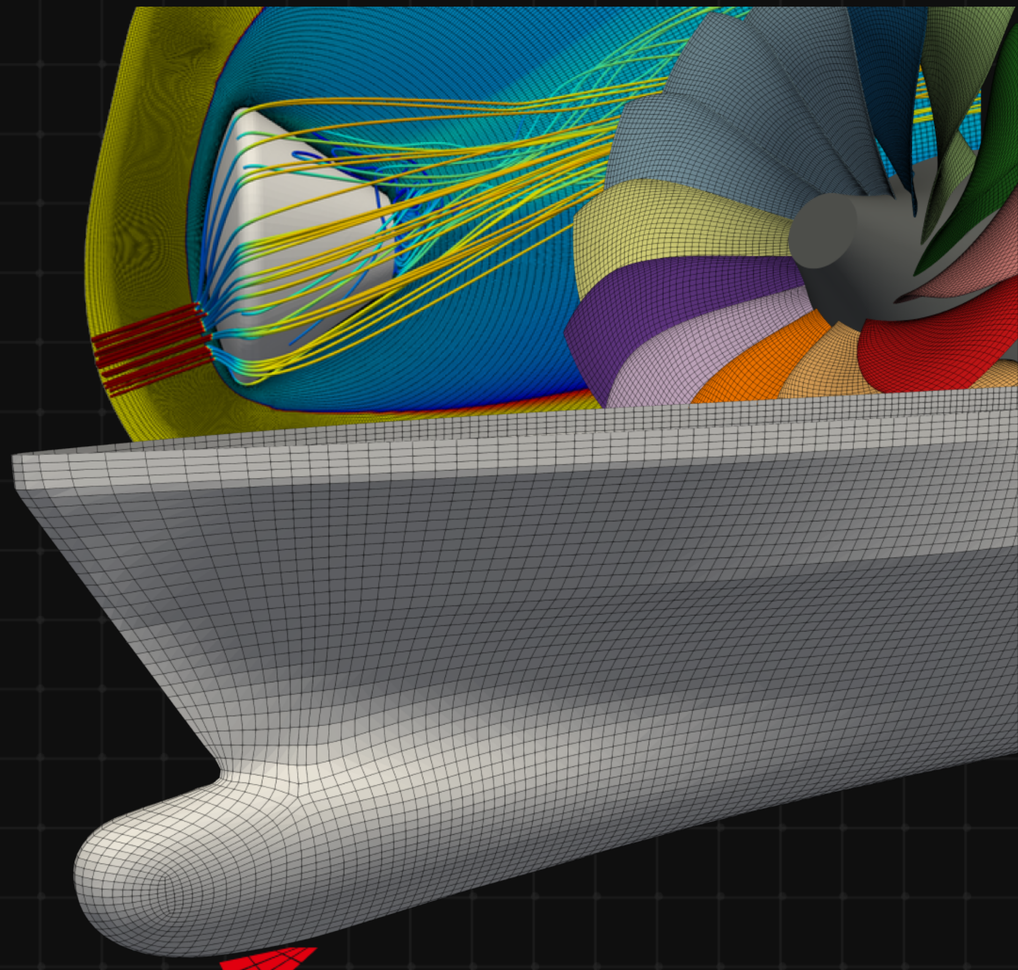
Automated Multi-block Deformation for Design Variants Using GridPro and CAESES



Colloborators :

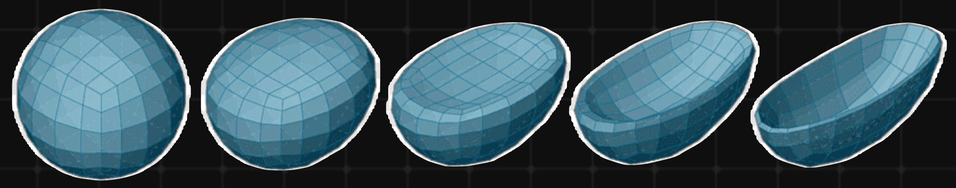
- Pratik , GridPro
- Vijay Sudharsanam, GridPro
- Carl Benz , Friendship Systems

