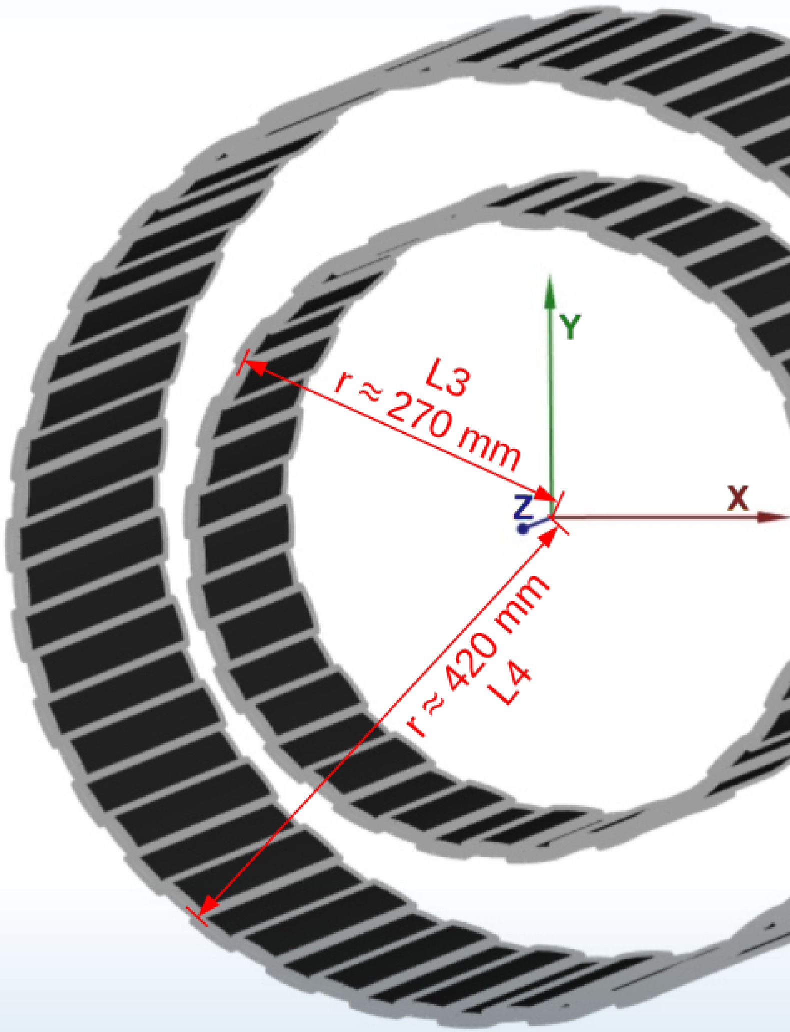
ePIC Silicon Vertex Tracker
OB Mechanics and Cooling

Adam Huddart

Introduction

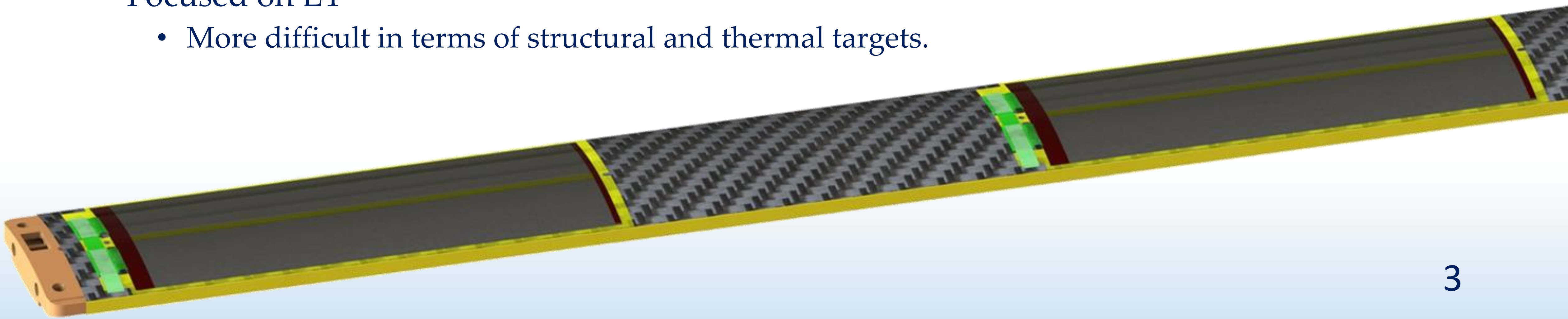
- L3
  - Inner - 23 staves with a (centre of mass) radius of 269 mm
  - Outer - 23 staves with a (centre of mass) radius of 275 mm
- L4
  - Inner - 35 staves with a (centre of mass) radius of 421 mm
  - Outer - 35 staves with a (centre of mass) radius of 427 mm
- Equal overlap between sensors, overlap set to fit stave within 45-degree cone.
- L3 and L4 support structure identical except for difference in length/number of and type of LAS

OB L3 (6RSU segments)

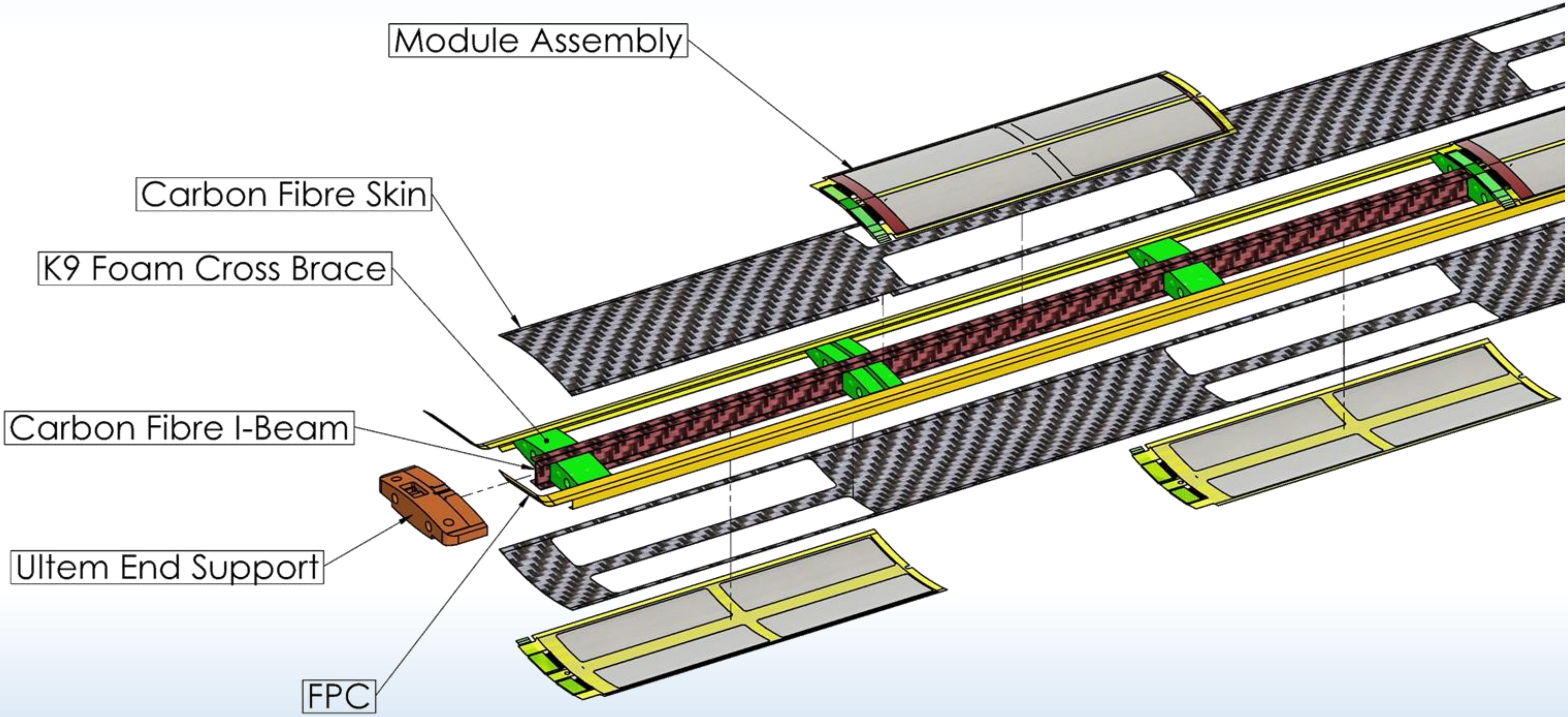


Introduction

- Stave structure is internally hollow to form channels for coolant airflow
- Majority of the stave structure is carbon fibre/foam
  - Assembled in a single co-curing operation
  - Preform FPC C channel and Central I-Beam
  - Vacuum bagged in autoclave with removable internal tooling
- Sensors are adhesively mounted as “modules” consisting of 2 EIC-LAS, ASICs, Bridge FPC and a Kapton carrier
- Focused on L4
  - More difficult in terms of structural and thermal targets.

