Vacuum Vessel Analysis and Design For The ARIES-ACT1 Fusion Power Plant

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I. Introduction

- Vacuum vessel provides high level vacuum environment to reach and maintain fusion plasma with high quality.
- like ITER, the vacuum vessel is made of austenitic steel, SS316, since this material has high neutron activation. Future material for AIRIES will be 3Cr-3WV steel.
- The vacuum vessel includes an inner cylinder attached to large maintenance ports. The fusion core is divided into 16 sectors.
- Vacuum vessel with different wall thicknesses are designed and analyzed to see if they can accommodate atmospheric pressure plus the weight of vessel or not.
- Parametric 3D finite element analysis is done to identify locations of high stress areas on the vessel under applied loads. Working temperature is 300 C^0 .

II. Thick solid single wall vacuum vessel, 10cm.

- A solid single wall vacuum vessel with 10cm wall thickness is analyzed under applied loads (Atmospheric pressure on the outer surface and gravity) .
- Because of symmetry, 1/16 of sectors is picked up for analysis (Frictionless BC).

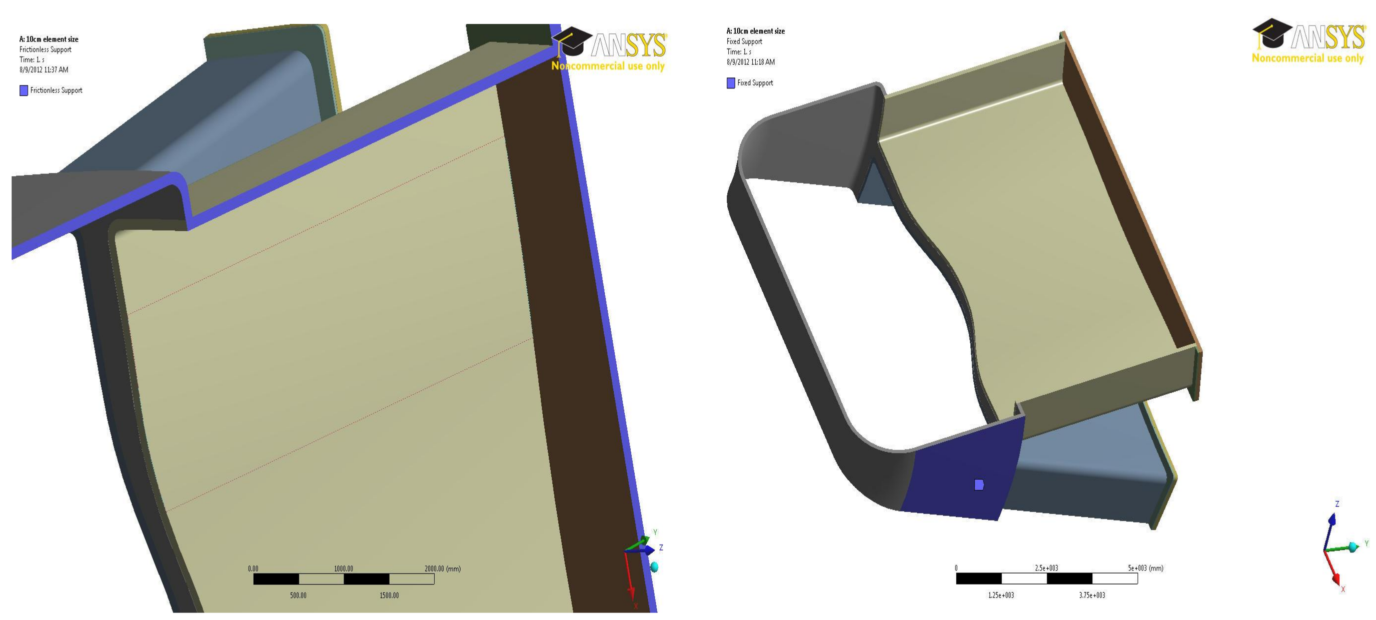

Figure 1 Frictionless and Fixed Boundary Conditions

Element size	Number of Elements	Maximum Stress (Mpa)
20cm×20cm×1cm	58'500	128
10cm×10cm1cm	230'140	141
6cm×6cm×1cm	578'260	150

