

Design Investigations of Cryostat Top Lid for DEMO

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Warsaw 12th November 2014

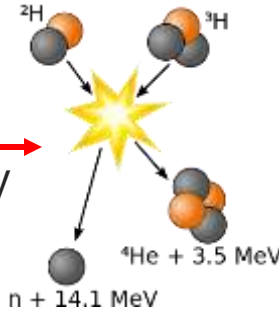
ITER (*International Thermonuclear Experimental Reactor*)

Aim: controlled nuclear Fusion / **Cadarache** / First ignition **2019**.

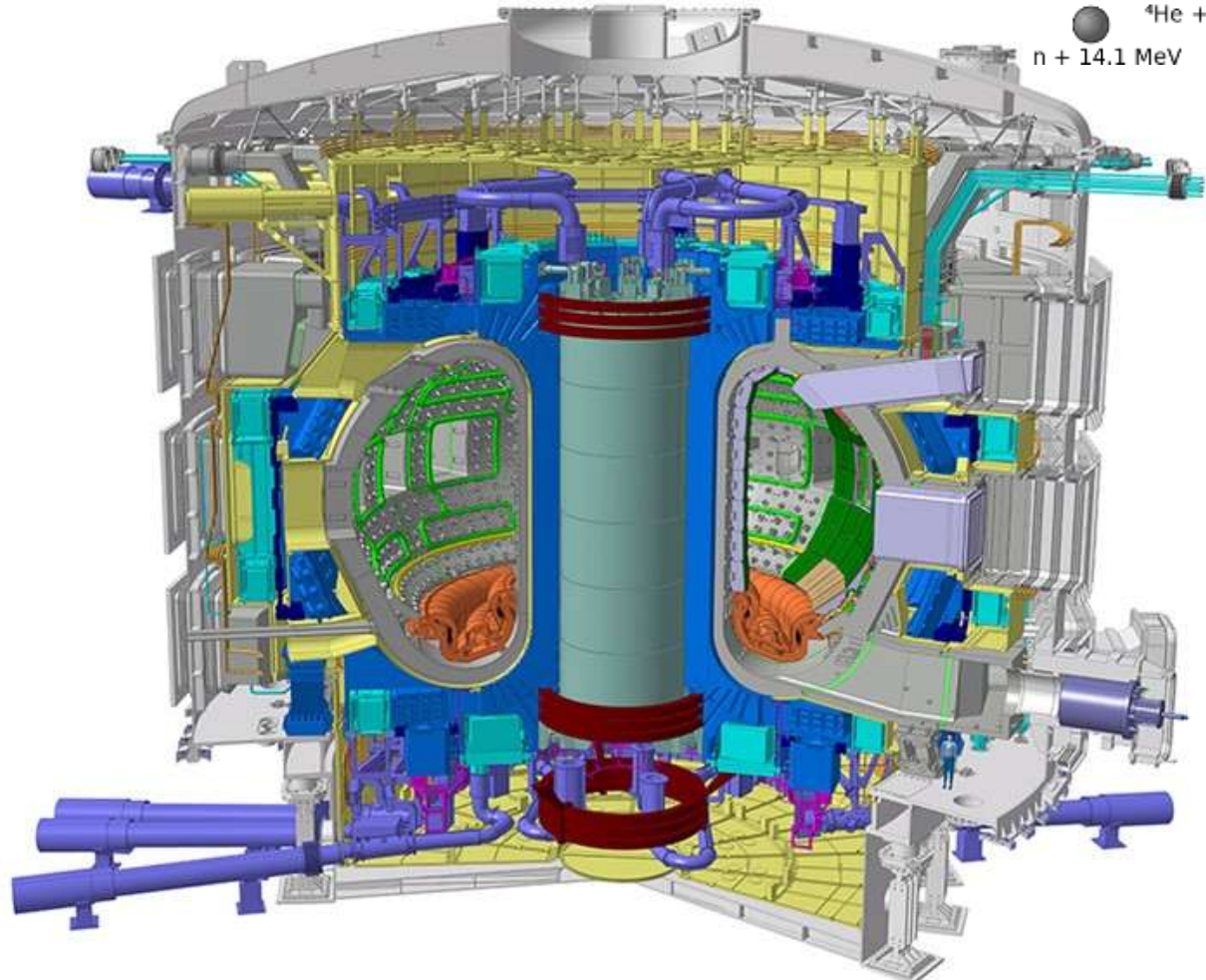
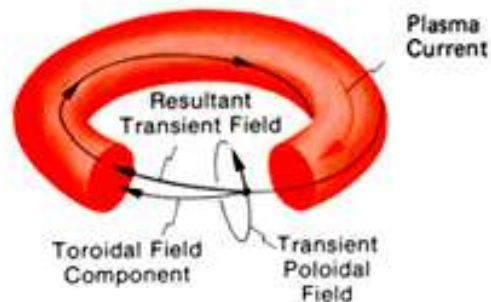
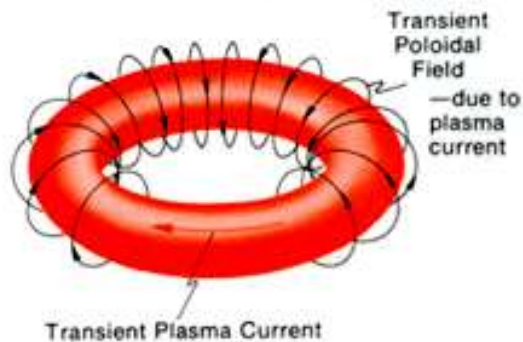
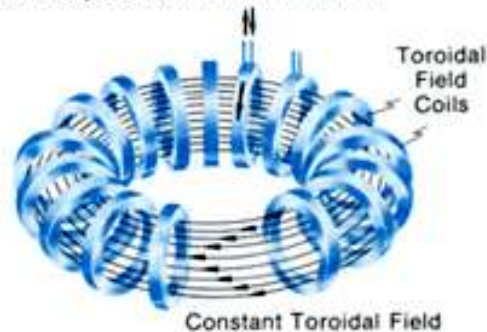
ITER is supposed to maintain the fusion reaction each time for approximately **1000 seconds**, reaching power of **500-1100MW**.

Tokamak

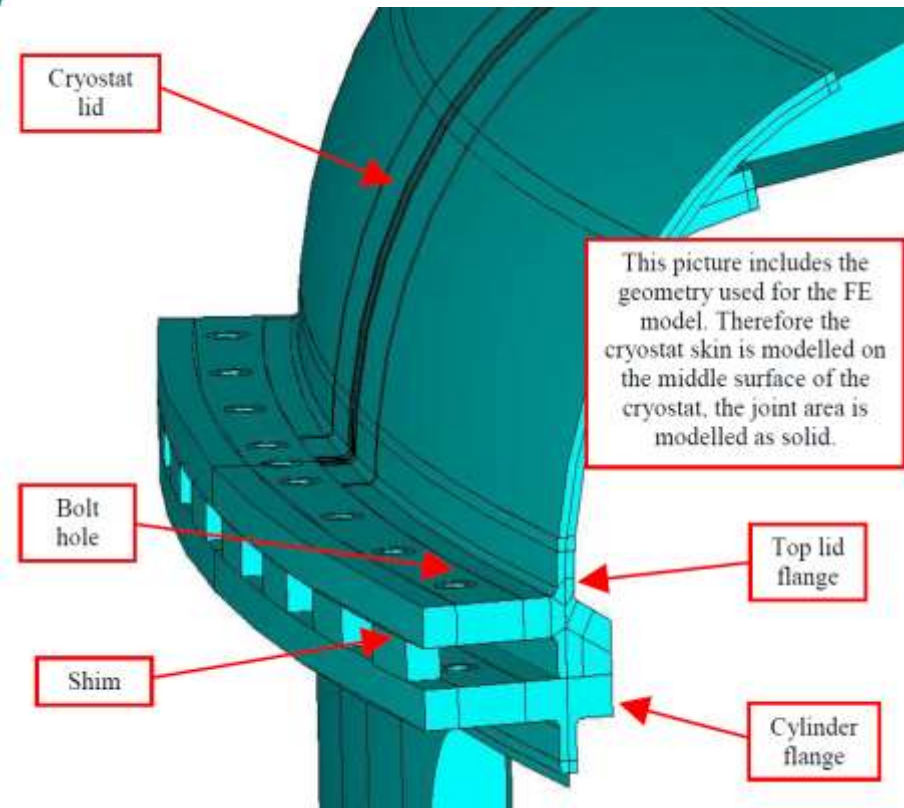
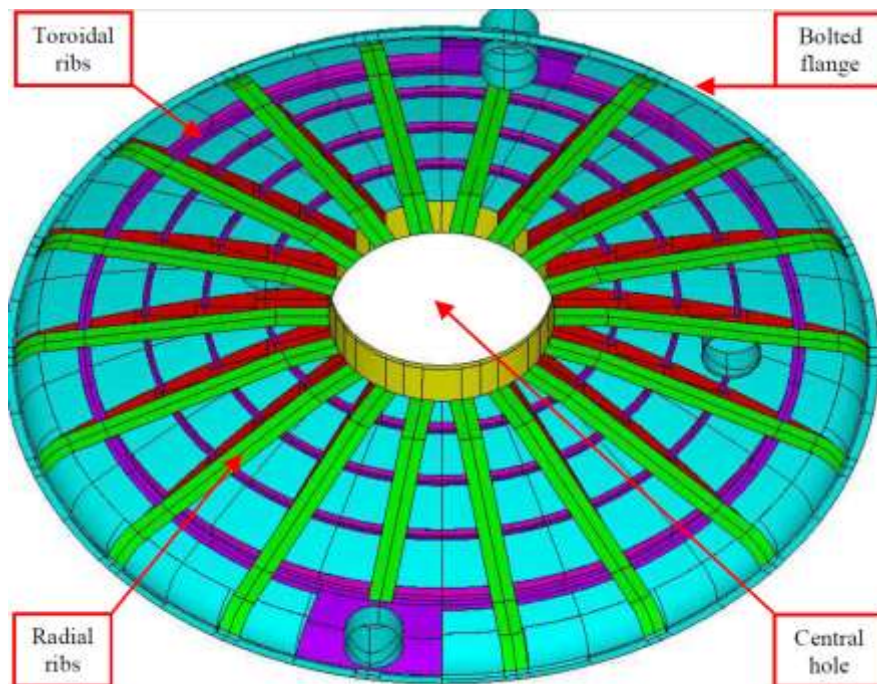
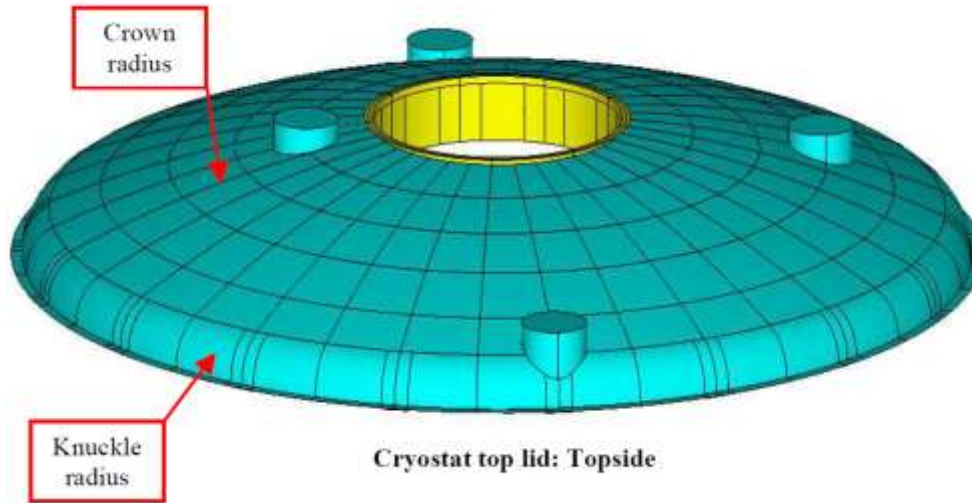
A single fusion reaction of deuterium and tritium, which produces: helium, neutron and energy is released 17.6 MeV



Relatively Constant Electric Current



Structural Analysis of Cryostat Top Lid of ITER



Load cases analysed in ITER

Structural Design Criteria – Based on ASMEVIII, Div. 2

Static Elastic Analysis

Load-cases required to be considered:

Category II:

- 1) $P + D$
- 2) $P + D + VDEII$
- 3) $P + D + SL-1$

Category III:

- 4) $0.83 \cdot [P_{III} + D]$
- 5) $0.83 \cdot [P + D + SL-1 + VDEII]$
- 6) $0.83 \cdot [P + D + VDEIII]$

Category IV:

- 7) $0.5 \cdot [P_{IV} + D]$
- 8) $0.5 \cdot [P + D + SL-2]$

Von Mises stress allowable values:

$$P_m \leq S$$

$$P_m + P_b \leq 1.5S$$

Elastoplastic Analysis

Load-cases required to be considered:

Category II:

- 1) $2.4(P + D)$
- 2) $2.1(P + D) + 2.6VDEII$
- 3) $2.1(P + D) + 2.6SL-1$
- 4) $2.4(P + D) + 1.7VDEII$
- 5) $2.4(P + D) + 1.7SL-1$

Category III:

- 6) $0.83 \cdot (2.4(P_{III} + D))$
- 7) $0.83 \cdot (2.1(P + D) + 2.6 (SL-1 + VDEII))$
- 8) $0.83 \cdot (2.1(P + D) + 2.6VDEIII)$

Category IV:

- 9) $(1/0.7) \cdot (P_{IV} + D)$
- 10) $(1/0.7) \cdot (P + D + SL-2)$

Collapse Load Factor > 1

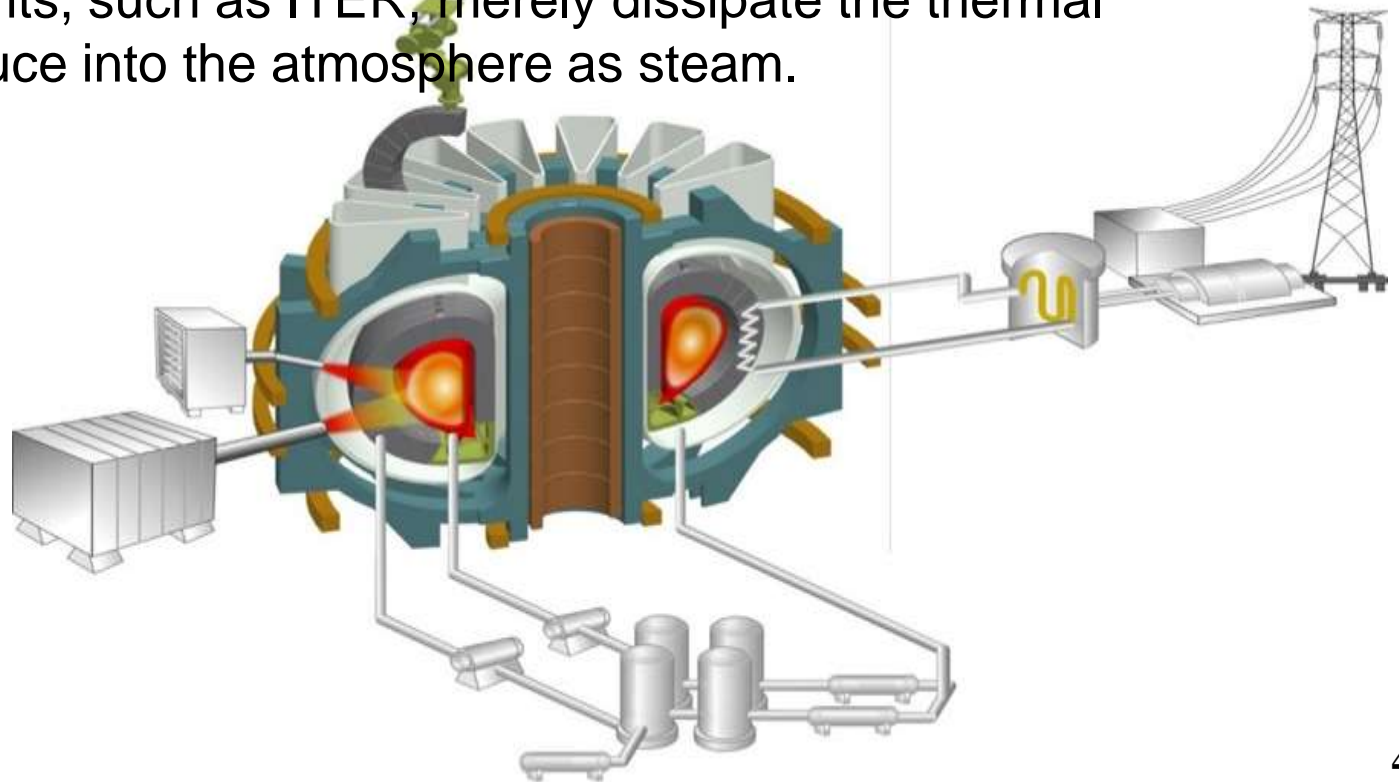


DEMO (DEMONstration Power Plant) is intended to build upon the expected success of the ITER.

