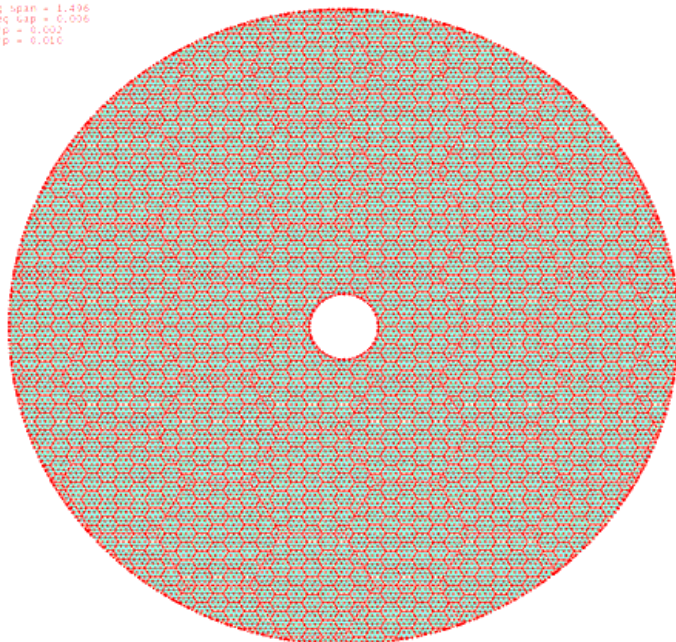
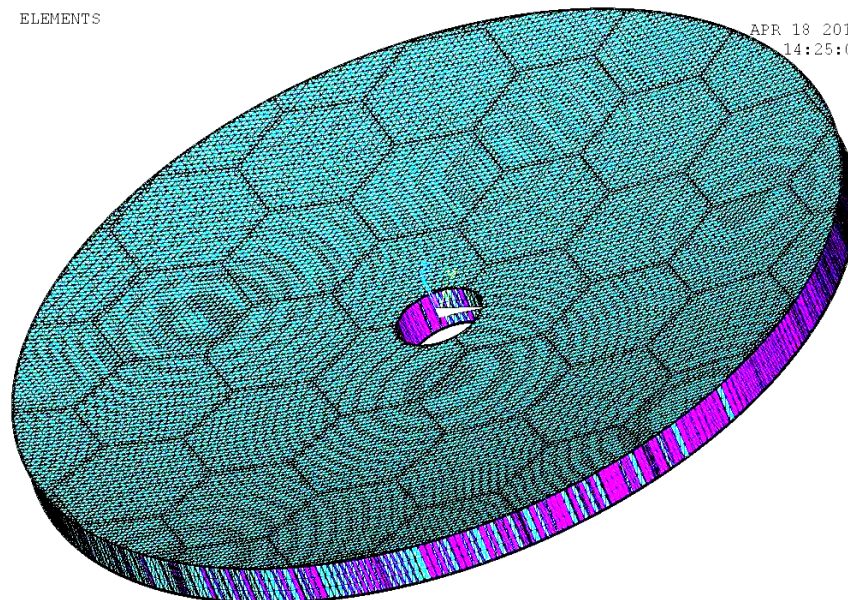


Next-generation lightweight mirror modeling software

Seq. Gap = 1.436
Seq. Gap = 0.006
DTP = 0.002
TLP = 0.010



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.
Ryan M. Bevan, 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.**

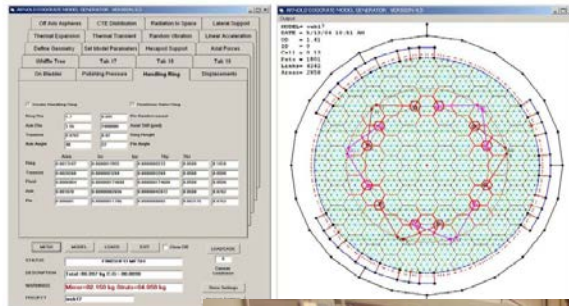
INTRODUCTION

TOOLS FOR INTEGRATED DESIGN OF MIRRORS & SUSPENSION SYSTEMS

- WHY WE ARE INTERESTED IN THESE TOOLS
 - LARGER SPACE-BASED UV TELESCOPES BEING PLANNED.
 - LAUNCH CAPABILITIES REMAIN UNCERTAIN
 - COST & SCHEDULE TO BUILD COMPLEX FEM MODELS
 - THIS APPROACH WAS VERY SUCCESSFUL ON KEPLER
- SUBSTRATE MATERIALS & FABRICATION ADVANCES
 - ULE (FRIT OR LOW TEMPERATURE FUSION)
 - ZERODUR (POCKET MILLED & ACID)
 - BOROSILICATE (CAST)
- SUSPENSION SYSTEMS & LIGHTWEIGHT OPTICS
 - OPERATIONAL (KINEMATIC)
 - AUXILLARY LAUNCH (DISENGAGES ON ORBIT)
 - HOW MIRROR DESIGN INTERACTS WITH SUSPENSION(S)

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

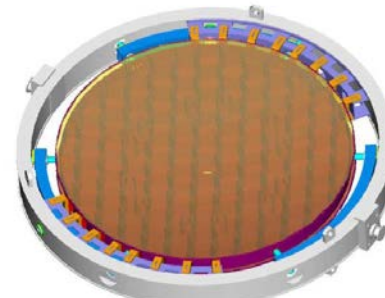
Integrated Design of Handling Equipment



Design tool allows evaluation of the mirror blank. As mirrors manufacturing requires careful attention, the design tool allows evaluation of the mirror blank. As mirrors manufacturing requires careful attention, the design tool allows evaluation of the mirror blank. As mirrors manufacturing requires careful attention, the design tool allows evaluation of the mirror blank.



Primary Mirror in Flipping Ring



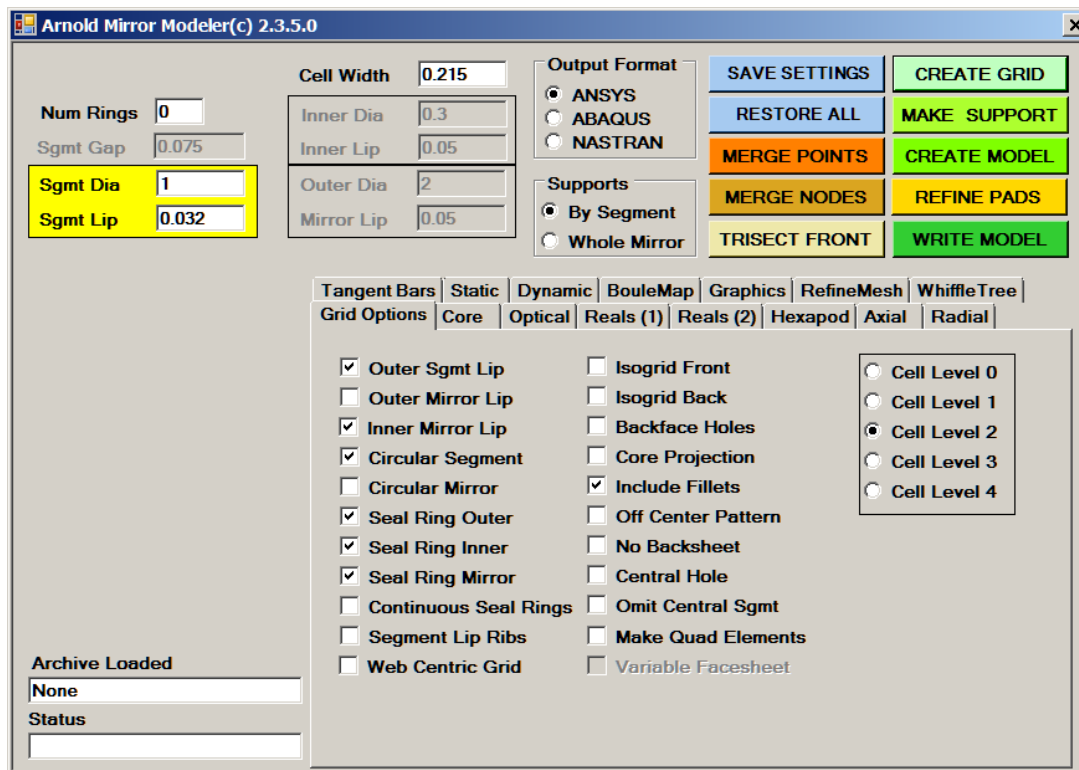
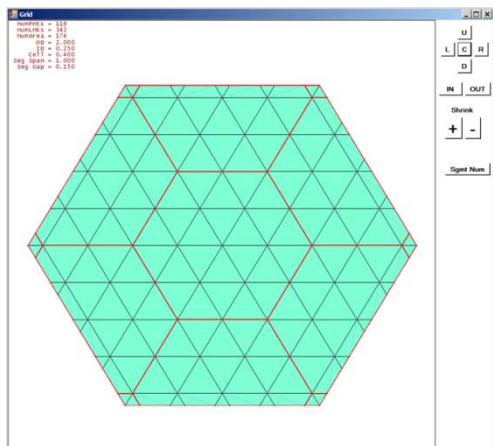
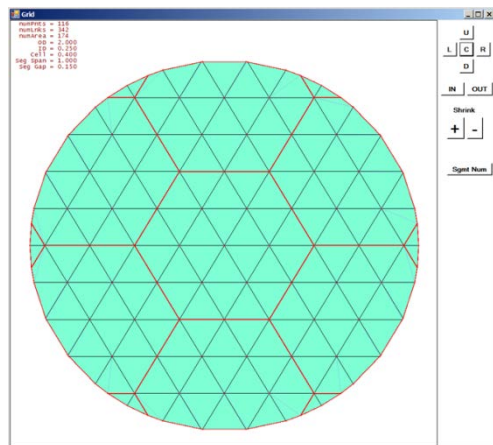
reinforced slots in the mirror the unit can act as a support for the mirror surfaces or fragile edges.



2004

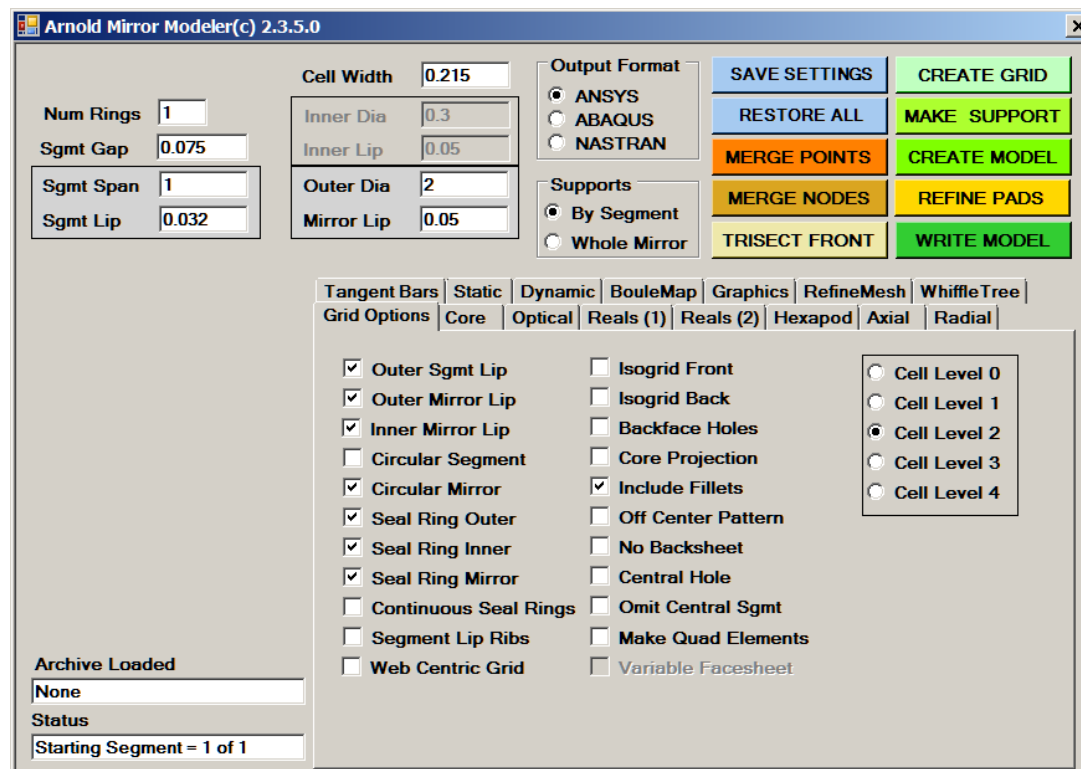
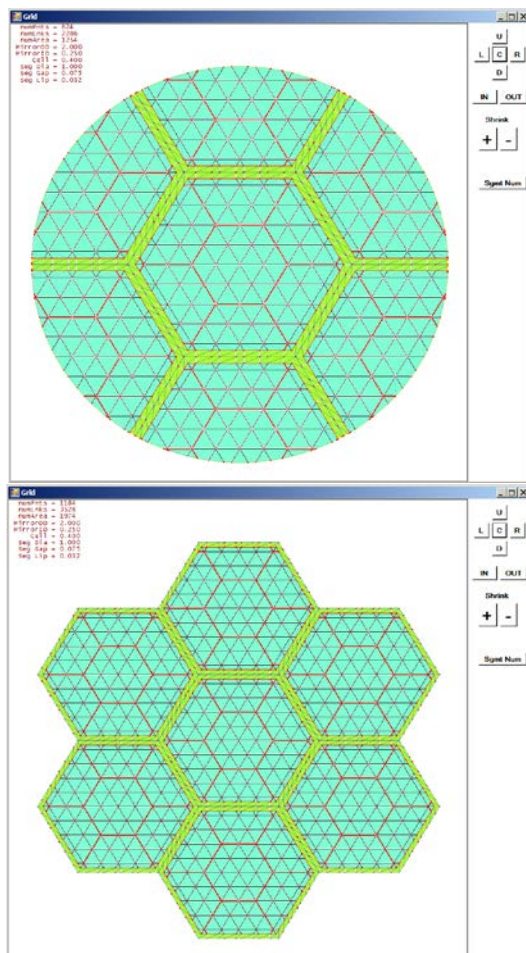
18

