Bottom CRU Installation Mechanical Analysis

November 7th, 2024

Agenda

1. Reminder of constraints, thermal properties of materials, and boundary conditions.
2. Warm Install Position Results with new adapter plate made from G10/FR-4.
3. Warm Install Position Results with new adapter plate made from stainless-steel.
4. Modelling Techniques for PEEK Spacers Discussion
5. Cold Install Position Results with new adapter plate from G10/FR-4.
6. Cold Install Position Results with new adapter plate from stainless-steel.
7. Possible Refinement of Cold Install Position Model
8. Unistrut Frame Modelling Progress

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CRU Rivet Nut Locations

- The rivet nut locations are determined by the CRU structure.
- Currently they accept M4 hardware.
- The contraction of the CRU and adapter plates could add shear forces to the hardware.
- Want to minimize the thermal contraction between these bolts
- Clearly 1040mm will be the limiting case, as the total contraction is proportional to the length by way of the CTE.
- There exists 0.4996mm of clearance between the fastener thread and adapter plate @ cold.

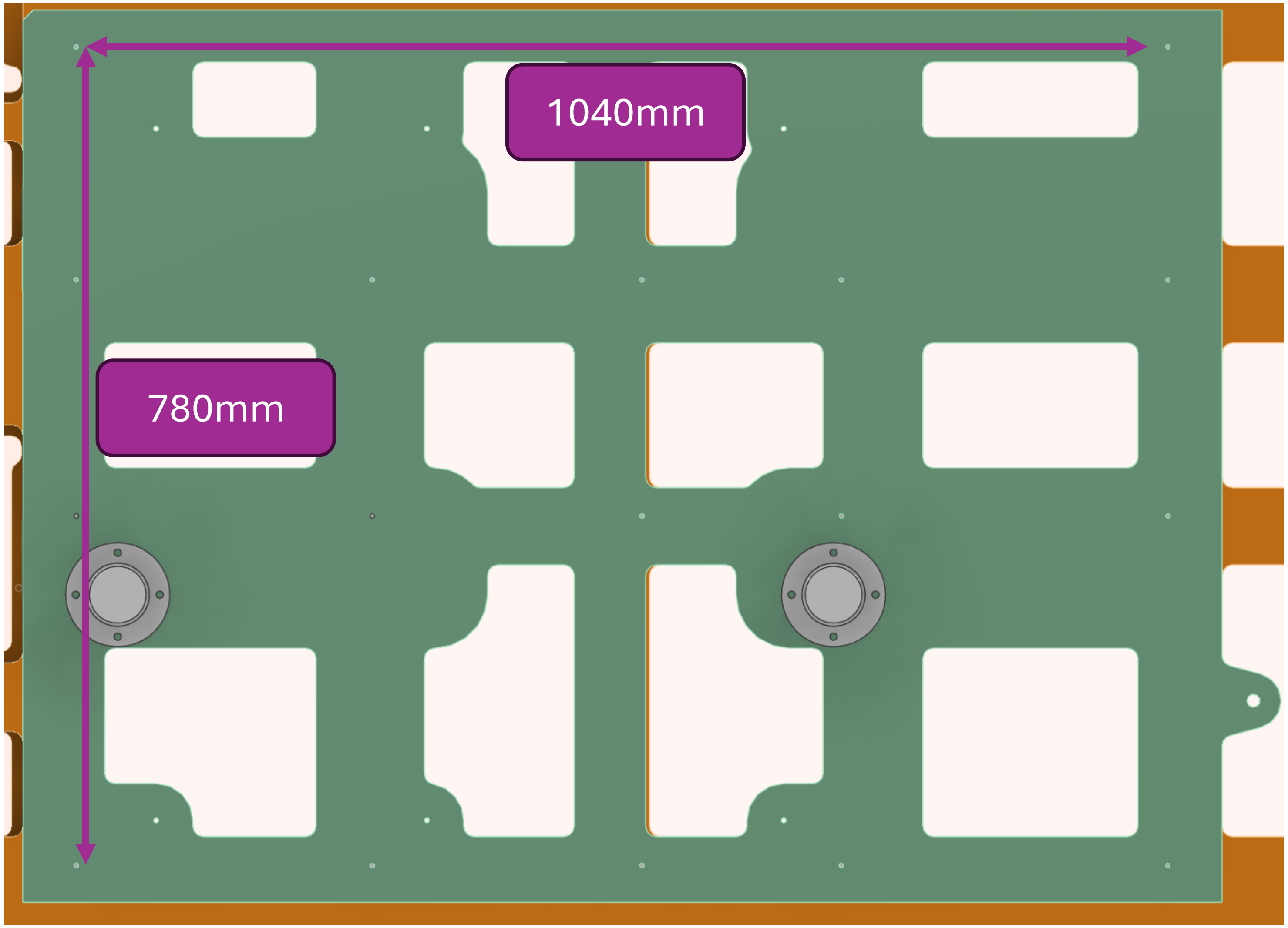
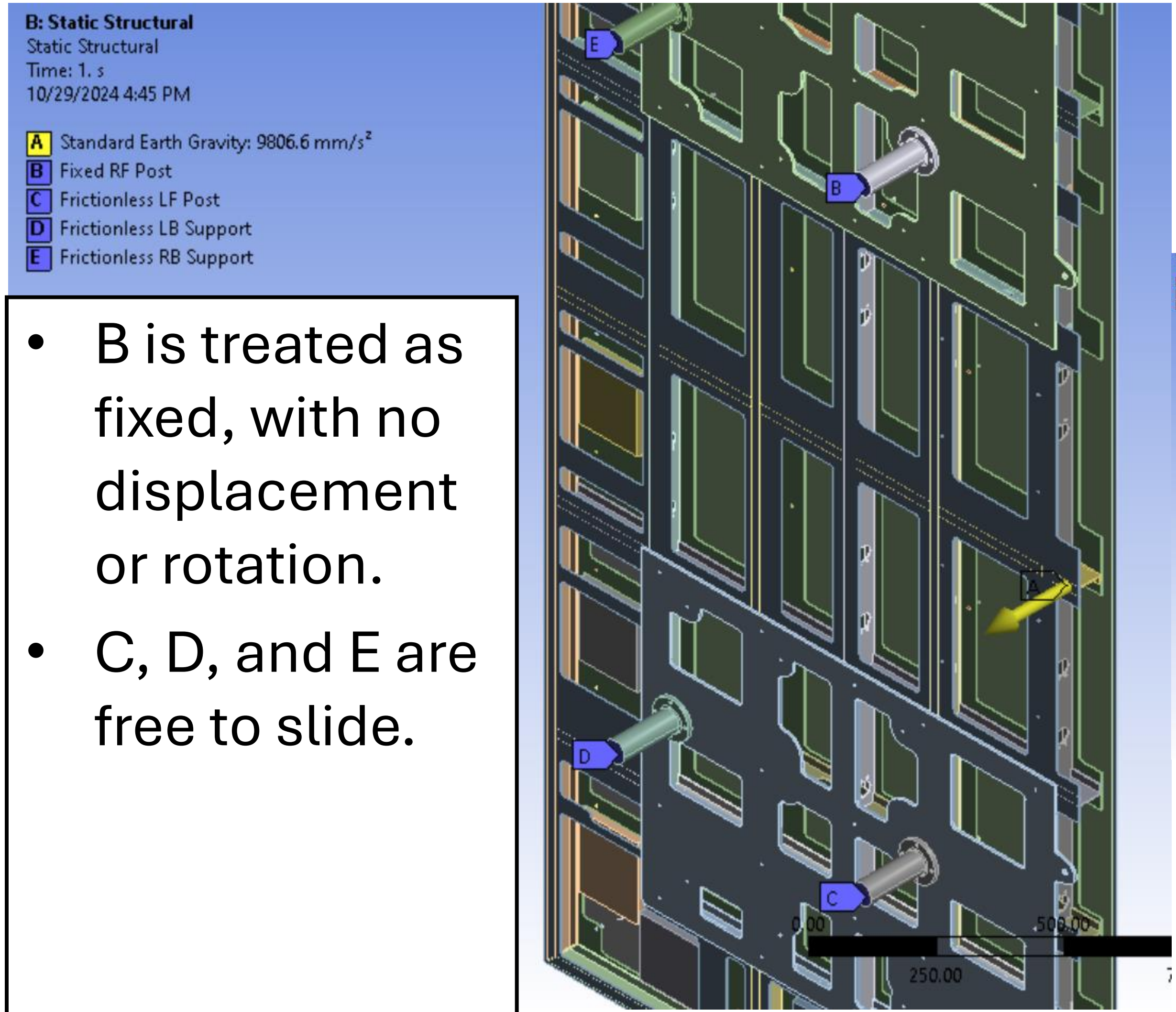


Table of Contractions over 1040mm.

Material	Total Thermal Contraction [mm]	Magnitude Difference from CRU [mm]
CRU	2.694	N/A
G10	2.261	0.4331
Pultrusion (Estimated as Pyrex)	0.5886	2.106
Stainless Steel	2.923	0.2289
Carbon Steel	1.933	0.7616

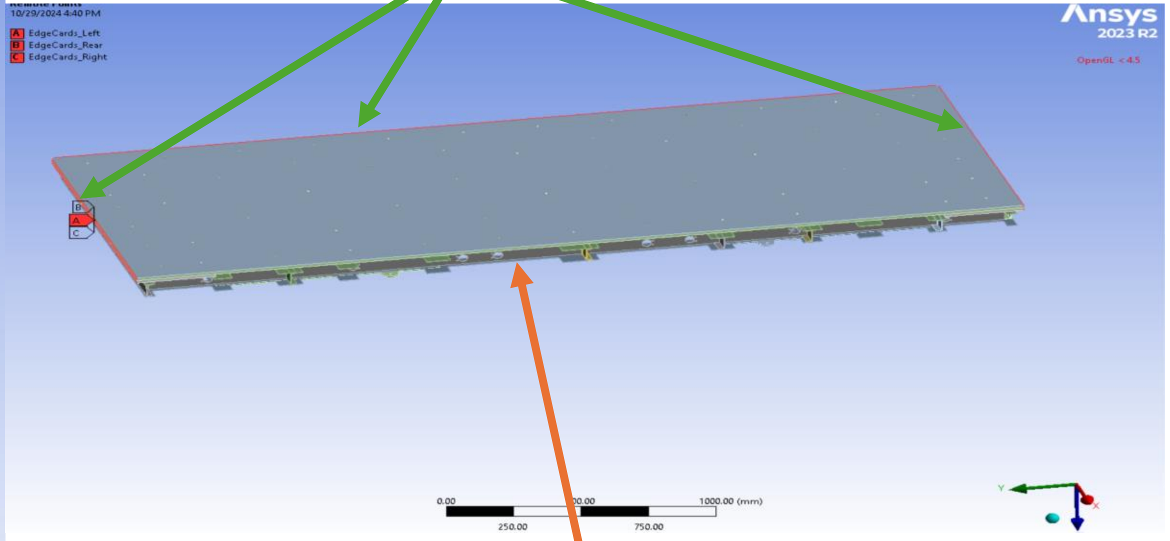
- Since there is 0.4996mm of clearance when cold, the only acceptable options are stainless steel and G10.
- Stainless steel has better thermal contraction compatibility than G10.

Reminder of CRU Install Position Model Boundary Conditions



- B is treated as fixed, with no displacement or rotation.
- C, D, and E are free to slide.

Remote Points constrain the edges of the PCB to move together in Z. This simulates the edge cards



Note the free edge here!

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Updated Comparison to LAPP Model

- Last time we compared to a slightly outdated CRP mechanical analysis report.
- On the right we see the total deformation in the anode.
- Maximum deformation is approximately 2mm.
- Most of this deformation is in the composite structure.
- Observed asymmetry is due to asymmetric foot positions.

