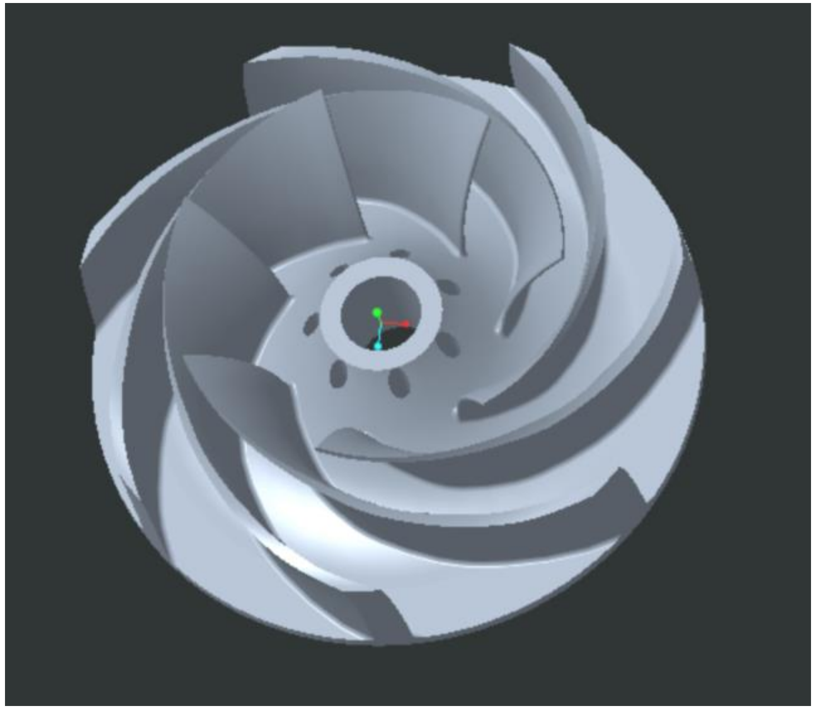


Distortion and residual stress simulation of complex AM parts

P. Michaleris*, E. Denlinger*, G. Adams**, & E. Pierson**

2023 TechConnect World Innovation Conference

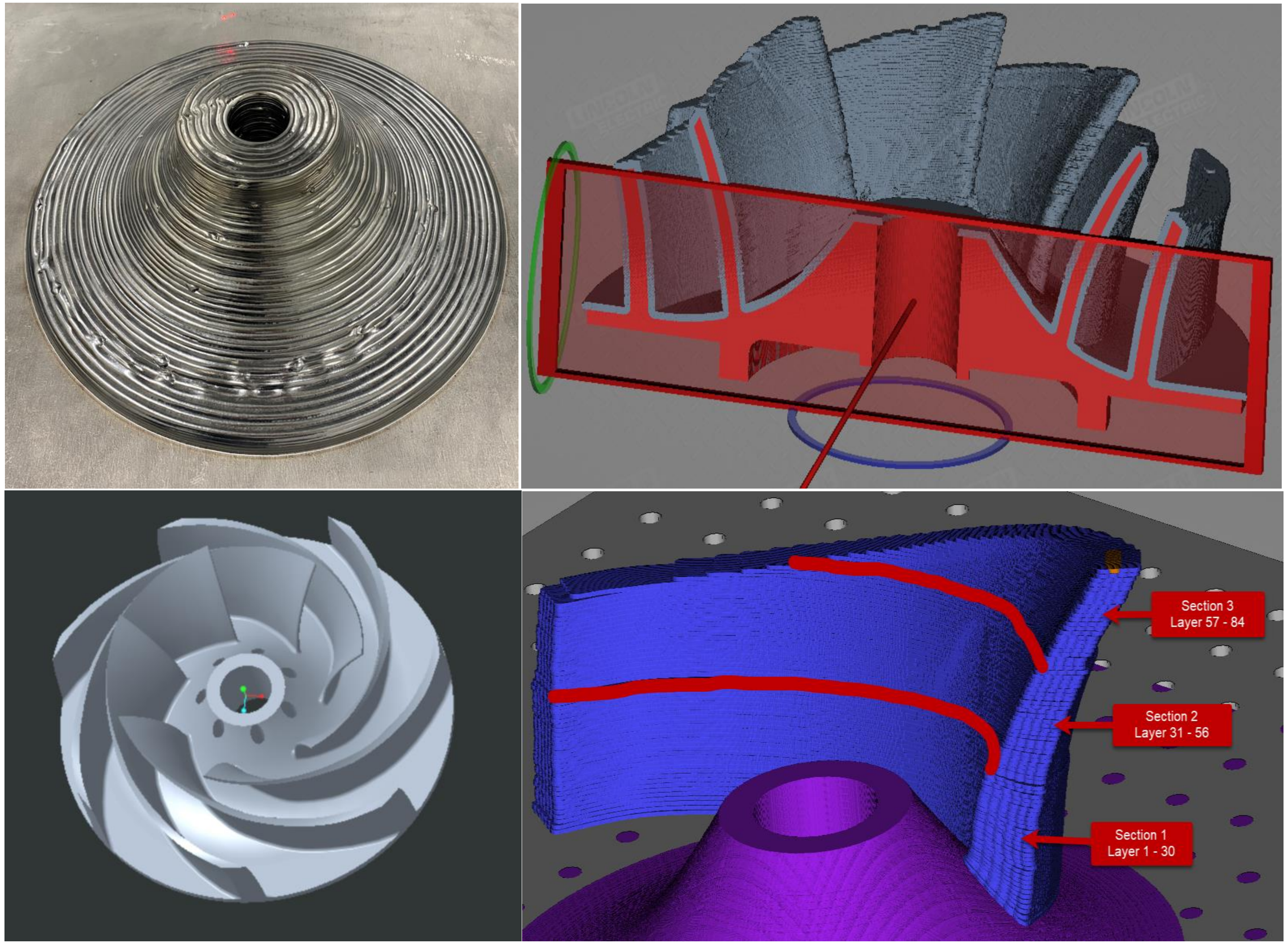
*PanOptimization **Lockheed Martin

P

LOCKHEED MARTIN

America Makes 1113: ONR Quality Made Program

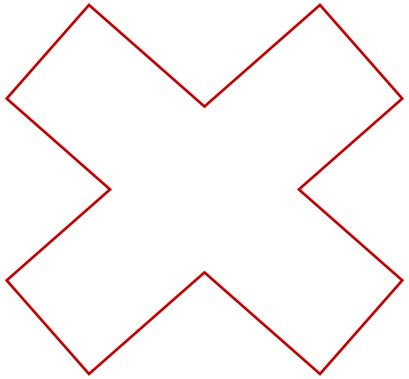
- "The program objective is to define a framework that couples modeling tools, in-situ process measurements, real-time closed-loop control, and machine learning to meet performance requirements for AM parts"
- Laser hot-wire directed energy deposition (DED) of Ti-6Al-4V
- Impeller experiences cracking at the interface of the vanes and the build plate



PanOptimization offers software licensing and consulting services for AM process modeling

- Primarily focused on FEA simulation/optimization of large and/or complex AM parts
- Part-scale simulation approach is applicable to both LPBF and DED processes
- Company founded in 2022

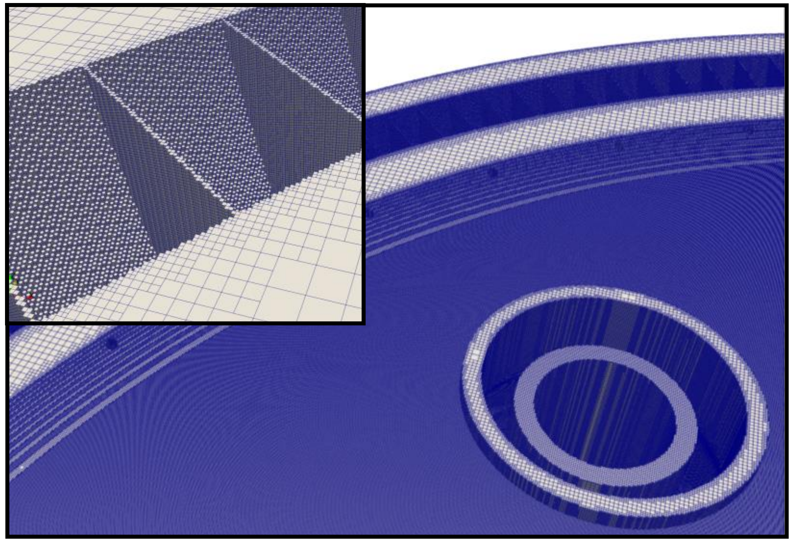
PanX mesher dramatically reduces mesh size and consumes minimal RAM



Uniform voxel mesh:

Nodes = ~6B

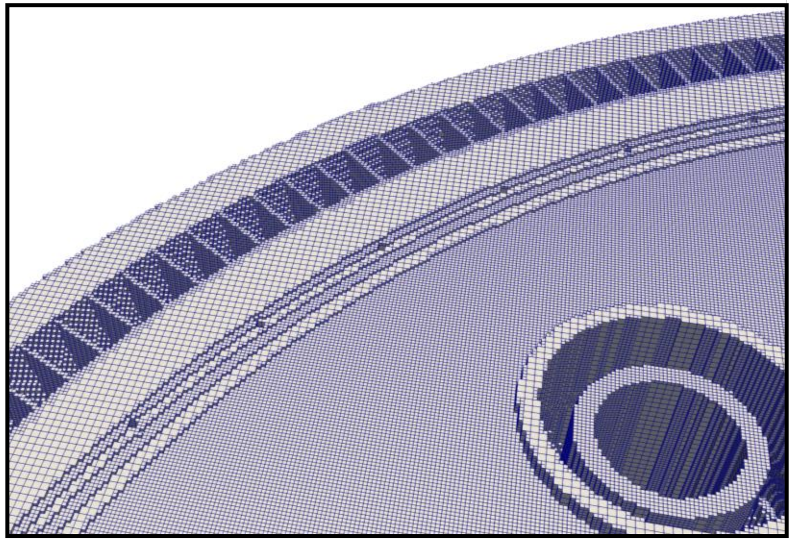
Solve time = impossible



Traditional adaptive mesh:

Nodes = ~60M

Solve time = impractical/impossible



PanX mesher:

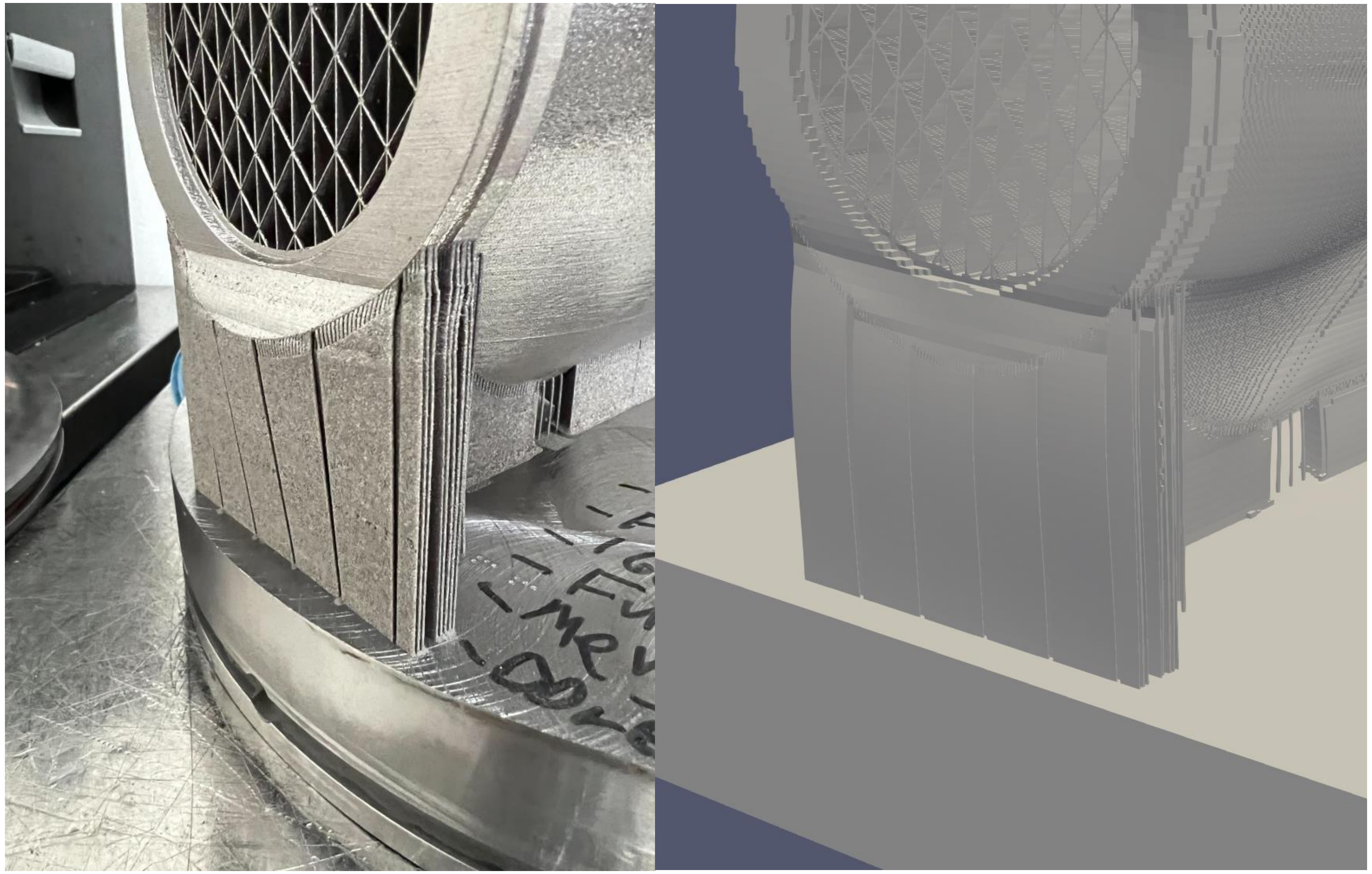
Nodes = 3.4M

Solve time = 1.5 hrs (48 cores)

When combined, the PanX architecture and mesher allow for extremely complex geometries to be solved layer-by-layer

Heat Exchanger example

- Highly parallelized and vectorized code improves computational speed
- Hybrid OMP-MPI architecture allows for running efficiently on anything from a laptop to a cluster
- 76M equations
- 9hr runtime (48 cores)



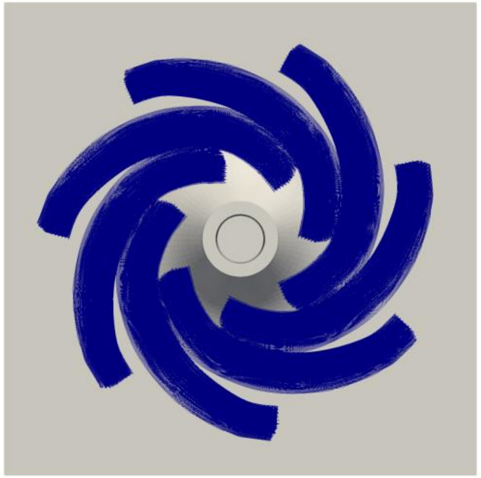
The model is setup to run four different deposition cases for the impeller

Case 1: Baseline

Case 2: Fillet

Case 3: Unclamped

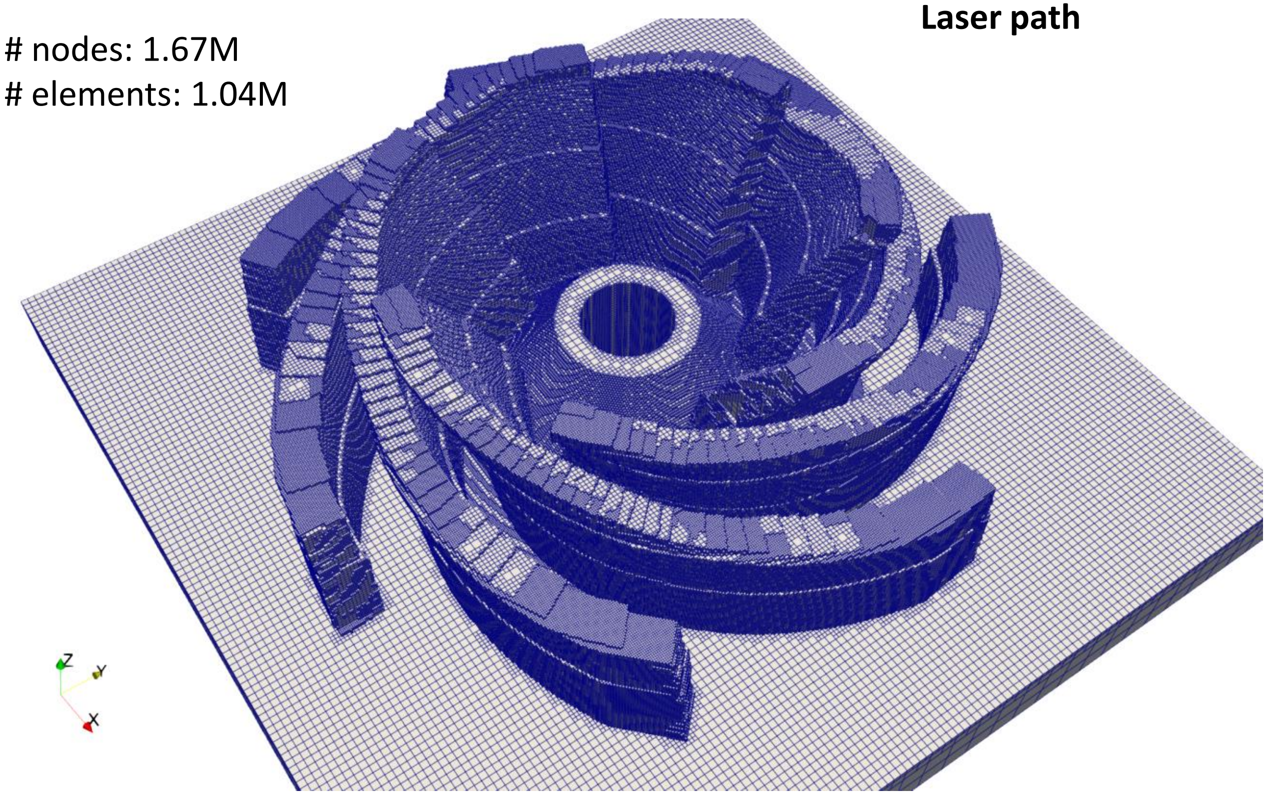
Case 4: Heat-treated

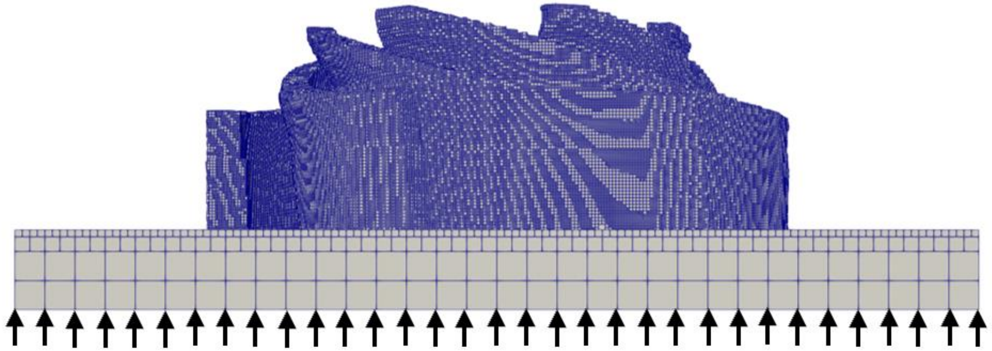


Laser path

Case 1 FEA mesh:

nodes: 1.67M
elements: 1.04M





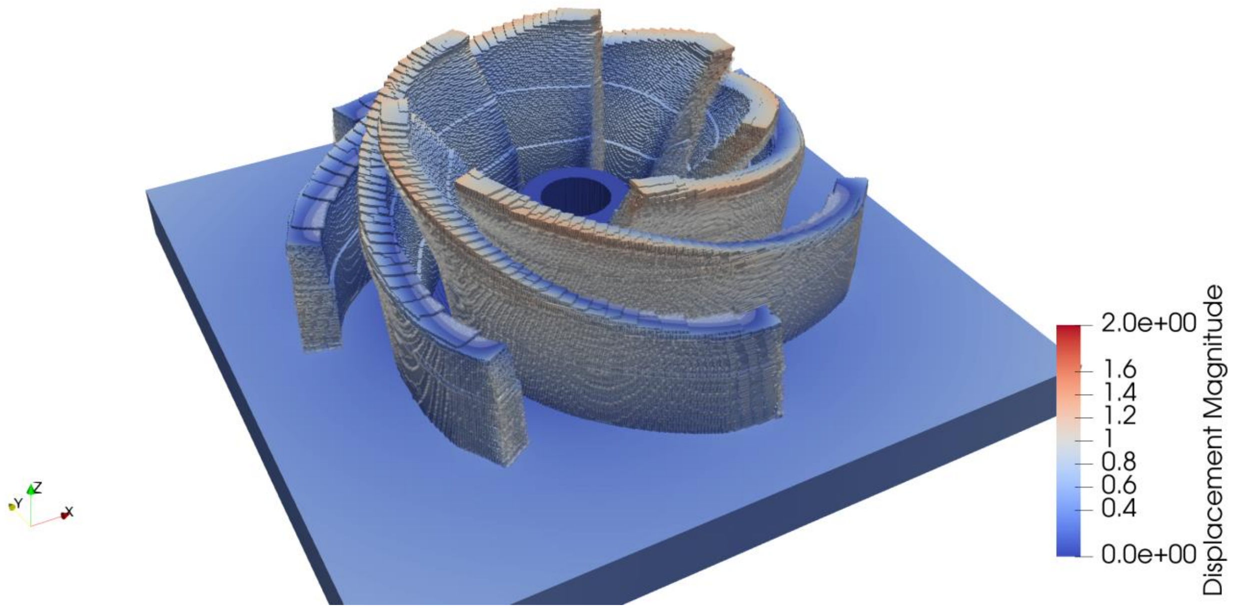
Case 1 BCs

The model is used to calculate the mechanical response of each case

Case 1 (Baseline)

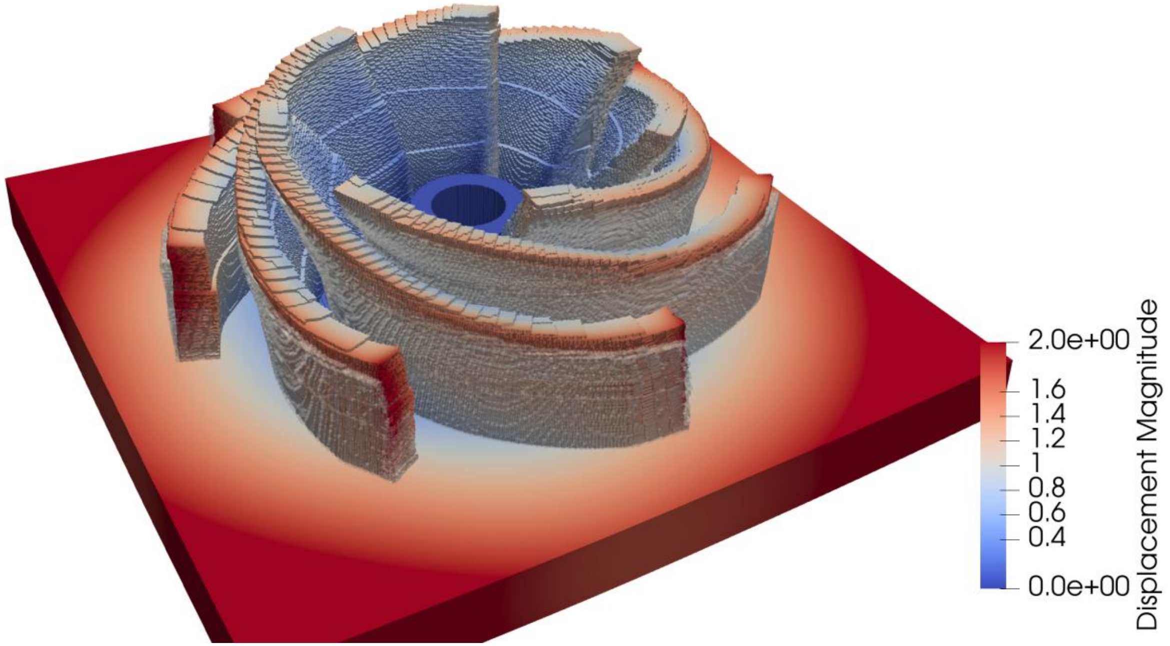
Distortion magnitude (10x)

- Runtime: 30 mins 48 sec (48 core cpu)
- Memory: 19.9 GB



Before clamp release

u = 1.3 mm



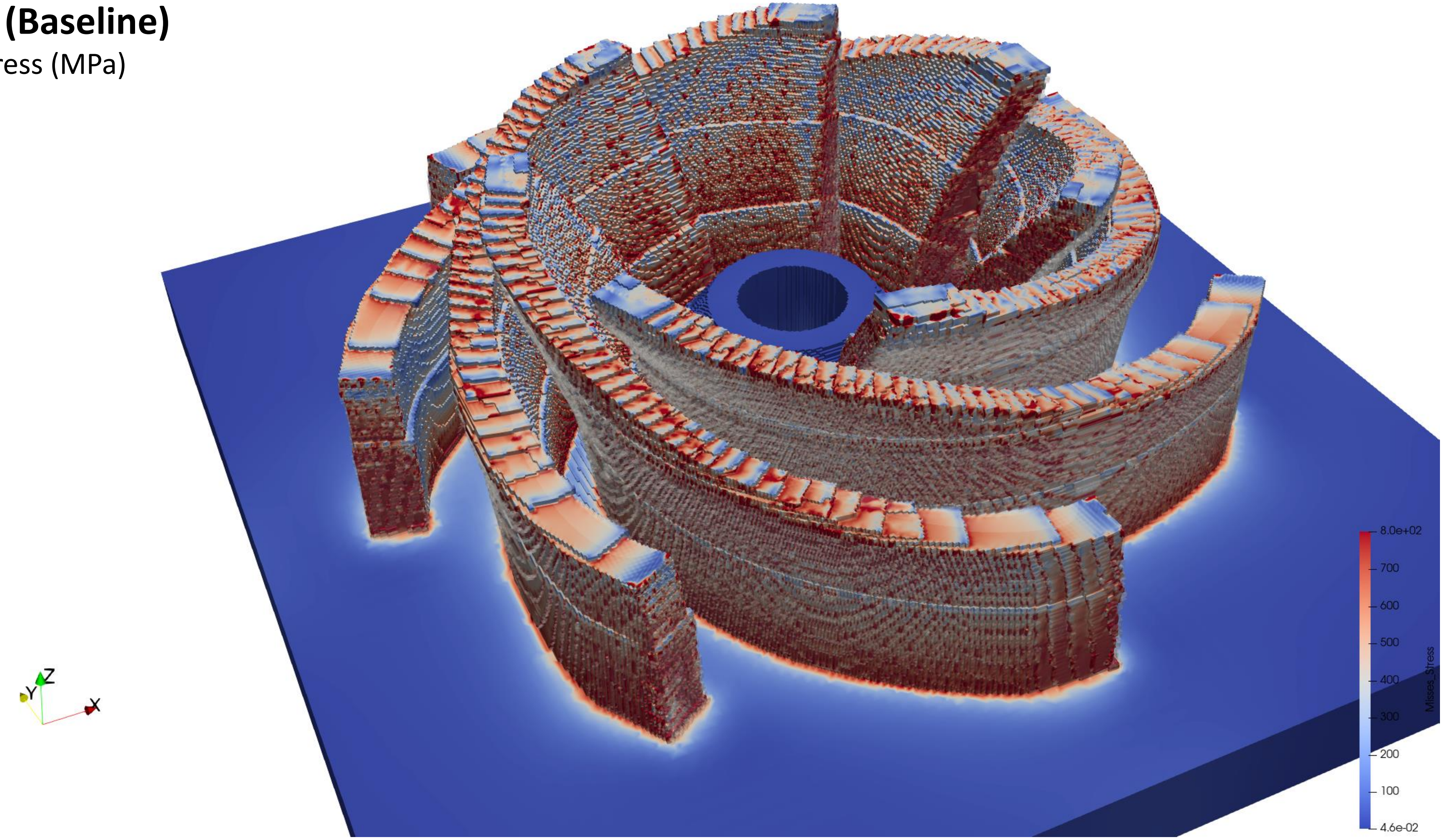
After clamp release

u = 2.9 mm

High residual stress builds up at the interface of the vanes and the build plate

Case 1 (Baseline)