WIDE VARIETY OF OPTIONS TO MODEL ALMOST ANY MIRROR STYLE



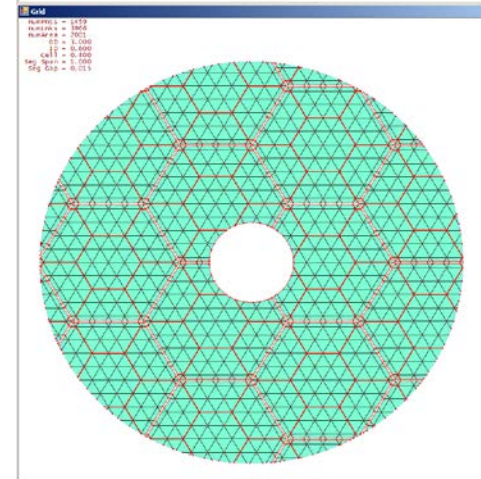
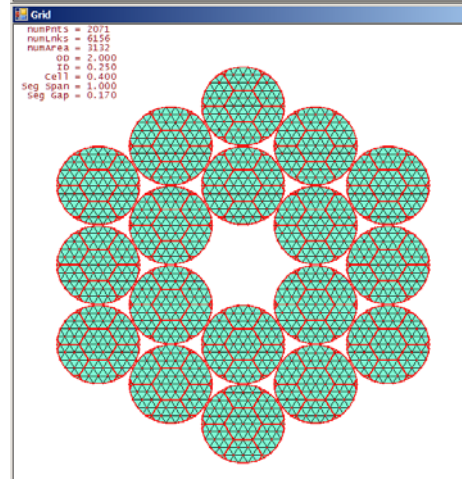
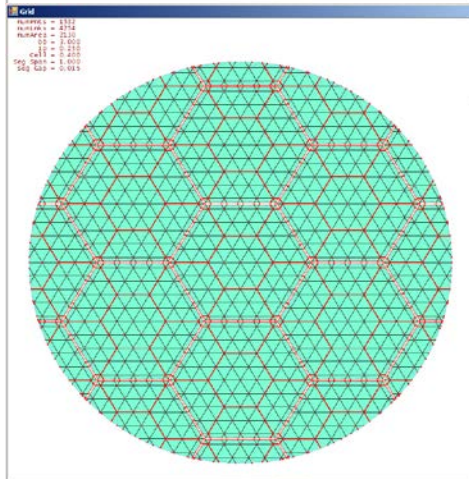
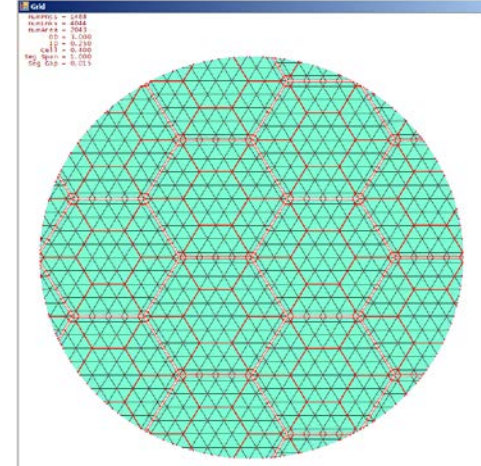
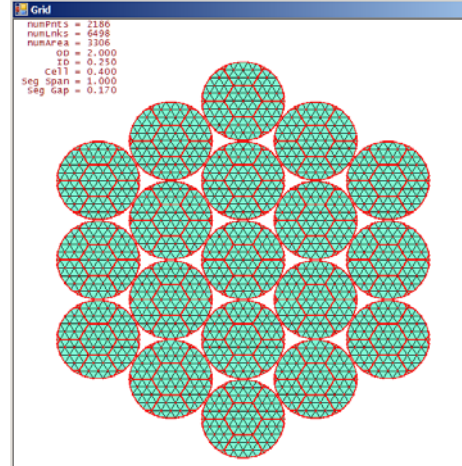
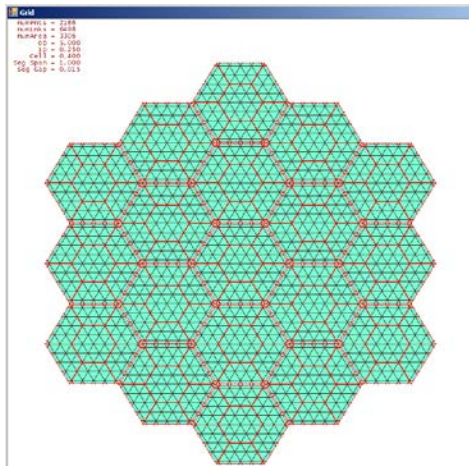
SIMPLE SINGLE BLANK MIRRORS

WIDE VARIETY OF OPTIONS TO MODEL ALMOST ANY MIRROR STYLE

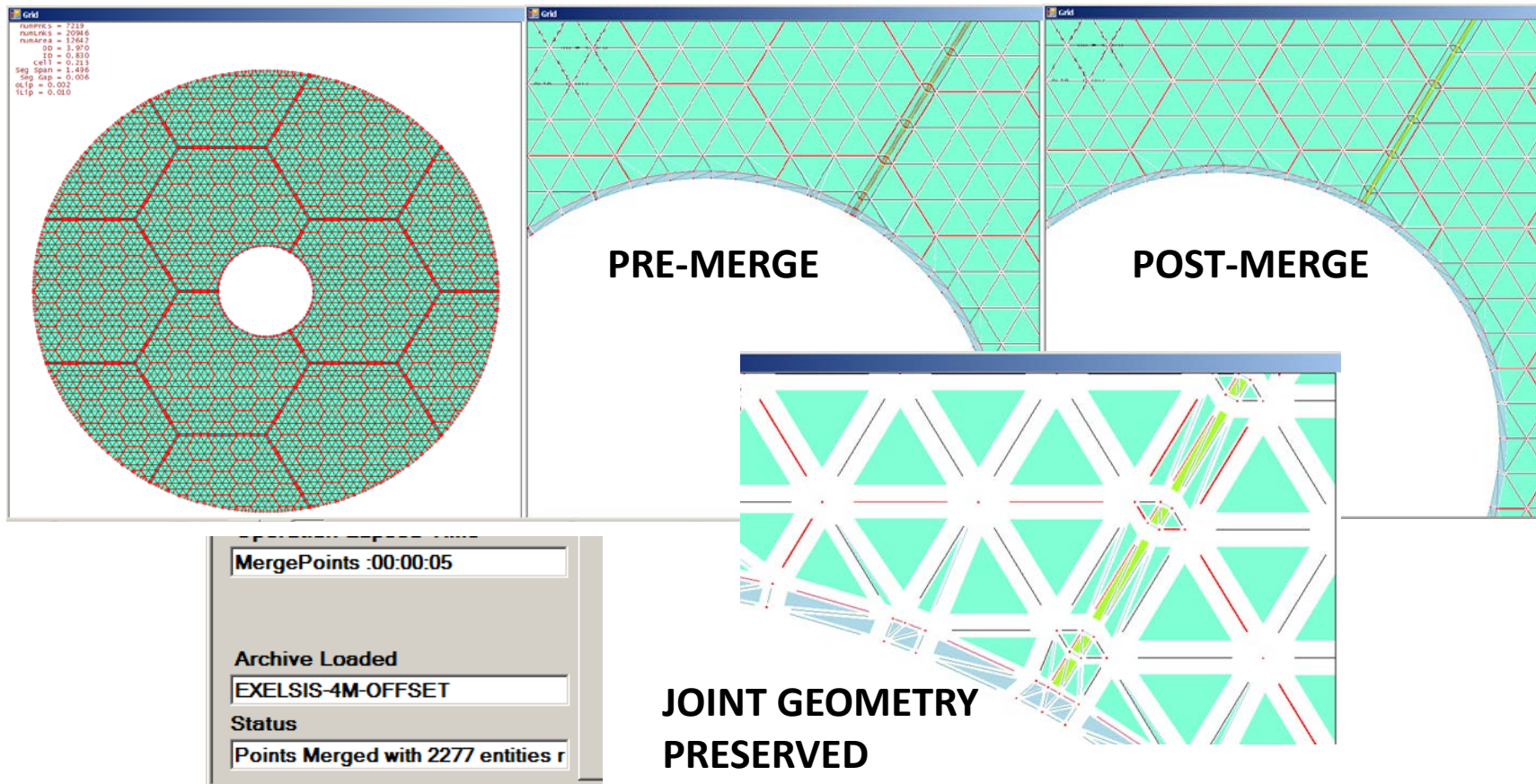


MULTIPLE SEGMENT MIRRORS

MANY CONFIGURATION OPTIONS ARE AVAILABLE

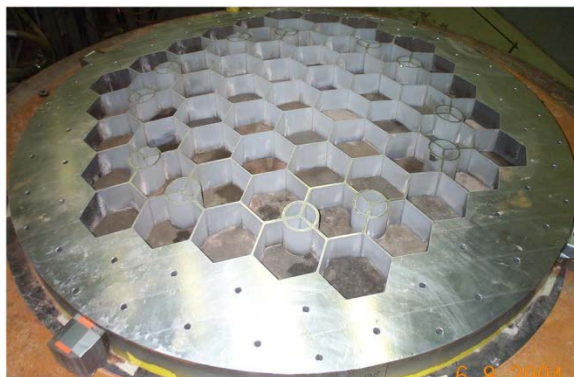


COMPLEX SEGMENTED ASSEMBLIES CAN BE MERGED INTO A SINGLE STRUCTURE

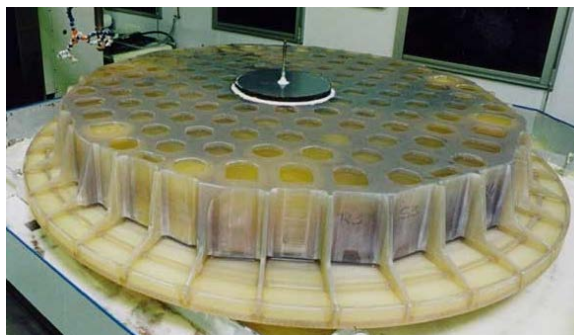


MATERIAL CHOICE DICTATES CONSTRUCTION METHOD

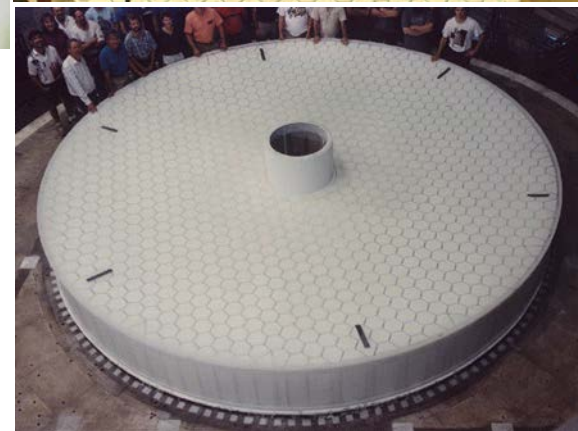
FRIT BONDED ULE



POCKET MILLED ZERODUR



CAST BOROSILICATE



***LOW TEMPERATURE FUSION IS AN
ALTERNATIVE ASSEMBLY, REQUIRES SLUMPING**

ANY CONSTRUCTION METHOD AND MATERIAL CAN BE MODELED

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 Elems
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

