Design Investigations of Cryostat Top Lid for DEMO

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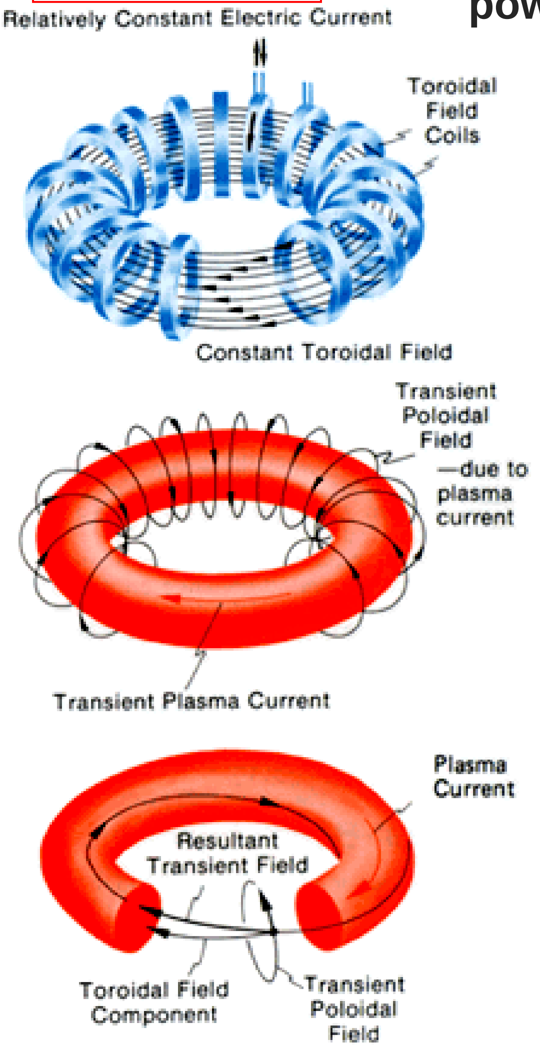
Warsaw 12th November 2014

ITER *(International Thermonuclear Experimental Reactor)*

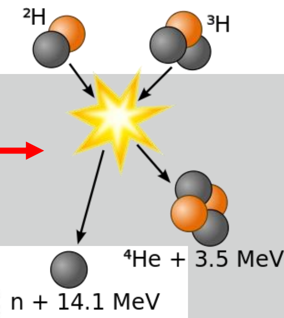
Cel: kontrolowana fuzja jądrowa / **Cadarache** / Pierwszy zapłon **2019**.

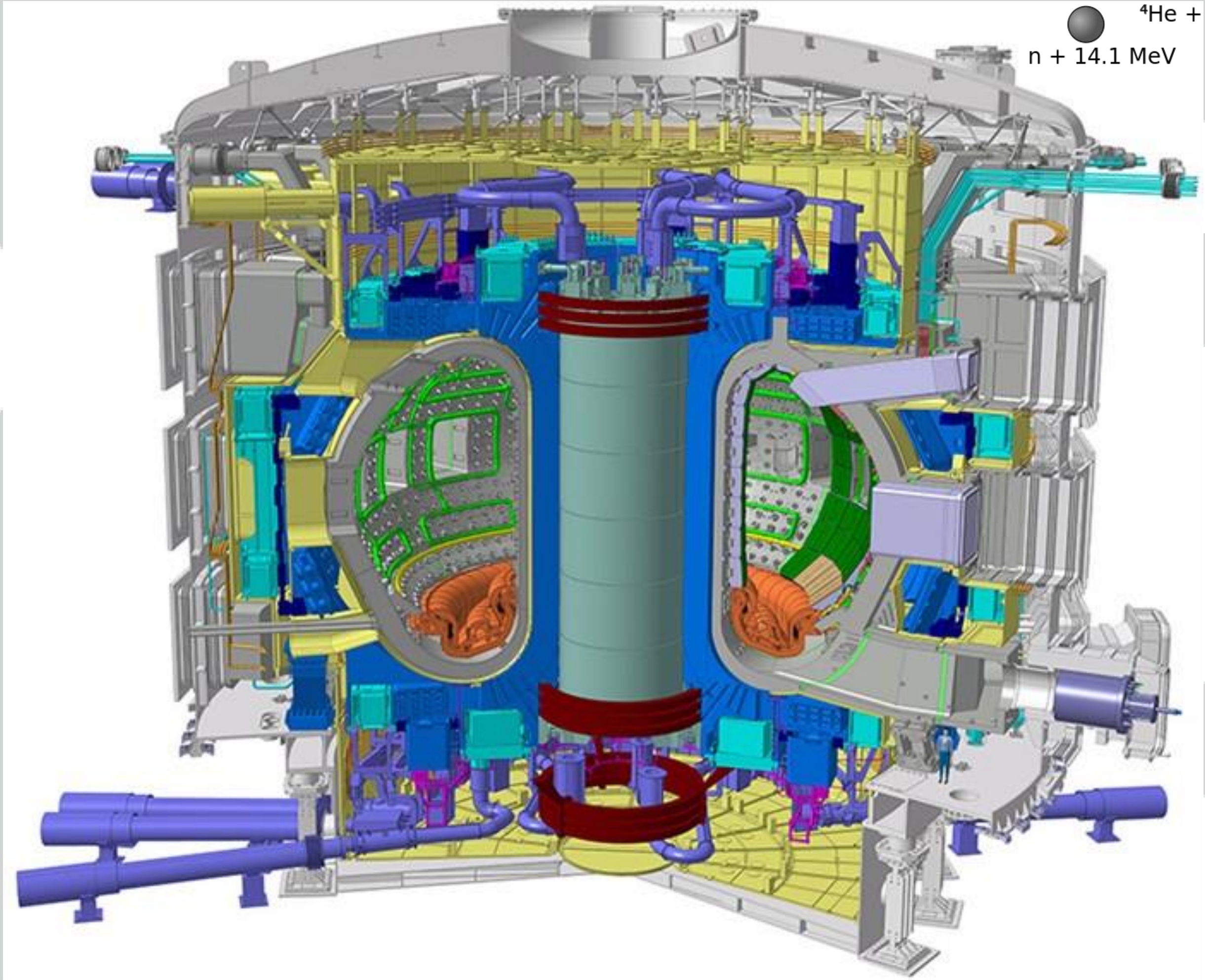
ITER ma każdorazowo <u>podtrzymywać reakcję fuzyjną</u> przez około **1000 sekund**, osiągając moc **500-1100MW**.

Tokamak

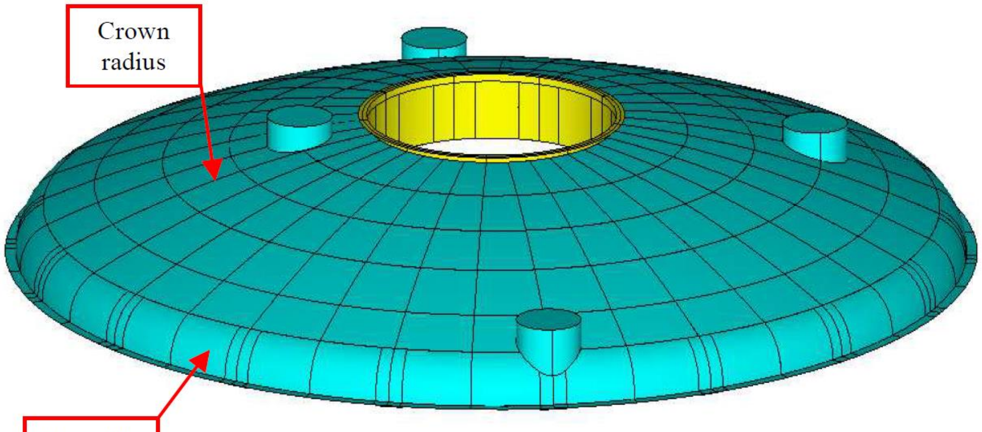


Pojedyncza **reakcja fuzji deuteru i trytu**, w której **powstaje:** hel, neutron i wydzielana jest energia 17.6 MeV

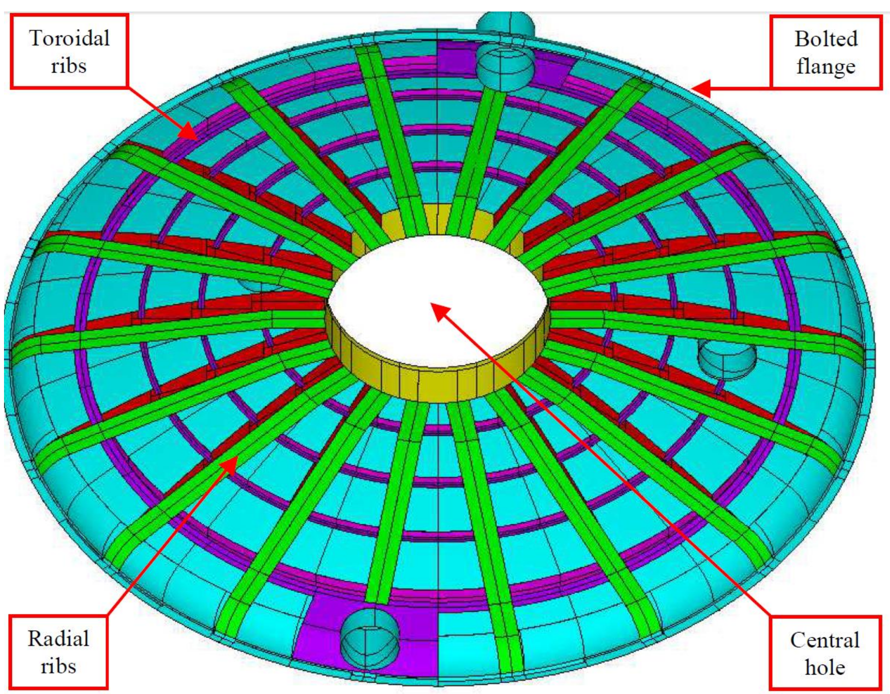


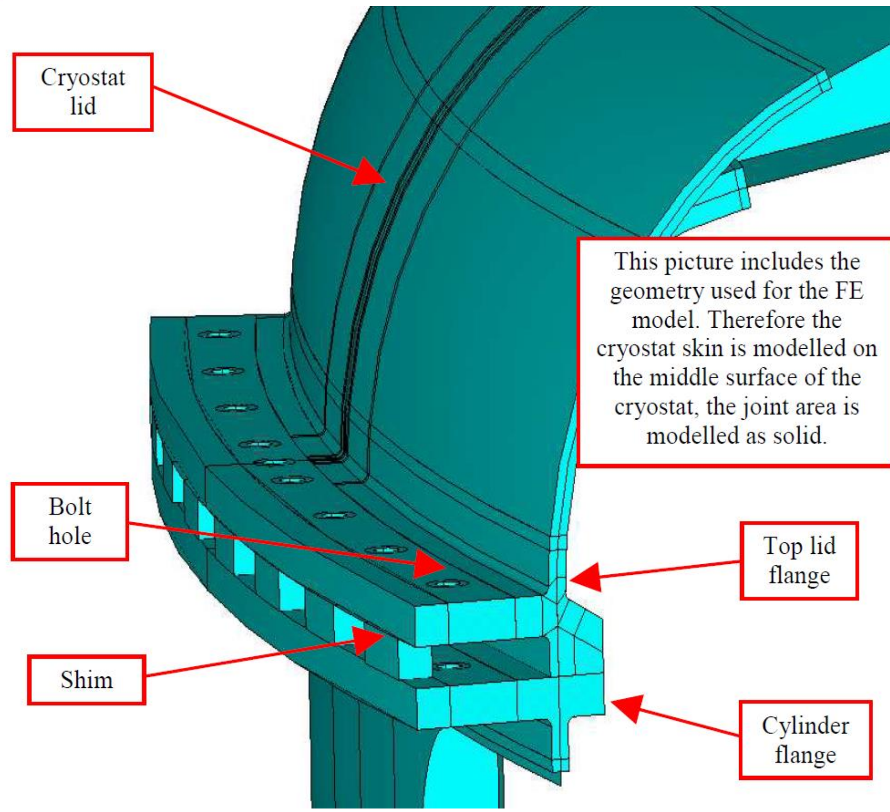


Structural Analysis of Cryostat Top Lid of ITER



Cryostat top lid: Topside





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) $P + D + SL\text{-}1$

Elastoplastic Analysis

Load-cases required to be considered:

Category II:

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

Category III:

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

Category III:

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

Category IV:

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

Category IV:

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

Von Mises stress allowable values:

$$P_m \leq S$$
$$P_m + P_b \leq 1.5S$$

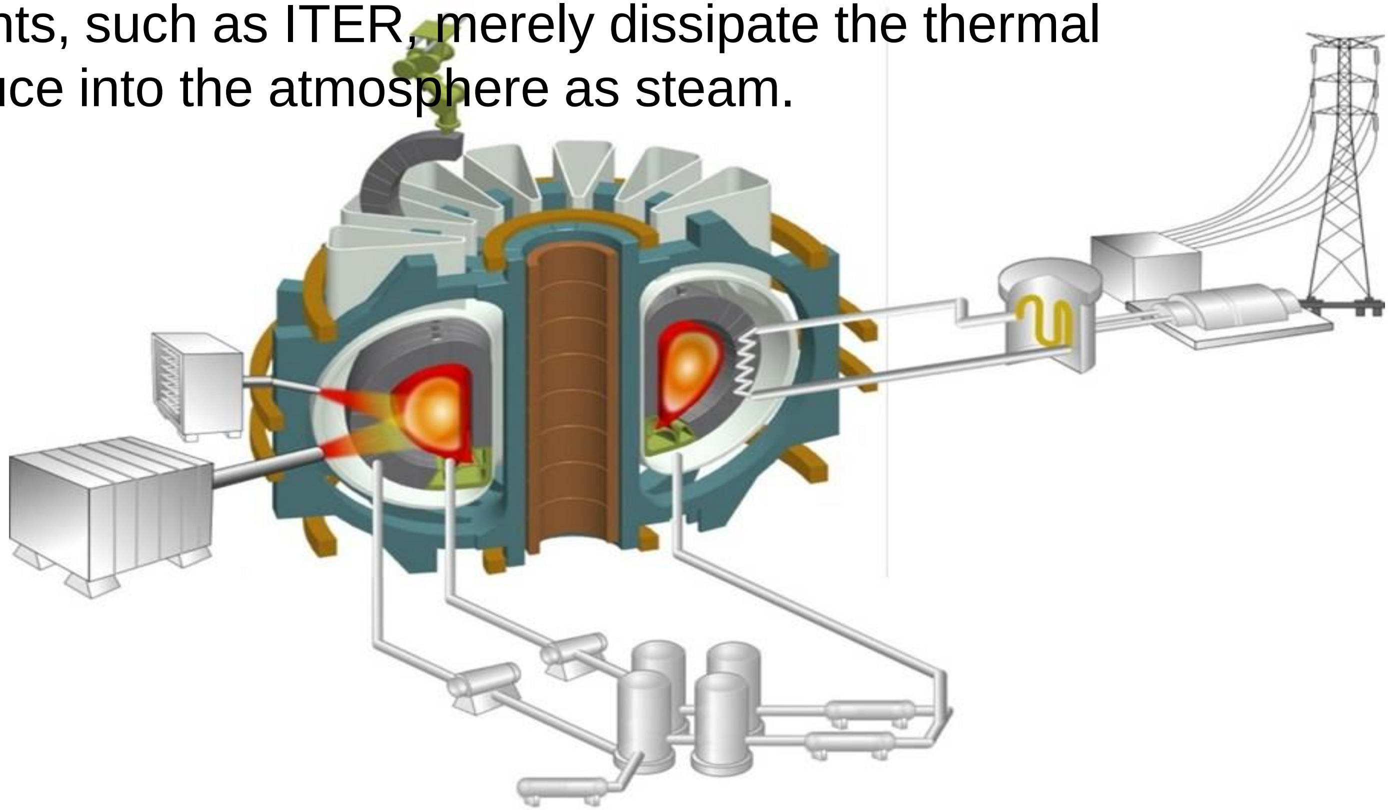
Collapse Load Factor > 1

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

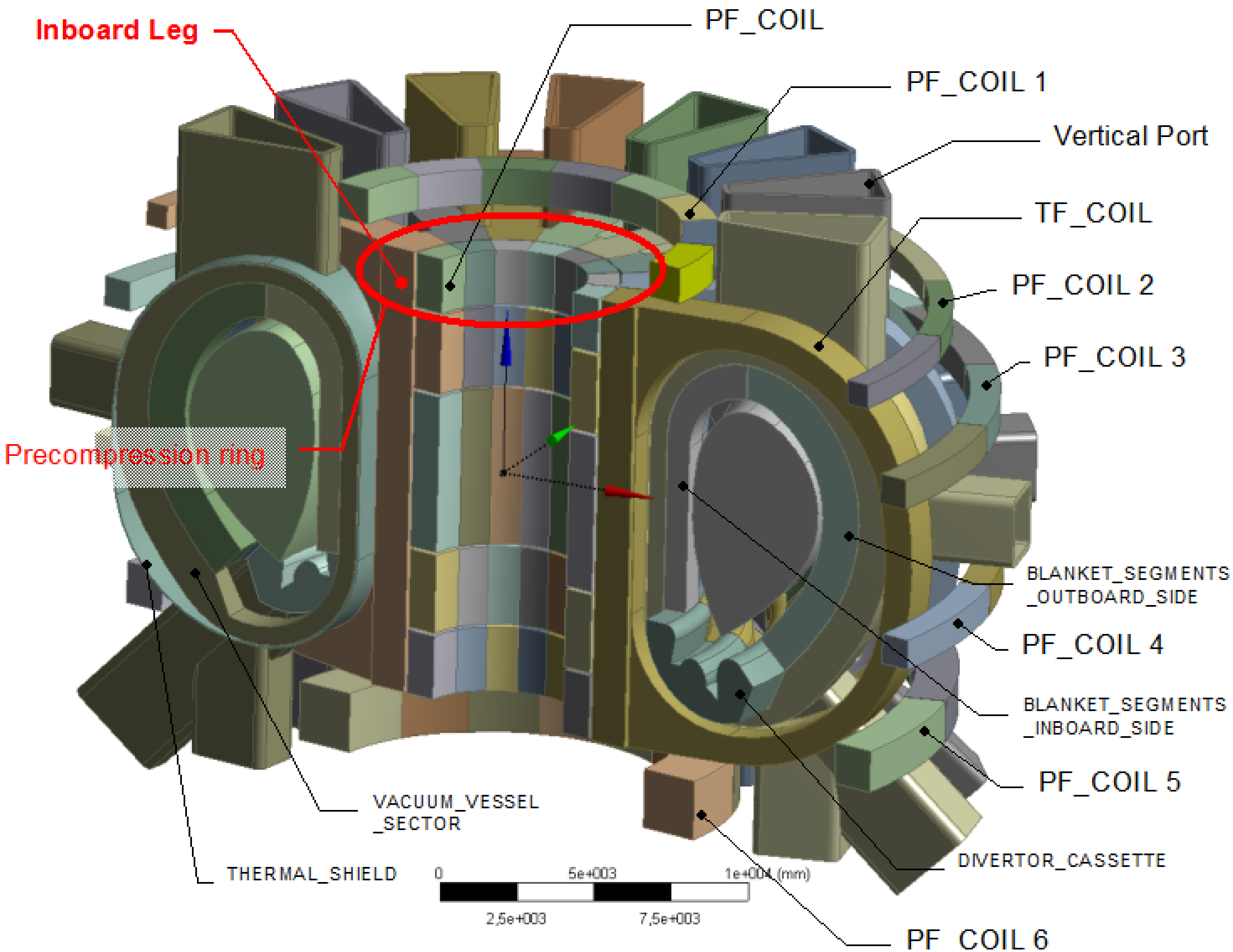
DEMO's **2 to 4 gigawatts** of thermal output will be on the scale of a modern electric power plant.

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.

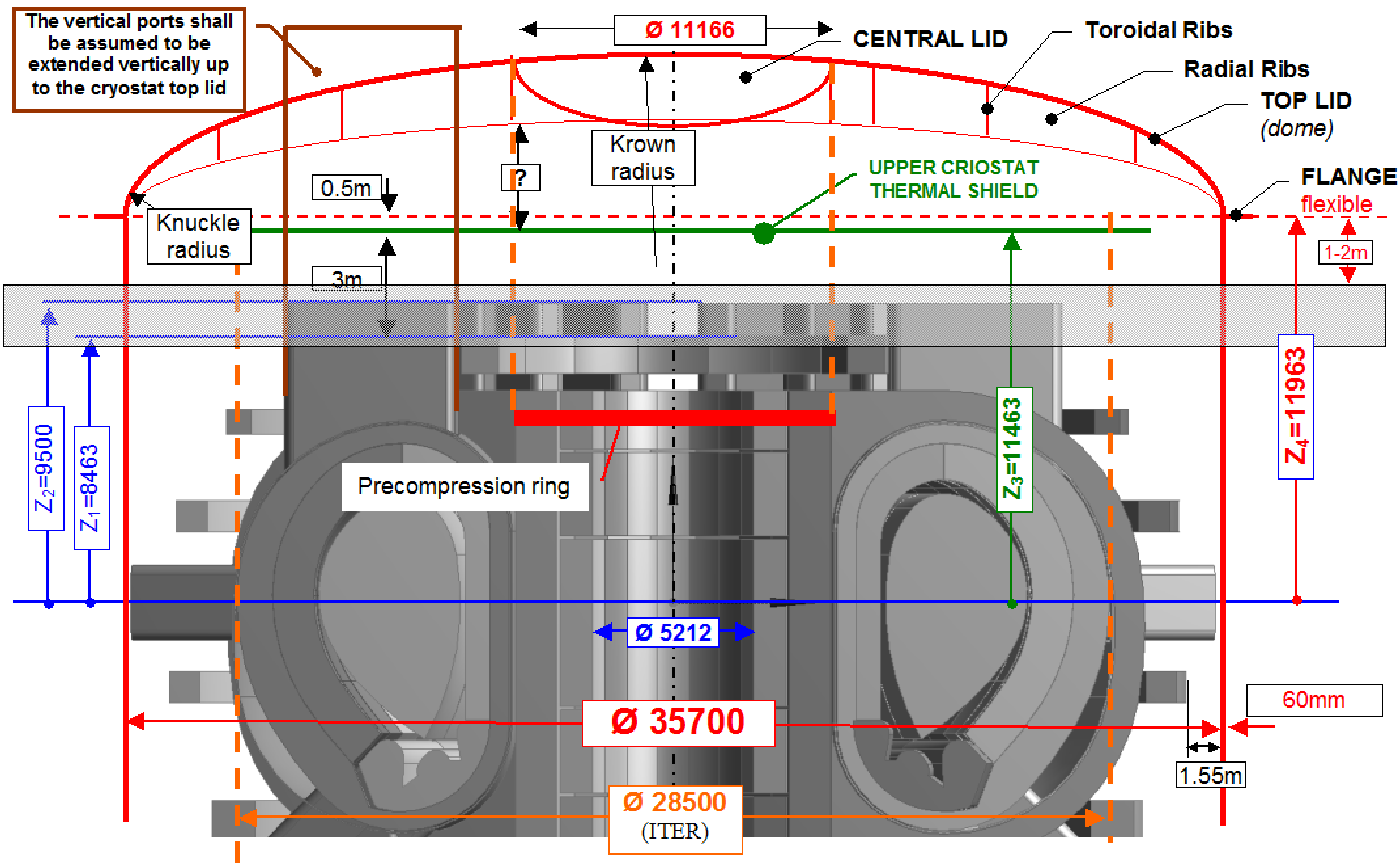


Geometrical Indications and Assumptions for Cryostat Top Lid in DEMO

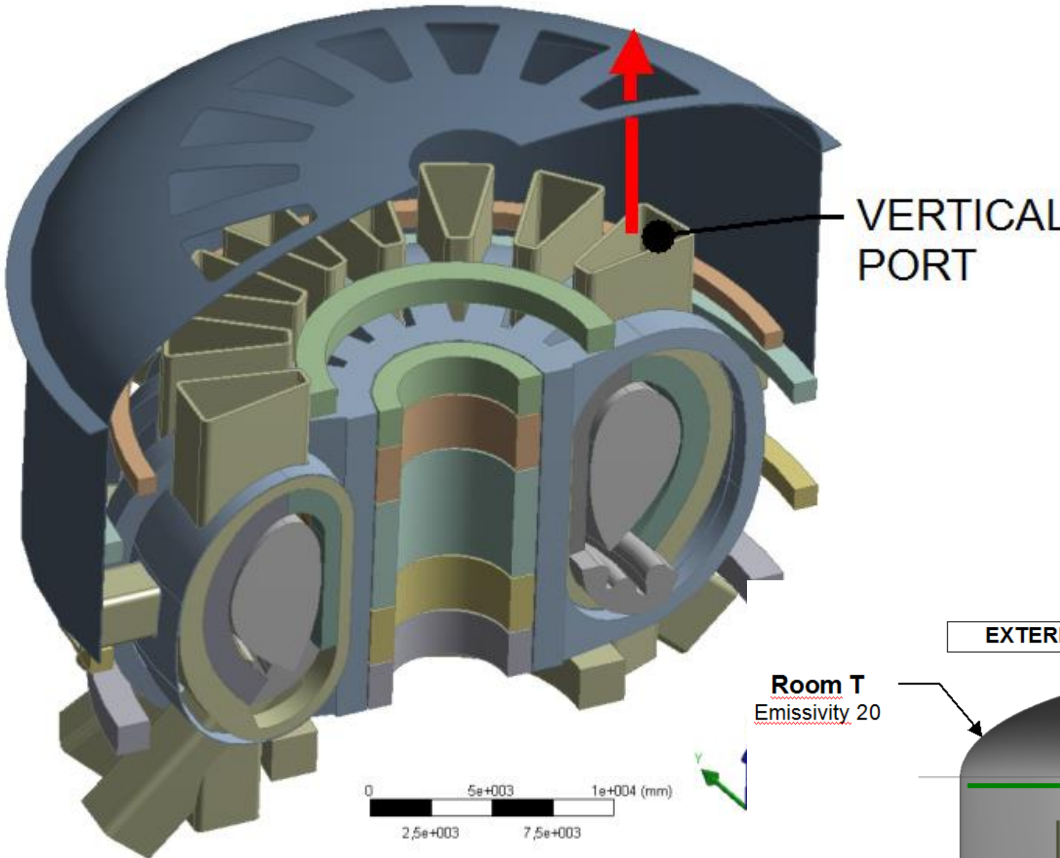


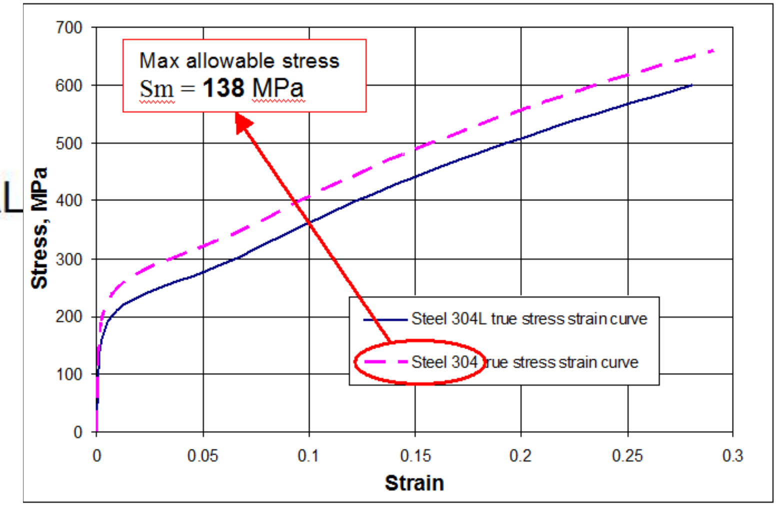
Model Data File: **201405_DEMO_TOKAMAK_COMPLEX.zip**

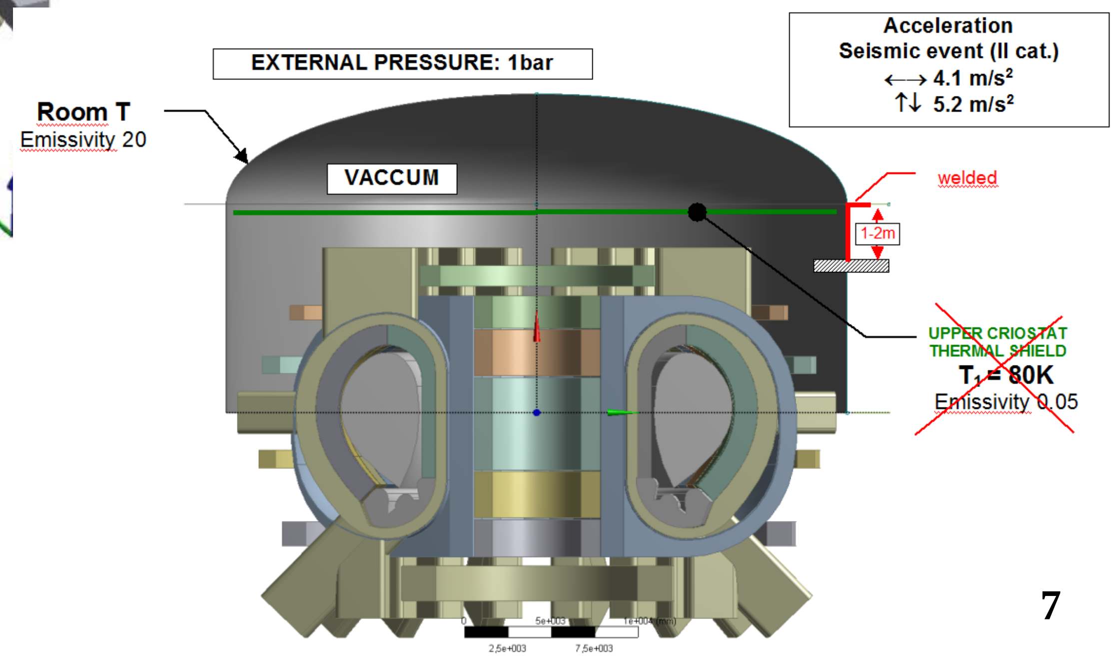
Geometrical Indications and Assumptions for Cryostat Top Lid in DEMO