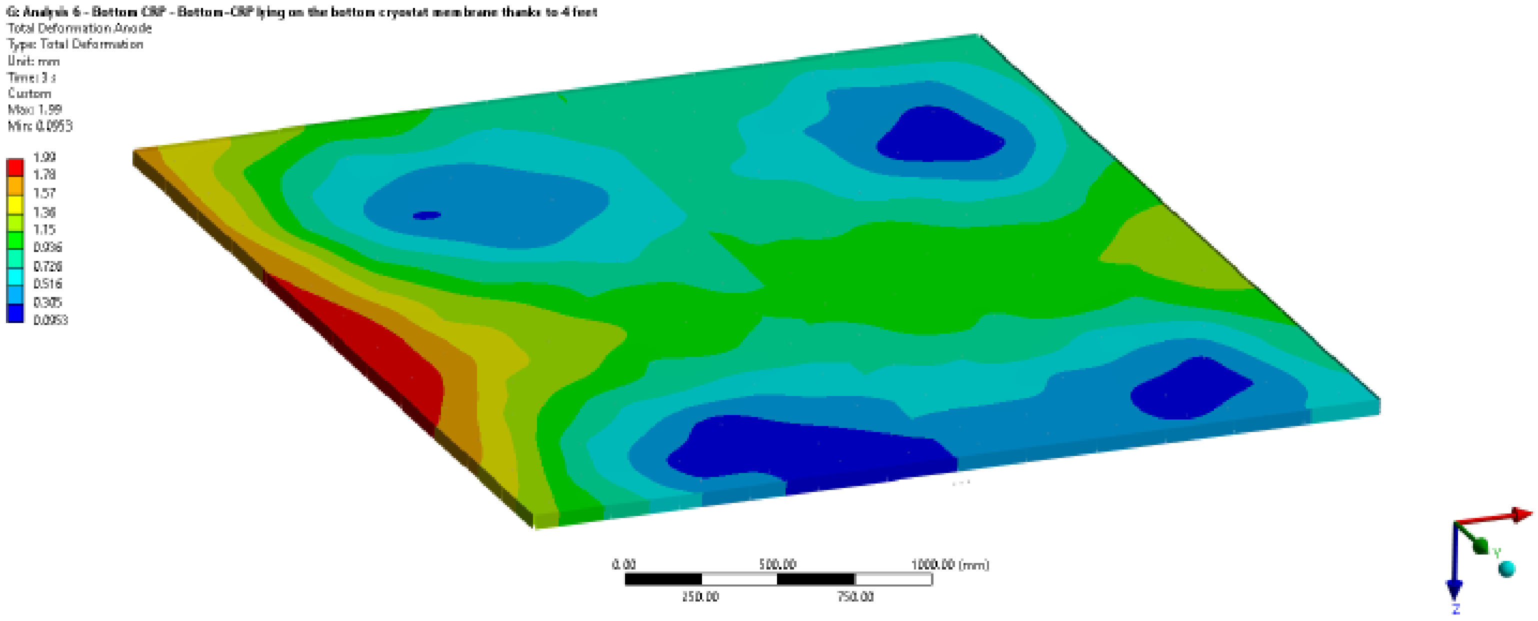
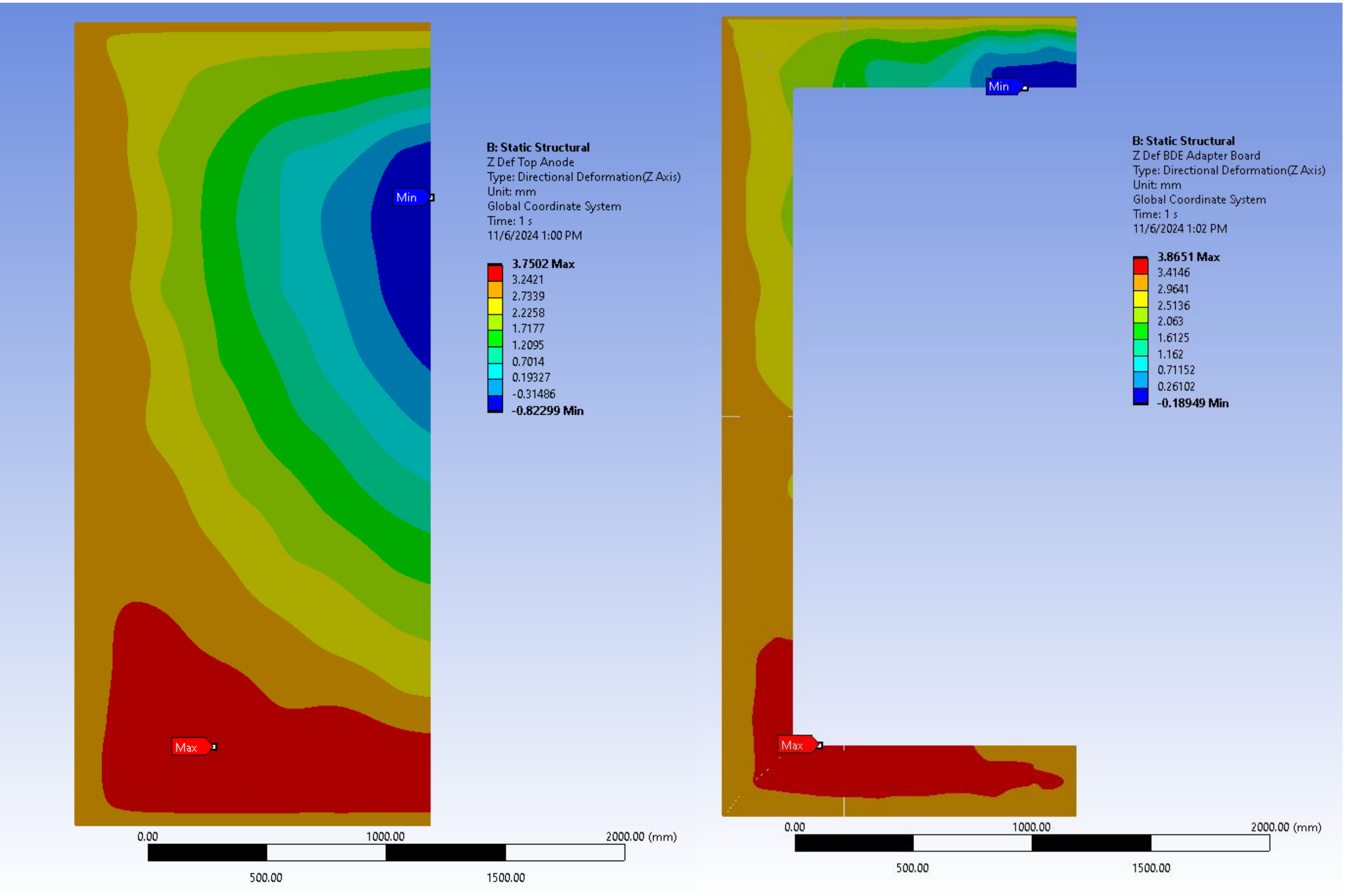


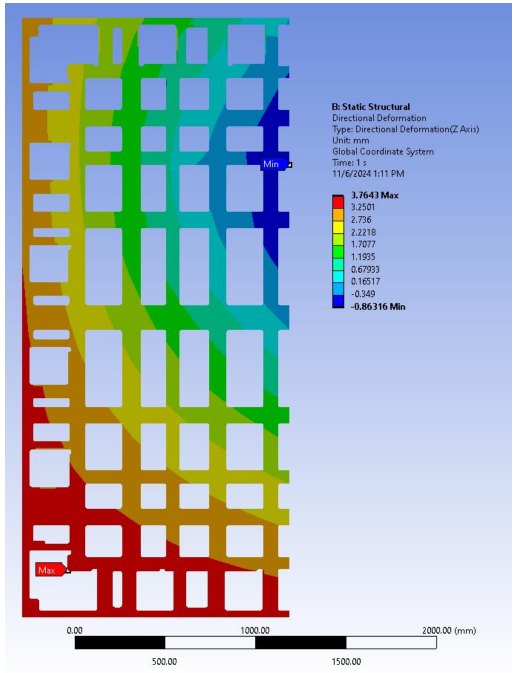
Figure 115: Analysis 6 step 1 - Anode - Total deformation

CRU w/ G10 Adapter Plate PCB Plane Z-Deflections



- Maximum deflection of 3.87mm in the BDE PCB.
- The top and bottom anode displace identically.
- BDE displaces more due to the mass of the FEMBs hanging from the BDE board.
- This is greater than that of the CRP, but this is expected due to the lack of edge cards and stiffness added by the bolted connection of the two CRU together.
- Asymmetry is also due to asymmetric foot placement.

Source of the Deformation in the PCB



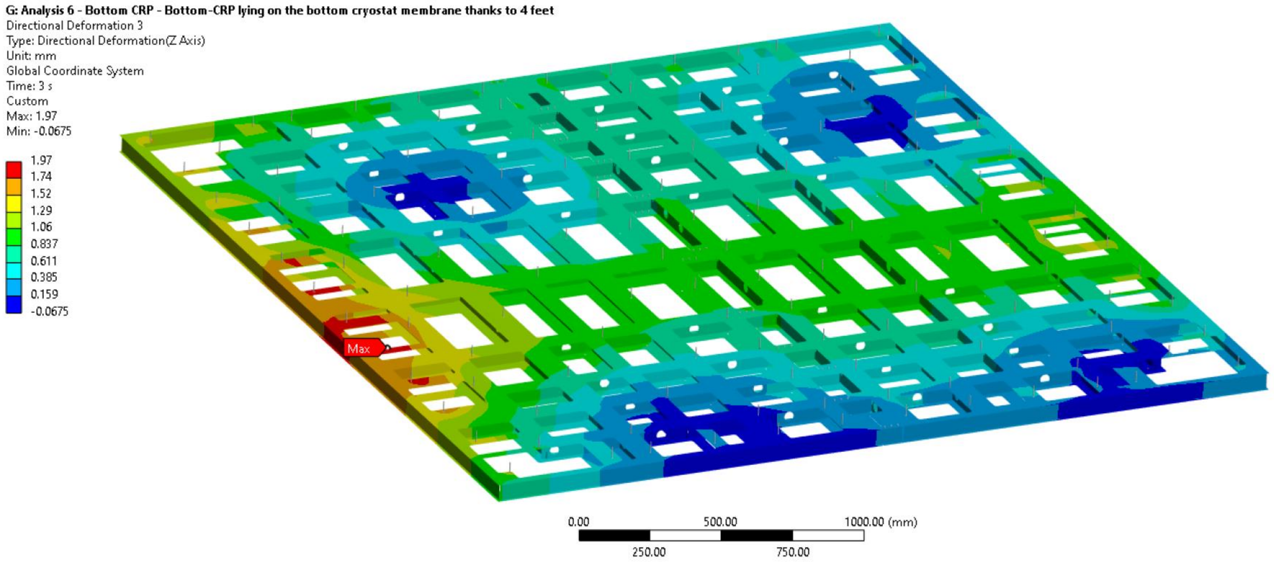
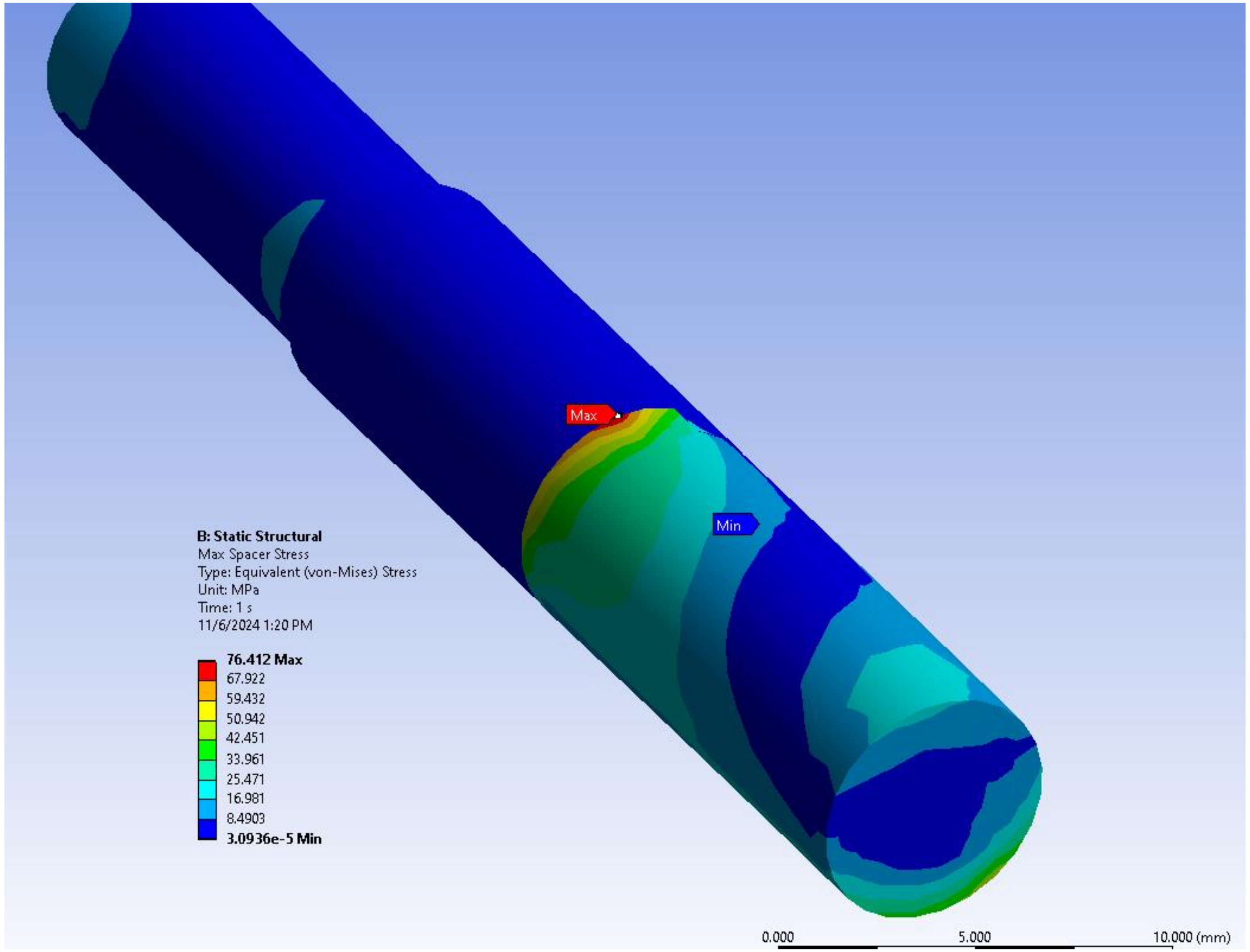


Figure 113: Analysis 6 step 1 - Composite frame - Directional deformation Z

- LAPP model of the CRP shows that most of the Z-deformation is in the composite structure itself.
  - (1.97mm of 2.02mm in top Anode)
- Our model agrees with this behavior.
  - 3.76mm of 3.76mm in top Anode

Maximum Stress in PEEK Spacers

- This spacer shows the highest maximum von Mises stress, and the highest integral average.
- The maximum appears much higher than LAPP model due to different modelling technique.
  - Discussing this in a following slide.
- However, the integral average is much lower than the maximum at 6.00 MPa.