11%

6%

Table 1 Convergence check by reducing the element size

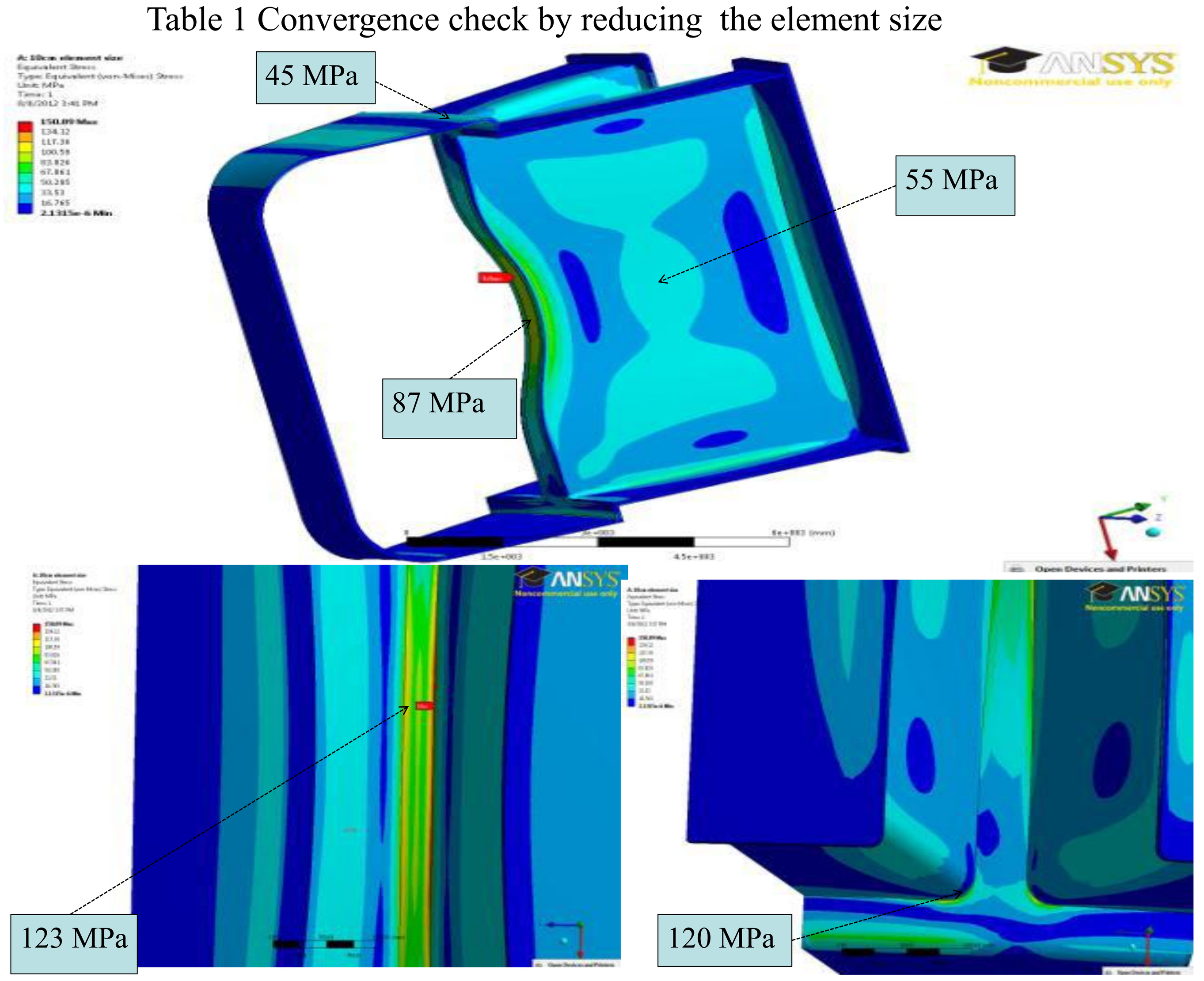

Figure 2 Stress distribution for a 10cm thick wall vessel

- 10cm thick wall solid single wall vacuum vessel can tolerate the atmospheric and gravity loads .