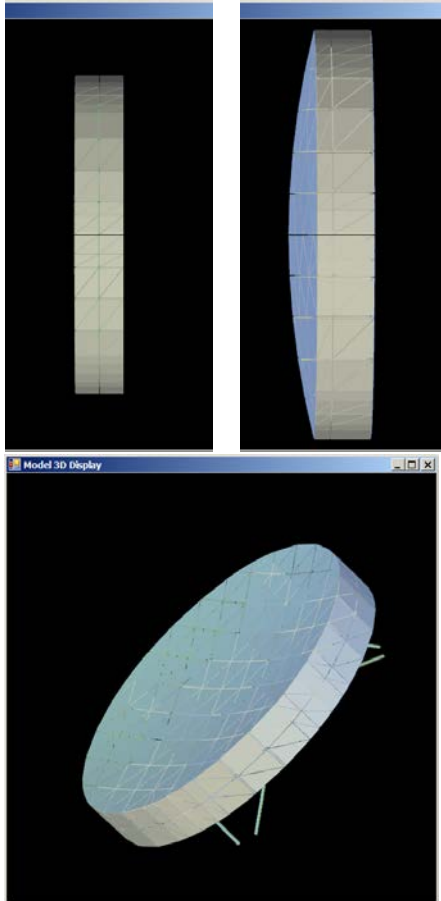
Back Mtrl: 1

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: <input type="text" value="1"/>	Cell Width: <input type="text" value="0.215"/>	Output Format: <input checked="" type="radio"/> ANSYS <input type="radio"/> ABAQUS <input type="radio"/> NASTRAN	SAVE SETTINGS	CREATE GRID
Sgmt Gap: <input type="text" value="0.075"/>	Inner Dia: <input type="text" value="0.3"/> Inner Lip: <input type="text" value="0.05"/>	Supports: <input checked="" type="radio"/> By Segment <input type="radio"/> Whole Mirror	RESTORE ALL	MAKE SUPPORT
Sgmt Span: <input type="text" value="1"/> Sgmt Lip: <input type="text" value="0.032"/>	Outer Dia: <input type="text" value="2"/> Mirror Lip: <input type="text" value="0.05"/>		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

Radius	<input type="text" value="2"/>	<input checked="" type="checkbox"/> Flat Mirror
Conic	<input type="text" value="-1"/>	<input type="checkbox"/> Flat Backed Mirror
Aspheric Order	<input type="text" value="0"/>	<input type="checkbox"/> Convex Mirror
Coefficient(1)	<input type="text" value="0"/>	
Coefficient(2)	<input type="text" value="0"/>	
Coefficient(3)	<input type="text" value="0"/>	
Coefficient(4)	<input type="text" value="0"/>	
Coefficient(5)	<input type="text" value="0"/>	

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"/>

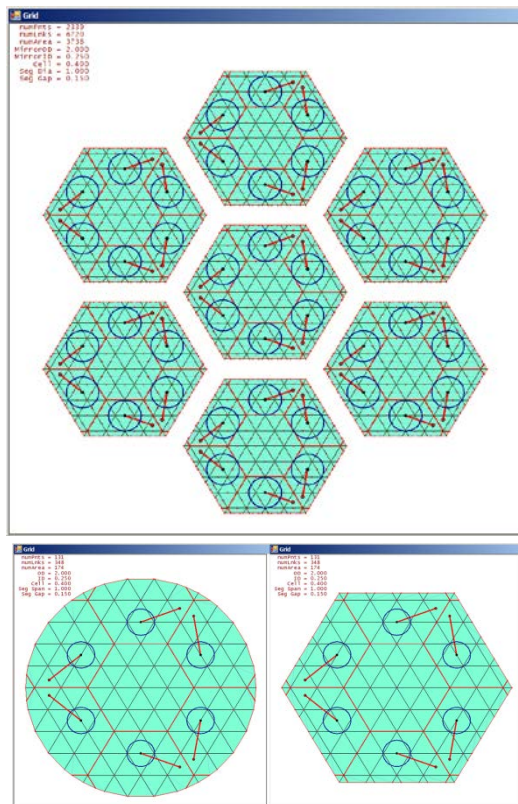
Archive Loaded:
Status:

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

**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 **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**

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)

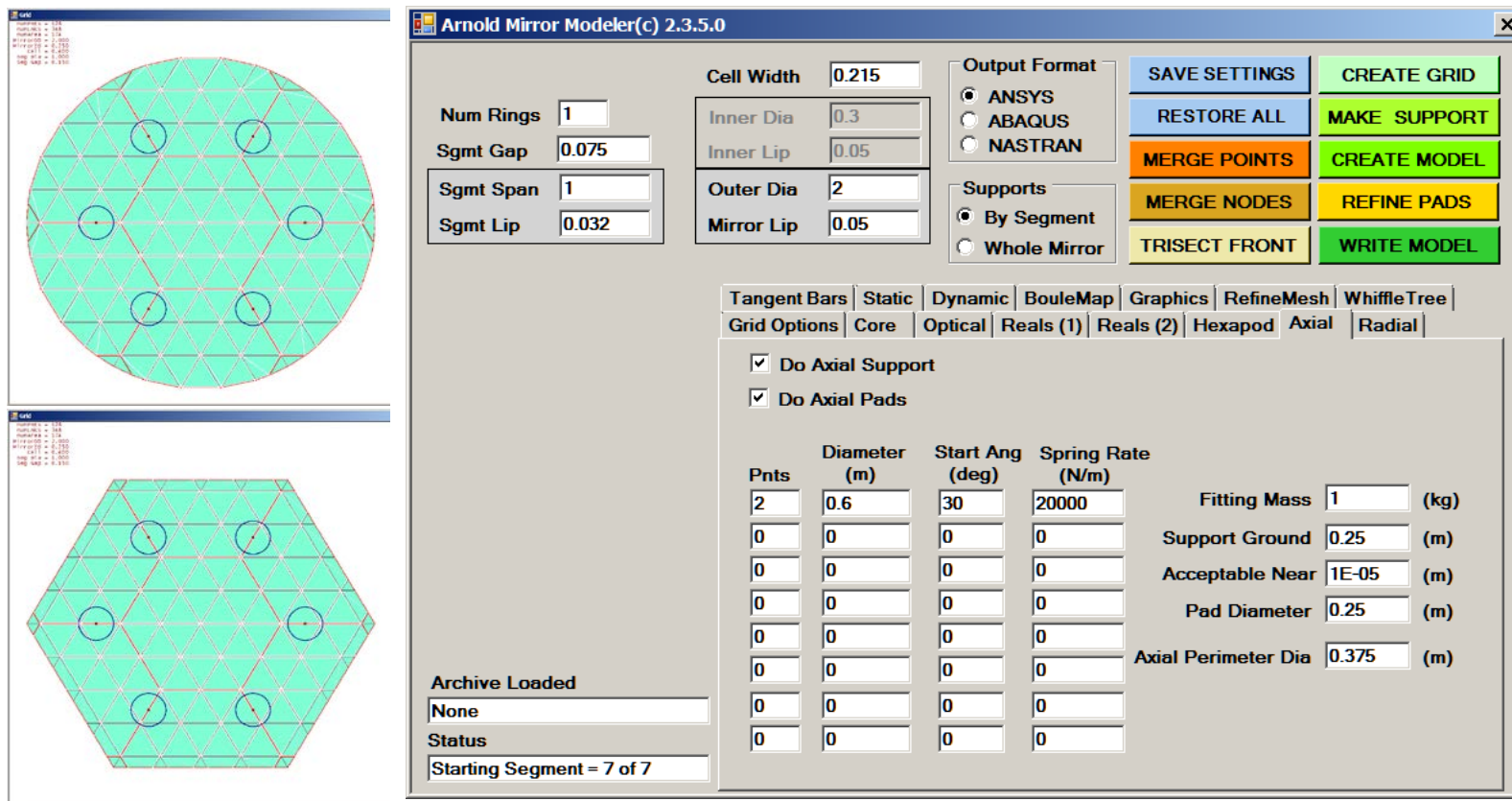
Archive Loaded

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 **Cell Width**

Sgmt Gap **Inner Dia**

Sgmt Span **Inner Lip**

Sgmt 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**

☒ **Do Axial Support**
☒ **Do Axial Pads**

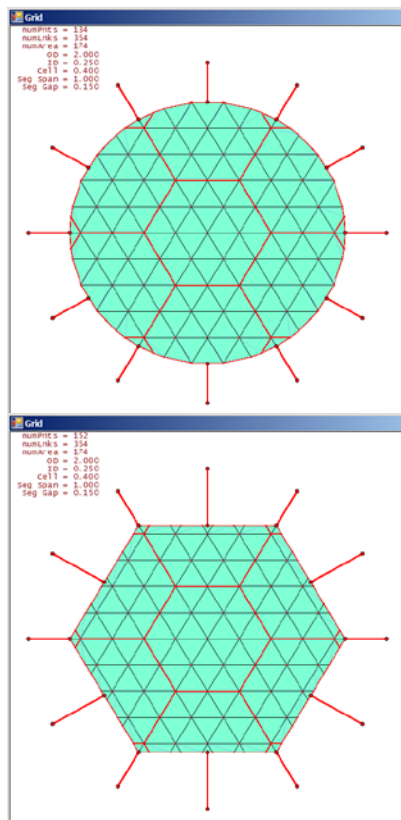
Pnts	Diameter (m)	Start Ang (deg)	Spring Rate (N/m)
2	0.6	30	20000
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0

Fitting Mass (kg)
Support Ground (m)
Acceptable Near (m)
Pad Diameter (m)
Axial Perimeter Dia (m)

Archive Loaded

Status

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)

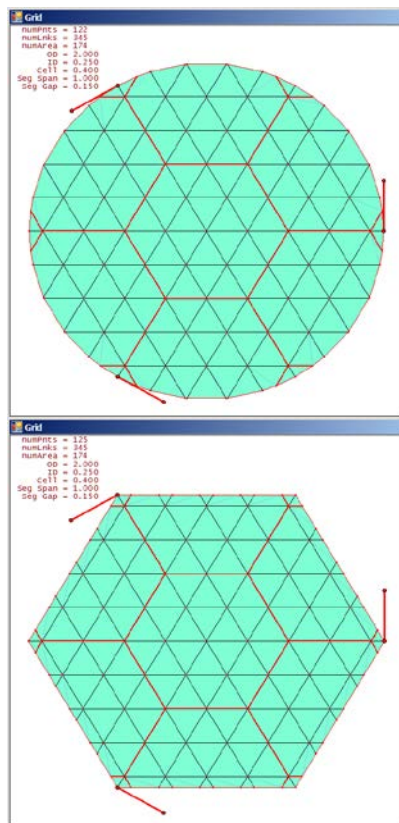
Fitting Mass: 1 (kg)

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

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

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: 3

Tangent Bar Start Angle: 0

Tangent Bar Length: 0.15

Tangent Bar Spring Rate: 20000

Tangent Fitting Mass: 1 (kg)

