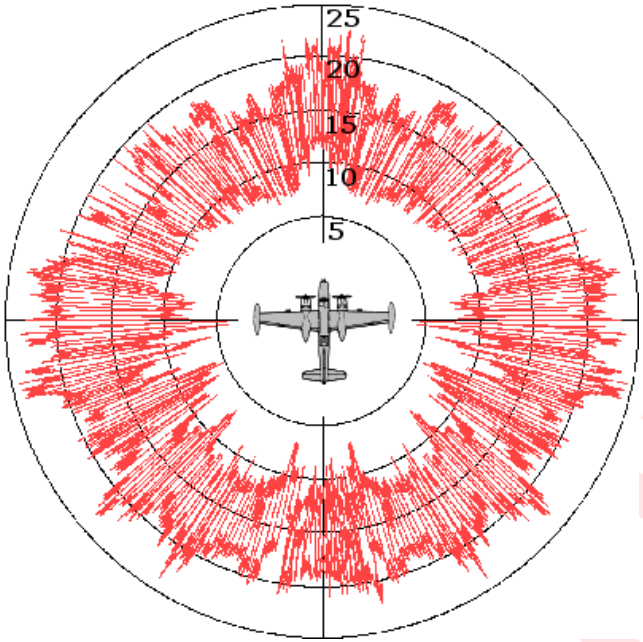
April 11, 2020

Scope: A Snapshot of Progress

1. Fourier Decomposition Results
2. Polynomial Decomposition Results

Vision



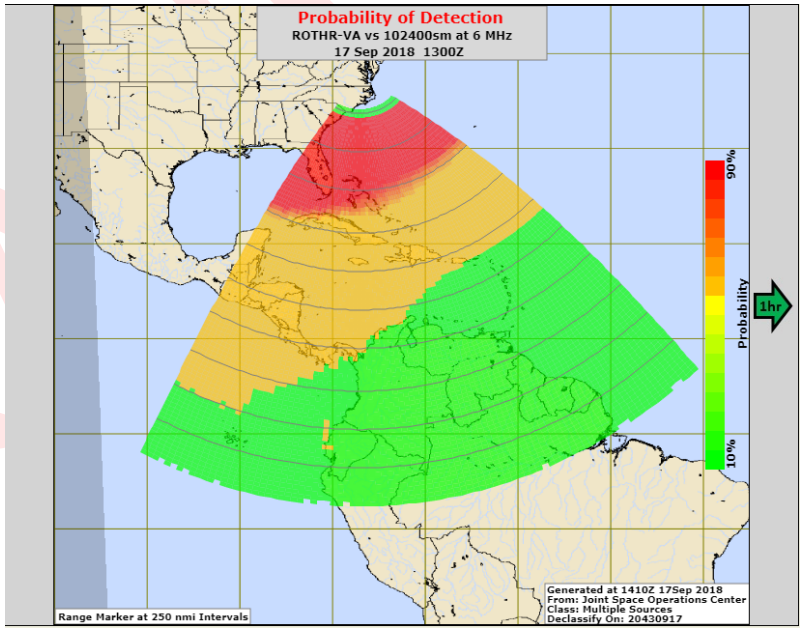
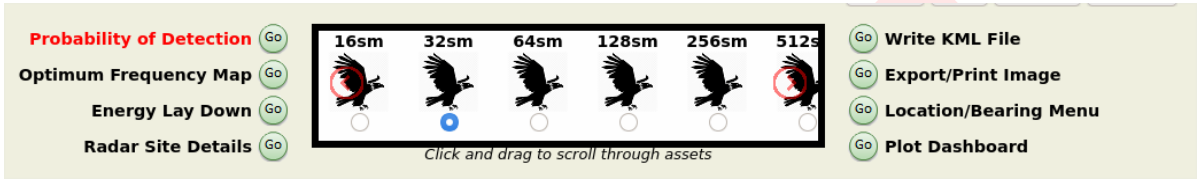
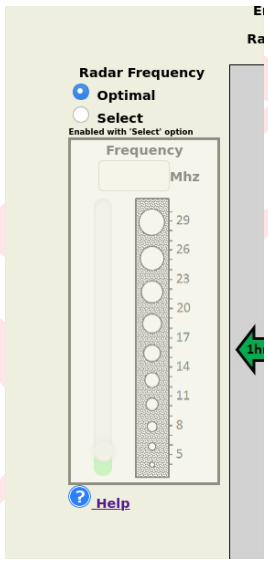