III. Very thin solid single wall vacuum vessel (5cm)

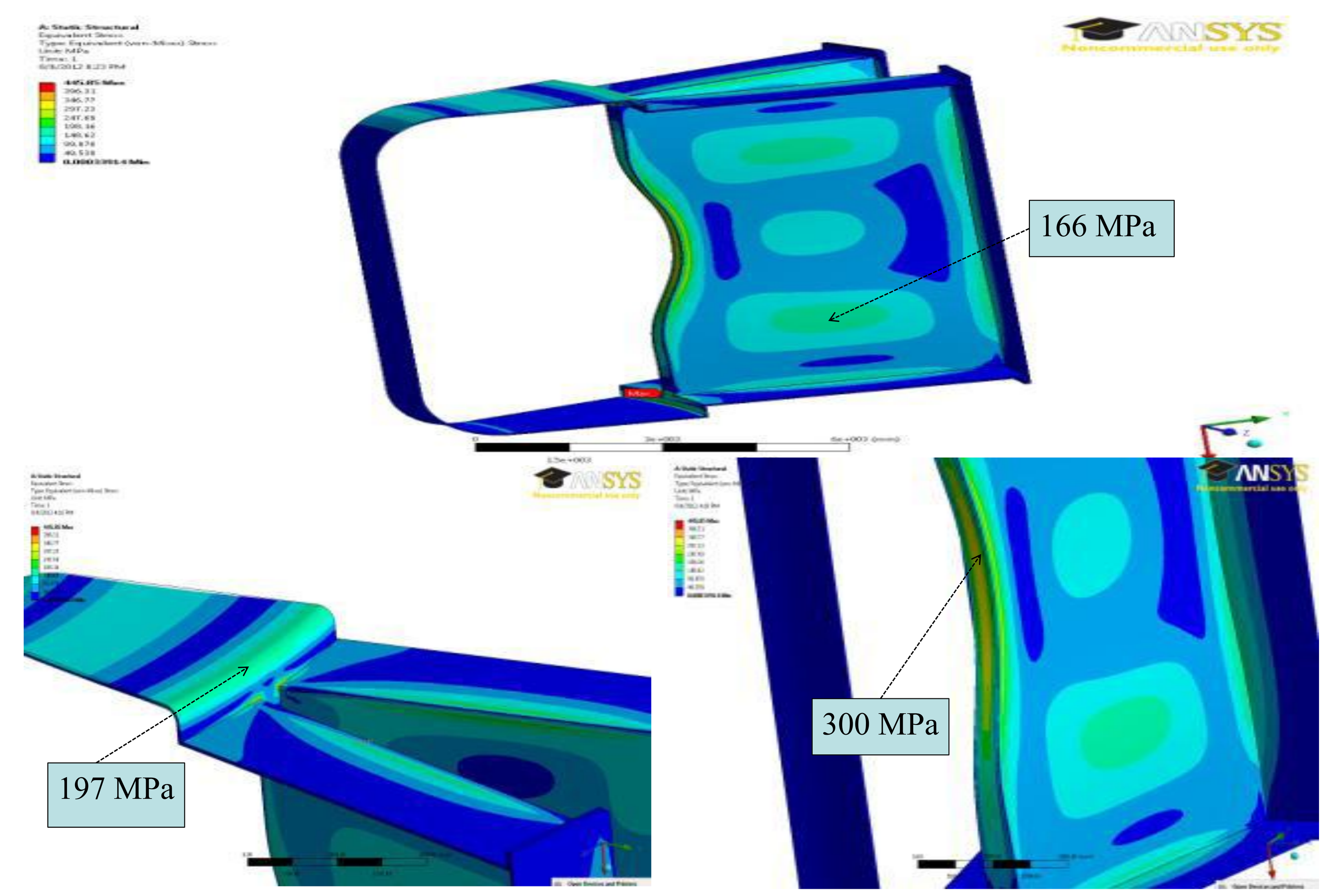

Figure 3 Stress distribution for 5cm solid single wall vacuum vessel

- The very thin vacuum vessel has lots of overstressed areas (>140 MP), not able to tolerate the desired loads.

IV. Ribbed Structure (Double Wall Structure)

- The need for using He coolant throughout the vessel and reducing stress intensity besides the need for designing vacuum vessel with thinner wall will lead us towards the ribbed structure model analysis.
- Ribbed structure, increases the strength of structure and provides sufficient space for the coolant He to follow between the ribs.
- Rib configuration on the port and door (the largest area of vacuum vessel) is to be determined which includes ribs thickness, ribs direction, distance between ribs and thickness of each wall (sheet).
- A simplified structure model for this optimization is considered which includes the detachment of port and door from the main body and using fixed BC.