Mises stress (MPa)

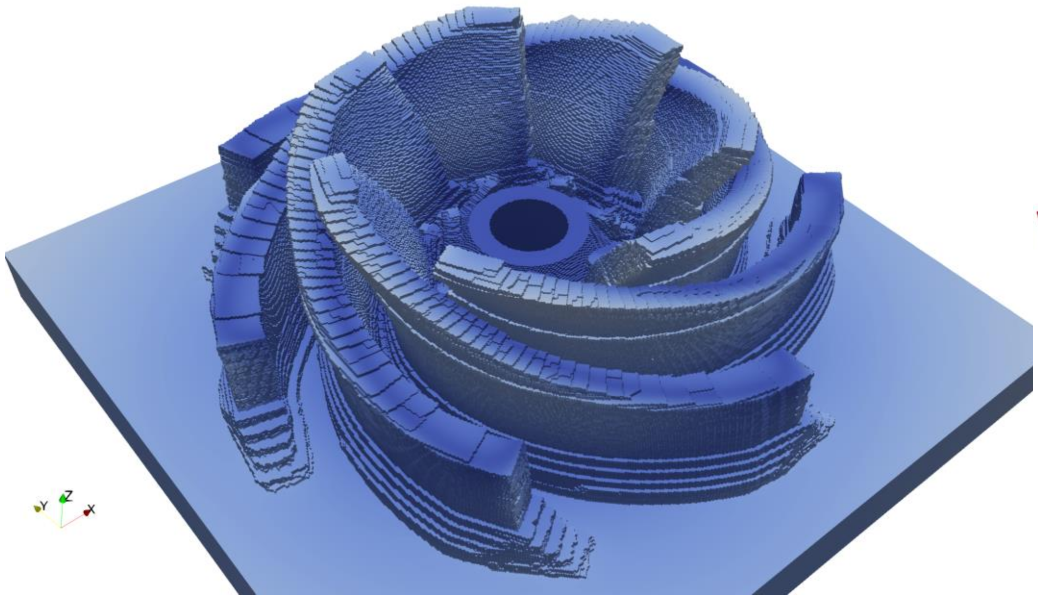


Case 2 (Fillet) adds material to the vanes to form a fillet at the interface of the vanes and the build plate

Case 2 (Fillet)

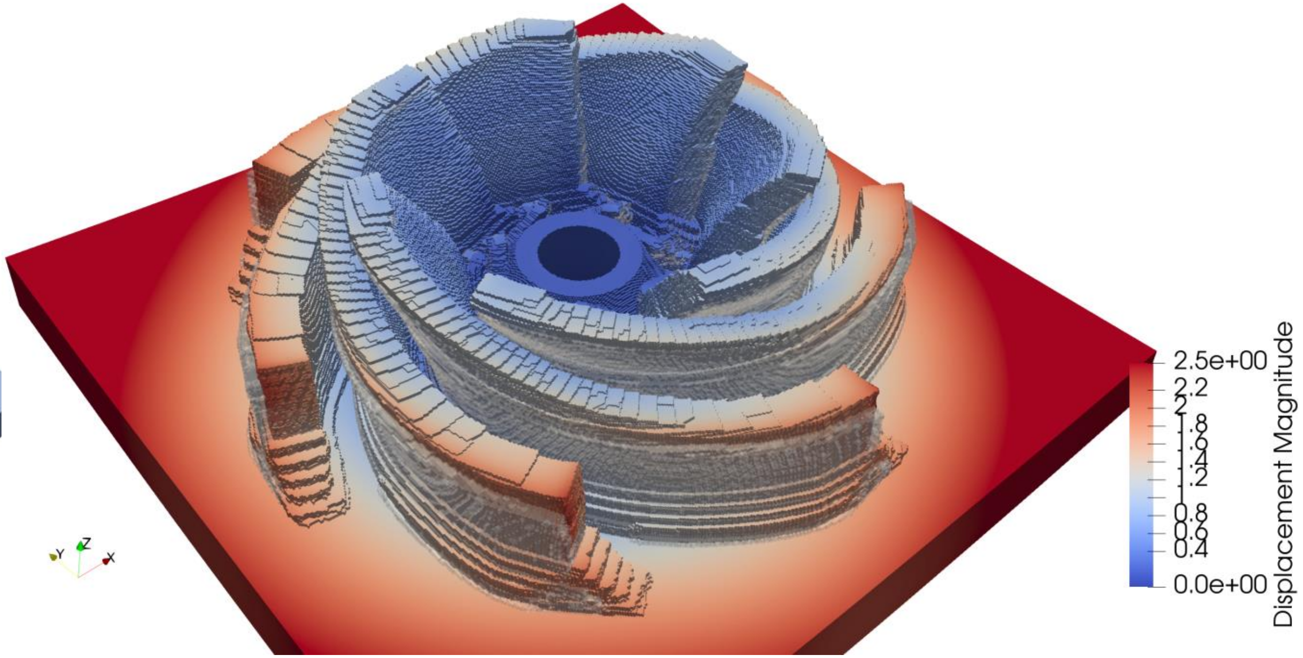
Distortion magnitude (10x)

- Runtime: 40 mins 17 sec (48 core cpu)
- Memory: 23.0 GB



Before clamp release

u = 1.0 mm

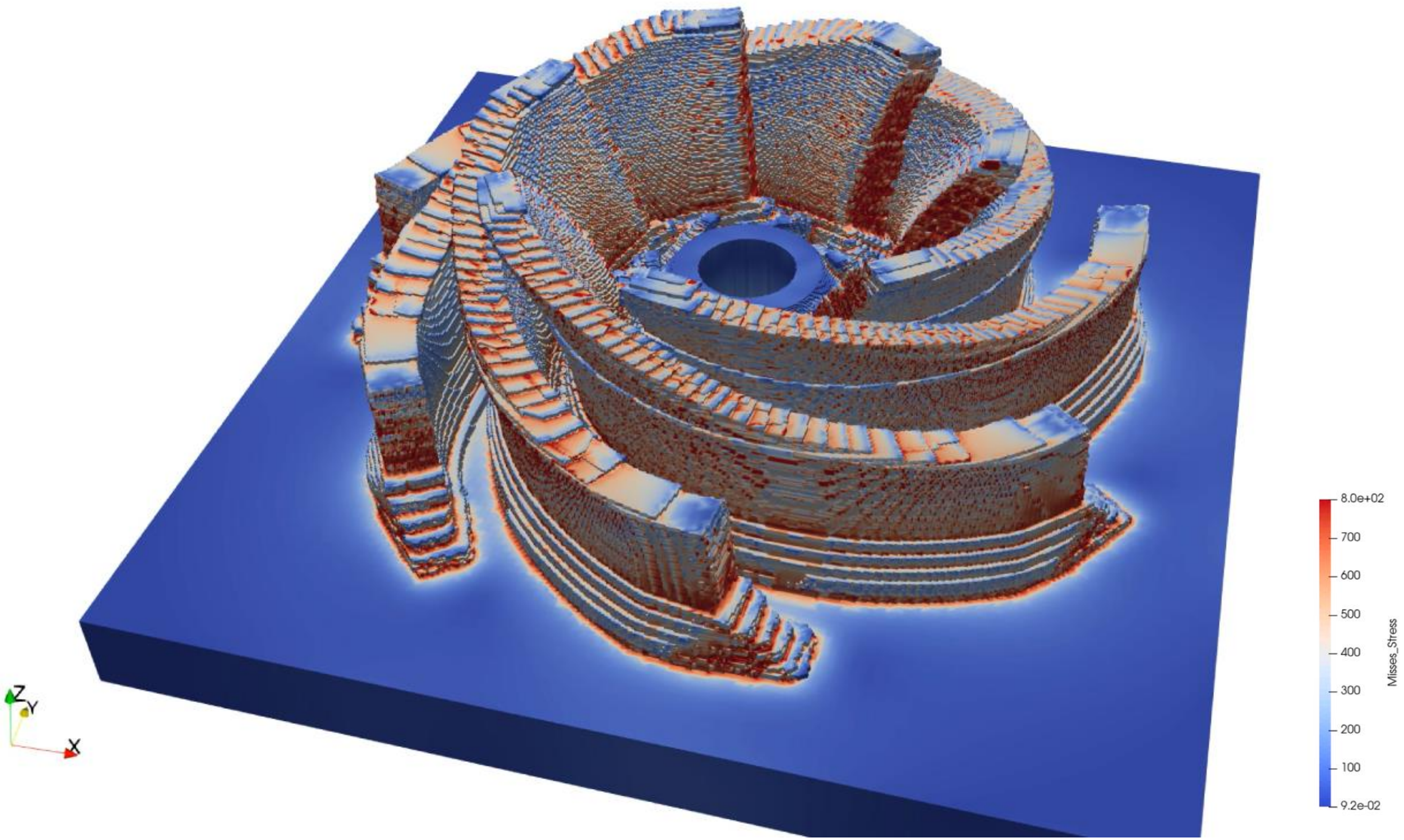


After clamp release

u = 3.8 mm

The maximum residual stress at the interface is reduced compared with the baseline