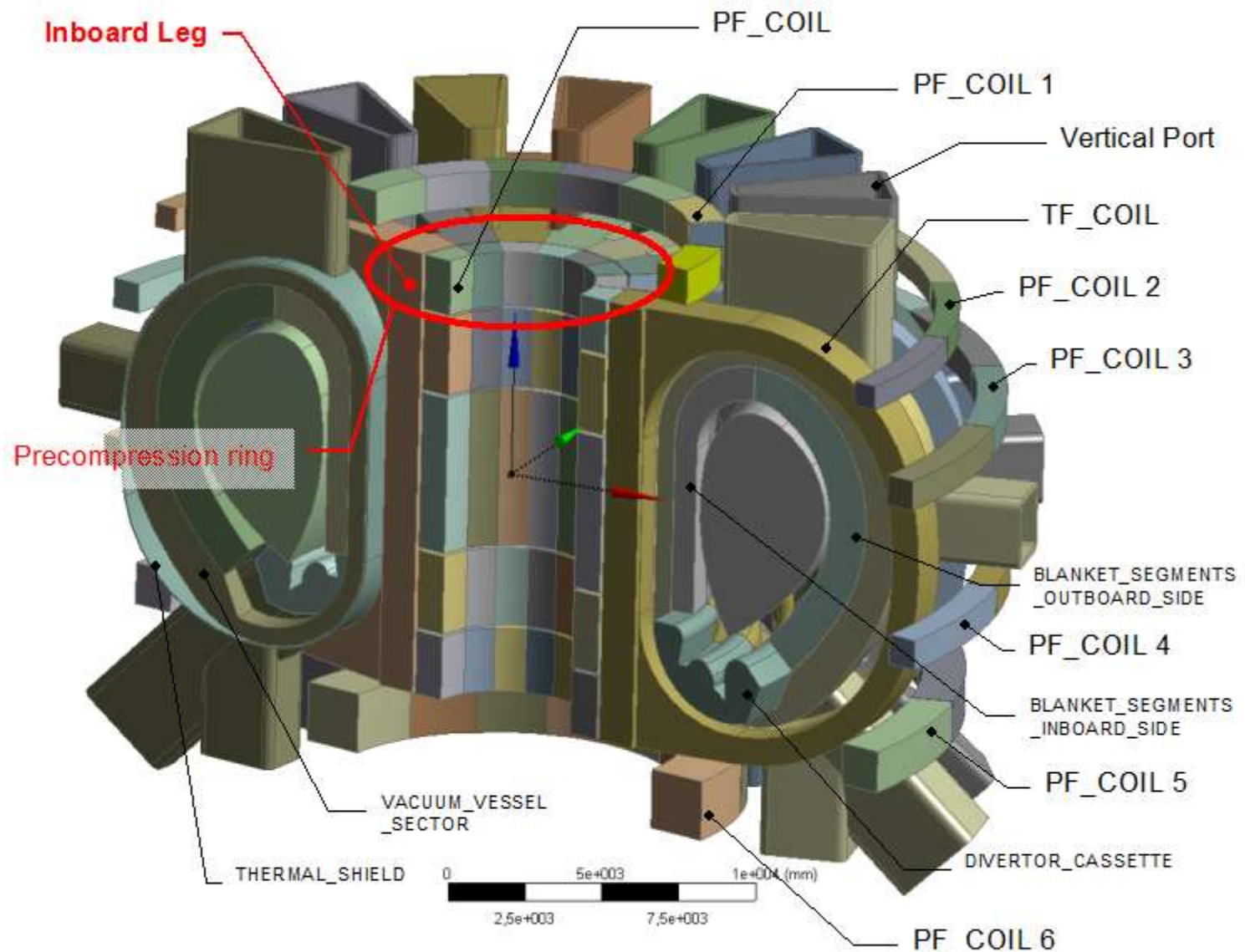
DEMO's **2 to 4 gigawatts** of thermal output will be on the scale of a modern electric power plant.

DEMO is intended to be the first fusion reactor to generate electrical power.

Earlier experiments, such as ITER, merely dissipate the thermal power they produce into the atmosphere as steam.

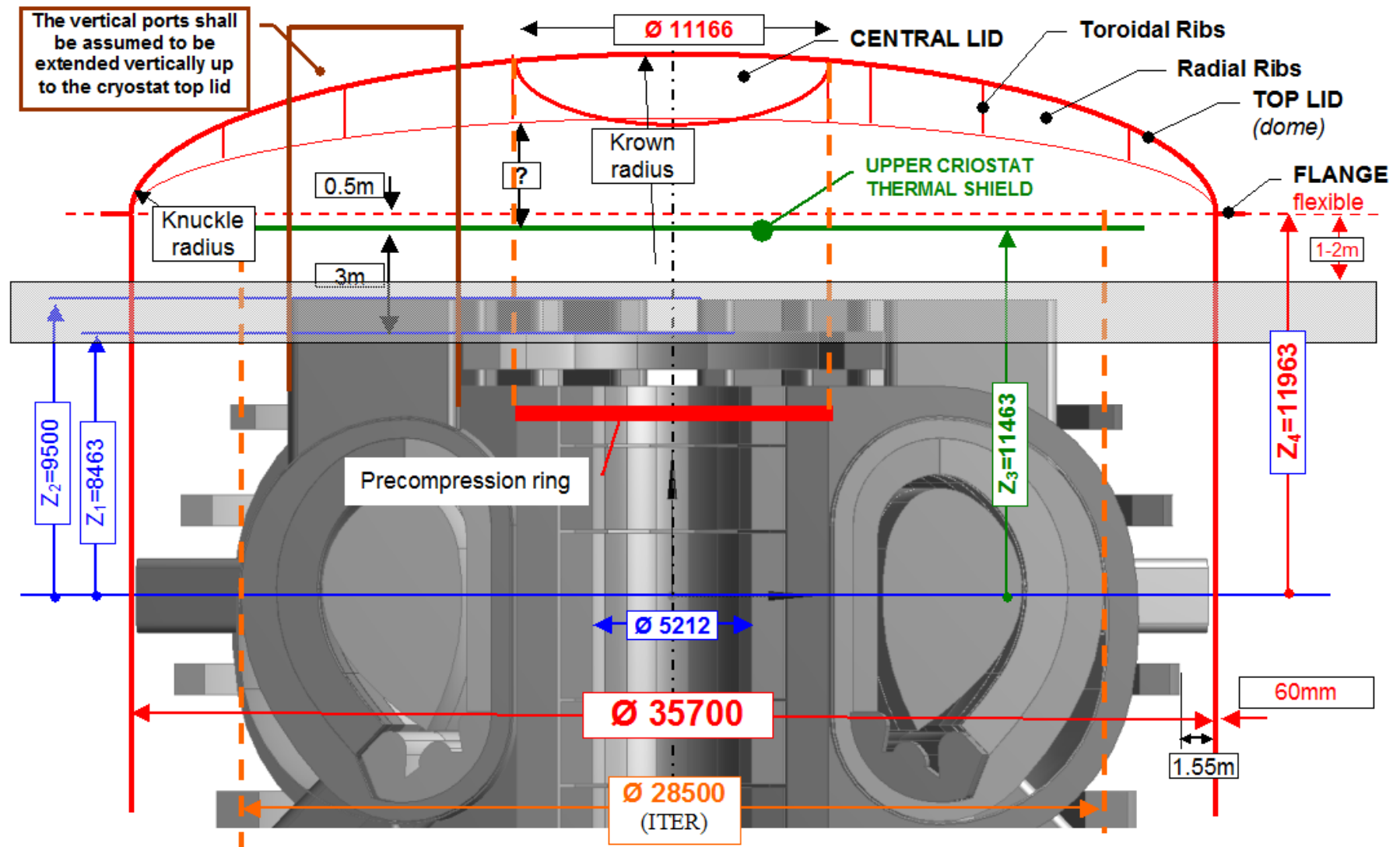


Geometrical Indications and Assumptions for Cryostat Top Lid in DEMO

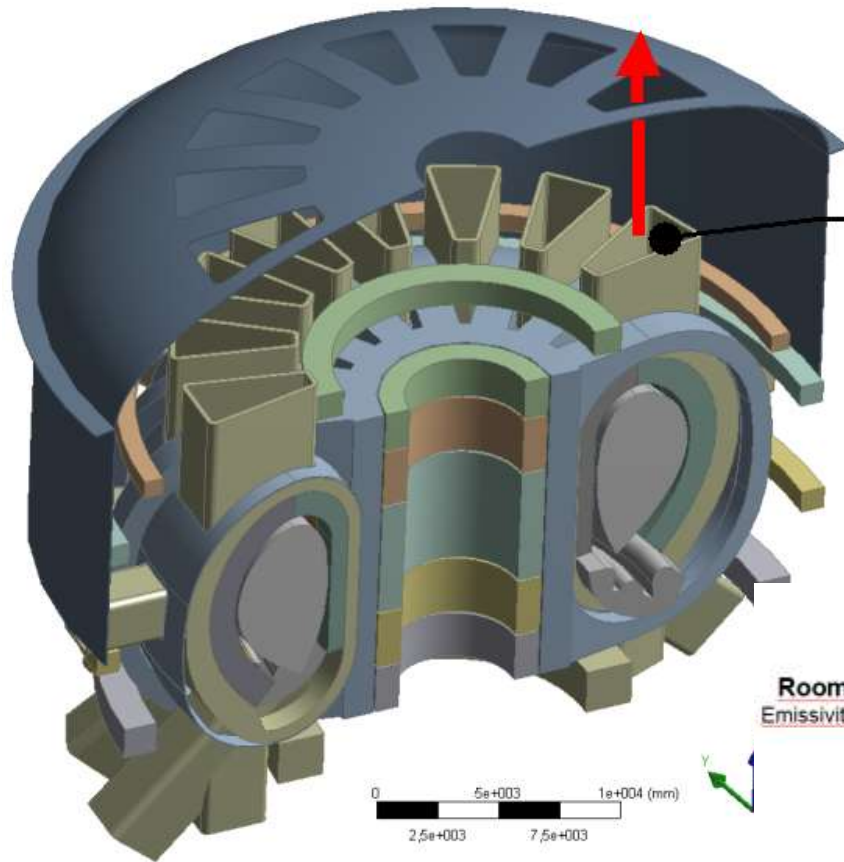


Model Data File: [201405_DEMO_TOKAMAK_COMPLEX.zip](#)

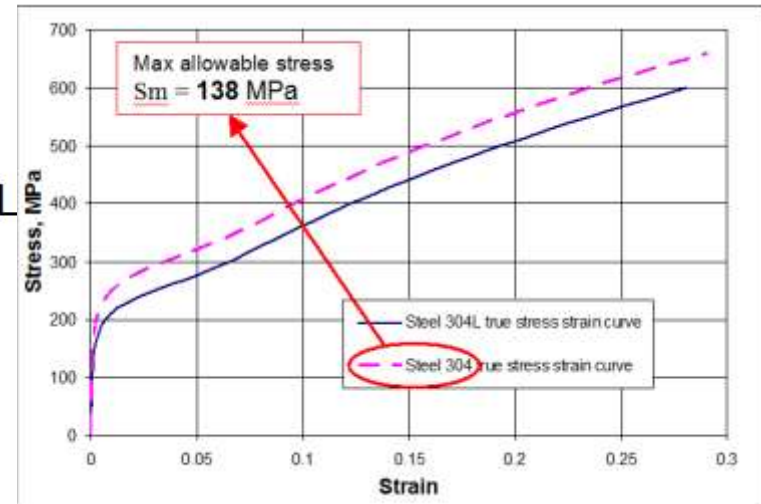
Geometrical Indications and Assumptions for Cryostat Top Lid in DEMO



Geometrical Indications and Assumptions for Cryostat Top Lid in DEMO

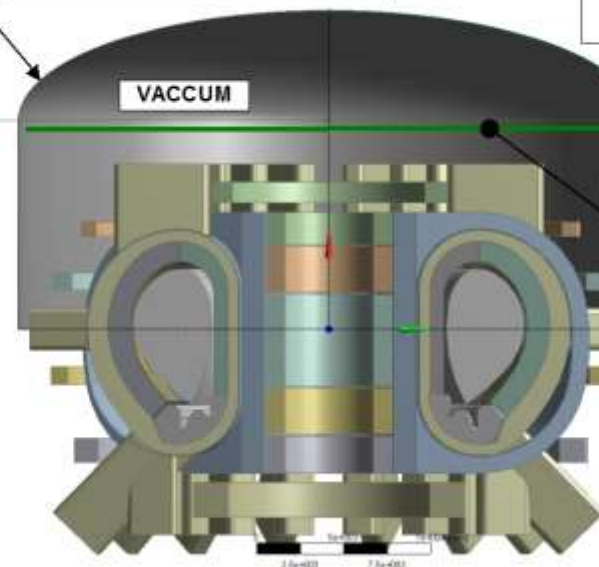


VERTICAL
PORT



Room T
Emissivity 20

EXTERNAL PRESSURE: 1bar



Acceleration
Seismic event (II cat.)
 $\leftrightarrow 4.1 \text{ m/s}^2$
 $\updownarrow 5.2 \text{ m/s}^2$