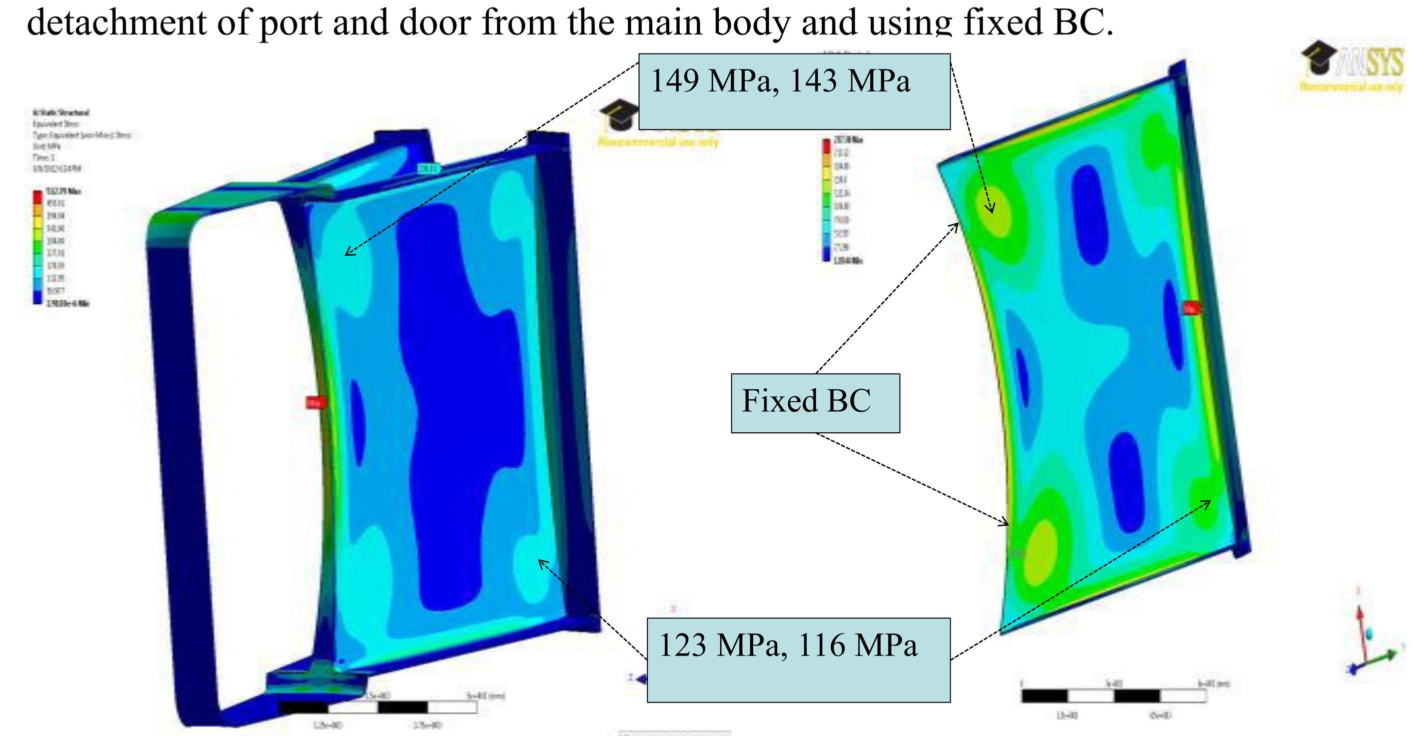

Figure 4 Simplified Structure Model (Less than 5% difference between similar point)

- For the ribbed structure with horizontal ribs, there are always hot spot regions where stress goes higher than the yield point on different locations.
- Based on the simplified model and the fact that horizontal ribs get overstressed spots, a variety of vertical ribbed structure (different rib thicknesses, wall or sheet thickness and distances between ribs) are designed and analyzed.
- There is always a substantial reduction in stress intensity on the outer wall (sheet) comparing to the inner wall.