Presenter : Samuel James

Topology based Grid Generator

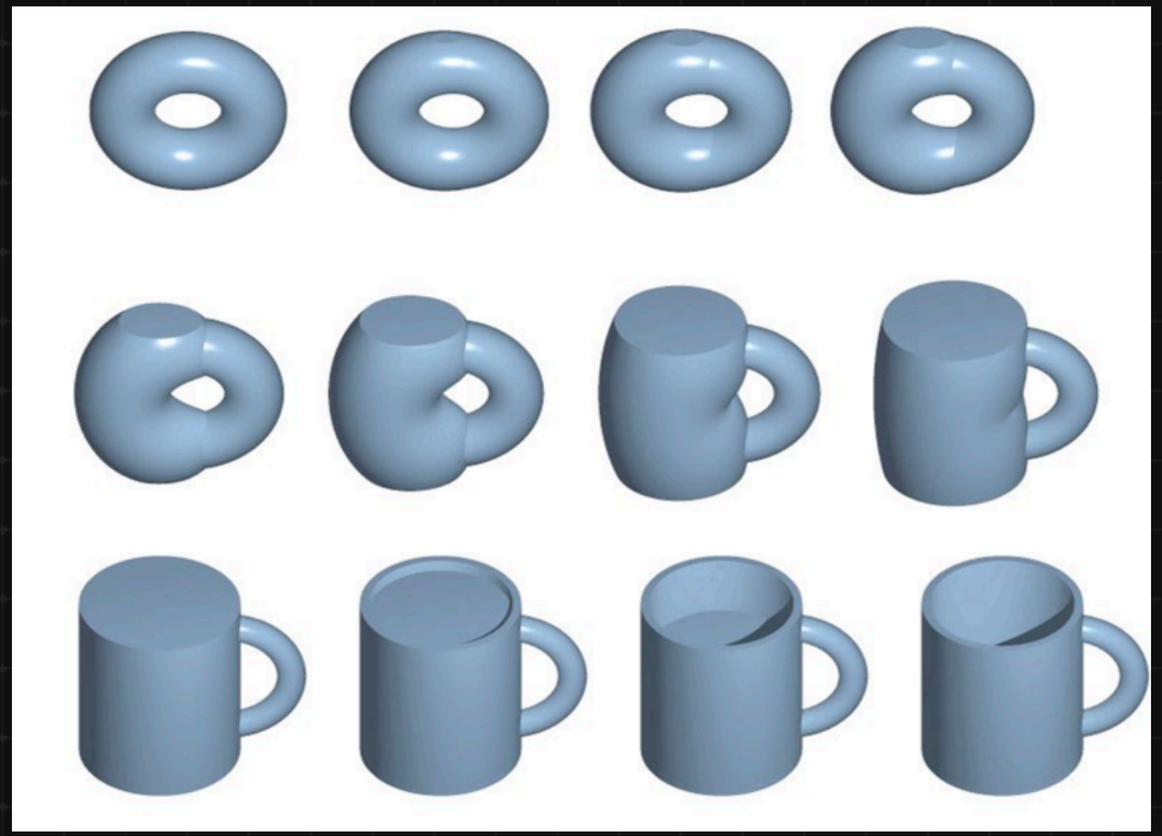
Geometry Topology

- In mathematics, topology is concerned with the properties of a geometric object that are preserved under continuous deformations, such as **stretching**, **twisting**, **crumpling**, and **bending**; that is, without closing holes, opening holes, tearing, gluing, or passing through itself.