Geometrical Indications and Assumptions for Cryostat Top Lid in DEMO







Geometric Model of 1/16 of the Top Lid

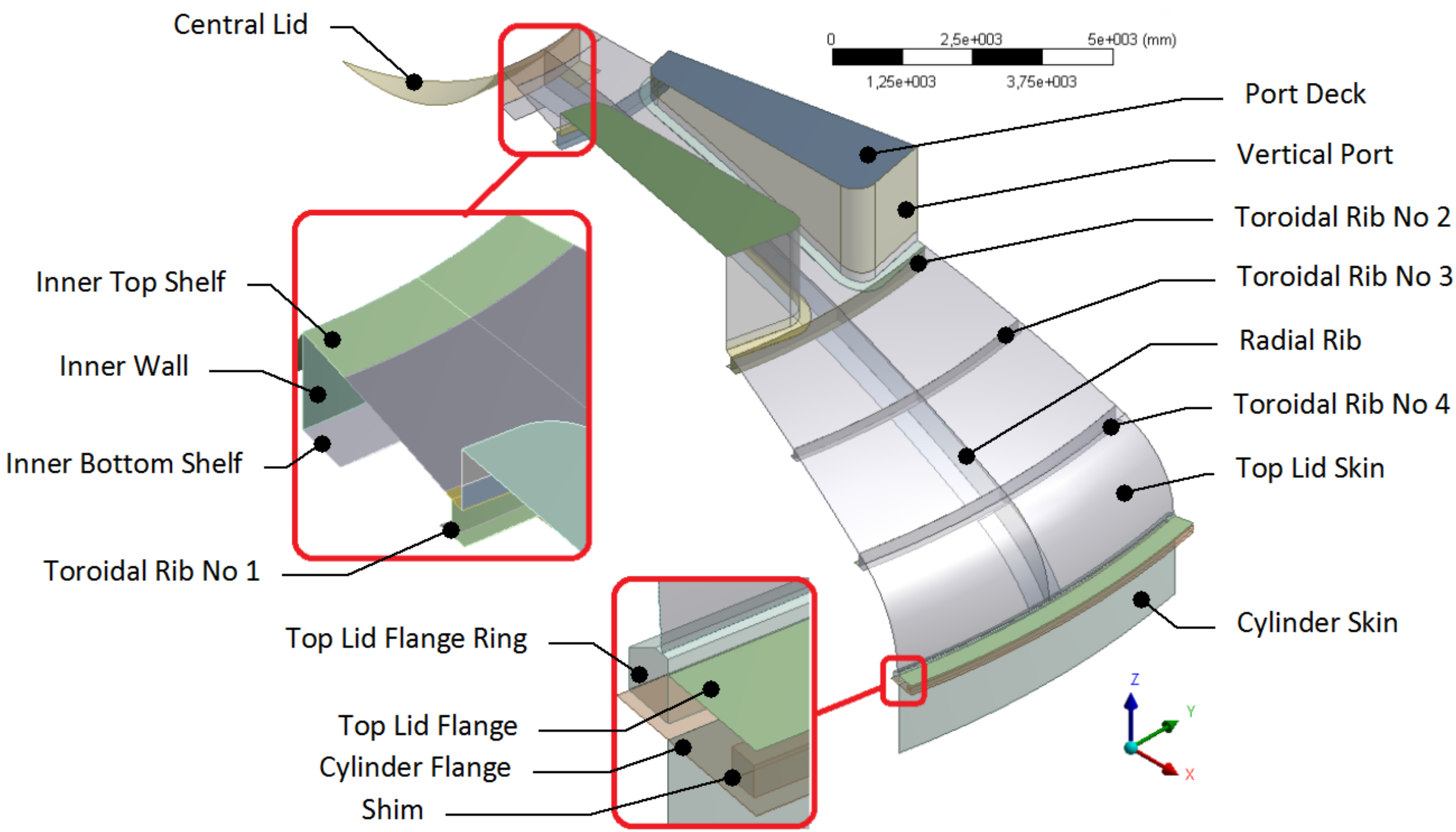


Figure 2-1 Geometrical model of 1/16 of the top lid

Parametric Model in ANSYS WB DesignModeler

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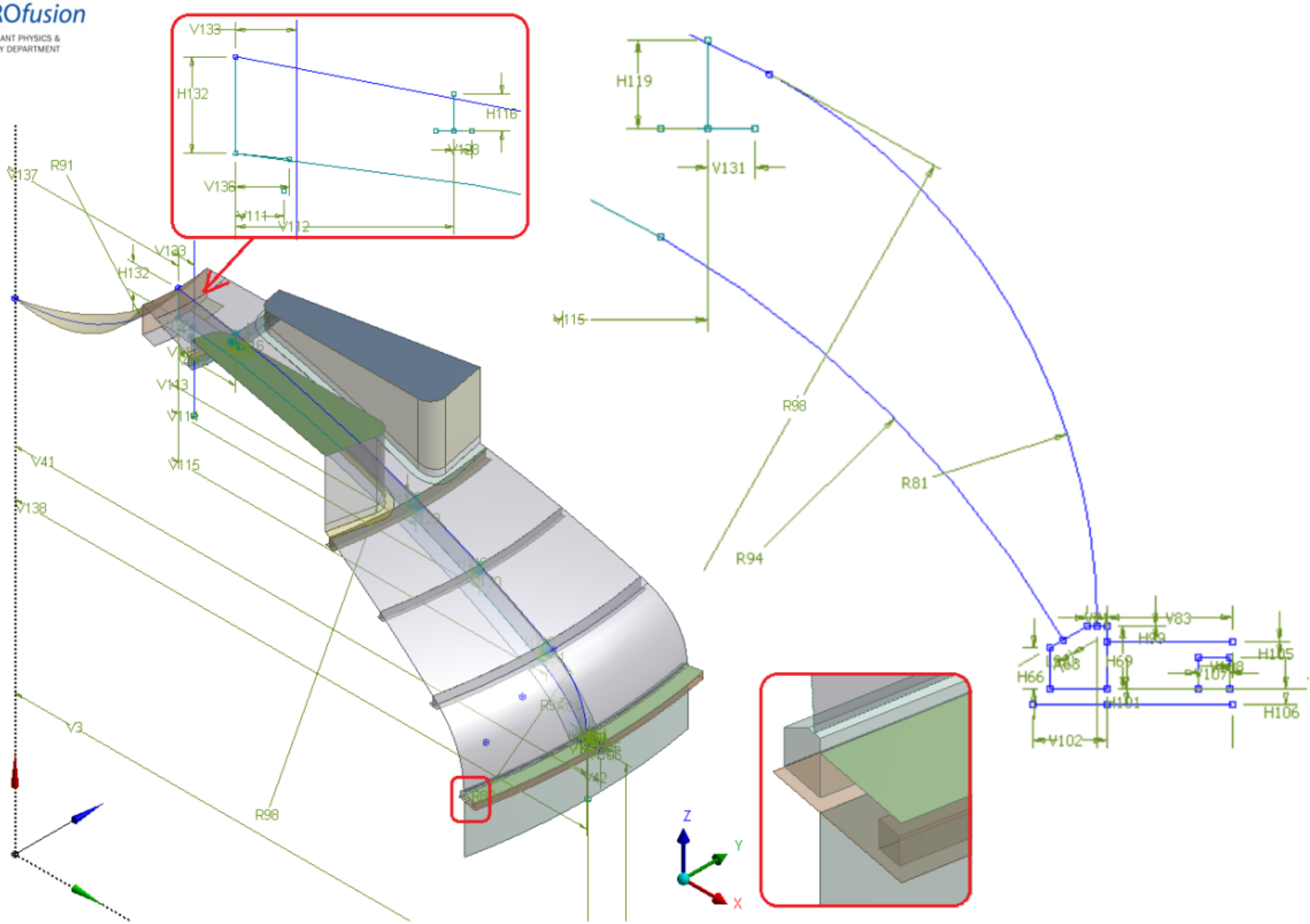
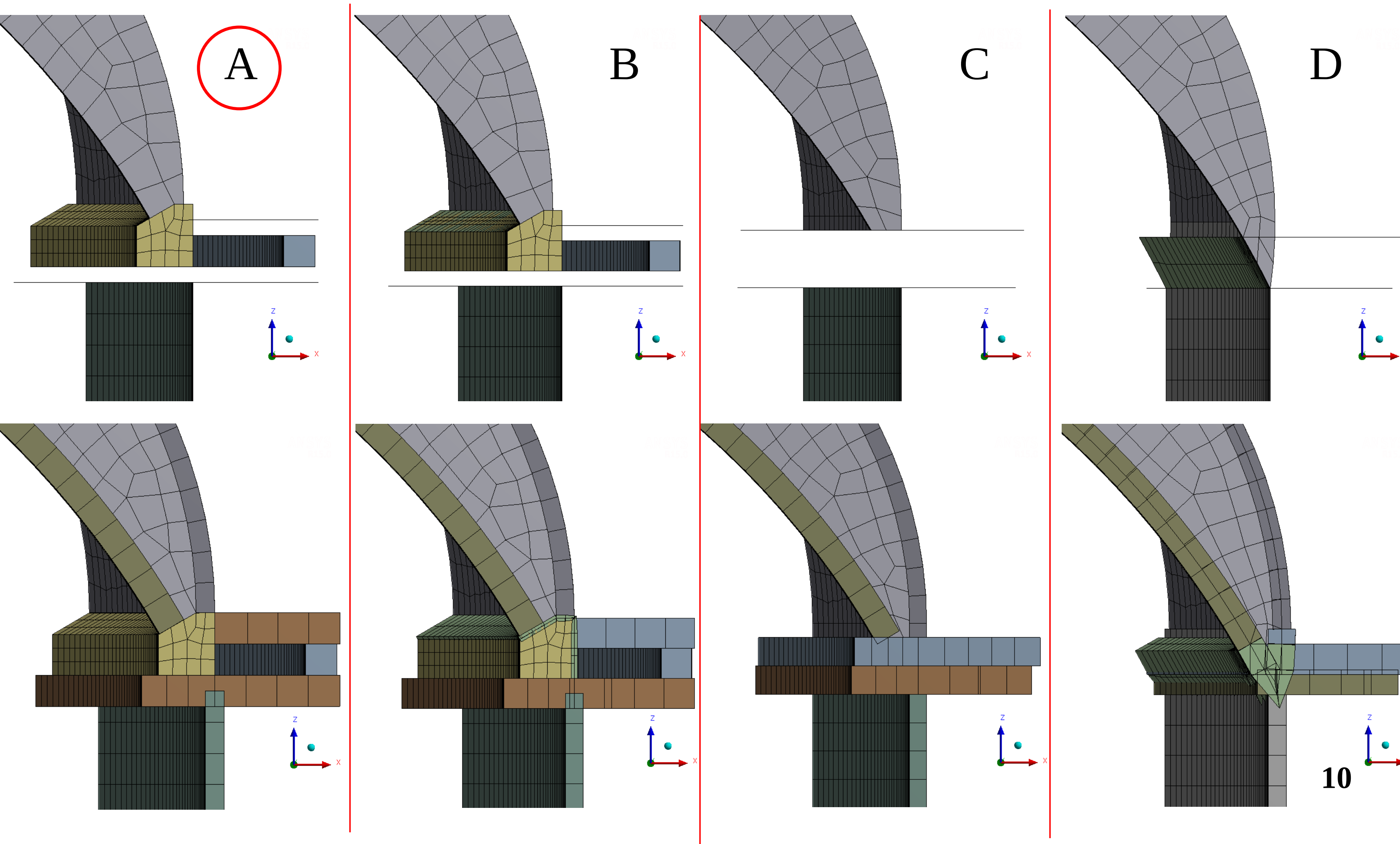
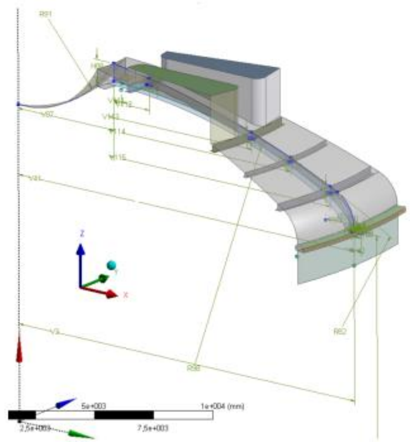


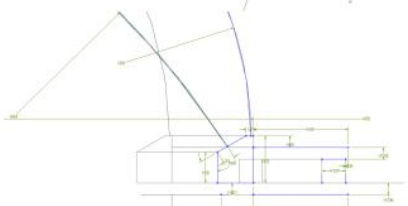
Figure 2-2 Parameters describing geometry of the model

Modelling Shell to Flange Connection



Searching for Optimum Stress Distribution in the Model

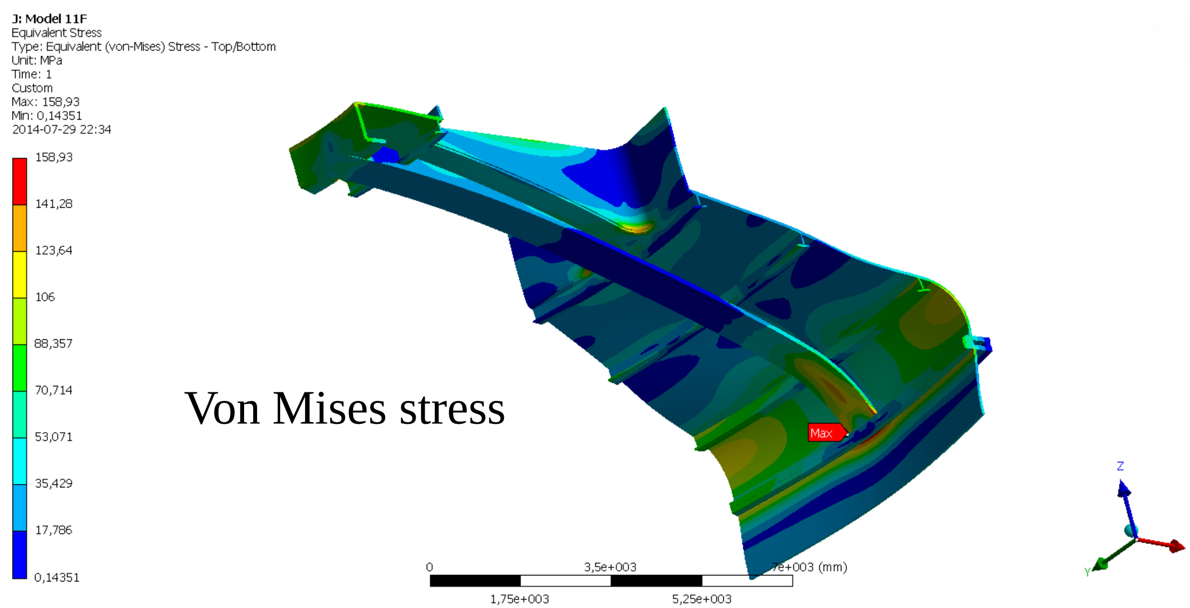




Different Models

Model parameters

	R82 Rcrown	R81/H Rcnuckle		R98 Rrib1	R58 Rrib2	Shelf/thick V136/H61	Layer/thick V133/H61	H_rib H132	V112/H116 *V128/thick*	V113/H117 *V129/thick*	V114/H118 *V130/thick*	V115/H119 *V131/thick*	B Shelf [m]	Th0_Lid [mm]	Th1_Shell [mm]	Th2_flange [mm]	Th3_Shelf [mm]	Th4_Web [mm]	Th5_iner [mm]	Th6_cylind [mm]	Th7_Port [mm]	uwaga
Model 10	DENSER MESH							Pm=138 MPa Pm+Pb=207 MPa														
Midside nodes dropped																						
Model 10	40	1,5/5,144		25	3,5	446/90	500/60	0,8	1800/300 *150/30*	7400/300 *150/30*	9400/200 *100/30*	11500/300 *150/30*	0,8	50	60	100	90	60	80	60	50	Thoroidal ribs
Model 10A	40	1,5/5,144	V71=120	25	3,5	446/90	500/60	0,8	1800/300 *150/30*	7400/300 *150/30*	9400/200 *100/30*	11500/300 *150/30*	0,8	50	60	100	90	60	80	60	50	Thoroidal ribs
Model 10B	40	1,5/5,144	V71=120	27	3,5	446/90	500/60	0,8	1800/300 *150/40*	7400/300 *100/40*	9550/250 *100/40*	11865/300 *150/40*	0,8	50	60	100	90	60	80	60	50	Thoroidal ribs
Model 10C	35	1,5/5,761	V71=120	27	3,5	446/90	500/60	0,8	1800/300 *150/40*	7400/300 *100/40*	9550/250 *100/40*	11865/300 *150/40*	0,8	50	60	100	90	60	80	60	50	Thoroidal ribs
Model 11	40	1,5/5,144		25	3,5	446/90	500/60	0,8	1800/300 *150/30*	7400/300 *150/30*	9400/200 *100/30*	11500/300 *150/30*	0,8	50	60	100	90	60	80	60	50	opaski/400/80
Model 11C	35	1,5/5,761	V71=120	27	3,5	446/90	500/60	0,8	1800/300 *150/40*	7400/300 *100/40*	9550/200 *100/40*	11865/300 *150/40*	0,8	50	60	100	90	60	80	60	50	opaski/400/80
Model 11D	35	1,5/5,761	V71=120	27	3,5	446/90	500/60	0,8	1800/300 *150/40*	7400/300 *100/40*	9550/200 *100/40*	11865/300 *150/40*	0,8	50	60	100	100	60	80	60	50	opaski/400/80
Model 11E	35	1,5/5,761	V71=120	27	3,5	446/90	500/60	0,8	1800/300 *150/40*	7400/300 *150/40*	9550/300 *150/40*	11865/300 *150/40*	0,8	50	60	100	100	60	80	60	60	opaski/400/80
Model 11F	35	1,5/5,761	V71=120	27	3,5	446/90	500/60	0,8	1800/300 *150/40*	7400/300 *150/40*	9550/300 *150/40*	11865/300 *150/40*	0,8	50	65	100	100	60	80	60	60	opaski/400/80
Model 11G	35	1,5/5,761	V71=120	27	3,5	446/130	500/60	0,8	1800/300 *150/40*	7400/300 *150/40*	9550/300 *150/40*	11865/300 *150/40*	0,6	50	60	100	130	60	80	60	60	opaski/400/80
Pin supported																						
Model 11F pin sup	35	1,5/5,761	V71=120	27	3,5	446/90	500/60	0,8	1800/300 *150/40*	7400/300 *150/40*	9550/300 *150/40*	11865/300 *150/40*	0,8	50	65	100	100	60	80	60	60	opaski/400/80



Von Mises stress

Different Shapes Studied

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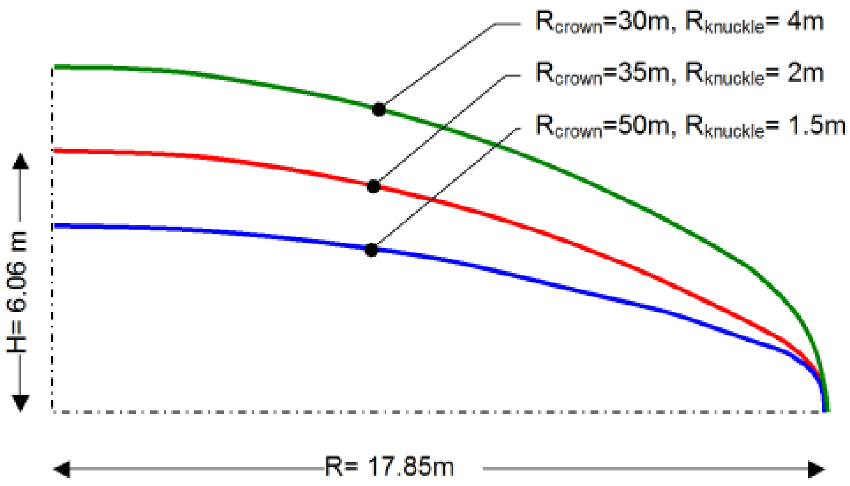

Figure 2-3 Different radii configurations tested

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
Localtion of Toroidal Rib No 1	**V112**	1800
Localtion of Toroidal Rib No 2	**V113**	7400
Localtion of Toroidal Rib No 3	**V114**	9400
Localtion 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