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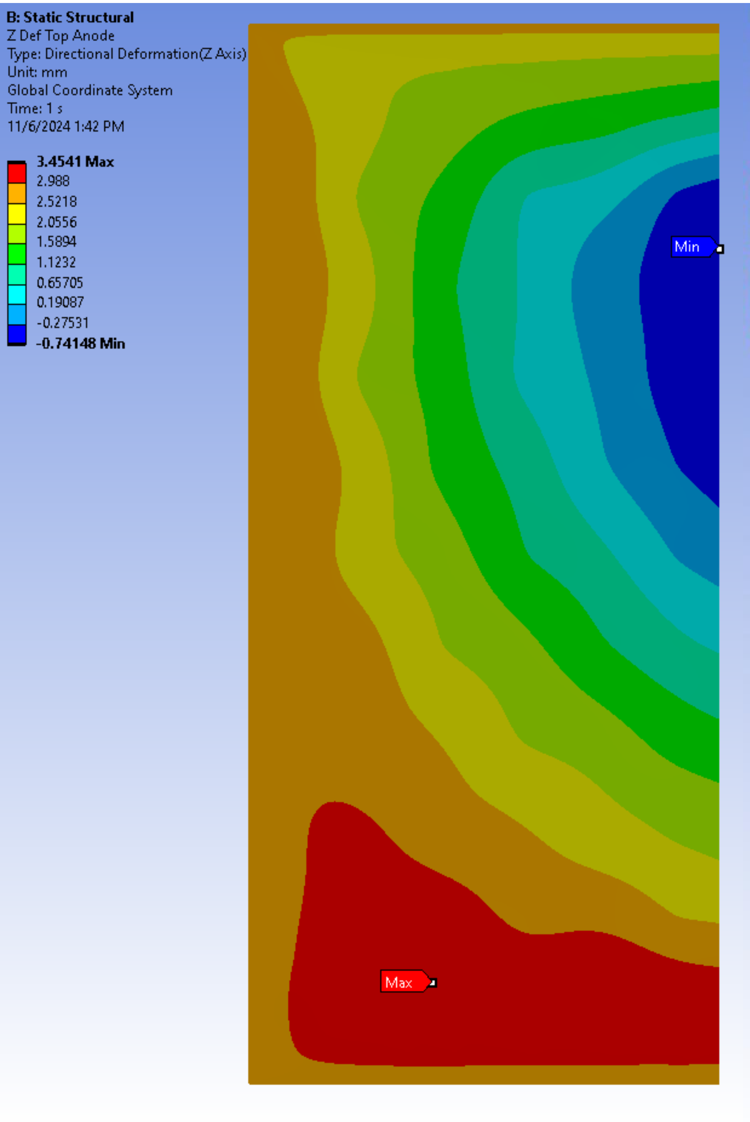
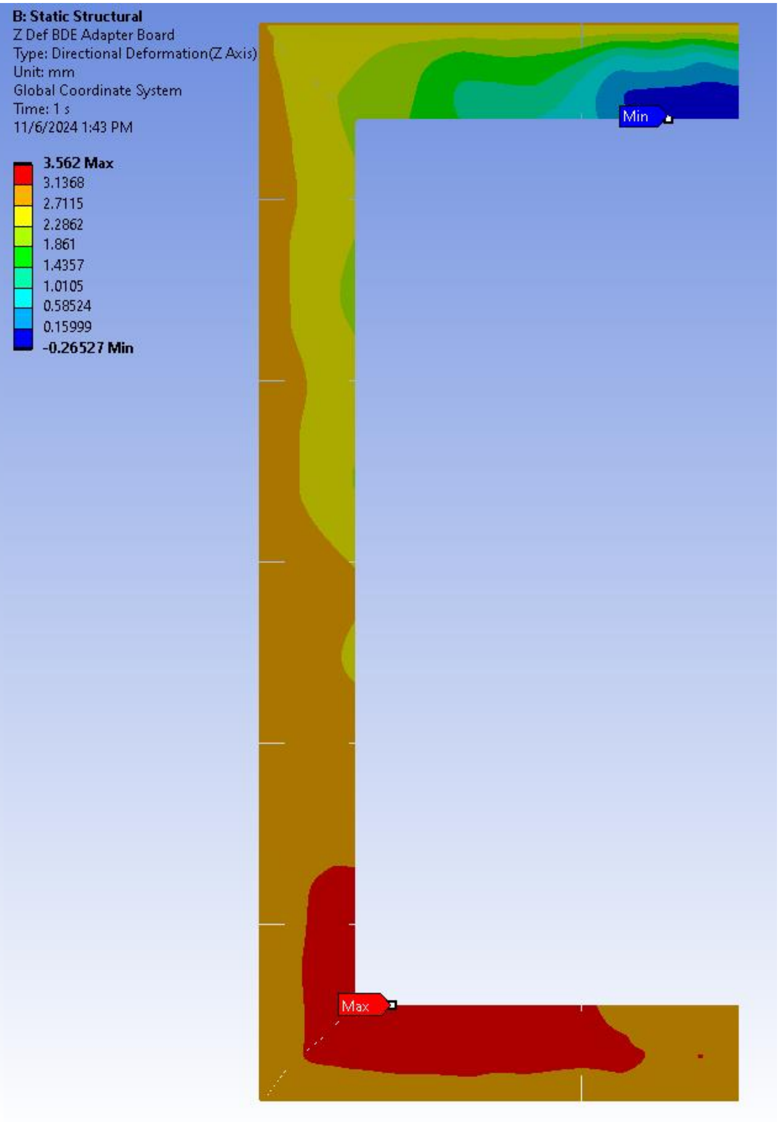
Stainless-Steel Adapter Plate PCB Plane Z-Deflections

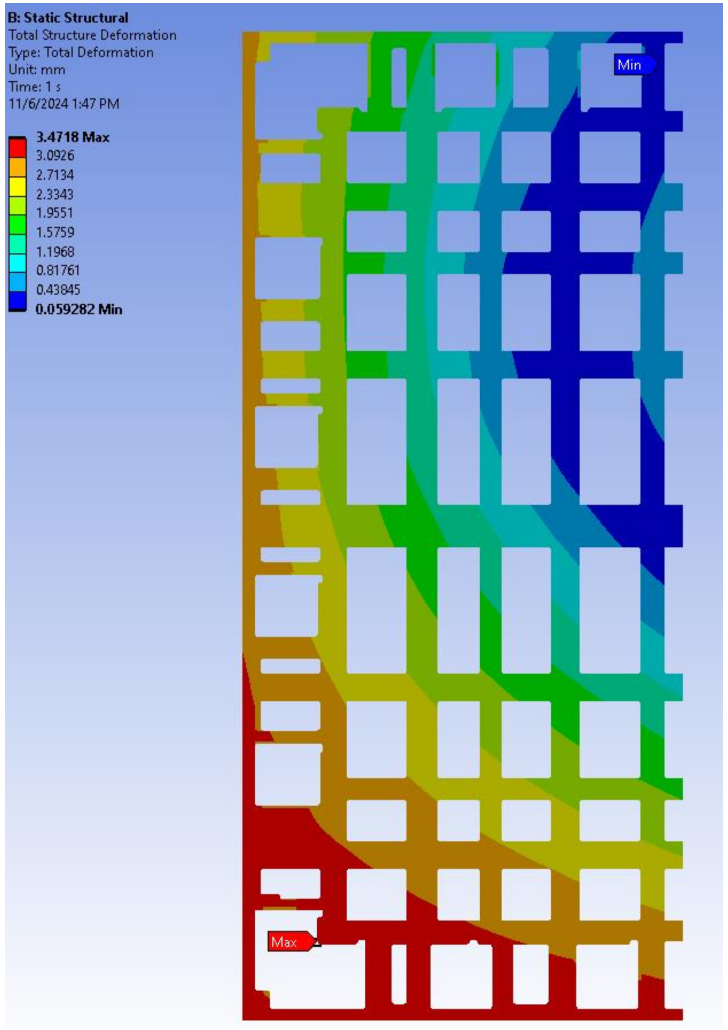




- Maximum deformation occurs in the BDE Board of 3.562mm.
  - 0.3031mm less than G10.
- Anodes deform by 3.45mm.
  - 0.2961mm less than G10.
- This shows that the stiffness of the mechanism which attaches the feet to the composite structure has a significant impact on deflections.

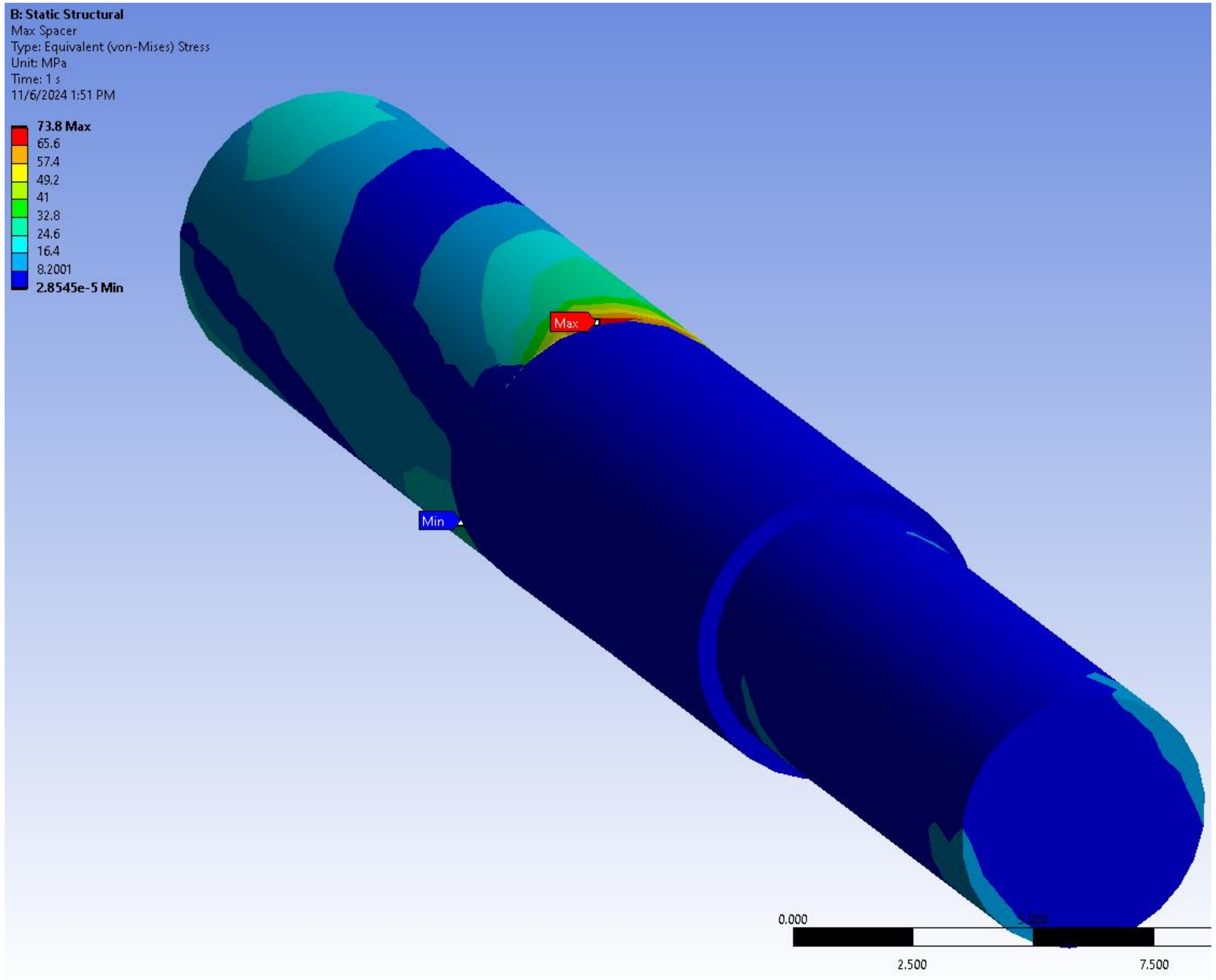
Composite Structure Deformation with Stainless Steel Adapter Plate

- Most of the deformation in the PCBs is once again from the deformation of the structure.
- Stiffening the feet to structure attachment reduces the deformation within the structure.



PEEK Anode Spacer Stress

- The maximum stress is reduced from 76.45 MPa to 73.8 MPa.
- The integral average decreases from 6.00 MPa to 5.7 MPa.



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Review of Modelling the Anode Spacers

- We have presented results about the PEEK spacers so far.
- These results appeared different than those from LAPP.
- We have decided to review the original LAPP report in further detail to determine why this difference in results is occurring.

LAPP Modelling of the Anode Spacers

- Modelled as a 1-Dimensional Beam Element.
- This element pierces the anode and BDE boards, which are 2D plane elements.
- ANSYS cannot generate contacts for this type of connection, it is difficult to make the contact and target elements.
- Therefore, the way that these connections are made is with remote points.
- The remote points specify that the coincident nodes of the beam elements and plane elements must displace together.
- Additionally, the beam and remote points are considered rigid, except for those coincident with the top anode.

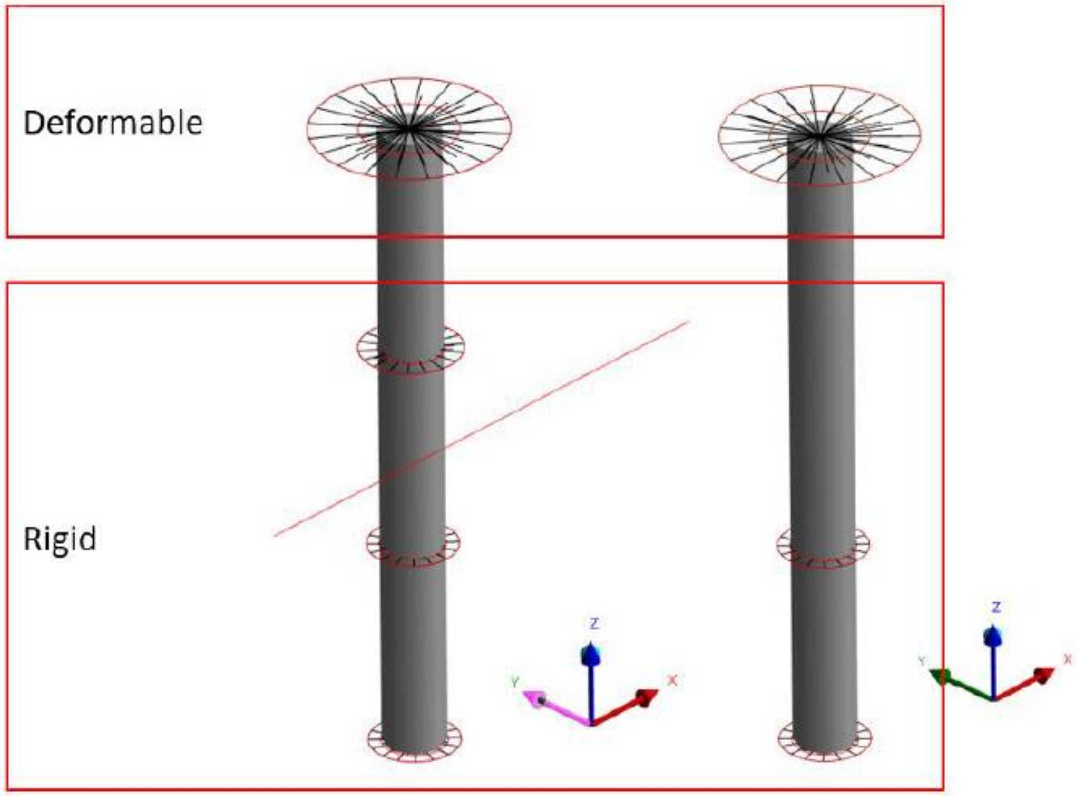


Figure 31 : Connections between the spacers and the others parts

Example of the Mesh Connections of Spacers and PCB Planes

Rigid Remote Points and Elements

Deformable Remote Point and Elements

Is this gap present in the actual model, or for illustration?

