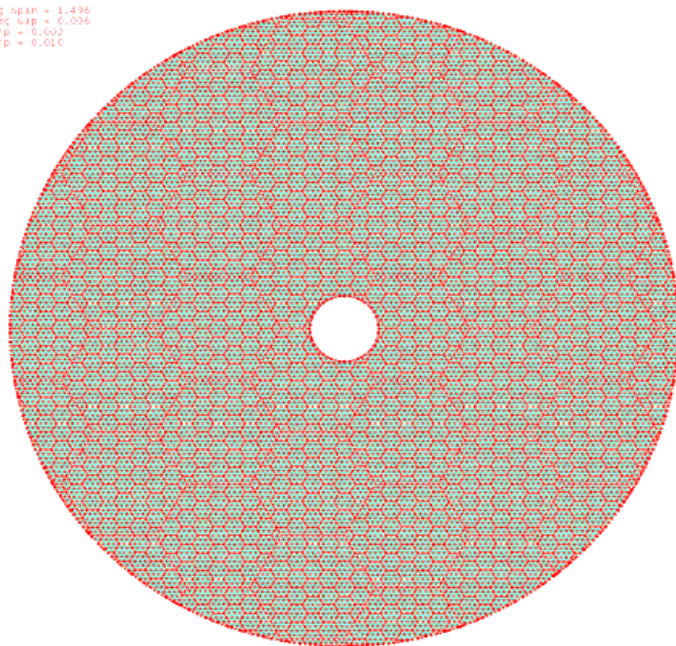
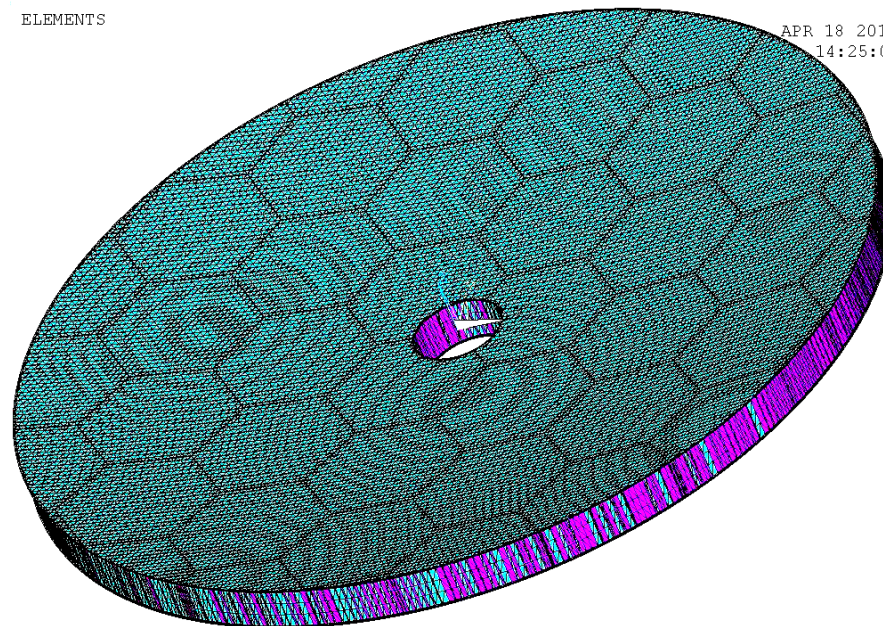


# Next-generation lightweight mirror modeling software

seq span = 1.496  
seq gap = 0.036  
slip = 0.002  
tlp = 0.016



ELEMENTS



APR 18 2013  
14:25:05

**William R. Arnold Sr., Sr. Principal Engineer, DAI, Huntsville, AL.**  
**Mathew Fitzgerald, NASA Intern, NASA MSFC, Huntsville, Al.**  
**Rubin Jaca Rosa, NASA Intern, NASA MSFC, Huntsville, Al.**  
**Dr. Phil Stahl, AMTD PI, NASA MSFC, Huntsville, Al.**

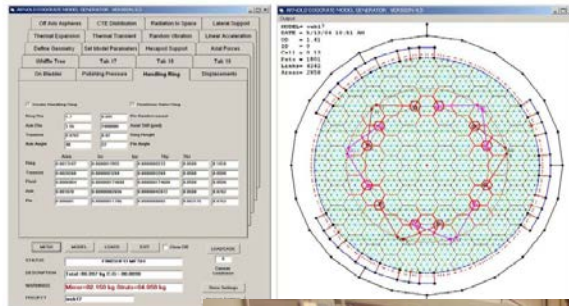
# INTRODUCTION

- **The modeler was developed to handle all current and projected mirror construction techniques and materials.**
- **It can be used to model both individual mirrors, arrays of mirrors and “fused segmented” mirrors**
- **It uses a new generation of algorithms and code written for Windows 7 © and beyond**
- **Designed for rapid trade studies of both gross geometry as well as detailed parameter (thickness) optimization and integrated suspension design.**



# INTEGRATED APPROACH TO DESIGN WORKS (PREDECESSOR PROGRAM USED ON KEPLER)

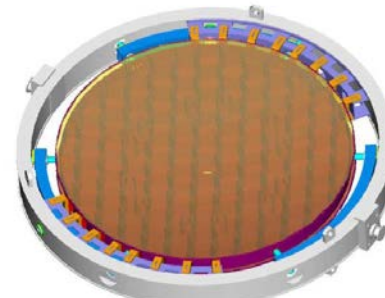
## Integrated Design of Handling Equipment



Design tool allows evaluation of the mirror blank. As mirrors manufacturing requires careful handling, the blank specifications were added to the blank specifications.



## Primary Mirror in Flipping Ring



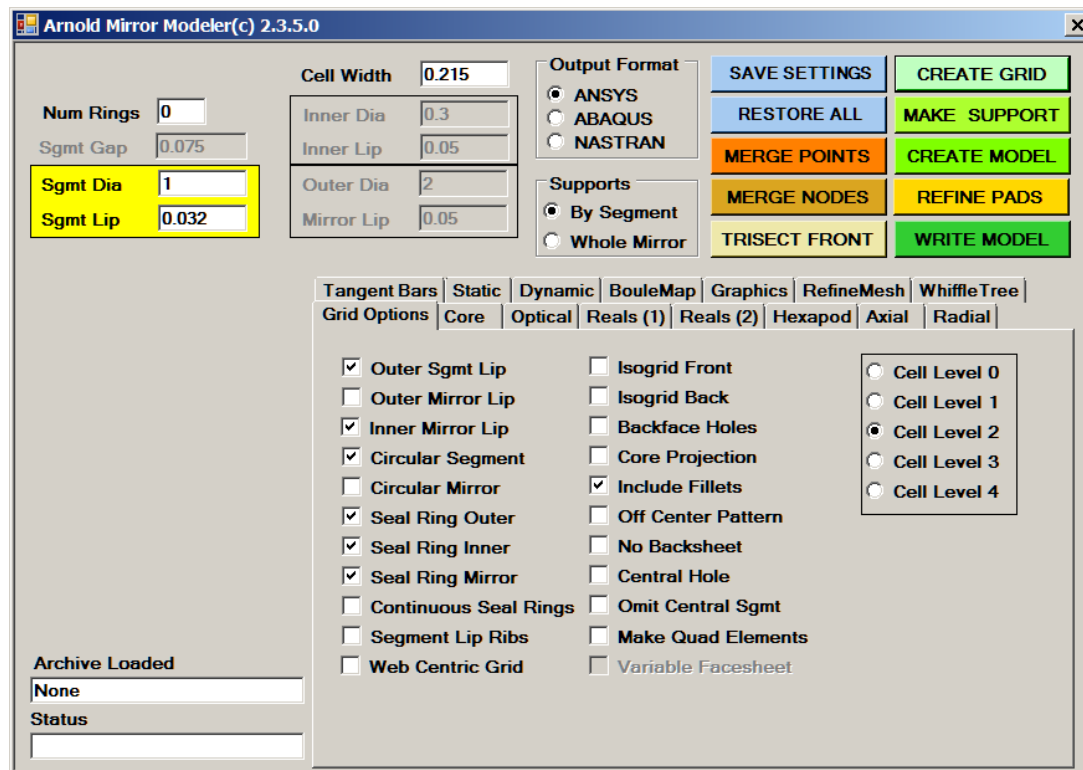
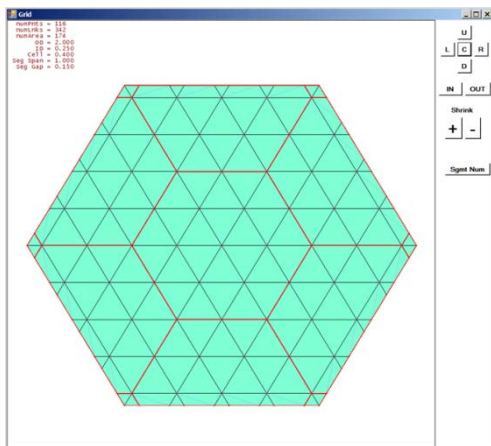
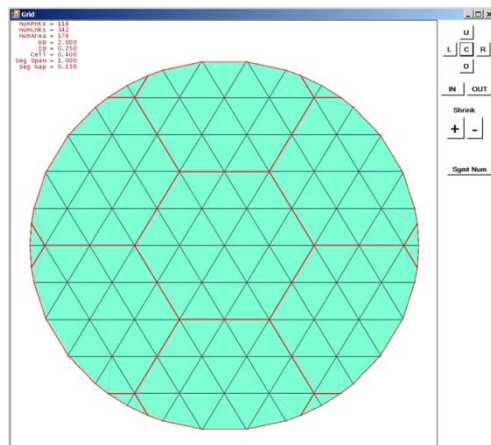
reinforced slots in the mirror unit can act as a support for the mirror surfaces or fragile edges.



