Bottom CRU Installation:

Bottom Support Design and CRU Structural Modeling

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CRU Mass Evaluation

- Volumes extracted from CAD.
- Mass calculated using material densities from CRP ANSYS project.
- Components without CAD use mass estimates from their designers.
- Each CRU is expected to have a mass of 91.3kg.
- Does this align with measurements and/or expectation?

Component	Piece Mass [kg]	Quantity	Assm Mass [kg]
FEMB	0.60	12	7.20
FEMB Cables	0.45	12	5.40
Composite Skin (Top and Bottom)	21.0	1	21
All Composite Beams	18.11	1	18.11
Anode Plane	12.94	2	25.88
BDE	10.19	1	10.19
Anode Spacer Assembly	0.092	1	0.092
Edge Card Assembly	0.42	1	0.42
Set of Spacers per FEMB	0.0010	1	0.0010
Patch Panels	1.50	2	3.00
Total of CRU w/o Adapter Plates			**91.3**

Adapter Plate Material – Stress

We analyzed three adapter plate base stock choices:

1. 6.35mm G10 Composite
2. 6.35mm AISI 304 Stainless Steel
3. 4.76mm AISI 304 Stainless Steel

We ran these materials through an ANSYS model which captures the most severe loading that the CRU would experience in the cryostat.

This state is when the CRU is being cooled to near liquid argon temperature as the liquid flashes to a vapor. We treat the neutral temperature of the material as 293.15K and cool it down to 87K while subjecting it to full standard earth gravity.

Summary of Cooldown Results

Component	Material Yield Stress [MPa]	Max von Mises Stress [MPa] (G10 Adapter Plate)	Max von Mises Stress [MPa] (6.35 AISI 304 Adapter Plate)	Max von Mises Stress [MPa] (4.76mm AISI 304 Adapter Plate)
Anodes	440.1	48.874	40.354	40.354
Composite Structure	440.1	90.41	105.82	110.77
Anode Spacers	90.9	33.695	53.406	53.957
BDE Board	440.1	171.84	146.17	146.18
Adapter Plate (G10)	375	113.09		
Adapter Plate (304)	472	-	405.95	

These stresses are actually lower due to compliance in the design which is not modelled in ANSYS.

Adapter Plate Material – Mass

Reducing the mass has several advantages, notably:

1. Decreased mechanical load on the CRU during flipping.
2. Decreased displacement when on the lifting tool.
3. Could change lifting equipment options (cranes, hardware, etc)
4. Could even allow the lifting tool itself to get lighter, further opening crane options.

Stock	Mass (2 Adapter Plates)	Mass of CRU and Adapter Plates
¼” G10	17.2kg	108.5kg
¼” Stainless	70.54kg	161.83kg
3/16” Stainless	52.91kg	144.21kg

Adapter Plate Material – Cost

- G10 can be machined.
- Thick stainless steel can be waterjet or machined.
  - Design changes to holes may allow for laser cutting.
- 3/16” stainless steel can be laser cut, waterjet, or machined.
- We try to avoid machining as it is generally the most expensive.
- Quotes were put out for a quantity of 8, as that would be enough for CERN cold box test.
- Each supplier had the freedom to purchase their own materials.
  - Most prefer this to supplied materials; some refuse to work with supplied materials.

Stock	Process	Piece Cost
¼” G10	CNC Router	$424.15
¼” 304	Water Jet	$852.03
3/16 304	Water Jet	$737.06
3/16 304	Laser Cut	$511.52

These numbers are estimates, and subject to change with any design changes.