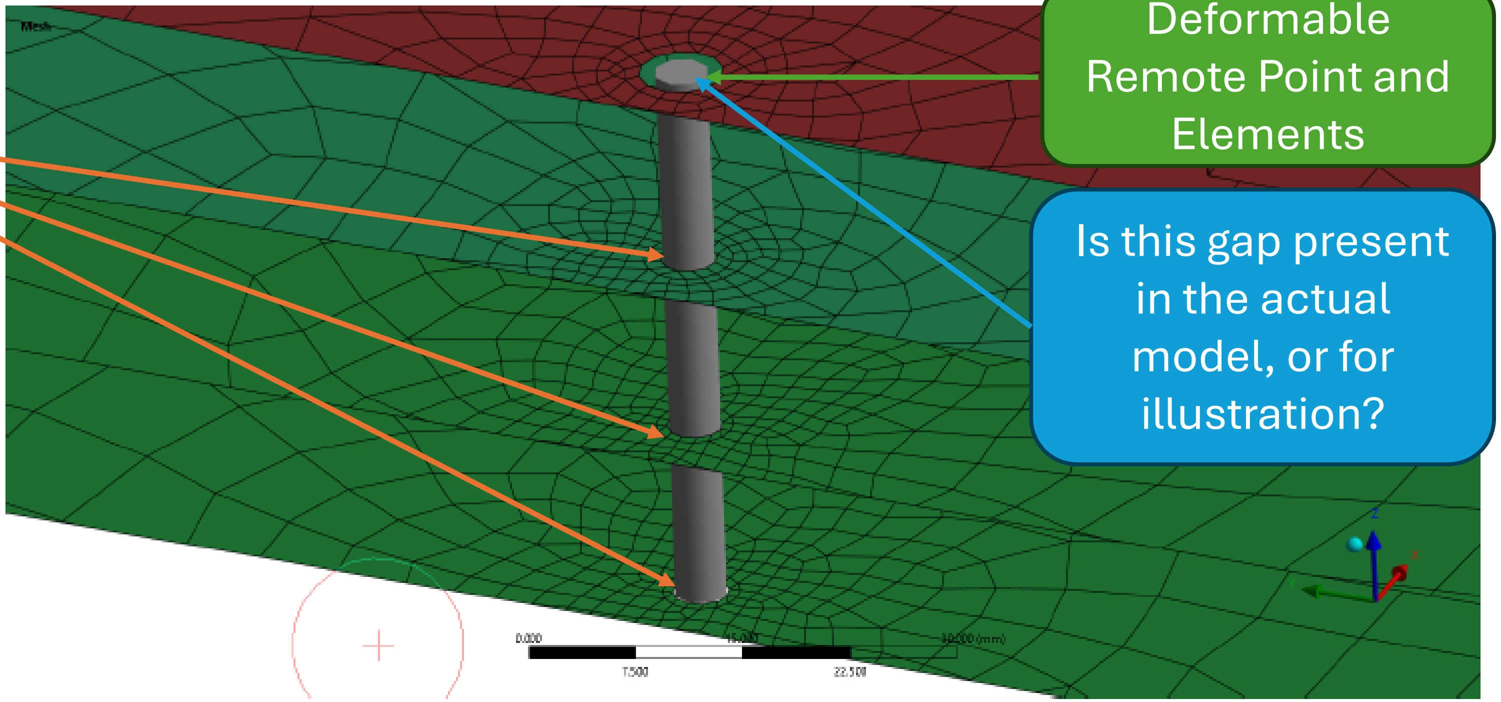


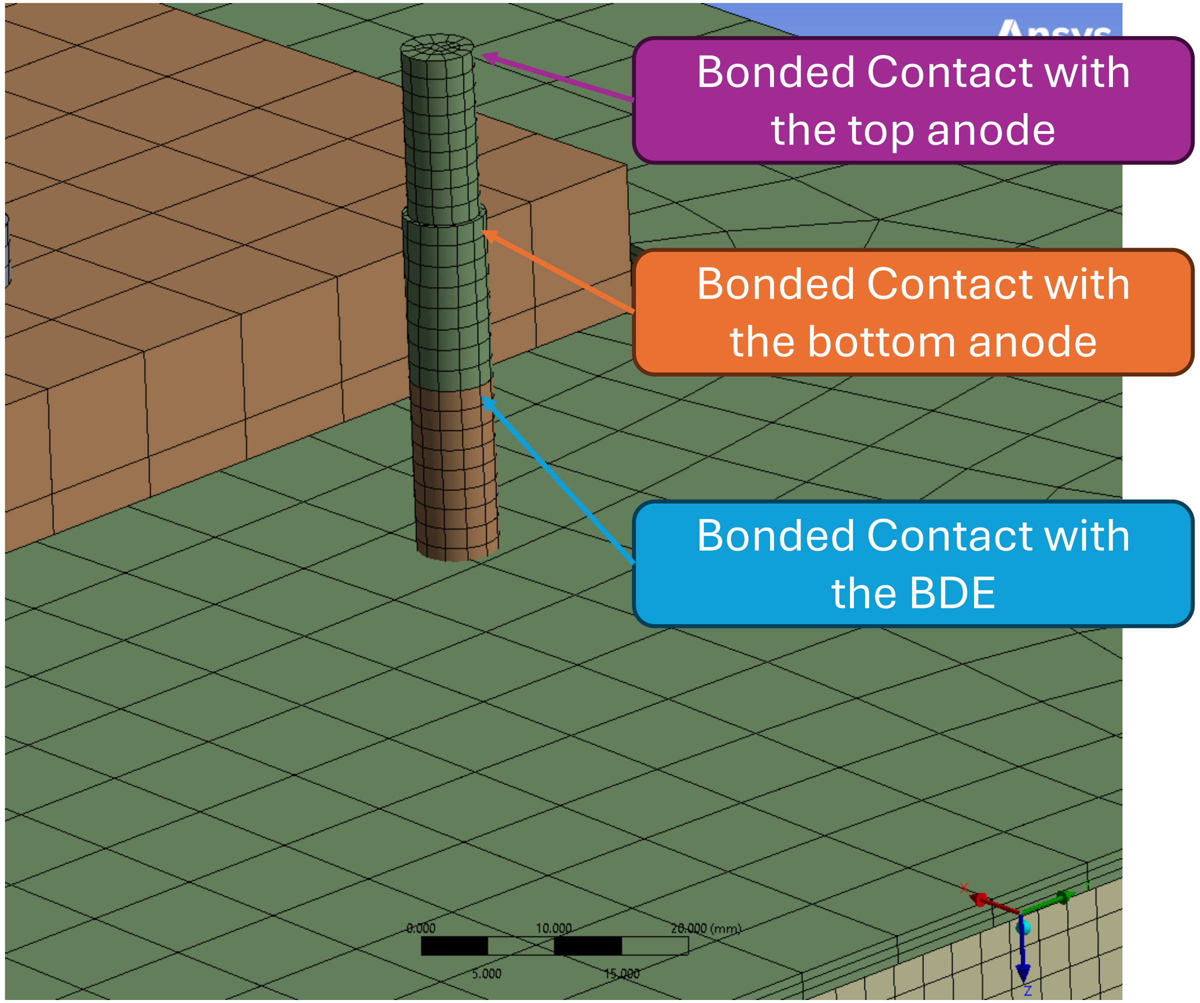
Figure 32 : Mesh connection of a spacer between the anodes, the adapter boards and the bottom skin of the composite frame

Comments on this Modelling Method

- Using beam elements compared with solid elements significantly reduces the number of nodes and elements; only one per some differential length ΔL.
- No contact and target elements, which can introduce difficulties with model convergence, and artificially increase stress by transmitting unrealistic local loads.
- Treating sections as rigid simplifies the matrices, which allows for better performance, but reduces the effective L/D ratio of the spacers, which artificially increases stiffness and decreases deformations.
- Overall, this method is good for performance and doesn’t show inflated stress and deformation values at connected regions.
- This method is different that the one used for the model presented last week, which will be described in the following slides.

UW Modelling of the Anode Spacers

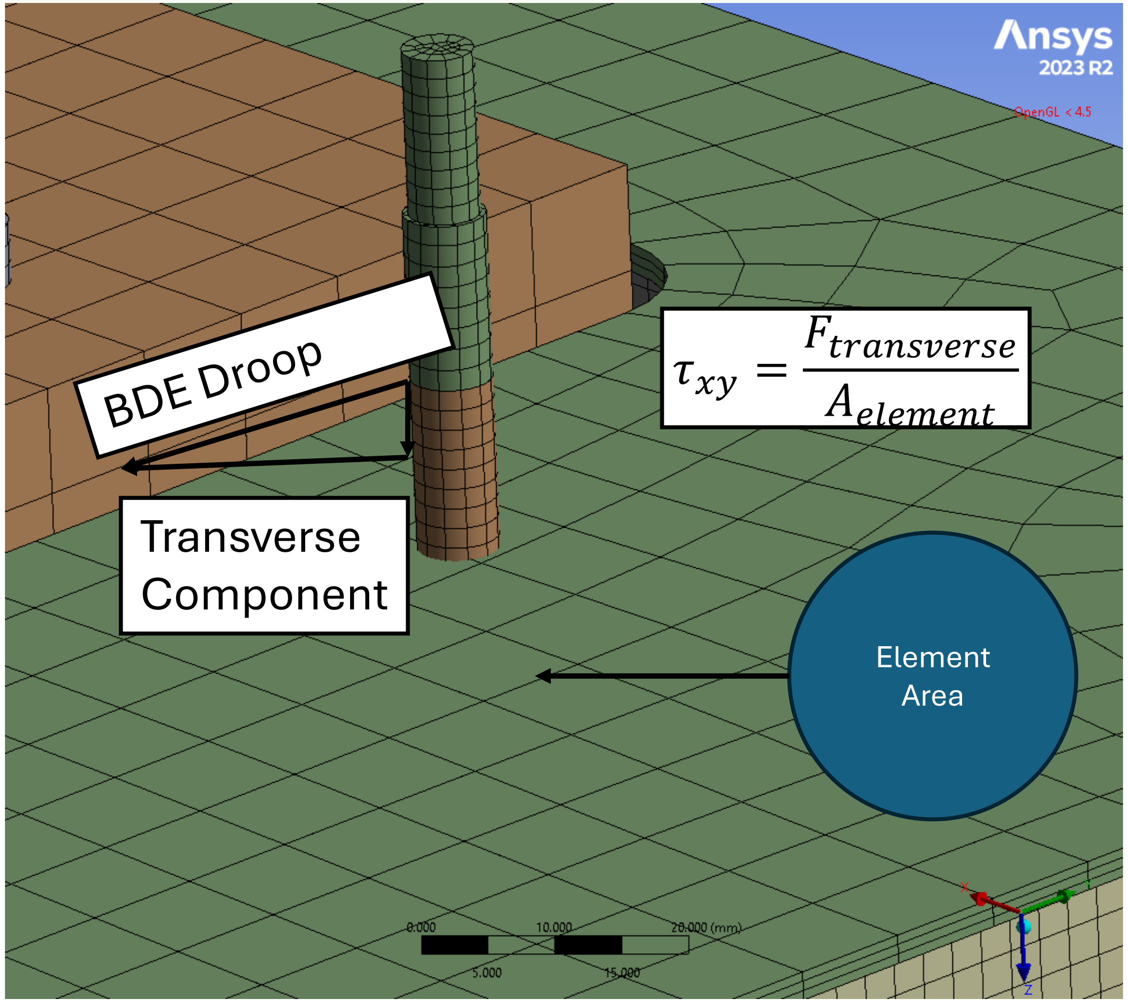
- The spacers are modelled as 3-dimensional solid elements,
- Individual solid elements can experience local stresses to a much greater degree than beam elements, which only experience beam theory stresses in individual sections.
- No elements considered rigid.
- Elements are quadratic in nature, each element can experience internal bending.
- The connection is done using bonded connection type: this connection not only forces bodies to displace together, but directly transmits loads in both the axial and transverse directions.



Comment about the Formulation of von Mises Stress

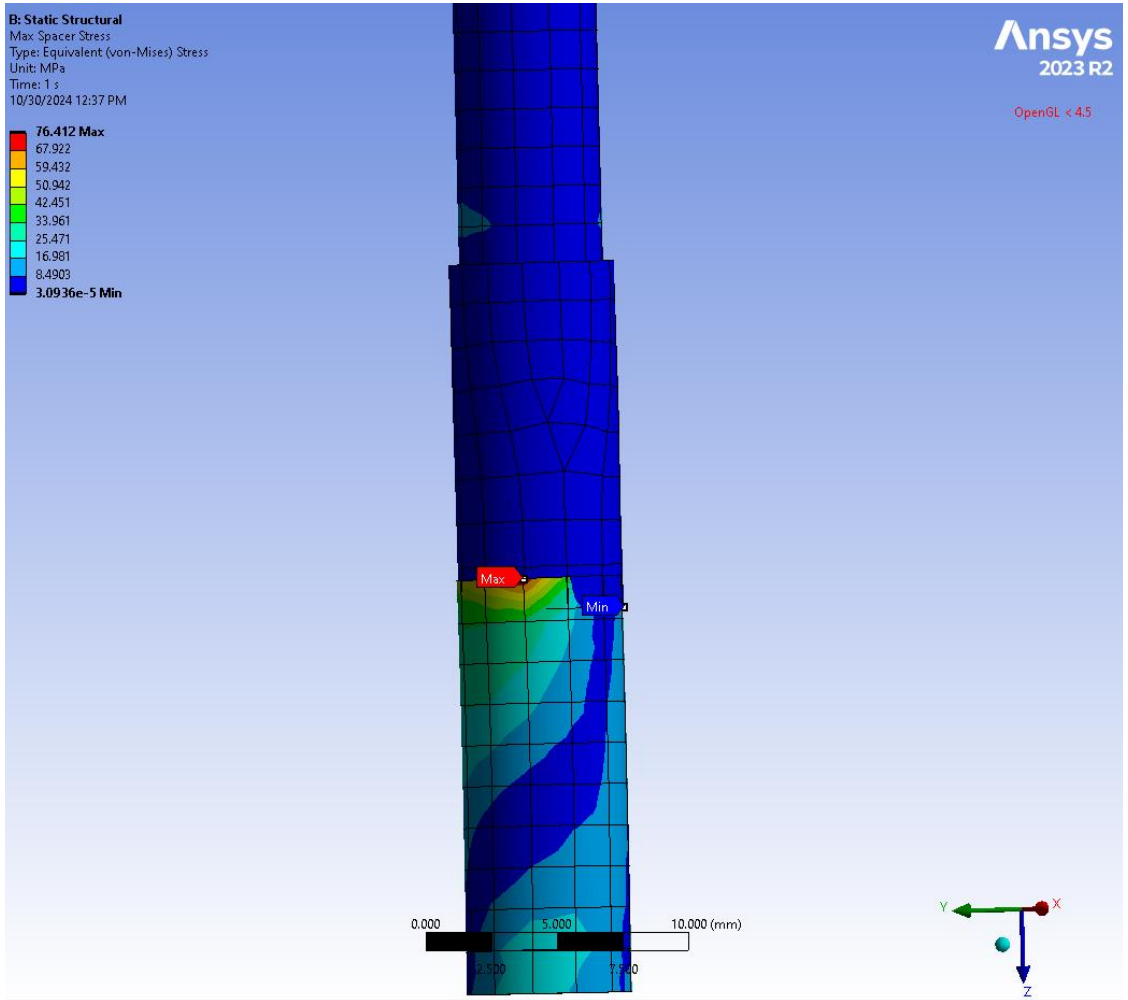
$$\sigma_{\mathrm{VM}} = \sqrt{\frac{1}{2}\left[(\sigma_{xx}-\sigma_{yy})^2 + (\sigma_{yy}-\sigma_{zz})^2 + (\sigma_{zz}-\sigma_{xx})^2\right] + 3\left(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2\right)}$$

- According to the von Mises failure criterion, the shear stress is weighted much more heavily than axial stresses.
- For example, take the image to the right. The FEMB is weighing down the BDE board right next to this spacer.
- The BDE board then deflects downwards pulling itself away from the spacer.
- The transverse component produces a shear stress in the x-y plane. Let's assume the bonded contact applies all this force to a single node on the outside of the spacer.
- So, in this case, we expect to see a large von Mises stress at the outside node and element.



Detailed View of this Spacer

- As predicted, the elements where most of the contact load is being applied show very high von Mises stresses.
- The next question becomes is this physical?
- I do not think so, I think ANSYS is applying the contact load to a very small number of nodes for performance reasons, when much more of the curved face will participate in contact.