welded

~~UPPER CRYOSTAT
THERMAL SHIELD
 $T_s = 80\text{K}$
Emissivity 0.05~~

Geometric Model of 1/16 of the Top Lid

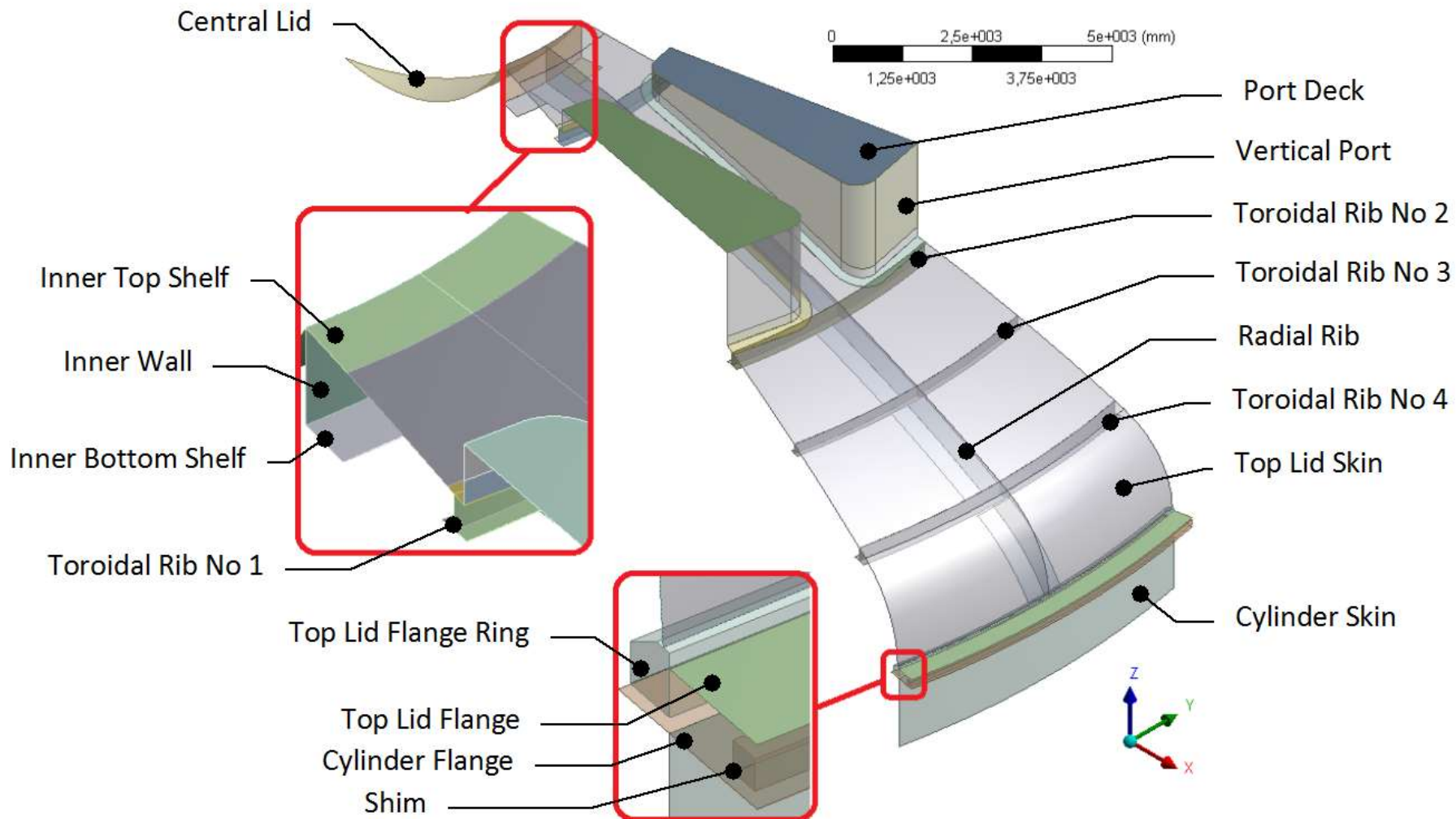


Figure 2-1 Geometrical model of 1/16 of the top lid

Parametric Model in ANSYS WB DesignModeler

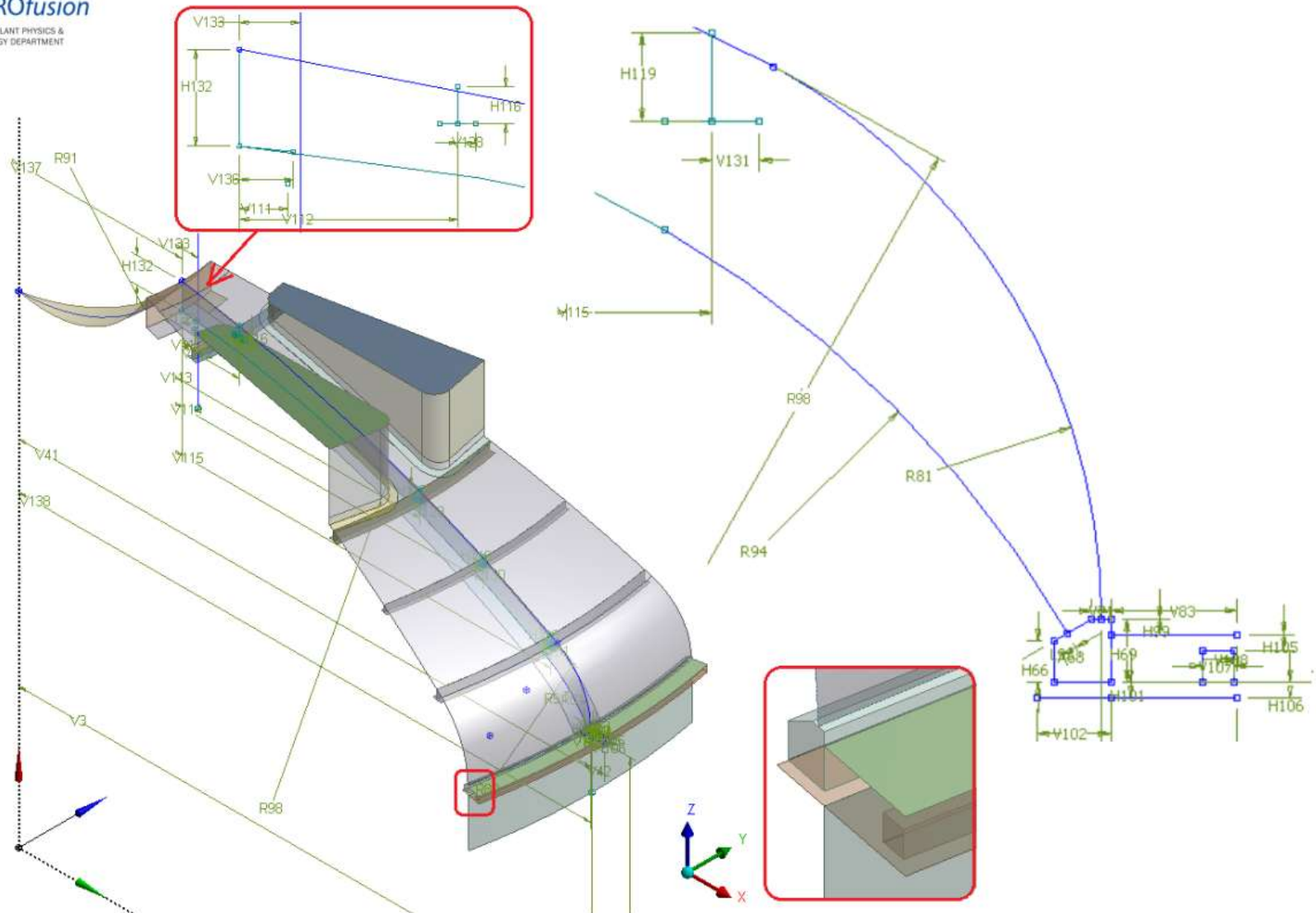
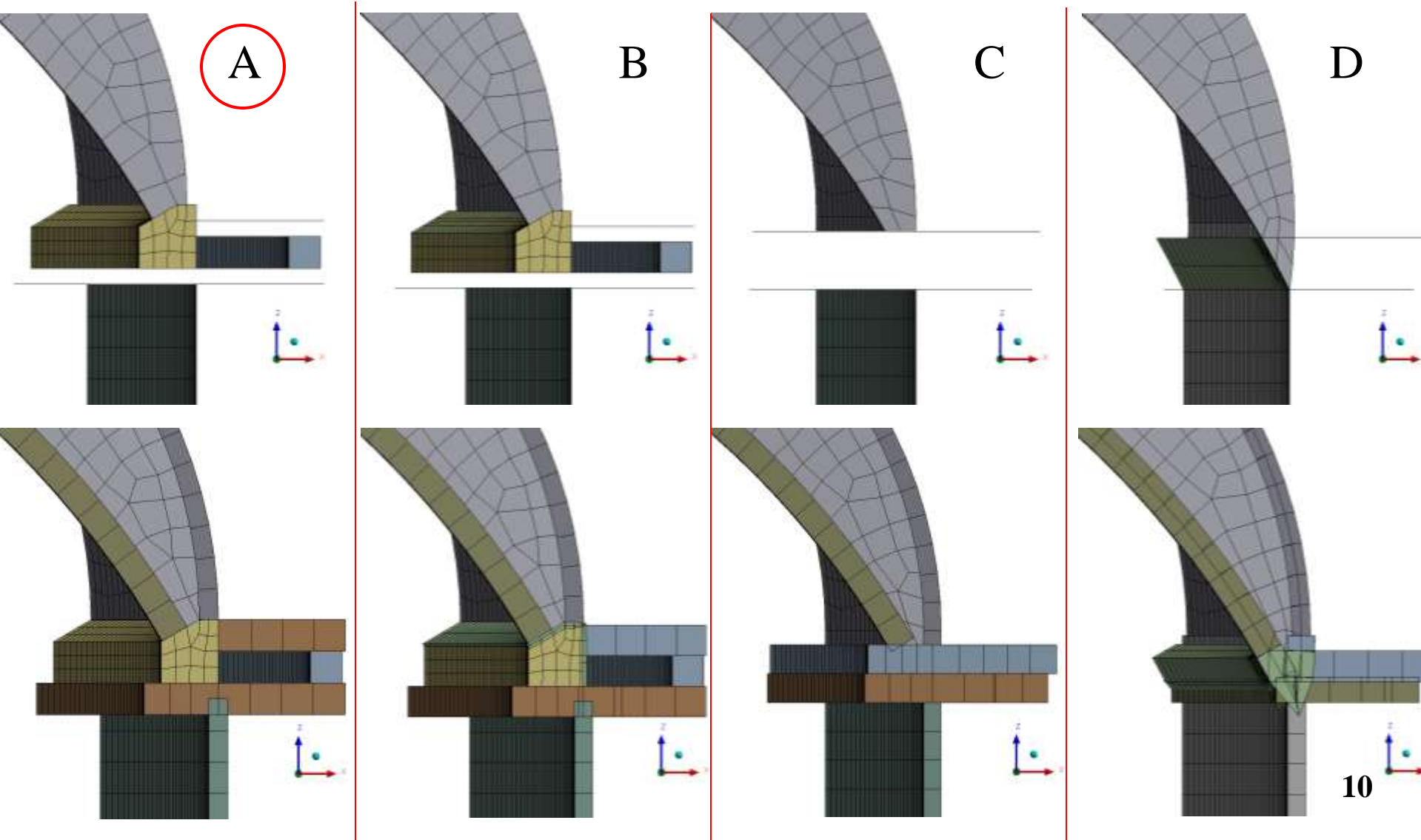
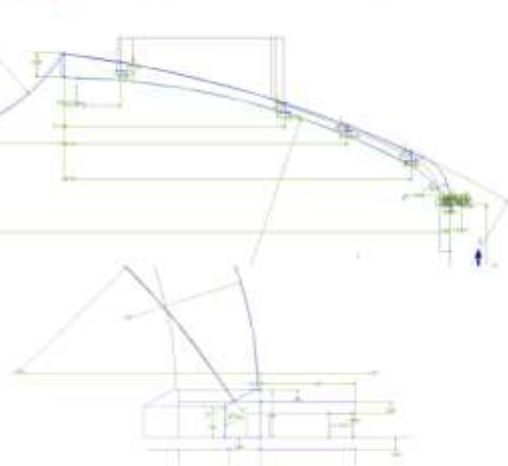
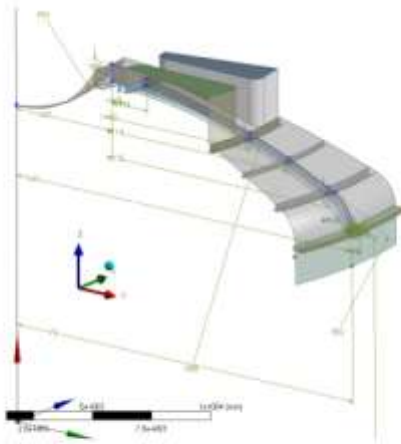


Figure 2-2 Parameters describing geometry of the model

Modelling Shell to Flange Connection



Searching for Optimum Stress Distribution in the Model

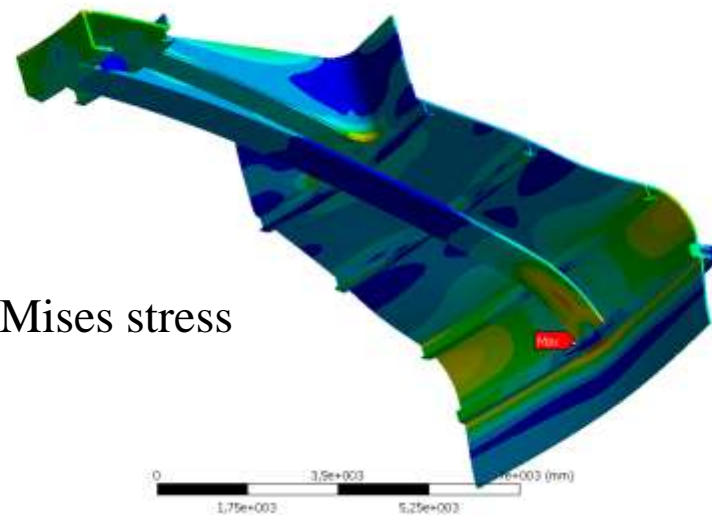


Different Models										Model parameters															
GENEBOI MECH										Pre=118 MPa Pre=Phi=202 MPa															
Model ID	FEZ [mm]	RESIN [mm]	RES [mm]	RES [mm]	Shell/Block [mm]	Layer/Block [mm]	H_R [mm]	V123456 [mm]	V123456 [mm]	V123456 [mm]	V123456 [mm]	V123456 [mm]	V123456 [mm]	V123456 [mm]	V123456 [mm]	V123456 [mm]	V123456 [mm]	V123456 [mm]	V123456 [mm]	V123456 [mm]	V123456 [mm]	V123456 [mm]	V123456 [mm]	V123456 [mm]	average
Model 10	40	1,015,144	30	1,0	440/90	100/40	0,8	1000/500	7400/100	9400/100	11000/500	0,8	0	0	100	0	0	0	0	0	0	0	0	0	Thermal rib
Model 10a	40	1,015,144	V71+120	30	1,0	440/90	100/40	0,8	1000/500	7400/100	9400/100	11000/500	0,8	0	0	100	0	0	0	0	0	0	0	0	Thermal rib
Model 10b	40	1,015,144	V71+120	27	1,0	440/90	100/40	0,8	1000/500	7400/100	9400/100	11000/500	0,8	0	0	100	0	0	0	0	0	0	0	0	Thermal rib
Model 10c	40	1,015,144	V71+120	27	1,0	440/90	100/40	0,8	1000/500	7400/100	9400/100	11000/500	0,8	0	0	100	0	0	0	0	0	0	0	0	Thermal rib
Model 11	40	1,015,144	30	1,0	440/90	100/40	0,8	1000/500	7400/100	9400/100	11000/500	0,8	0	0	100	0	0	0	0	0	0	0	0	0	Thermal rib
Model 11c	40	1,015,144	V71+120	27	1,0	440/90	100/40	0,8	1000/500	7400/100	9400/100	11000/500	0,8	0	0	100	0	0	0	0	0	0	0	0	Thermal rib
Model 11d	40	1,015,144	V71+120	27	1,0	440/90	100/40	0,8	1000/500	7400/100	9400/100	11000/500	0,8	0	0	100	0	0	0	0	0	0	0	0	Thermal rib
Model 11e	40	1,015,144	V71+120	27	1,0	440/90	100/40	0,8	1000/500	7400/100	9400/100	11000/500	0,8	0	0	100	0	0	0	0	0	0	0	0	Thermal rib
Model 11f	40	1,015,144	V71+120	27	1,0	440/90	100/40	0,8	1000/500	7400/100	9400/100	11000/500	0,8	0	0	100	0	0	0	0	0	0	0	0	Thermal rib
Model 11g	40	1,015,144	V71+120	27	1,0	440/90	100/40	0,8	1000/500	7400/100	9400/100	11000/500	0,8	0	0	100	0	0	0	0	0	0	0	0	Thermal rib
Model 11f (no rib)	40	1,015,144	V71+120	27	1,0	440/90	100/40	0,8	1000/500	7400/100	9400/100	11000/500	0,8	0	0	100	0	0	0	0	0	0	0	0	Thermal rib
Pre supported	40	1,015,144	V71+120	27	1,0	440/90	100/40	0,8	1000/500	7400/100	9400/100	11000/500	0,8	0	0	100	0	0	0	0	0	0	0	0	Thermal rib
Model 11f (no rib)	40	1,015,144	V71+120	27	1,0	440/90	100/40	0,8	1000/500	7400/100	9400/100	11000/500	0,8	0	0	100	0	0	0	0	0	0	0	0	Thermal rib

3- Model 11f
Equivalent Stress
Type: Equivalent (von-Mises) Stress - Top/Bottom
Unit: MPa
Time: 1
Custom
Max: 150,93
Min: 0,14351
2014-07-29 22:34



Von Mises stress



Different Shapes Studied

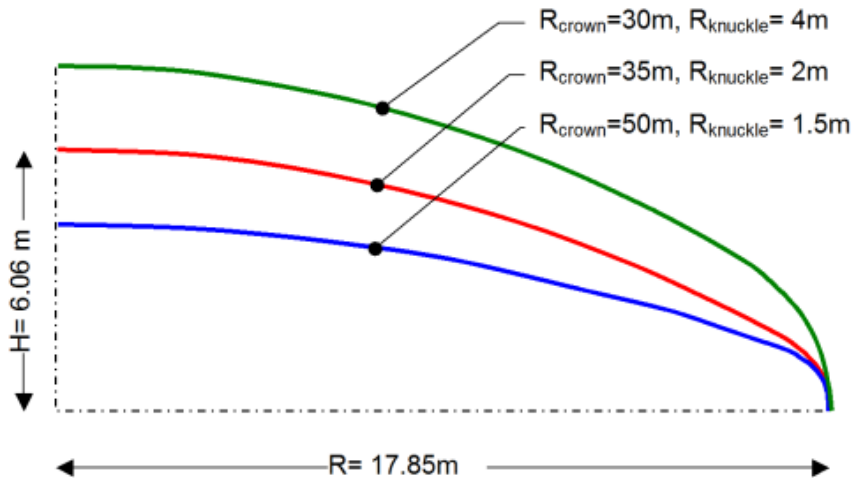


Figure 2-3 Different radii configurations tested

Parameter description	symbol in the database	Value [mm]
Knuckle Radius	R81	2000
Crown Radius	R82	35000
Flange Width	V83	400
Rib Radius 1	R94	3500
Rib Radius 2	R98	28000
Height of the Radial Rib	H132	800
Inner Top Shelf Width	V133	500
Inner Bottom Shelf Width	V136	446.26
Location of Toroidal Rib No 1	V112	1800
Location of Toroidal Rib No 2	V113	7400
Location of Toroidal Rib No 3	V114	9400
Location of Toroidal Rib No 4	V115	11500
Height of Toroidal Rib No 1	H116	300
Height of Toroidal Rib No 2	H117	280
Height of Toroidal Rib No 3	H118	200
Height of Toroidal Rib No 4	H119	280
Half Width of Toroidal Rib No 1	V128	150
Half Width of Toroidal Rib No 2	V129	150
Half Width of Toroidal Rib No 3	V130	100
Half Width of Toroidal Rib No 4	V131	150
Central Opening Radius	V137	5083
Radius of Curvature of the Central Lid	R91	6000