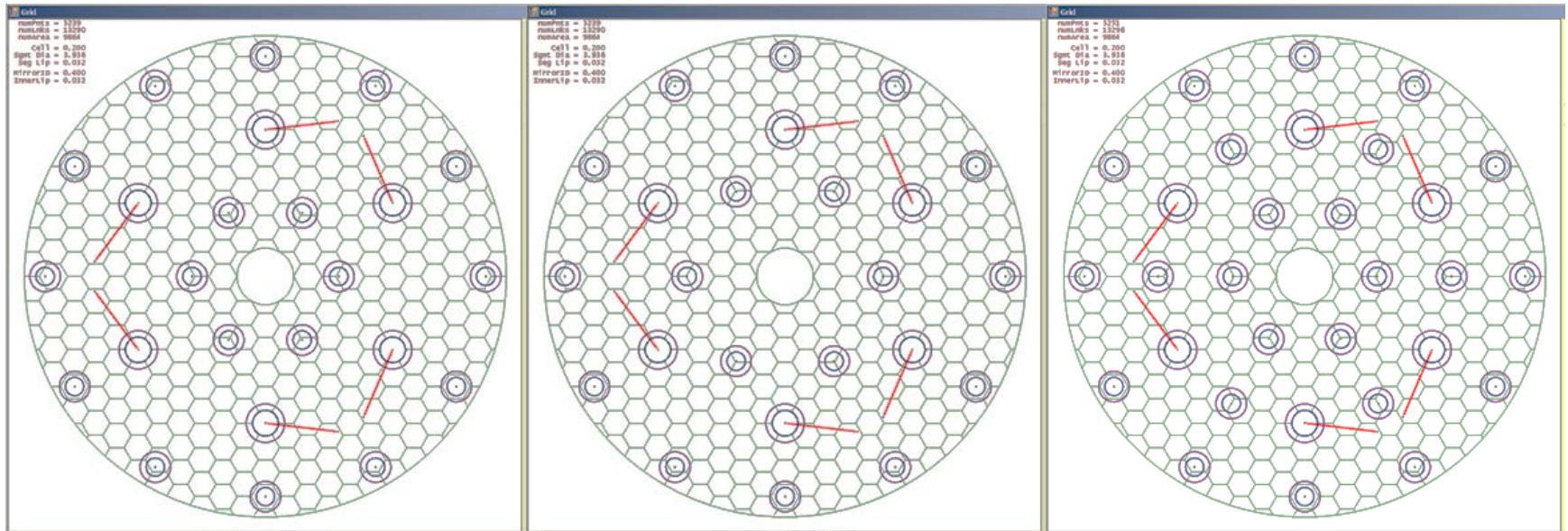
Archive Loaded

None

Status

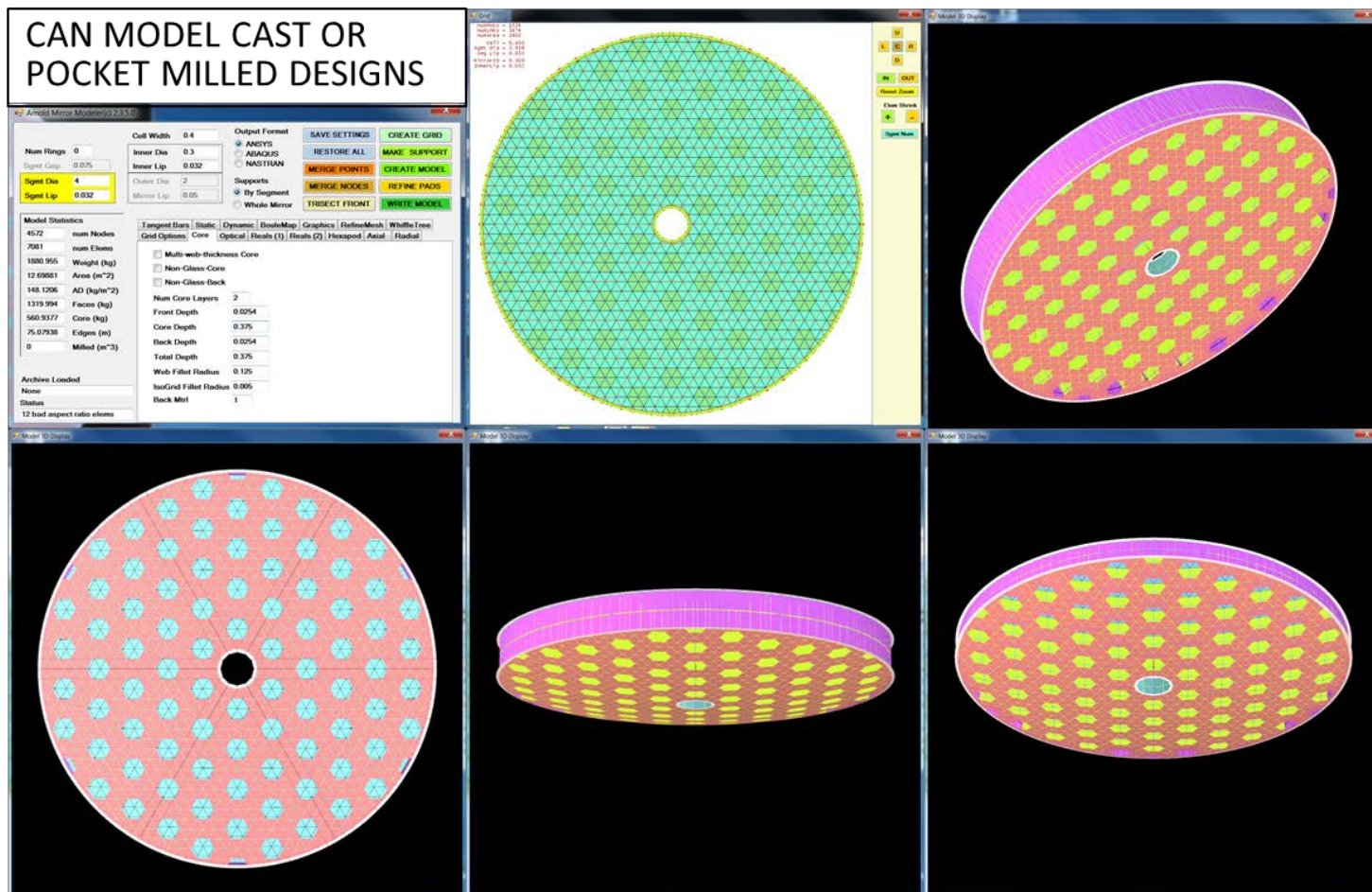
Starting Segment = 7 of 7

MULTIPLE SUPPORT TYPES CAN BE COMBINED

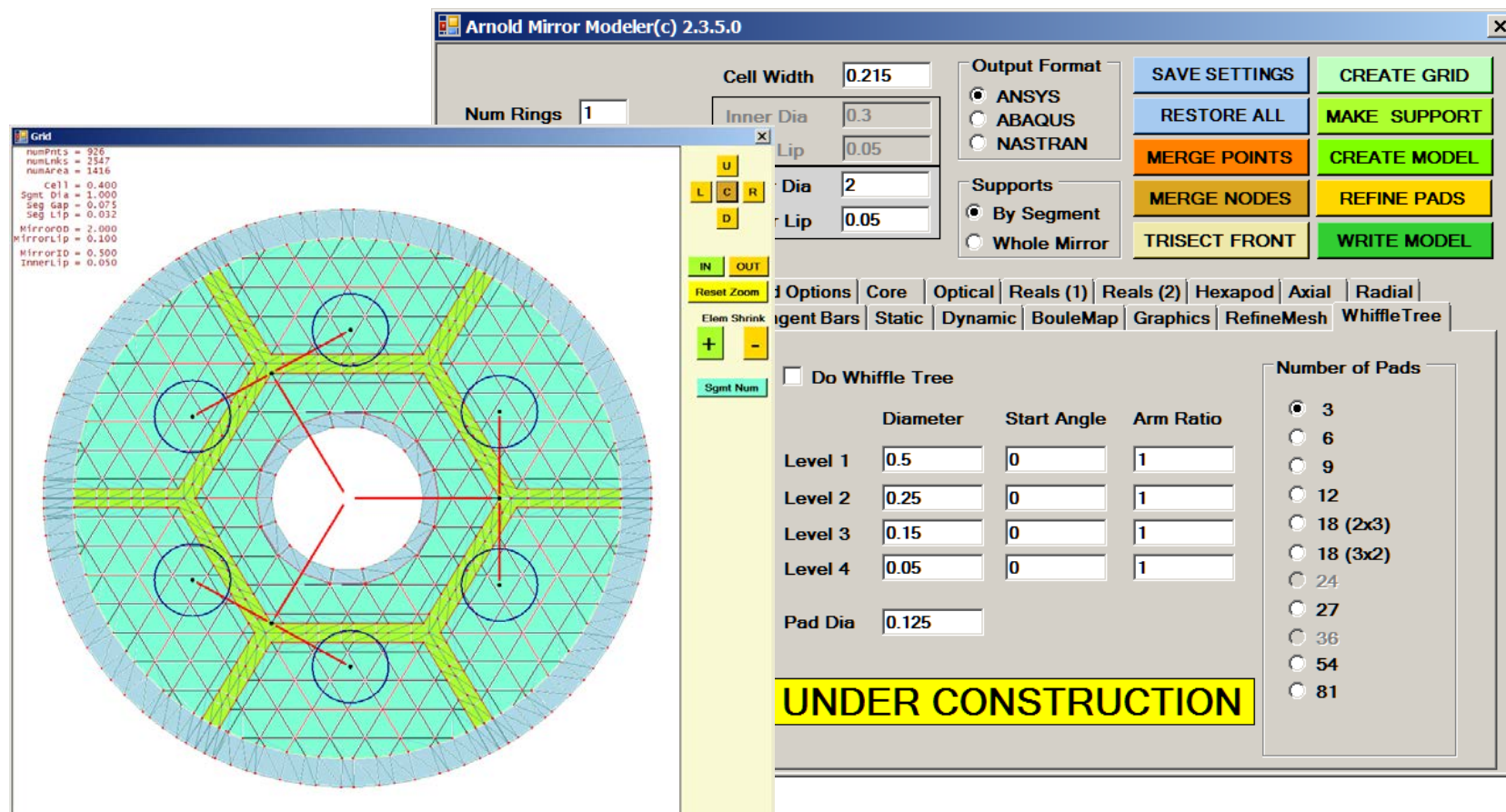


**ADJUSTING GROUP DIAMETERS, NUMBER OF
DIAMETERS AND STARTING ANGLES**

EVALUATE MATERIAL CHOICES & CONSTRUCTION

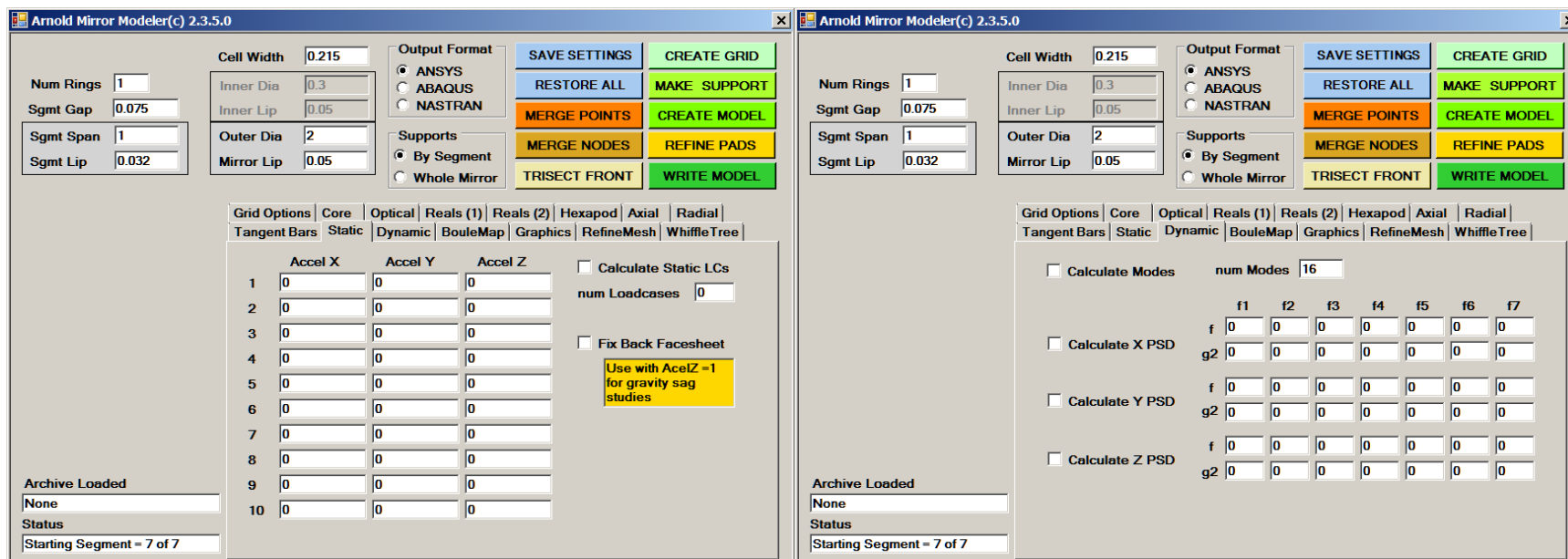


WHIFFLE TREE SUPPORTS CURRENTLY UNDER DEVELOPMENT



YOU CAN DEFINE LOAD CASES

STATIC, MODAL & PSD



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 REFINER PADS WRITE MODEL

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

Tangent Bars Static Dynamic BouleMap Graphics RefineMesh WhiffleTree

	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

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 REFINER PADS WRITE MODEL