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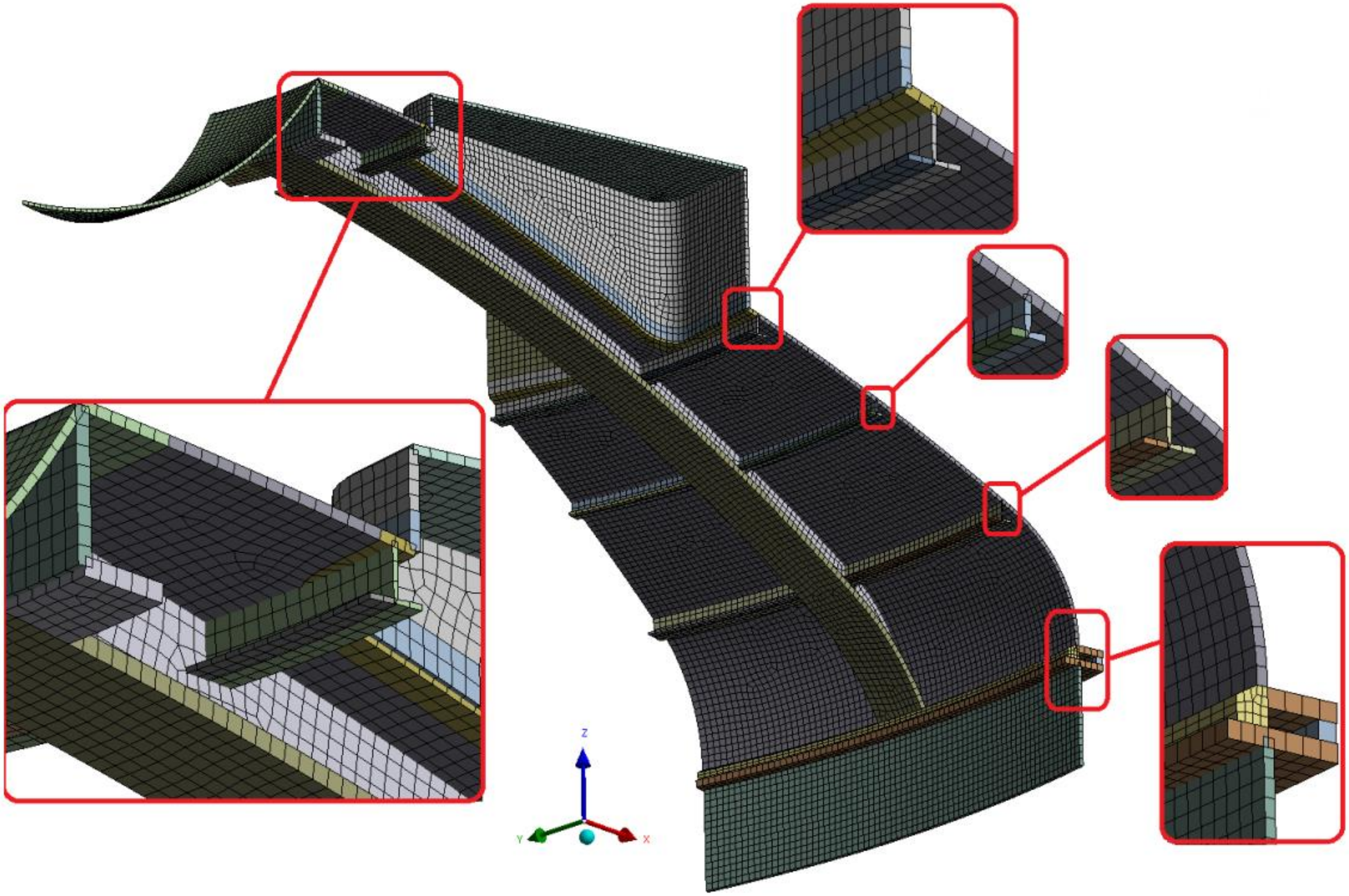

Figure 2-6 FE mesh used in Model 22E A of the top lid

Connections in Model 22_E

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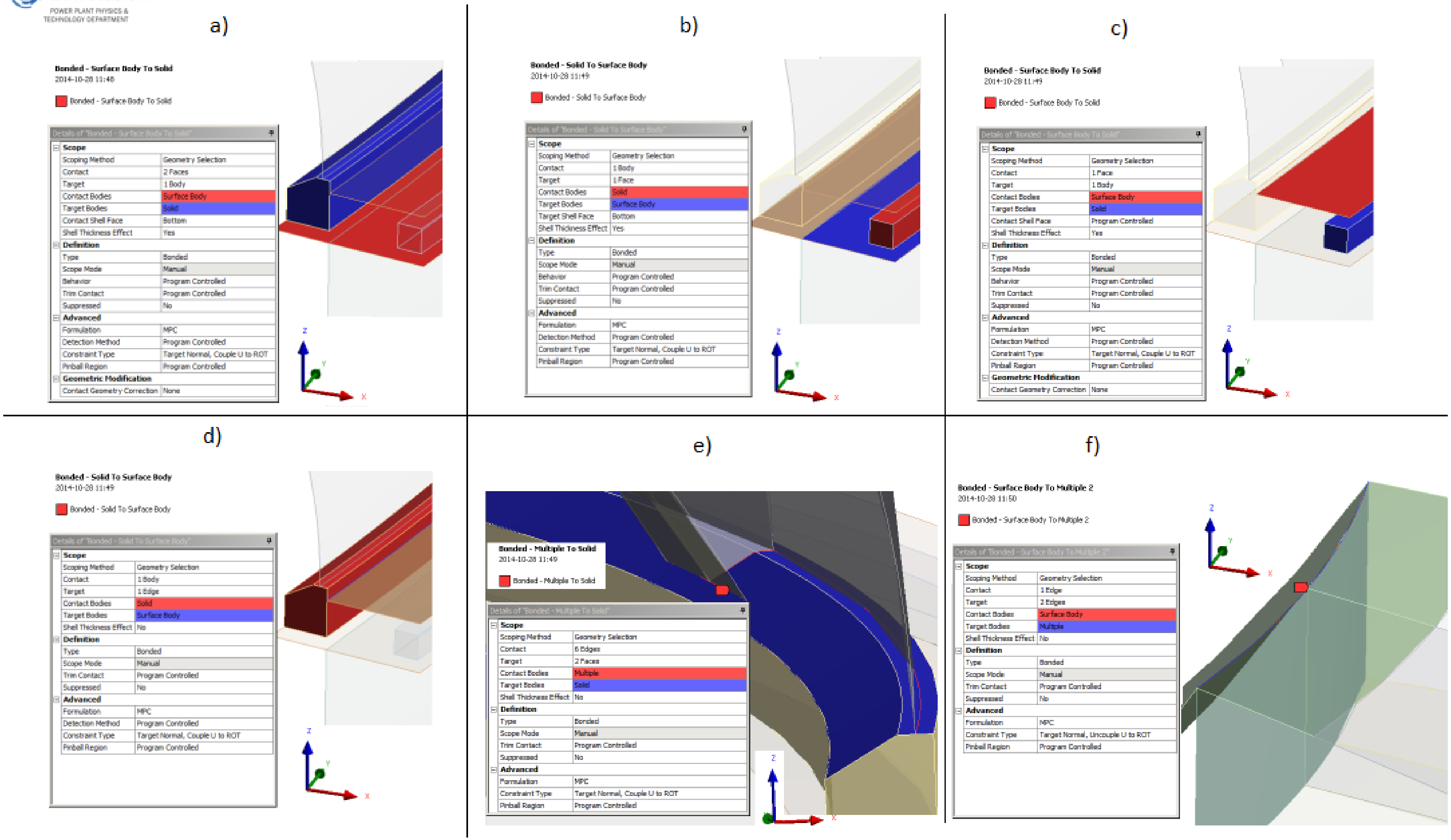