Table 2-1 Main parameters of the geometry for Model 22E A

Details of the model and stress distribution in Model 22_E

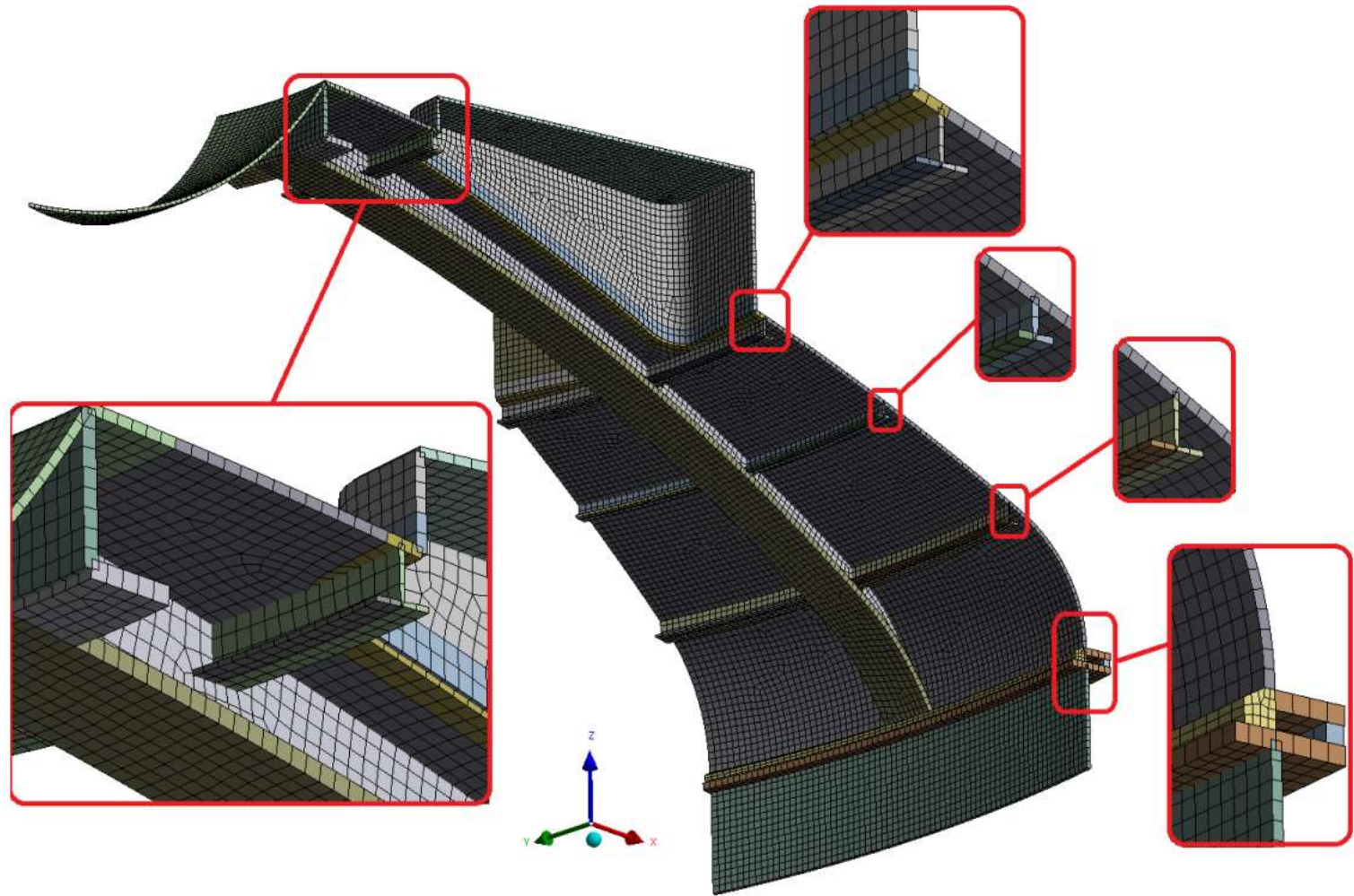


Figure 2-6 FE mesh used in Model 22E A of the top lid

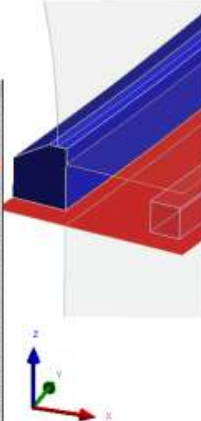
Connections in Model 22_E

a)

Bonded - Surface Body To Solid
2014-10-28 11:48

 Bonded - Surface Body To Solid

Scope of Bonded - Surface Body To Solid	
Scoping Method	Geometry Selection
Contact	2 Faces
Target	1 Body
Contact Bodies	Surface Body
Target Bodies	Solid
Contact Shell Face	Bottom
Shell Thickness Effect	Yes
Definition	
Type	Bonded
Scope Mode	Manual
Behavior	Program Controlled
Trim Contact	Program Controlled
Suppressed	No
Advanced	
Formulation	MPC
Detection Method	Program Controlled
Constraint Type	Target Normal, Couple U to ROT
Pinball Region	Program Controlled
Geometric Modification	
Contact Geometry Correction	None

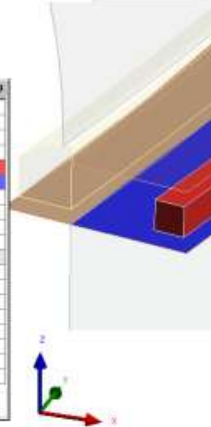


b)

Bonded - Solid To Surface Body
2014-10-28 11:49

 Bonded - Solid To Surface Body

Scope of Bonded - Solid To Surface Body	
Scoping Method	Geometry Selection
Contact	1 Body
Target	1 Face
Contact Bodies	Solid
Target Bodies	Surface Body
Target Shell Face	Bottom
Shell Thickness Effect	Yes
Definition	
Type	Bonded
Scope Mode	Manual
Behavior	Program Controlled
Trim Contact	Program Controlled
Suppressed	No
Advanced	
Formulation	MPC
Detection Method	Program Controlled
Constraint Type	Target Normal, Couple U to ROT
Pinball Region	Program Controlled

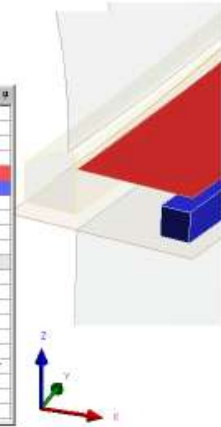


c)

Bonded - Surface Body To Solid
2014-10-28 11:49

 Bonded - Surface Body To Solid

Scope of Bonded - Surface Body To Solid	
Scoping Method	Geometry Selection
Contact	1 Face
Target	1 Body
Contact Bodies	Surface Body
Target Bodies	Solid
Contact Shell Face	Program Controlled
Shell Thickness Effect	Yes
Definition	
Type	Bonded
Scope Mode	Manual
Behavior	Program Controlled
Trim Contact	Program Controlled
Suppressed	No
Advanced	
Formulation	MPC
Detection Method	Program Controlled
Constraint Type	Target Normal, Couple U to ROT
Pinball Region	Program Controlled
Geometric Modification	
Contact Geometry Correction	None



d)

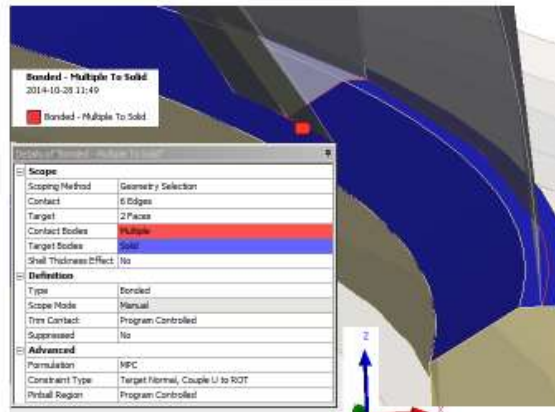
Bonded - Solid To Surface Body
2014-10-28 11:49

 Bonded - Solid To Surface Body

Scope of Bonded - Solid To Surface Body	
Scoping Method	Geometry Selection
Contact	1 Body
Target	1 Edge
Contact Bodies	Solid
Target Bodies	Surface Body
Shell Thickness Effect	No
Definition	
Type	Bonded
Scope Mode	Manual
Trim Contact	Program Controlled
Suppressed	No
Advanced	
Formulation	MPC
Detection Method	Program Controlled
Constraint Type	Target Normal, Couple U to ROT
Pinball Region	Program Controlled



e)



Scope of Bonded - Multiple To Solid	
Scoping Method	Geometry Selection
Contact	6 Edges
Target	2 Faces
Contact Bodies	Multiple
Target Bodies	Solid
Shell Thickness Effect	No
Definition	
Type	Bonded
Scope Mode	Manual
Trim Contact	Program Controlled
Suppressed	No
Advanced	
Formulation	MPC
Detection Method	Program Controlled
Constraint Type	Target Normal, Couple U to ROT
Pinball Region	Program Controlled

f)

Bonded - Surface Body To Multiple 2
2014-10-28 11:50

 Bonded - Surface Body To Multiple 2

Scope of Bonded - Surface Body To Multiple 2	
Scoping Method	Geometry Selection
Contact	1 Edge
Target	2 Edges
Contact Bodies	Surface Body
Target Bodies	Multiple
Shell Thickness Effect	No
Definition	
Type	Bonded
Scope Mode	Manual
Trim Contact	Program Controlled
Suppressed	No
Advanced	
Formulation	MPC
Detection Method	Program Controlled
Constraint Type	Target Normal, Uncouple U to ROT
Pinball Region	Program Controlled

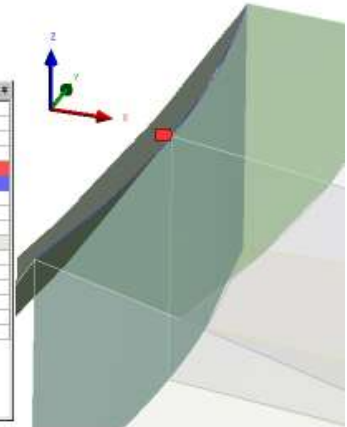


Figure 2-7 The connection regions in Model 22E A of the top lid

Symmetry Conditions

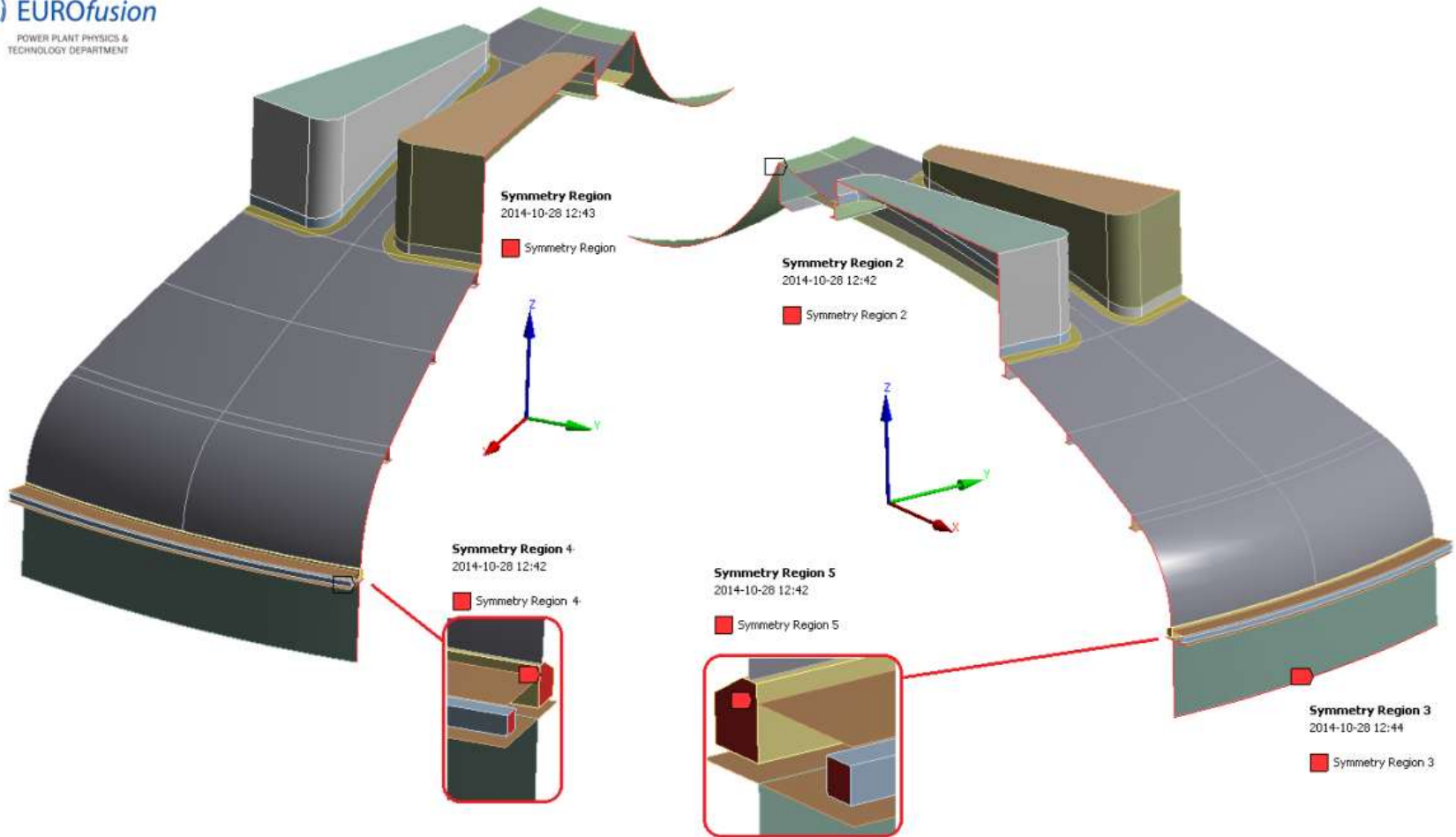


Figure 2-8 Symmetry conditions in Model 22E A of the top lid

Operational Load

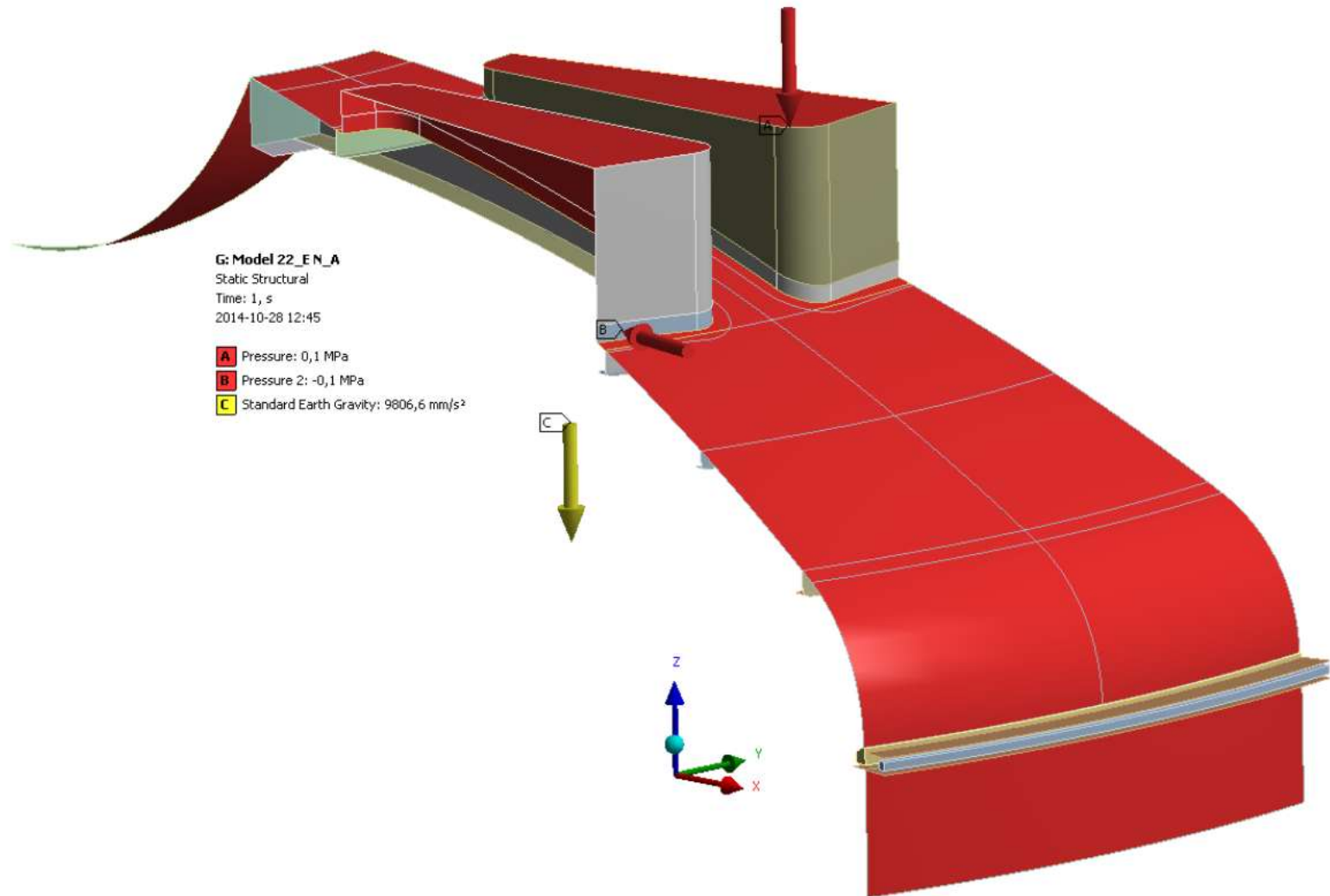


Figure 2-9 Operation load in 1/16 Model 22E A of the top lid

Operational Load and Boundary Conditions

C: Model 22_E_A_FULL

Static Structural

Time: 1, s

2014-10-28 13:06

- A** Pressure: 0,1 MPa
- B** Pressure 2: -0,1 MPa
- C** Standard Earth Gravity: 9806,6 mm/s²
- D** Displacement 3