2004

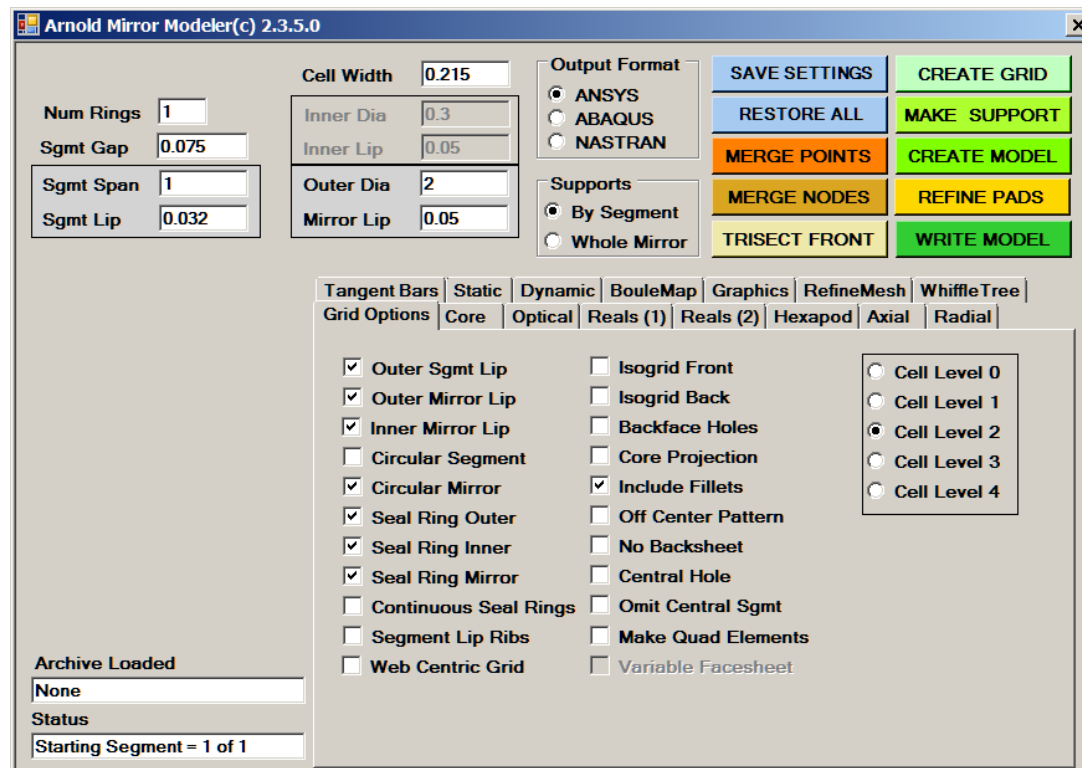
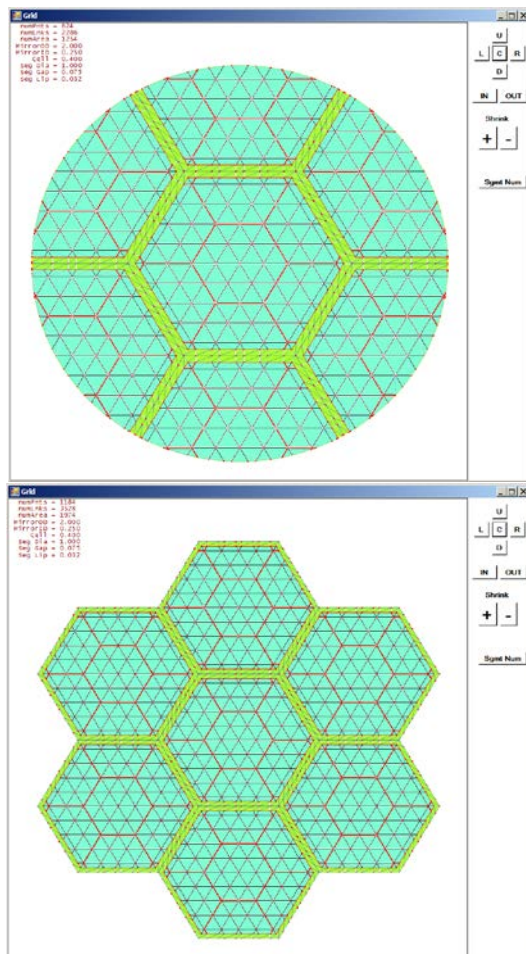
18

# WIDE VARIETY OF OPTIONS TO MODEL ALMOST ANY MIRROR STYLE



## SIMPLE SINGLE BLANK MIRRORS

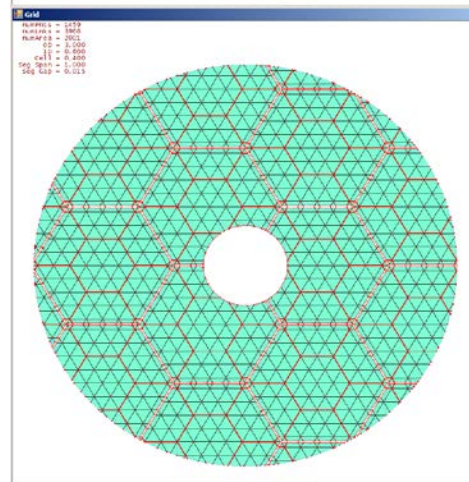
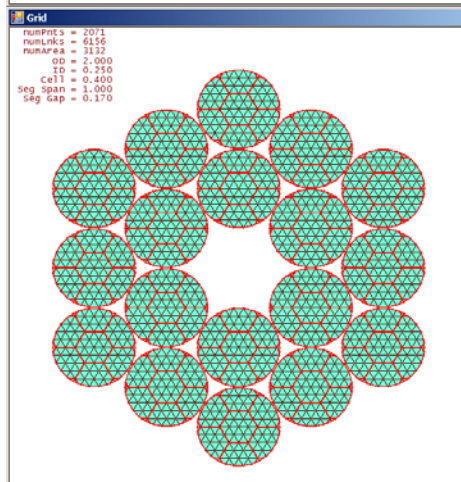
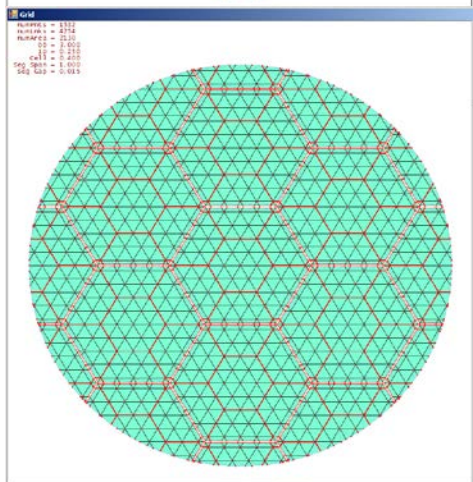
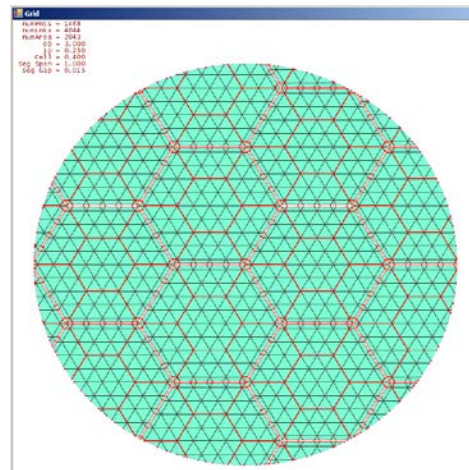
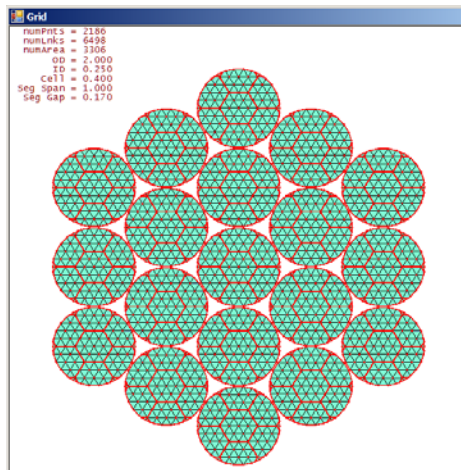
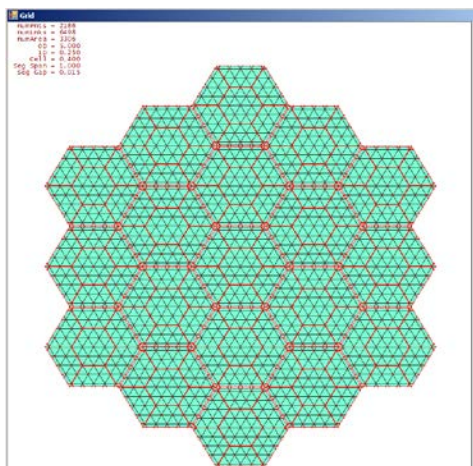
# WIDE VARIETY OF OPTIONS TO MODEL ALMOST ANY MIRROR STYLE



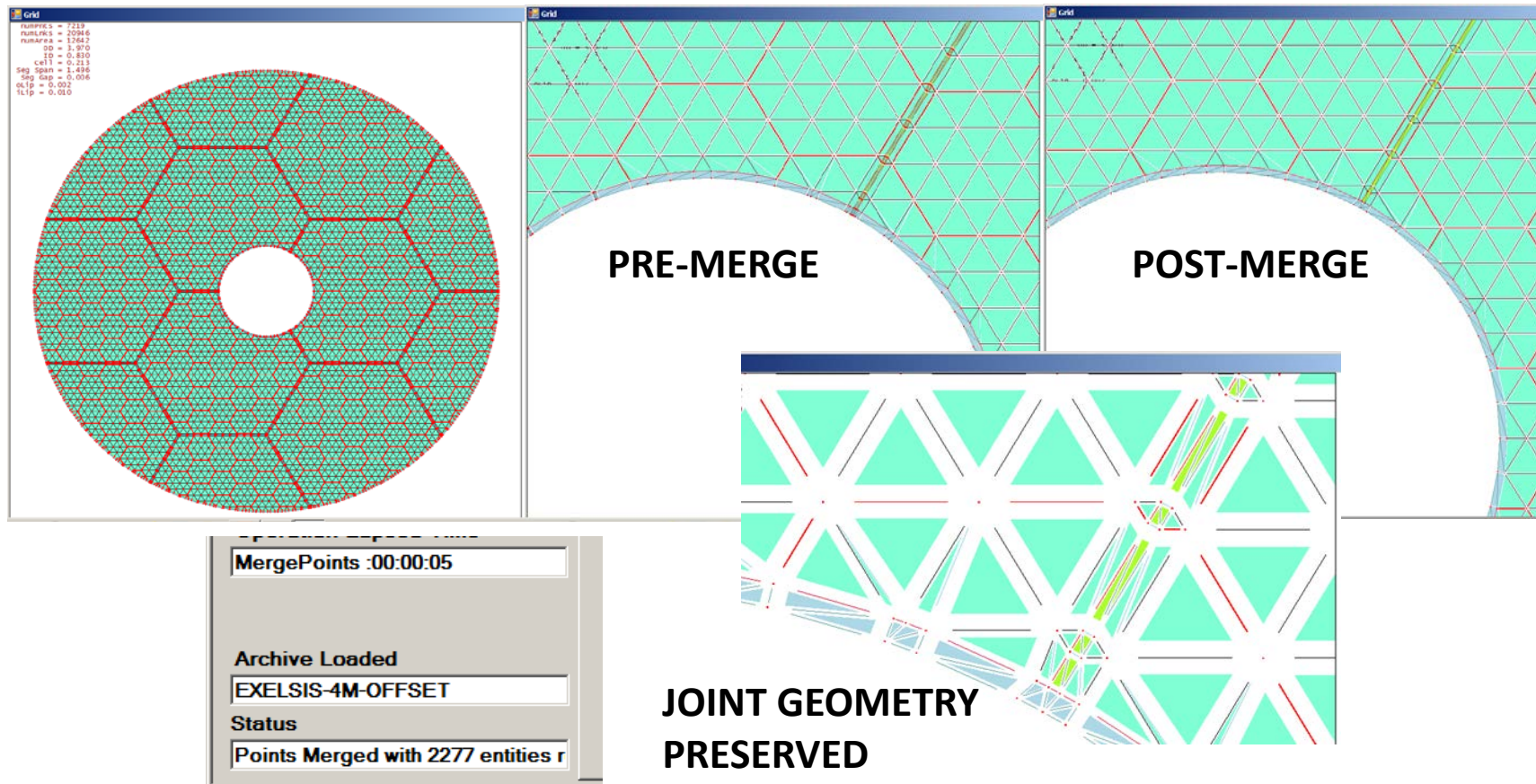
## MULTIPLE SEGMENT MIRRORS



# MANY CONFIGURATION OPTIONS ARE AVAILABLE



# COMPLEX SEGMENTED ASSEMBLIES CAN BE MERGED INTO A SINGLE STRUCTURE





# CORE WEB THICKNESSES CAN BE VARIED THRU DEPTH

Arnold Mirror Modeler(c) 2.3.5.0

Cell Width: 0.215

Num Rings: 1

Sgmt Gap: 0.075

Sgmt Span: 1

Sgmt Lip: 0.032

Inner Dia: 0.3

Inner Lip: 0.05

Outer Dia: 2

Mirror Lip: 0.05

Output Format: ☒ ANSYS ☐ ABAQUS ☐ NASTRAN

Supports: ☒ By Segment ☐ Whole Mirror

SAVE SETTINGS RESTORE ALL MERGE POINTS MERGE NODES TRISECT FRONT CREATE GRID MAKE SUPPORT CREATE MODEL REFINE PADS WRITE MODEL