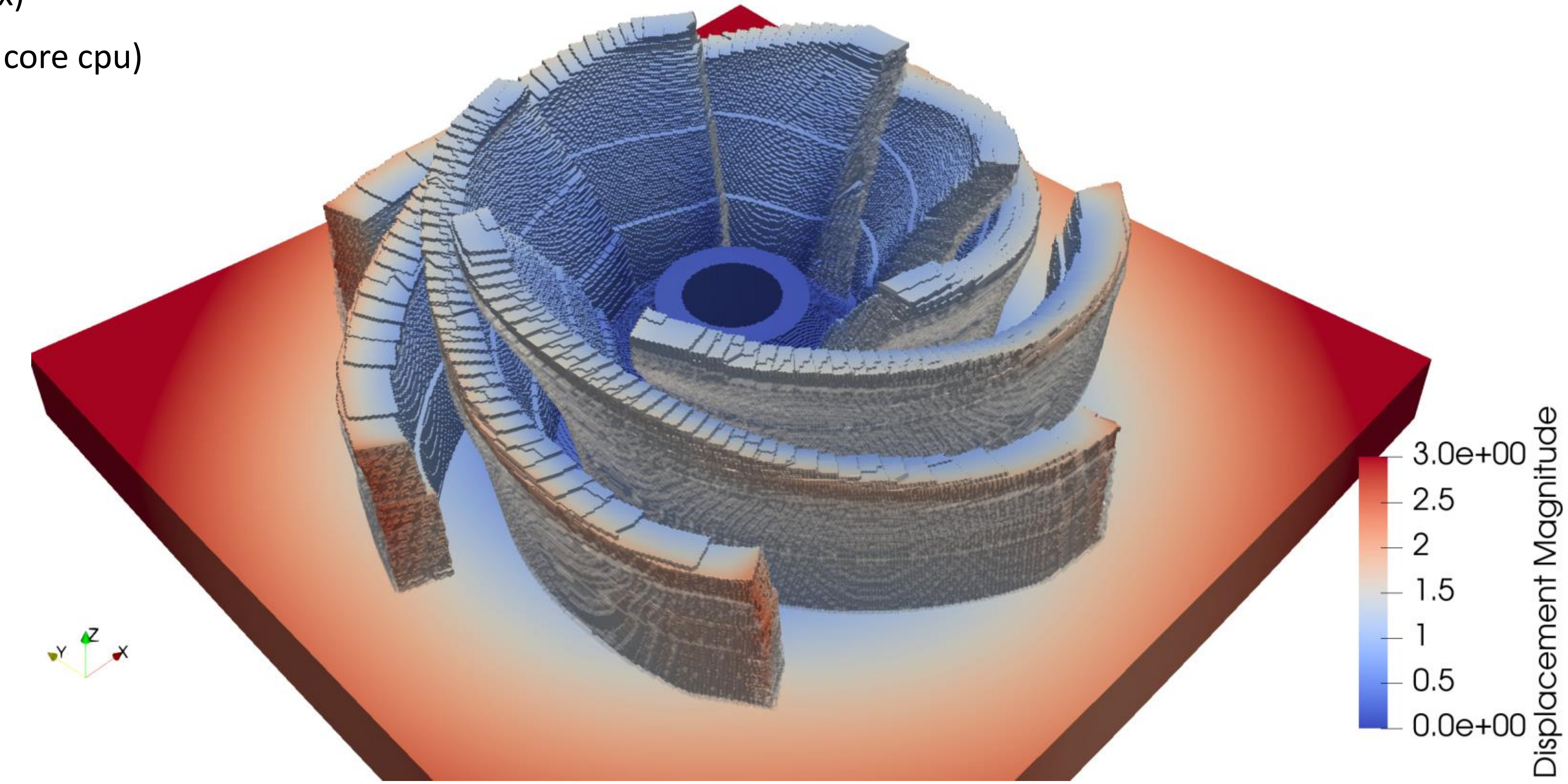
Case 2 (Fillet)
Mises stress (MPa)



Case 3 (Unclampled) removes the fixturing from the simulation

Case 3 (Unclamped)
Distortion magnitude (10x)