Figure 2-7 The connection regions in Model 22E A of the top lid

Symmetry Conditions

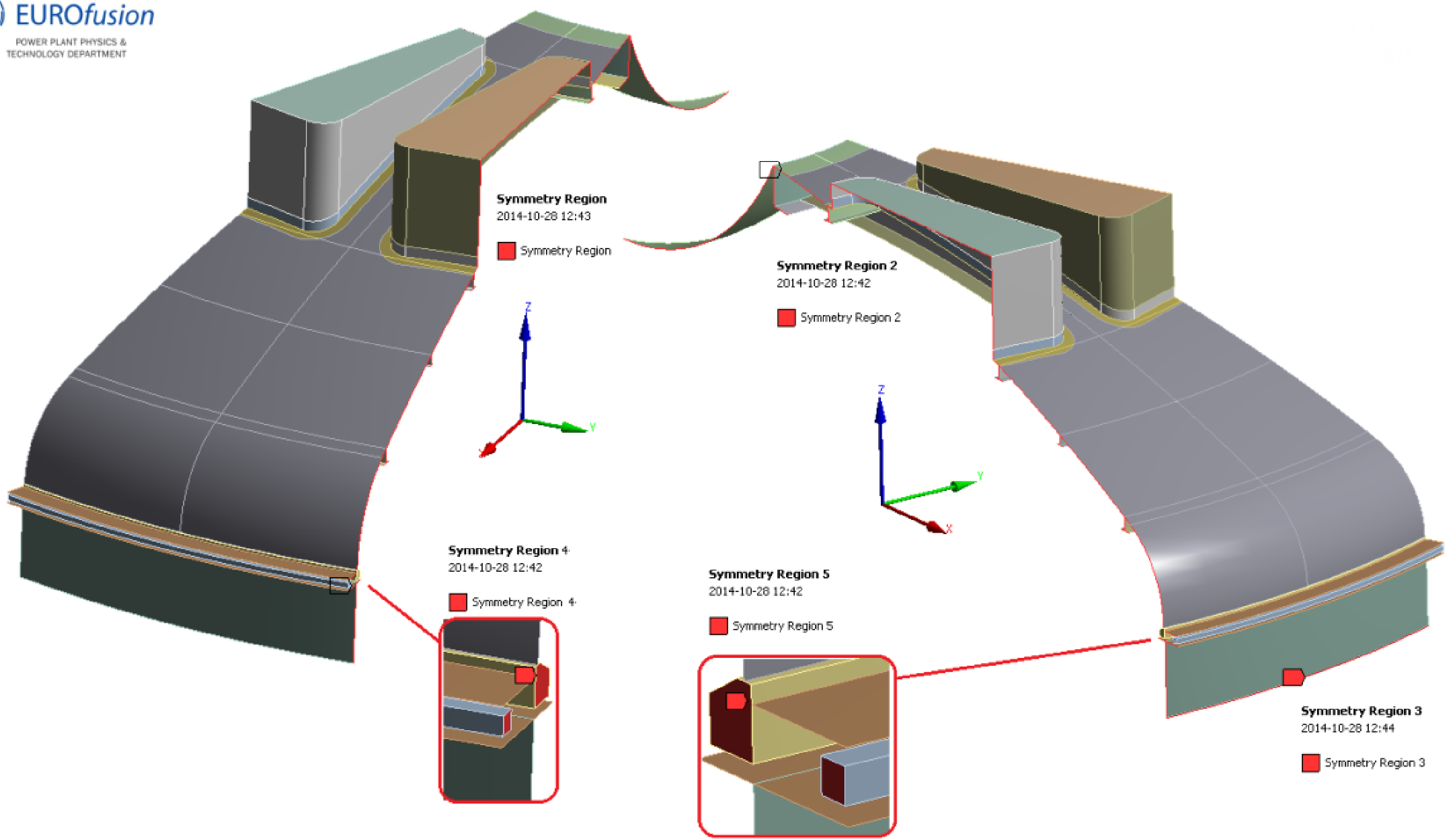


Figure 2-8 Symmetry conditions in Model 22E A of the top lid

Operational Load

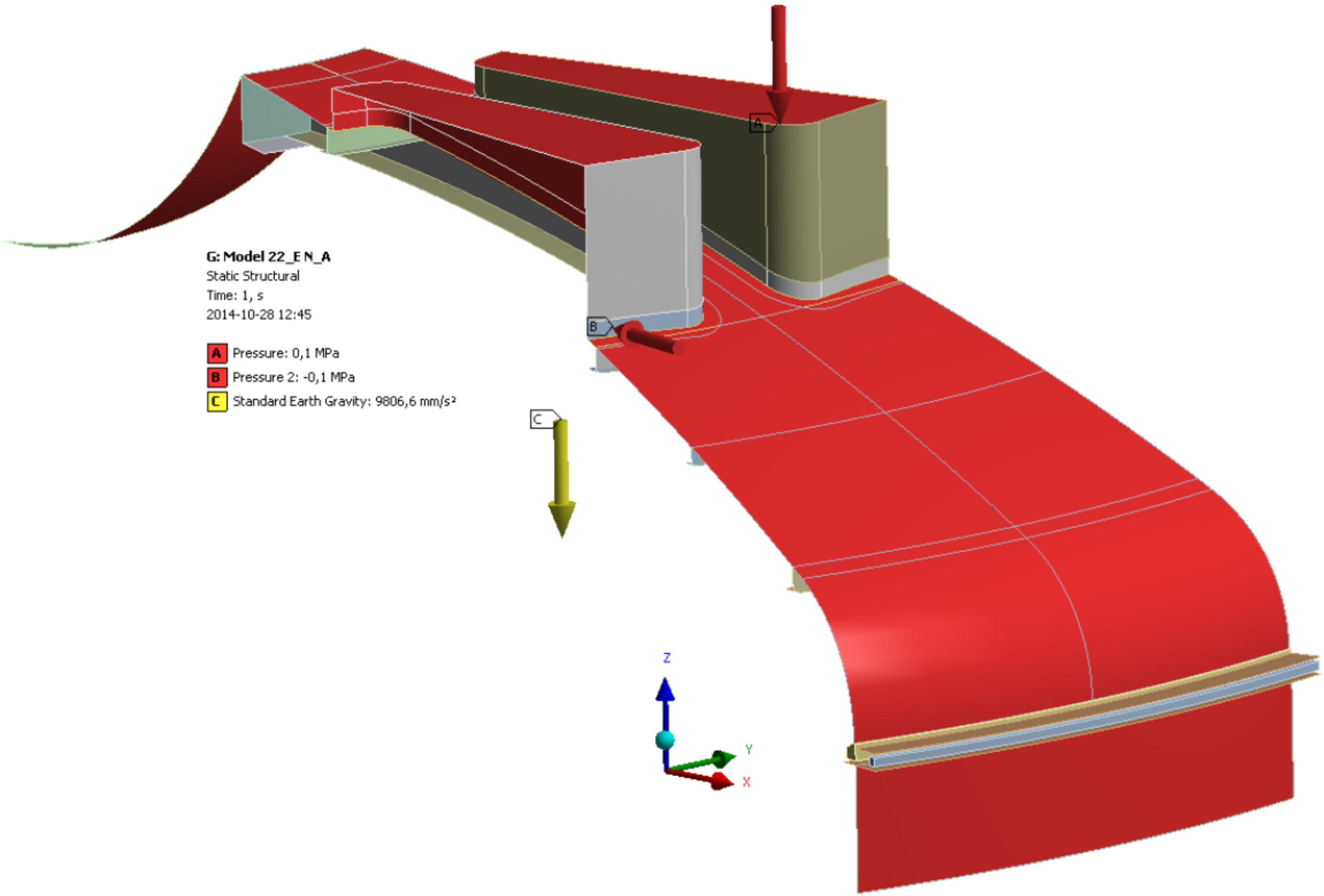


Figure 2-9 Operation load in 1/16 Model 22E A of the top lid

Operational Load and Boundary Conditions

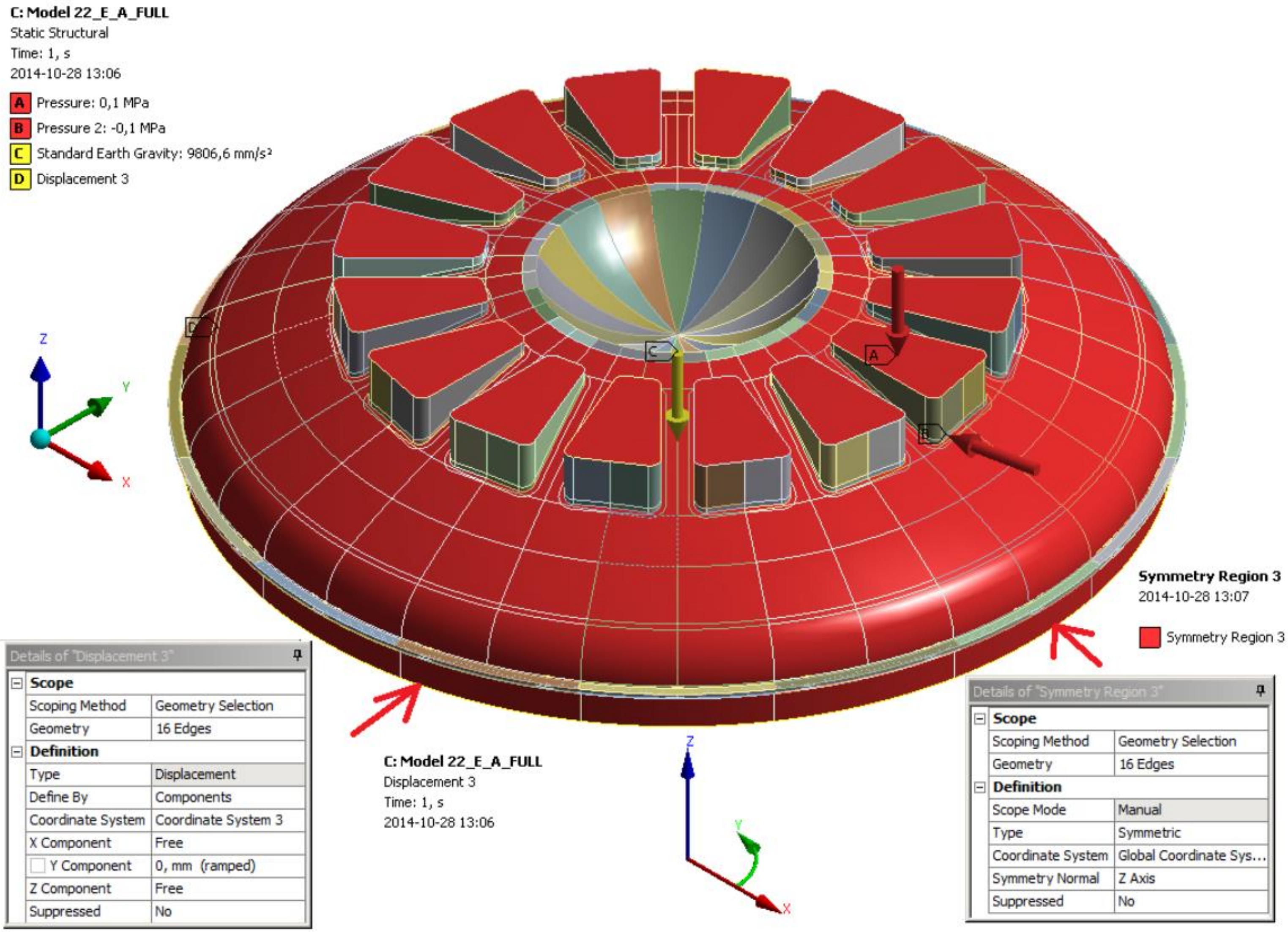


Figure 2-10 Operation load and boundary conditions in FULL Model of the top lid

Linear Structural Analysis for Model 22_E

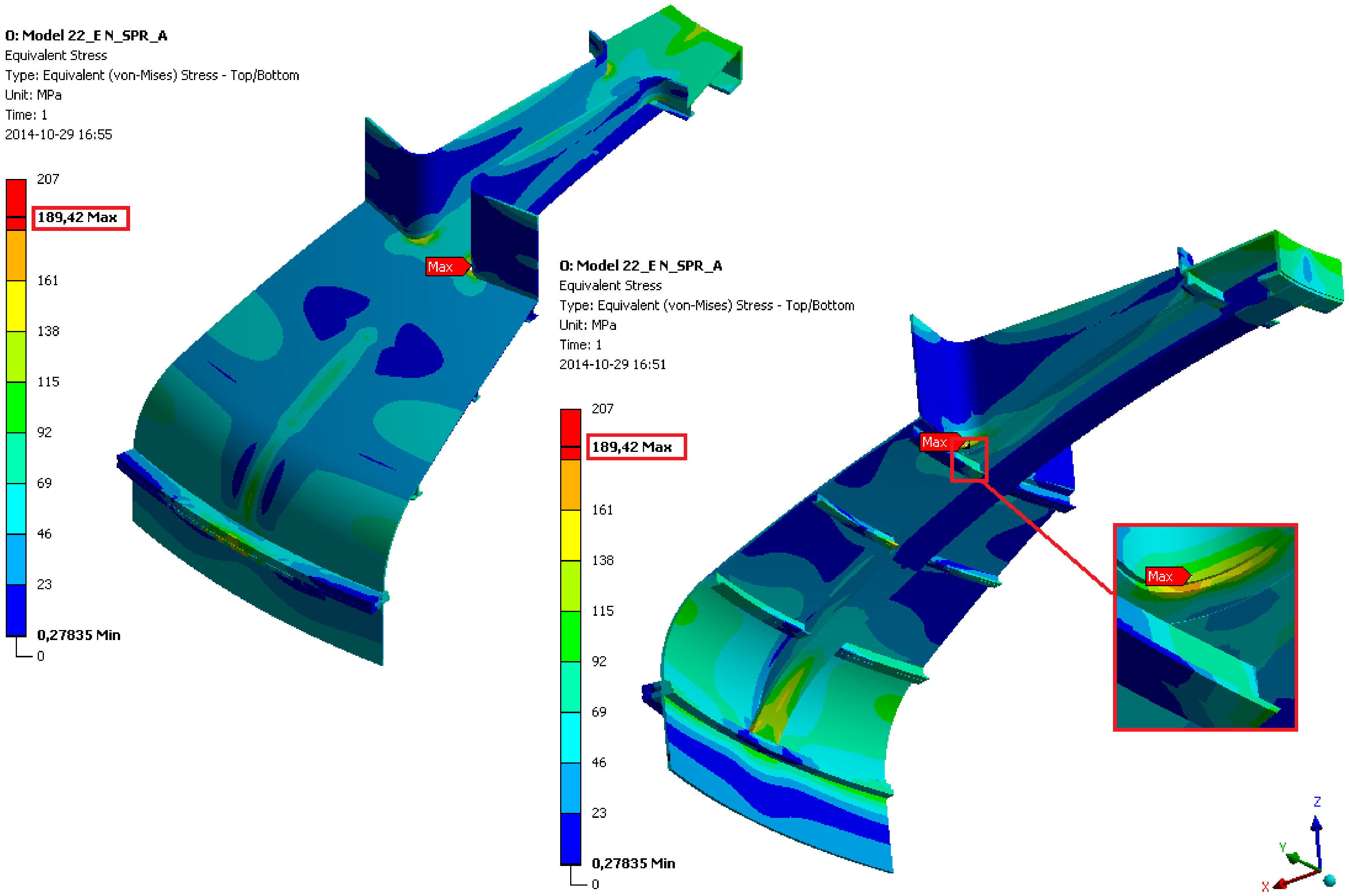


Fig. 3-1 Von Mises stress (Pm+Pb) in 1/16 model: Category II (P+D)

Linear Structural Analysis for Model 22_E

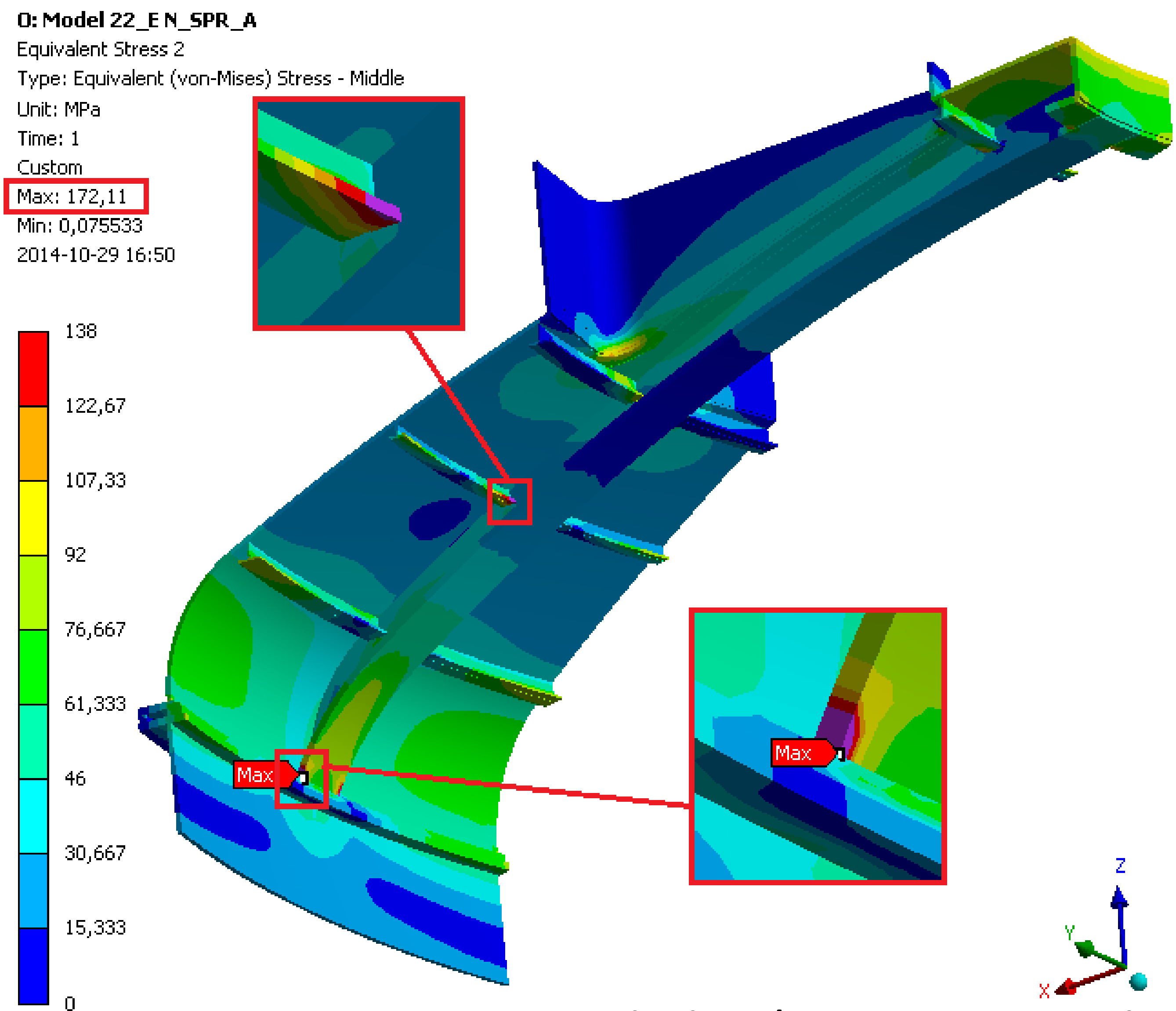
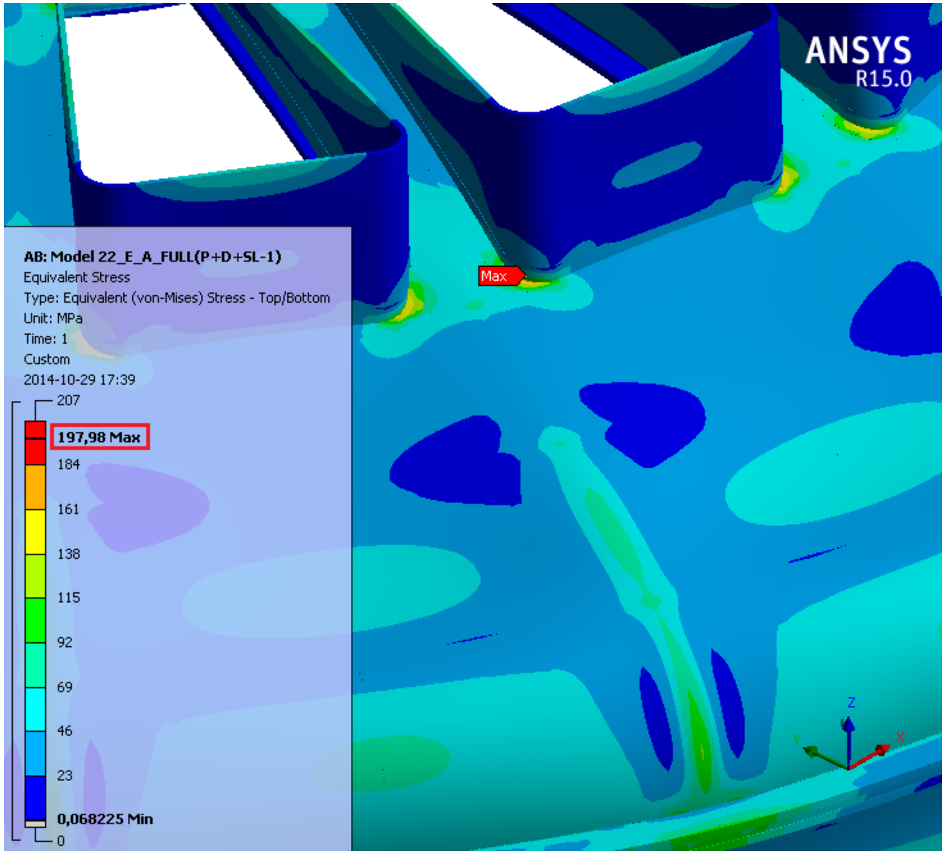


Fig. 3-2 Von Mises membrane stress (Pm) in 1/16 model: Category II (P+D)

Linear Structural Analysis for Model 22_E



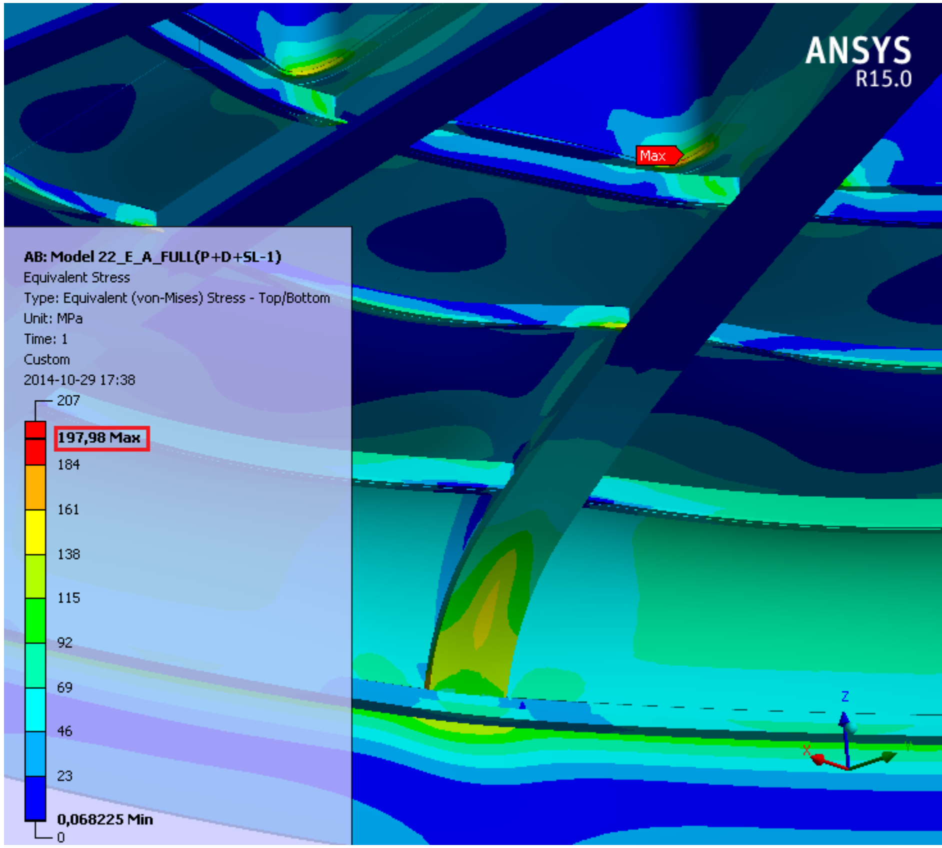
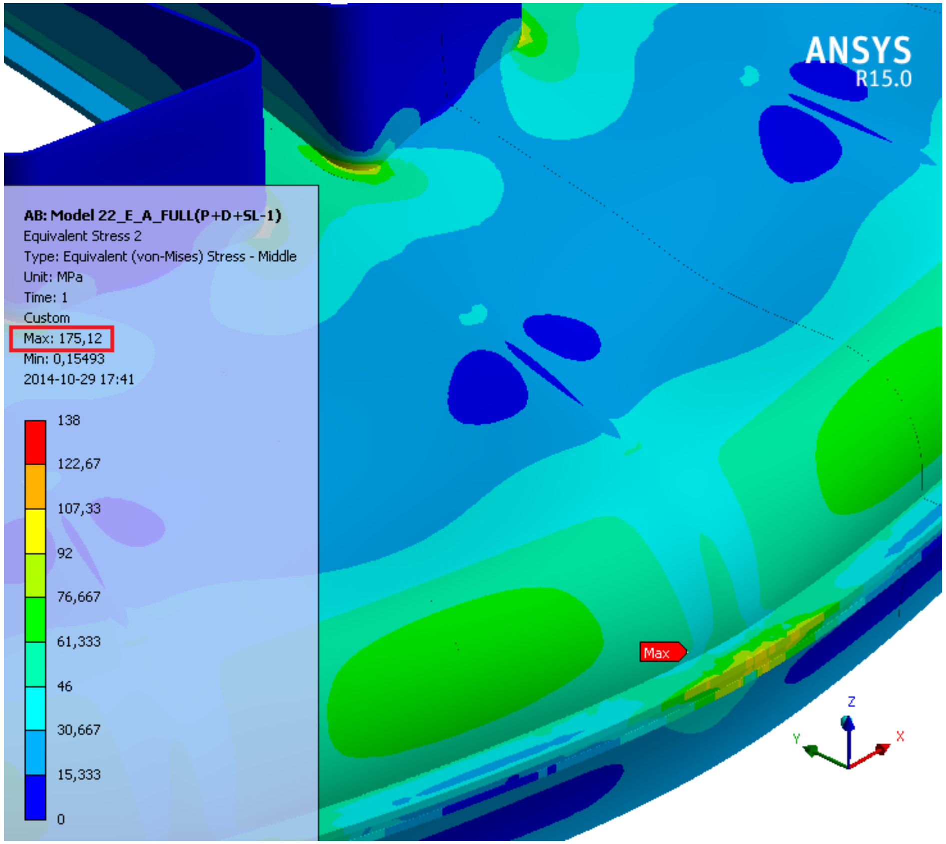