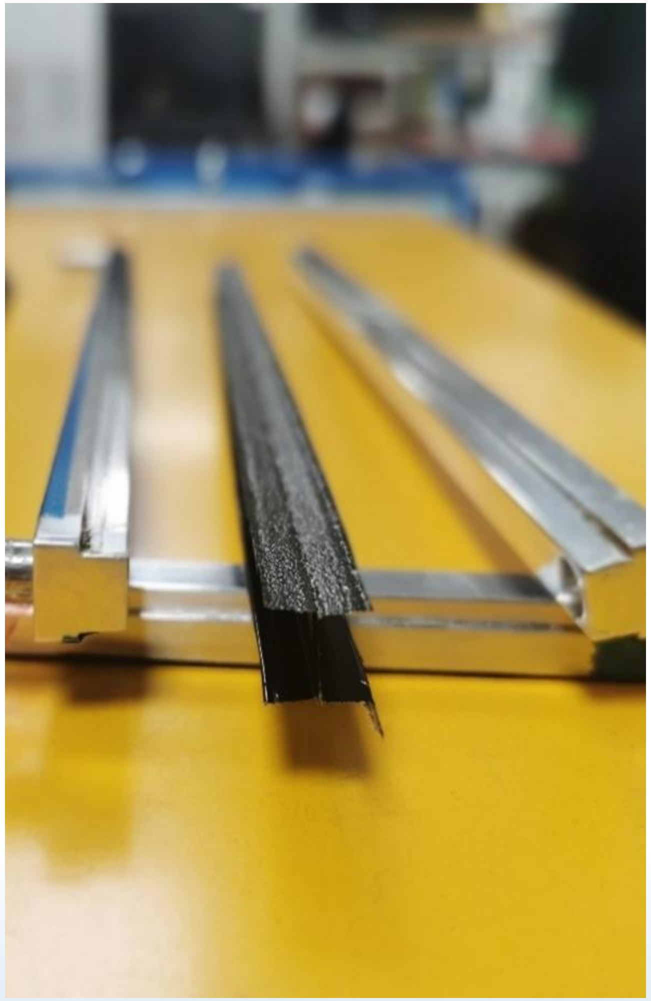


L3/L4 Stave Structure Overview

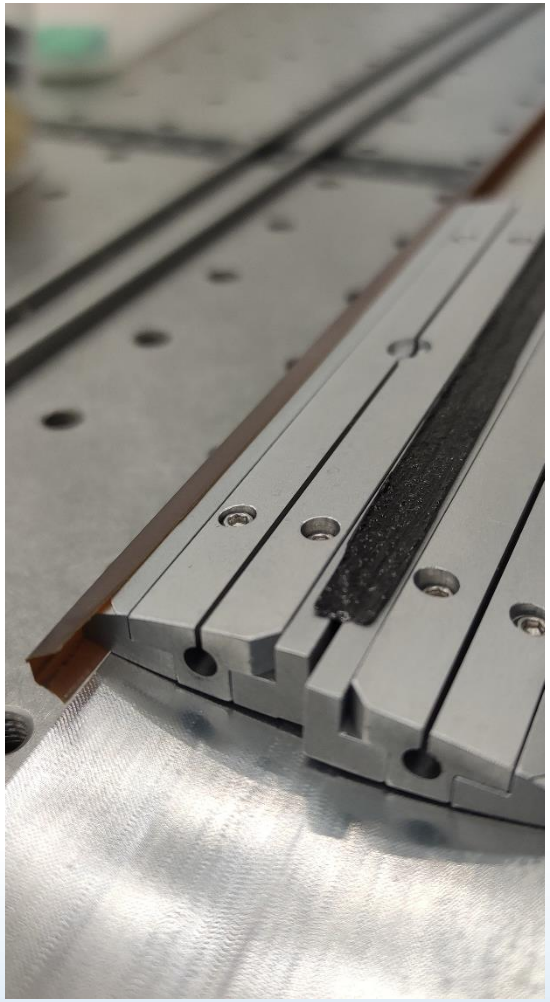


Brief Overview of ¼ Stave Prototype

Kapton Former



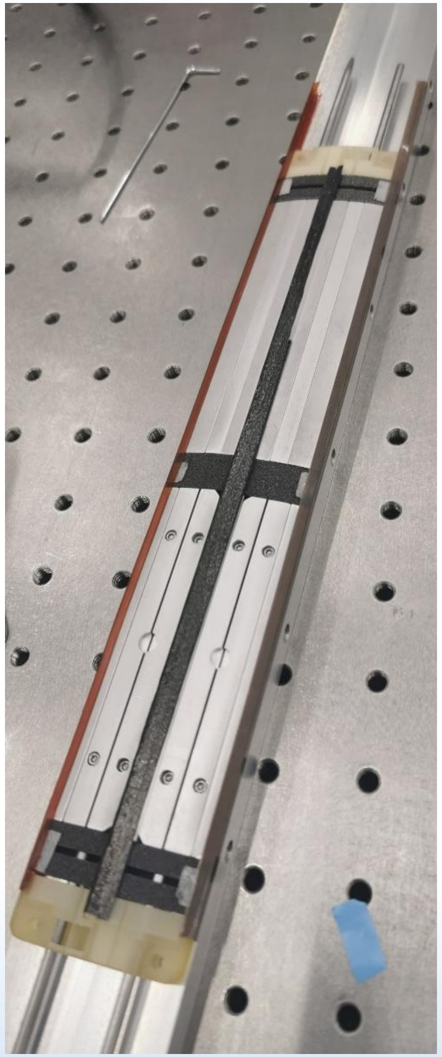
Carbon Fibre I-beam Mould



Internal Formers

- 1/4 of an L4 stave
  - One top one bottom module
- Preformed I beam and Kapton C Channel FPC Mock-ups
- SLA 3D printed end supports
- Multipart aluminium internal tooling
- 2 x 3mm rod runs through end supports, K9 foam cross braces & internal tooling to constrain and align stave components

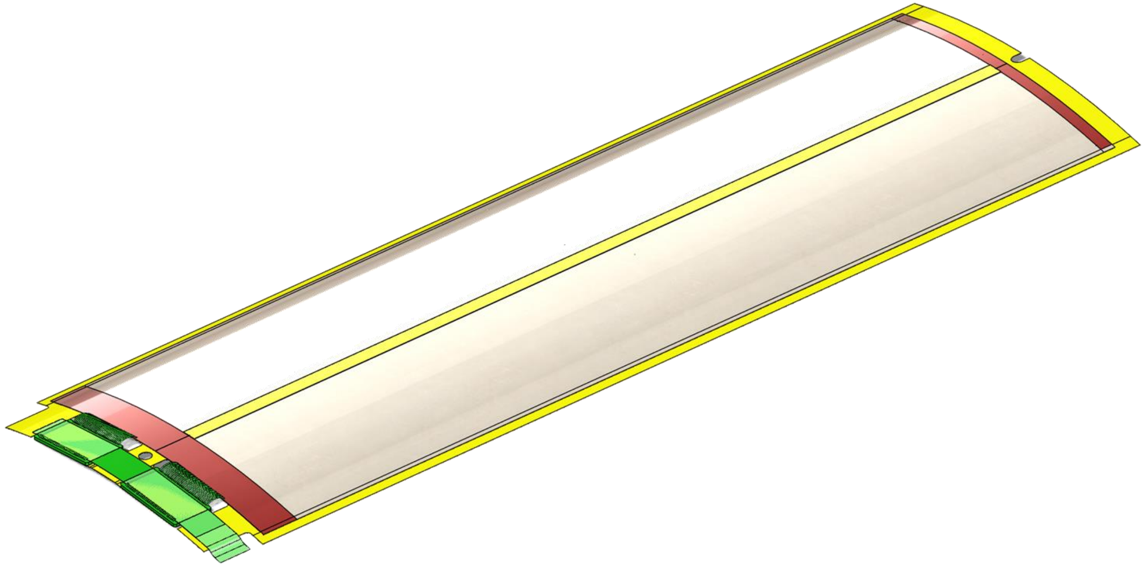
Brief Overview of ¼ Stave Prototype



- 1/4 of an L4 stave
  - One top one bottom module
- Preformed I beam and Kapton C Channel FPC Mock-ups
- SLA 3D printed end supports
- Multipart aluminium internal tooling
- 2 x 3mm rod runs through end supports, K9 foam cross braces & internal tooling to constrain and align stave components