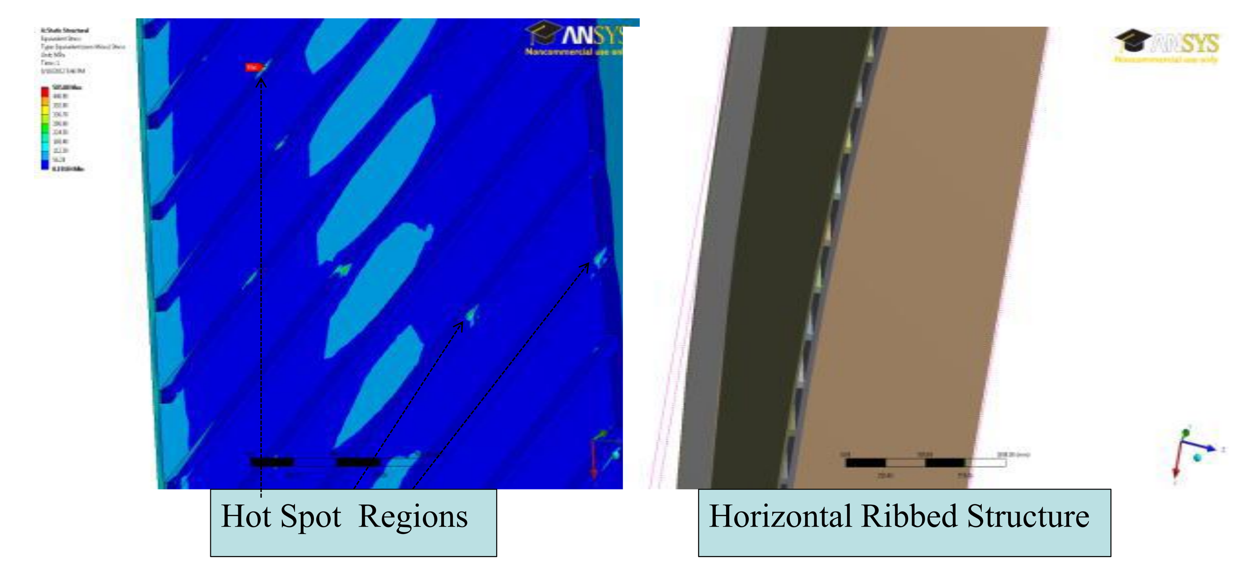

Figure 5 Hot spot points, overstressed horizontal ribs

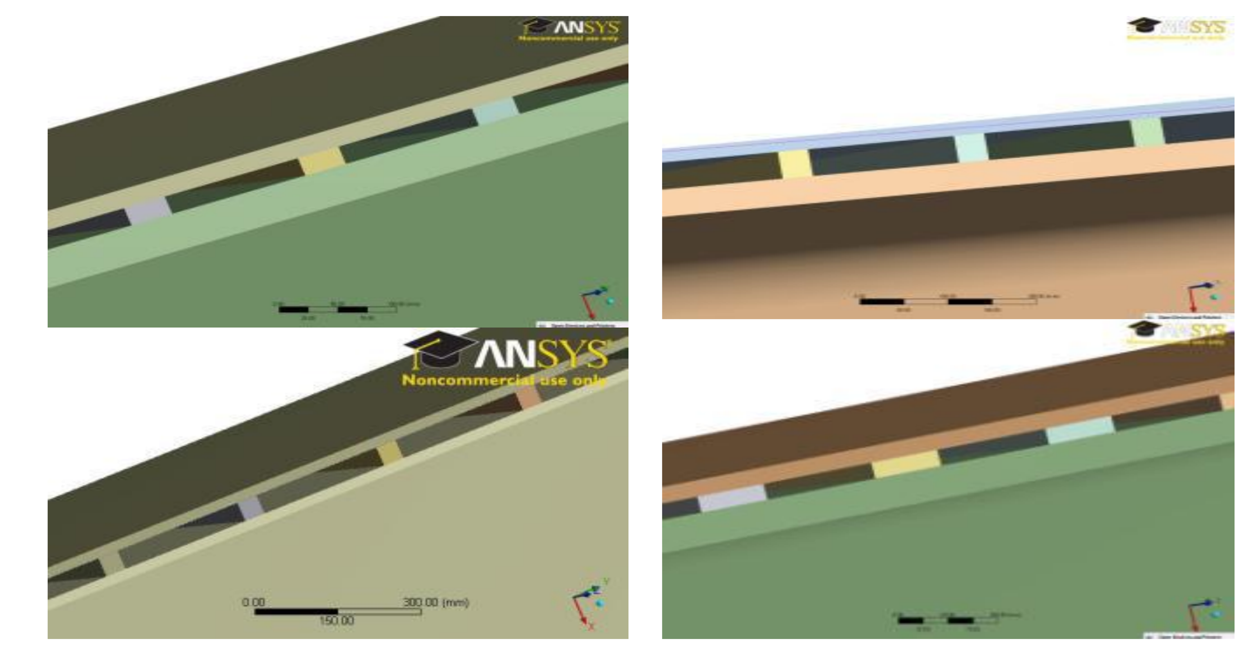

Figure 6 Variety of vertical ribbed structure on port

- Thickness of inner sheet is designed to be two times of the outer sheet. The gap between these sheets is designed to be half of the outer sheet thickness.
- 43% stress reduction on the corner area in the ribbed structure model.