Fig. 3-3 Von Mises stress (Pm+Pb) in FULL model: Category II (P+D+SL-1)

Linear Structural Analysis for Model 22_E



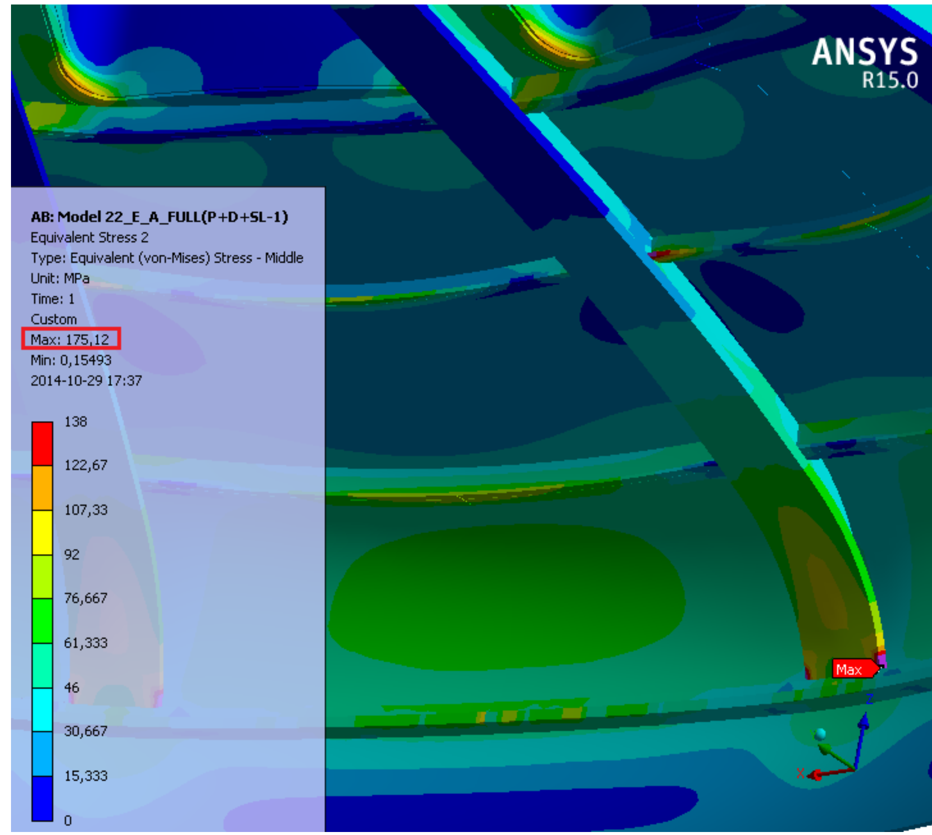


Fig. 3-4 Von Mises membrane stress (Pm) in FULL model: Category II (P+D+SL-1)

Linear Buckling Analysis for Model 22_E

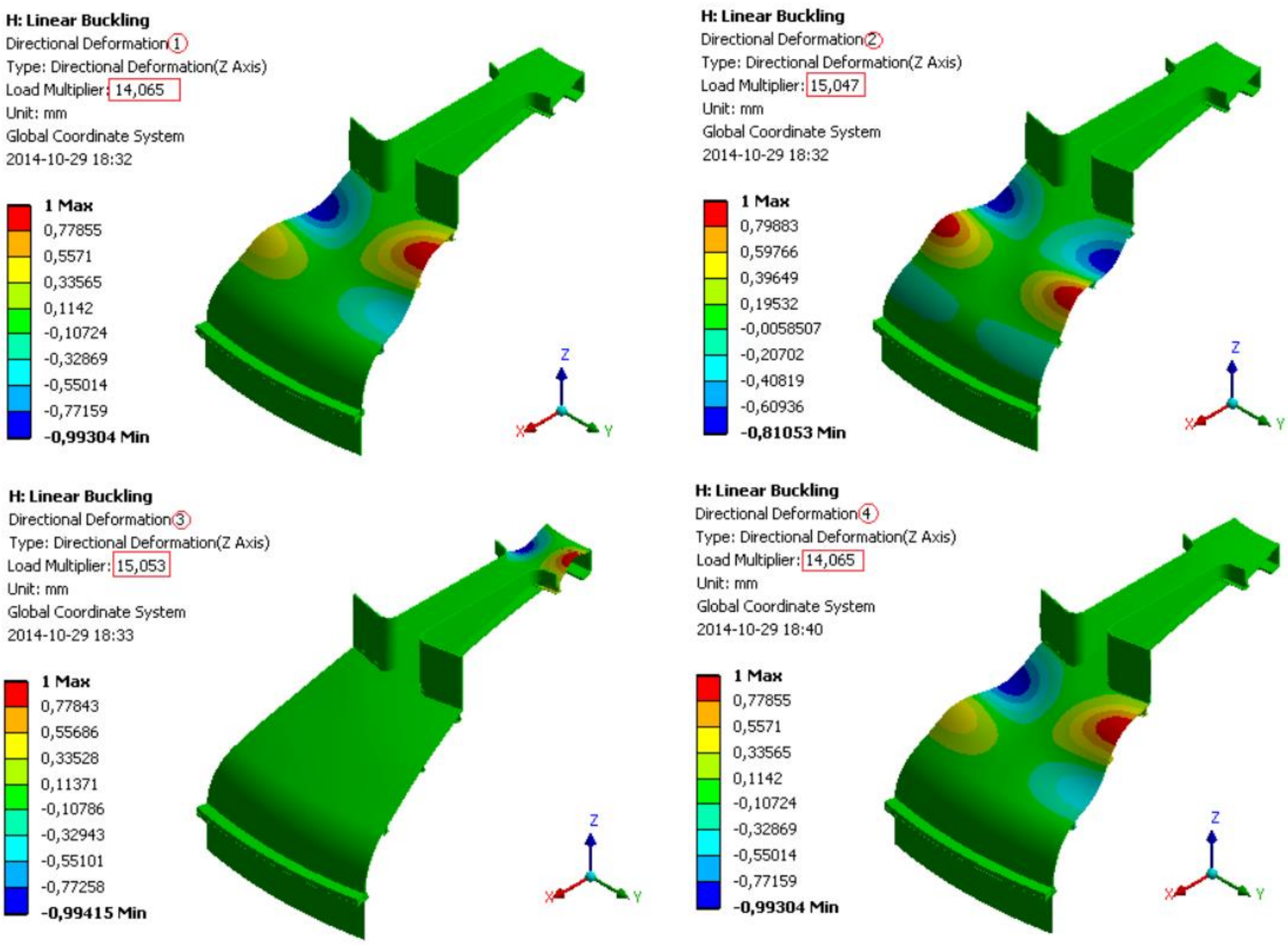


Fig. 3-5 Linear buckling : Category II (P+D) for 1/16 model – mode shapes No 1,2,3 & 4

Linear Buckling Analysis for Model 22_E

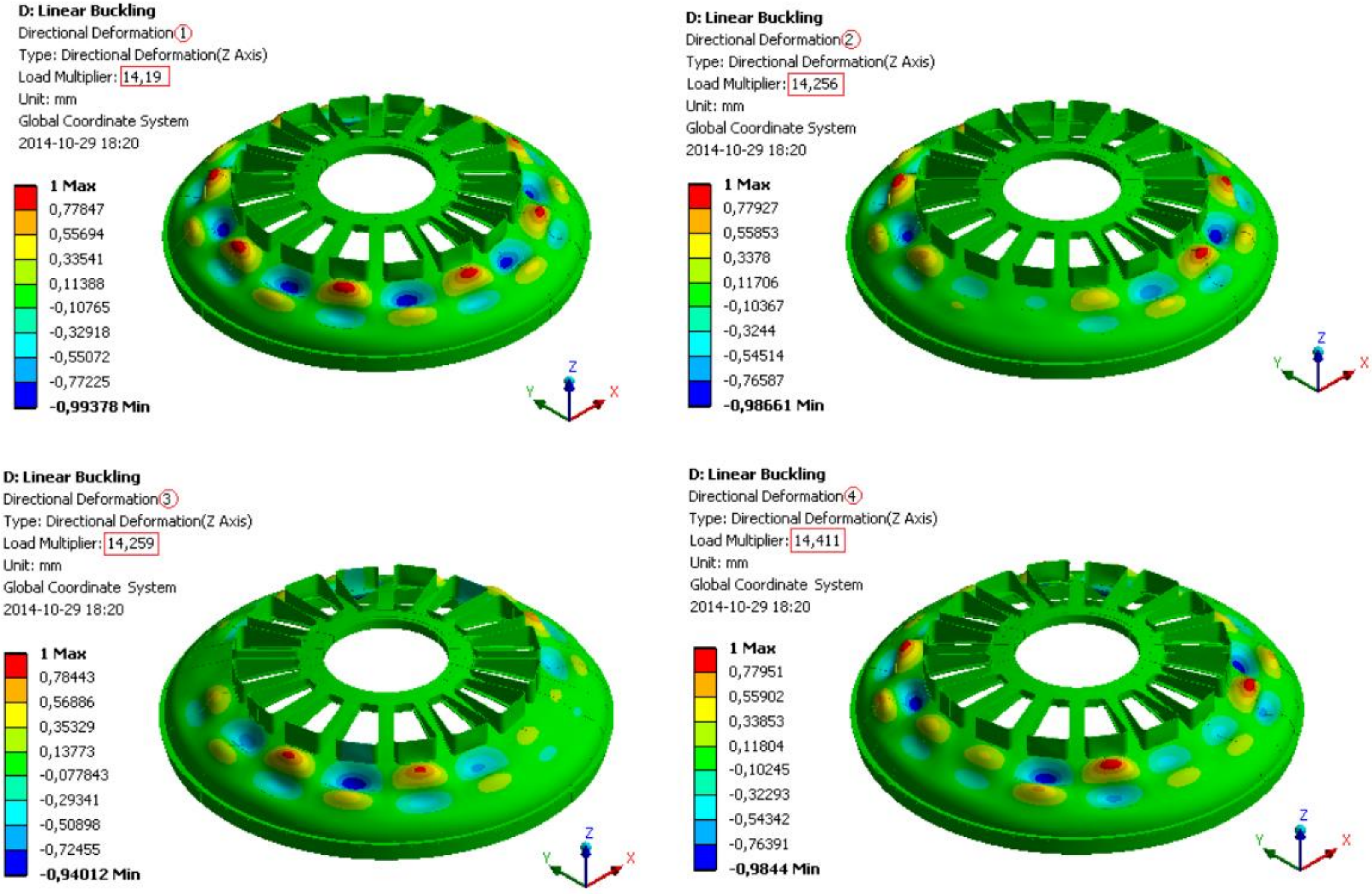


Fig. 3-6 Linear buckling : Category II (P+D) for FULL model – mode shapes No 1,2,3 & 4

Plastic Collapse in 1/16 Model

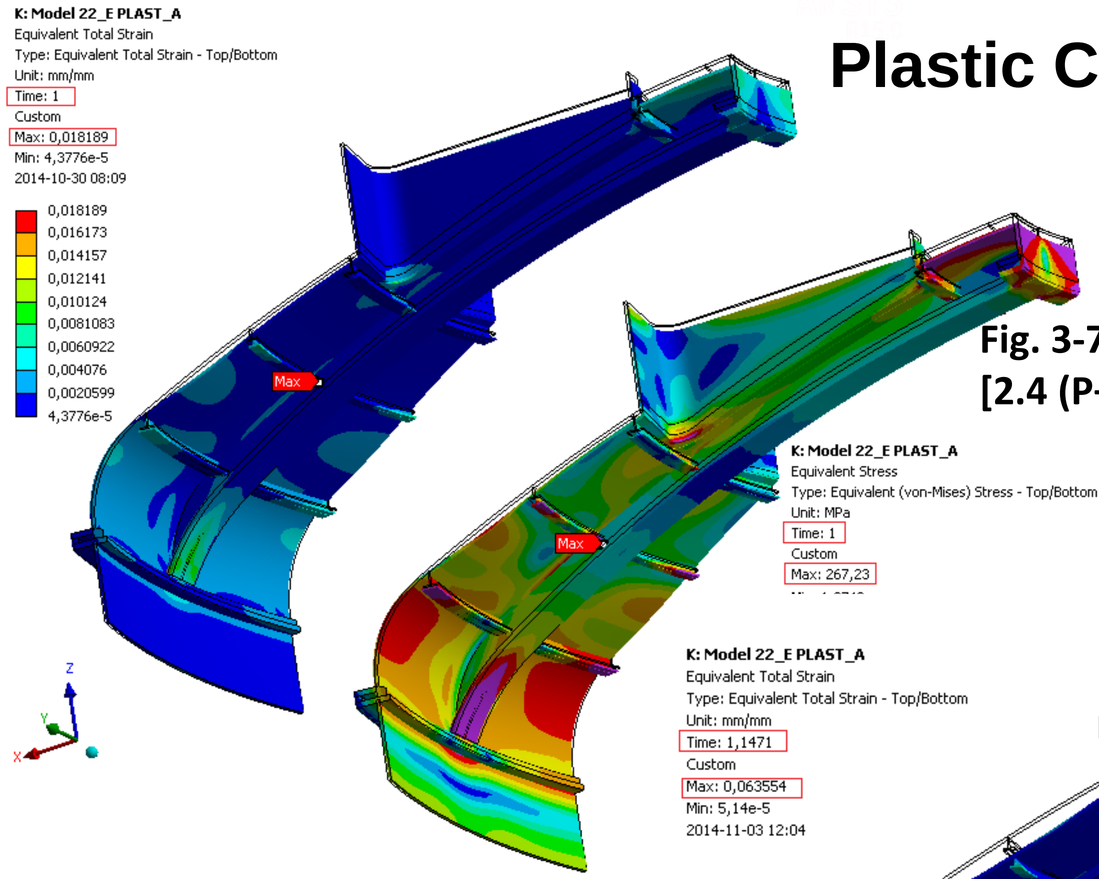


Fig. 3-7 Non-linear analysis for 1/16 model: [2.4 (P+D)] – E_{VM} and S_{VM} at LF=1

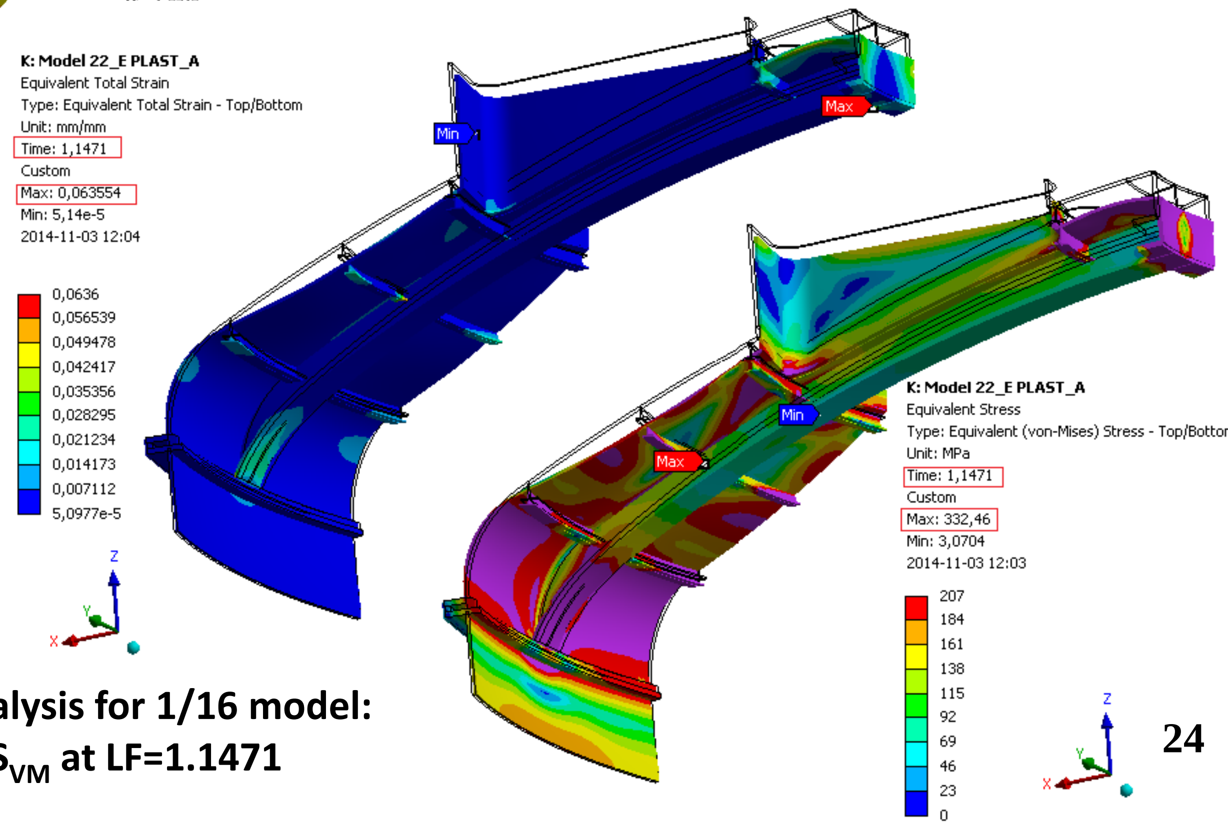


Fig. 3-8 Non-linear analysis for 1/16 model: [2.4 (P+D)] – E_{VM} and S_{VM} at LF=1.1471