EIC-LAS Module

- Module Consists of:
  - 2 EIC-LAS
  - 2 ASIC
  - Bridge FPC
  - Kapton Carrier



- Modules are assembled on tooling and transferred with sensors held into a curved shape with vacuum tooling
- Module transfer tooling will be tested on quarter length stave

What we Need to Prove

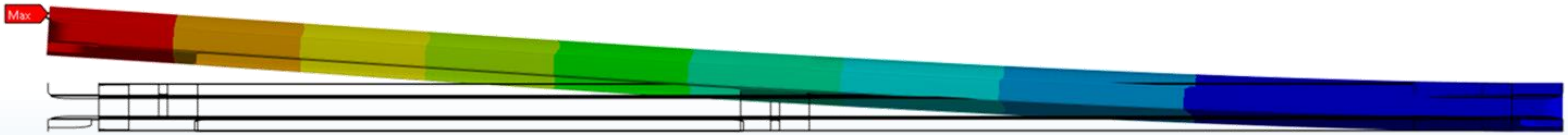
- Structure is sufficiently stiff
  - Does not vibrate excessively due to internal airflow
  - Stave structure must withstand internal pressure requirements

- Electronics temperatures stay within their target temperature window
  - FEA and CFD studies have informed prototype stave design
  - For prototype testing we will use dummy heat loads, measure temperature of LEC & ASIC mock-ups on stave prototypes

- Planned manufacturing methods are achievable and resulting assembly is within required dimensional tolerances.

Proving Mechanical Stiffness

- Modal Analysis through FEA
  - Must include the mass and stiffness or all components (and bonding methods) of the stave
  - Target first mode of 100 Hz
  - FEA analysis can be validated using piezo driven vibration table
- Prove pressure capacity of stave through pressure testing
  - Difficult to model/predict adhesive bond strength when surfaces are not rigid.



Quarter Length Stave FEA – First mode 97 Hz

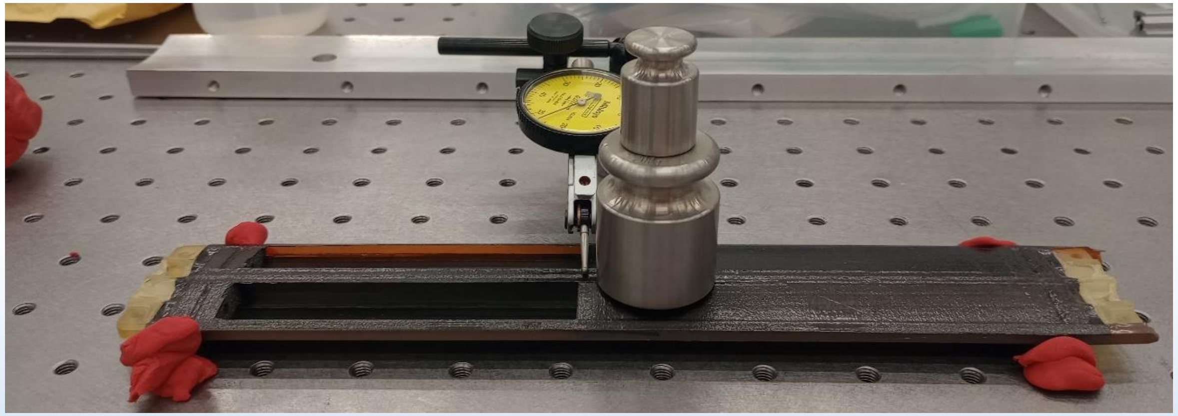
Quantitative Structural Results

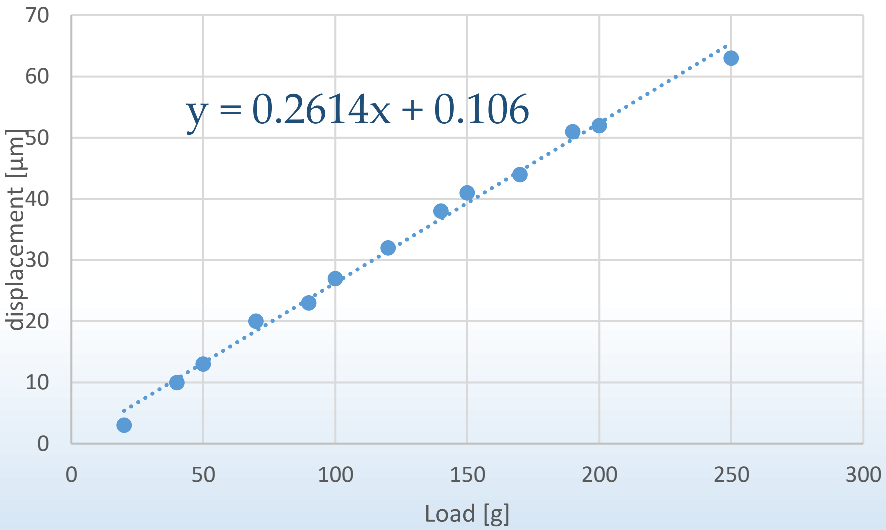
- Mass estimate

Component	Volume mm^3	Density kg/m^3	QTY	Mass	
Carbon Fibre Skin Upper	657.837628	1580	1	1.039383	g
Carbon Fibre Skin Lower	690.516991	1580	1	1.091017	g
Kapton C Channel	206.136635	1420	2	0.585428	g
Stave End Mounts	1462.491448	1210	2	3.539229	g
I Beam (Half)	322.104359	1580	2	1.01785	g
K9 Foam Block	1295.980514	200	6	1.555177	g
			Total Mass	8.828084	g