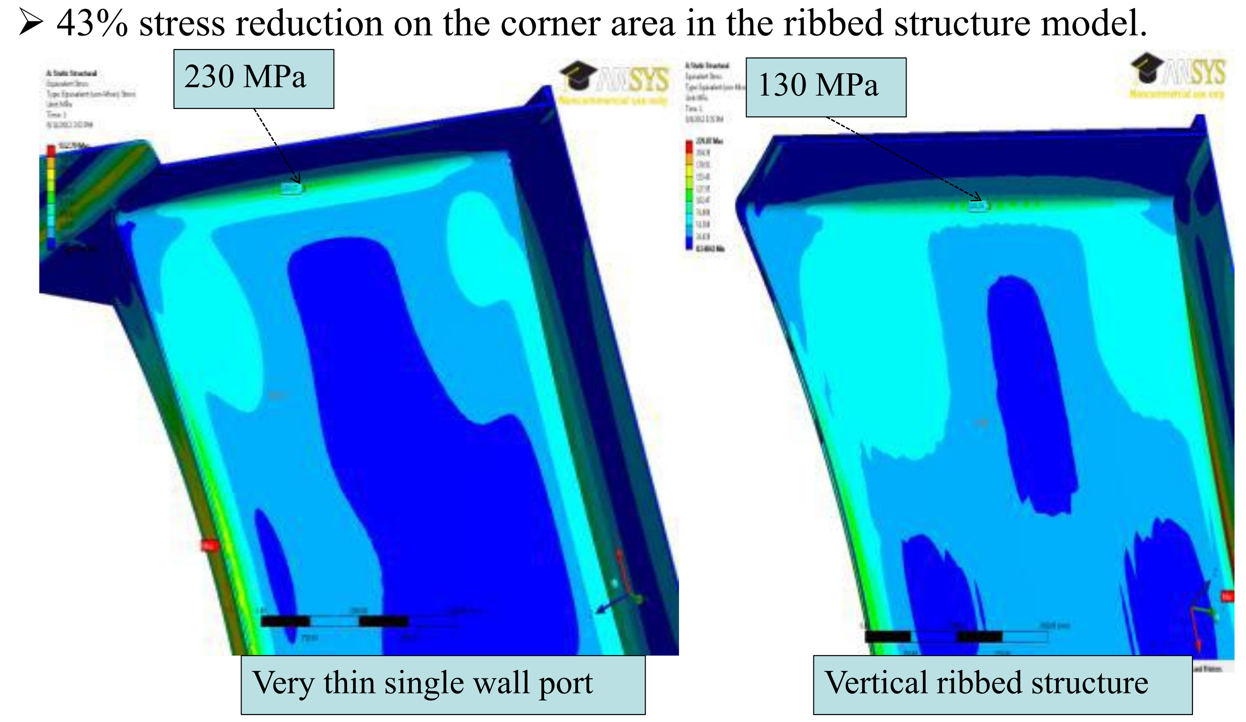

Figure 7 Single wall vessel comparing to the vertical ribbed structure

V. Mixed Ribbed Structure (Vertical & Horizontal)

- Leading cooling channels from the main body to ports and doors.