Plastic Collapse in FULL Model

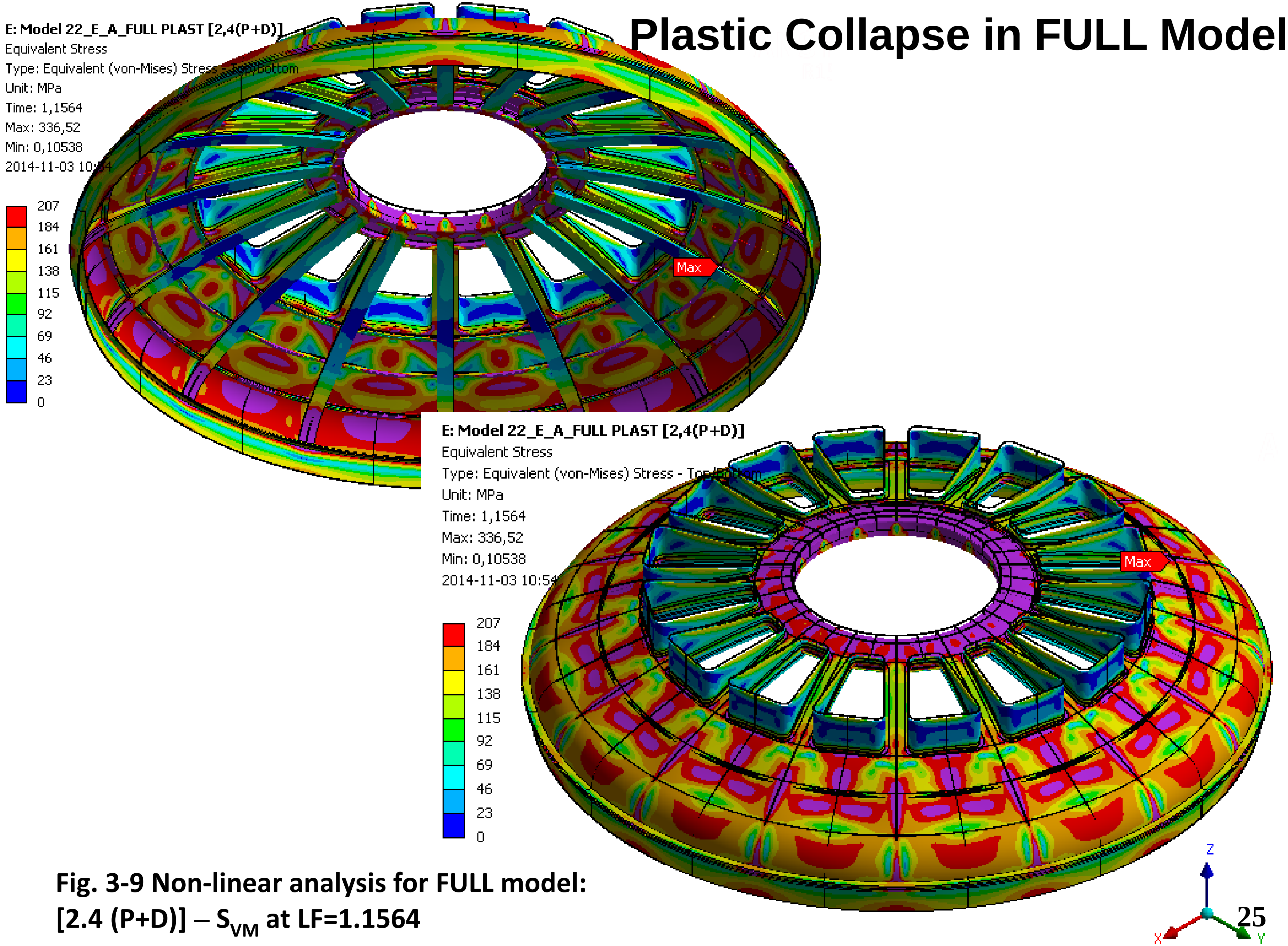
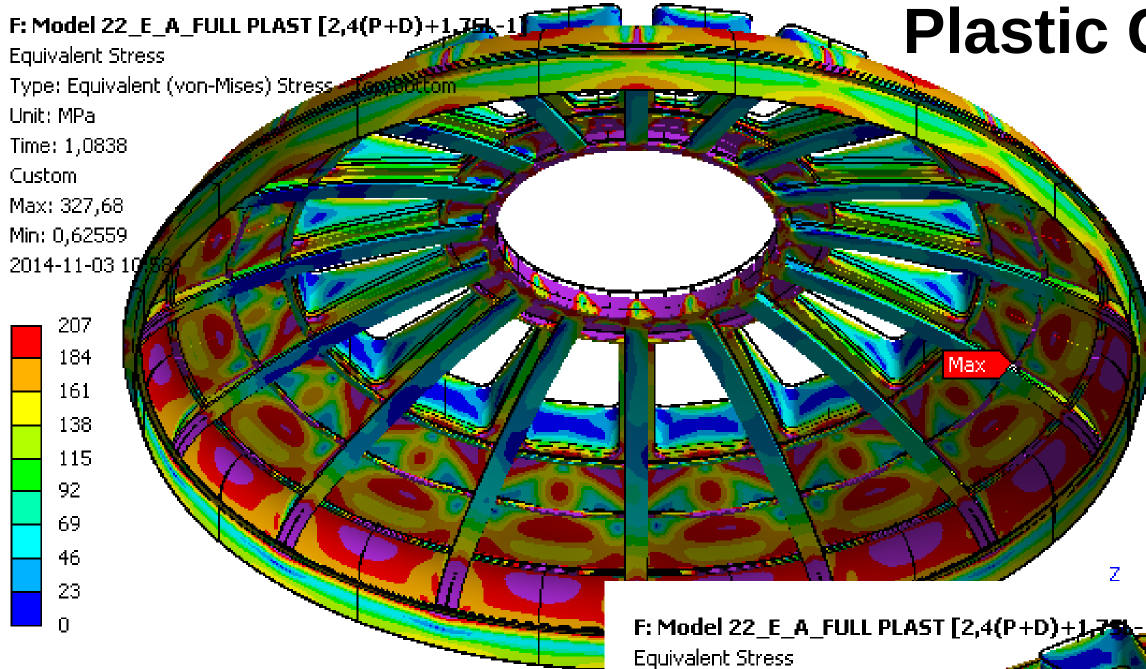


Fig. 3-9 Non-linear analysis for FULL model: [2.4 (P+D)] – S_{VM} at LF=1.1564

Plastic Collapse in FULL Model



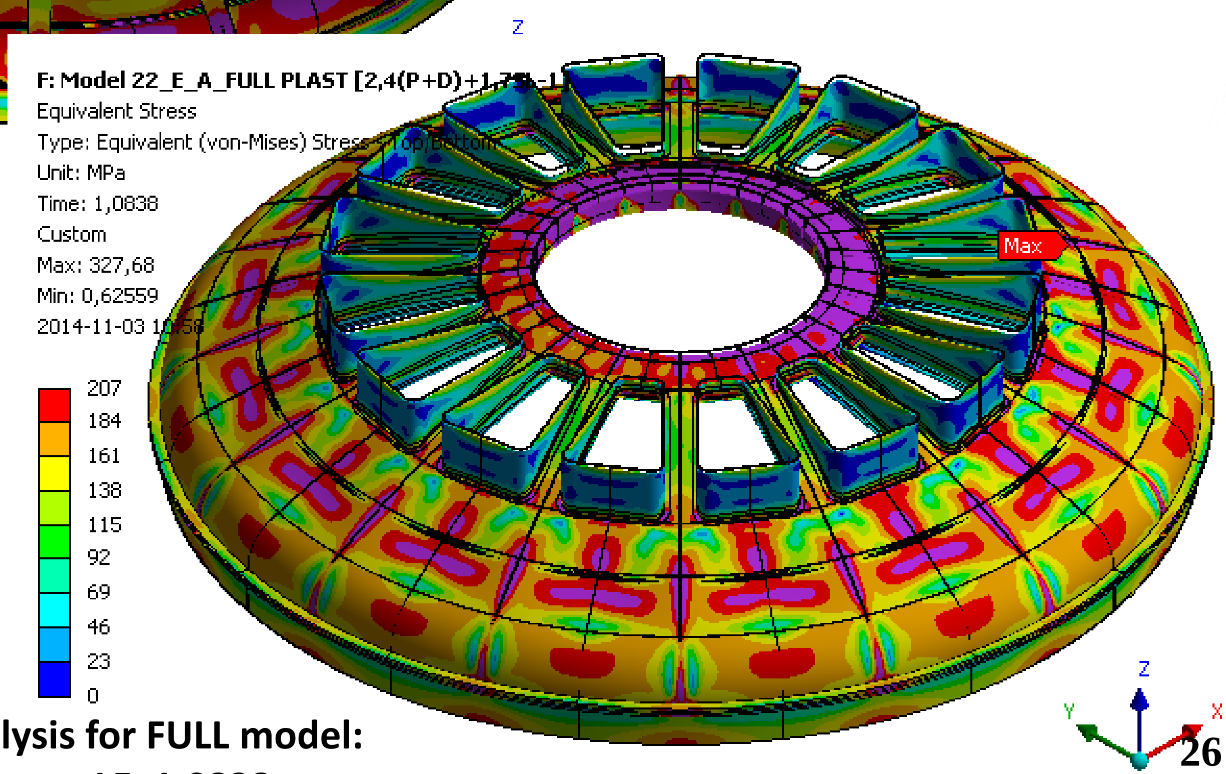
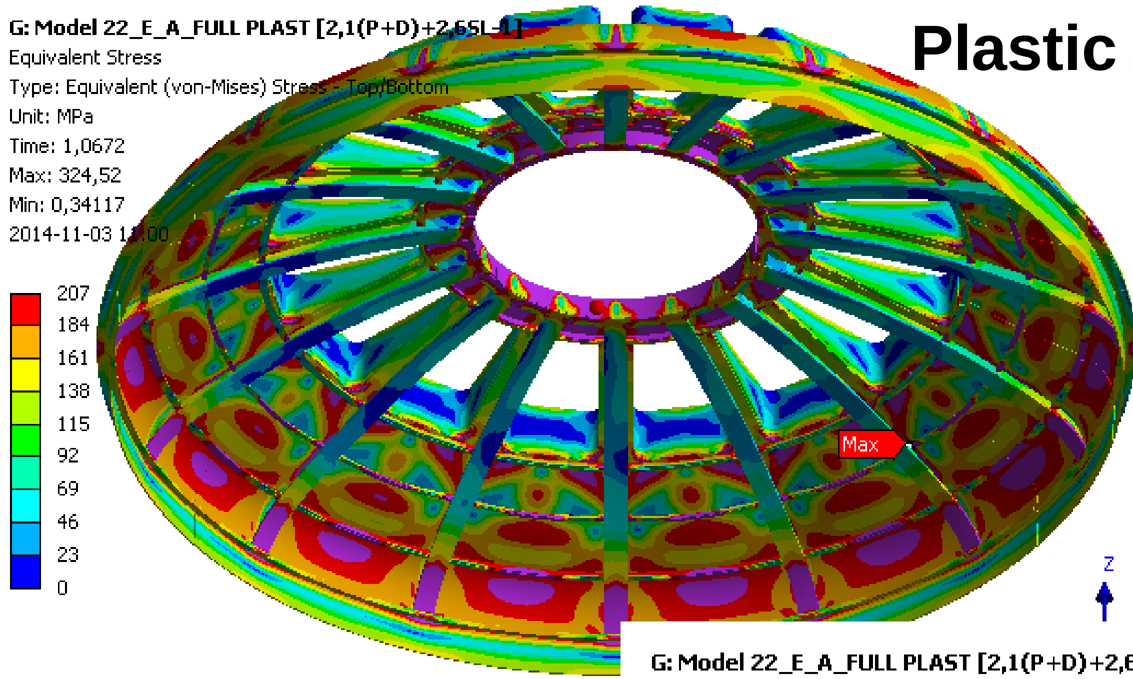


Fig. 3-10 Non-linear analysis for FULL model: [2.4(P+D) + 1.7 SL-1] – S_{VM} at LF=1.0838