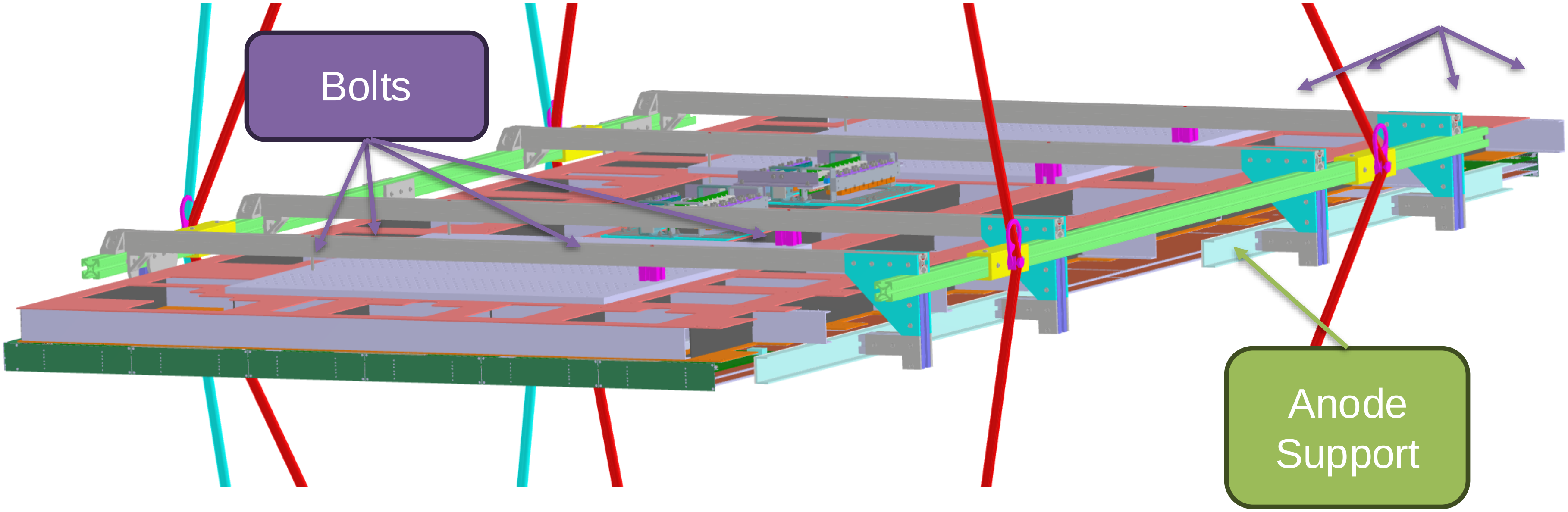
G10 and laser cut stainless are price comparable.

NOTE: G10 and stainless steel are the only materials with similar enough thermal contraction to the CRU.

Adapter Plate Material – Discussion

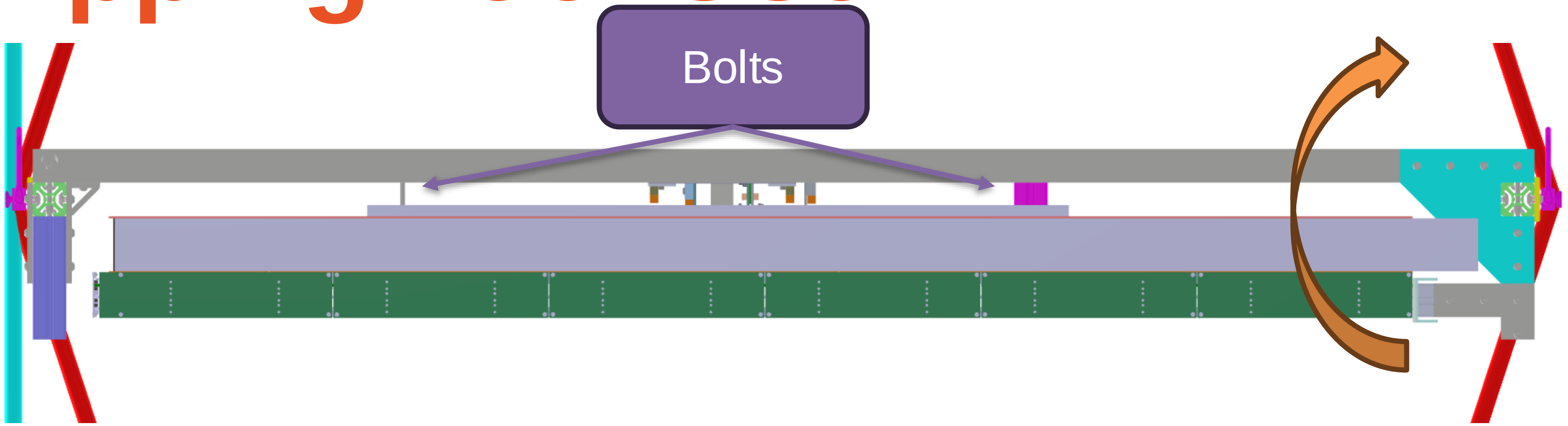
- Generally, the G10 adapter plate has better stress performance, especially for the anode spacers.
  - I think it will be easier to make a convincing argument to the compliance office that our design has sufficient safety factor.
- Stainless steel is much heavier, this by itself a downside for installation. A heavier CRU requires heavier tooling and reduces lifting equipment options.
- Best case manufacturing cost estimates are similar between G10 and 4.76mm stainless.
- I think that G10 is the better choice; it provides a higher safety factor for most components, is lighter, and has already been used in the cold box without any issue.