Model Statistics

6105	num Nodes
11233	num Elms
191.4439	Weight (kg)
3.457069	Area (m^2)
55.37753	AD (kg/m^2)
122.642	Faces (kg)
68.80779	Core (kg)
40.92183	Edges (m)
0	Milled (m^3)

Archive Loaded: None

Status: Finished Making Model

Tangent Bars Static Dynamic BouleMap Graphics RefineMesh WhiffleTree

Grid Options Core Optical Reals (1) Reals (2) Hexapod Axial Radial

☒ Multi-web-thickness Core ☐ Non-Glass-Core ☐ Non-Glass-Back

Num Core Layers: 2

Front Depth: 0.0254

Core Depth: 0.152

Back Depth: 0.0254

Total Depth: 0.152

Web Fillet Radius: 0.01

IsoGrid Fillet Radius: 0.005

Back Mtrl: 1

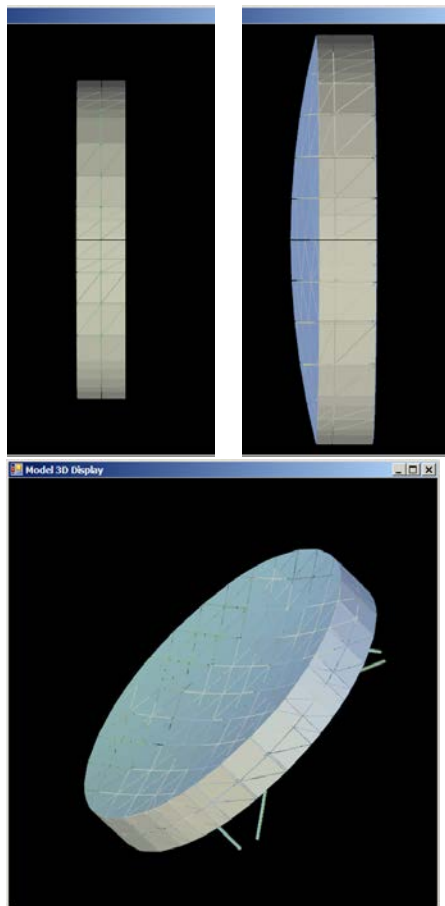
Variable Core Web Thickness

Layer Thick	Core Mtrl
Layer Thick 1: 0.0015	Show 1
Layer Thick 2: 0.0015	Show 1
Layer Thick 3: 0.0015	Show 1
Layer Thick 4: 0.0015	Show 1
Layer Thick 5: 0.0015	Show 1
Layer Thick 6: 0.0015	Show 1
Layer Thick 7: 0.0015	Show 1
Layer Thick 8: 0.0015	Show 1
Layer Thick 9: 0.0015	Show 1

**MODEL STATISTICS AVAILABLE ONCE CREATE MODEL FINISHES**



# MIRROR OPTICAL PRESCRIPTION FLATS, PRIMARY & SECONDARIES



**Arnold Mirror Modeler(c) 2.3.5.0**

Num Rings:  Cell Width:  Output Format: ☒ ANSYS ☐ ABAQUS ☐ NASTRAN

Sgmt Gap:  Inner Dia:  Inner Lip:

Sgmt Span:  Outer Dia:  Mirror Lip:

Sgmt Lip:

Supports: ☒ By Segment ☐ Whole Mirror

Tangent Bars | Static | Dynamic | BouleMap | Graphics | RefineMesh | WhiffleTree | Grid Options | Core | Optical | Reals (1) | Reals (2) | Hexapod | Axial | Radial

Radius:  ☒ Flat Mirror

Conic:  ☐ Flat Backed Mirror

Aspheric Order:  ☐ Convex Mirror

Coefficient(1):

Coefficient(2):

Coefficient(3):

Coefficient(4):

Coefficient(5):

Archive Loaded:

Status:

# INITIAL ELEMENT THICKNESS & MIRROR MATERIAL OPTIONS

Arnold Mirror Modeler(c) 2.3.5.0

Num Rings:   
 Sgmt Gap:   
 Sgmt Span:   
 Sgmt Lip:

Cell Width:   
 Inner Dia:   
 Inner Lip:   
 Outer Dia:   
 Mirror Lip:

Output Format:  
☒ ANSYS  
☐ ABAQUS  
☐ NASTRAN

Supports:  
☒ By Segment  
☐ Whole Mirror

SAVE SETTINGS | CREATE GRID  
 RESTORE ALL | MAKE SUPPORT  
 MERGE POINTS | CREATE MODEL  
 MERGE NODES | REFINE PADS  
 TRISECT FRONT | WRITE MODEL

Tangent Bars | Static | Dynamic | BouleMap | Graphics | RefineMesh | WhiffleTree  
 Grid Options | Core | Optical | Reals (1) | Reals (2) | Hexapod | Axial | Radial

Ring	Thickness	Feature	Show
r, 1	0.005	Front Facesheet	<input type="checkbox"/>
r, 2	0.005	Back Facesheet	<input checked="" type="checkbox"/>
r, 3	0.005	Front IsoGrid Web	<input type="checkbox"/>
r, 4	0.005	Segment Outer Seal	<input type="checkbox"/>
r, 5	0.005	Inner Seal Ring	<input type="checkbox"/>
r, 6	0.005	Core Web	<input checked="" type="checkbox"/>
r, 7	0.005	Back IsoGrid Web	<input type="checkbox"/>
r, 8	0.015	Front Outer Seg Lip	<input type="checkbox"/>
r, 9	0.015	Back Outer Seg Lip	<input type="checkbox"/>
r, 10	0.015	Isogrid Fillet Front	<input type="checkbox"/>
r, 11	0.015	Isogrid Fillet Back	<input type="checkbox"/>
r, 12	0.015	Mirror Outer Seal	<input type="checkbox"/>

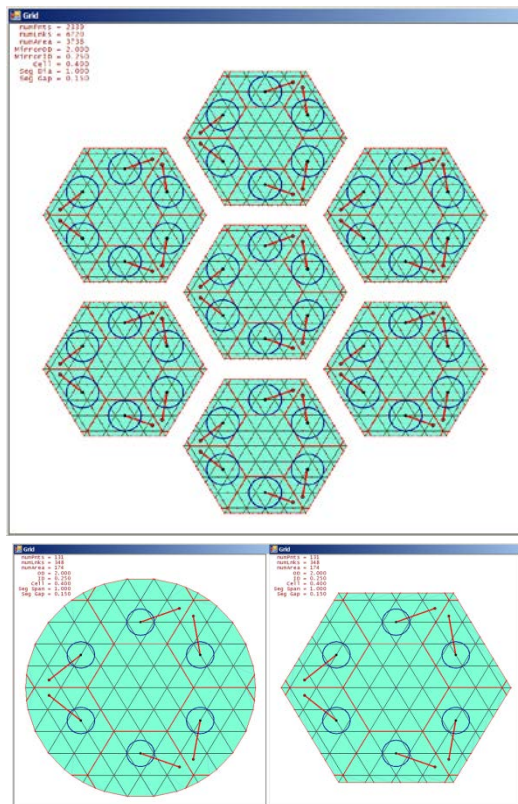
Mirror Material:  
☒ ULE  
☐ Zerodur  
☐ E6  
☐ Fused Silica  
☐ BK7  
☐ Silicon Carbide

Archive Loaded:   
 Status:

ALL SETTINGS  
CAN BE ARCHIVED  
AND RETRIEVED

INPUT DECKS CAN BE GENERATED FOR  
ANSYS, ABAQUS or NASTRAN

# HEXAPOD STYLE SUSPENSION PER SEGMENT OR WHOLE MIRROR



**Arnold Mirror Modeler(c) 2.3.5.0**

Cell Width: 0.215

Num Rings: 1

Sgmt Gap: 0.075

Sgmt Span: 1

Sgmt Lip: 0.032

Inner Dia: 0.3

Inner Lip: 0.05

Outer Dia: 2

Mirror Lip: 0.05

Output Format:

- ☒ ANSYS
- ☐ ABAQUS
- ☐ NASTRAN

Supports:

- ☒ By Segment
- ☐ Whole Mirror

SAVE SETTINGS

RESTORE ALL

MERGE POINTS

MERGE NODES

TRISECT FRONT

CREATE GRID

MAKE SUPPORT

CREATE MODEL

REFINE PADS

WRITE MODEL

Tangent Bars | Static | Dynamic | BouleMap | Graphics | RefineMesh | WhiffleTree

Grid Options | Core | Optical | Reals (1) | Reals (2) | Hexapod | Axial | Radial

Upper Diameter: 0.6 (m) ☐ Do Hexapod

Lower Diameter: 0.8 (m) ☐ Do Hexapod Pad

Height (ground): 0.25 (m) ☐ Three Pads Only

Start Angle: 0 (deg)

Upper Spread: 30 (deg)

Lower Spread: 5 (deg)

Acceptable Near: 1E-05 (m)

Spring Rate: 200000 (N/m)

Fitting Mass: 1 (kg)

Pad Diameter: 0.21 (m)

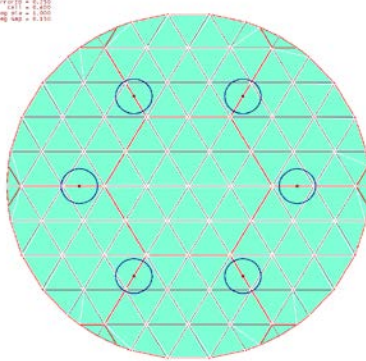
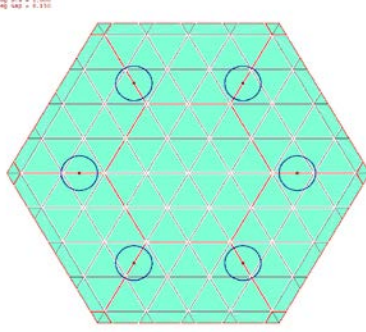
Perimeter Dia: 0.315 (m)

Archive Loaded: None

Status: Starting Segment = 7 of 7



# AXIAL STYLE SUSPENSION PER SEGMENT OR WHOLE MIRROR

**Arnold Mirror Modeler(c) 2.3.5.0**

Num Rings:

Sgmt Gap:

Sgmt Span:

Sgmt Lip:

Cell Width:

Inner Dia:

Inner Lip:

Outer Dia:

Mirror Lip:

Output Format

☒ ANSYS

☐ ABAQUS

☐ NASTRAN

Supports

☒ By Segment

☐ Whole Mirror

SAVE SETTINGS

RESTORE ALL

MERGE POINTS

MERGE NODES

TRISECT FRONT

CREATE GRID

MAKE SUPPORT

CREATE MODEL

REFINE PADS

WRITE MODEL

Tangent Bars

Static

Dynamic

BouleMap

Graphics

RefineMesh

WhiffleTree

Grid Options

Core

Optical

Reals (1)

Reals (2)

Hexapod

Axial

Radial

☒ Do Axial Support

☒ Do Axial Pads

Pnts	Diameter (m)	Start Ang (deg)	Spring Rate (N/m)
2	0.6	30	20000
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0

Fitting Mass:  (kg)

Support Ground:  (m)

Acceptable Near:  (m)

Pad Diameter:  (m)

Axial Perimeter Dia:  (m)