- Runtime: 35mins (48 core cpu)
- Memory: 19.3 GB

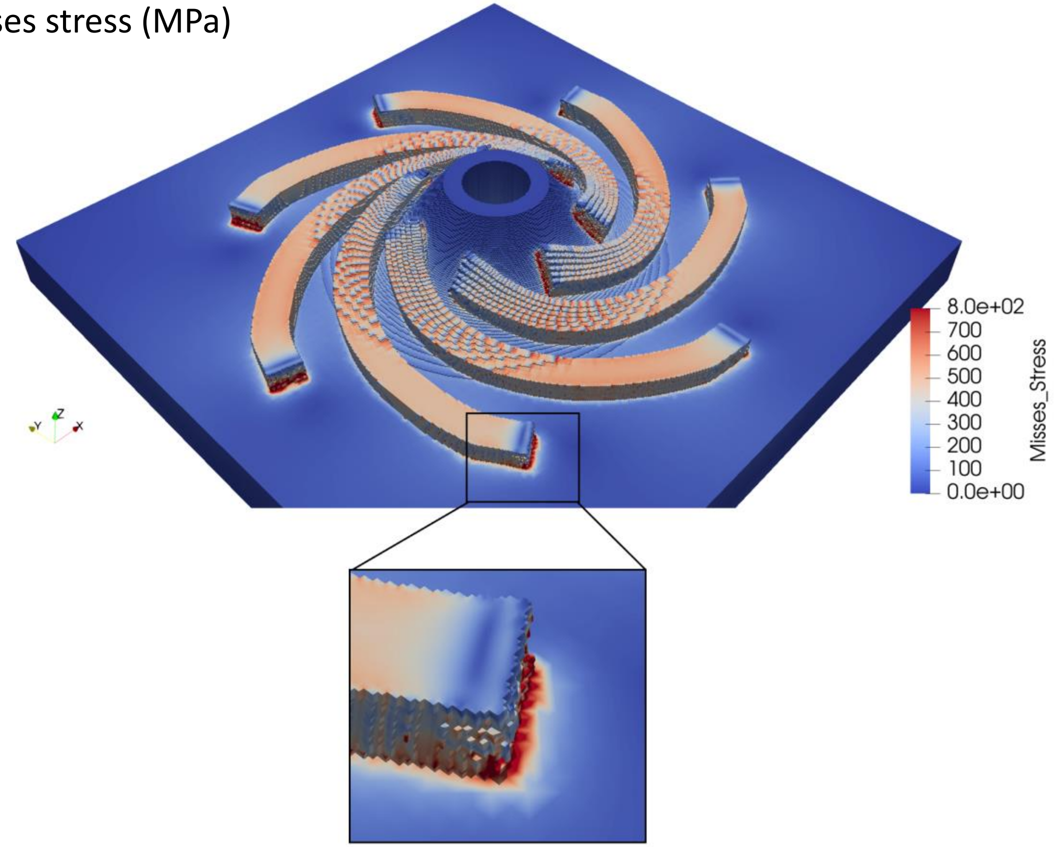


u = 4 mm

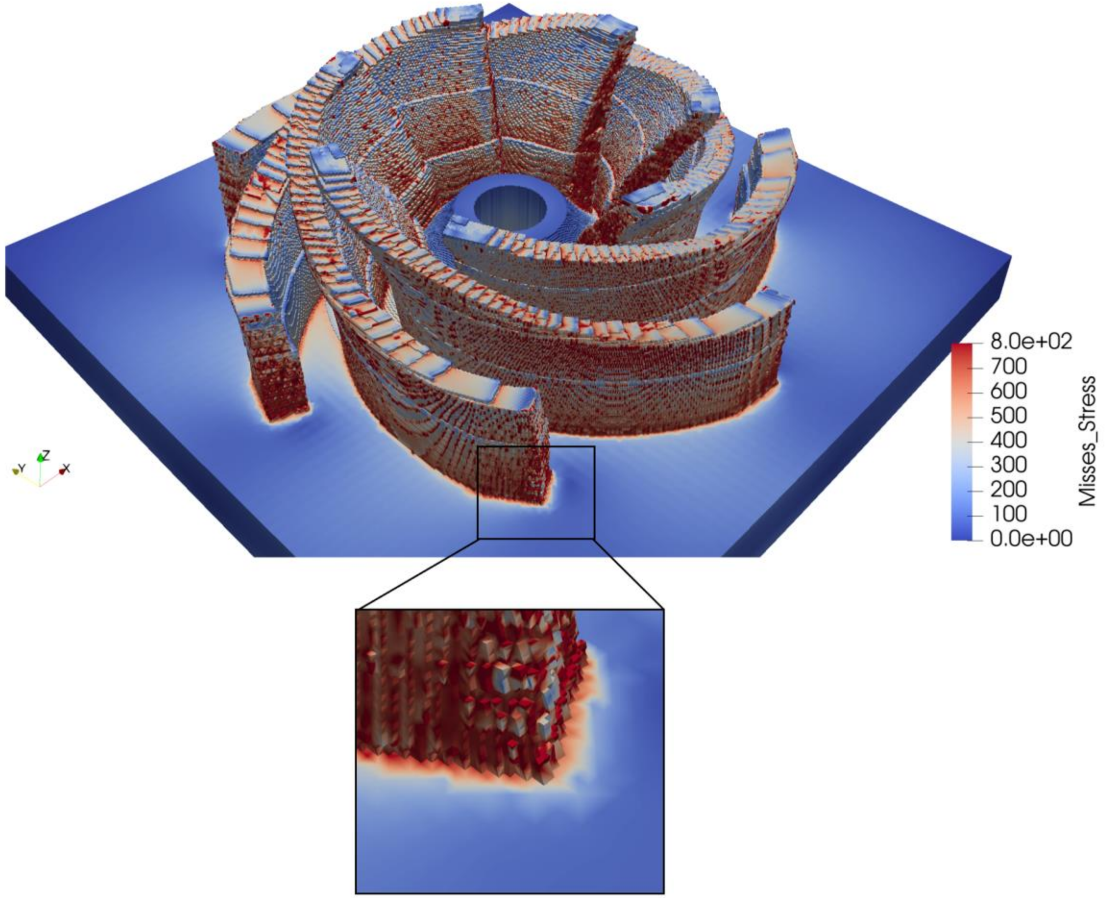
Case 3 (Unclamped) maximum Mises stress at the interface is close to the baseline

Case 3 (Unclamped)

Mises stress (MPa)



Layer 10



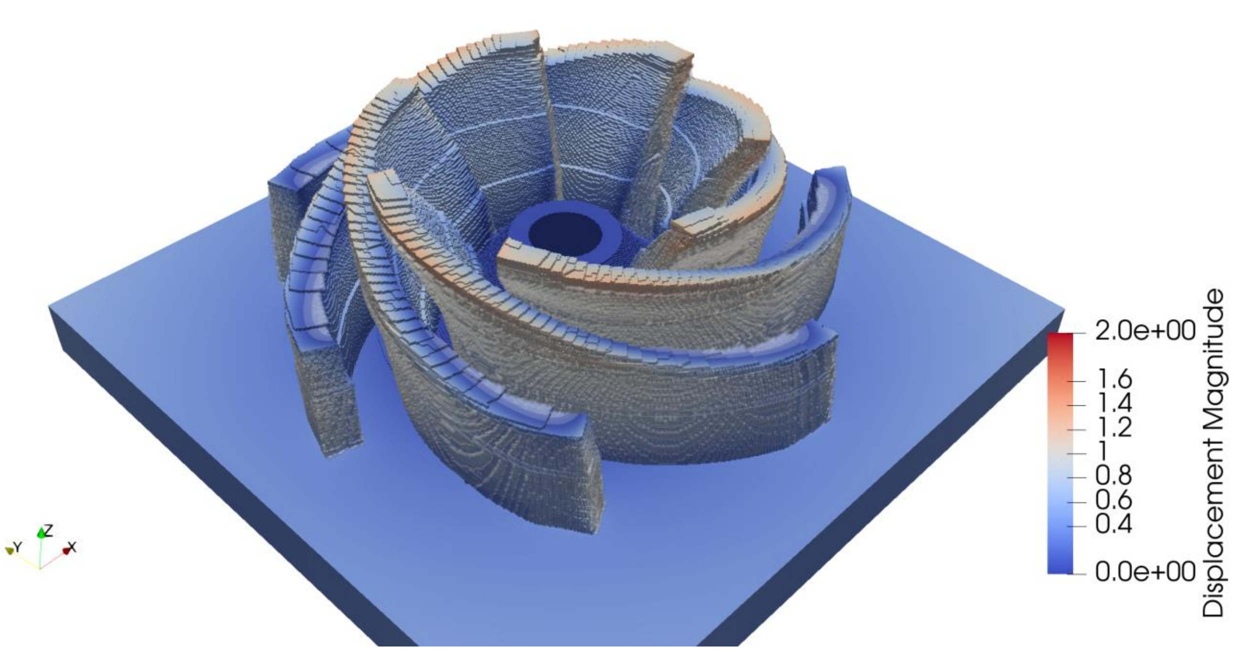
After deposition

Case 4 (Heat-treated) adds a heat-treatment step after 7 layers of deposition

Case 4 (Heat-treated)

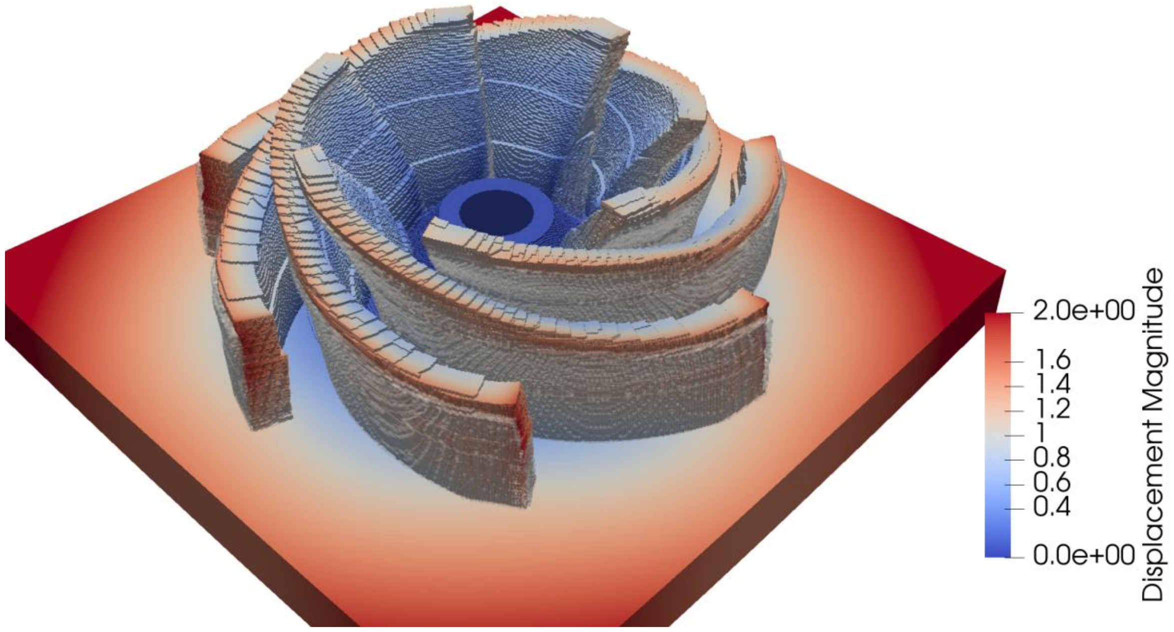
Distortion magnitude (10x)