Flipping Tool Analysis



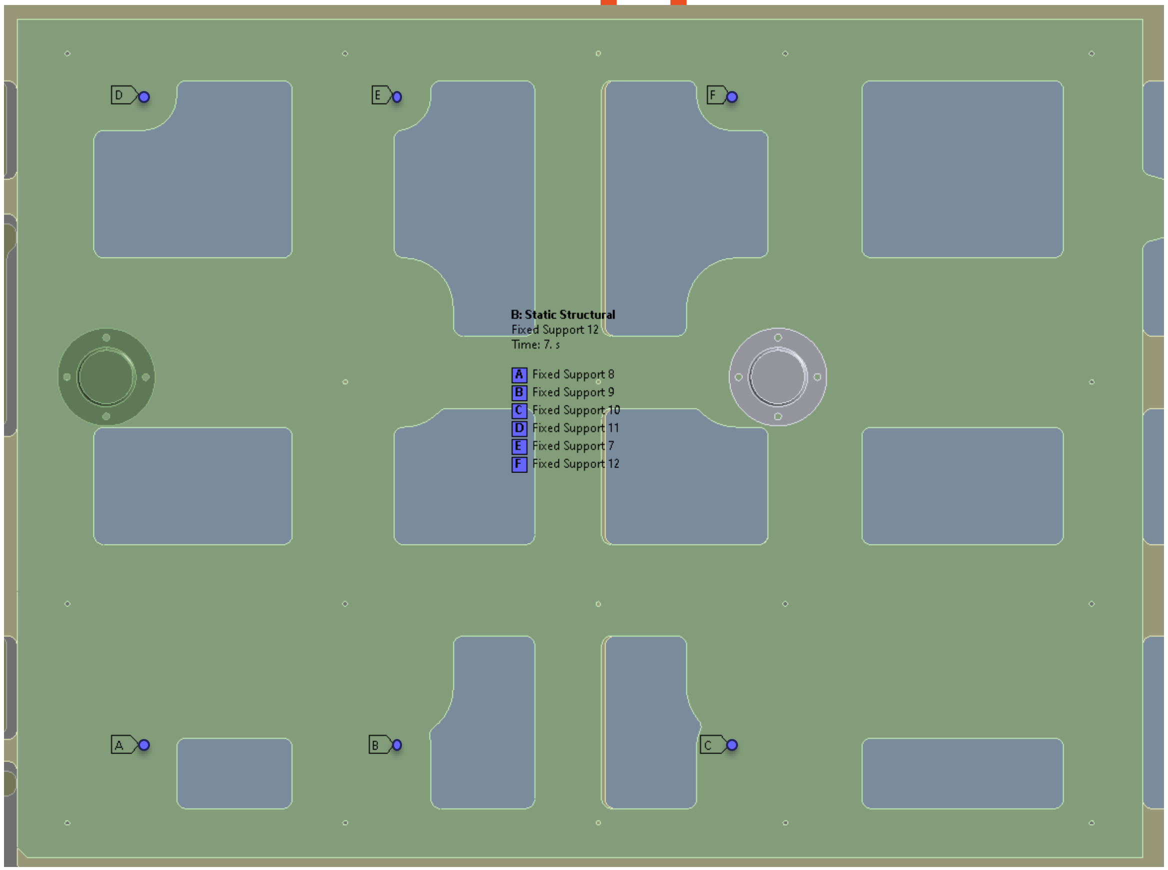
- The right shows a CRU mounted to the proposed flipping tool.
- There are bolted connections from the tool to the adapter plate.
- The free edge of the anodes are supported by the tool.

Flipping Tool Use

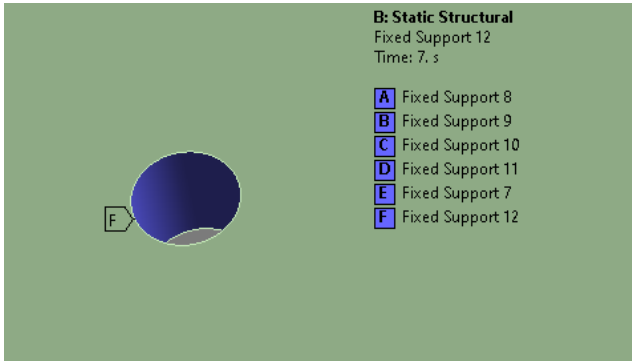


- The CRU is rotating about the position of the anode supports.
- The anode supports prevent motion of the anodes in directions towards the supports.
- Due to the shown direction of rotation, there is no point during flipping where the anodes separate from their support.
- Therefore, we can treat this as a fixed support in our model.