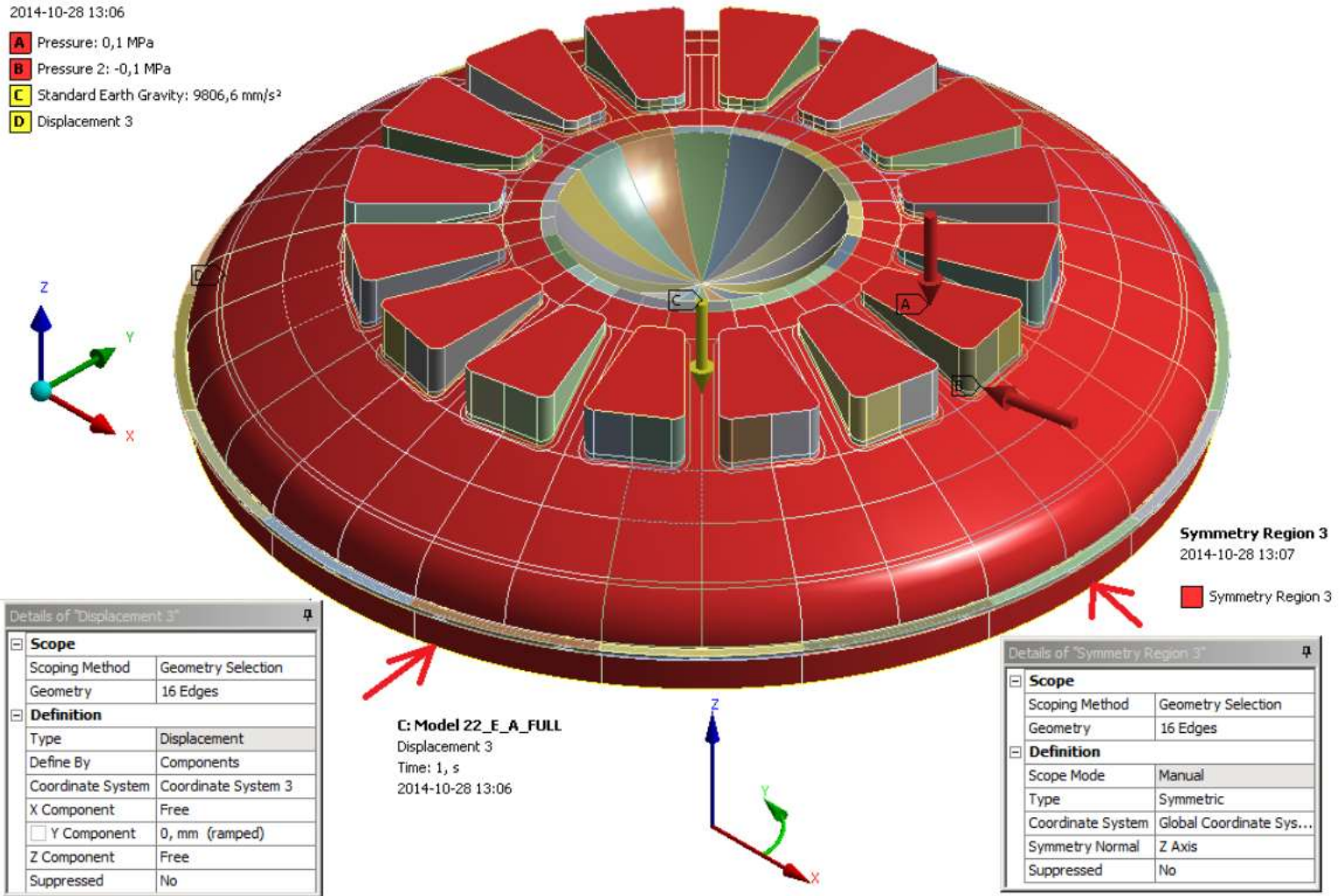


Figure 2-10 Operation load and boundary conditions in FULL Model of the top lid

Linear Structural Analysis for Model 22_E

O: Model 22_E_N_SPR_A

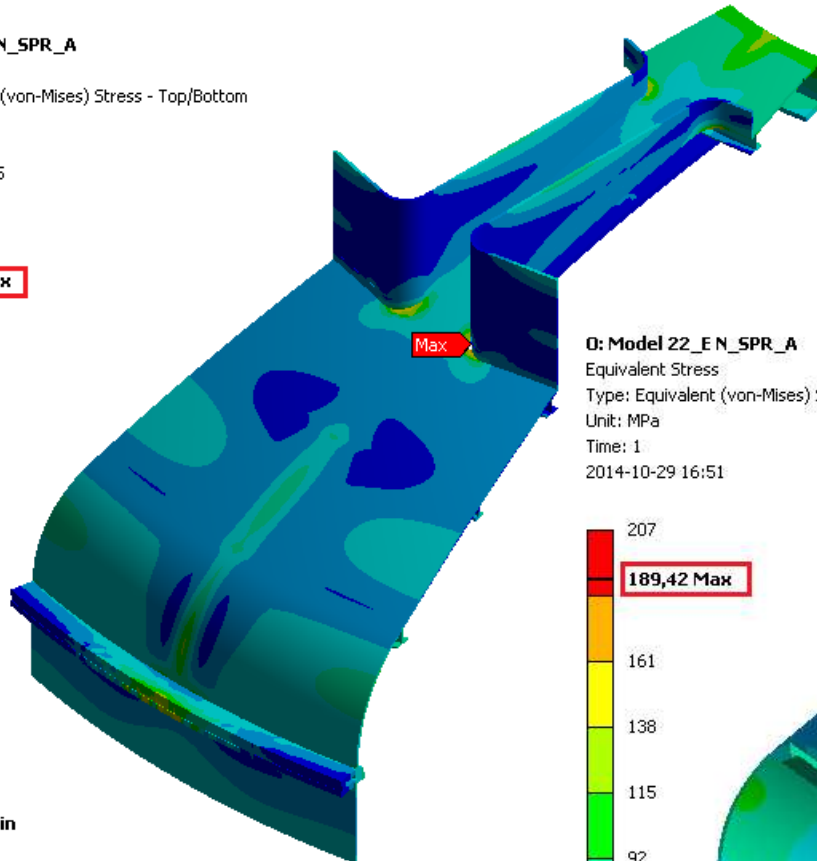
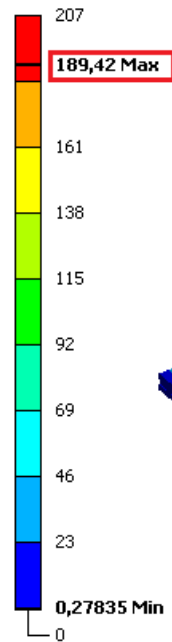
Equivalent Stress

Type: Equivalent (von-Mises) Stress - Top/Bottom

Unit: MPa

Time: 1

2014-10-29 16:55



O: Model 22_E_N_SPR_A

Equivalent Stress

Type: Equivalent (von-Mises) Stress - Top/Bottom

Unit: MPa

Time: 1

2014-10-29 16:51

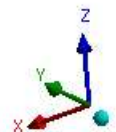
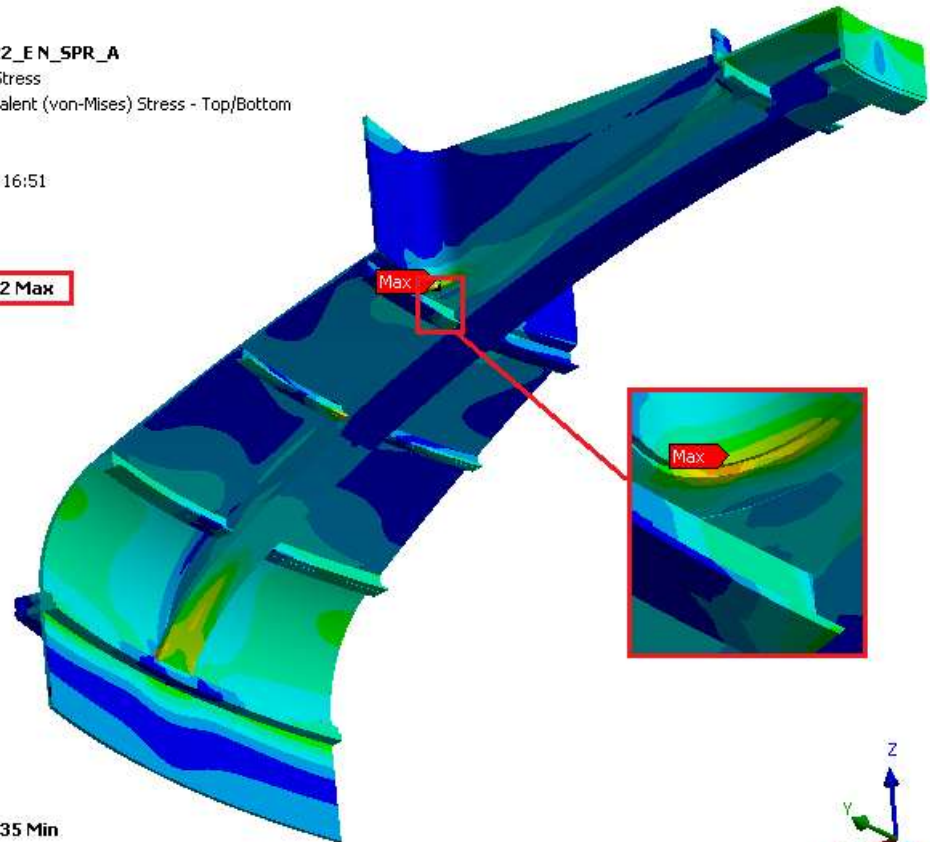
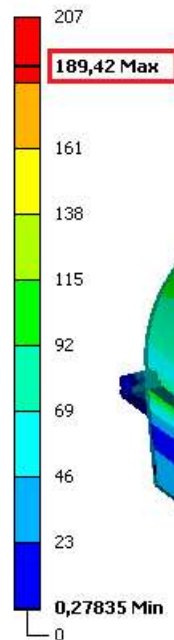


Fig. 3-1 Von Mises stress ($P_m + P_b$) in 1/16 model: Category II (P+D)

Linear Structural Analysis for Model 22_E

O: Model 22_E_N_SPR_A

Equivalent Stress 2

Type: Equivalent (von-Mises) Stress - Middle

Unit: MPa

Time: 1

Custom

Max: 172,11

Min: 0,075533

2014-10-29 16:50

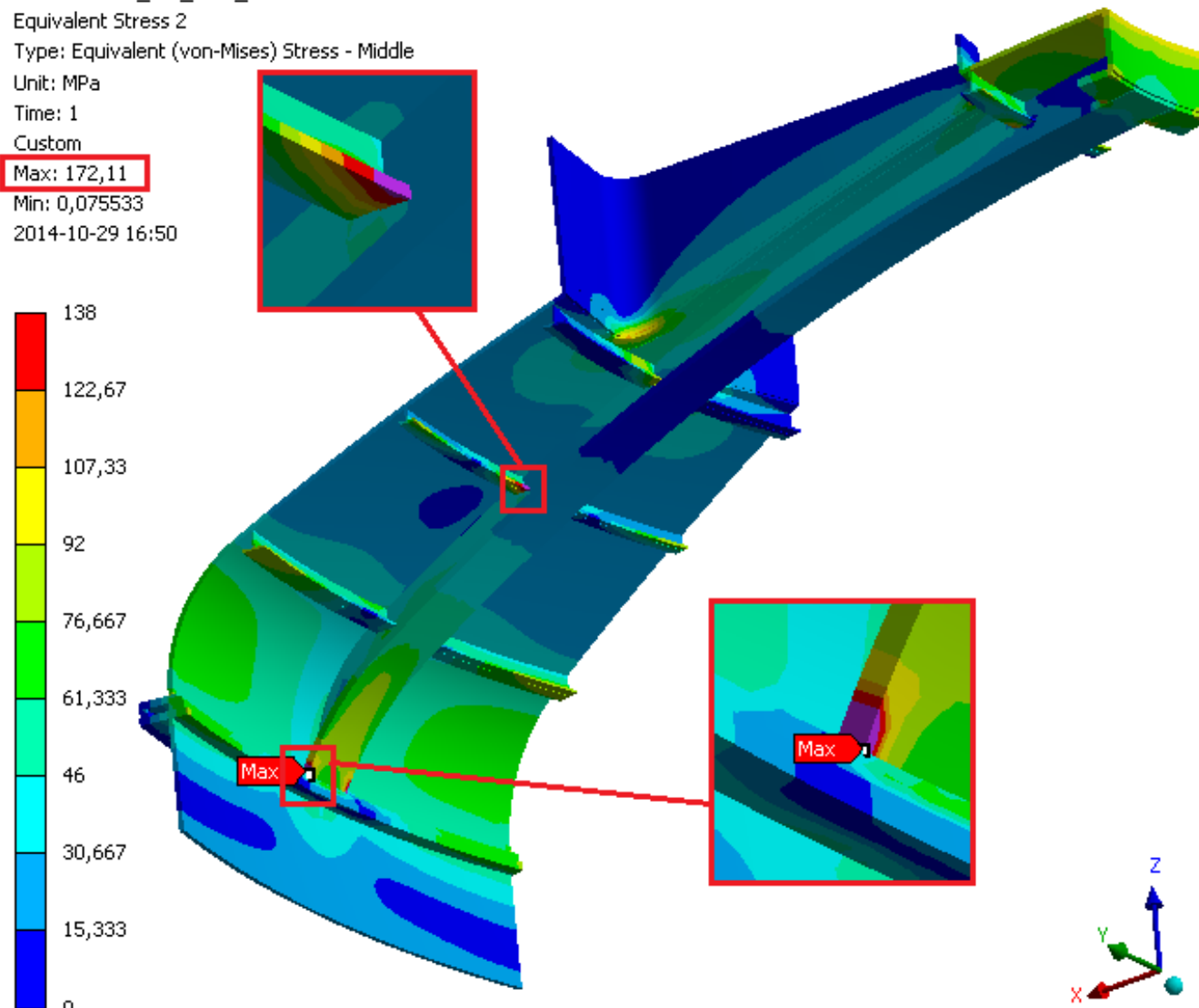


Fig. 3-2 Von Mises membrane stress (Pm) in 1/16 model: Category II (P+D)