Table: Capture RCS Variablity

Dashboard Controls



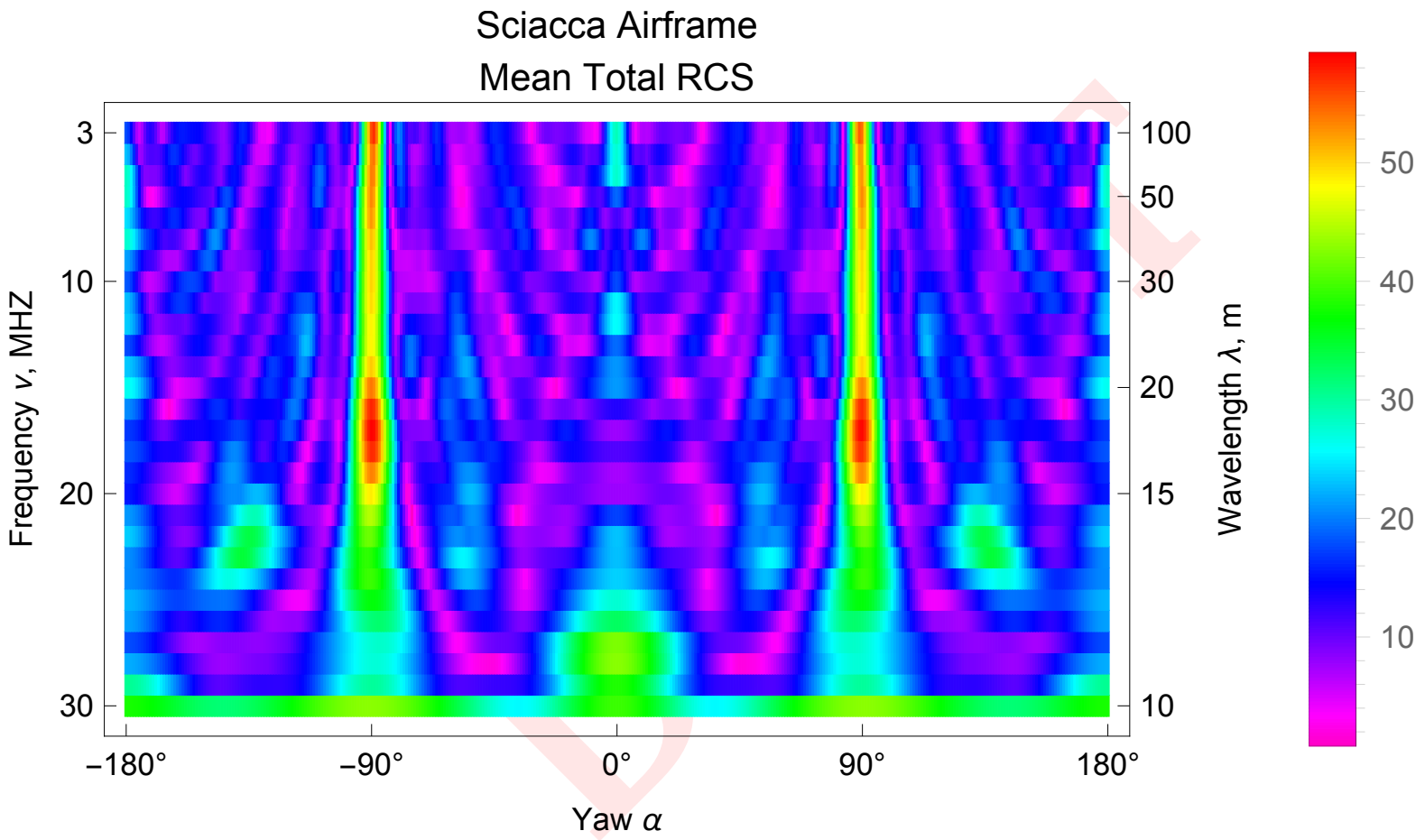


Config.xml

```
<Asset>
 <Label>16sm</Label>
 <ICONImage>Bald Eagle-sm.png</ICONImage>
 <crossSection>16</crossSection>
 <description>Aircraft</description>
 <nominalSpeed>400</nominalSpeed>
 <CIT>2.0</CIT>
</Asset>
```

Probability of Detection

```
from frOPCclass.js
function plotProbability (ctx, jsonObj, jsonCoord, \
 xSection, assetCIT, nomSpeed) {
 ...
 var xSecRadius = Math.sqrt(xSection/Math.PI)
 var sphereArea = Math.PI * xSecRadius * xSecRadius;
 ...
 }
```


Sciacca Airframe
Mean Total RCS
Frequency ν, MHZ
3
10
20
30
100
50
30
20
15
10
−180°
−90°
0°
90°
180°
Yaw α
Wavelength λ, m
50
40
30
20
10

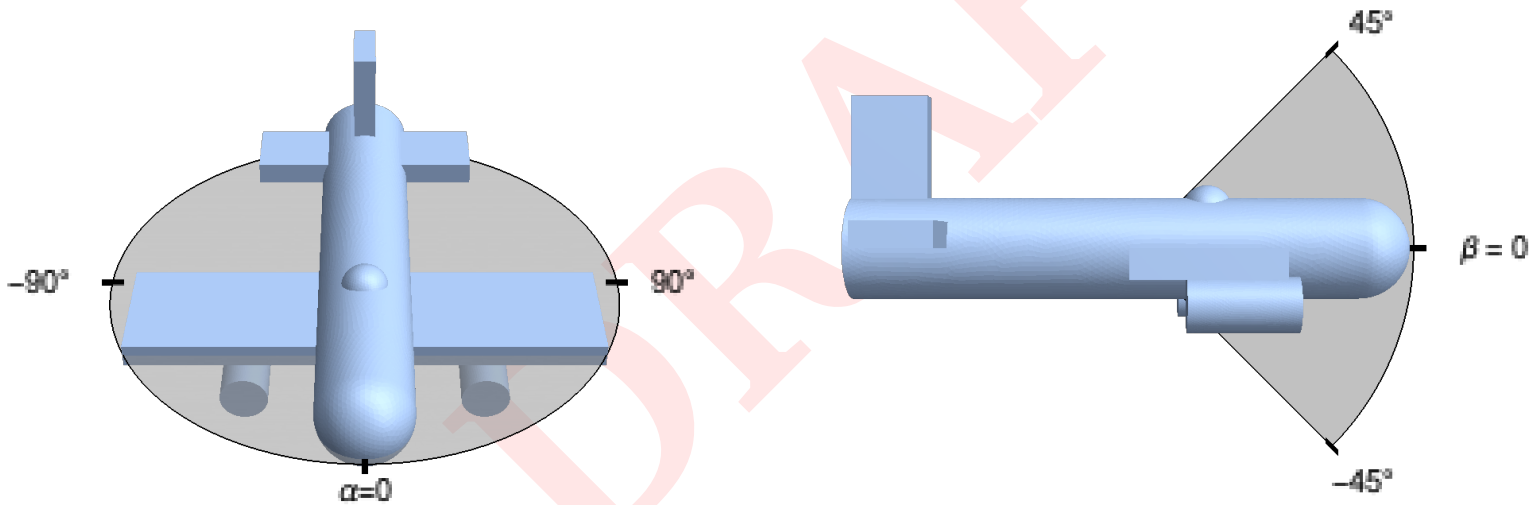
Defining Angles

Yaw α

$-180 \leq \alpha < 180$

Pitch β

$\beta_0 = 30°$



Best Way To Update Dashboard?