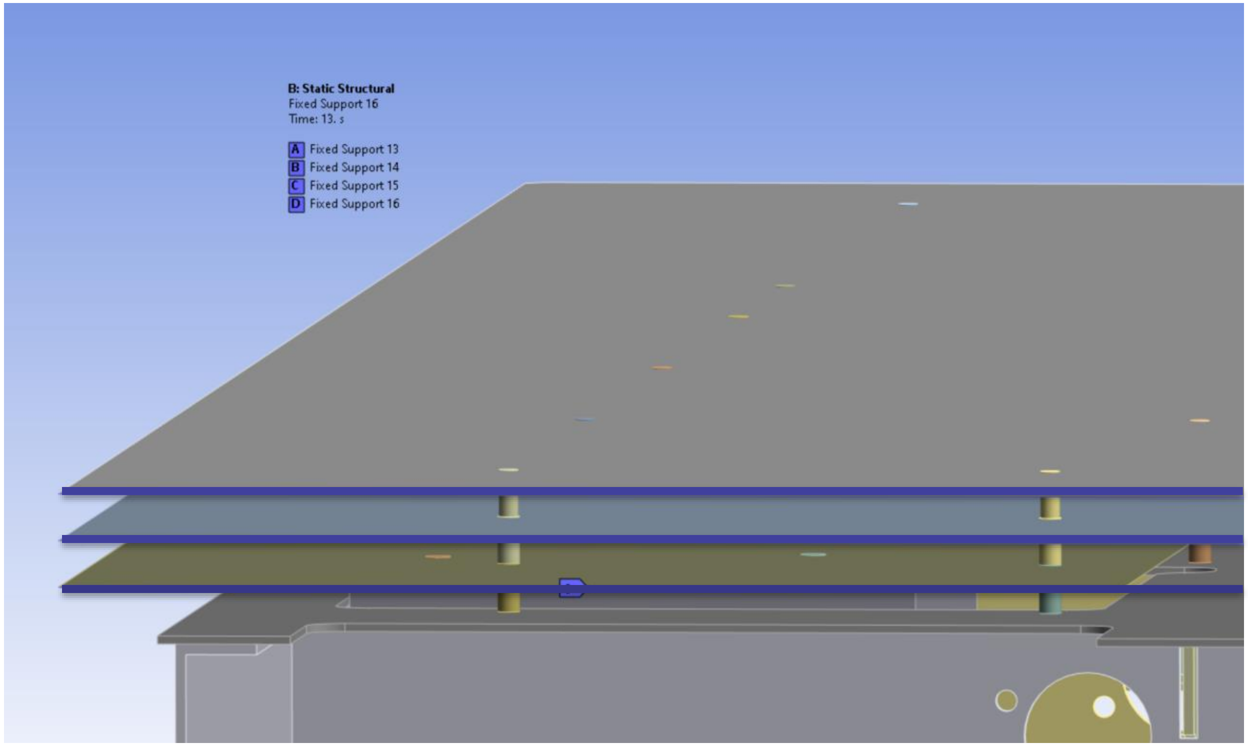
ANSYS Supports – Bolts



- Cylindrical faces are treated as fixed.
- This represents the threaded connection.