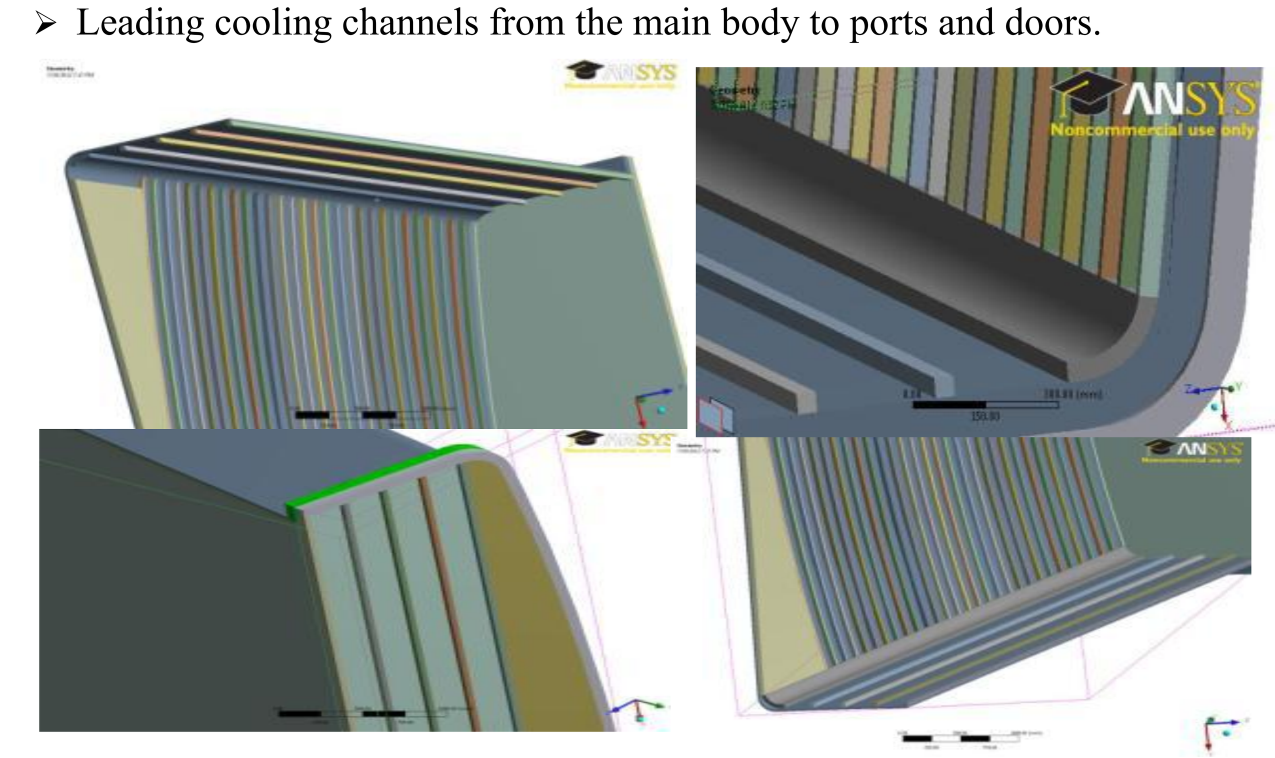

Figure 8 Mixed ribbed structure model

Design Parameter	Size
Distance between vertical ribs	18-19cm
Distance between horizontal ribs	25cm
Rib thickness	4cmx4cm
Gap between inner and outer wall	4cm
Outer wall (sheet) thickness	2cm
Inner wall (sheet) thickness	4cm

Table 2 Design parameters for the mixed ribbed structure

- The outer and inner walls (sheets) are always safe and stress in most parts is close to 100MPa which is less than the yield stress (140MPa).

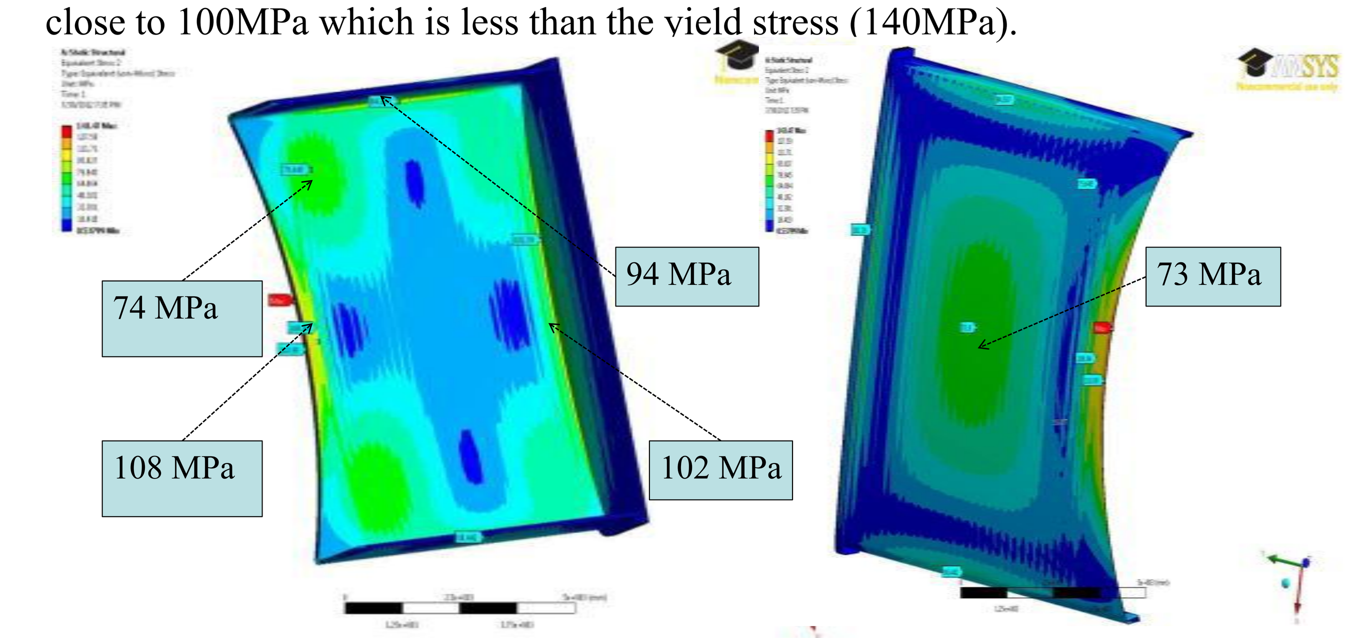

Figure 9 Stress distribution on the inner and outer wall

- Vertical and horizontal ribs have no hot spot region with high stress intensity, mostly less than 100MPa.