- Runtime: 35mins 3s (48 core cpu)
- Memory: 19.7 GB



Before clamp release

u = 1.3 mm



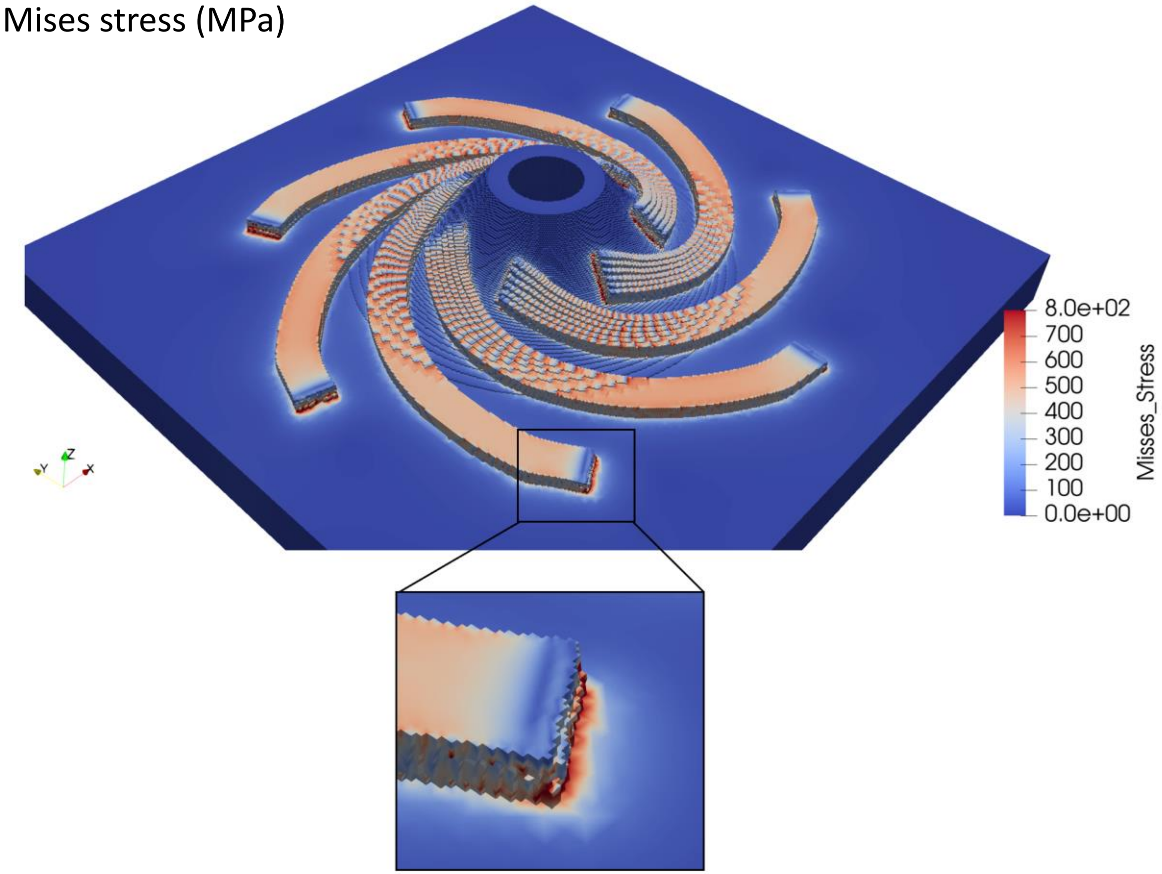
After clamp release

u =2.5mm

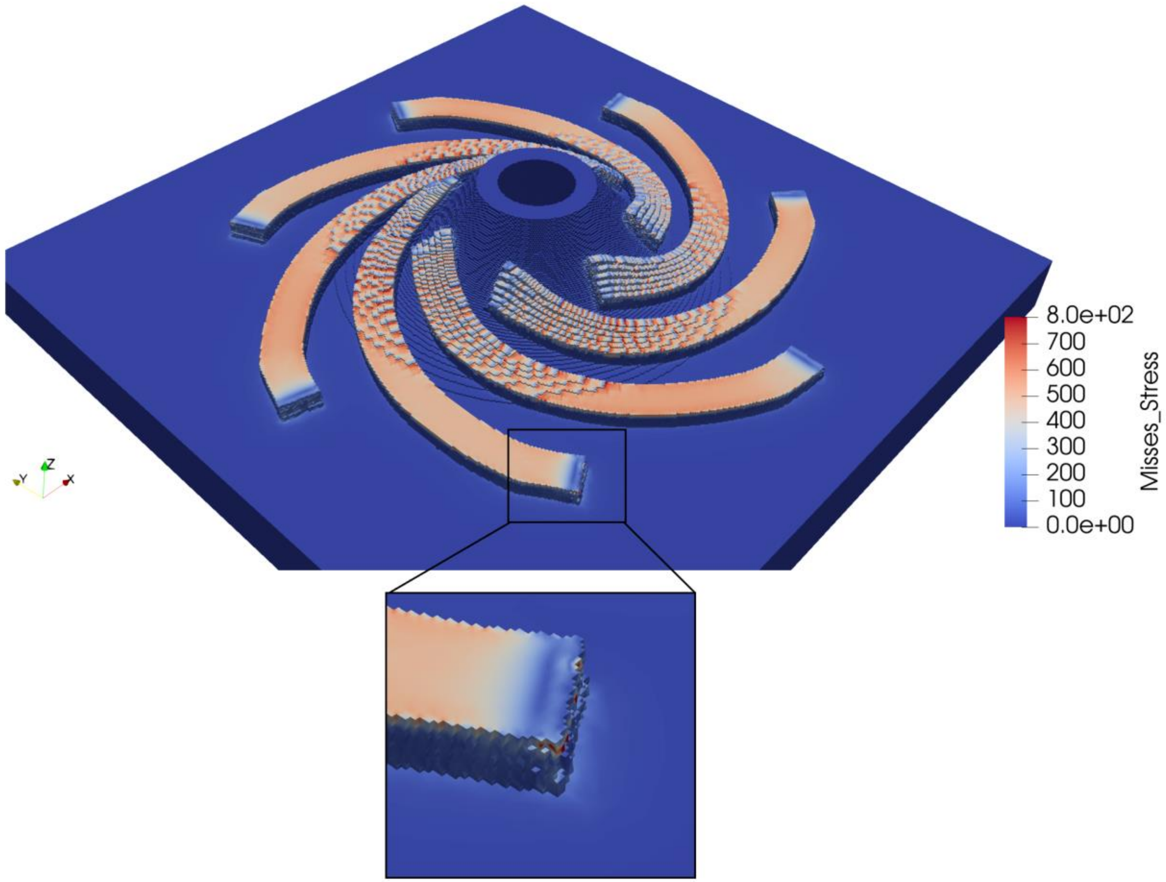
Heat-treatment substantially reduces residual stress at the interface

Case 4 (Heat-treated)

Mises stress (MPa)