Linear Structural Analysis for Model 22_E

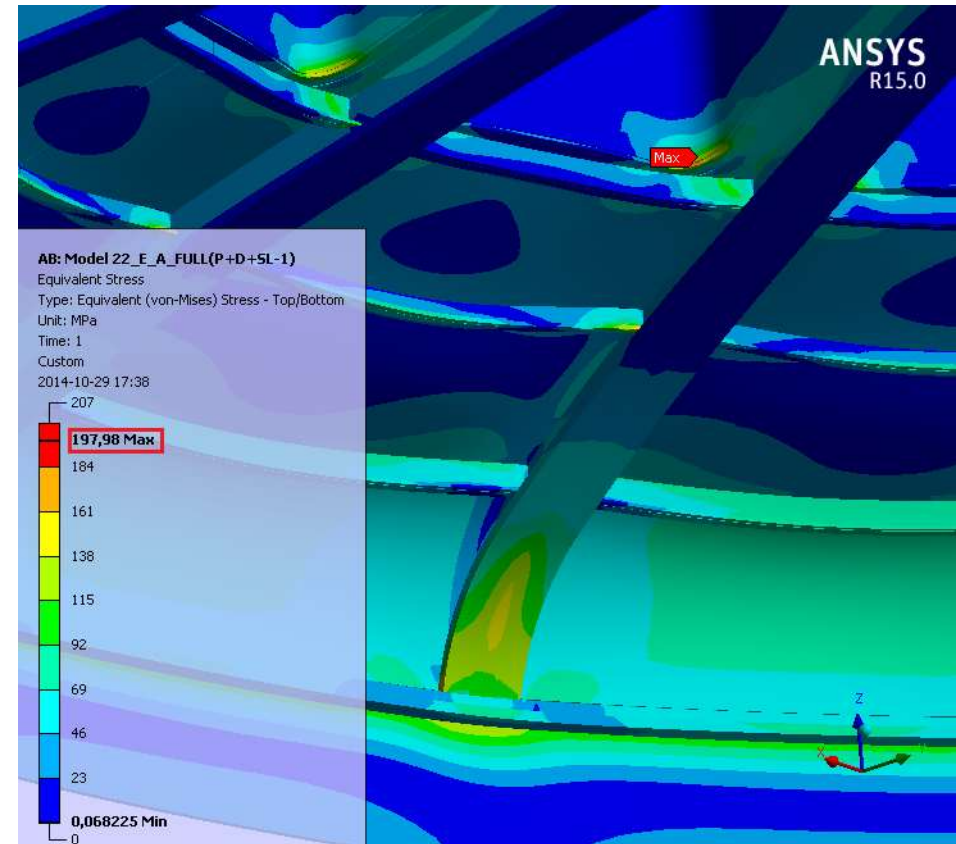
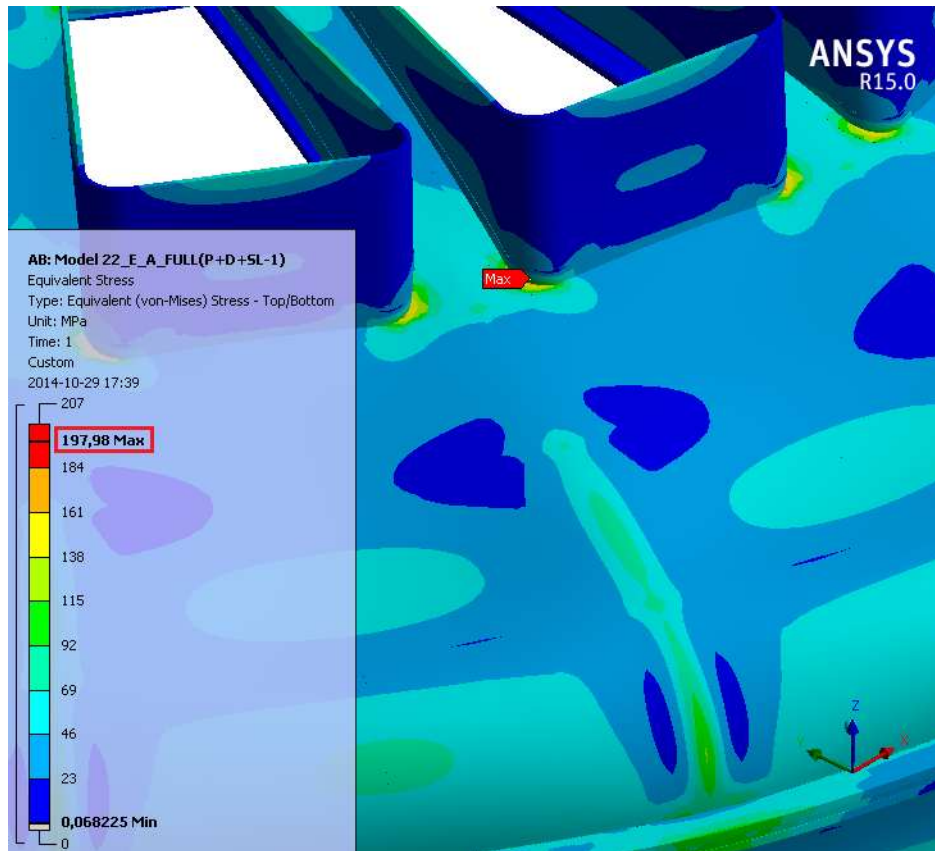


Fig. 3-3 Von Mises stress (Pm+Pb) in FULL model: Category II (P+D+SL-1)

Linear Structural Analysis for Model 22_E

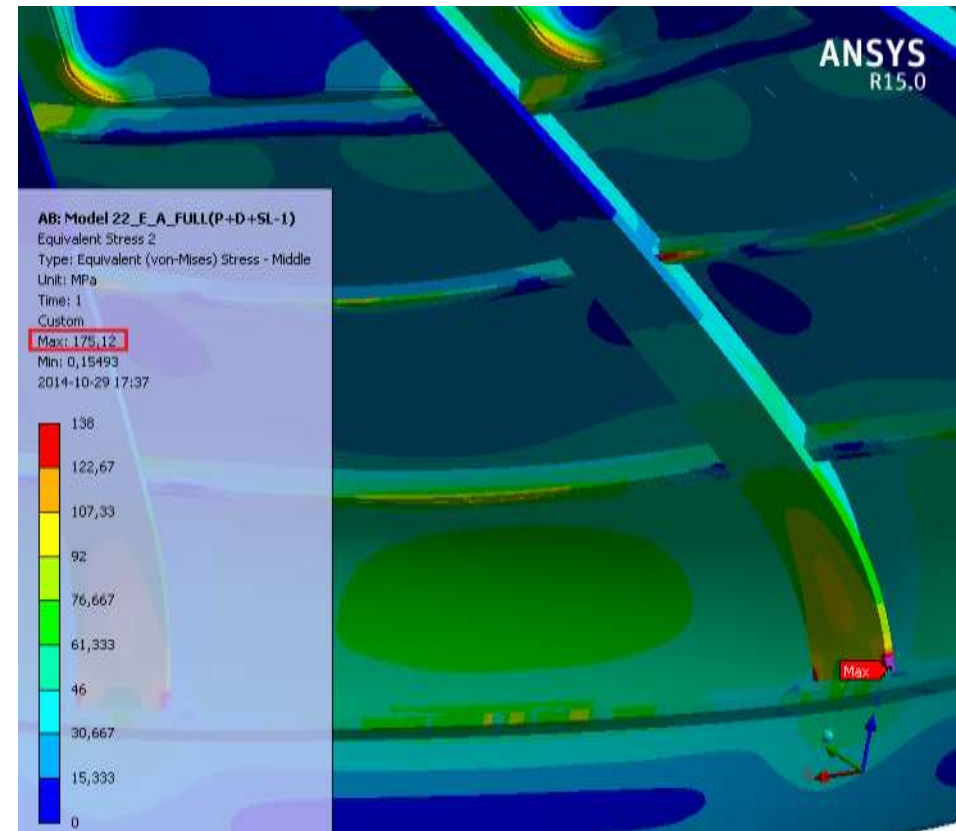
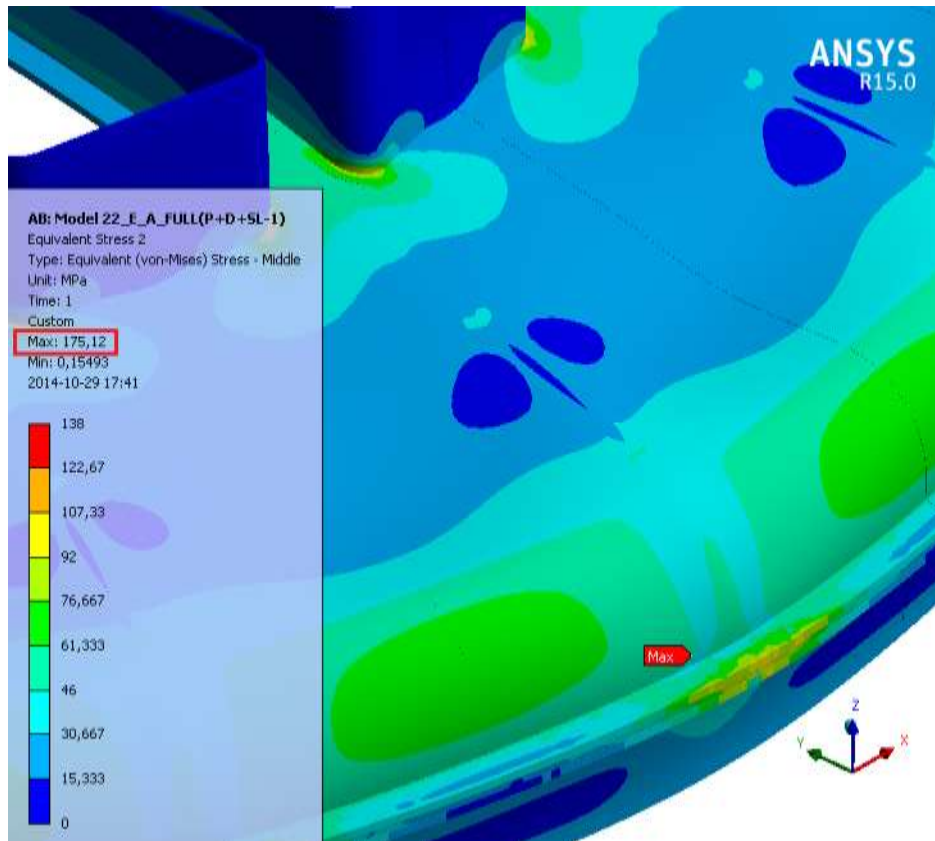


Fig. 3-4 Von Mises membrane stress (Pm) in FULL model: Category II (P+D+SL-1)

Linear Buckling Analysis for Model 22_E

H: Linear Buckling

Directional Deformation①

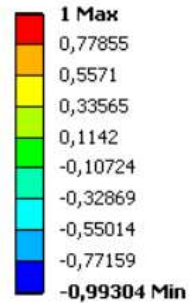
Type: Directional Deformation(Z Axis)

Load Multiplier: 14,065

Unit: mm

Global Coordinate System

2014-10-29 18:32



H: Linear Buckling

Directional Deformation②

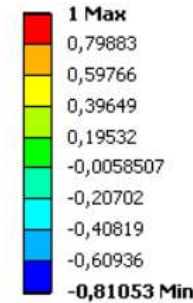
Type: Directional Deformation(Z Axis)

Load Multiplier: 15,047

Unit: mm

Global Coordinate System

2014-10-29 18:32



H: Linear Buckling

Directional Deformation③

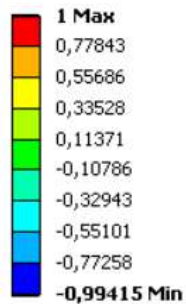
Type: Directional Deformation(Z Axis)

Load Multiplier: 15,053

Unit: mm

Global Coordinate System

2014-10-29 18:33



H: Linear Buckling

Directional Deformation④

Type: Directional Deformation(Z Axis)

Load Multiplier: 14,065

Unit: mm

Global Coordinate System

2014-10-29 18:40

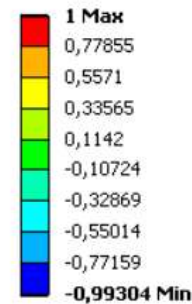
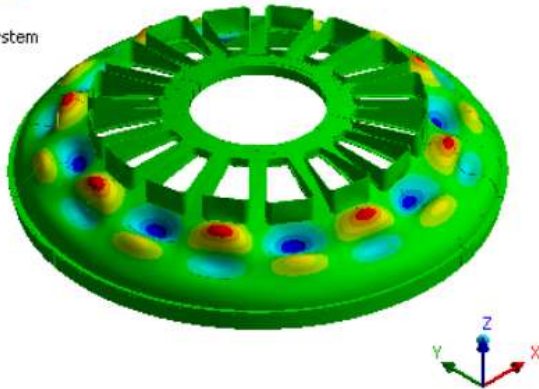
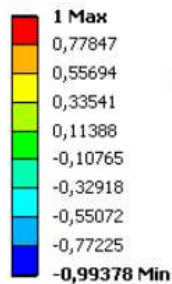


Fig. 3-5 Linear buckling : Category II (P+D) for 1/16 model – mode shapes No 1,2,3 & 4

Linear Buckling Analysis for Model 22_E

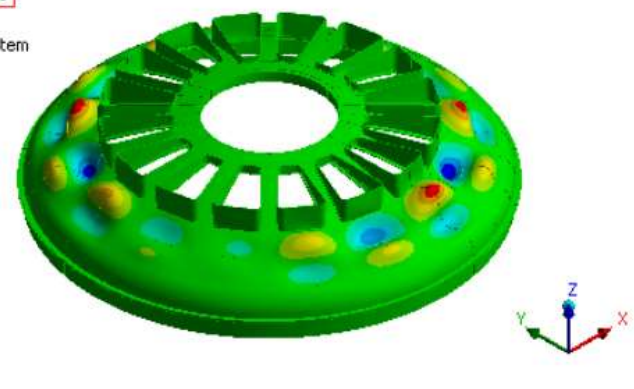
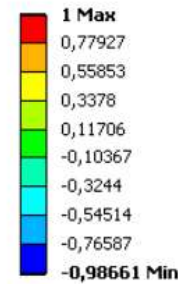
D: Linear Buckling

Directional Deformation①
Type: Directional Deformation(Z Axis)
Load Multiplier: 14,19
Unit: mm
Global Coordinate System
2014-10-29 18:20



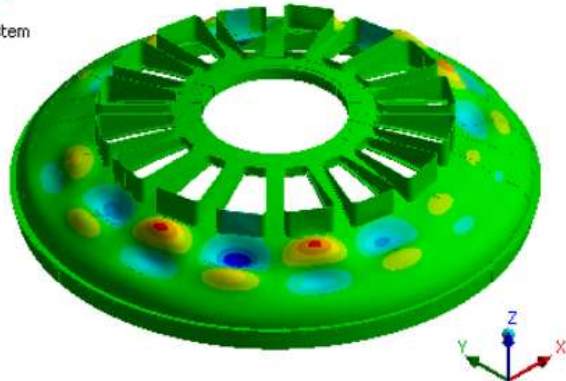
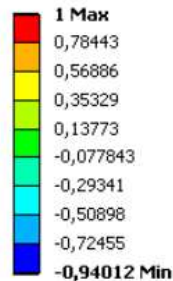
D: Linear Buckling

Directional Deformation②
Type: Directional Deformation(Z Axis)
Load Multiplier: 14,256
Unit: mm
Global Coordinate System
2014-10-29 18:20



D: Linear Buckling

Directional Deformation③
Type: Directional Deformation(Z Axis)
Load Multiplier: 14,259
Unit: mm
Global Coordinate System
2014-10-29 18:20



D: Linear Buckling

Directional Deformation④
Type: Directional Deformation(Z Axis)
Load Multiplier: 14,411
Unit: mm
Global Coordinate System
2014-10-29 18:20

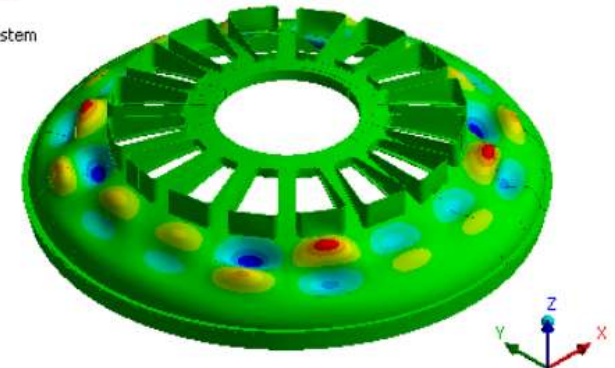
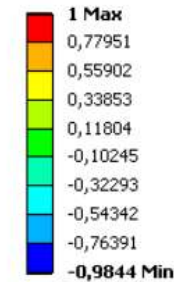
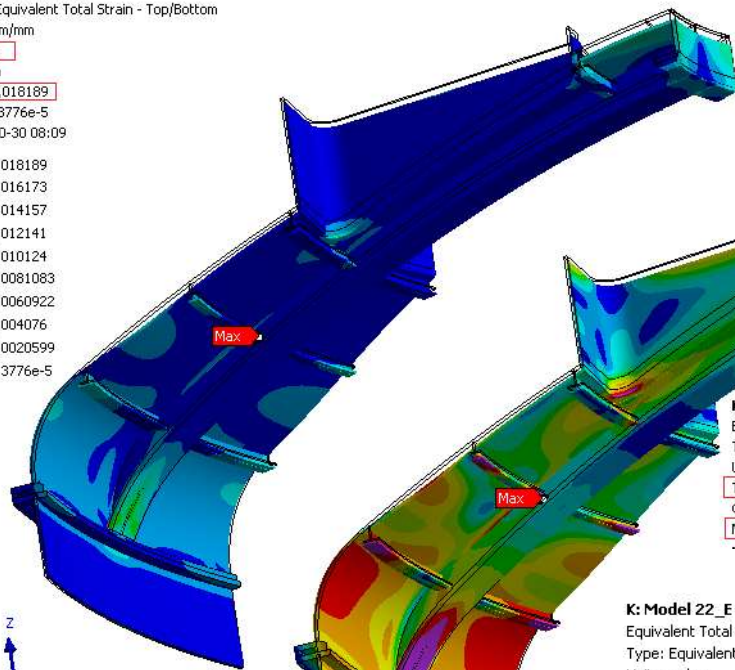
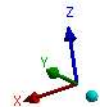


Fig. 3-6 Linear buckling : Category II (P+D) for FULL model – mode shapes No 1,2,3 & 4

K: Model 22_E PLAST_A
 Equivalent Total Strain
 Type: Equivalent Total Strain - Top/Bottom
 Unit: mm/mm
 Time: 1
 Custom
 Max: 0,018189
 Min: 4,3776e-5
 2014-10-30 08:09

0,018189
 0,016173
 0,014157
 0,012141
 0,010124
 0,0081083
 0,0060922
 0,004076
 0,0020599
 4,3776e-5