Comments about the UW Modelling Method

- This method creates a significantly larger number of nodes and elements, with many per differential length ΔL.
- The model models contacts directly, which causes a slower model not only because of the added contact and target elements, but because in introduces more convergence criteria.
- We have seen that the contacts can artificially increase local stresses within the contact region.
- No elements are considered rigid, and each can experience internal bending due to quadratic meshing. This allows for more realistic deformation of the anode and BDE planes.

Comparison of Methods

Advantages of LAPP Method

- More efficient computation.
- More reliable convergence.
- No artificially extreme local stresses

Disadvantages of LAPP Method

- Limited ability to capture true deformation of the anode planes
- Artificially increased stiffness due to rigid modelling.
- Lower detail regarding stresses within the anode spacers.

Advantages of UW Method

- More detailed stresses within the anode spacers.
- More realistic deformation of the anode planes due to spacer deformation.
- No artificial stiffening.

Disadvantages of UW Method

- Less efficient computation
- More picky convergence.
- Contact areas may experience artificially extreme local stresses.

Key Takeaway: Neither method is overall better, but they are different. Need to be aware of the differences in results caused by each method and select the appropriate method for the load case and information desired.

Summary of Methods

- Neither method is better or objectively more correct. The real condition is somewhere between these two bounds.
- It is important to know which method was used to obtain results from the model, and to understand how it has impacted the results.
- All model results shown last week used the UW solid method.
- All model results shown today are also use this method, unless otherwise stated.
- When we run the CRU flipping model, I anticipate these differences to occur again.
  - Is there a preference from the group for either method?
  - Which method should we run for this case? We can run both but understand that it would take more effort and therefore time to debug and tune two models.

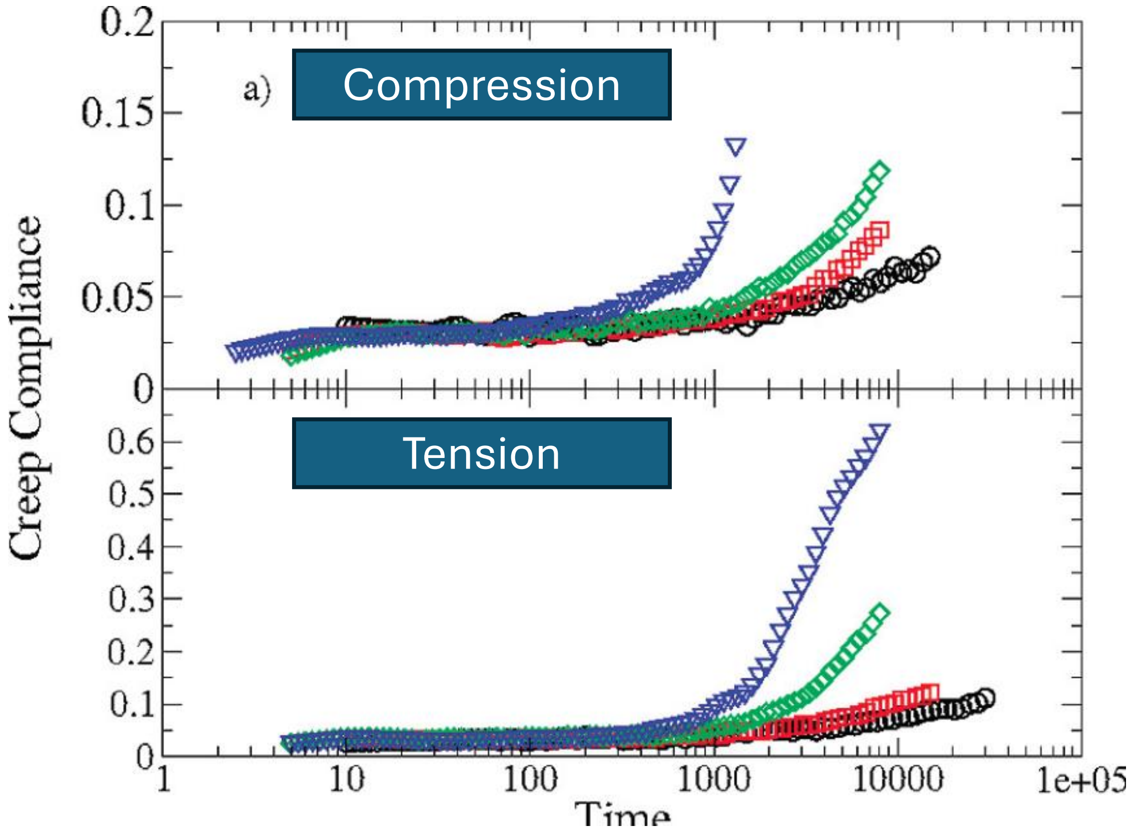
Acceptable Stress According to LAPP Report

#	Analysis	Composite structural parts	Von Mises Stress (MPa)	Load factor	Max yield Strenght (MPa)	Strenght Factor	Allowable max Strenght	SF
1	½ CRP handle with spreader	Skin composite	21.0	1.4	205	0.245	50.2	1.7
		G11 composite	NA	1.4	375	0.245	91.9	NA
		C beam composite	3.7	1.4	250	0.245	61.3	11.8
		Anode	4.9	1.4	440	0.245	107.8	15.9
		Spacers	1.3	1.4	90.9	0.245	22.3	12.4
		Adapter plate	15.1	1.4	375	0.245	91.9	4.4
2	½ CRP handle with spreader - cold test factory	Skin composite	12.3	1.4	205	0.245	50.2	2.9
		G11 composite	NA	1.4	375	0.245	91.9	NA
		C beam composite	1.7	1.4	250	0.245	61.3	25.4
		Anode	11.6	1.4	440	0.245	107.8	6.6
		Spacers	0.8	1.4	90.9	0.245	22.3	20.6
		Adapter plate	4.1	1.4	375	0.245	91.9	15.9
3	CRP on assembly table	Skin composite	11.9	1.4	205	0.245	50.2	3.0
		G11 composite	35.0	1.4	375	0.245	91.9	1.9
		C beam composite	13.7	1.4	250	0.245	61.3	3.2
		Anode	2.6	1.4	440	0.245	107.8	29.5
		Spacers	3.2	1.4	90.9	0.245	22.3	5.0
		Adapter plate	0.3	1.4	375	0.245	91.9	214.2
4	CRP handled for reversal	Skin composite	29.6	1.4	205	0.245	50.2	1.2
		G11 composite	35.2	1.4	375	0.245	91.9	1.9
		C beam composite	15	1.4	250	0.245	61.3	2.9
		Anode	5.1	1.4	440	0.245	107.8	15.2
		Spacers	1.3	1.4	90.9	0.245	22.3	12.0
		Adapter plate	15.1	1.4	375	1.245	466.9	22.1
5	CRP handled with two tines (handling tool)	Skin composite	26.3	1.4	205	0.245	50.2	1.4
		G11 composite	38.0	1.4	375	0.245	91.9	1.7
		C beam composite	6.8	1.4	250	0.245	61.3	6.4
		Anode	52.7	1.4	440	0.245	107.8	1.5
		Spacers	1.4	1.4	90.9	0.245	22.3	11.4
		Adapter plate	10.7	1.4	375	1.245	466.9	31.2
6	CRP on feet on the cryostat floor	Skin composite	17.9	1.4	205	0.245	50.2	2.0
		G11 composite	36.2	1.4	375	0.245	91.9	1.8
		C beam composite	13.7	1.4	250	0.245	61.3	3.2
		Anode	6.2	1.4	440	0.245	107.8	12.4
		Spacers	1.6	1.4	90.9	0.245	22.3	10.0
		Adapter plate	8.4	1.4	375	0.245	91.9	7.8
7	CRP in use in the cryostat	Skin composite	12.0	1.4	205	0.215	44.1	2.6
		G11 composite	35.3	1.4	375	0.215	80.6	1.6
		C beam composite	14.3	1.4	250	0.215	53.8	2.7
		Anode	7.6	1.4	440	0.215	94.6	8.9
		Spacers	0.8	1.4	90.9	0.215	19.5	17.0
		Adapter plate	9.1	1.4	375	0.215	80.6	6.3

- The acceptable yield strength is reduced to 0.245 of its real value for all the composite and polymer components.
- The weighting criteria are from JRC “Prospect for New Guidance in the Design of FRP” (Fiber Reinforced Plastic).
- From my brief reading of the document, our strength factor should be about 0.4.
  - We should ask Sebastien how he got to this value.
- PEEK is not fiber reinforced, so I am not sure why the spacers are on this list.
- Also, is creep really a concern for our application? Operation conditions are well below glass transition temperature for PEEK or most epoxy resins.
- Even install conditions are below the GCT for PEEK and most resins. (PEEK: 143C ,Epoxy: 50C)

Example of Creep in Glassy 6-6 Nylon

- Creep compliance is a measure of how much a material will flow under a constant stress. Lower values indicate a more stable compound.
- Units are 1/Pressure, which represents a strain per unit of applied pressure over time.
- The time axis is not labelled here, nor is it specified in the source document, but I assume it is in seconds.
- Nylon is not very stable.



R. A. Riggleman, K. S. Schweizer, and J. J. de Pablo, "Nonlinear Creep in a Polymer Glass," *Macromolecules*, vol. 41, no. 13, pp. 4969–4977, Jul. 2008, doi: 10.1021/ma8001214.

PEEK at Room Temperature

- PEEK at room temperature has very good creep resistance (0.0003 at t=1year).
- Creep resistance generally improves with decreasing temperature, even below Tg.
- I’m not sure that we should be as worried about creep in the PEEK spacers as the LAPP report implies that we are.

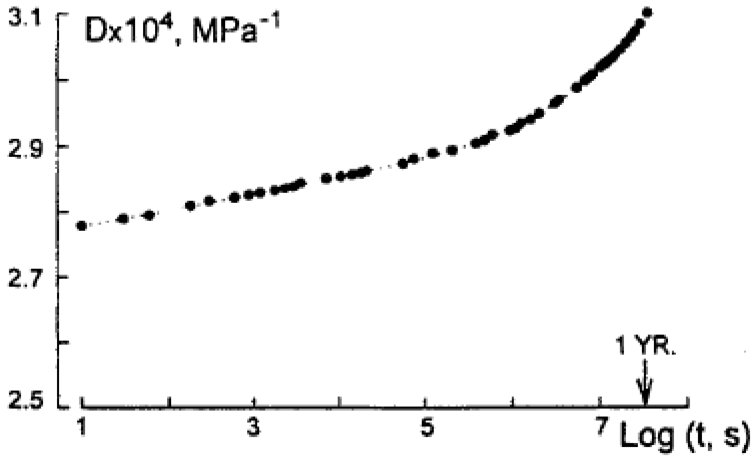


Fig. 8. Long-term (14 month) creep compliance of PEEK at 20°C as a function of logarithmic time.

R. D. Maksimov and J. Kubat, “Time and temperature dependent deformation of poly(ether ether ketone) (PEEK),” *Mech Compos Mater*, vol. 33, no. 6, pp. 517–525, Nov. 1997, doi: 10.1007/BF02269611.

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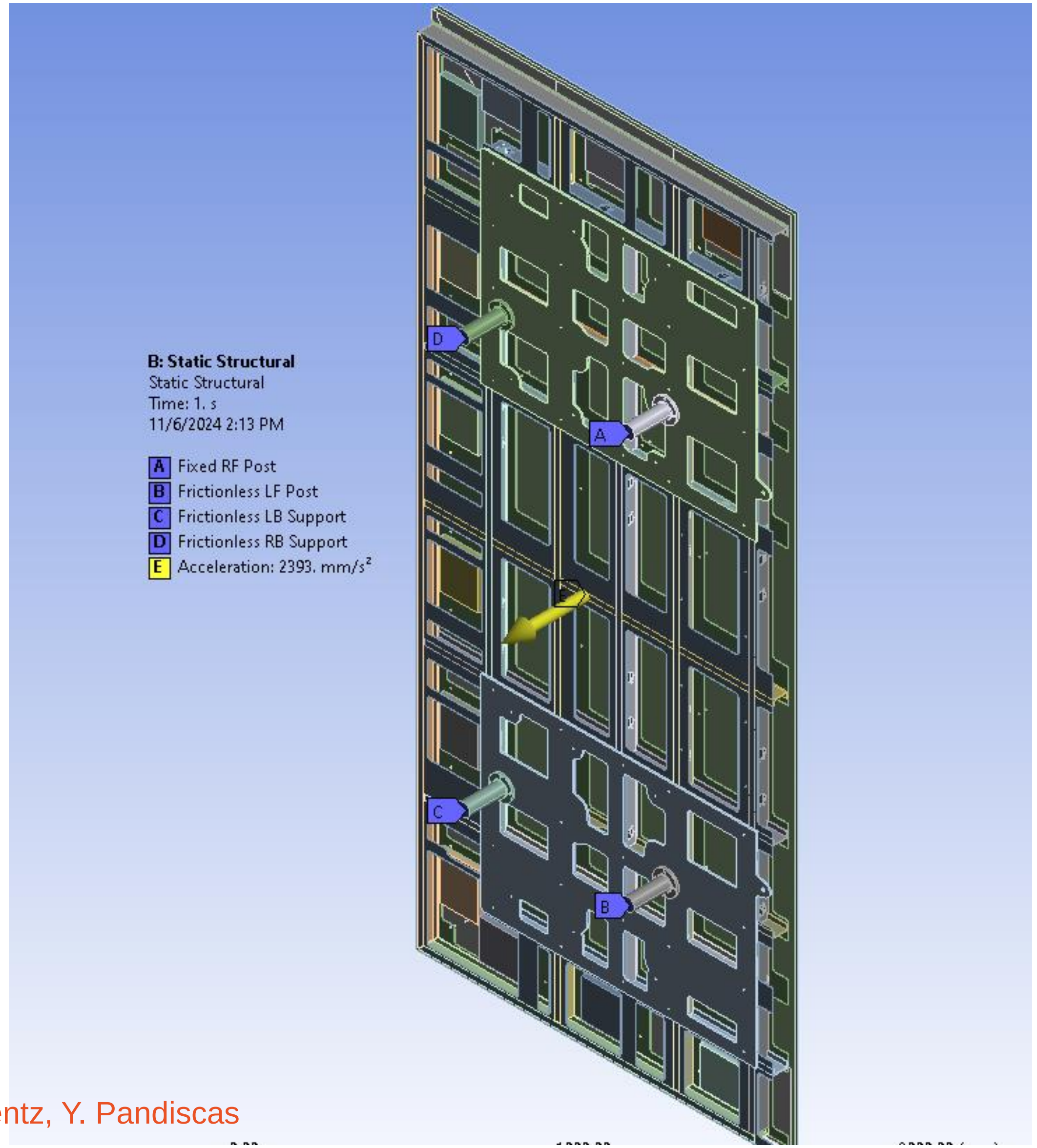
Cold Static Mechanical Model

- Rather than apply gravity and buoyant forces to the model, we modify the acceleration.
- LAPP CRP model also used this method.
- The acceleration used is the same as the LAPP model and comes from Archimedes Principle.
- The solid density used is that of the composite structure.
- This gives the result of 2393mm/s^2.