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

Tangent Bars Static Dynamic BouleMap Graphics RefineMesh WhiffleTree

☐ 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

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

☐ Calculate Y PSD

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

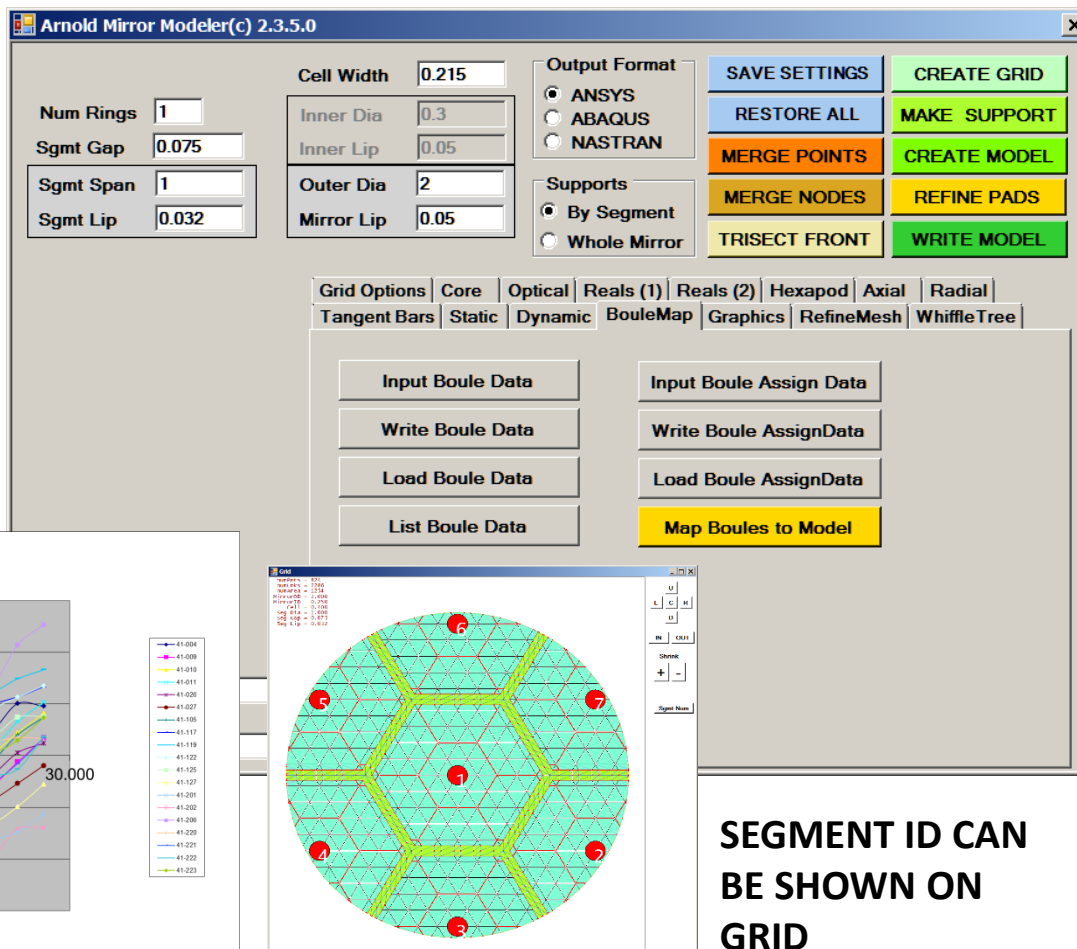
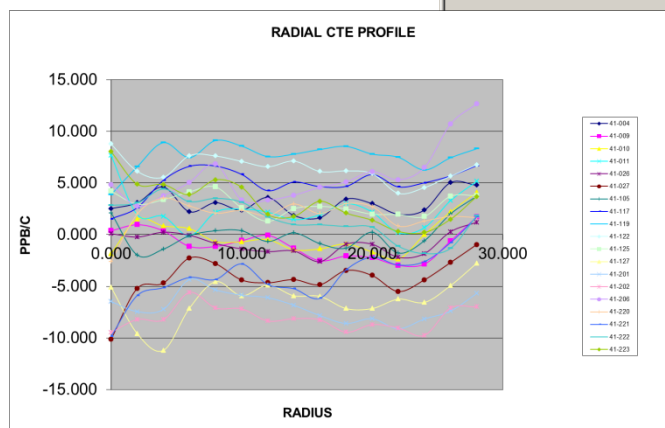
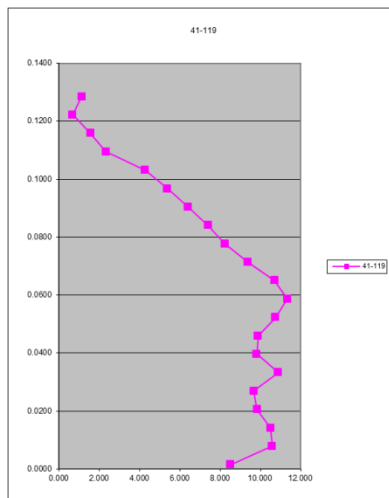
☐ Calculate Z PSD

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

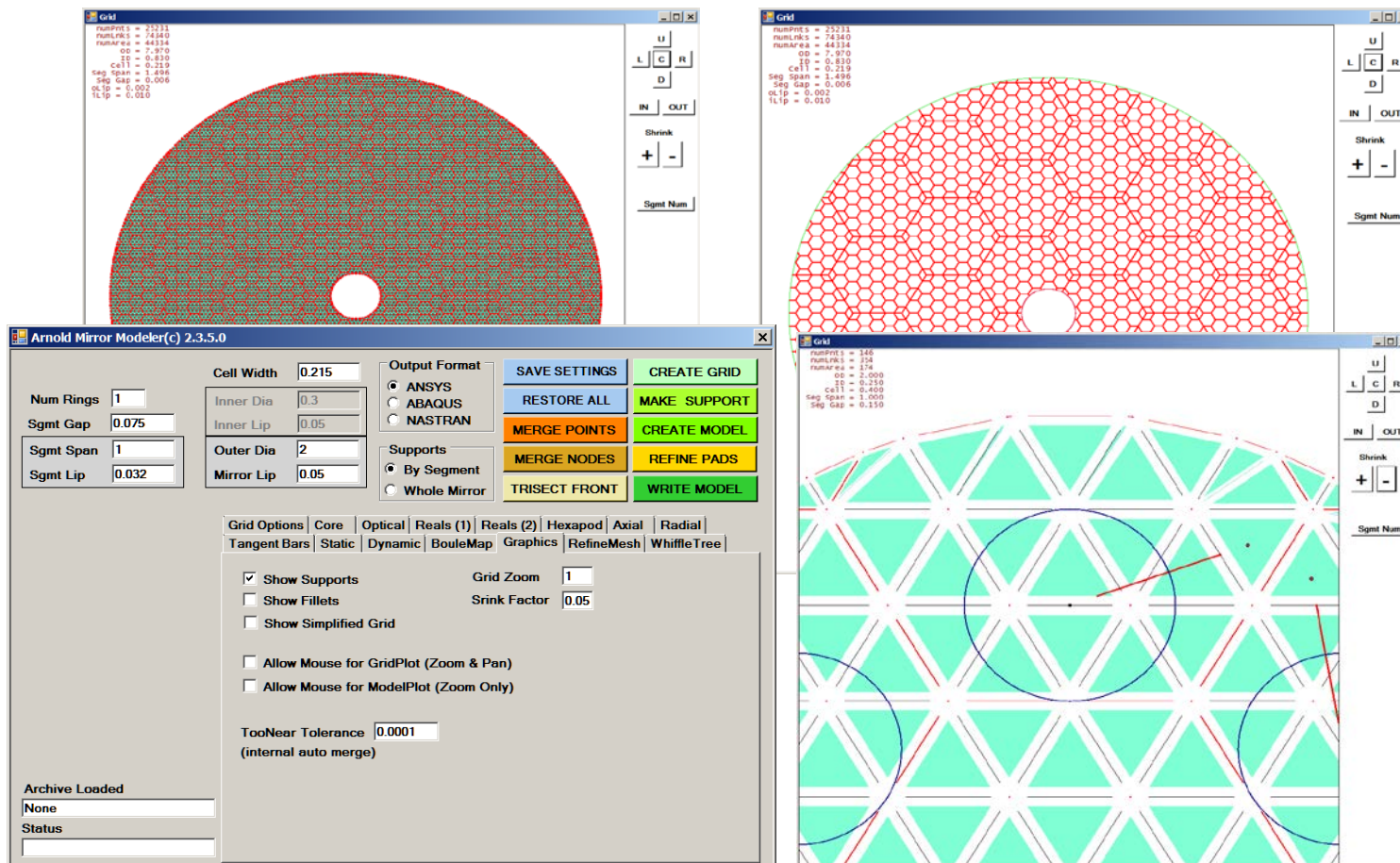
Archive Loaded: None

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

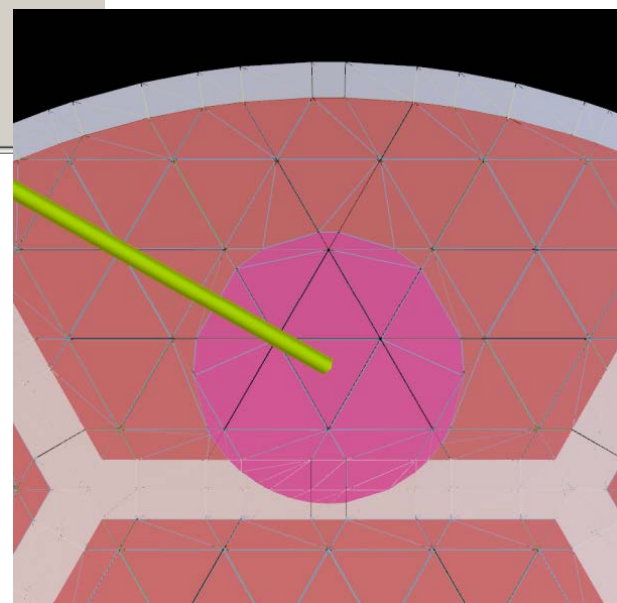
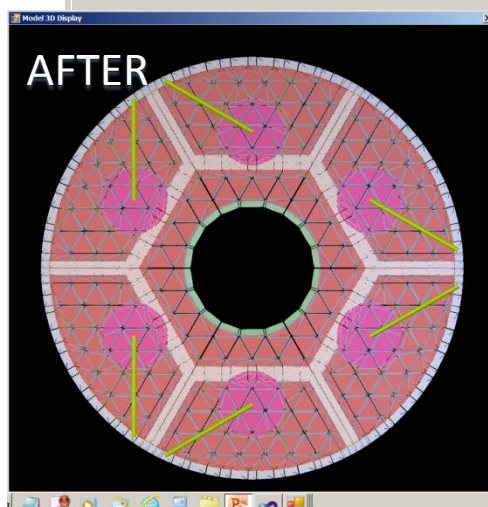
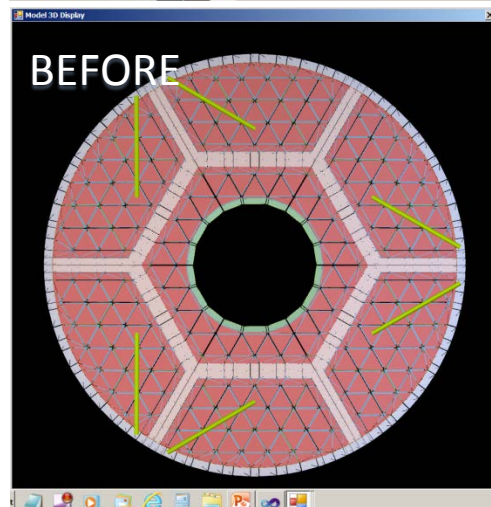
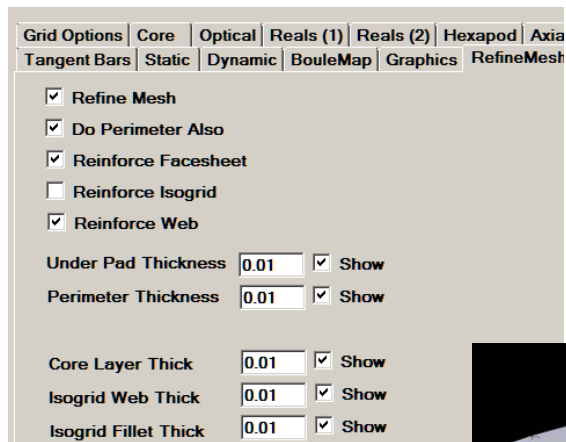
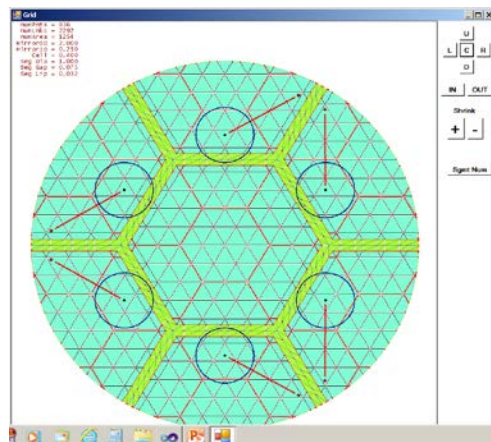