1. Compression
   - Fourier decomposition
   - Taylor decomposition
   - wavelets
2. Reduction
   - Average neighbors
   - Sampling

Best Way To Update Dashboard?

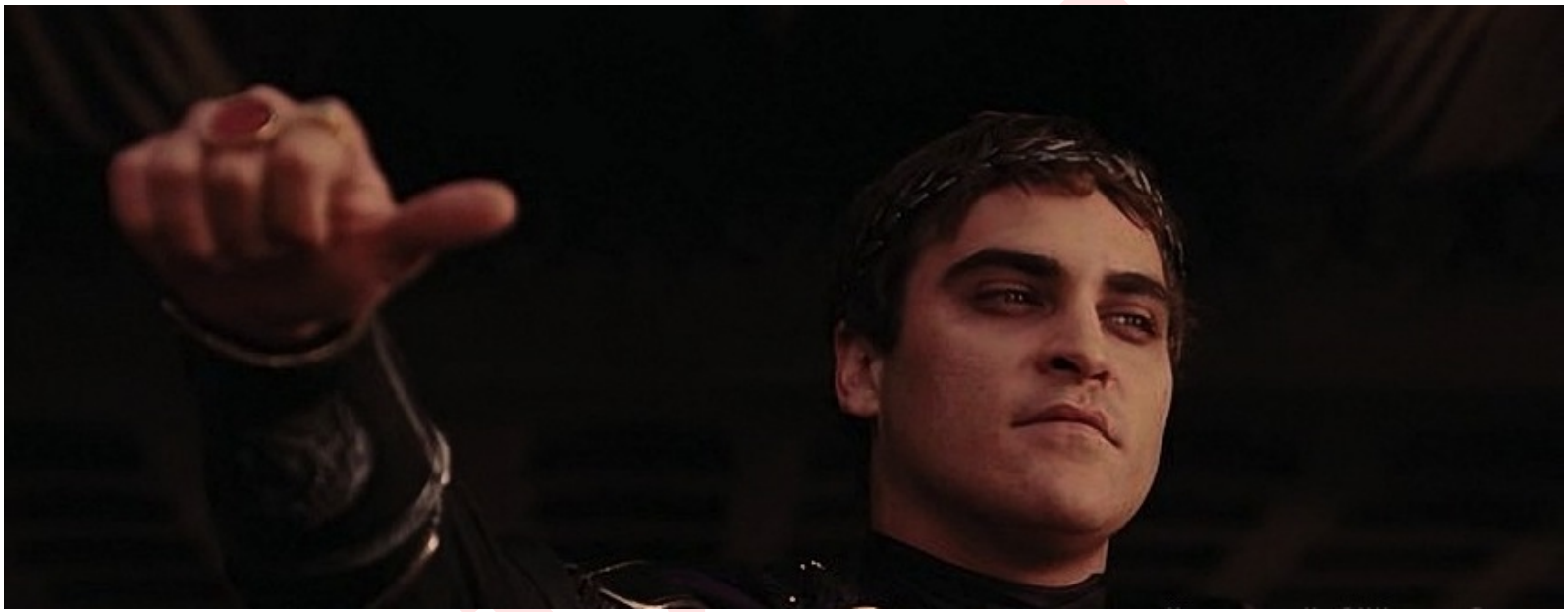
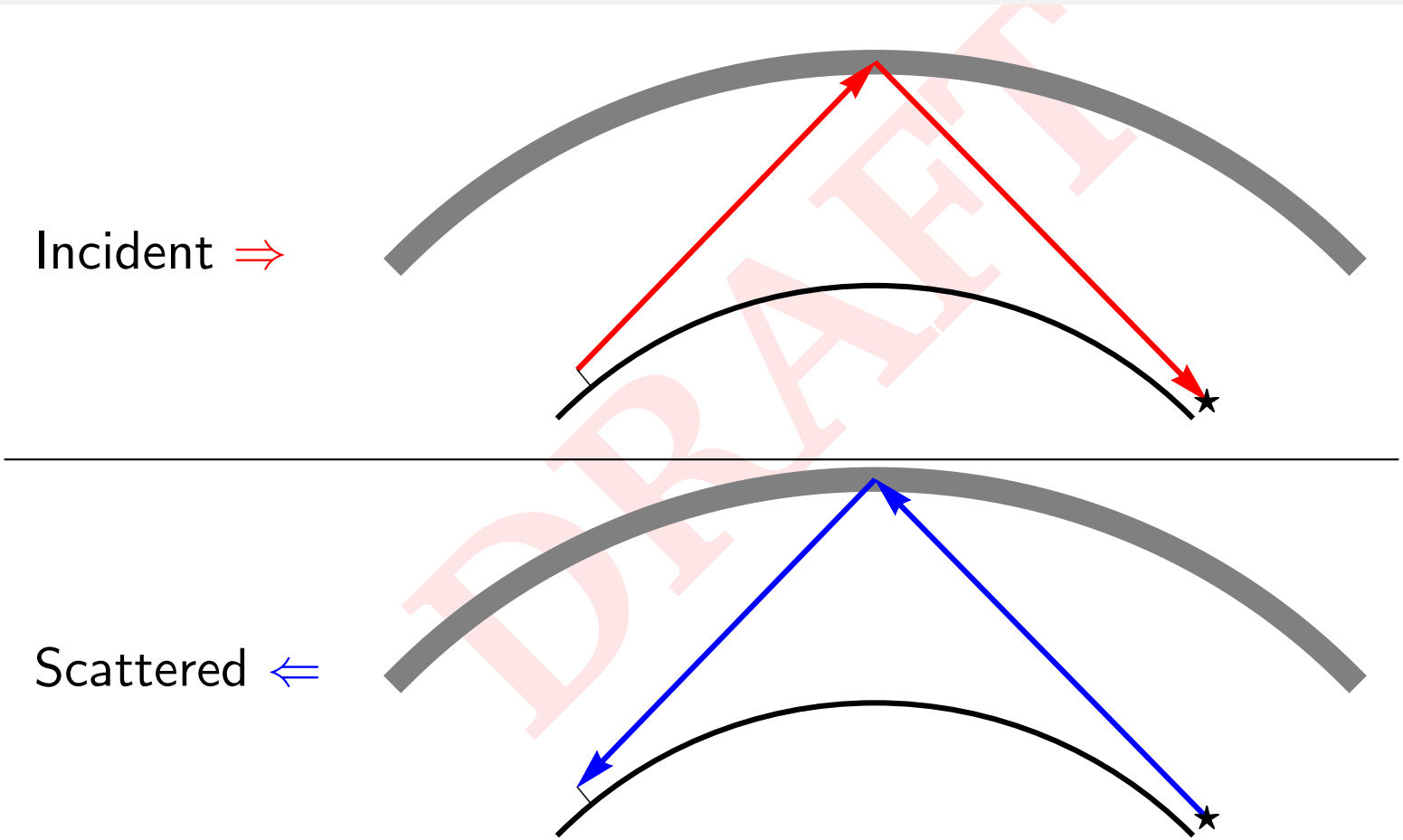