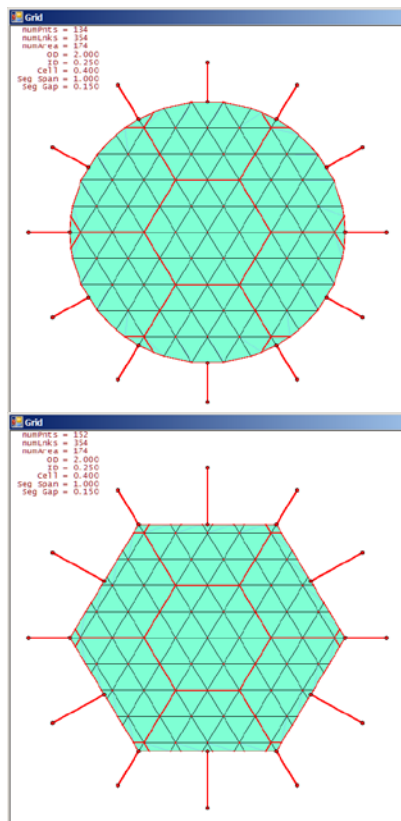
Archive Loaded

None

Status

Starting Segment = 7 of 7

# RADIAL STYLE SUSPENSION PER SEGMENT OR WHOLE MIRROR



**Arnold Mirror Modeler(c) 2.3.5.0**

Cell Width: 0.215

Num Rings: 1

Sgmt Gap: 0.075

Sgmt Span: 1

Sgmt Lip: 0.032

Inner Dia: 0.3

Inner Lip: 0.05

Outer Dia: 2

Mirror Lip: 0.05

Output Format:

- ☒ ANSYS
- ☐ ABAQUS
- ☐ NASTRAN

Supports:

- ☒ By Segment
- ☐ Whole Mirror

SAVE SETTINGS | CREATE GRID

RESTORE ALL | MAKE SUPPORT

MERGE POINTS | CREATE MODEL

MERGE NODES | REFINE PADS

TRISECT FRONT | WRITE MODEL

Tangent Bars | Static | Dynamic | BouleMap | Graphics | RefineMesh | WhiffleTree

Grid Options | Core | Optical | Reals (1) | Reals (2) | Hexapod | Axial | Radial

☐ Do Radial Support

Num Points: 12

Support Length: 0.15 (m)

Spring Rate: 20000 (N/m)

Start Angle: 0 (deg)

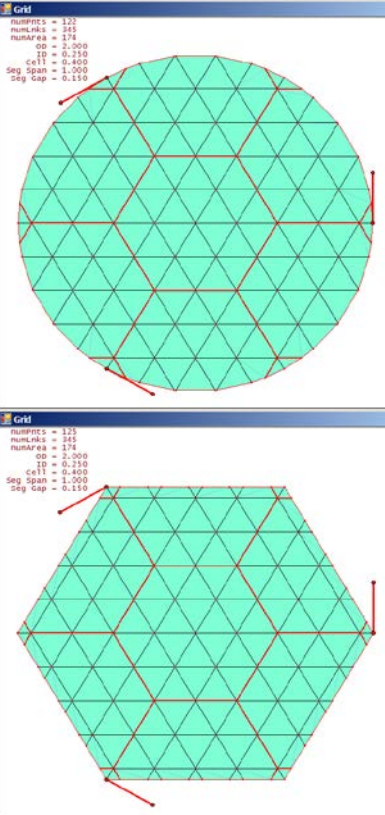
Fitting Mass: 1 (kg)

Acceptable Near: 1E-05 (m)

Archive Loaded: None

Status: Starting Segment = 7 of 7

# TANGENT BAR SUSPENSION PER SEGMENT OR WHOLE MIRROR



**Arnold Mirror Modeler(c) 2.3.5.0**

Num Rings:

Sgmt Gap:

Sgmt Span:

Sgmt Lip:

Cell Width:

Inner Dia:

Inner Lip:

Outer Dia:

Mirror Lip:

Output Format

☒ ANSYS

☐ ABAQUS

☐ NASTRAN

Supports

☒ By Segment

☐ Whole Mirror

SAVE SETTINGS

RESTORE ALL

MERGE POINTS

MERGE NODES

TRISECT FRONT

CREATE GRID

MAKE SUPPORT

CREATE MODEL

REFINE PADS

WRITE MODEL

Grid Options | Core | Optical | Reals (1) | Reals (2) | Hexapod | Axial | Radial

Tangent Bars | Static | Dynamic | BouleMap | Graphics | RefineMesh | WhiffleTree

☐ Do Tangent Bars

Number of Tangent Bars:

Tangent Bar Start Angle:

Tangent Bar Length:

Tangent Bar Spring Rate:

Tangent Fitting Mass:  (kg)

Archive Loaded:

Status:

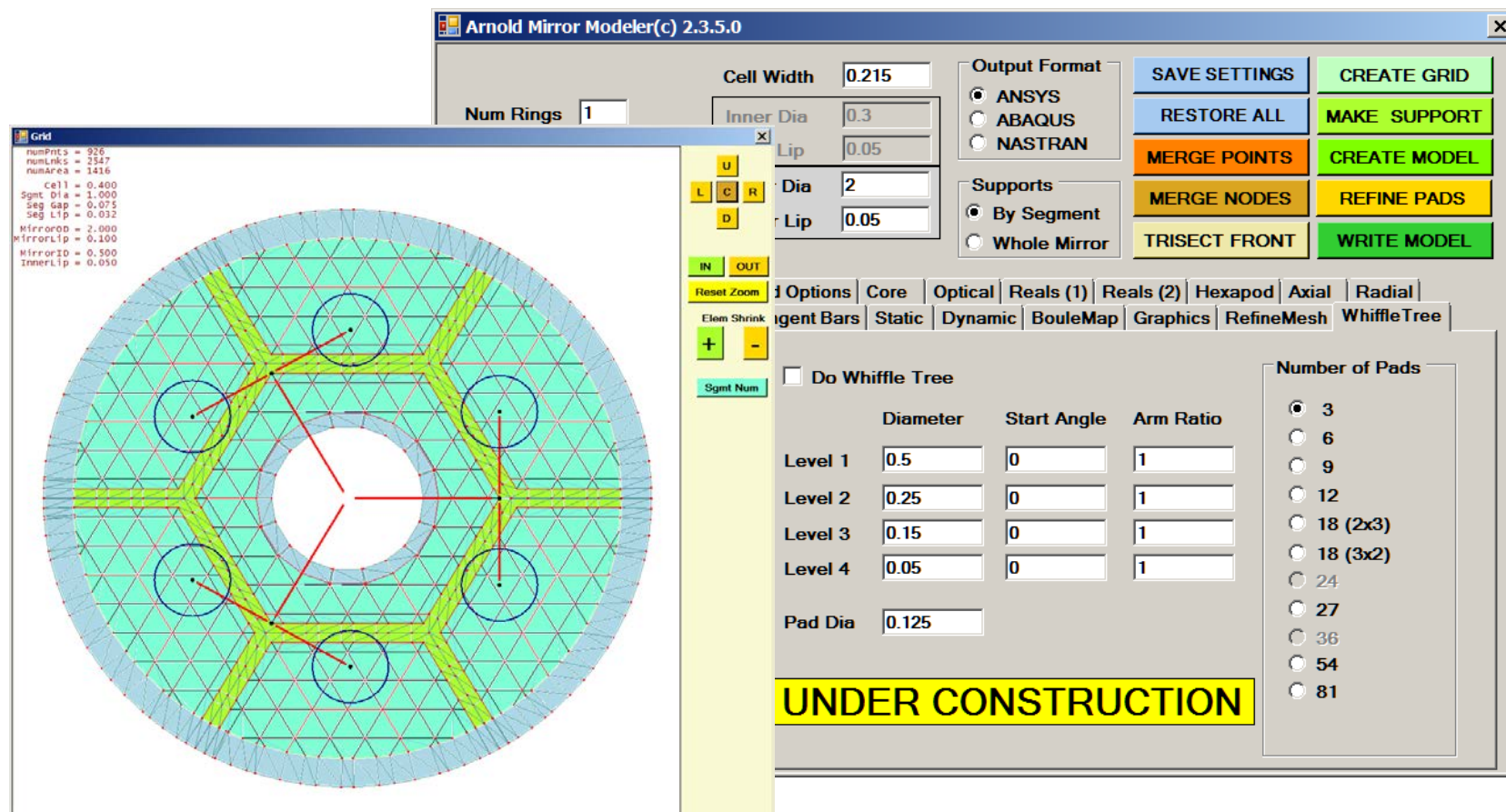
5/4/2013

SPIE 8836-15 Optomechanical Engineering 2013  
25 - 29 August 2013 in San Diego, Ca United States

14

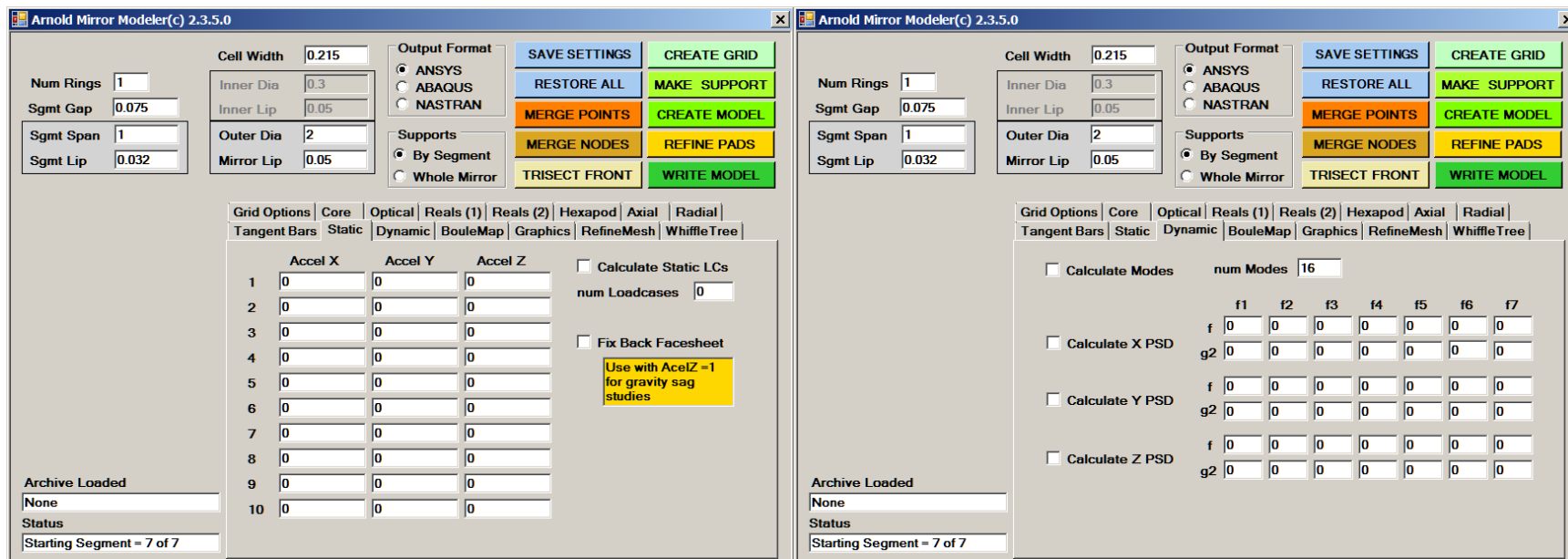


# WHIFFLE TREE SUPPORTS CURRENTLY UNDER DEVELOPMENT



# YOU CAN DEFINE LOAD CASES

## STATIC, MODAL & PSD



**Arnold Mirror Modeler(c) 2.3.5.0 - Static Tab**

Cell Width: 0.215  
 Num Rings: 1  
 Sgmt Gap: 0.075  
 Sgmt Span: 1  
 Sgmt Lip: 0.032  
 Inner Dia: 0.3  
 Inner Lip: 0.05  
 Outer Dia: 2  
 Mirror Lip: 0.05