Deformation of a Sphere to a Bowl

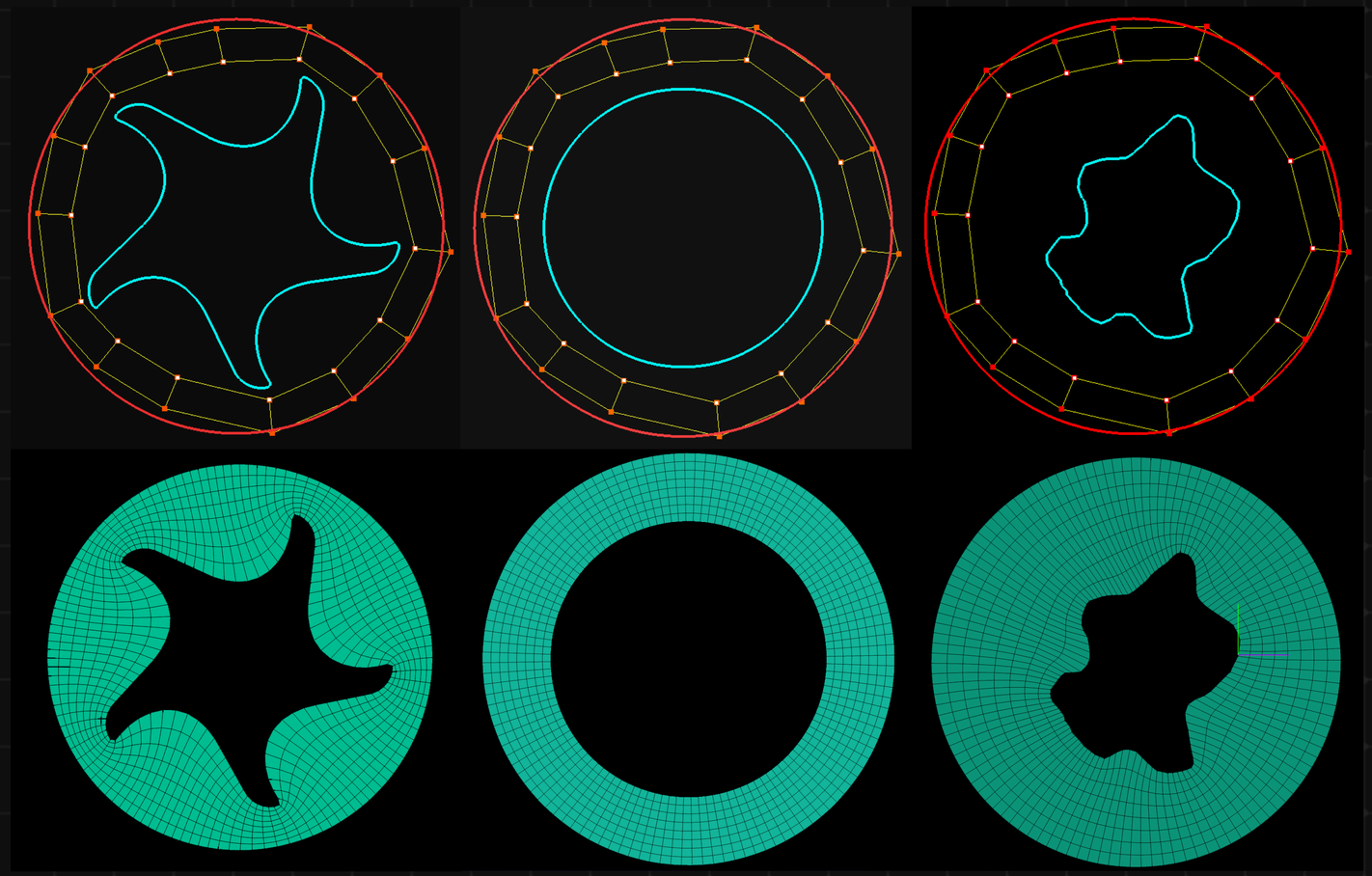
Topologists are mathematicians who cannot tell difference between their donut from their coffee cups!!



Courtesy: Wikipedia

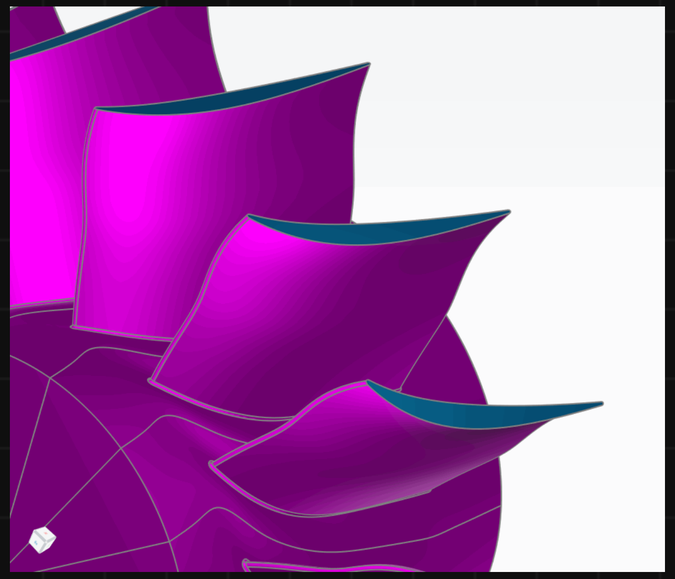
Topology based Ggrid Generation

- Blocking created for 1 geometry can mesh topologically similar geometries.
- Replacing one shape with another creates a new grid for the new geometry.
- Different Geometry Variations created from CAESES can be meshed with one blocking.