GRID PLOTTING OPTIONS

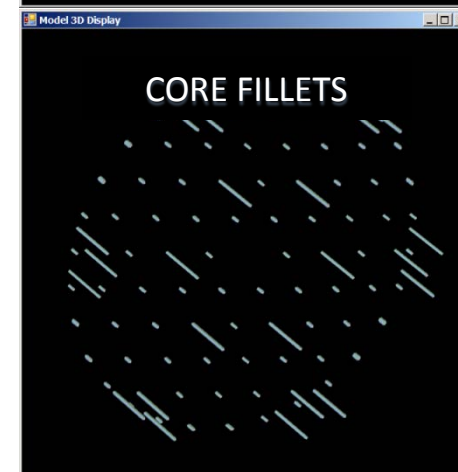
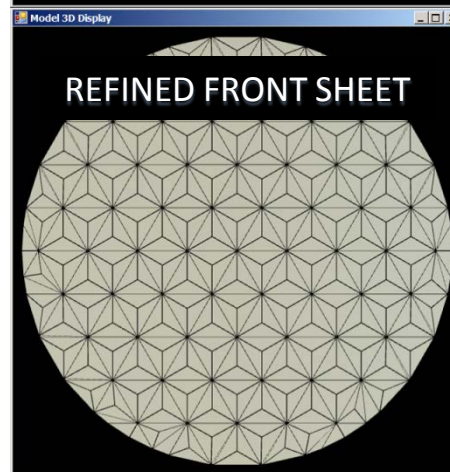
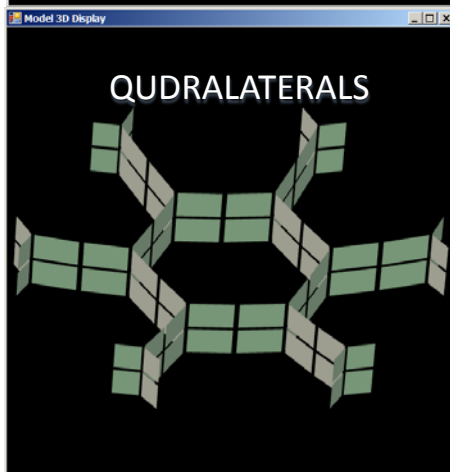
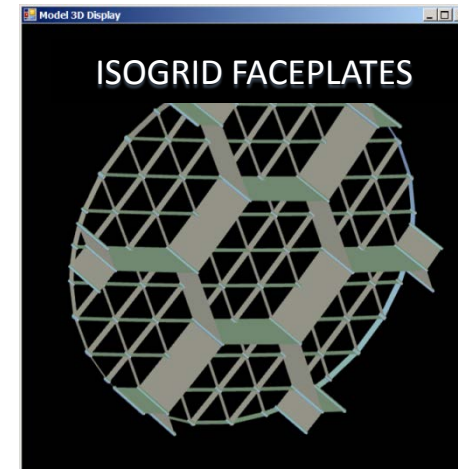
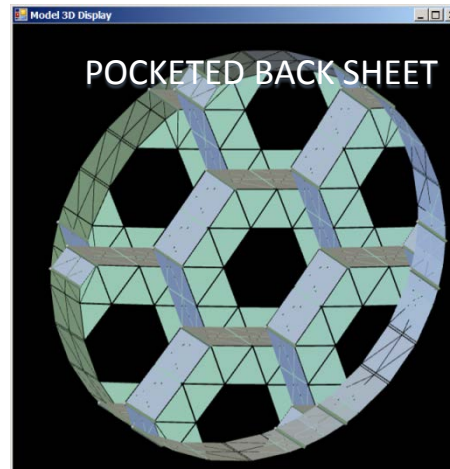
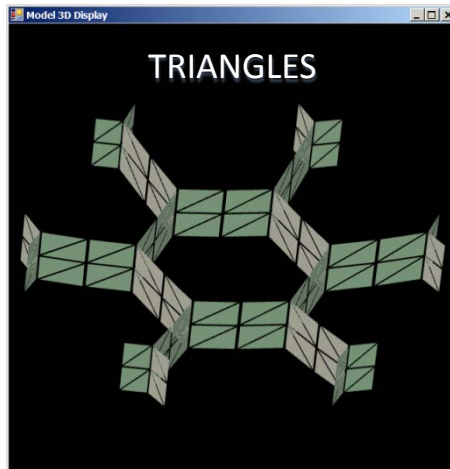


SIMPLIFIED MESH, PAN & ZOOM, ELEMENT SHRINK

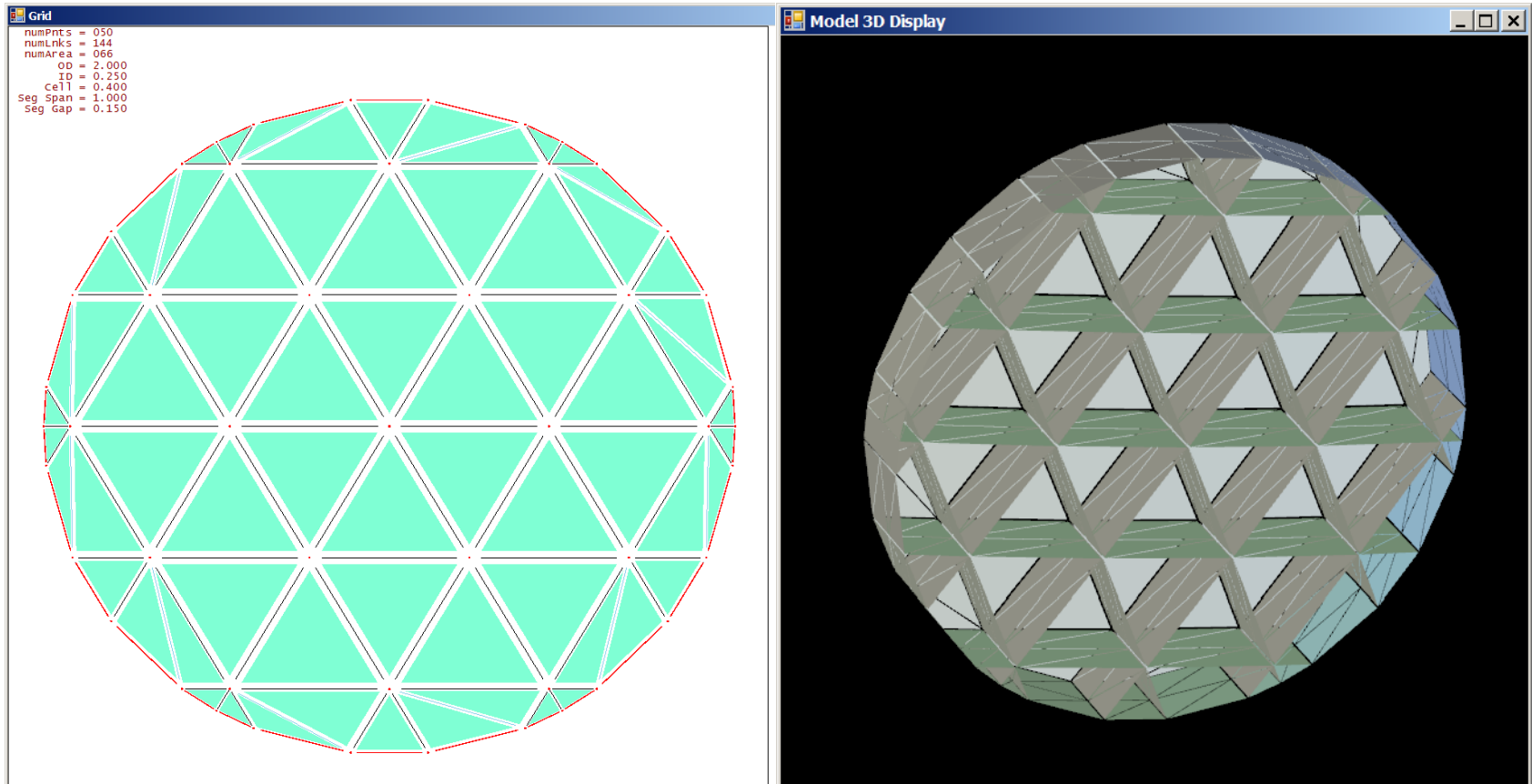
LOCALIZED MESH REFINEMENT UNDER SUPPORT PADS



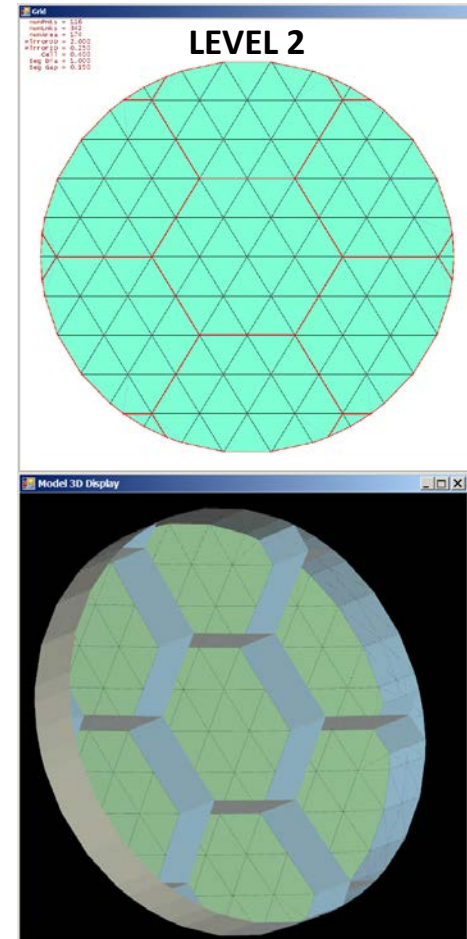
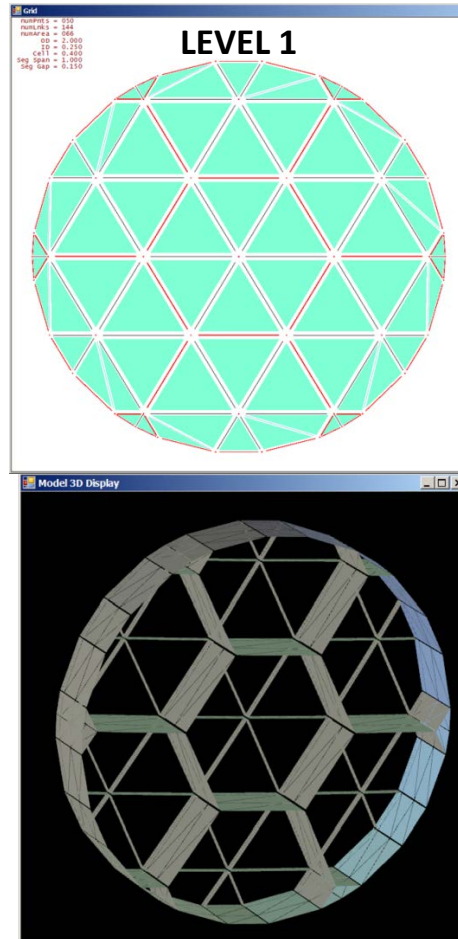
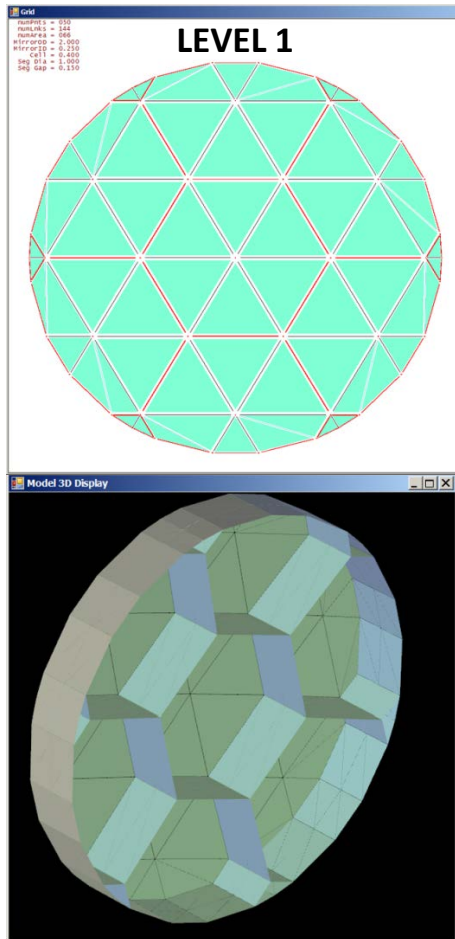
A LOT OF MESHING OPTIONS AVAILABLE