Output Format: ☒ ANSYS, ☐ ABAQUS, ☐ NASTRAN  
 Supports: ☒ By Segment, ☐ Whole Mirror

Buttons: SAVE SETTINGS, RESTORE ALL, MERGE POINTS, MERGE NODES, TRISECT FRONT, CREATE GRID, MAKE SUPPORT, CREATE MODEL, REFINES PADS, WRITE MODEL

	Accel X	Accel Y	Accel Z
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	0	0	0
10	0	0	0

Calculate Static LCs: num Loadcases: 0  
 Fix Back Facesheet: ☐  
 Use with AccZ = 1 for gravity sag studies

Archive Loaded: None  
 Status: Starting Segment = 7 of 7

**Arnold Mirror Modeler(c) 2.3.5.0 - Modal Tab**

Cell Width: 0.215  
 Num Rings: 1  
 Sgmt Gap: 0.075  
 Sgmt Span: 1  
 Sgmt Lip: 0.032  
 Inner Dia: 0.3  
 Inner Lip: 0.05  
 Outer Dia: 2  
 Mirror Lip: 0.05

Output Format: ☒ ANSYS, ☐ ABAQUS, ☐ NASTRAN  
 Supports: ☒ By Segment, ☐ Whole Mirror

Buttons: SAVE SETTINGS, RESTORE ALL, MERGE POINTS, MERGE NODES, TRISECT FRONT, CREATE GRID, MAKE SUPPORT, CREATE MODEL, REFINES PADS, WRITE MODEL

Calculate Modes: num Modes: 16

	f1	f2	f3	f4	f5	f6	f7
f	0	0	0	0	0	0	0
g2	0	0	0	0	0	0	0

Calculate X PSD: f, g2 (all 0)

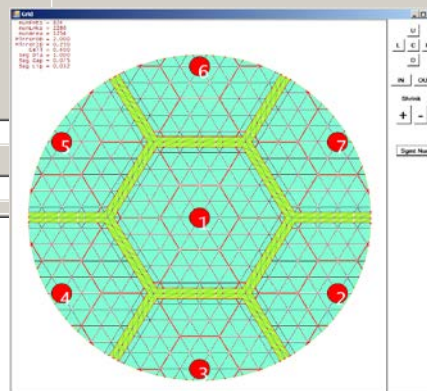
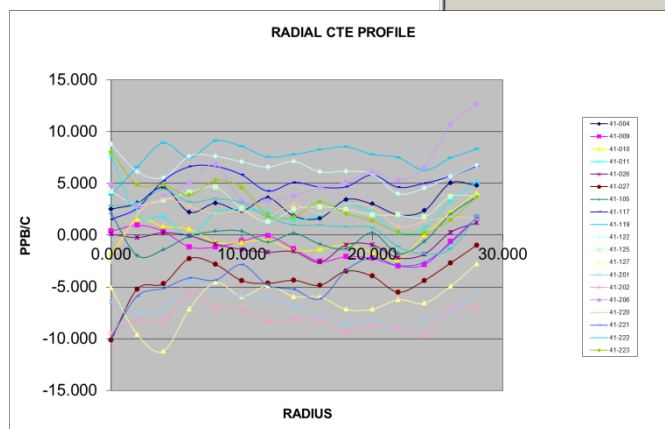
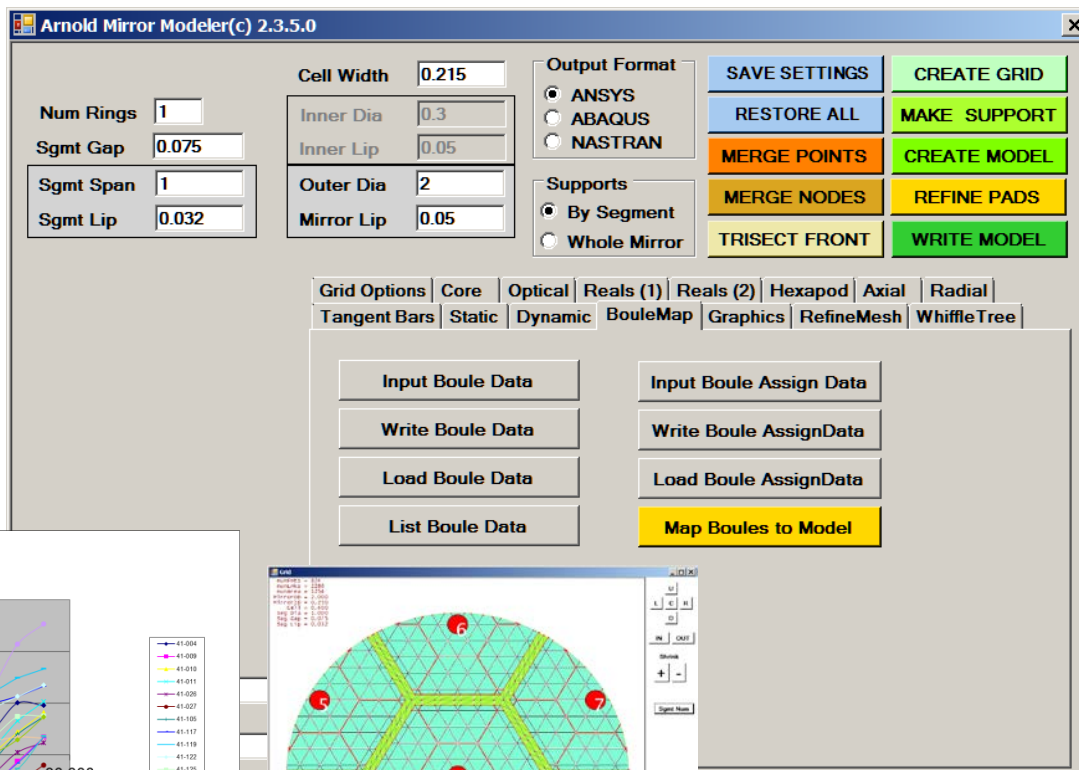
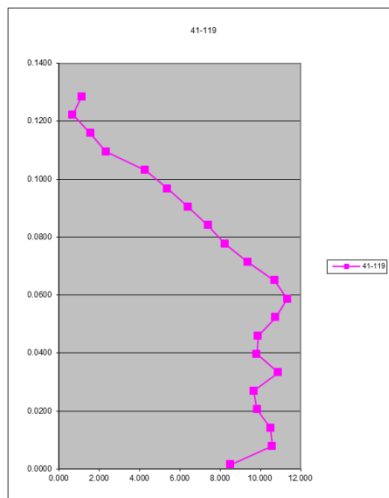
Calculate Y PSD: f, g2 (all 0)

Calculate Z PSD: f, g2 (all 0)

Archive Loaded: None  
 Status: Starting Segment = 7 of 7

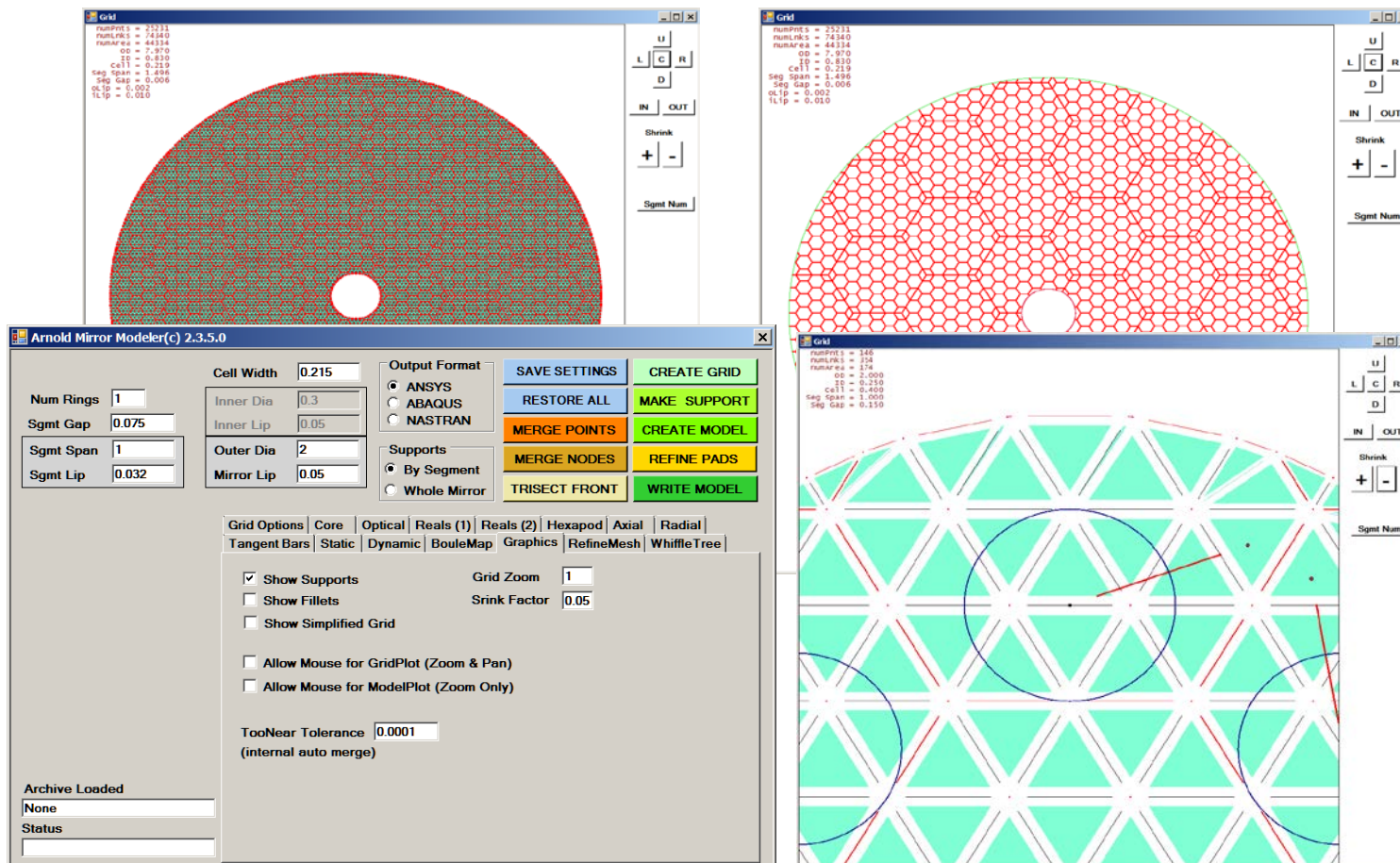
- ANSYS: GENERATES ANALYSIS STREAM COMPLETE WITH PLOTS AND RESULT FILES
- ABAQUS: GENERATES ANALYSIS STREAM, USES ABAQUS/CAE PYTHON SCRIPT FOR PLOTS & RESULTS
- NASTRAN: GENERATES ANALYSIS STREAM, USES FEMAP OR PATRAN FOR PLOTS & RESULTS