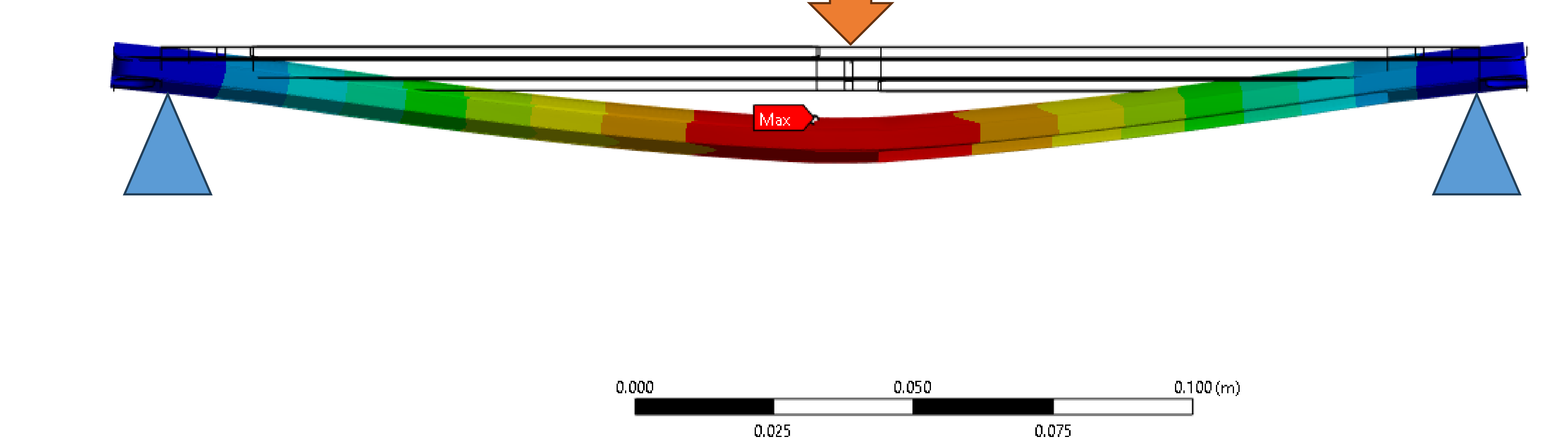
Measured: 8.95 g

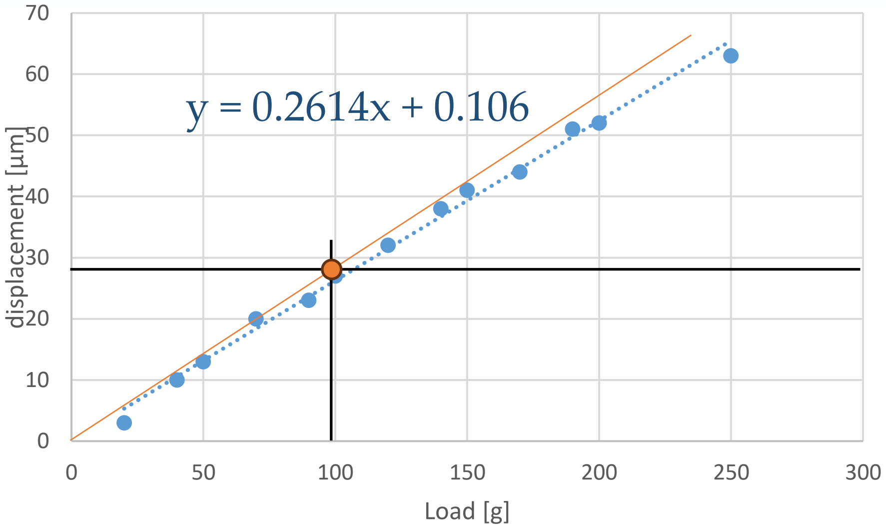
- 3pt bend test





¼ Stave Finite Element Analysis

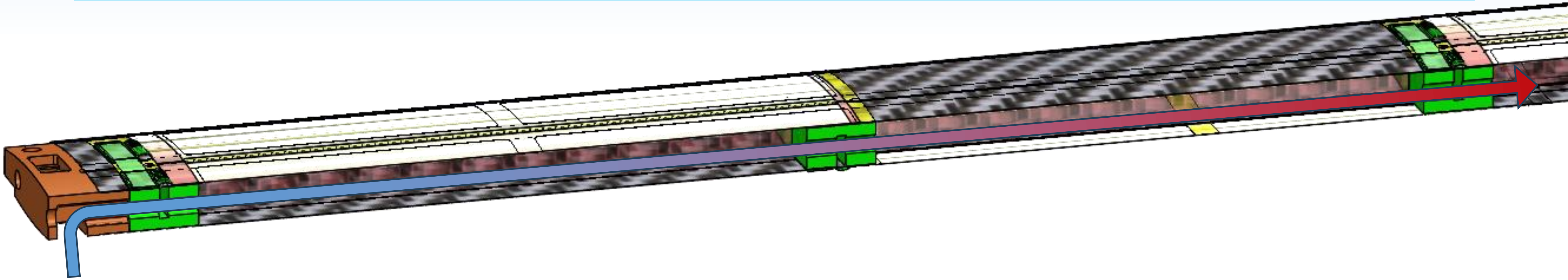




Thermal Modelling

- FEA/CFD models of the L4 stave and ASIC
  - Detailed modelling of thermal pathway for ASIC cooling to optimise it’s layout
  - L4 model to estimate required flow velocity, coolant outlet temperatures and pressure drop.
- Keeping LEC and ASIC close to 25°C significantly decreases thermal output

Cooling Requirements



- Target delta T between all LEC or coolant or RSU of 10K
- Coolant (low pressure) enters the stave at the end support and flows down central air channel in the stave
- High power density components LEC and ASIC in close thermal contact with K9 foam for enhanced cooling
  - Porosity (and strategically positioned holes) allows air to pass cross braces

Numbers used

OB and disks

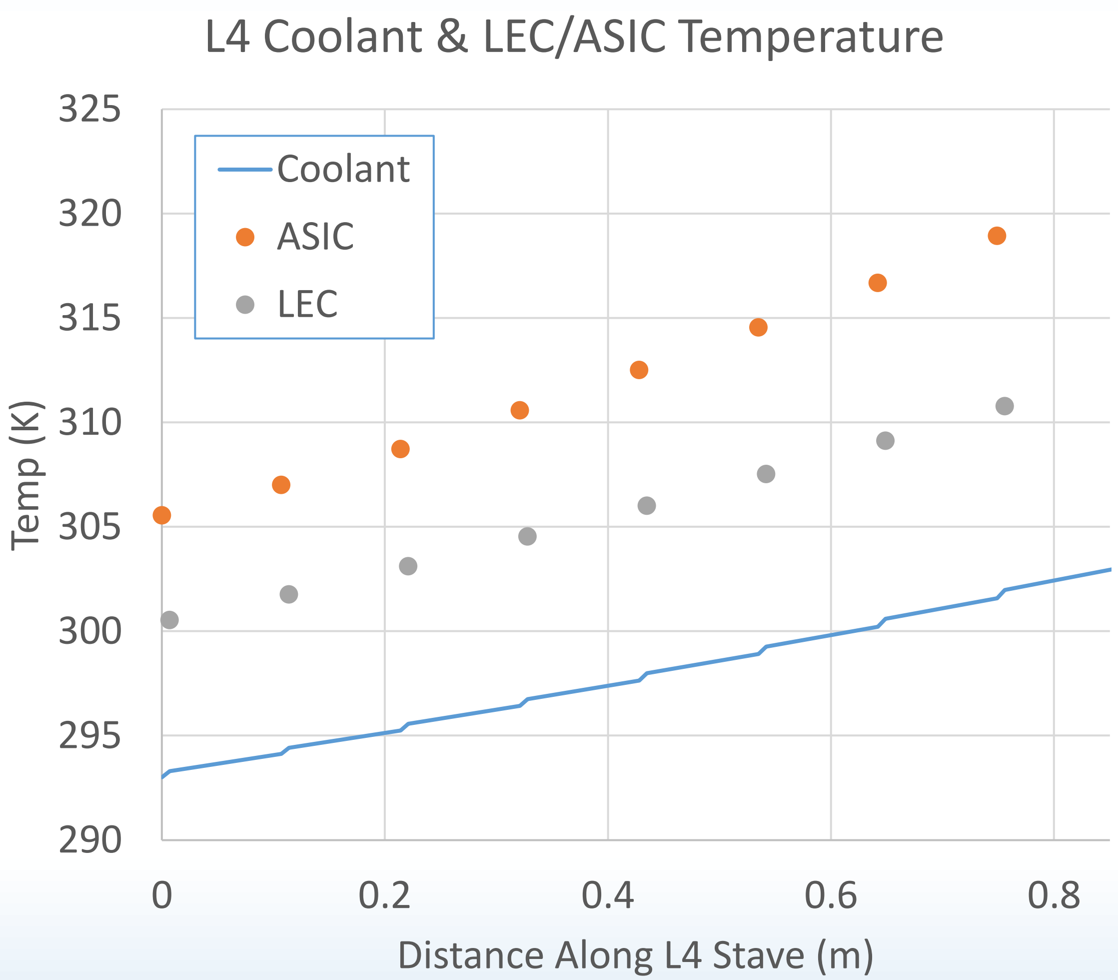
Power [mW]	5 RSU			6 RSU		
	LAS	AncASIC	FPC	LAS	AncASIC	FPC
Nominal	1092	382 (35% of LAS)	218 (20% of LAS)	1224	428 (35% of LAS)	245 (20% of LAS)
Max	1689 (+55%)	759 (45% of LAS)	507 (30% of LAS)	1897 (+55%)	853 (45% of LAS)	569 (30% of LAS)