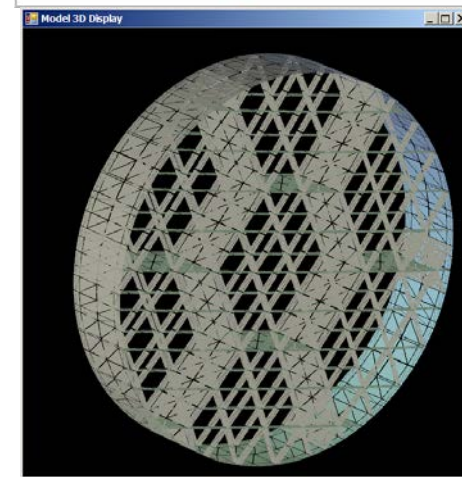
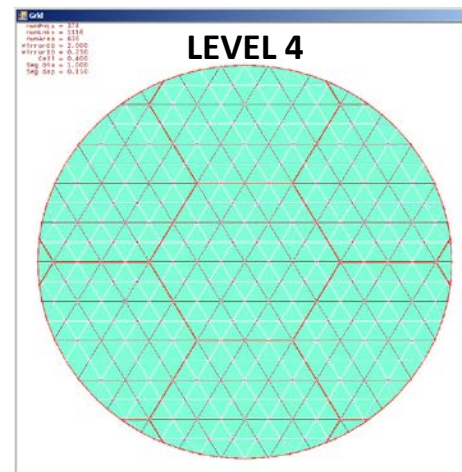
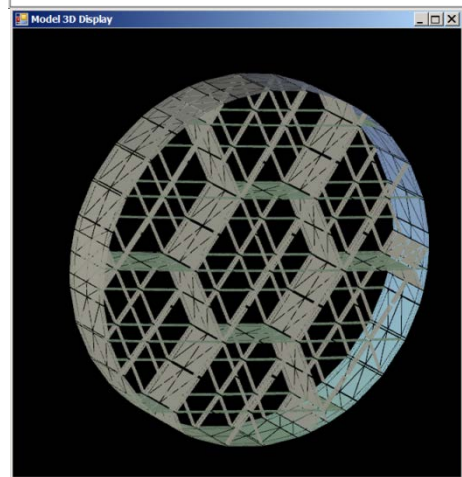
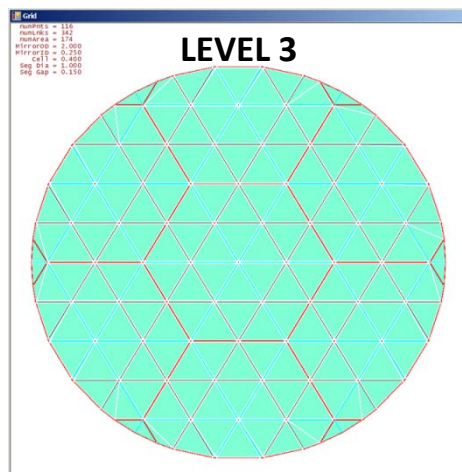
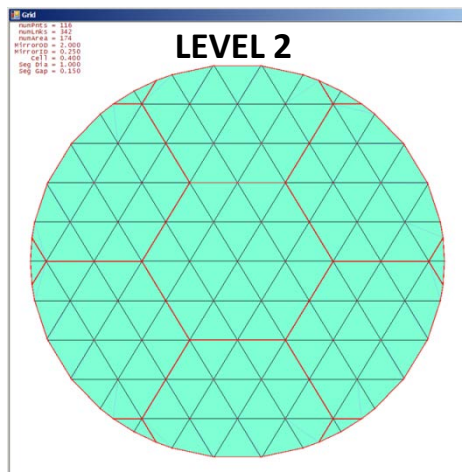
CAN MODEL A PURE ISOGRID CORE [LEVEL0]



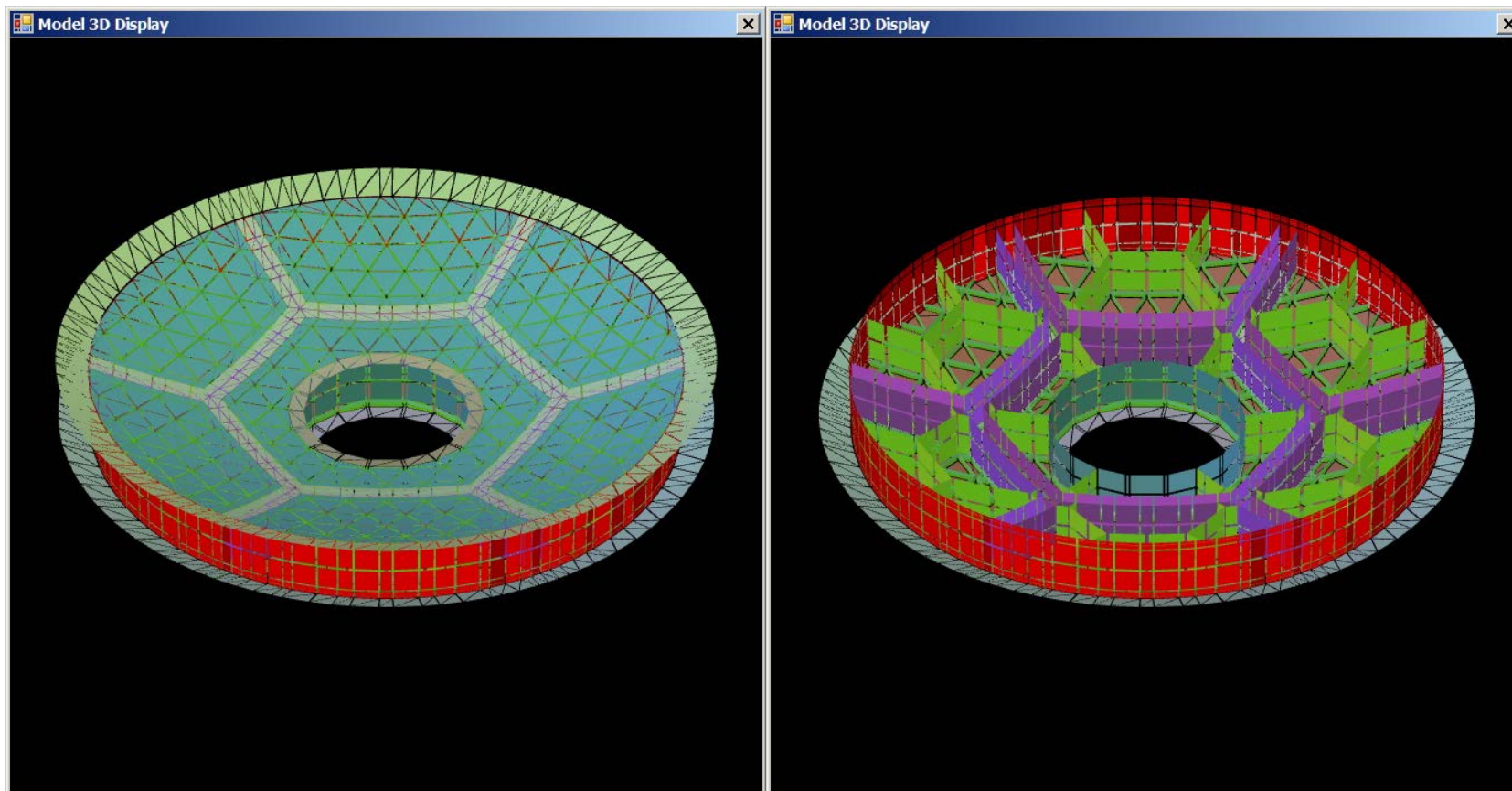
GRID COMPLEXITY LEVELS (CONT)



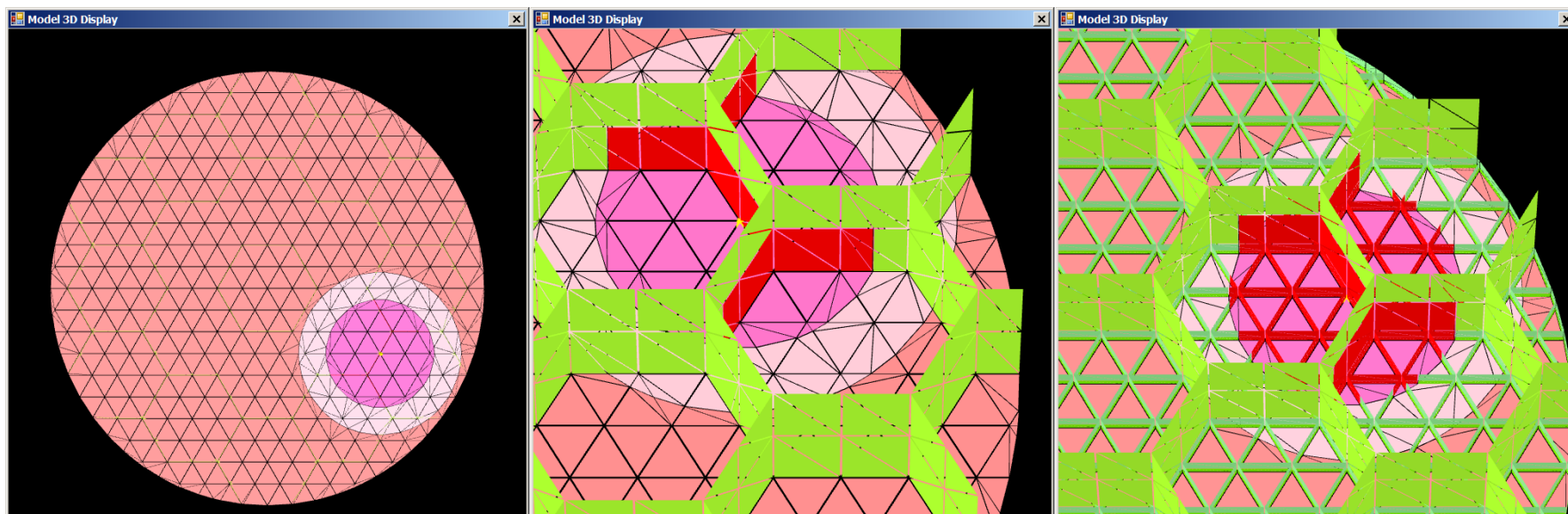
GRID COMPLEXITY LEVELS (CONT)