# IF ULE<sup>®</sup> BOULE CTE DATA AVAILABLE IT CAN BE MAPPED ONTO THE MODEL



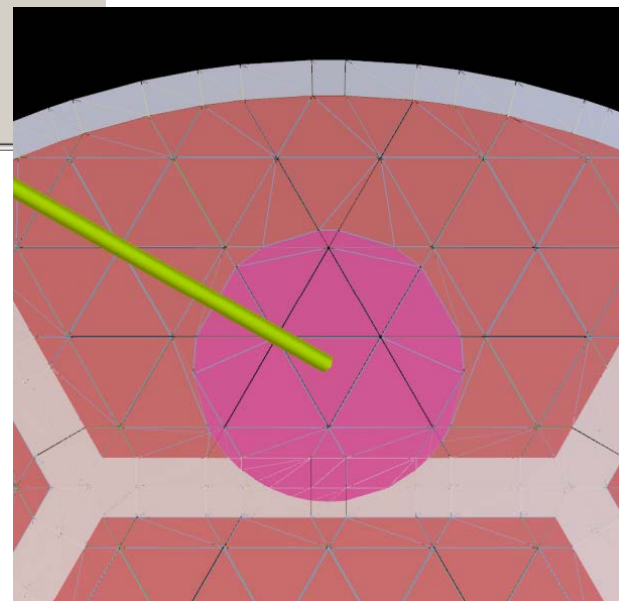
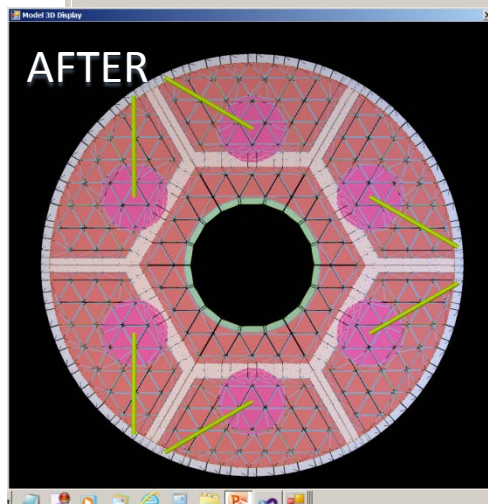
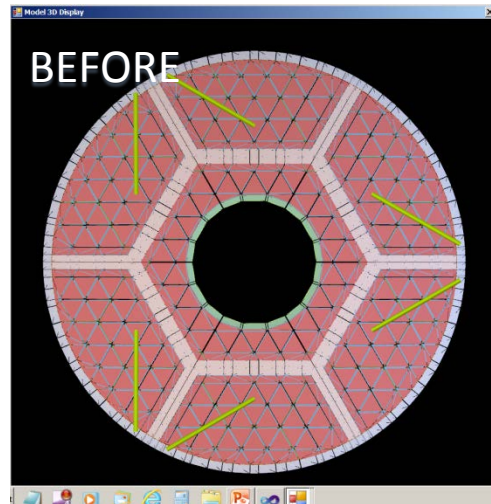
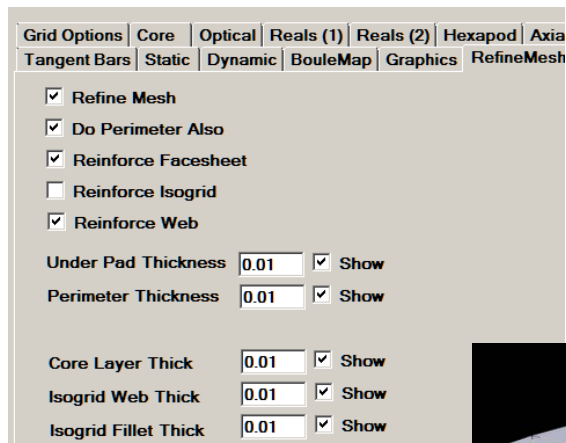
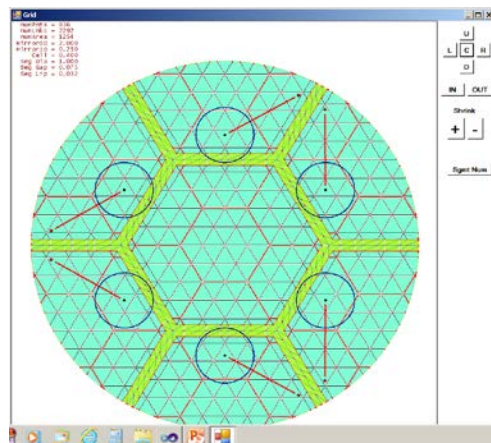
**SEGMENT ID CAN  
BE SHOWN ON  
GRID**



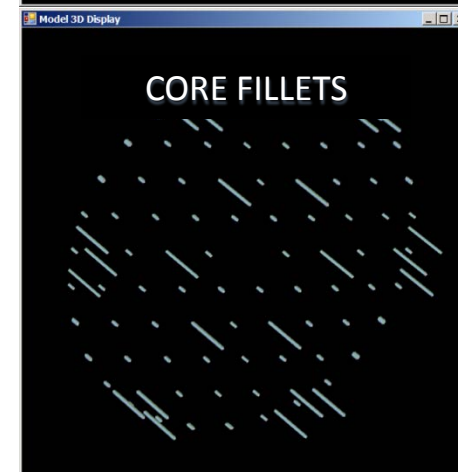
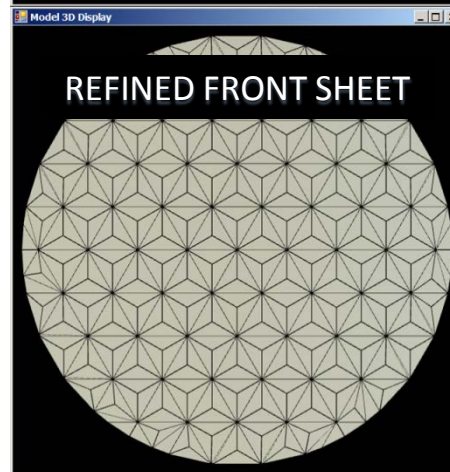
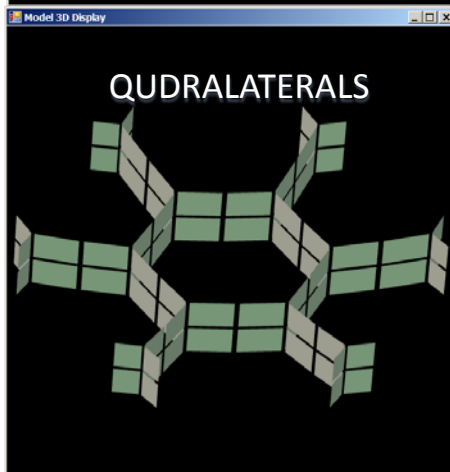
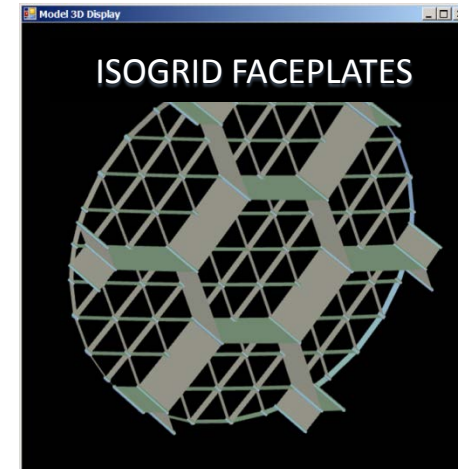
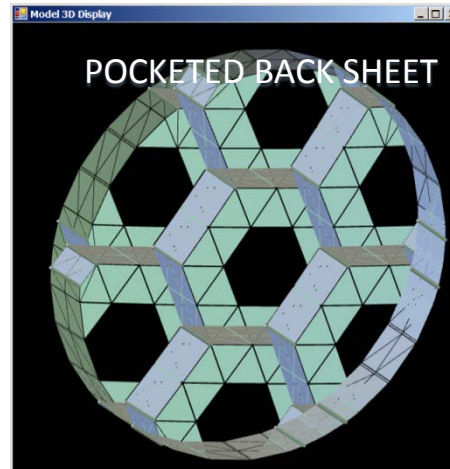
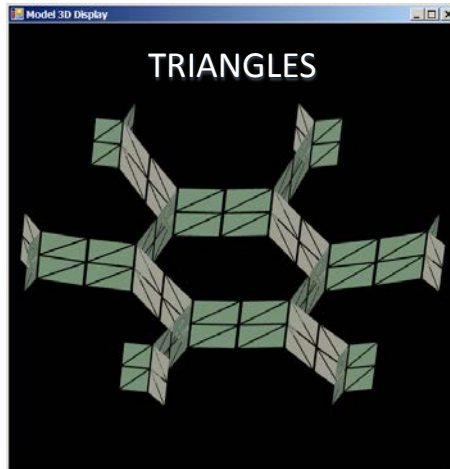