OB		# of LAS/stave	# of staves	Total # of LAS
L4	5-RSU LAS	16	70	1120
L3	6-RSU LAS	8	46	368

disks	Total # of LAS
5-RSU LAS	1104
6-RSU LAS	1312

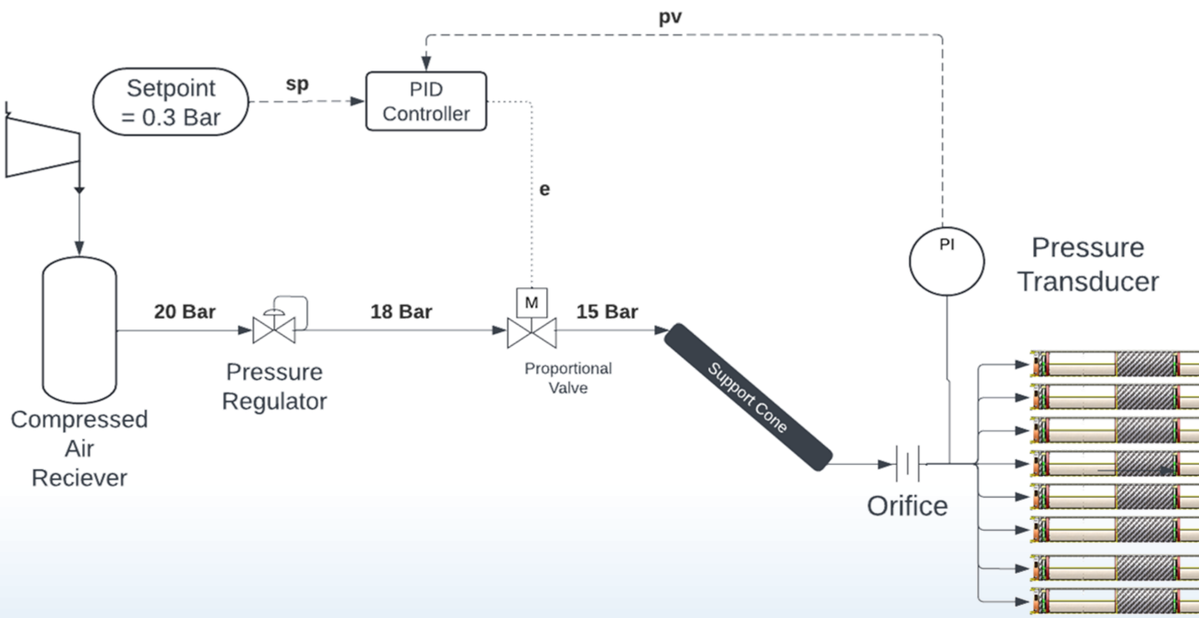
Stave Temperature & Flow

- L4 Stave Power
  - Nominal – 27.1 W
  - Max – 47.3 W
- L3 Stave Power
  - Nominal – 13.2 W
  - Max – 22.0 W
- Stave CSA = 260 mm^2
- Required flow velocity
  - Nominal – 9,8 m/s (135 l/min)
  - Max – 17.0 m/s (235 l/min)



Air Supply

- OB airflow requirement – 12500 – 21500 L/min (0.2-0.35 m^3/s)
  - Equivalent flow velocity through 30cm (12”) duct = 3-5 m/s
- Could we supply at pressure and locally reduce
  - 15 Bar through 16 x 10mm ID tubes
  - Flow Velocity - 11 to 19 m/s
  - System will need to be well tested and tolerant to blockages to avoid rupturing staves



Next Steps

- Build another ¼ Length stave for flow testing
  - Dummy heat loads to represent LEC, RSU and ASIC
  - Compare CFD studies with experimental results

- Feasibility of flat staves
  - Significantly easier for module assembly
  - Preliminary FEA studies show this has a limited effect on global stave stiffness
  - Further modelling of effect of internal pressure needed

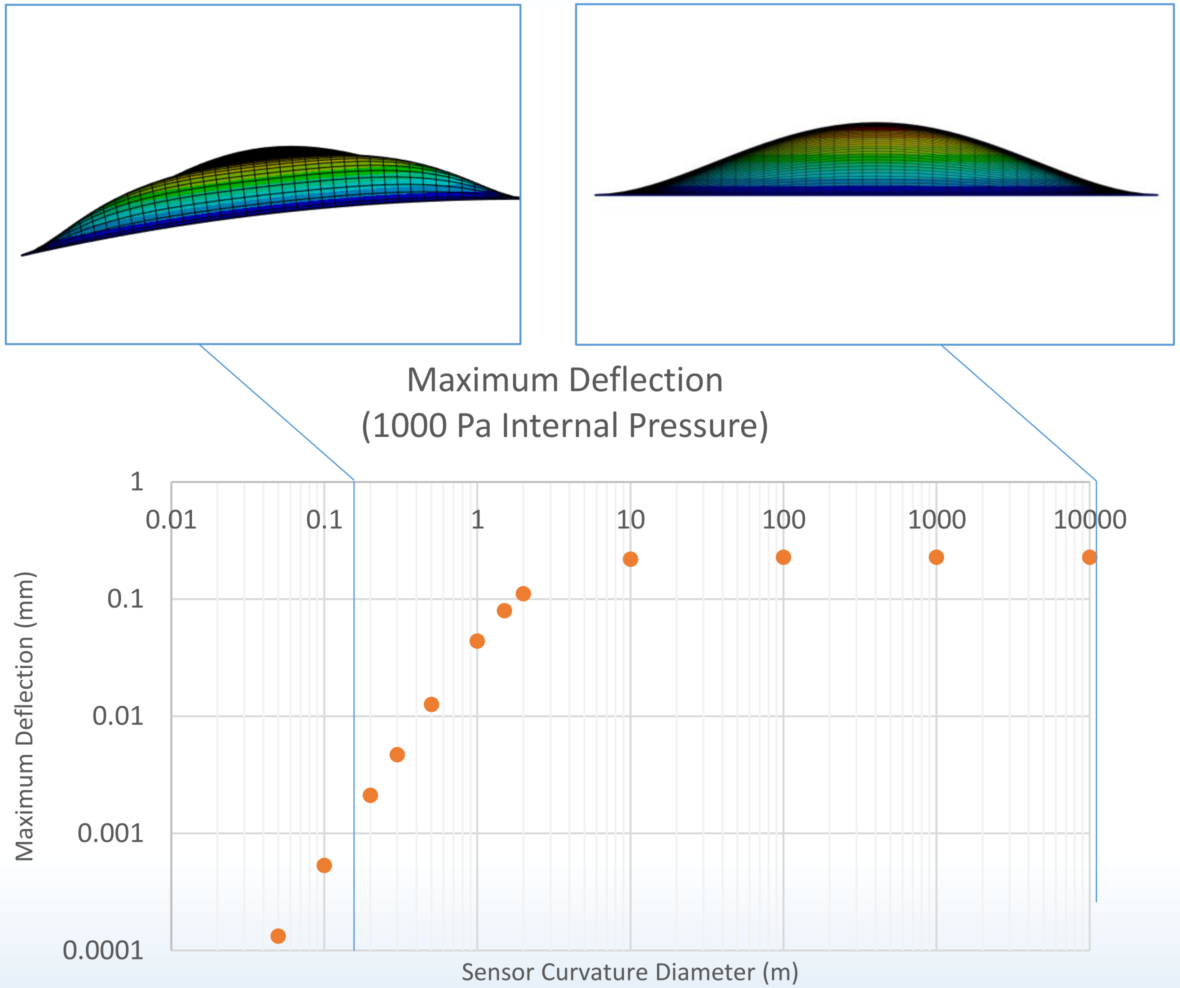
Conclusions

- First ¼ Stave prototype was both successful and informative
  - Static load testing showed similar (slightly better) stiffness than FEA
  - Redesign end supports & try with silicone intensifier to reduce imperfections in the carbon fibre skins.
- Second ¼ Stave will allow us to test modal response of stave and validate thermal models
- More extensive analysis of a flat sensor stave needed