LAPP Model Results

- These results include thermal contraction effects, ours do not yet.
  - We plan to add this to our model soon, we just wanted to get a quick reference.
- The maximum deformation in the composite structure is 1.01mm.
- We know that this deformation is the primary driver of PCB deformations.

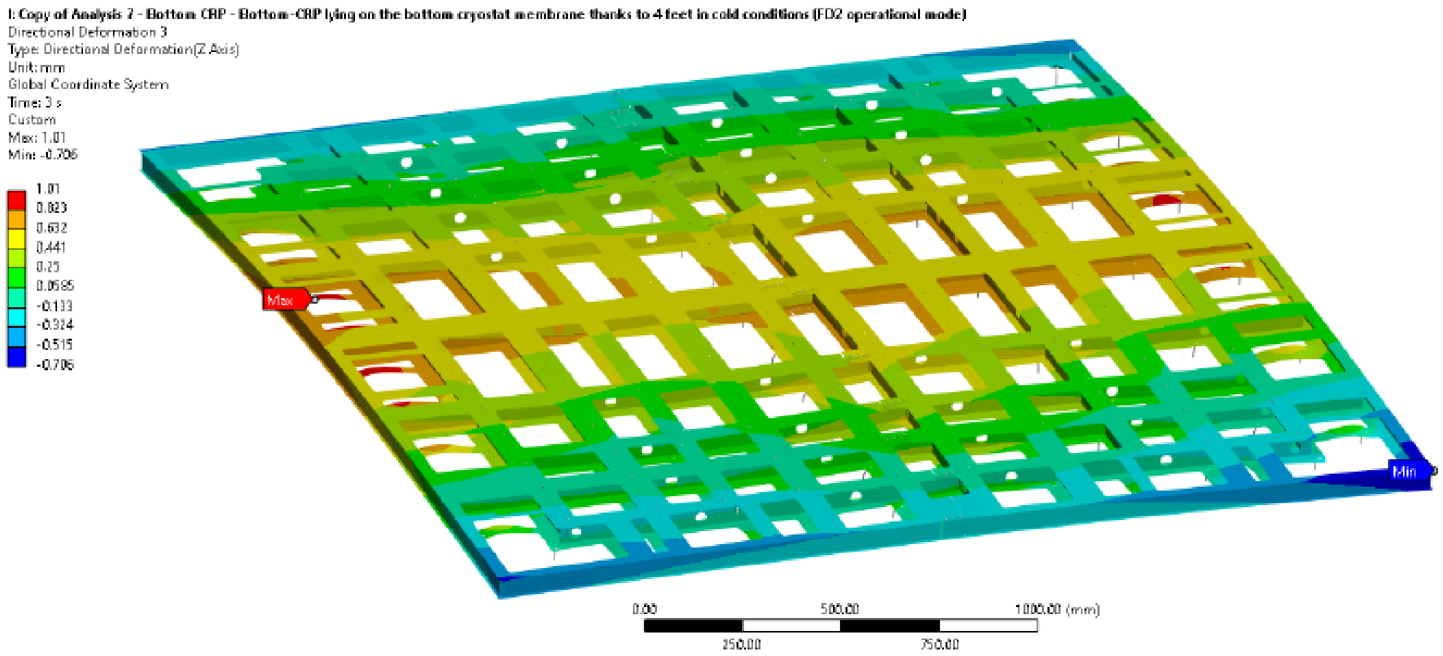
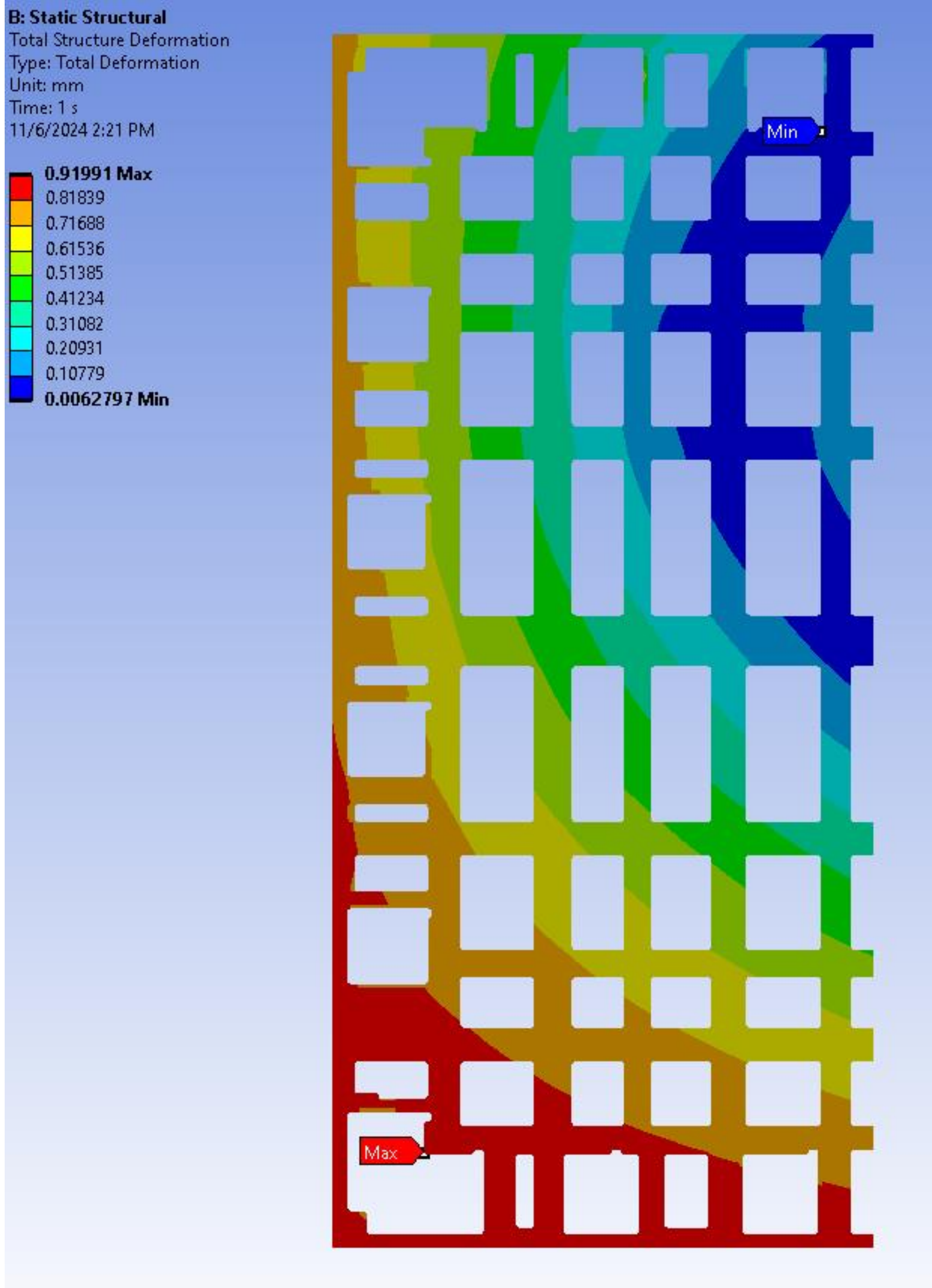


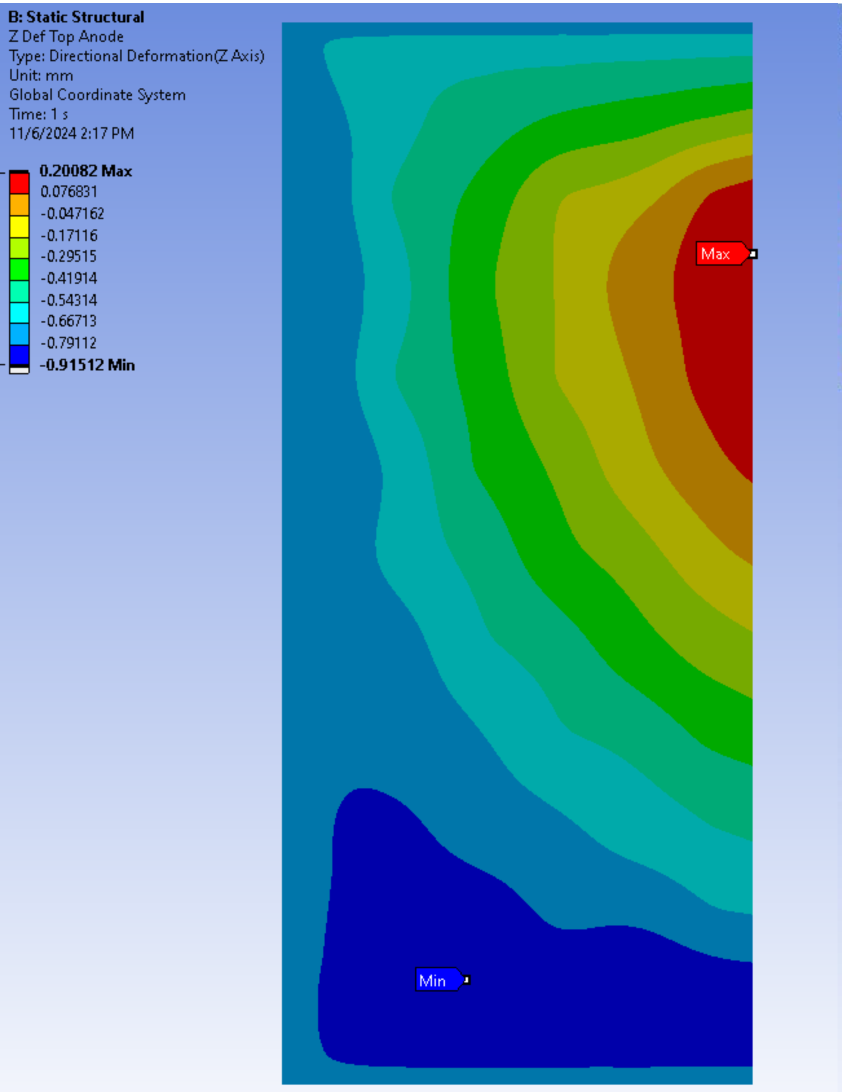
Figure 121: Analysis 6 step 2 - Composite frame - Directional deformation Z

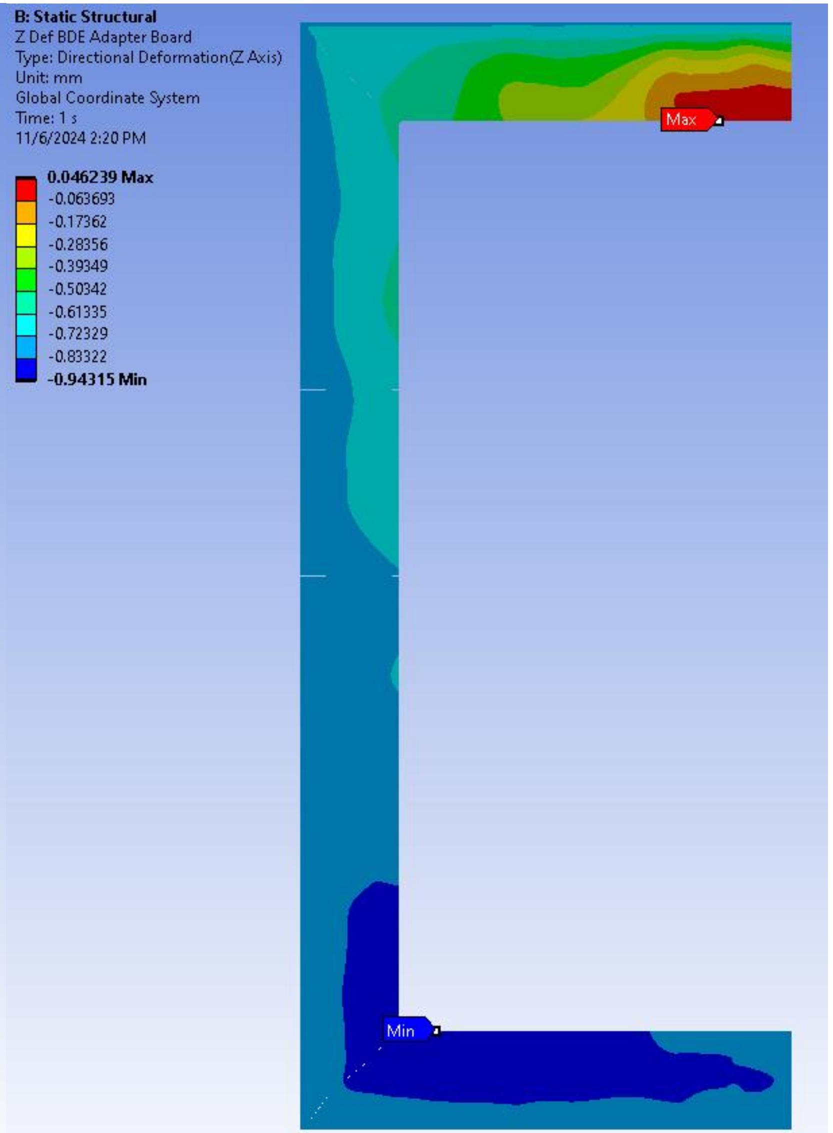
UW Model Results

- Does not include thermal contraction effects, but since the thickness's are small, the contraction will also be small.
- Again, we will run a model that includes the thermal conditions shortly.
- The frame shows a maximum Z-deformation of 0.92mm, which is comparable to the LAPP modelling of the CRP.