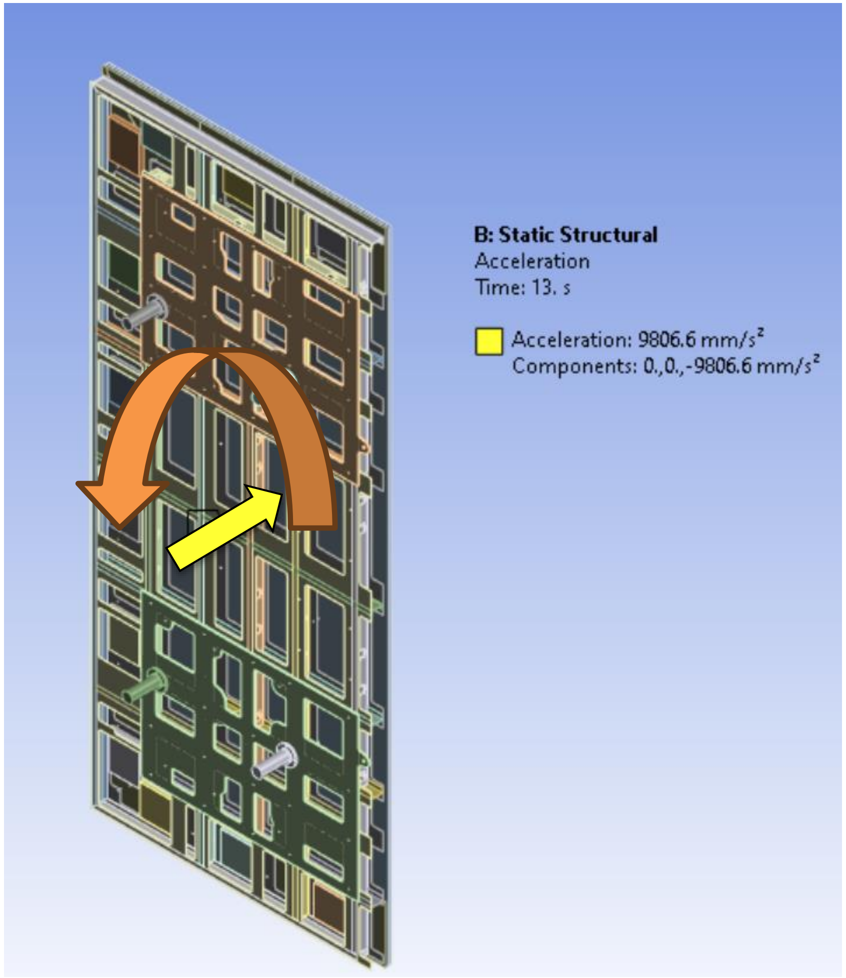
ANSYS Supports – Anode Support



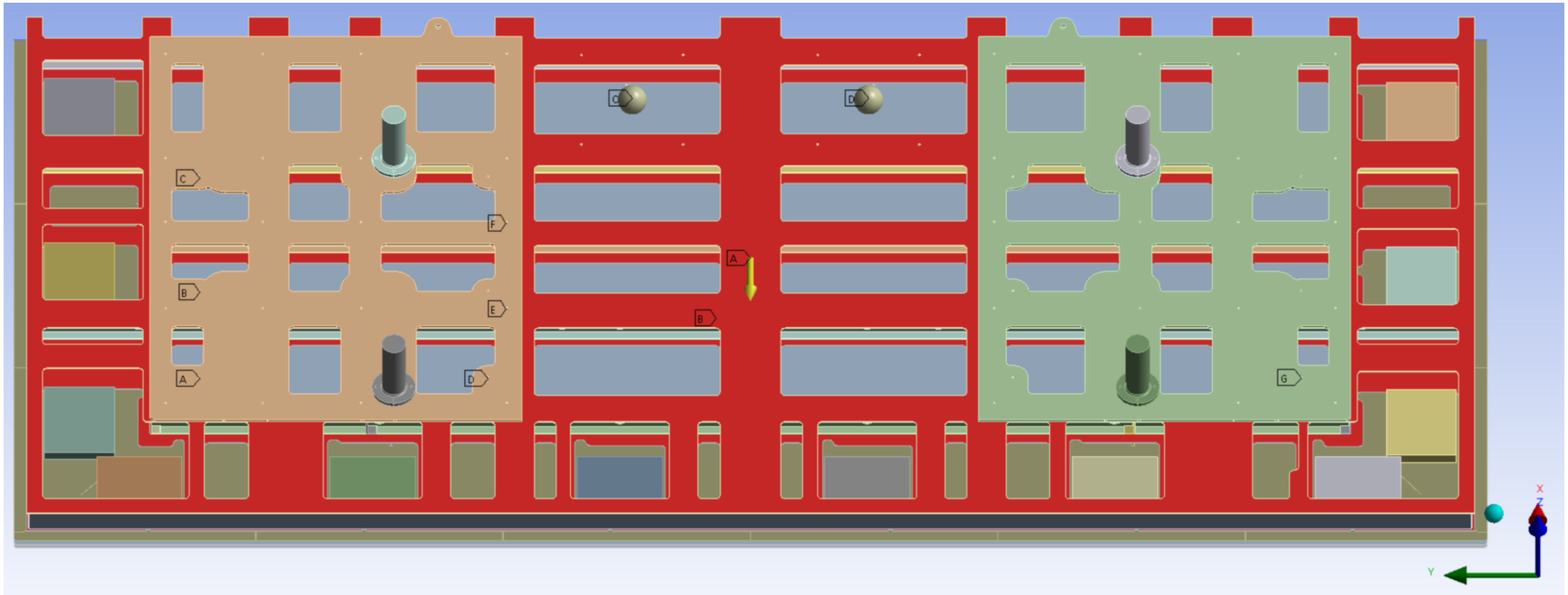
- The blue edges are fixed.
- Fixed means:
  - No displacements in any direction.
  - No rotations about any axis.

ANSYS Loads – Acceleration

- Acceleration within the static structural ANSYS environment is treated as the acceleration of the observer's reference frame.
- So, the acceleration vector pointing in the inverse direction to the applied force.
- In the image to the right, the acceleration vector is pointing away from the floor.
- The CRU experiences force downwards.