Figure: Criterion: Bonito Thumb Test

Radar Cross Section: A Measure of Energy Difference



Effective Radar Cross Section: Definition

$$\sigma_\star = \frac{\text{power scattered per unit solid angle}}{\text{incident power density per } 4\pi} \tag{2.1}$$

Effective Radar Cross Section: Definition

$$\sigma_\star = 4\pi \lim_{r\to\infty} r^2 \left| \frac{E_{incident}}{E_{scattered}} \right|^2 \tag{2.2}$$

Radar Cross Section: Discussion

- Radar cross section is a far field phenomenon
- Assumes single polarization to and from target
- Target is completely metallic:
  E field results from surface currents
- Shape is quasi-dimensional
  - Dimensions in two known directions
  - Fuselage, wings
- Resonant scattering:
  Ratio of typical dimension to wavelength ≈ 1
- See Kolosov, §4.6

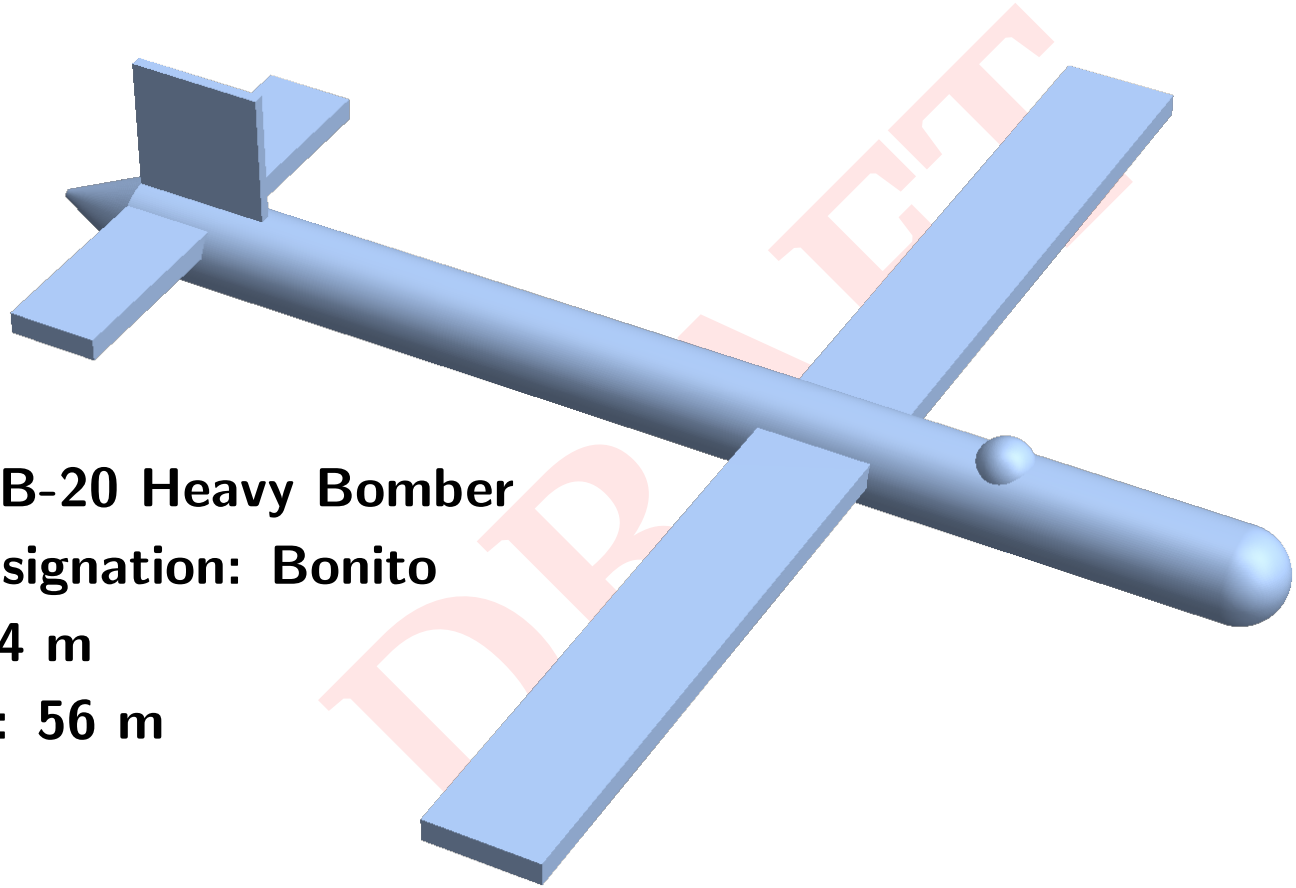
Radar Scattering

1. Rayleigh scattering
2. Assumes single polarization to and from target

Polarization Scattering Matrix