Cold Install Position w/ G10 Adapter Plate PCB Z-Deformation

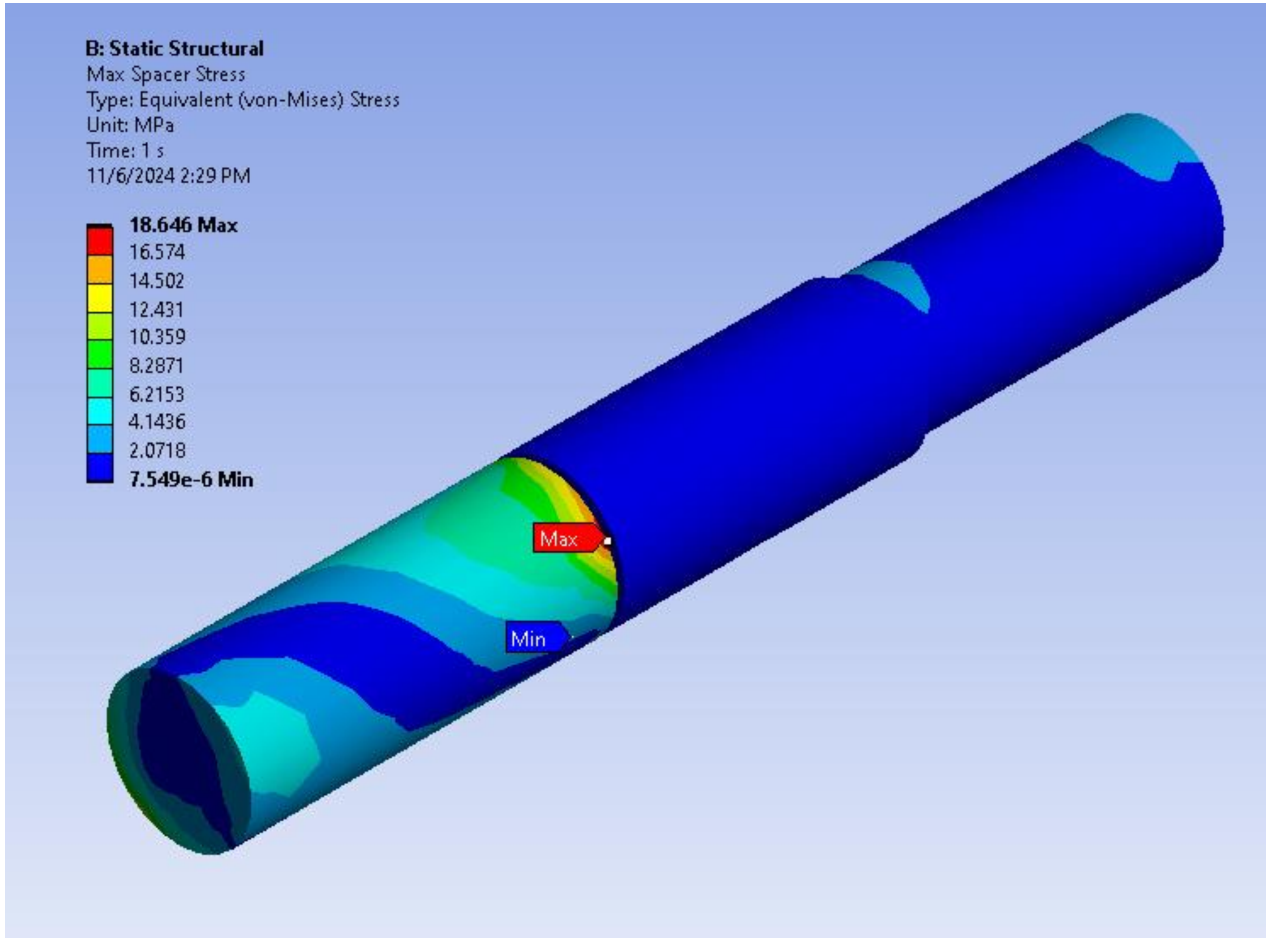




- Notice the signs of the contour colors.
- The greatest magnitude in the anodes is 0.915mm.
- The greatest magnitude in the BDE boards is 0.94315mm.
- This is mostly transmitted through from the composite structure deformation.

Cold Install Position w/ G10 Adapter Plate PEEK Spacer Stresses

- The maximum stress in the spacer goes down to 18.646 MPa.
- The integral average is 1.45 MPa.
- At this temperature it is worth noting that creep is less significant than room temperature.



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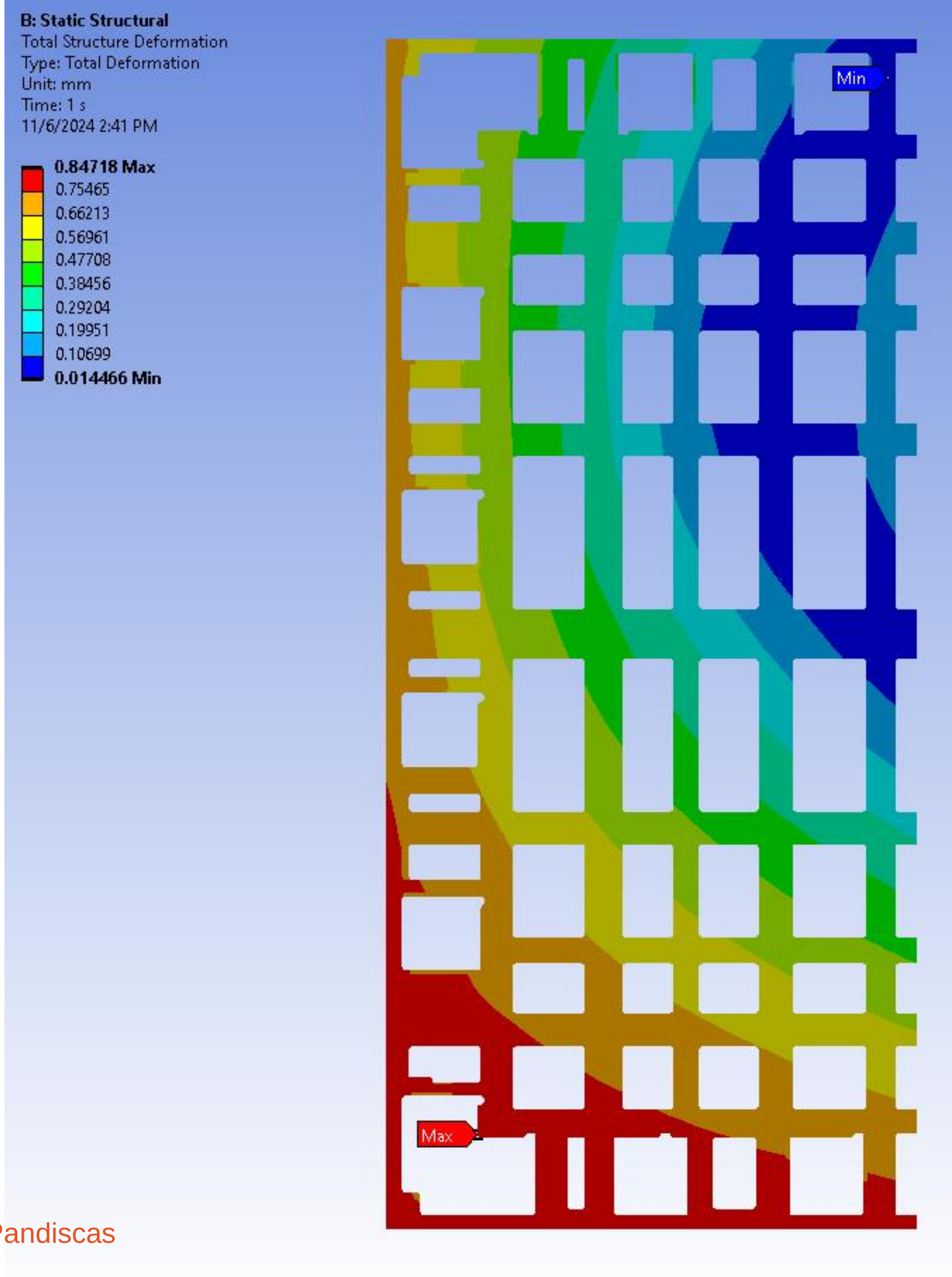
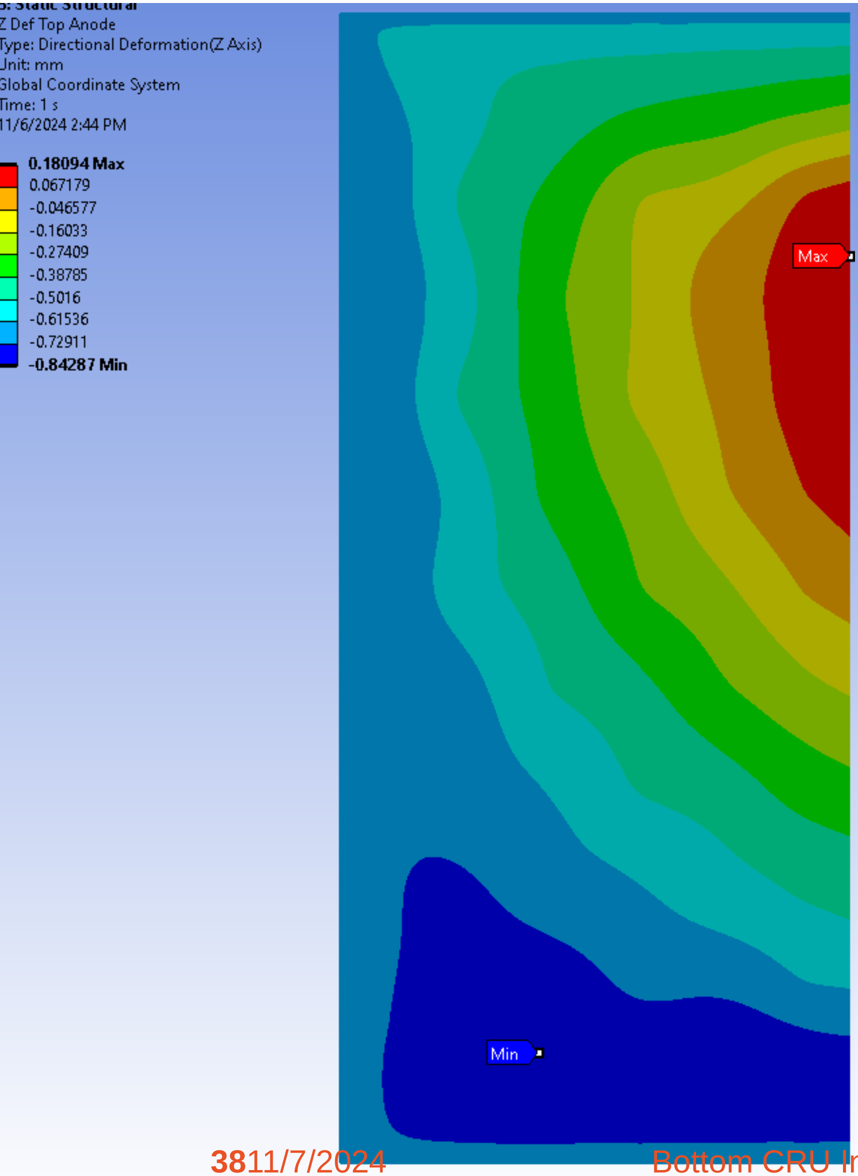
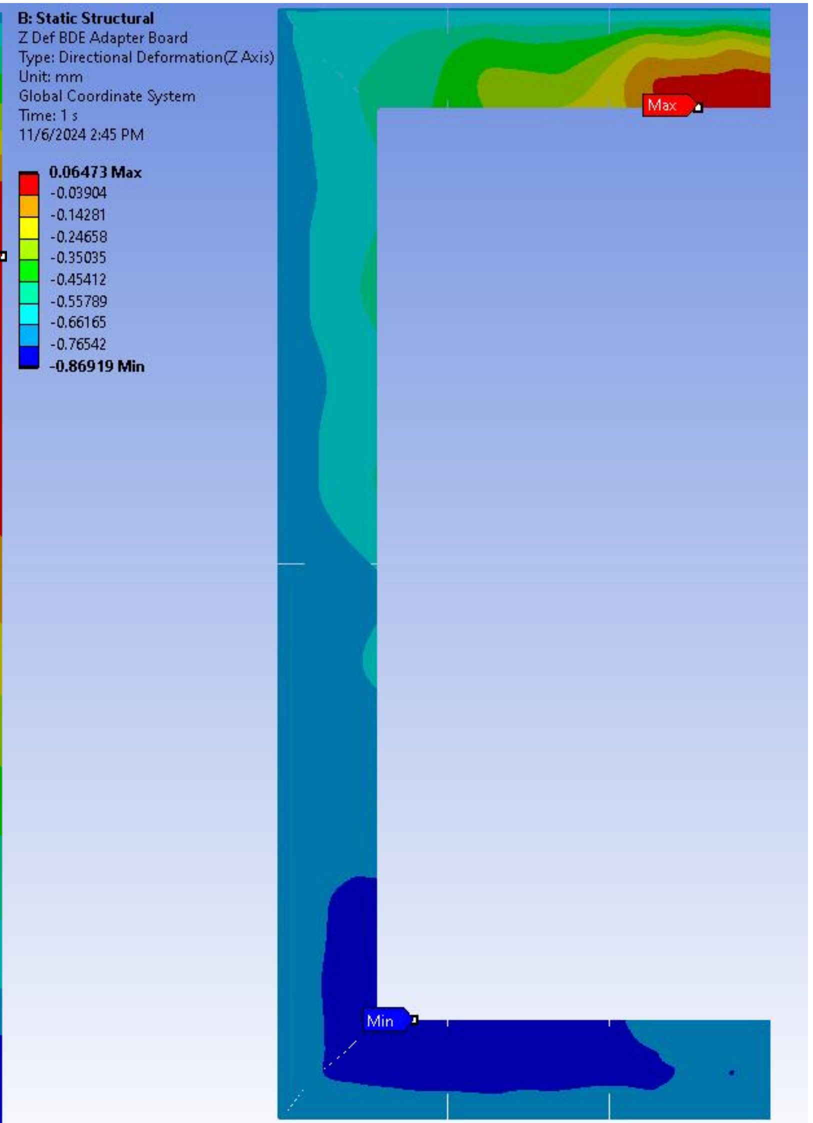
Stainless Steel Adapter Plate, Cold Install, Composite Structure Deformation

- 0.85mm deformation in the structure.
  - 0.07mm decrease compared to G10/FR-4.