Plastic Collapse in FULL Model



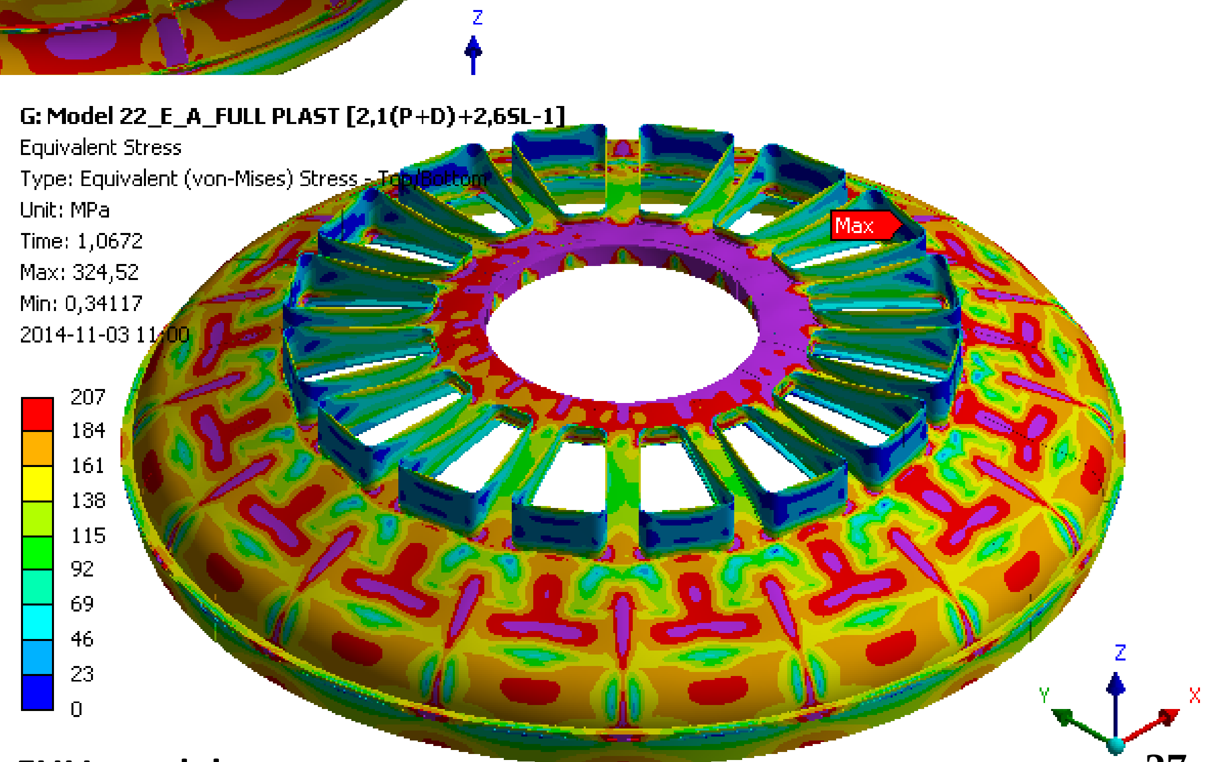
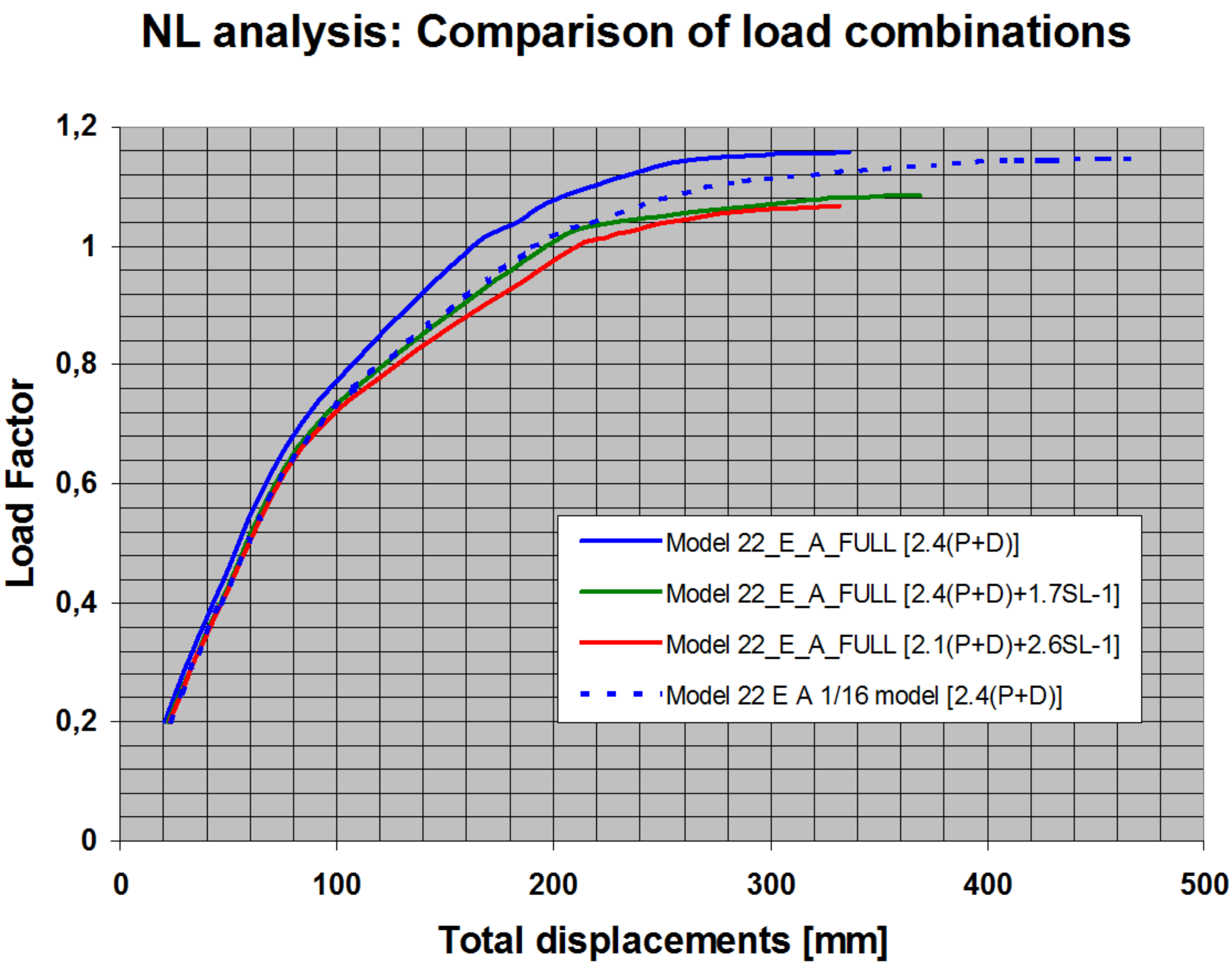
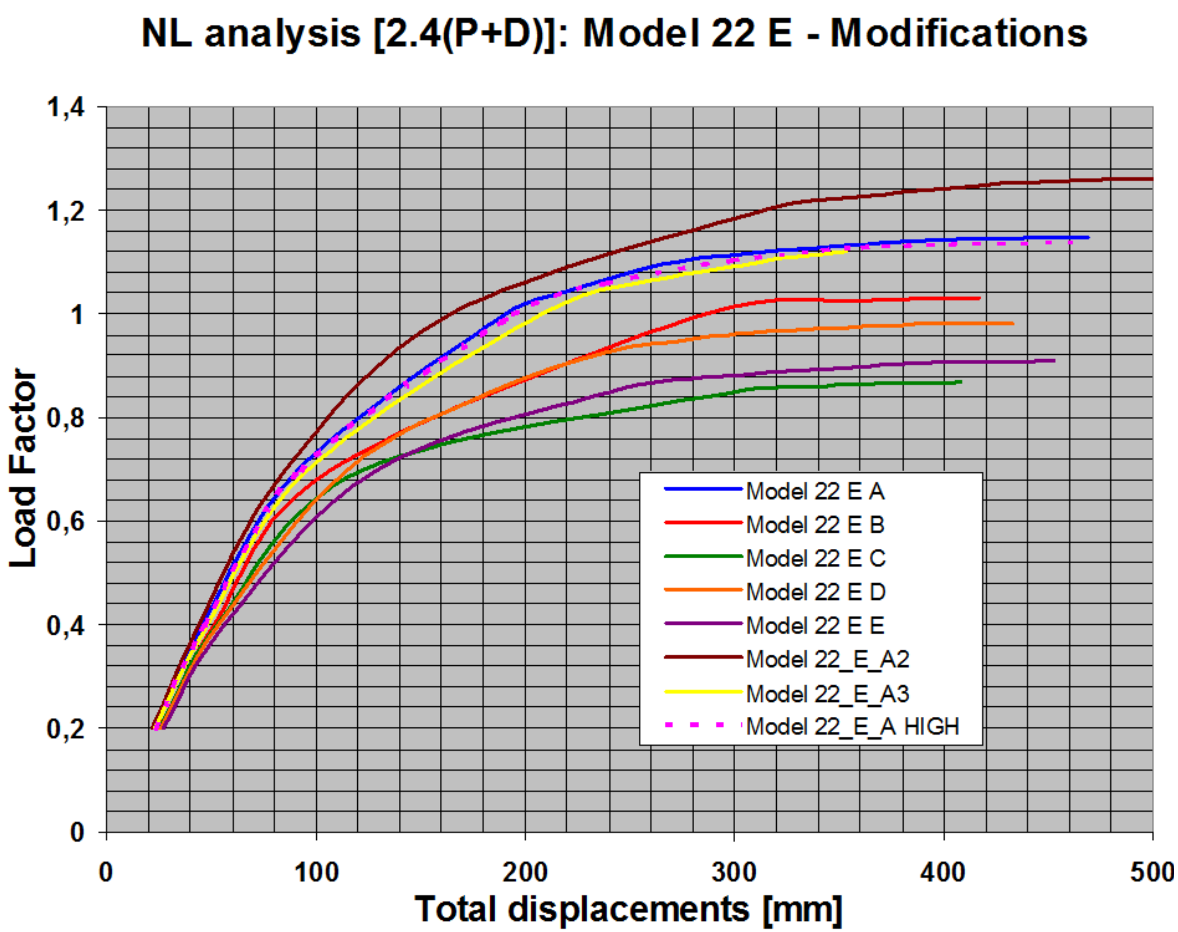


Fig. 3-11 Non-linear analysis for FULL model: [2.1(P+D) + 2.6 SL-1] – S_{VM} at LF=1.0672

Plastic Collapse



Plastic Collapse

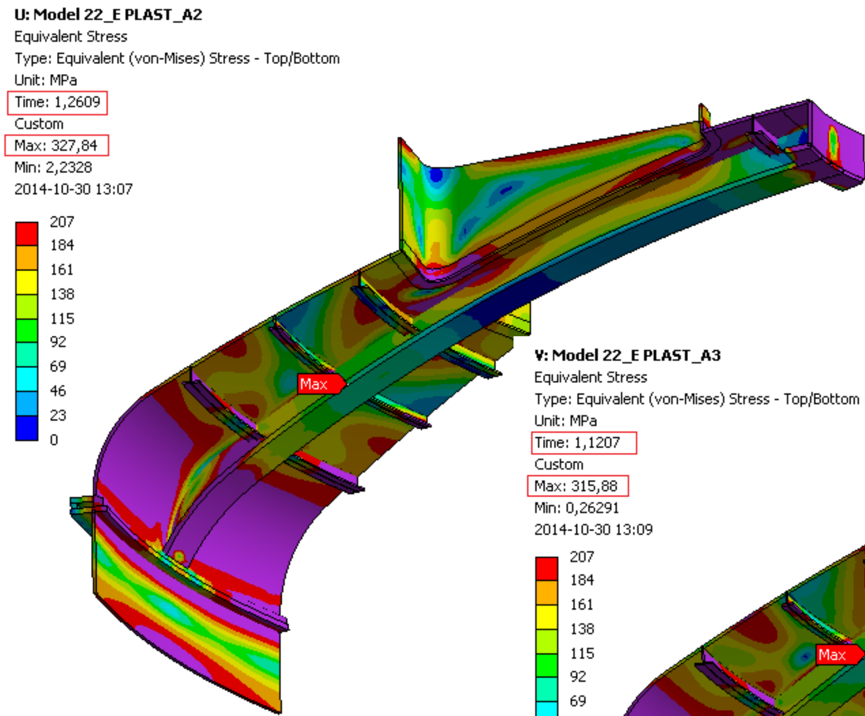


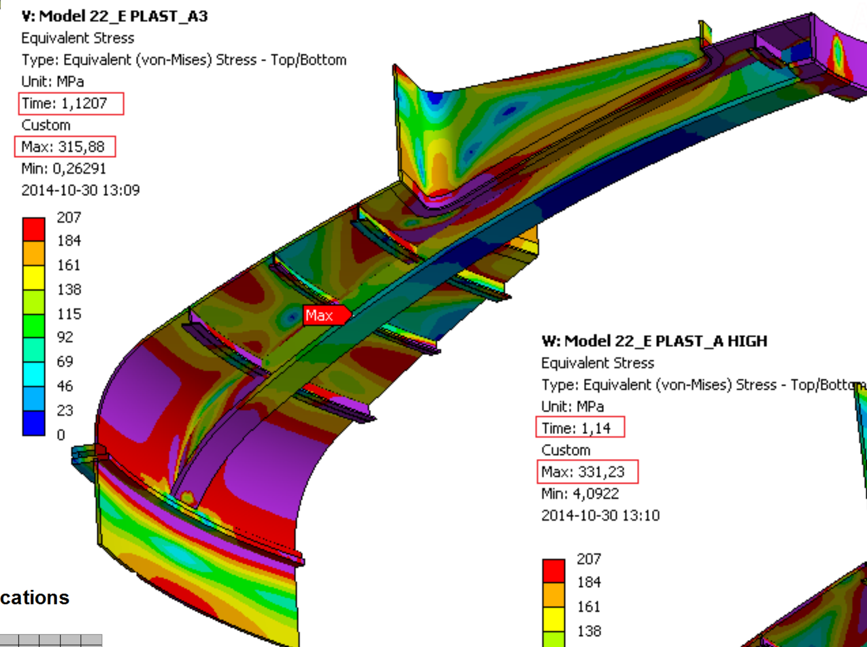
Comparison of different geometrical modifications for [2.4 (P+D)]

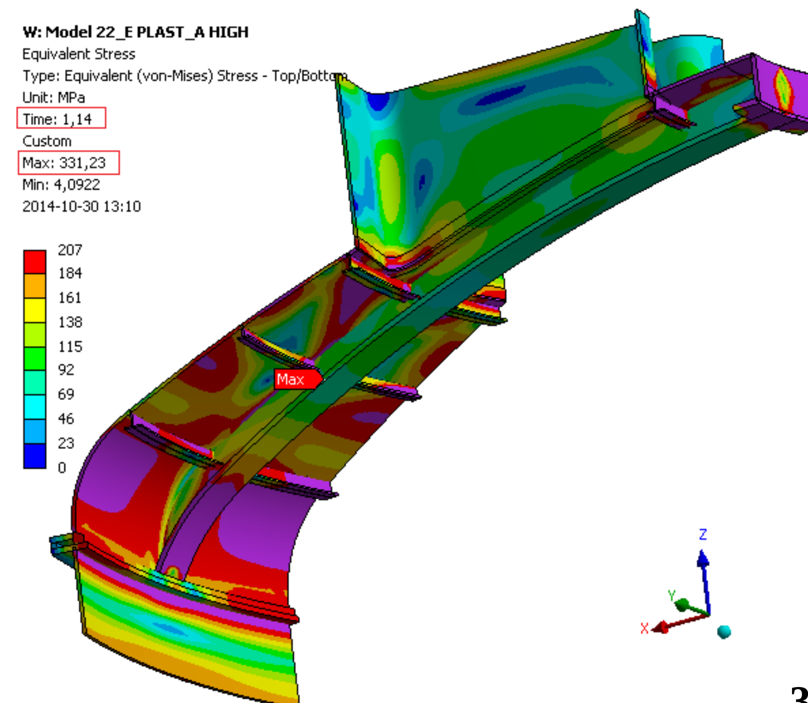
Parameter description	Symbol	M	O	D	E	L	22	E
		A [mm]	B [mm]	C [mm]	D [mm]	E [mm]	A2 [mm]	A3 [mm]
Top Lid Skin thickness	Th_01	60	50	50	50	50	60	50
Radial Rib Shelf thickness	Th_03	100	100	100	80	60	100	100
Inner Bottom Shelf thickness	Th_05	100	100	No shelf	80	60	100	100
Inner Top Shelf thickness	Th_07	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
Localtion of Toroidal Rib No 1	V112	1800	1800	1800	1800	1800	1000	1000
Localtion of Toroidal Rib No 2	V113	7400	7400	7400	7400	7400	8000	8000
Localtion of Toroidal Rib No 3	V114	9400	9400	9400	9400	9400	9500	9500
Localtion 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

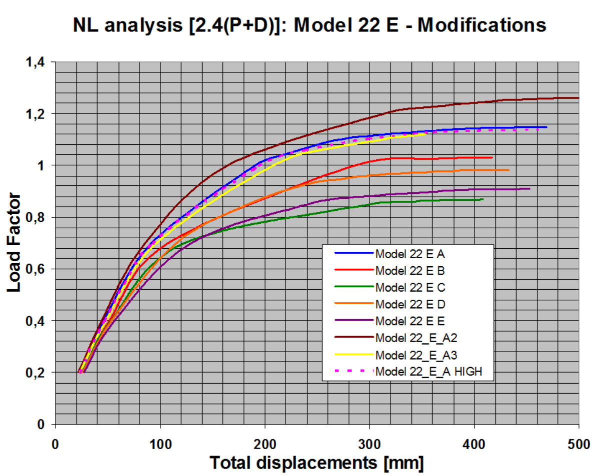
Table 3-1 Geometrical modifications used in 1/16 Model 22E of the top lid (Fig.2-5)

Plastic Collapse in 1/16 Model









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

Linear Buckling Analysis (modifications)

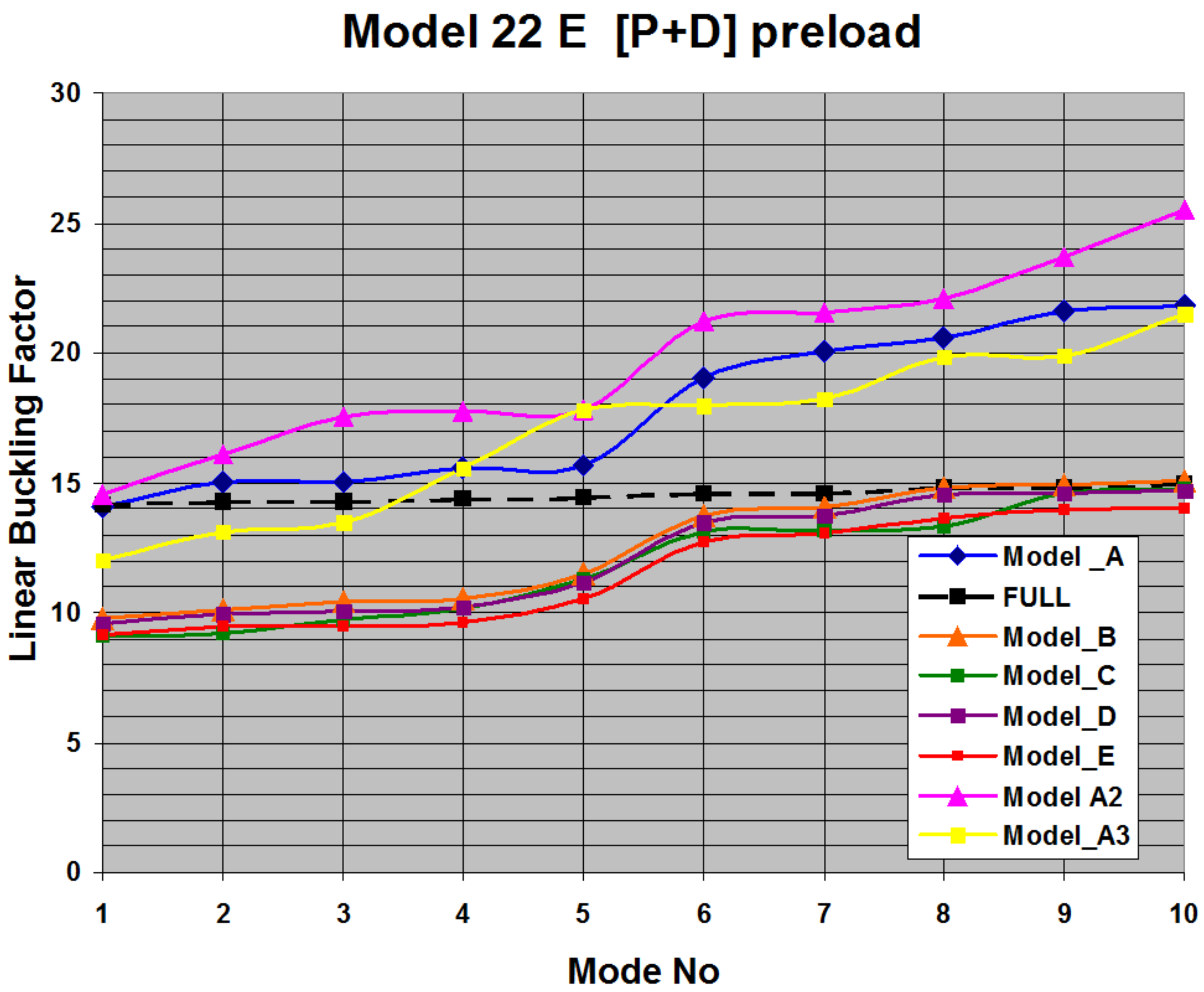


Figure 3-17 Linear buckling: Comparison of different geometrical modifications