$$S = \begin{bmatrix} \sqrt{\sigma_{HH}} e^{i\phi_{HH}} & \sqrt{\sigma_{HV}} e^{i\phi_{HV}} \\ \sqrt{\sigma_{VH}} e^{i\phi_{VH}} & \sqrt{\sigma_{VV}} e^{i\phi_{VV}} \end{bmatrix} \tag{2.3}$$

B-20 Heavy Bomber



FreeCAD B-20 Heavy Bomber

NATO Designation: Bonito

Length: 54 m

Wingspan: 56 m

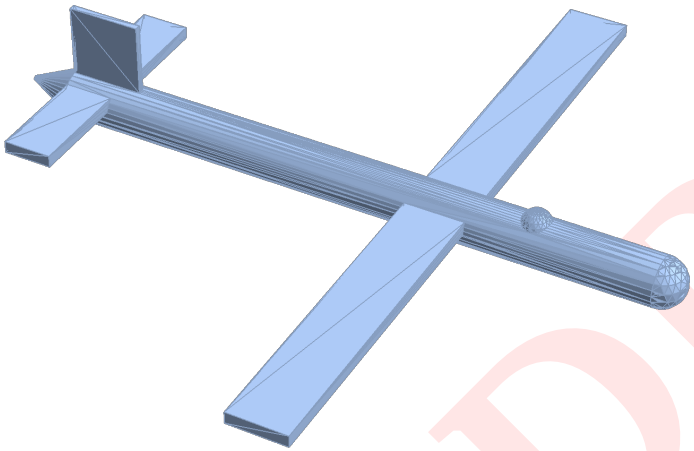
Meshing Schemes

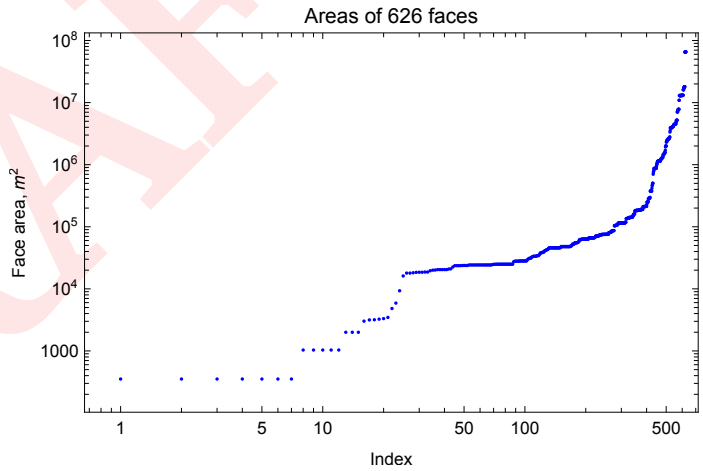
	Method	Mesh Resolution	Faces	Points	Spectral Radius
✓	Standard	1.0 m	626	315	5.3
✓	Standard	0.1 m	766	385	5.3
✓	Standard	0.05 m	1,198	601	5.3
✗	Standard	0.01 m	3,352	1,678	6.5
✗	Standard	0.001 m	28,394	14,199	8.7
✗	Mefisto	1.0 m	3,974	1,992	2.5
✗	Netgen	very fine	10,098	5,051	3.0

Table: One model, many meshes. How does Mercury MoM fare?

Standard meshing, 1 m resolution

Mesh	Spectrum

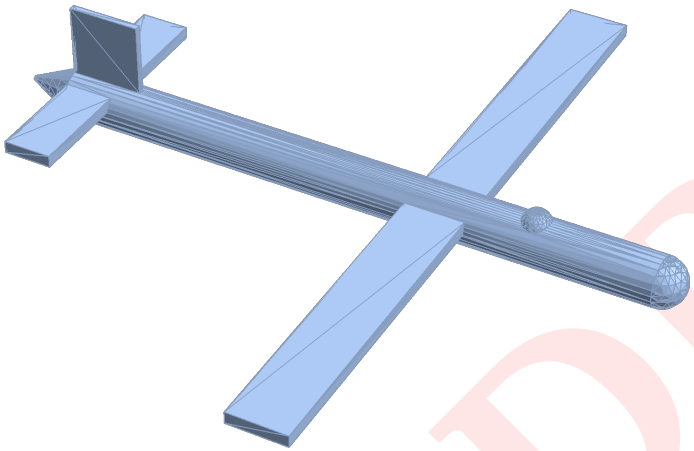




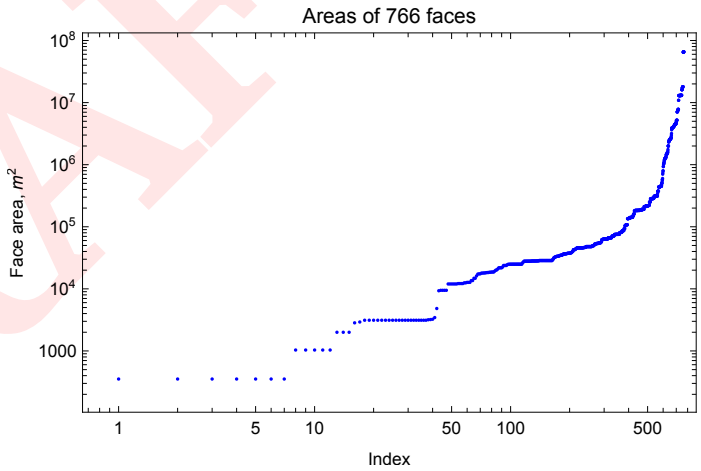

```
------------------------------------------------------------------------------
---| Mercury MOM Completed Sucessfully |---
------------------------------------------------------------------------------
```

