# Tooling Design for the Pixel Support Tube and Level One Instrument Mounts

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**Abstract**

The ATLAS project at CERN is already responsible for the discovery of fundamental particles and plans to continue its groundbreaking research with a series of upgrades. Large, thin shells made of high modulus carbon fiber provide a structure that can rigidly hold the improved pixel and strip style detectors while having a minimal density as to not interfere with a particle's trajectory. The shells are made by layering woven carbon fiber around an aluminum mandrel and cured in an autoclave. The size of these two shells is very close to the limit of what can fit in the autoclave and requires careful engineering to properly fabricate them. The PST and L1 shells will be made by breaking the tooling design into three distinct stages, layup, curing, and cantilevered, to minimize the length of the tooling. The design process will be iterative with simulations being performed in ANSYS.

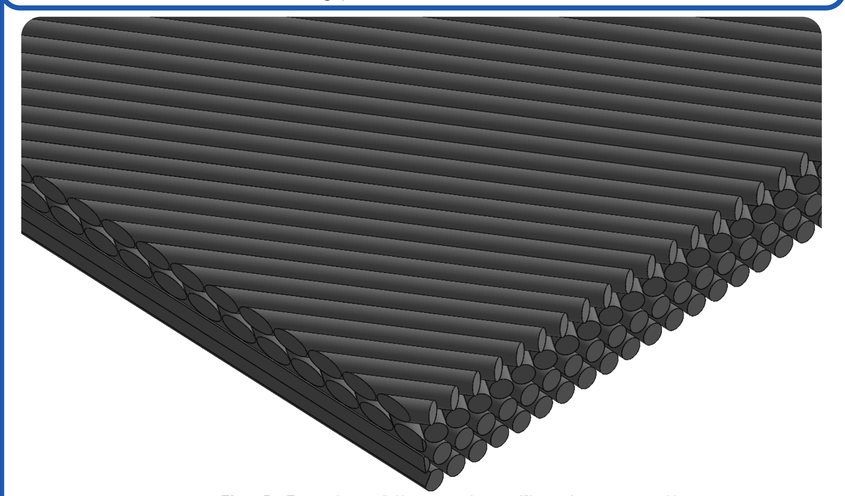

Fig. 2: Render ot the carbon tiber layup pattern

## Carbon Fiber

Eight layers of K13C2U carbon fiber in the form of unidirectional strands, pre-preg with EX-1515 epoxy, formed the PST and L1 shells. The shells are designed to be almost three meters in length and one meter in diameter, but will only be 600 microns thick. The lay-up pattern followed was [90/90/60/-60] to make a quasi-isotropic material to maximize stiffness in the radial direction while minimizing the over all thickness.

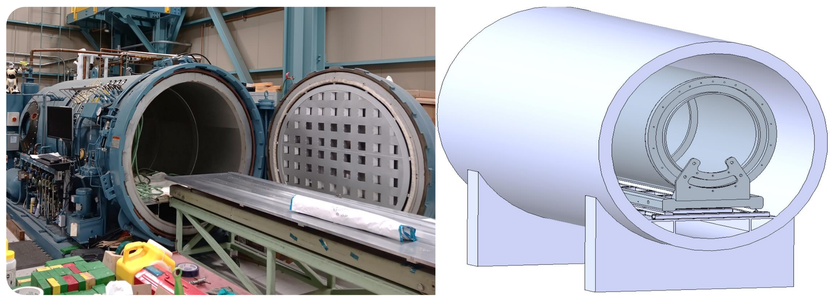

Fig. 3: 5x10 ft autoclave next to the CAD model of the autoclave

## Autoclave

An autoclave is used to cure the laid-up carbon fiber shells into their final shape. The carbon fiber is sealed in a bag around the mandrel so that a vacuum can be pulled on it while the autoclave pressurizes the outside of the bag to 5.5 atmospheres and is heated to 121 C.

The length of the LBNL Composites Shop autoclave drove the overall design for the shell tooling. Once the PST shell was in the autoclave, there would only be approximately 210 mm left on either side to design tooling. More configurable assemblies were designed to take up only a third of the length compared to previous designs.

While the aluminum mandrel will contract when its temperature is reduced, the cured shell will expand. This was compensated for by a two step CTE calculation and reducing the machined diameter of the mandrel by 2.49 mm.

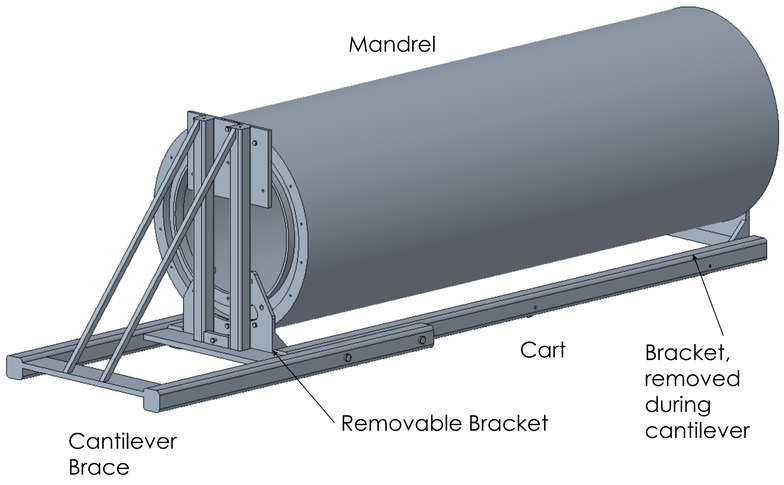


Fig.1: L1 Mandrel in the cantilevered assembly

## Hand Calculations

Before models can be significantly detailed, rough models were made to provide size and mass estimates for hand calculations. These calculations were used to verify the results obtained in ANSYS and for values ANSYS not accurately calculate.