## SIMPLIFIED MESH, PAN & ZOOM, ELEMENT SHRINK

# LOCALIZED MESH REFINEMENT UNDER SUPPORT PADS

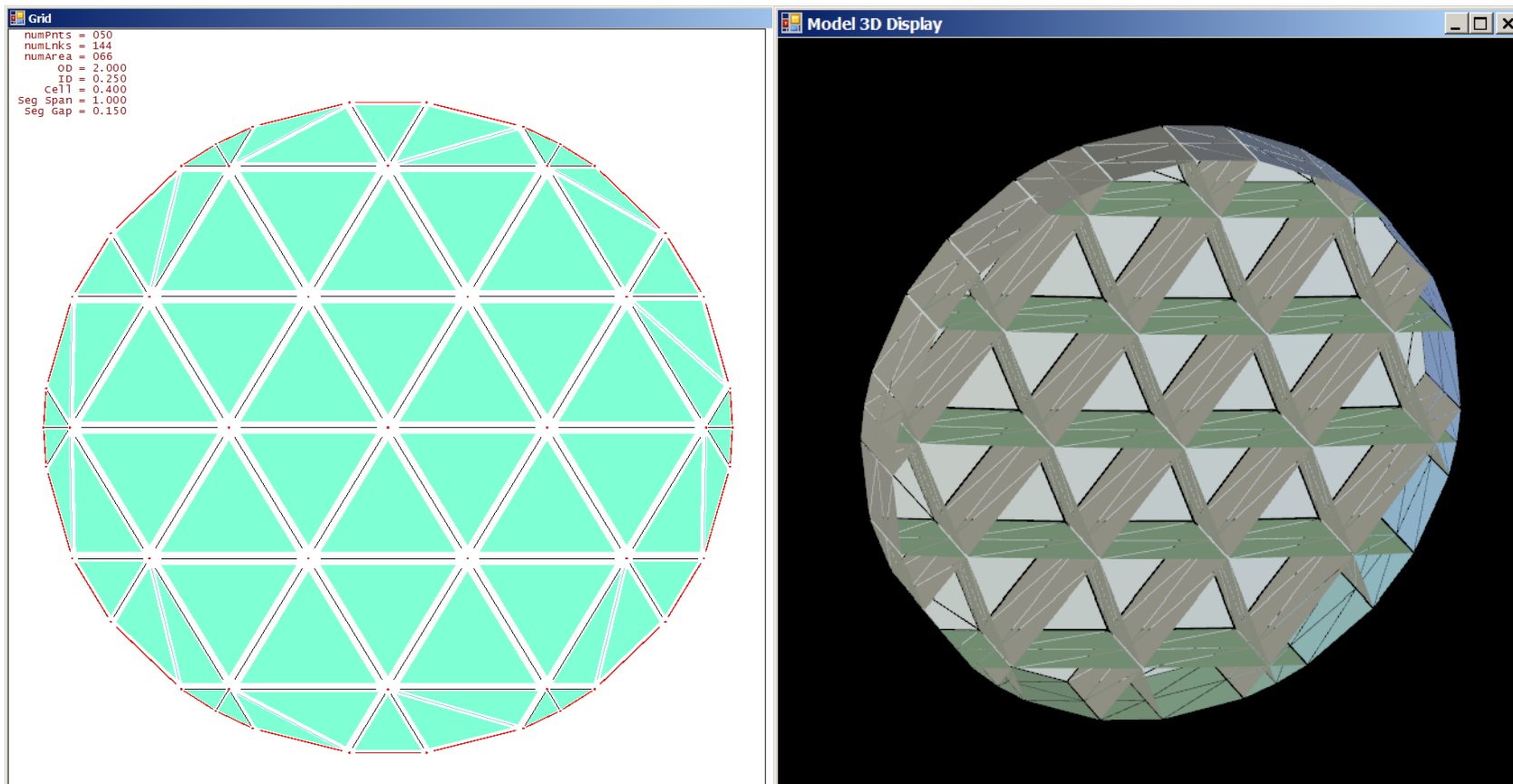


# A LOT OF MESHING OPTIONS AVAILABLE

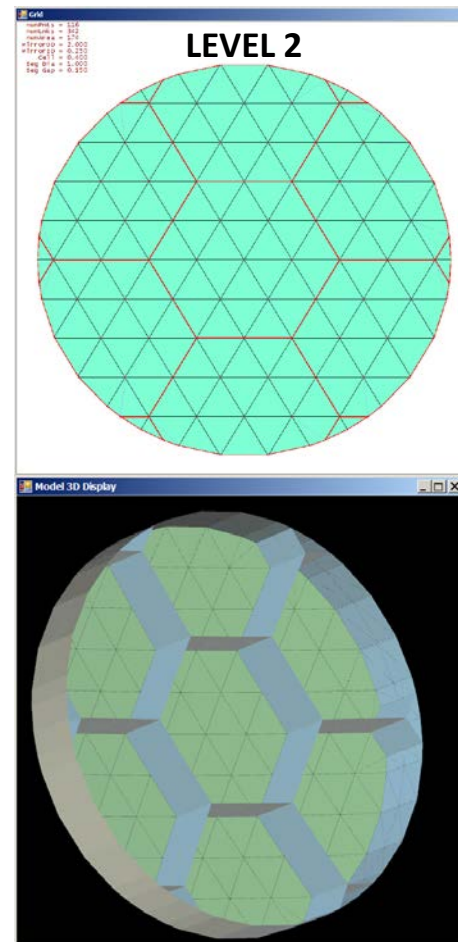
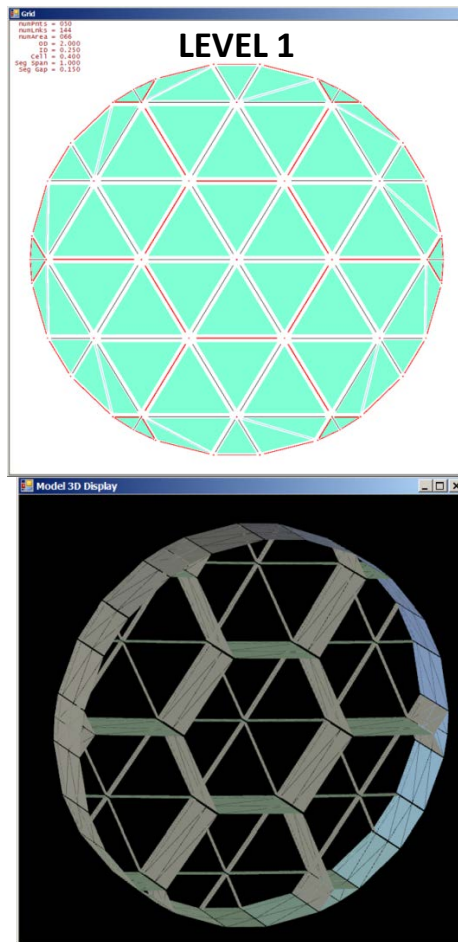
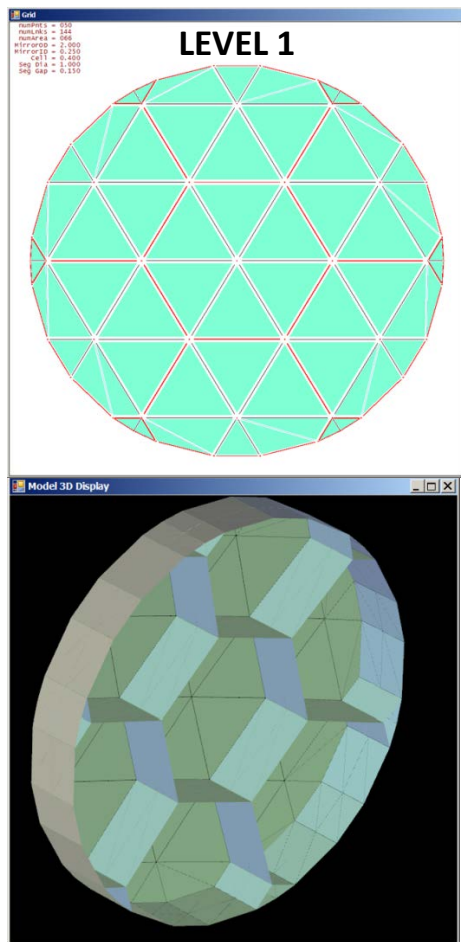




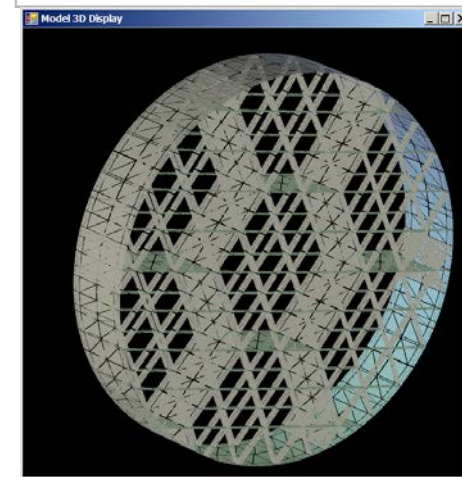
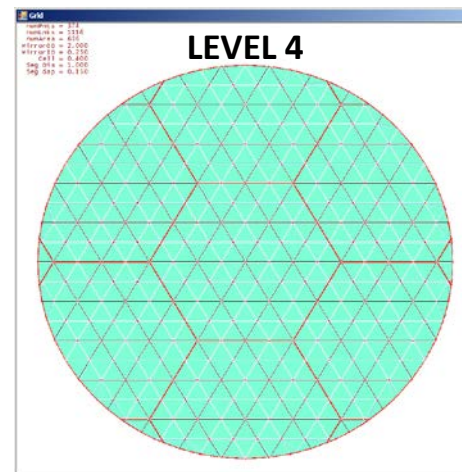
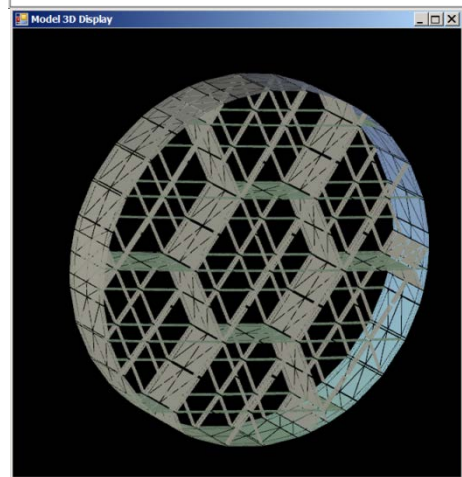
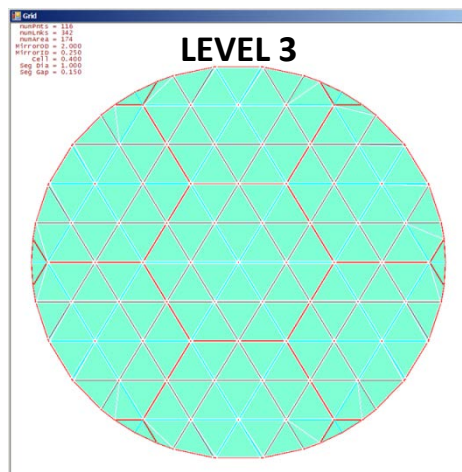
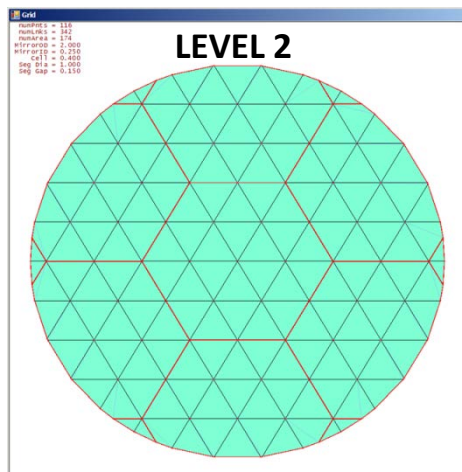
# CAN MODEL A PURE ISOGRID CORE [LEVEL0]