Standard meshing, 0.1 m resolution

Mesh



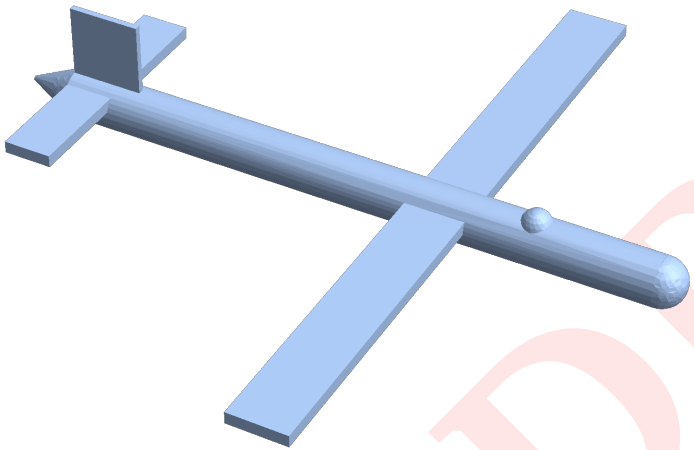
Spectrum



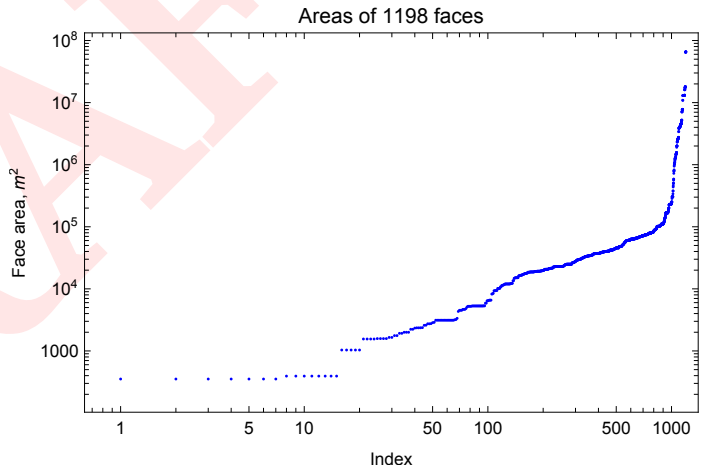

```
------------------------------------------------------------------------------
---| Mercury MOM Completed Sucessfully |---
------------------------------------------------------------------------------
```

Standard meshing, 0.05 m resolution

Mesh



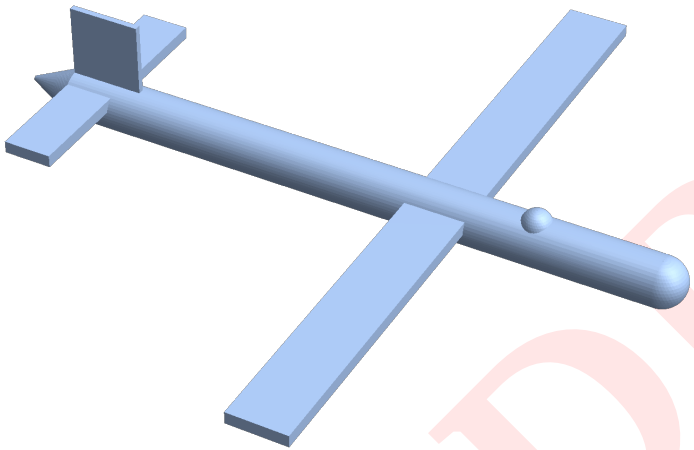
Spectrum



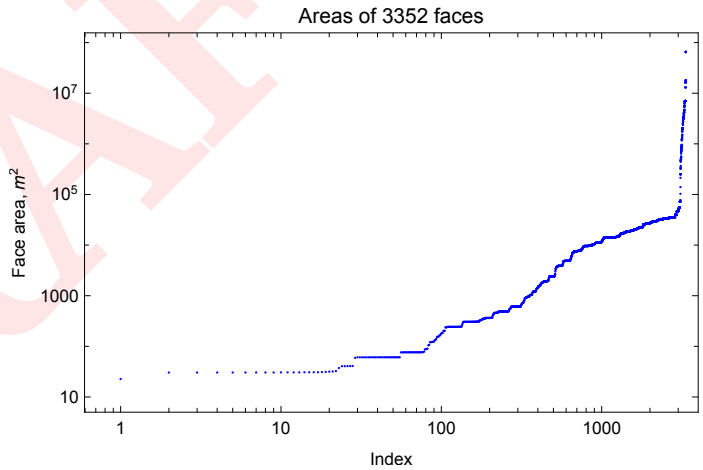

```
------------------------------------------------------------------------------
---| Mercury MOM Completed Sucessfully |---
------------------------------------------------------------------------------
```