Cold Install Position w/ Stainless Adapter Plate PCB Z-Deformation

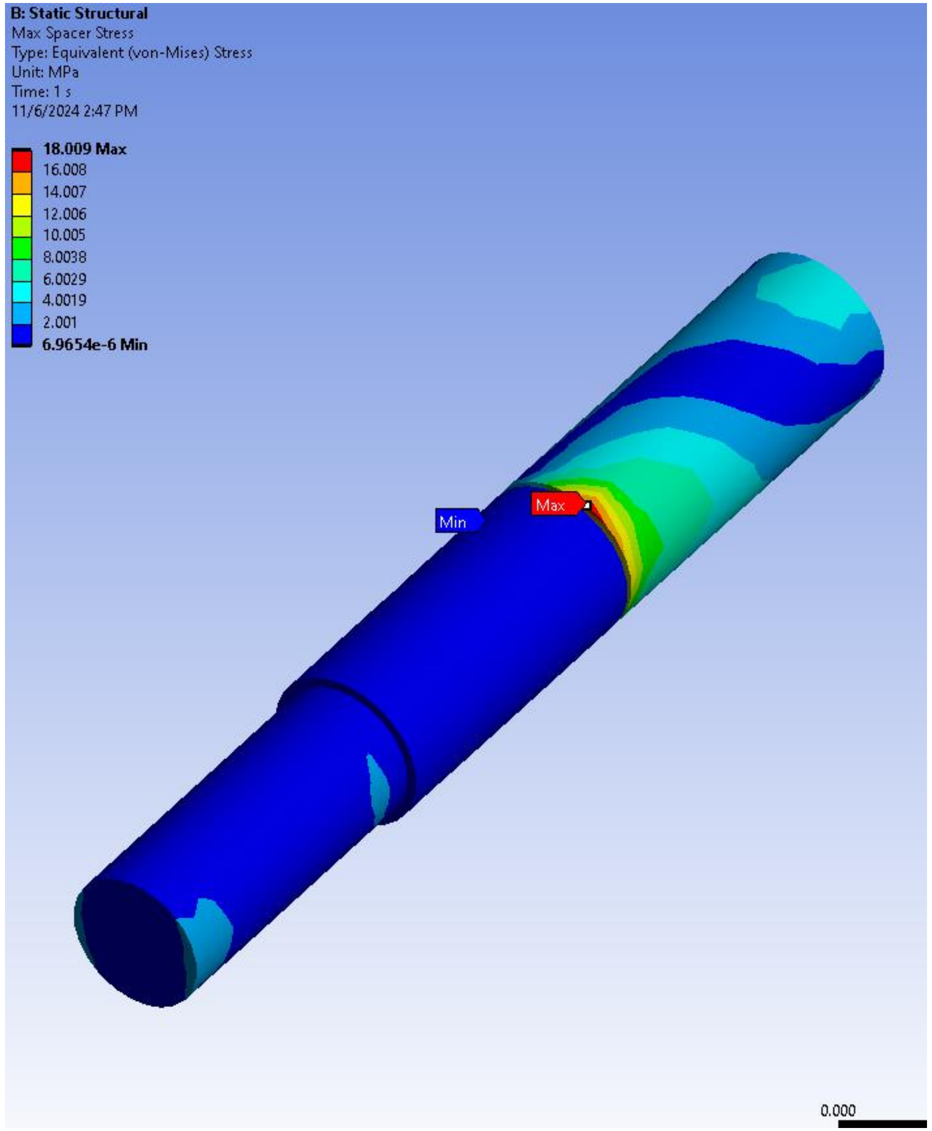




- This reduction in deformation is transmitted to the PCB planes as expected.

Cold Install Position w/ Stainless Adapter Plate PEEK Spacer Stresses

- Reduction in peak stress of about 0.6 MPa compared to G10/FR-4 adapter plate.
- Integral average here is 1.3885 MPa, compared to 1.45 MPa.
    - A decrease of about 0.06 Mpa.



Agenda

1. Reminder of constraints, thermal properties of materials, and boundary conditions.
2. Warm Install Position Results with new adapter plate made from G10/FR-4.
3. Warm Install Position Results with new adapter plate made from stainless-steel.
4. Modelling Techniques for PEEK Spacers Discussion
5. Cold Install Position Results with new adapter plate from G10/FR-4.
6. Cold Install Position Results with new adapter plate from stainless-steel.
7. Possible Refinement of Cold Install Position Model
8. Unistrut Frame Modelling Progress

Comment About this Method of Modelling Buoyancy

- Archimedes principle used to change the body acceleration applied to the entire CRU, assuming that the density is that of the composite structure.
- We know that the FEMBs, Anodes, stainless-steel and PEEK do have significantly different densities than the composite structure.
- A more accurate model would be to apply body accelerations to each body based on its material.
- We are unsure how much this will affect computational difficulty for the solver.

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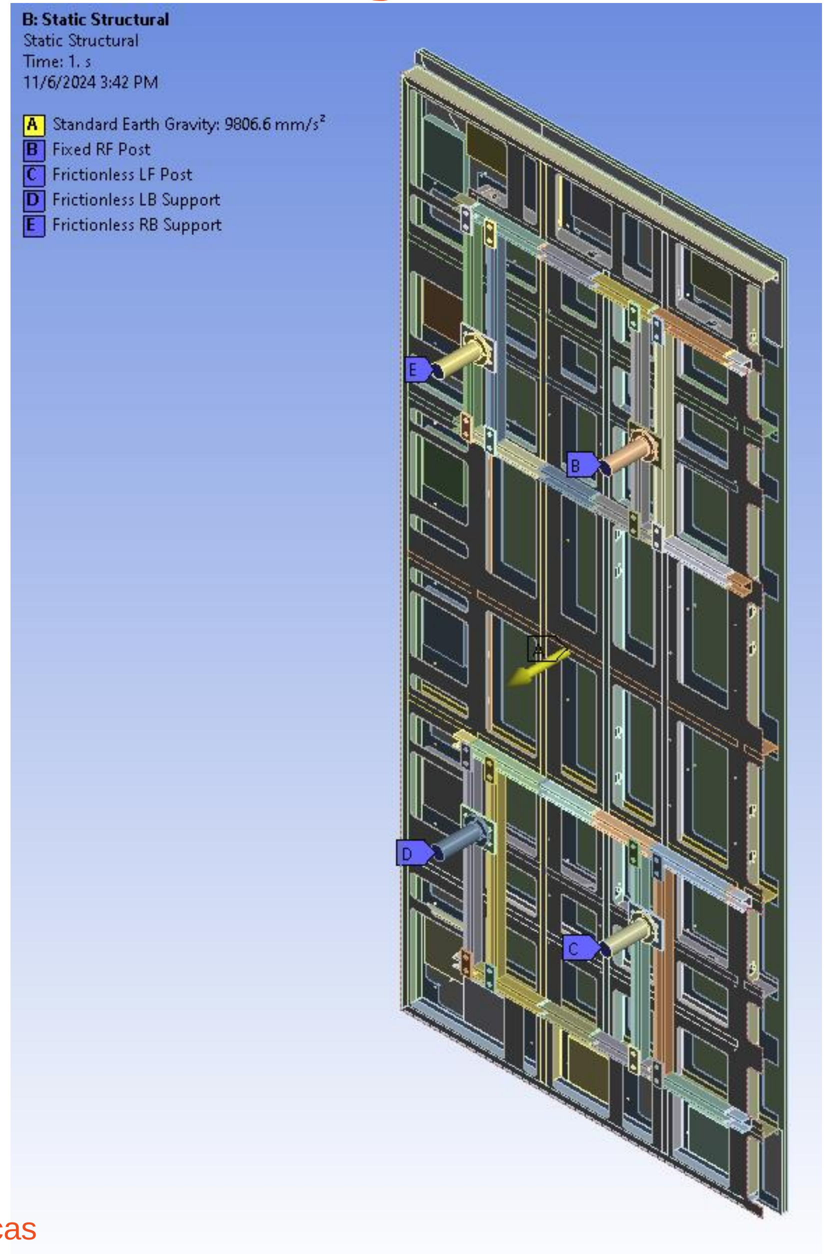
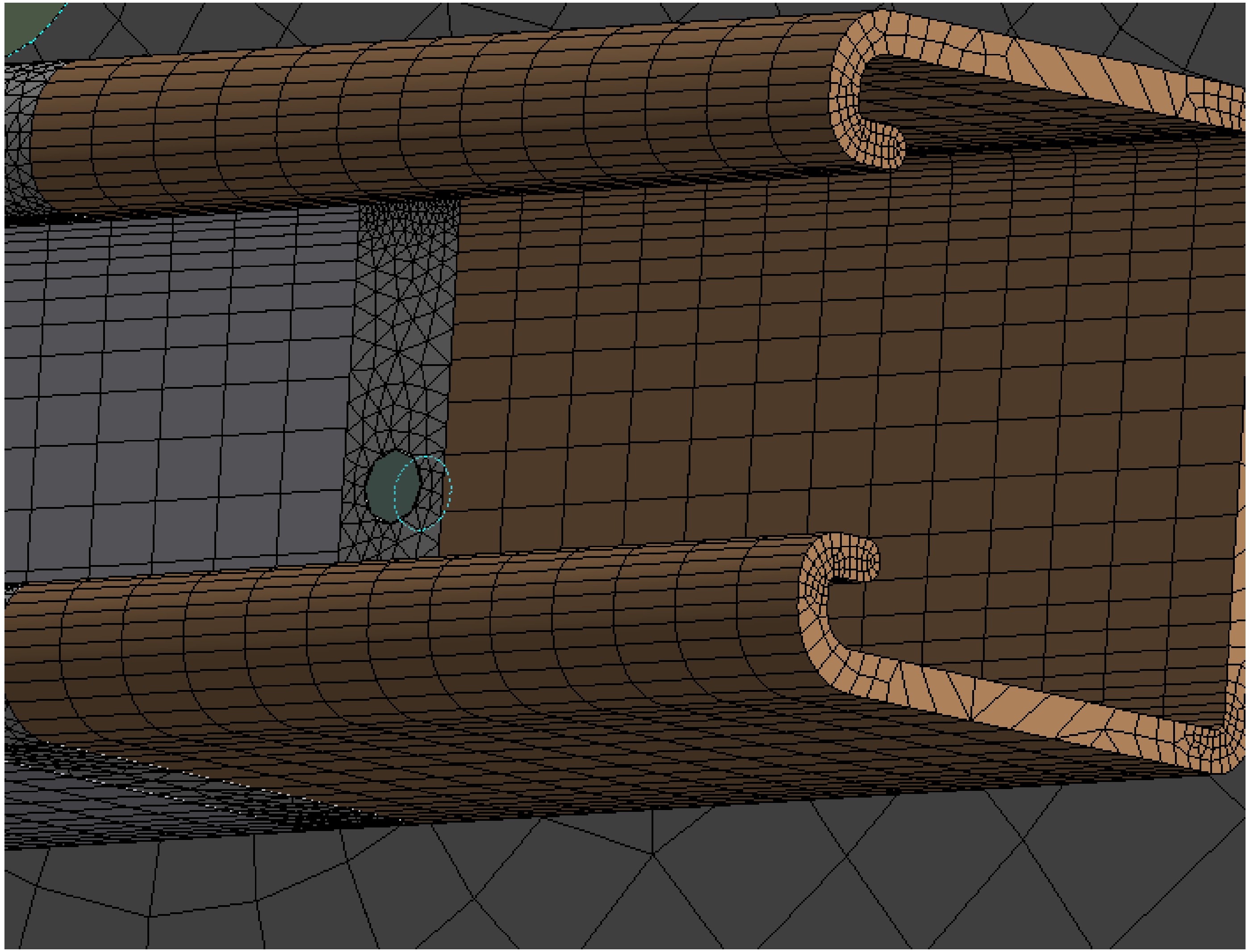
Overview of Geometry and Boundary Conditions

- Same boundary conditions, with different contacts and geometry.



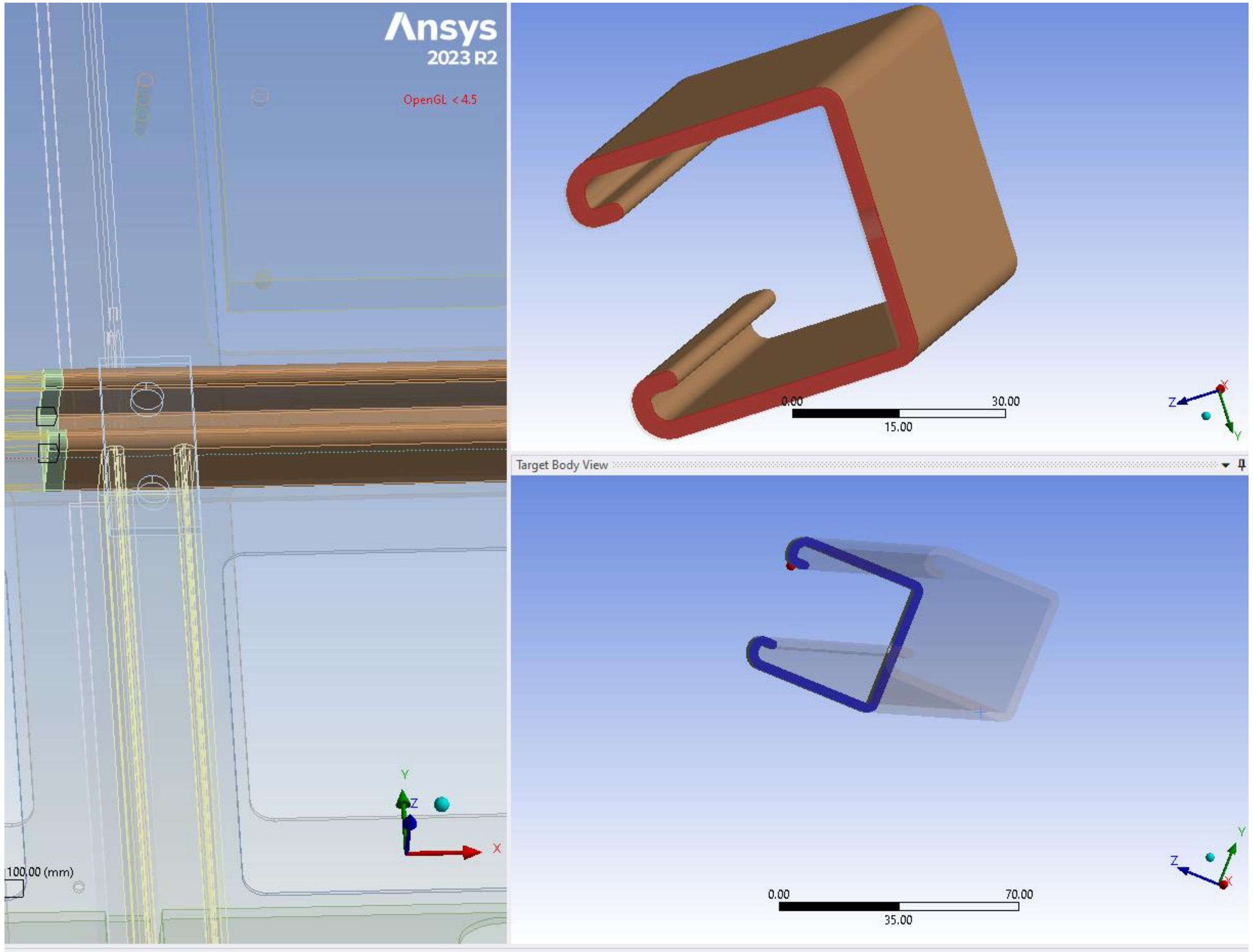
Geometry Simplifications

- Removed Unistrut slots and replaced with simple holes.
- Bodies split into sweep-able regions where there are no bolts and bolted regions.
  - Required in order to make element and node numbers reasonable. (RAM limitation)
- Working on improving mesh conformity.
- Bolts modeled as beam elements whose vertices contact the composite skin and the Unistrut.



Contact Between Members

- Currently working on defining these contacts, cleaning up any duplicates, and defining as much as possible.
- This will help the software build the solver input file, where it is currently struggling.



Frame Bolt Contact Modelling

- Here is an example of how the bolt contact is modelled. The vertex of the beam element will be the center of a web of contact beams.
- The beam stiffness is user controlled. This is a parameter that may require some tuning.