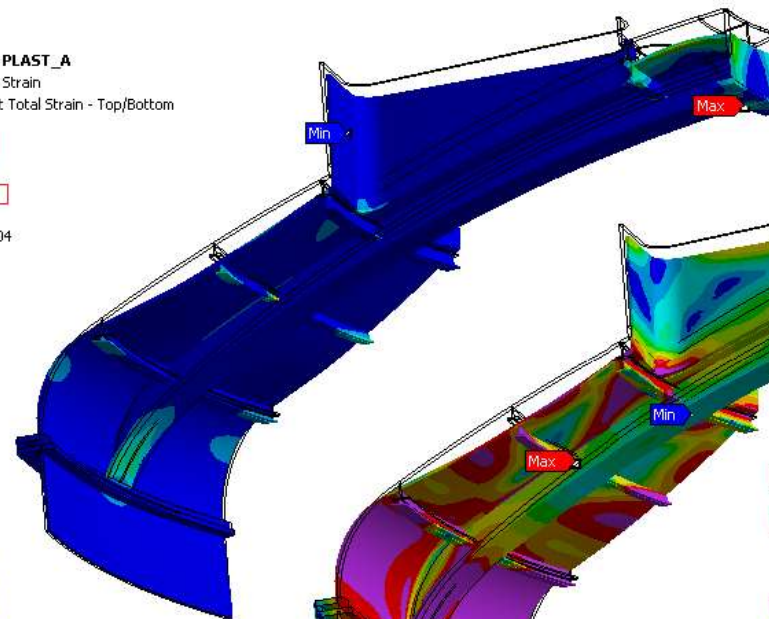
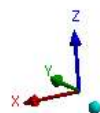
Plastic Collapse in 1/16 Model

Fig. 3-7 Non-linear analysis for 1/16 model:
 [2.4 (P+D)] – E_{VM} and S_{VM} at LF=1

K: Model 22_E PLAST_A
 Equivalent Stress
 Type: Equivalent (von-Mises) Stress - Top/Bottom
 Unit: MPa
 Time: 1
 Custom
 Max: 267,23

K: Model 22_E PLAST_A
 Equivalent Total Strain
 Type: Equivalent Total Strain - Top/Bottom
 Unit: mm/mm
 Time: 1,1471
 Custom
 Max: 0,063554
 Min: 5,14e-5
 2014-11-03 12:04

0,0636
 0,056539
 0,049478
 0,042417
 0,035356
 0,028295
 0,021234
 0,014173
 0,007112
 5,0977e-5



K: Model 22_E PLAST_A
 Equivalent Stress
 Type: Equivalent (von-Mises) Stress - Top/Bottom
 Unit: MPa
 Time: 1,1471
 Custom
 Max: 332,46
 Min: 3,0704
 2014-11-03 12:03

207
 184
 161
 138
 115
 92
 69
 46
 23
 0

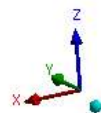


Fig. 3-8 Non-linear analysis for 1/16 model:
 [2.4 (P+D)] – E_{VM} and S_{VM} at LF=1.1471

Plastic Collapse in FULL Model

E: Model 22_E_A_FULL PLAST [2,4(P+D)]

Equivalent Stress

Type: Equivalent (von-Mises) Stress - Top/bottom

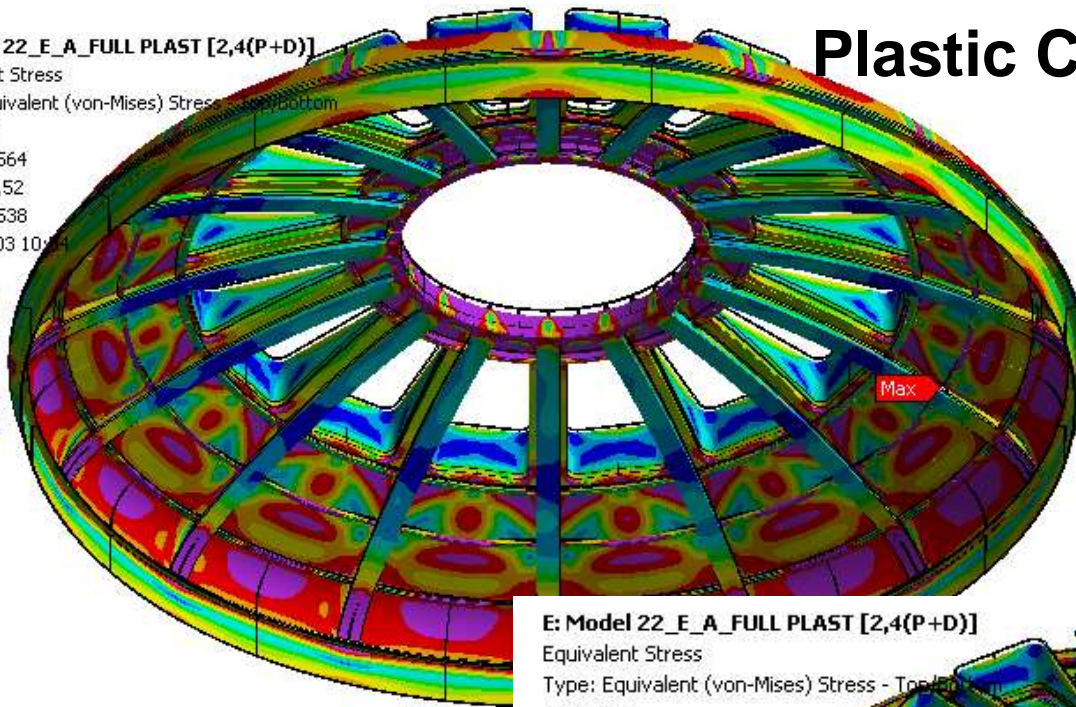
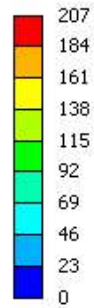
Unit: MPa

Time: 1,1564

Max: 336,52

Min: 0,10538

2014-11-03 10:54



E: Model 22_E_A_FULL PLAST [2,4(P+D)]

Equivalent Stress

Type: Equivalent (von-Mises) Stress - Top/bottom

Unit: MPa

Time: 1,1564

Max: 336,52

Min: 0,10538

2014-11-03 10:54

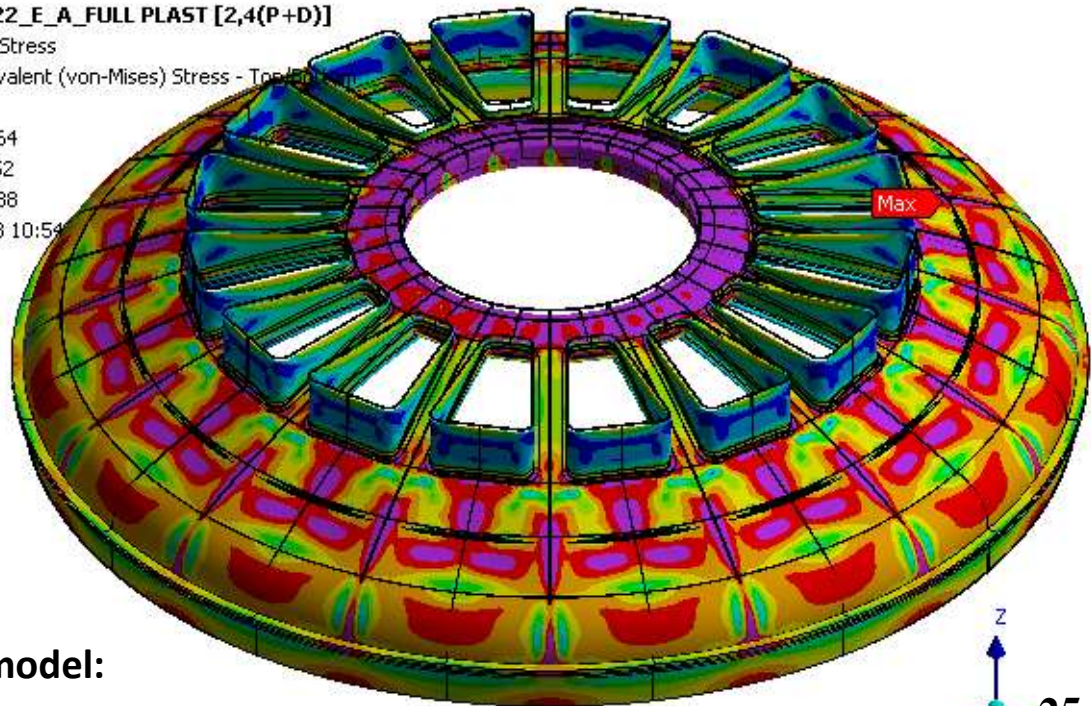
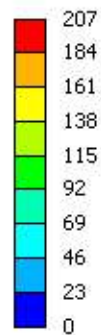
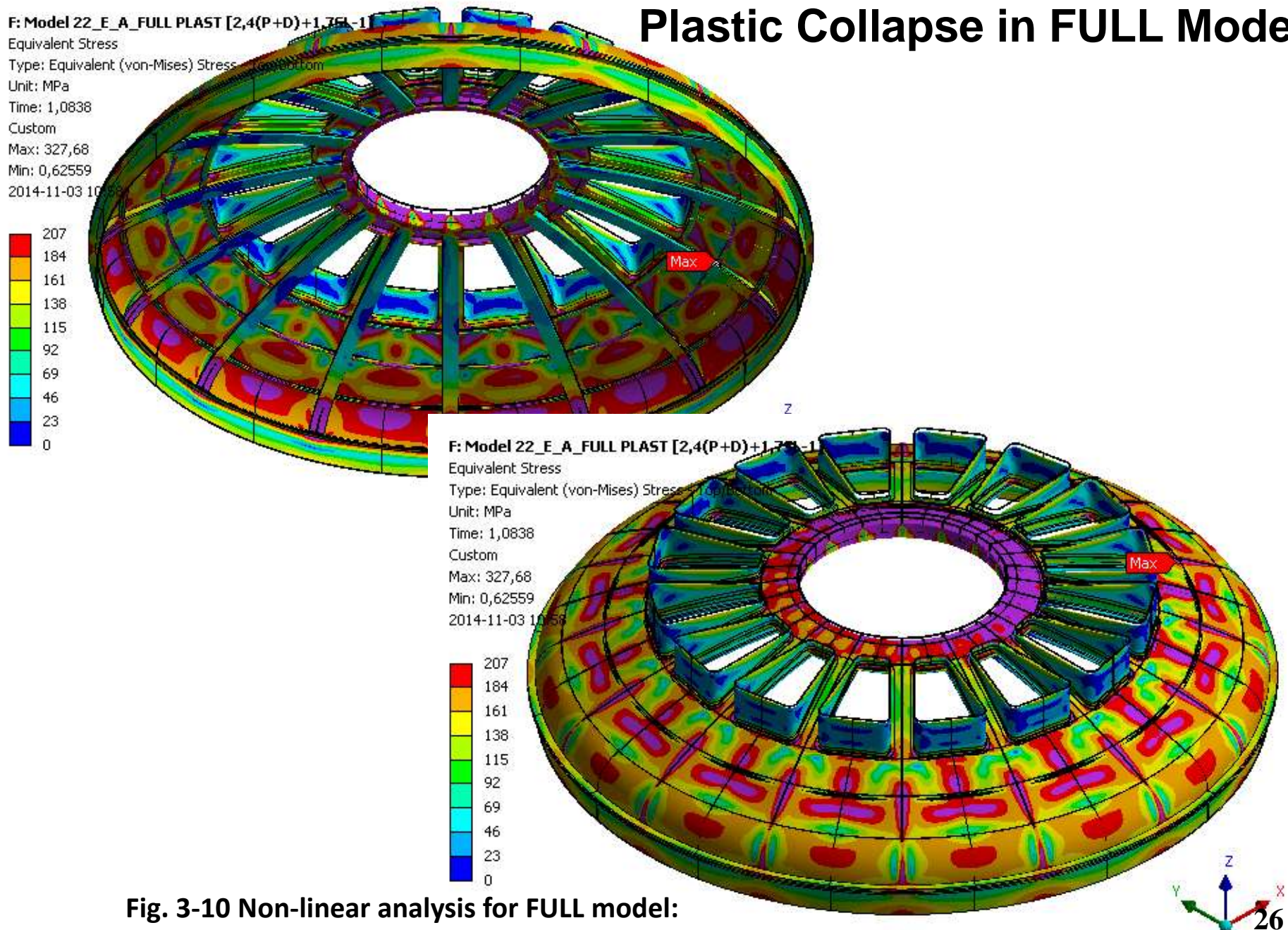


Fig. 3-9 Non-linear analysis for FULL model:
[2.4 (P+D)] – S_{VM} at LF=1.1564



Plastic Collapse in FULL Model



**Fig. 3-10 Non-linear analysis for FULL model:
 [2.4(P+D) + 1.7 SL-1] – S_{VM} at LF=1.0838**

Plastic Collapse in FULL Model

G: Model 22_E_A_FULL PLAST [2,1(P+D)+2,6SL-1]

Equivalent Stress

Type: Equivalent (von-Mises) Stress - Top/Bottom

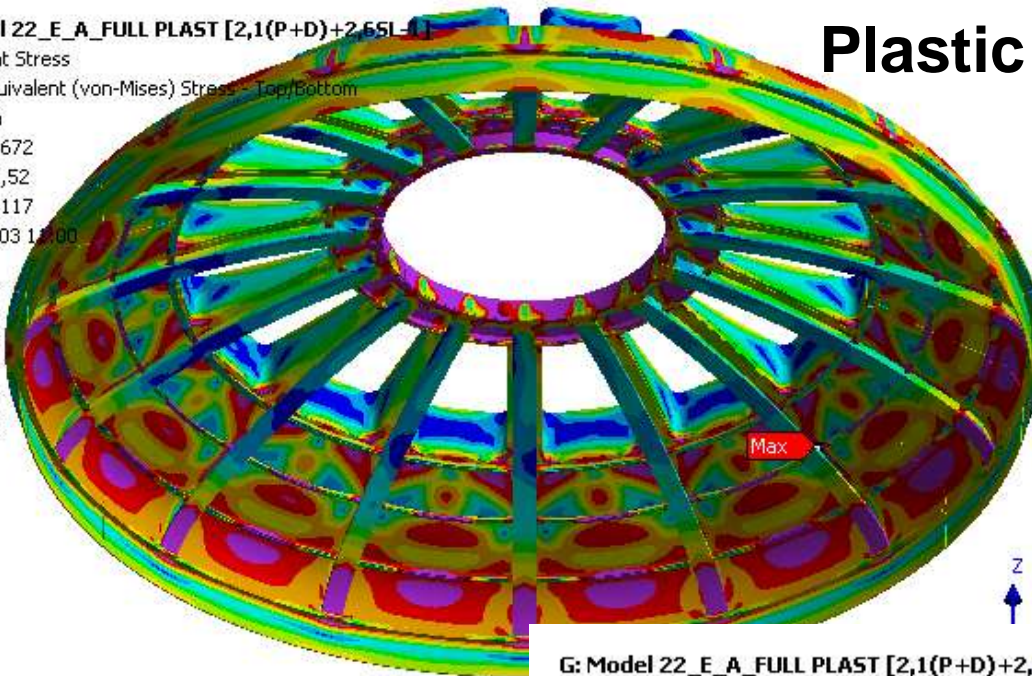
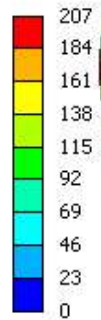
Unit: MPa

Time: 1,0672

Max: 324,52

Min: 0,34117

2014-11-03 11:00



G: Model 22_E_A_FULL PLAST [2,1(P+D)+2,6SL-1]