MODEL DISPLAY NOW SUPPORTS COLOR-BASED REAL CONSTANTS

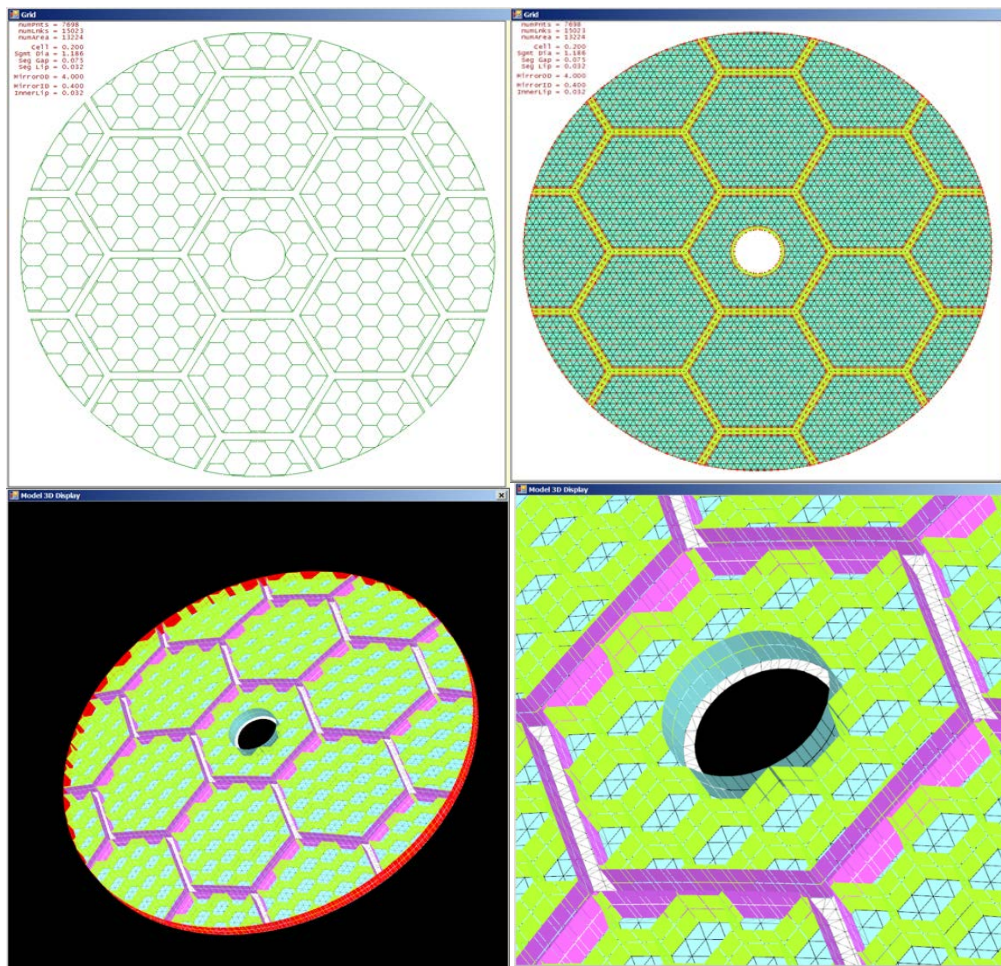


LOCALIZED REINFORCEMENT & MESH REFINEMENT UNDER PADS

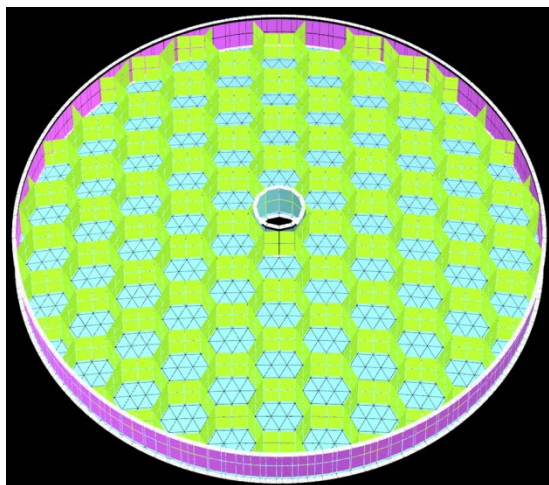


A perimeter around pad can be reinforced or just mesh refined . The core structure can be stiffened as well as any back facesheet isogrid pattern in region of bond pads.

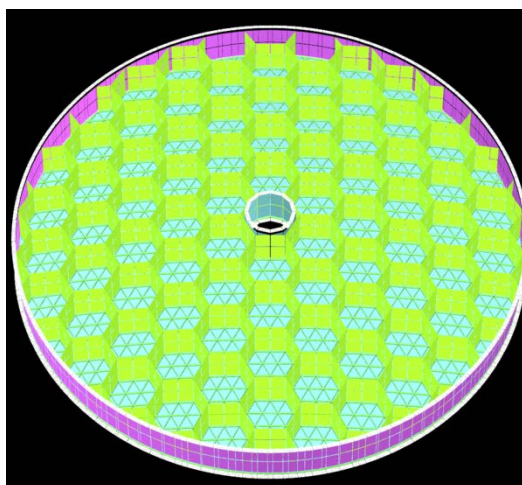
MULTI-SEGMENT LTF CONSTRUCTION CAN BE MODELED



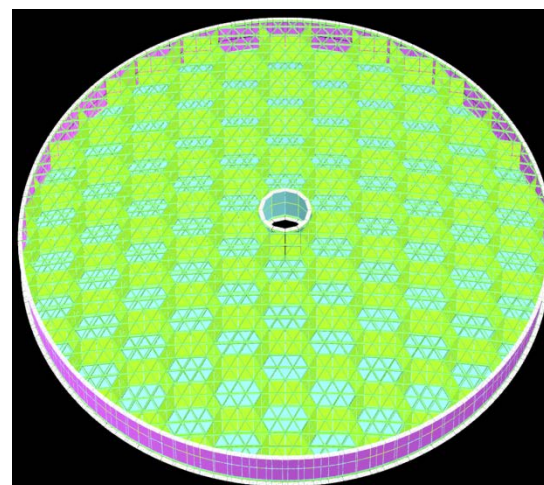
SAME GRID CAN GENERATE MULTIPLE CONSTRUCTION STYLES



NO ISOGRID

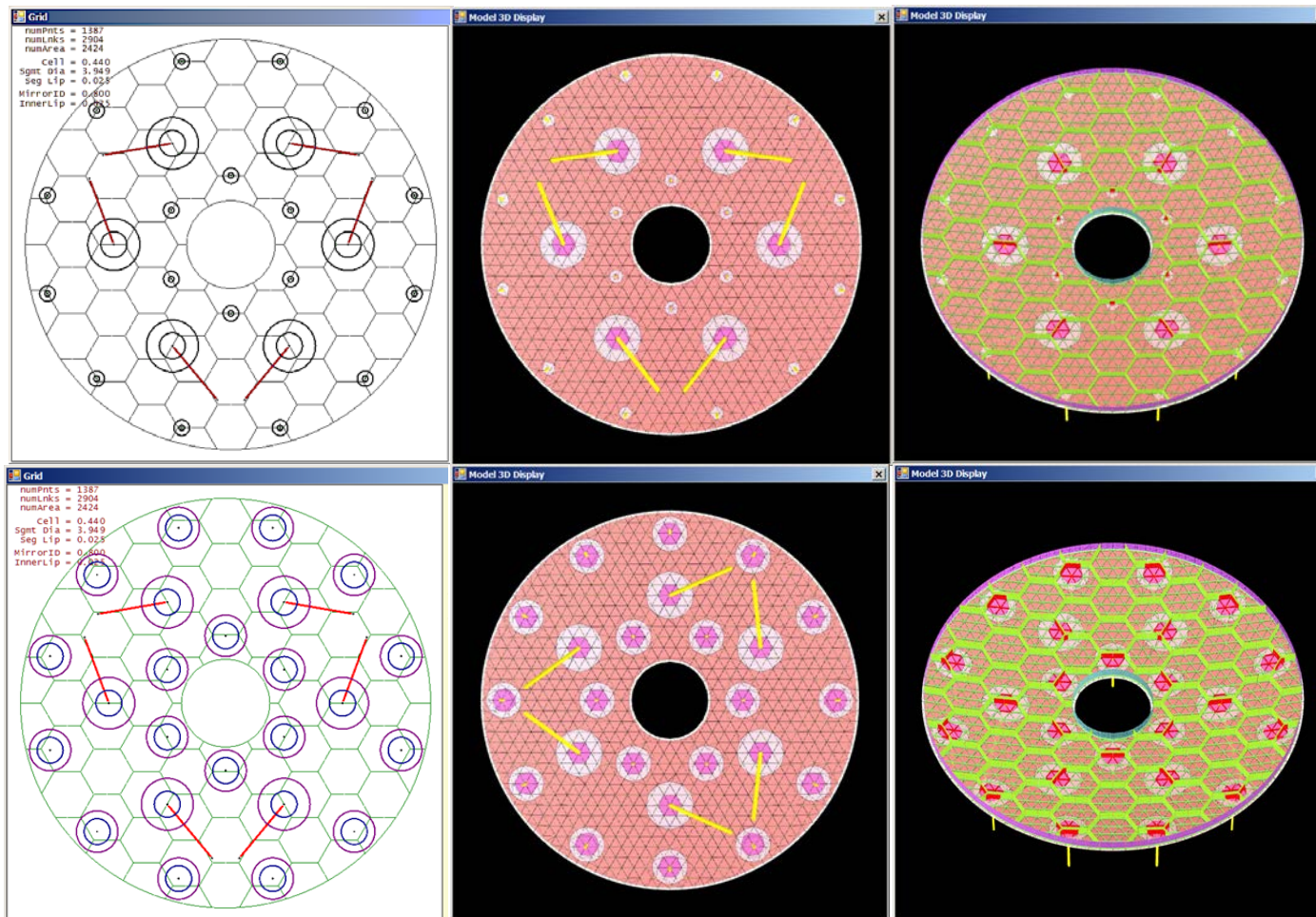


FRONT ONLY ISOGRID

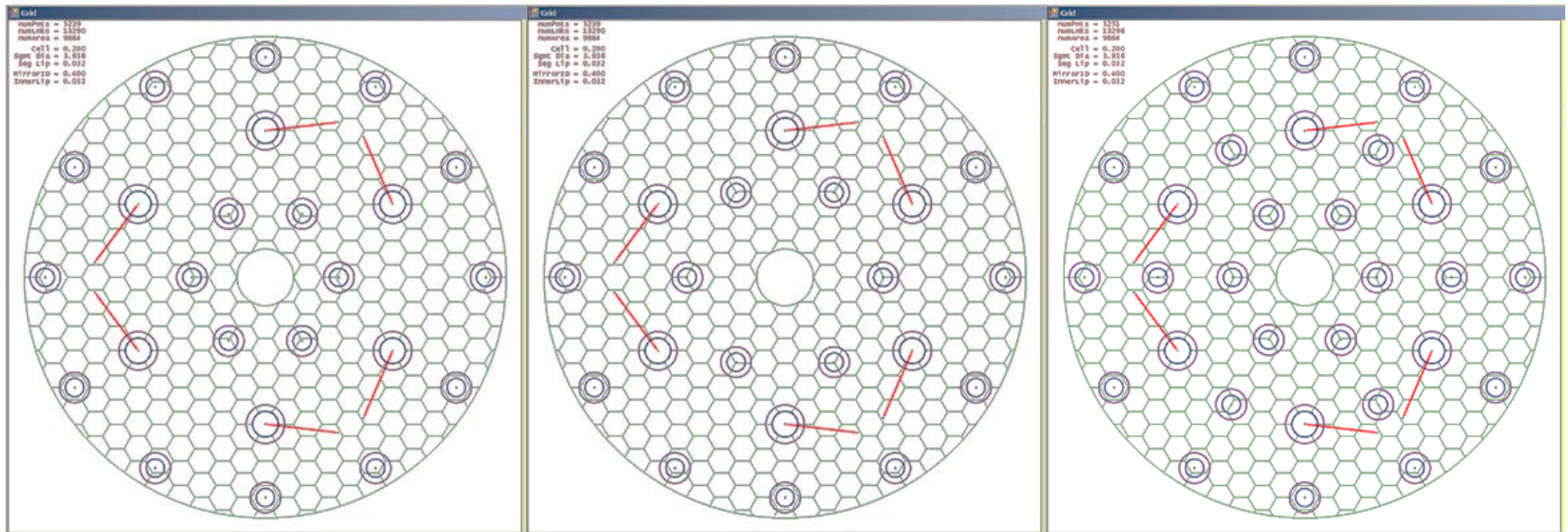


FRONT & REAR ISOGRID

ADJUSTING PARAMETERS TO IMPROVE STIFFNESS



TRY MULTIPLE VERSIONS OF AUXILLARY SUPPORT SYSTEM



**ADJUSTING GROUP DIAMETERS, NUMBER OF
DIAMETERS AND STARTING ANGLES**

SUMMARY



- FEATURES AND CAPABILITIES OF MODELER TO MAKE THE PROCESS ECONOMICAL
 - REDUCED MODEL GENERATION TIME
 - ANY MATERIAL AND CONSTRUCTION METHOD SUPPORTED
 - CAN PRESET LOADS AND RESULT PROCESSING
 - ARCHIVE AND RESTORE ALL SETTINGS IN MODELER
- VALUE OF INTEGRATED DESIGN METHOD
 - CAN EVALUATE FEASIBILITY OF CONSTRUCTION METHOD
 - OPTIMIZE OPERATIONAL PERFORMANCE
 - LAUNCH SURVIVAL
- TIME PERMITTING, QUESTIONS & DEMONSTRATION

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?**