Flipping Tool Load



- Yellow vector shows acceleration.
- Bolts and edges fixed.
- Patch panels added as point masses C and D.
- Cables to FEMB added as 5.4kg distributed over composite skin.

Other Notes about Flipping Tool Model

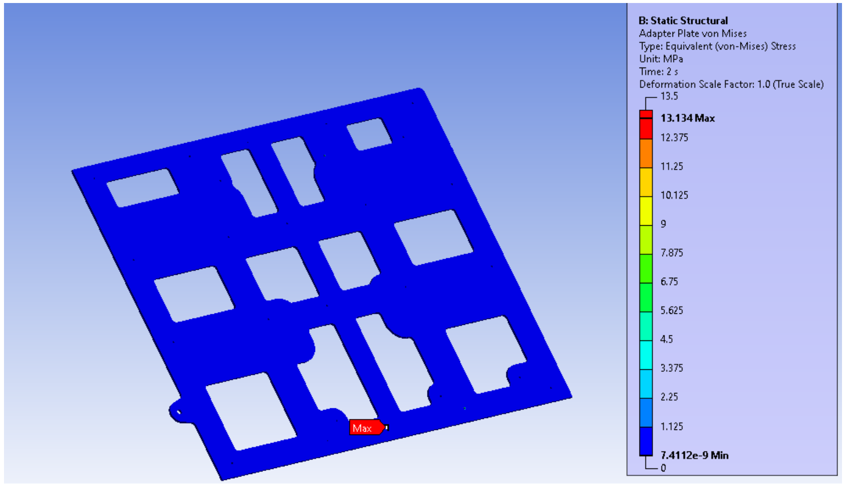
- The adapter plates are still bonded to the composite structure across their entire face.
- This distributes forces evenly across the contact face.
- With sufficient hardware and torque, this simplification is valid.
- All other contacts are the same.
- Inertial effects are not accounted for, this is a good assumption if the flipping operation occurs sufficiently slowly.

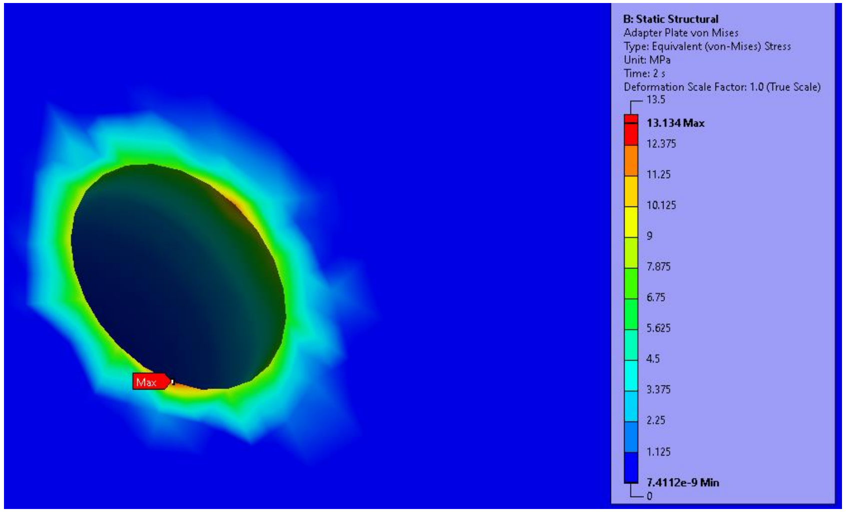
Quick Summary of Flipping Tool Results

- Across all components, the highest stress points in the process are when the CRU is flat on its back and when the CRU is in its install orientation.
- These stresses are comparable to the cases where the CRU is resting on its feet.
- There is not an orientation that causes unacceptably high stresses.
- 6 Standard M6 Class 8.8, Coarse Threaded bolts are sufficient for the flipping operation based on Eurocode 3 EN1993.
  - Maximum shear force on a bolt : 190 N
  - Single Shear Resistance: 7.72 kN
  - Maximum Tensile Force on a Bolt: 357.45 N
  - Tensile Resistance: 11.6 kN