One blocking to create mesh for geometry with similar topology

Automatic Meshing coupled with CAESES for Smaller design variations



Geometry Variation (video)

	thetaInt1	thetaInt2	thetaInt3	thetaShroud	f(x) eval_folds	f(x) eval_skewness
sobol_minor_variations_10_des0000	-0.5	1.25	-2	0.5	0	0
sobol_minor_variations_10_des0001	0.5	-0.25	0	-0.5	0	0
sobol_minor_variations_10_des0002	-0.75	1.625	0.5	-0.75	0	0
sobol_minor_variations_10_des0003	0.25	0.125	-1.5	0.25	0	0
sobol_minor_variations_10_des0004	-0.25	-0.625	-0.5	0.75	0	0
sobol_minor_variations_10_des0005	0.75	0.875	-2.5	-0.25	0	0
sobol_minor_variations_10_des0006	0.375	0.6875	-2.25	-0.875	0	0
sobol_minor_variations_10_des0007	-0.625	-0.8125	-0.25	0.125	0	0
sobol_minor_variations_10_des0008	0.875	-0.0625	-1.25	0.625	0	0
sobol_minor_variations_10_des0009	-0.125	1.4375	0.75	-0.375	0	0
sobol_minor_variations_10_des0010	0.125	0.3125	0.25	-0.625	0	0
sobol_minor_variations_10_des0011	-0.875	1.8125	-1.75	0.375	0	0
sobol_minor_variations_10_des0012	0.625	1.0625	-0.75	0.875	0	0
sobol_minor_variations_10_des0013	-0.375	-0.4375	-2.75	-0.125	0	0
sobol_minor_variations_10_des0014	-0.1875	-0.15625	-1.625	0.0625	0	0
sobol_minor_variations_10_des0015	0.8125	1.34375	0.375	-0.9375	0	0
sobol_minor_variations_10_des0016	-0.6875	0.59375	-2.625	-0.4375	0	0
sobol_minor_variations_10_des0017	0.3125	-0.90625	-0.625	0.5625	0	0
sobol_minor_variations_10_des0018	-0.4375	0.96875	-0.125	0.3125	0	0
sobol_minor_variations_10_des0019	0.5625	-0.53125	-2.125	-0.6875	0	0
sobol_minor_variations_10_des0020	-0.9375	0.21875	0.875	-0.1875	0	0

Advantages and Limitations of the Current Approach

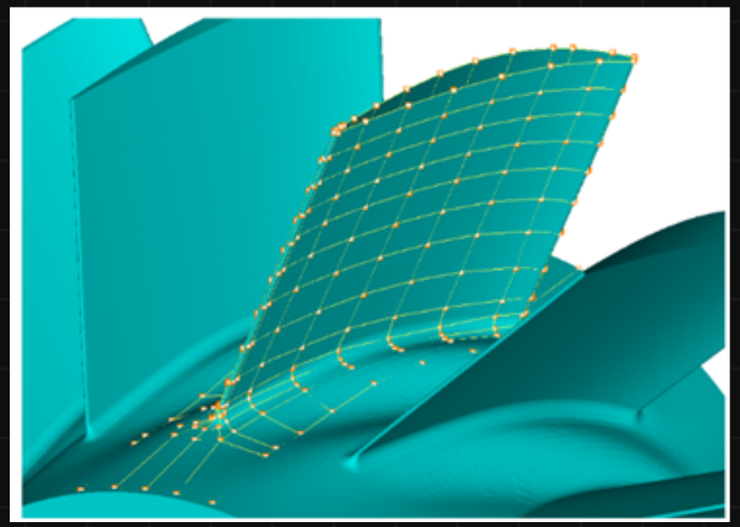
Advantages:

- Structured meshes for gentle variations of the geometry is fully automatic.
- Fast setup with CAESES - a new folder with a new design variant is all needed for the mesher to run.

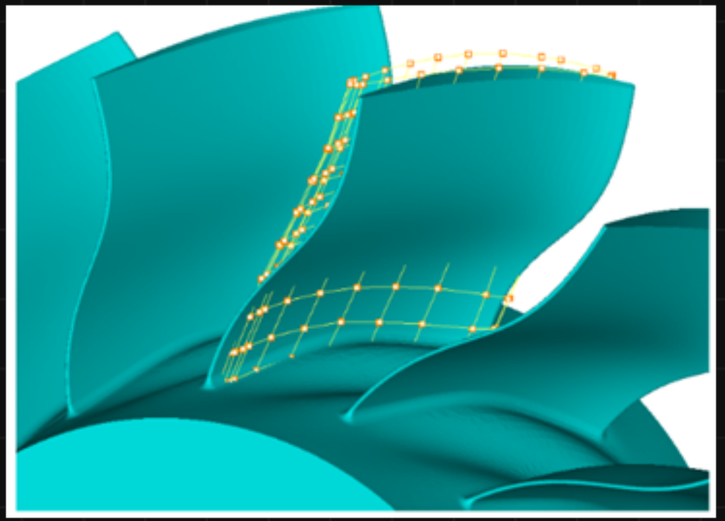
Limitation:

- When the geometry variant is positioned outside of the base blocking template, the projection algorithm has confusions.