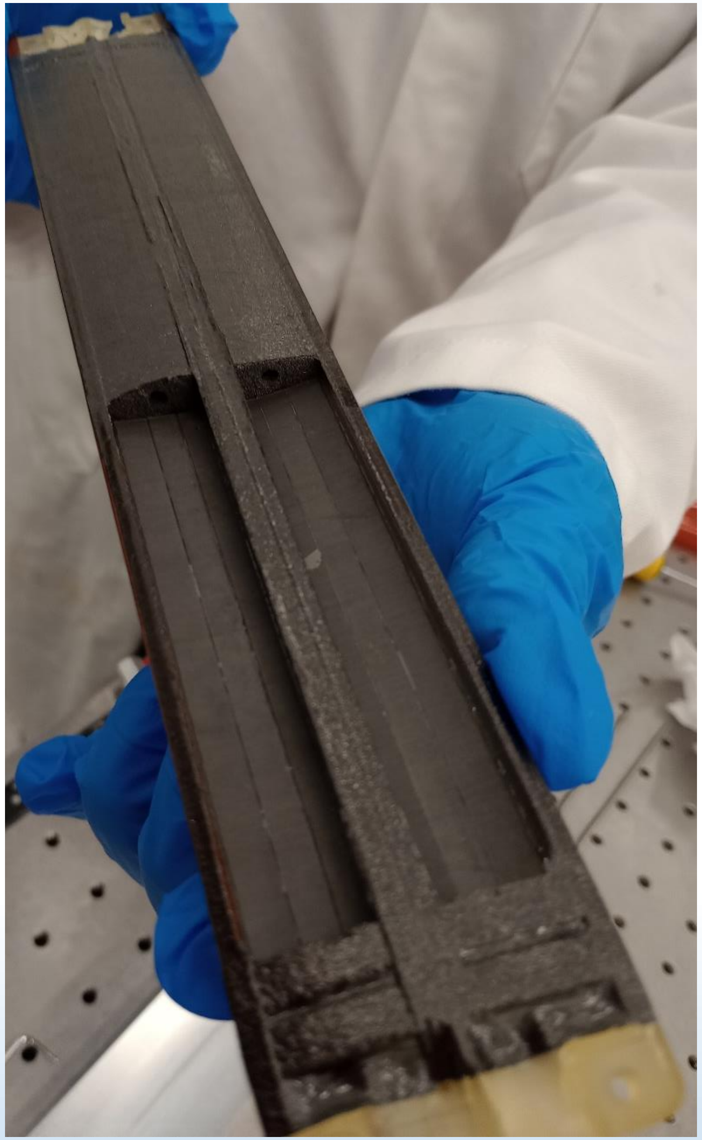
Additional Slides

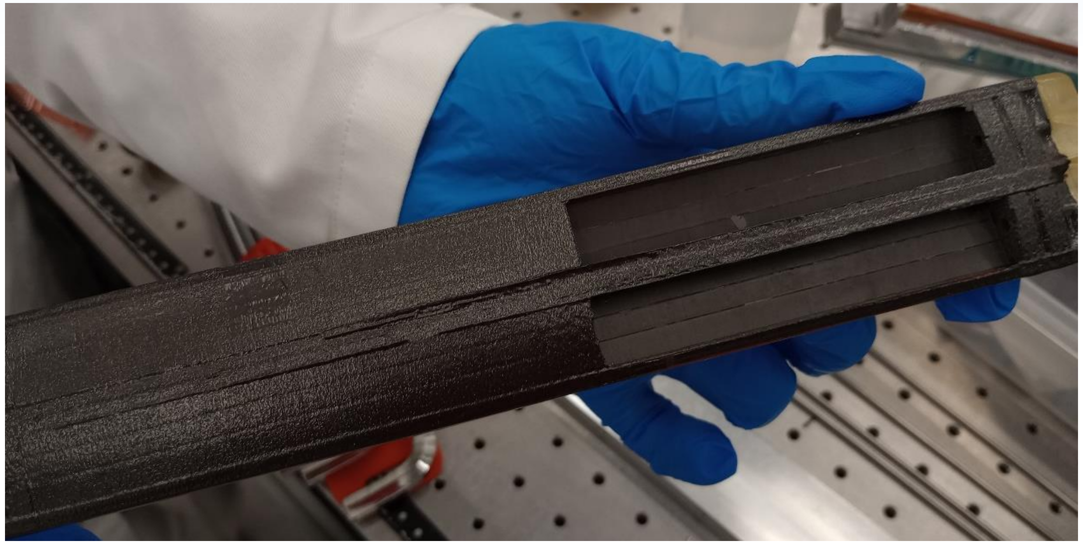
Local Stiffness of EIC-LAS

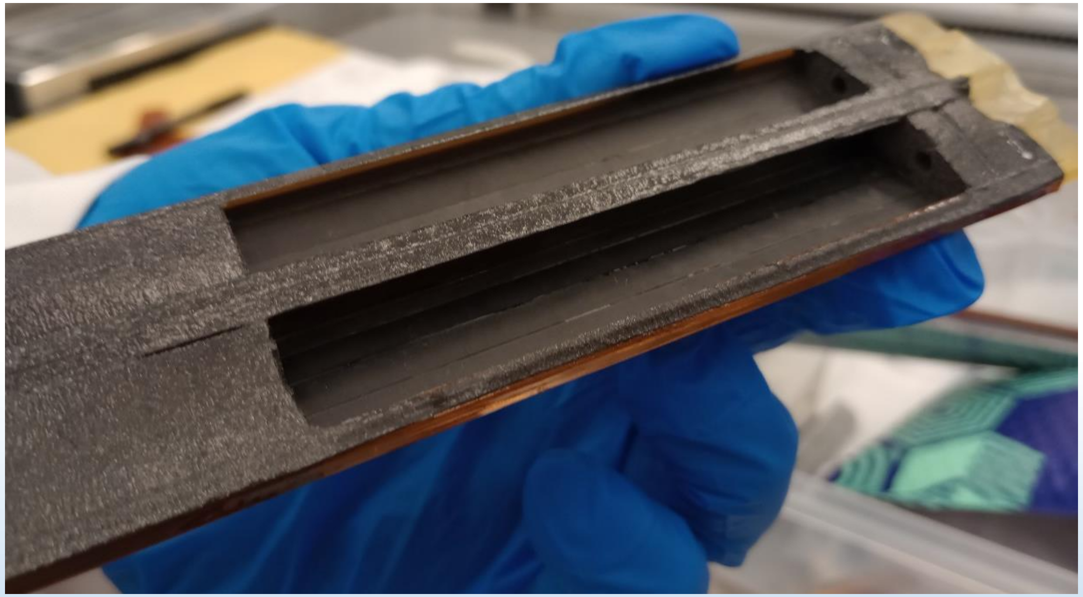
- Air velocities in flow channel will be high
  - High pressure drop/high inlet pressure
- Modelled assuming rigid mounting around glue locations
- Curvature reduces deformation due to internal pressure
- Sensor/module curvature of Ø180 mm results in micron level deformation due to 1000 Pa internal pressure