Standard meshing, 0.01 m resolution

Mesh



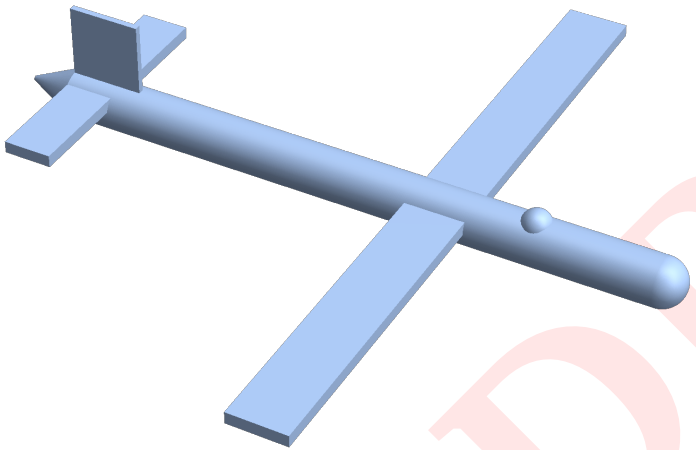
Spectrum



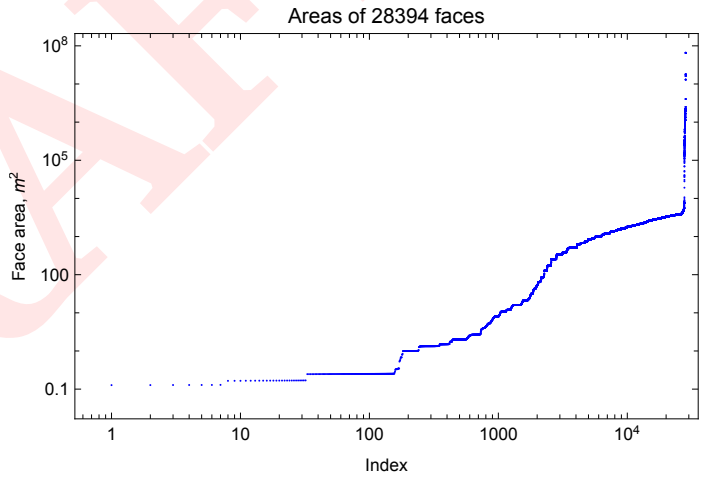

```
--------FATAL ERROR-------FATAL ERROR-------FATAL ERROR-------FATAL ERROR-------
 subroutine ACA_Sum_Update( A, S, Tol, RefNorm ) :  RHS: ACA did not converge
 =           0
```

Standard meshing, 0.001 m resolution

Mesh



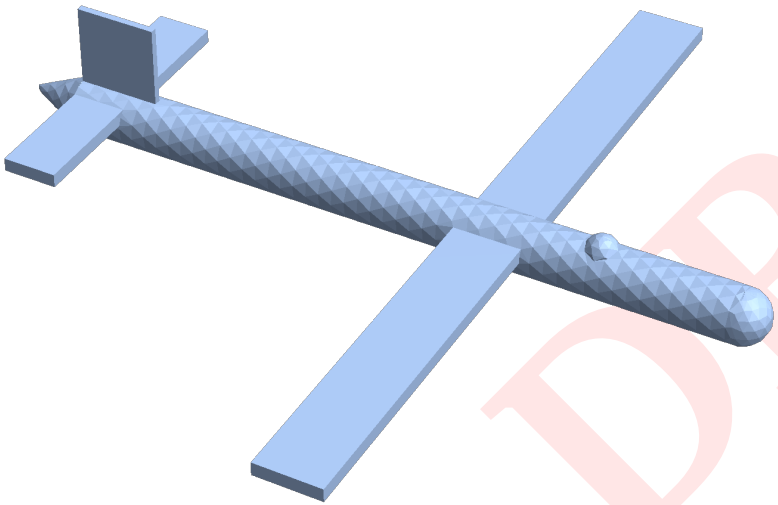
Spectrum



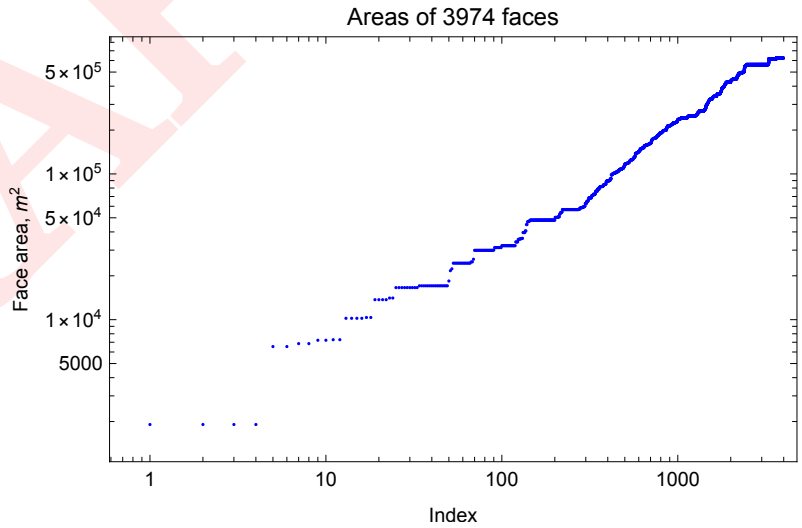

```
--------FATAL ERROR-------FATAL ERROR-------FATAL ERROR-------FATAL ERROR-------
subroutine Geometry_TRI_Compute( Tris, tol ) :Have Triangles with effective zero area
nTris_With_Zero_Area =          60
```