Equivalent Stress

Type: Equivalent (von-Mises) Stress - Top/Bottom

Unit: MPa

Time: 1,0672

Max: 324,52

Min: 0,34117

2014-11-03 11:00

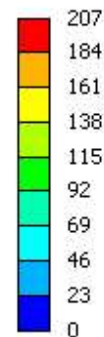
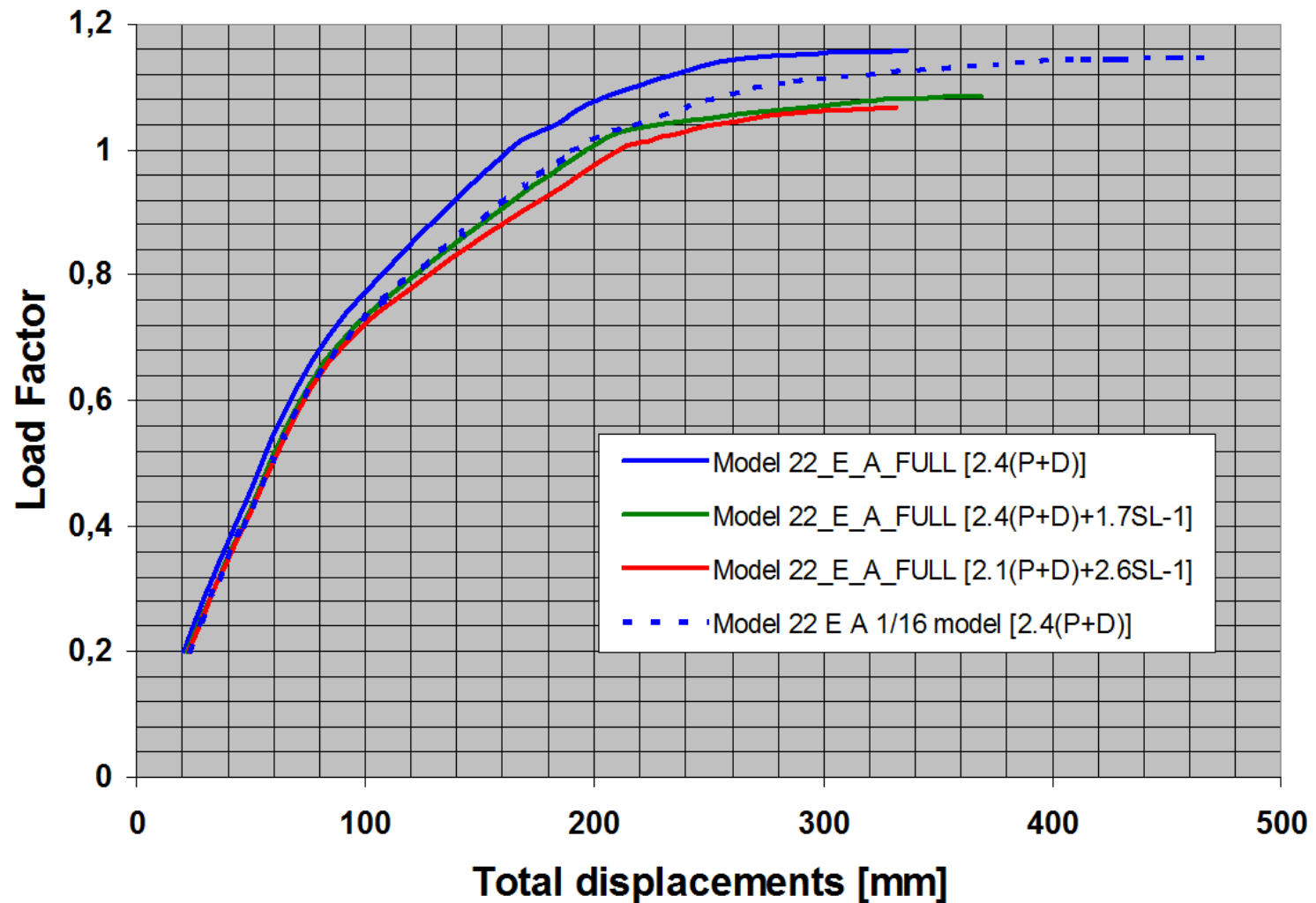


Fig. 3-11 Non-linear analysis for FULL model:
[2.1(P+D) + 2.6 SL-1] – S_{VM} at LF=1.0672

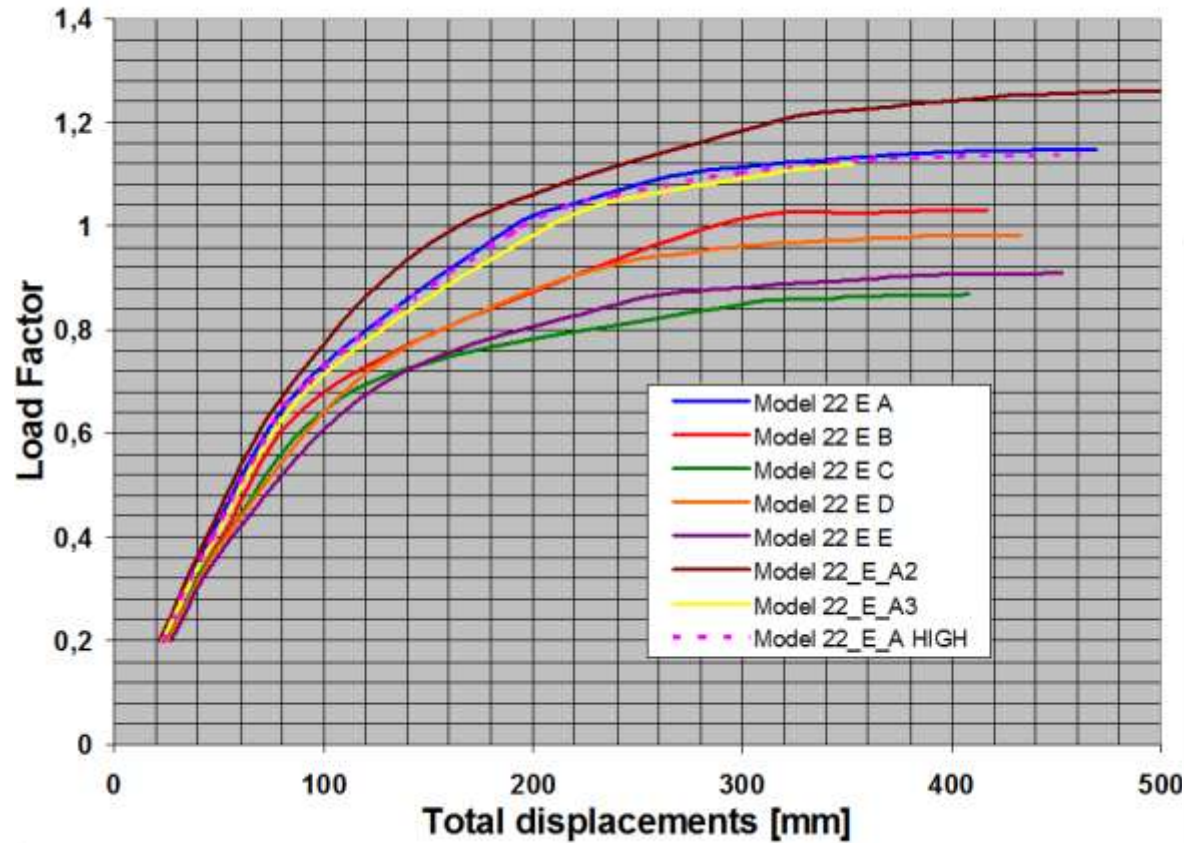
Plastic Collapse

NL analysis: Comparison of load combinations



Plastic Collapse

NL analysis [2.4(P+D)]: Model 22 E - Modifications

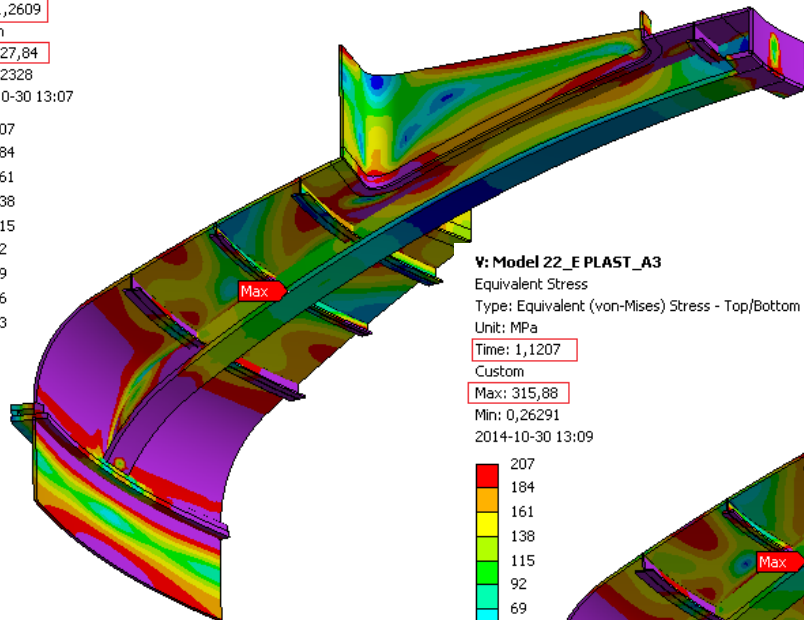


Comparison of different geometrical modifications for [2.4 (P+D)]

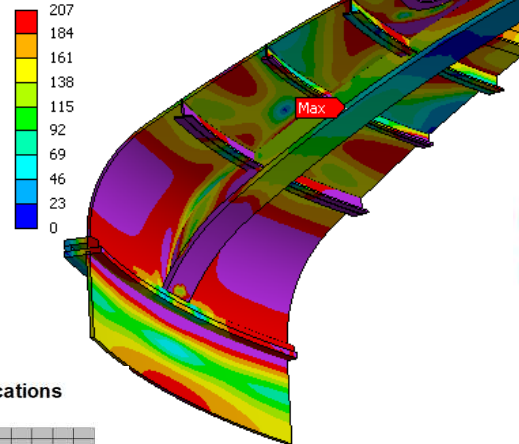
Parameter description	Symbol	M	O	D	E	L	22	E
		A [mm]	B [mm]	C [mm]	D [mm]	E [mm]	A2 [mm]	A3 [mm]
Top Lid Skin thickness	Th_01	60	50	50	50	50	60	50
Radial Rib Shelf thickness	Th_03	100	100	100	80	60	100	100
Inner Bottom Shelf thickness	Th_05	100	100	No shelf	80	60	100	100
Inner Top Shelf thickness	Th_07	60	50	50	50	50	60	50
Vertical Port Wall thickness	Th_12	60	50	50	50	50	50	50
Vertical Port to Top Lid Joint thickness	Th_14	60	50	50	50	50	50	50
Location of Toroidal Rib No 1	V112	1800	1800	1800	1800	1800	1000	1000
Location of Toroidal Rib No 2	V113	7400	7400	7400	7400	7400	8000	8000
Location of Toroidal Rib No 3	V114	9400	9400	9400	9400	9400	9500	9500
Location of Toroidal Rib No 4	V115	11500	11500	11500	11500	11500	11000	11000
Max. Load Factor: Achieved.		1.1453	1.0315	0.8676	0.9815	0.9088	1.2609	1.1207
Mass of 1/16 model [tonne]		74.67	68.68	68.22	66.81	64.94	72.96	68.63

Table 3-1 Geometrical modifications used in 1/16 Model 22E of the top lid (Fig.2-5)

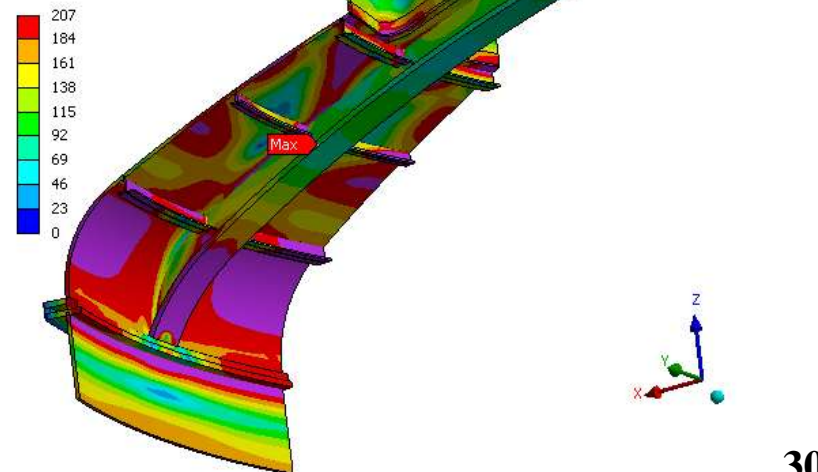
U: Model 22_E PLAST_A2
 Equivalent Stress
 Type: Equivalent (von-Mises) Stress - Top/Bottom
 Unit: MPa
 Time: 1,2609
 Custom
 Max: 327,84
 Min: 2,2328
 2014-10-30 13:07



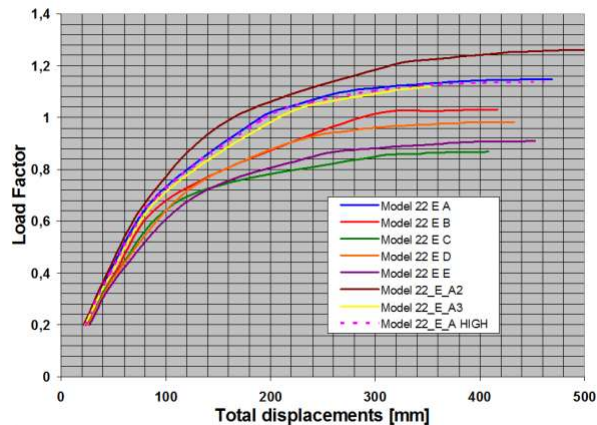
V: Model 22_E PLAST_A3
 Equivalent Stress
 Type: Equivalent (von-Mises) Stress - Top/Bottom
 Unit: MPa
 Time: 1,1207
 Custom
 Max: 315,88
 Min: 0,26291
 2014-10-30 13:09



W: Model 22_E PLAST_A HIGH
 Equivalent Stress
 Type: Equivalent (von-Mises) Stress - Top/Bottom
 Unit: MPa
 Time: 1,14
 Custom
 Max: 331,23
 Min: 4,0922
 2014-10-30 13:10



NL analysis [2.4(P+D)]: Model 22 E - Modifications



Comparison of different geometrical modifications for [2.4 (P+D)]

Plastic Collapse in 1/16 Model

Linear Buckling Analysis (modifications)

Model 22 E [P+D] preload

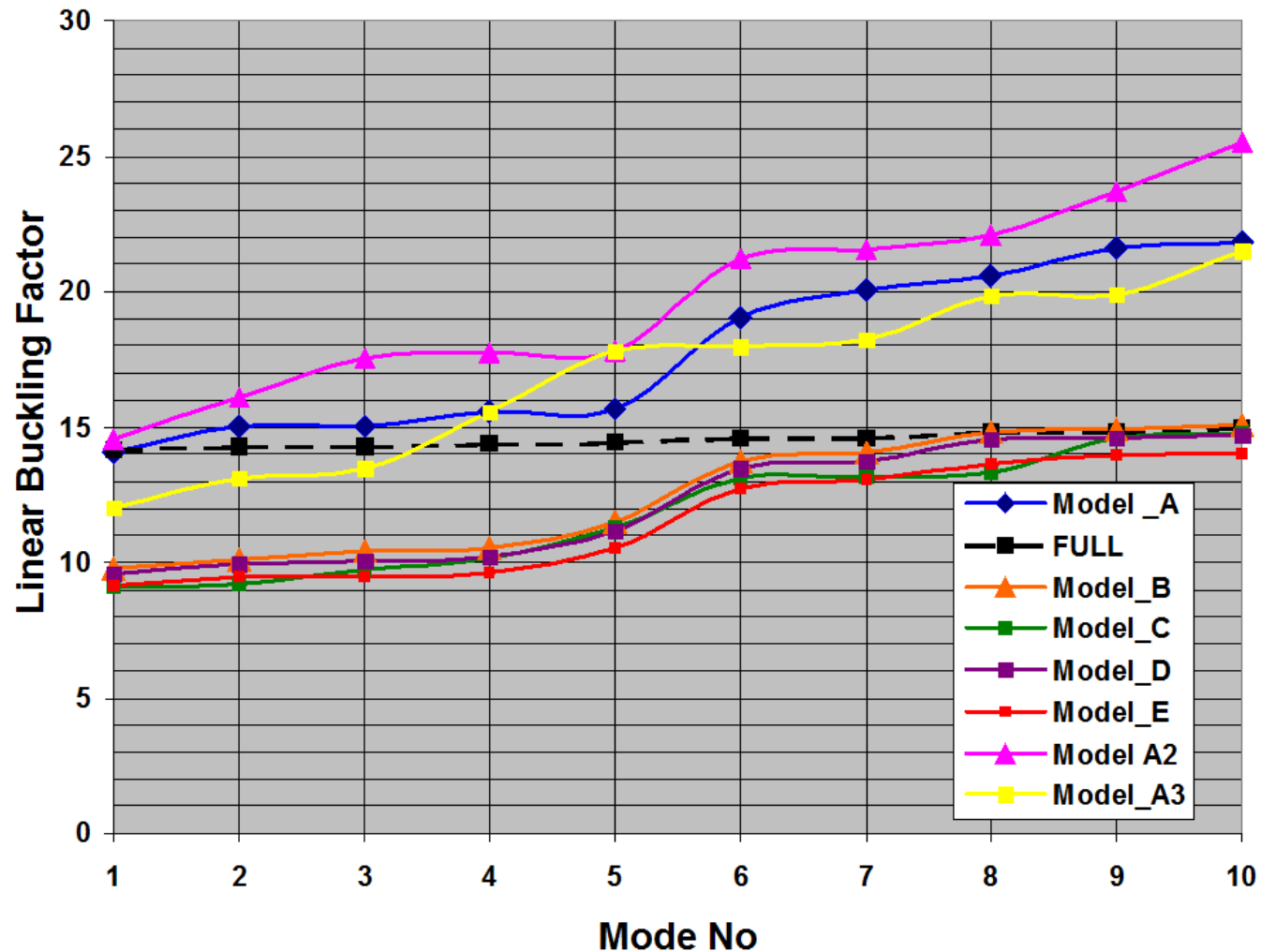


Figure 3-17 Linear buckling: Comparison of different geometrical modifications