# GRID COMPLEXITY LEVELS (CONT)

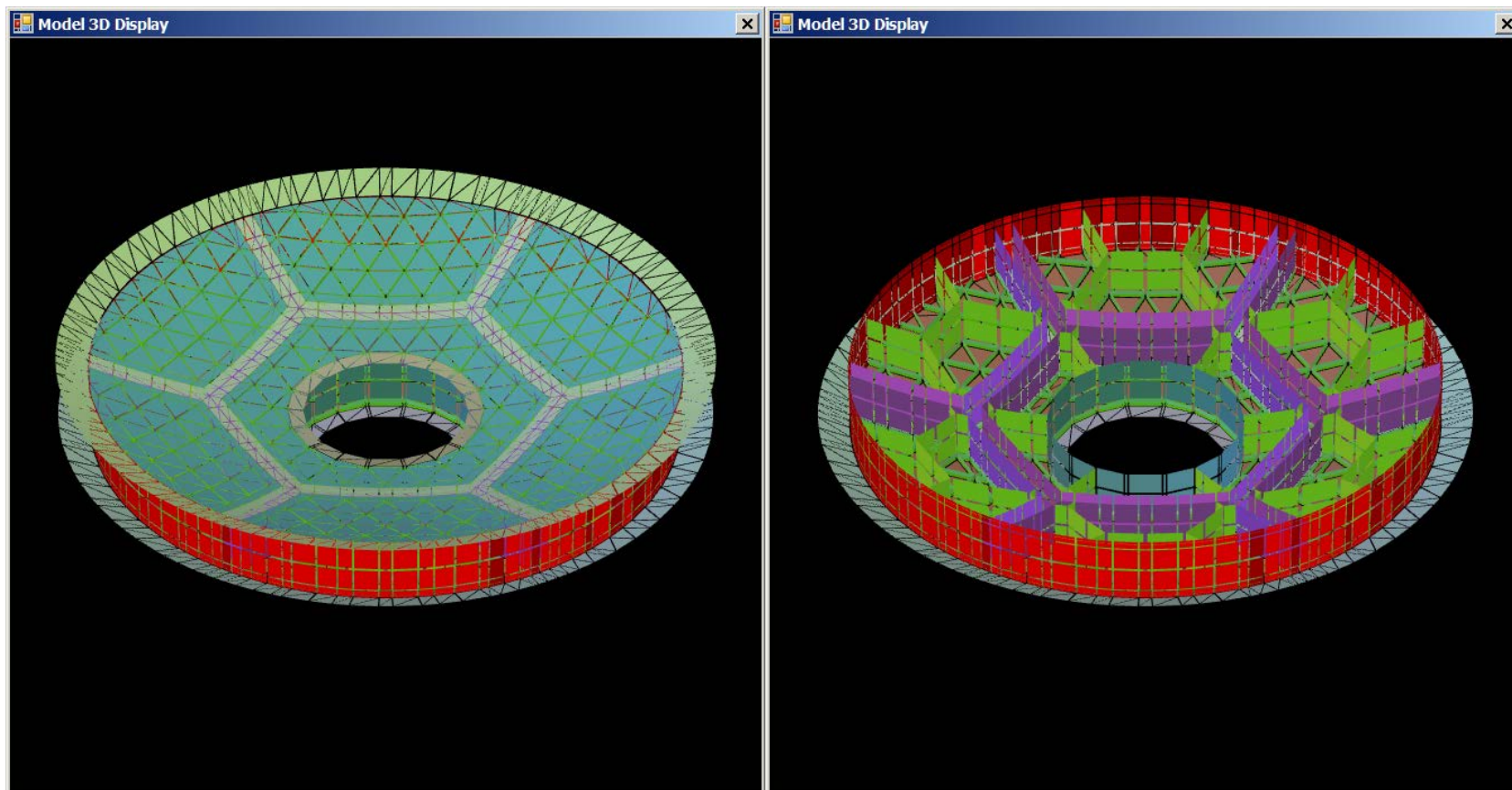


# GRID COMPLEXITY LEVELS (CONT)

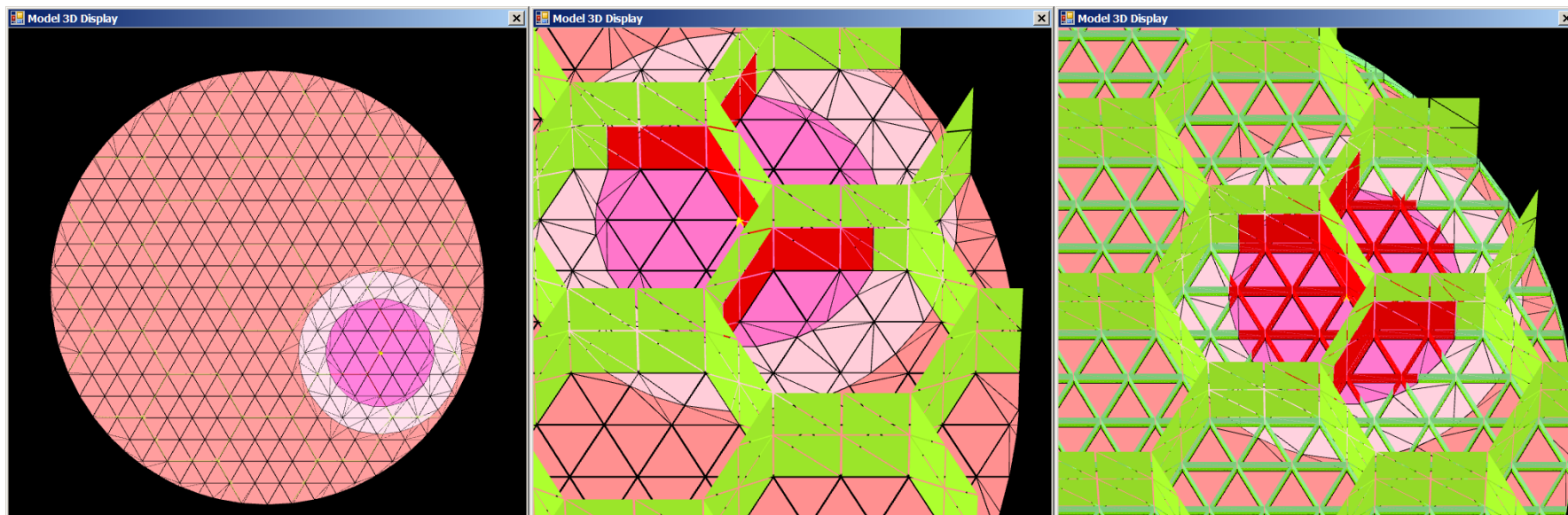




# MODEL DISPLAY NOW SUPPORTS COLOR-BASED REAL CONSTANTS

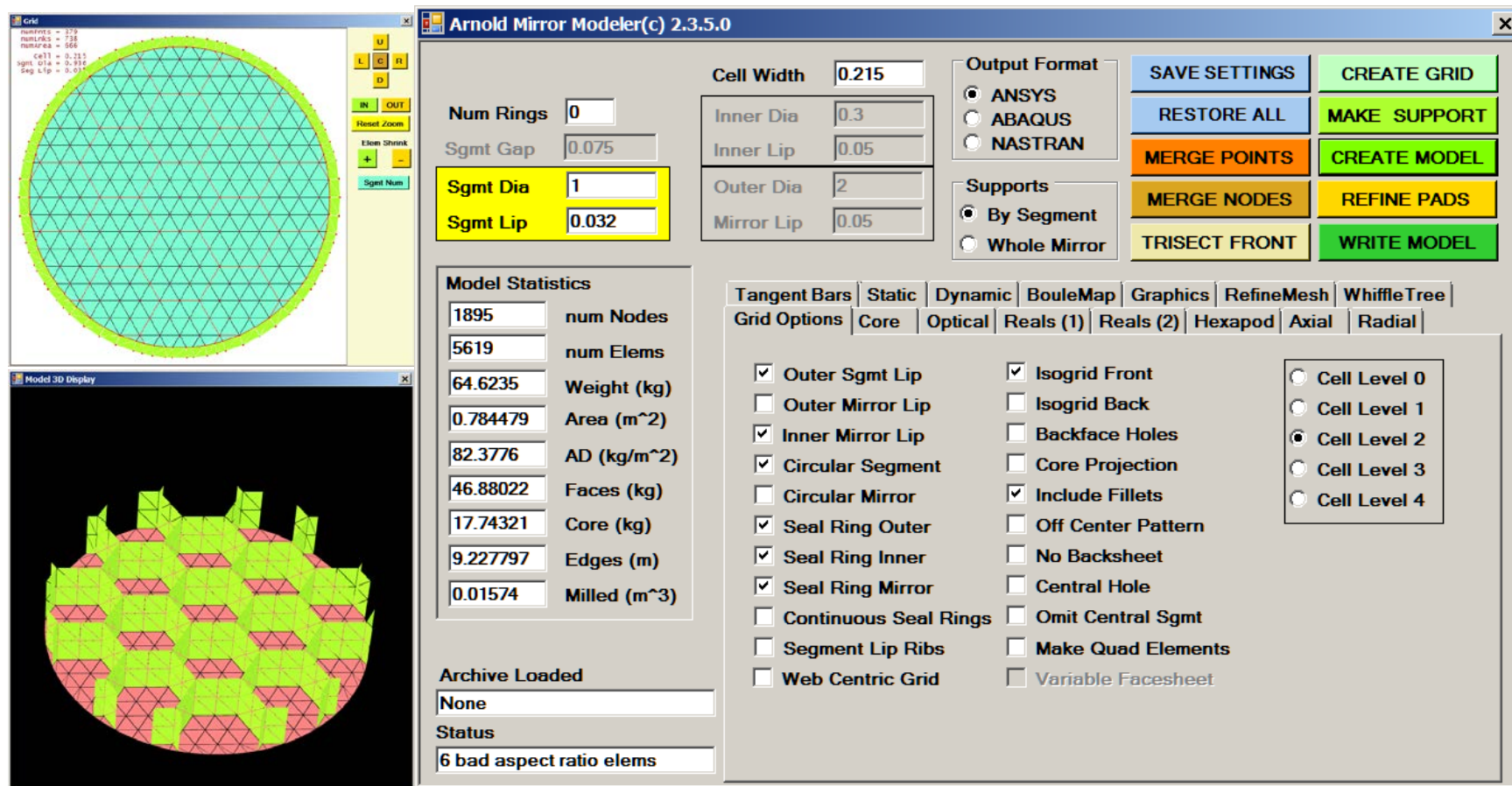


# LOCALIZED REINFORCEMENT & MESH REFINEMENT UNDER PADS



**A perimeter around pad can be reinforced or just mesh refined . The core structure can be stiffened as well as any back facesheet isogrid pattern in region of bond pads.**

# LASTEST GUI WITH MORE EFFICIENT MESH ALGORITHM





# ONLY APPROPRIATE ENTREES ACTIVE FOR INPUT

**Arnold Mirror Modeler(c) 2.3.5.0**

**Grid**

Num Rings: 1  
Sgmt Gap: 0.075  
Sgmt Span: 1  
Sgmt Lip: 0.032

**Cell Width**: 0.215  
**Inner Dia**: 0.3  
**Inner Lip**: 0.05  
**Outer Dia**: 2  
**Mirror Lip**: 0.05

**Output Format**  
☒ ANSYS  
☐ ABAQUS  
☐ NASTRAN

**Supports**  
☒ By Segment  
☐ Whole Mirror

**SAVE SETTINGS** **CREATE GRID**  
**RESTORE ALL** **MAKE SUPPORT**  
**MERGE POINTS** **CREATE MODEL**  
**MERGE NODES** **REFINE PADS**  
**TRISECT FRONT** **WRITE MODEL**

**Model Statistics**

5508	num Nodes
10471	num Elems
200.0832	Weight (kg)
3.065068	Area (m <sup>2</sup> )
65.27857	AD (kg/m <sup>2</sup> )
99.21635	Faces (kg)
100.8694	Core (kg)
40.9551	Edges (m)
0	Milled (m <sup>3</sup> )

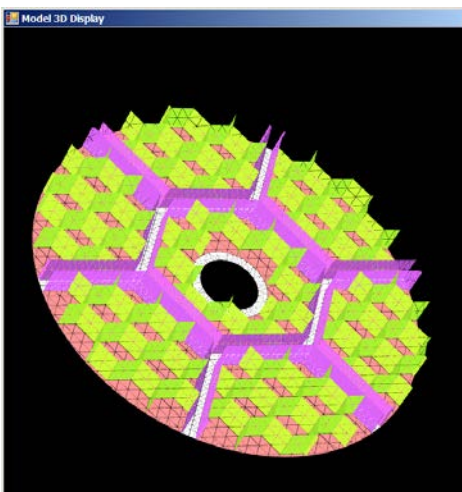
**Archive Loaded**: None  
**Status**: NodeMerge 0 elems removed

**Tangent Bars** | **Static** | **Dynamic** | **BouleMap** | **Graphics** | **RefineMesh** | **WhiffleTree**  
**Grid Options** | **Core** | **Optical** | **Reals (1)** | **Reals (2)** | **Hexapod** | **Axial** | **Radial**

Reals (1)	Reals (2)	Show
r, 1	0.005	Front Facesheet
r, 2	0.005	Back Facesheet
r, 3	0.005	Front IsoGrid Web
r, 4	0.005	Segment Outer Seal
r, 5	0.005	Inner Seal Ring
r, 6	0.005	Core Web
r, 7	0.005	Back IsoGrid Web
r, 8	0.015	Front Outer Seg Lip
r, 9	0.015	Back Outer Seg Lip
r, 10	0.015	Isogrid Fillet Front
r, 11	0.015	Isogrid Fillet Back
r, 12	0.015	Mirror Outer Seal

**Mirror Material**  
☒ ULE  
☐ Zerodur  
☐ E6  
☐ Fused Silica  
☐ BK7  
☐ Silicon Carbide

**Model 3D Display**





# STATUS

- **Currently undergoing ITAR review to determine any distribution restrictions.**
- **NASA is working on licensing, revision control and error reporting mechanisms.**
- **User Manual and tutorials under development.**
- **Short course or seminar under discussion.**
- **List of possible enhancements and requested features growing daily.**
- **Time permitting are there any questions?**