Mefisto meshing, 1 m resolution

Mesh



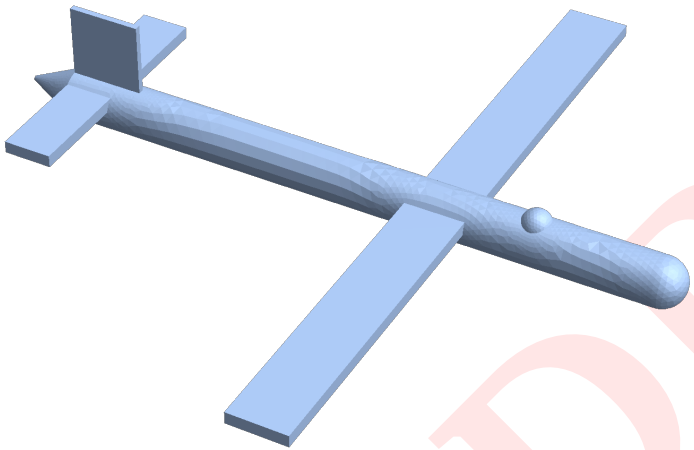
Spectrum

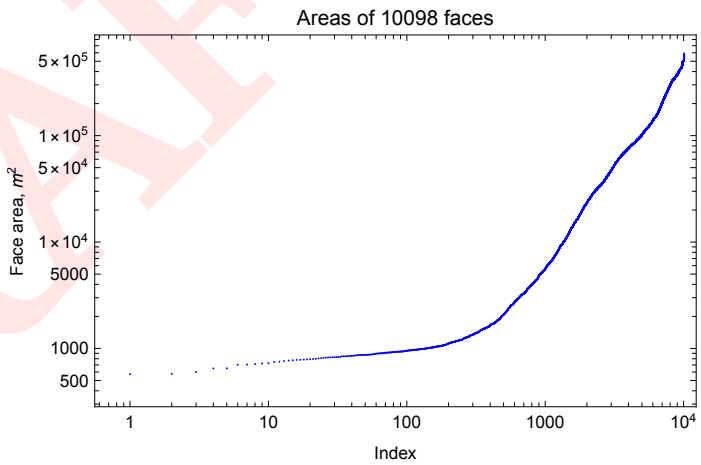



```
--------FATAL ERROR-------FATAL ERROR-------FATAL ERROR-------FATAL ERROR-------
 subroutine ACA_Sum_Update( A, S, Tol, RefNorm ) :  RHS: ACA did not converge
 =           0
```

Netgen meshing, *very fine* resolution

Mesh	Spectrum






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

Executables and libraries

```
bin $ ls -1
MMViz_4.1.12
MMoM_4.1.12
libQtCore.so.4
libQtGui.so.4
libQtOpenGL.so.4
libifcore.so.5
libifport.so.5
libimf.so
libintlc.so.5
libiomp5.so
libirng.so
libmkl_core.so
libmkl_intel_lp64.so
libmkl_intel_thread.so
libsvml.so
```

Linux Environment

```
$ lsb_release -a
Distributor ID: Ubuntu
Description:    Ubuntu Focal Fossa
Release:        20.04
Codename:       focal
```

Mercury MoM is Single Precision

Example: 8 MHz
Despite exact binary representation

$$8_{10} = 1000_2$$

```
Start Frequency = 7.9999994E-03GHz
```

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
```

Run sequence - completion

```
$./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
```

Minimum triangle size

Mercury MoM is very sensitive to minimum triangle size.
Spectral radius

Linux Environment

```
--------FATAL ERROR-------FATAL ERROR-------FATAL ERROR-------FATAL ERROR-------
subroutine Geometry_TRI_Compute( Tris, tol ) :Have Triangles with effective zero area
nTris_With_Zero_Area = 15244
```

Mercury MoM is a...

- Highly–capable
- Efficient
- Versatile

electromagnetic simulation package

Using Mercury MoM

Our use case is very restricted...

- Perfect electrical conductor
- Surface excitations
- Monostatic

Executables and libraries

```
bin $ ls -1
MMViz_4.1.12
MMoM_4.1.12
libQtCore.so.4
libQtGui.so.4
libQtOpenGL.so.4
libifcore.so.5
libifport.so.5
libimf.so
libintlc.so.5
libiomp5.so
libirng.so
libmkl_core.so
libmkl_intel_lp64.so
libmkl_intel_thread.so
libsvml.so
```

Input files

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

Input files

1. `B-20.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-20.facet`
   - 2.1 Vertex list
   - 2.2 Face list
3. `Materials.lib`
   - 3.1 Permiability
   - 3.2 Permittivity

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
```

Radar frequencies

```
FREQUENCY
 ghz
 0.003000 0.030000 28 !Freq Start, Freq Stop, Num Frequencies
```

Sampling

```
Angle Cut
 1
 0.000000 359.000000 360
 AZIMUTH
 90.000000
```

Monostatic or bistatic

```
Excitation
 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

Linux Environment

```
$ lsb_release -a
Distributor ID: Ubuntu
Description:    Ubuntu Focal Fossa
Release:        20.04
Codename:       focal
```

Mercury MoM is Single Precision

Example: 8 MHz
Despite exact binary representation

$$8_{10} = 1000_2$$

```
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```

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 =
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```

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```
 Freq   = 30.00E+00 MHz
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---| 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
```

Run sequence - completion

```
$./MMoM_4.1.12 b20.geo
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HOSTNAME = 3dd5a4b0d3c8
HOSTTYPE =
CPU =
OSTYPE =
MACHTYPE =
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OMP_NUM_THREADS =
PROCESSOR_ARCHITECTURE =
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Linux Environment

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```

Extracting Information

Phase		Amplitude	
$\frac{\partial \phi}{\partial x}$	angle	$\frac{\partial A}{\partial x}$	shape
$\frac{\partial \phi}{\partial t}$	relative velocity	$\frac{\partial A}{\partial t}$	rotation
$\frac{\partial \phi}{\partial f}$	range	$\frac{\partial A}{\partial f}$	size

Table: *Intro. to Radar Systems*, M. I. Skolnik, §10.2

References

- **Handbook of Radar Measurement**
  D. K. Barton, H.R. Ward
  1969 ISBN 13-380683-9
- **Introduction to Radar Systems**
  Merrill I. Skolnik
  1962 LoC CCN ISBN 61-17675
- **Over-The-Horizon Radar**
  A. A. Kolosov, et al.
  1987 ISBN 0-890006-233-1
- **Radar Cross Section**
  E. F. Knott, M. T. Tuley, J. F. Shaeffer
  1993 ISBN 9780890066188

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