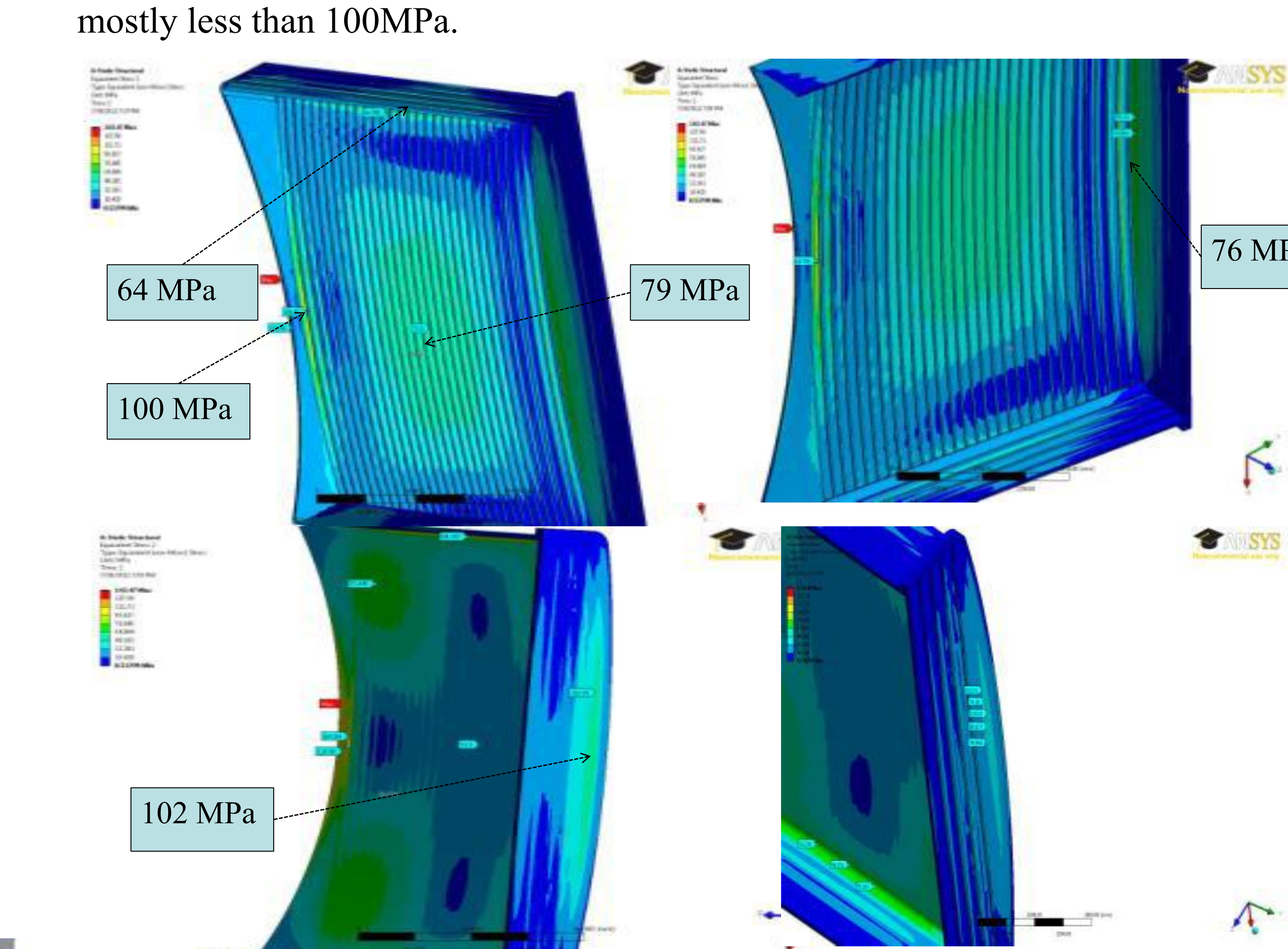

Figure 10 Stress distribution on the mixed ribs and door

Acknowledgment

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Summary & Conclusion

- 3D finite element analysis is performed on different models of solid single wall vacuum vessel subjected to atmospheric pressure and gravity
- high stress regions were identified. 5cm solid single wall vacuum vessel cannot tolerate the desired loads unlike the 10cm one.
- Off normal loads such as disruption loads are not considered here.
- Ribbed structure configuration on the port and door, as a way to minimize the vacuum vessel thickness and cooling the system is designed and optimized.
- Result show that there is a substantial reduction in stress intensity on the outer wall (sheet) comparing to the inner wall.