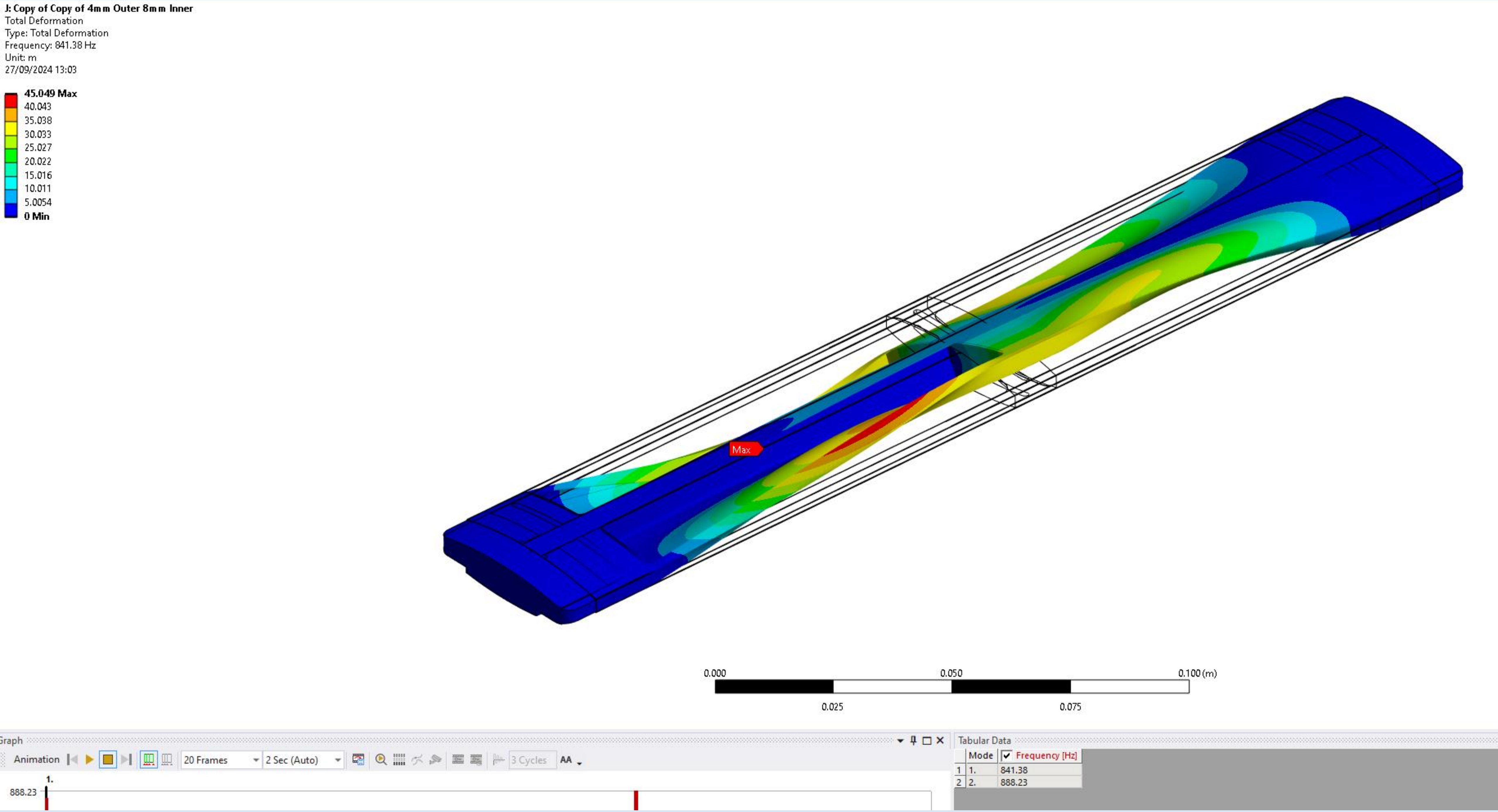


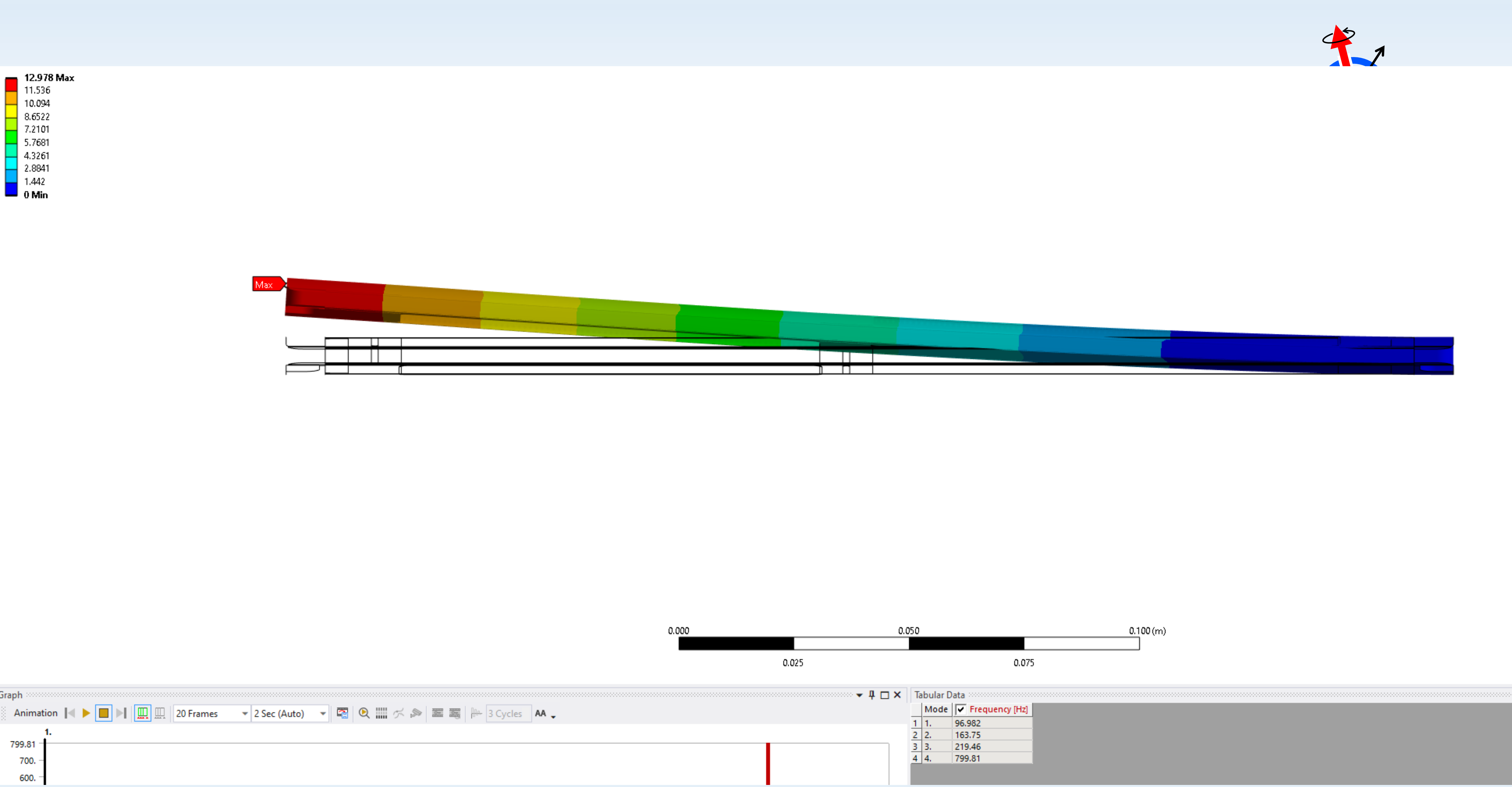
Pictures

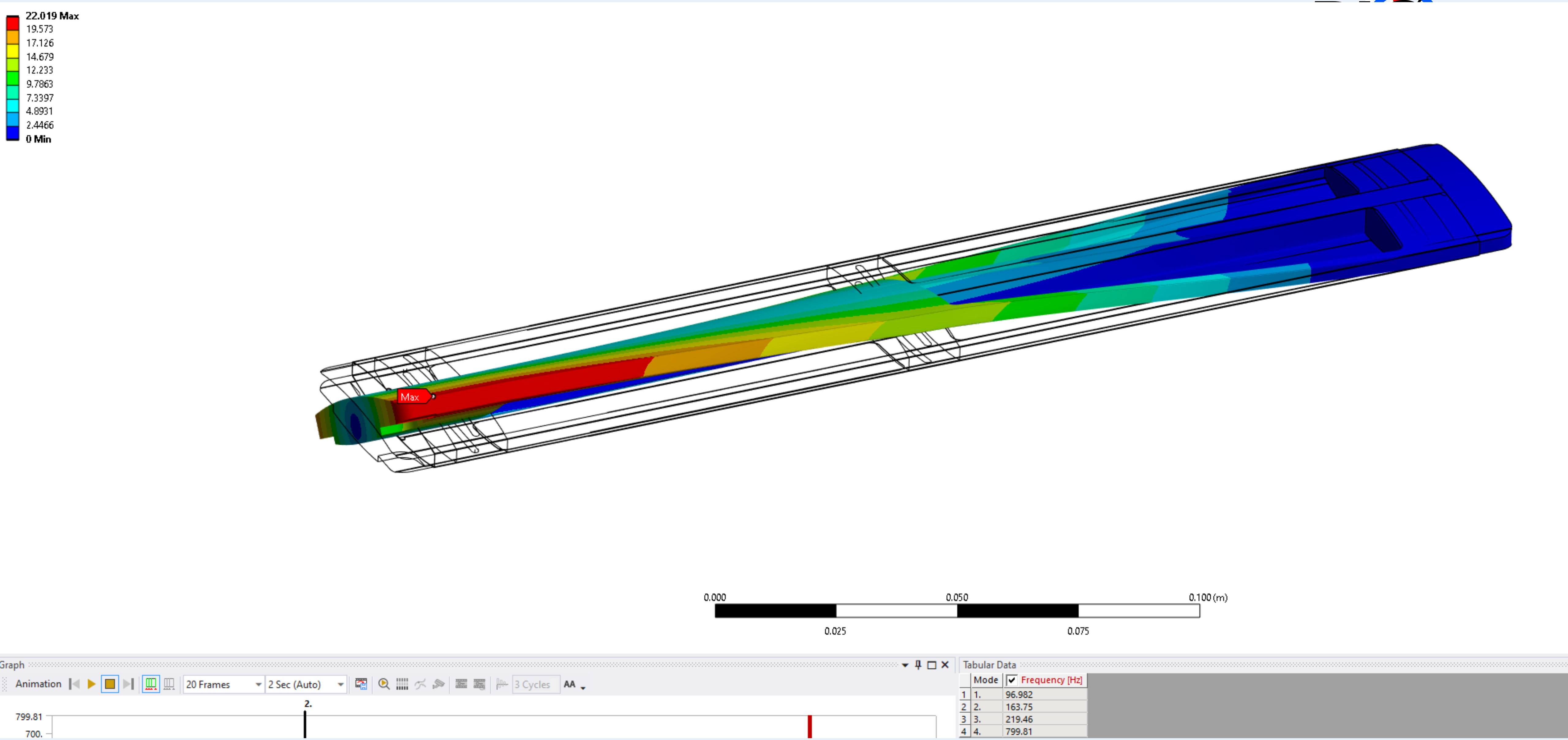


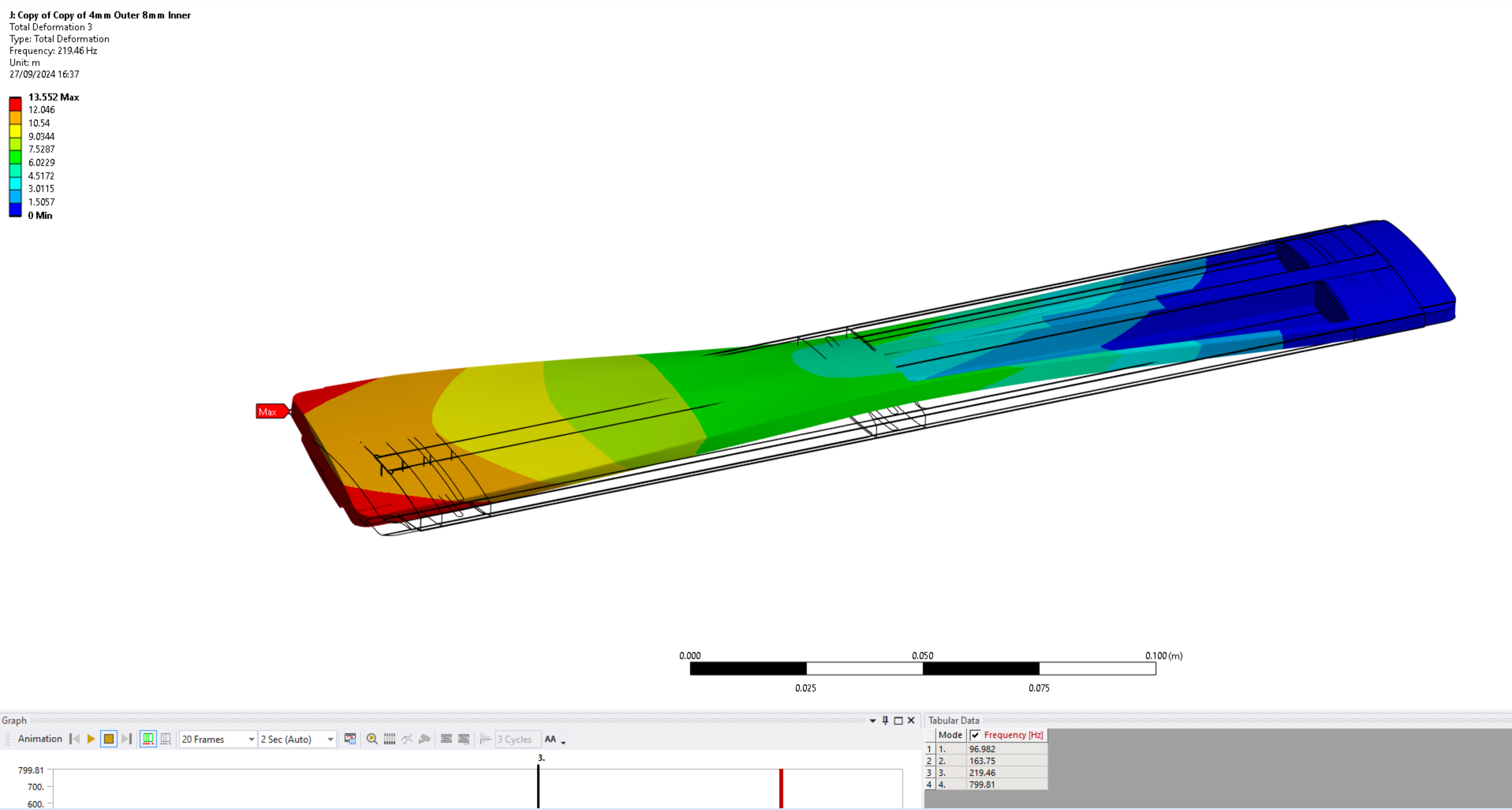





J: Copy of Copy of 4mm Outer 8mm Inner
Total Deformation
Type: Total Deformation
Frequency: 841.38 Hz
Unit: m
27/09/2024 13:03
45.049 Max
40.043
35.038
30.033
25.027
20.022
15.016
10.011
5.0054
0 Min
Max
0.000
0.050
0.100 (m)
0.025
0.075
Graph
Animation
20 Frames
2 Sec (Auto)
3 Cycles
AA
1.
888.23
Tabular Data
Mode
Frequency [Hz]
1 1. 841.38
2 2. 888.23


12.978 Max
11.536
10.094
8.6522
7.2101
5.7681
4.3261
2.8841
1.442
0 Min
Max
0.000
0.050
0.100 (m)
0.025
0.075
Graph
Animation
20 Frames
2 Sec (Auto)
3 Cycles
1.
799.81
700.
600.
Tabular Data
Mode
Frequency [Hz]
1 1. 96.982
2 2. 163.75
3 3. 219.46
4 4. 799.81


22.019 Max
19.573
17.126
14.679
12.233
9.7863
7.3397
4.8931
2.4466
0 Min
Max
0.000
0.050
0.100 (m)
0.025
0.075
Graph
Animation
20 Frames
2 Sec (Auto)
3 Cycles
AA
2.
799.81
700.
Tabular Data
Mode
Frequency [Hz]
1 1. 96.982
2 2. 163.75
3 3. 219.46
4 4. 799.81


J: Copy of Copy of 4mm Outer 8mm Inner
Total Deformation 3
Type: Total Deformation
Frequency: 219.46 Hz
Unit: m
27/09/2024 16:37
13.552 Max
12.046
10.54
9.0344
7.5287
6.0229
4.5172
3.0115
1.5057
0 Min
Max
0.000
0.050
0.100 (m)
0.025
0.075
Graph
Animation
20 Frames
2 Sec (Auto)
3 Cycles
AA
3.
799.81
700.
600.
Tabular Data
Mode
Frequency [Hz]
1 1. 96.982
2 2. 163.75
3 3. 219.46
4 4. 799.81

Future Design Work

- Current Staves have a dia 180 mm curvature
  - Curved surfaces may be difficult for wire bonding
  - FEA studies suggest curvature has minimum impact on structure stiffness
  - Future iterations may use a flat sensor/module