Adapter Plate

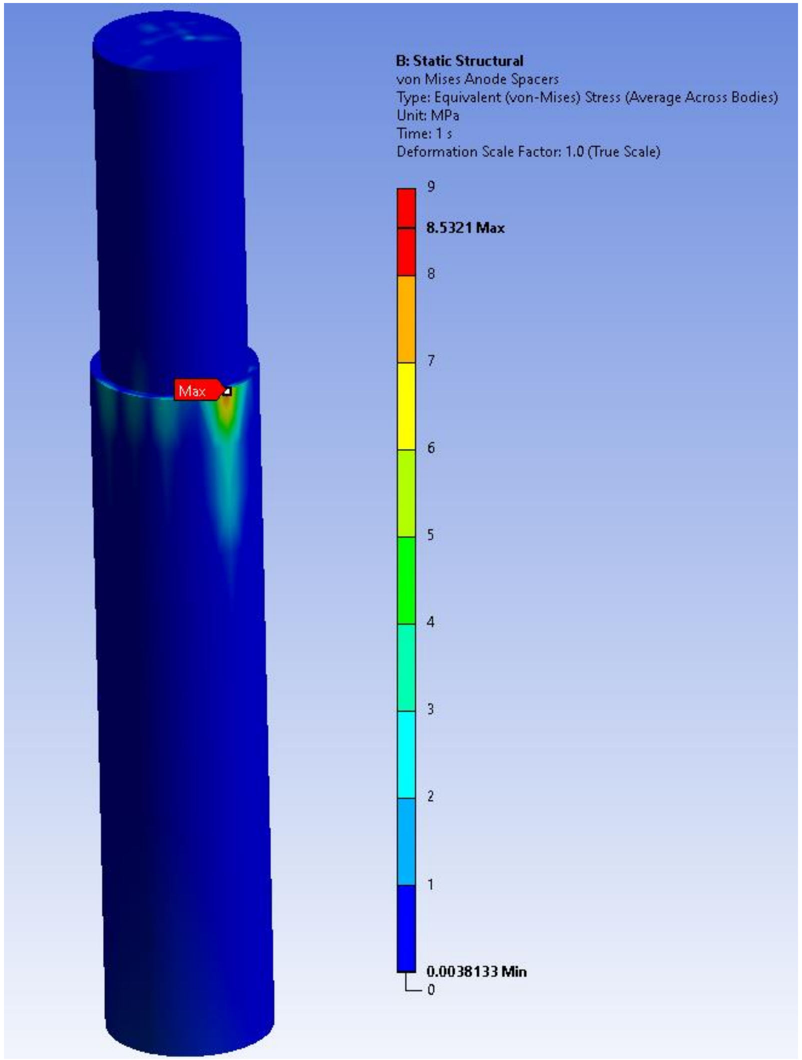
- Adapter Plate stress is very low, the maximum occurs at a bolt hole.





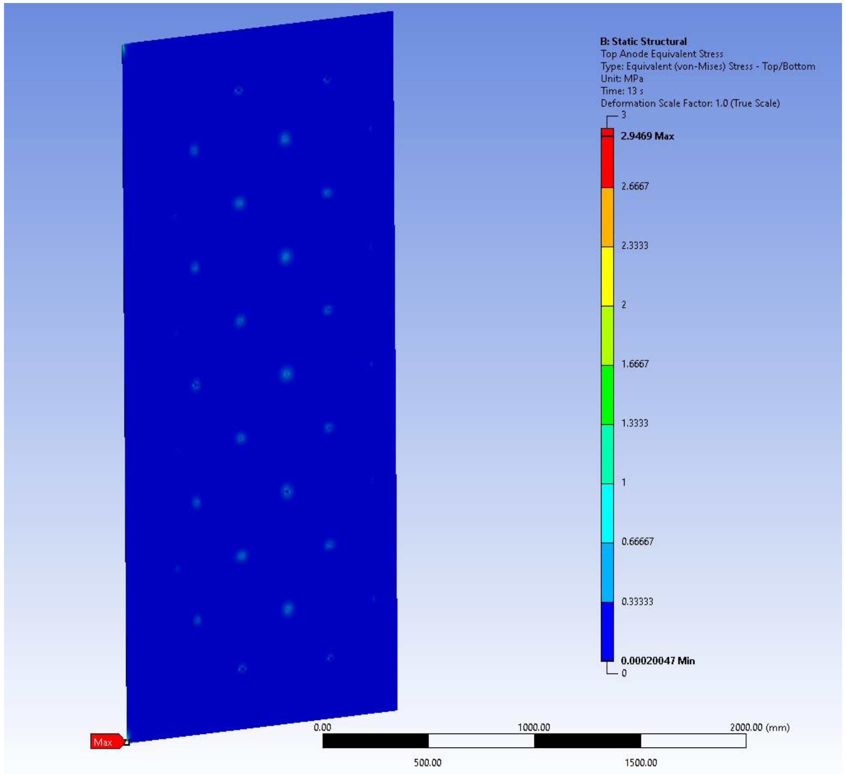
Anode Spacers

- Maximum stress is 8.5 MPa.
- Well below compliance office limit of 22.3 MPa.