$$\sum F_x = 0 \quad \sum F_y = 0 \quad \sum M_z = 0 \qquad \delta_{max} = \frac{\omega l^4}{8EI} \qquad \sigma = \frac{F}{A} \qquad f = \frac{1}{2\pi}\sqrt{\frac{g}{u}}$$

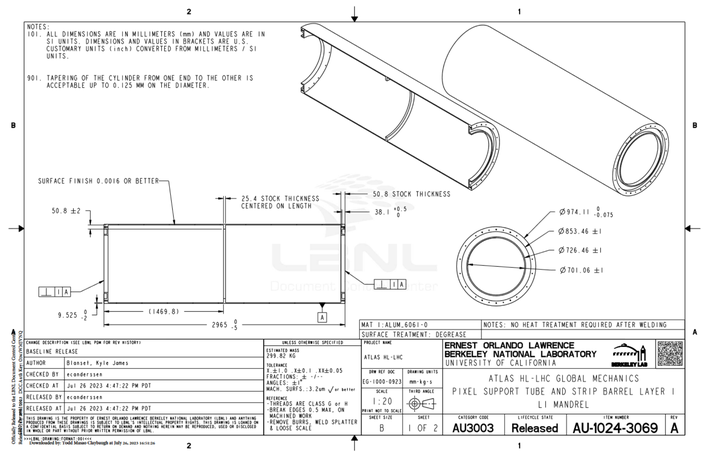

Fig. 7: Completed mandrel drawing submitted to machine shops

## Future Work

While the bulk of the design and simulation work is completed, there is still some work to be done before the PST and L1 shells are completed.

- Submit drawings of all tooling to machine shops for manufacturing.
- Assemble tooling and make shells
- Complete the design and manufacture shell stiffeners

## Conclusion

When provided with the proper tooling, carbon fiber can yield structural parts superior to most materials. This project has made significant progress in the design phase, by both proving that shells can be manufactured with the lab's equipment and providing a detailed and realistic path forward.

## Stress and deformation simulation

- Bolts were modeled with 25 mm diameter bonding zones.
- Displacement for all cart wheels zero in Z direction, and one wheel locked in all three directions.
- Normal Earth gravity applied.
- Elements were quadratic tetrahedral with a target size of 50 mm.
- Simulations ran until deformation converged with 5%.

Simulations showed that deformation would be less than 4.5 mm.

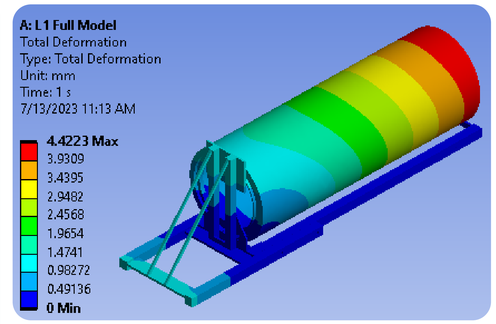


Fig. 4: L1 Cantilever assembly in ANSYS

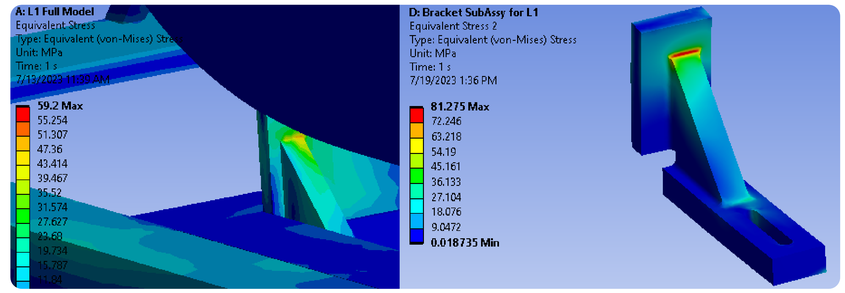


Fig. 5: Bracket on L1 cantilever assembly and sub-model

## Sub-model Stress Simulations

Analysis performed on the full cantilever assembly revealed the movable bracket had the highest stress. A sub-model analysis was performed on just the bracket. A significantly more realistic result was obtained using this method and the computation time was still reduced to a quarter of it's original time.

- Results from full assembly were imported into a smaller model.
- Target mesh size reduced from 50 mm to 5 mm.
- Weld filets were added.
- Convergence was on stress, not deformation.

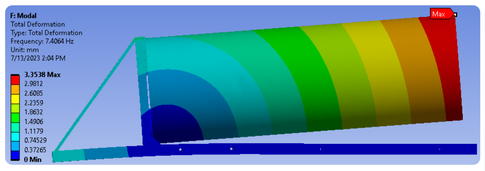


Fig. 6: L1 modal simulation

## Modal Simulations

Modal analysis in ANSYS provided a measure of the cantilever assembly's stability by finding it's natural frequency. Results were between 8.5 and 7.4 Hz. ANSYS results very closely matched hand calculations done with estimated deflections of the mandrel's end.

## Acknowledgments

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