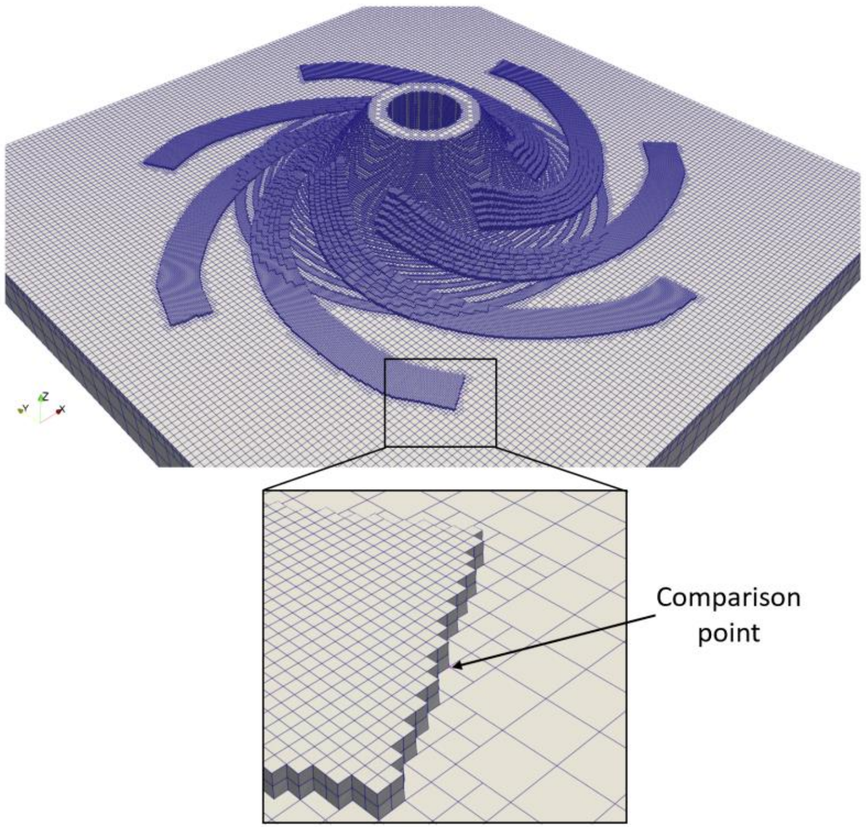


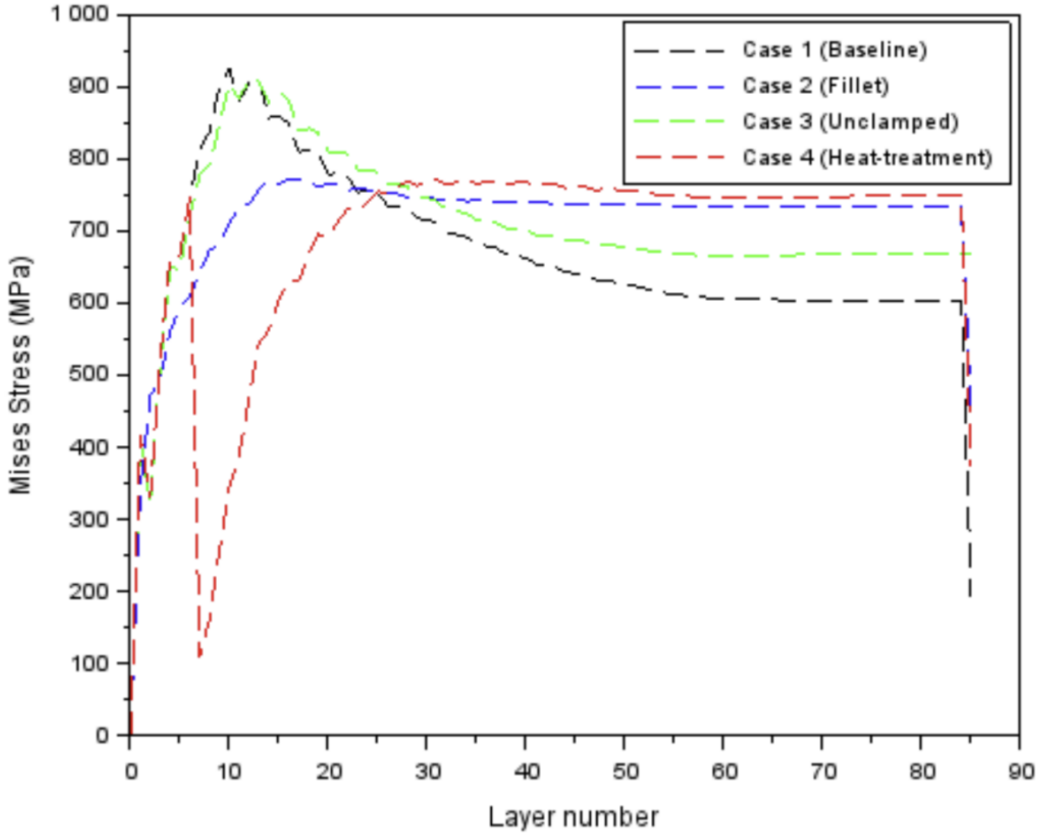
Layer 6



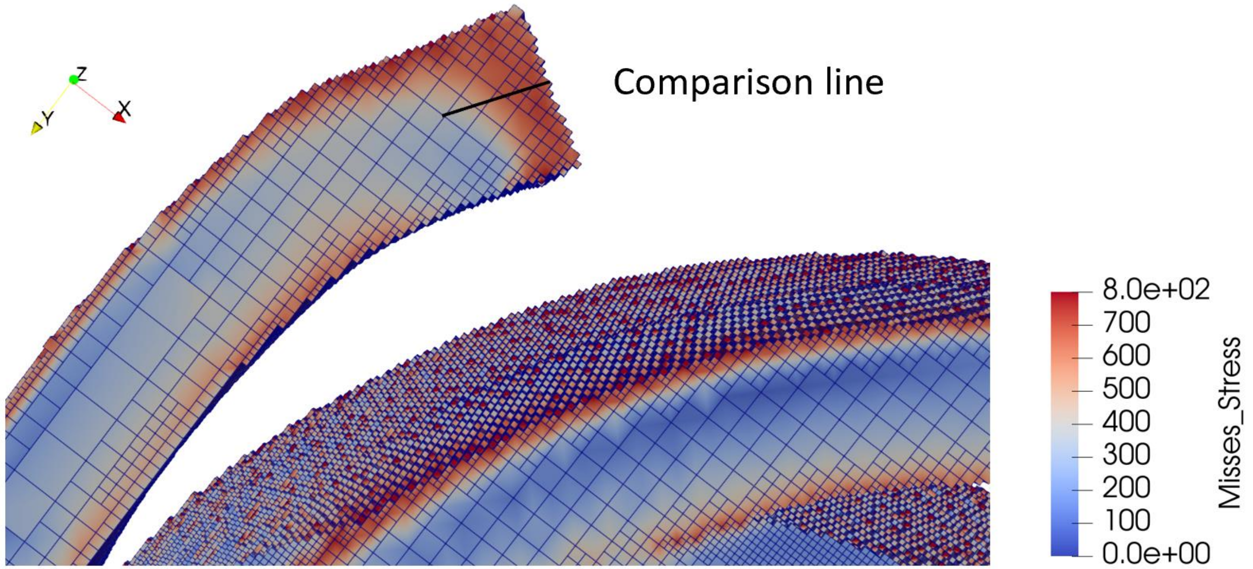
Layer 7

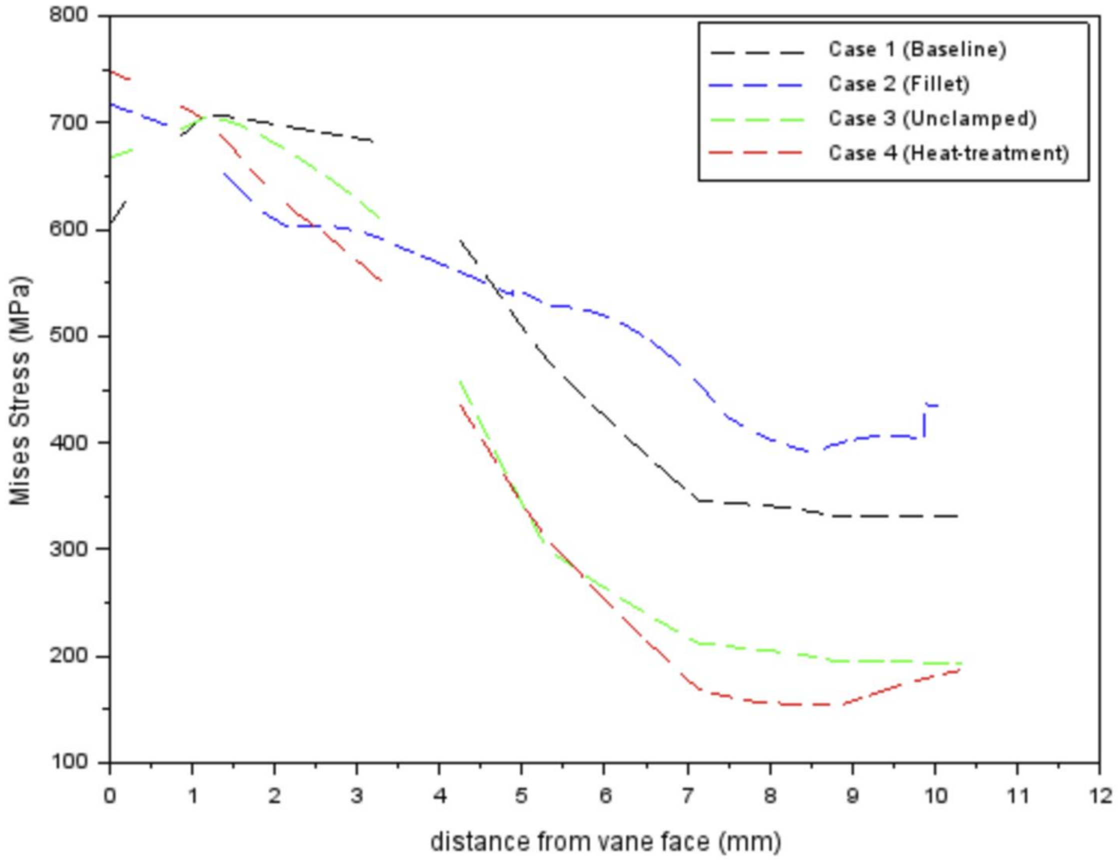
Differences in residual stress evolution over time are seen in each case



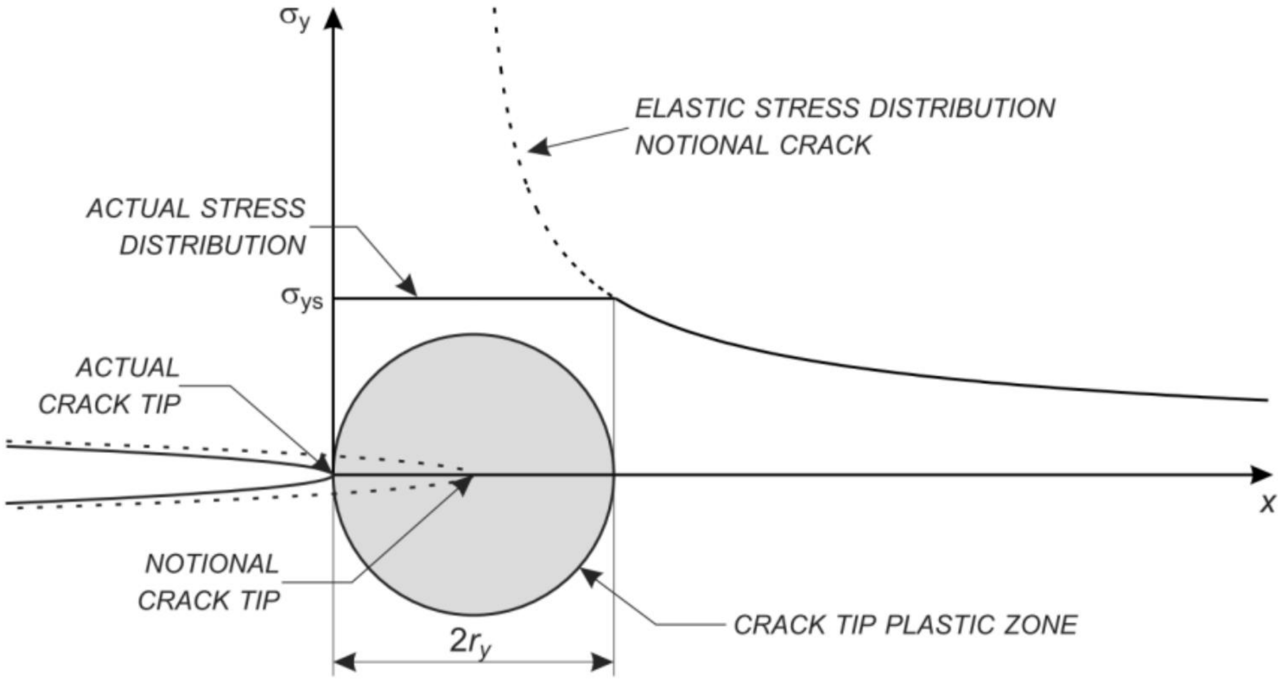


A J-Integral based approach should give a better indication of cracking risk





More experimental data will be needed to assess the suitability of fracture prediction criteria



Conclusions

- Adding fillets or performing a heat-treatment was successful in reducing the maximum Mises stress at the interface of the vane and the build plate

- Max Mises stress is not be the best indicator of crack propagation, most likely a J-integral based approach will be the solution

Contact us: **panoptimization.com**

Questions?