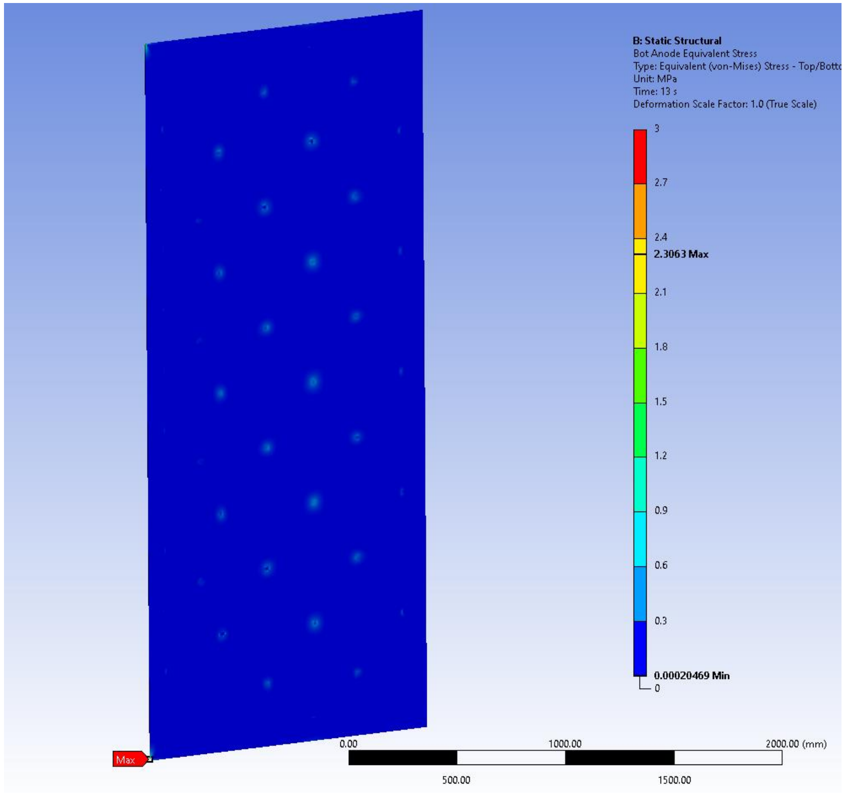
Top Anode

- 3 MPa maximum stress.
- Occurs at a stress concentration with a sharp corner.



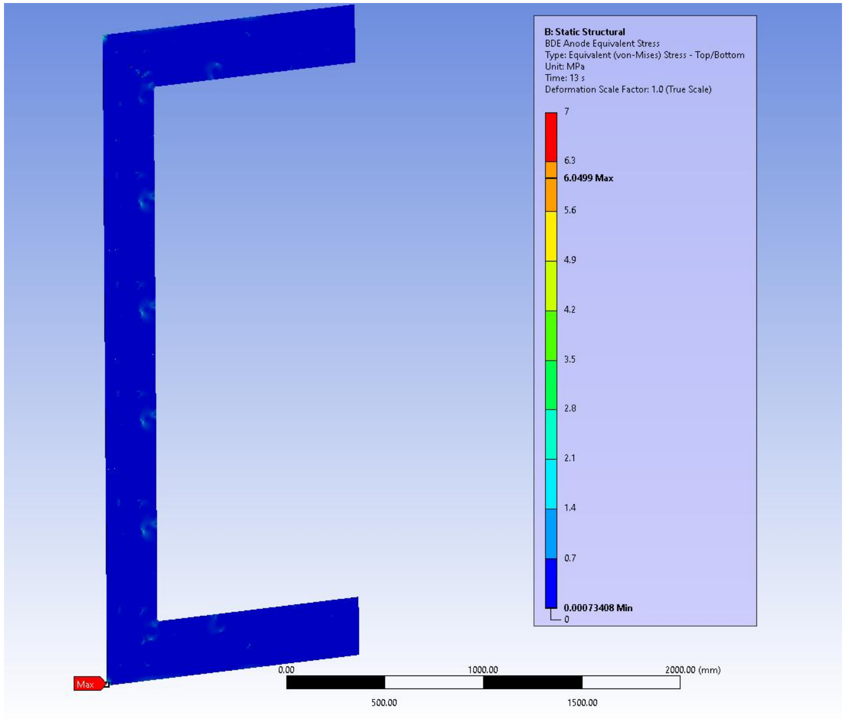
Bottom Anode

- Maximum stress of 2.3 MPa.
- Same concentration



BDE

- Maximum stress of 6 MPa
- Overall greater stress in BDE than anodes due to supporting FEMBs



Composite Structure

- Maximum of 7.5 MPa.
- Occurs at a corner junction between perpendicular beams where they meet the composite skin.
- Very sharp 3D corner gives very high stress concentration.