- When the design space is large. The blocking needs to be positioned more generically- This leads to slower convergence.



Baseline Design



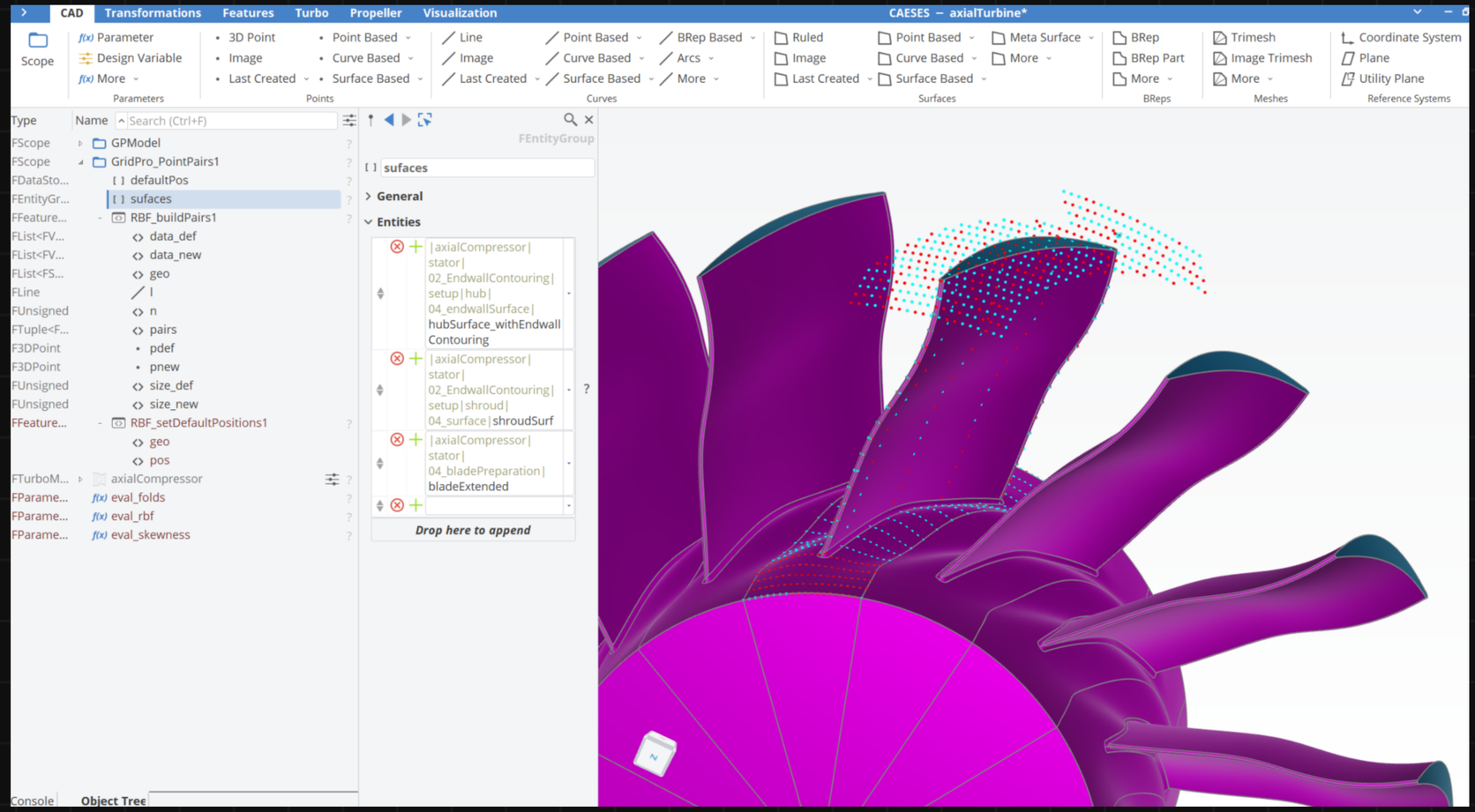
New Design

Need for a more Advanced Approach

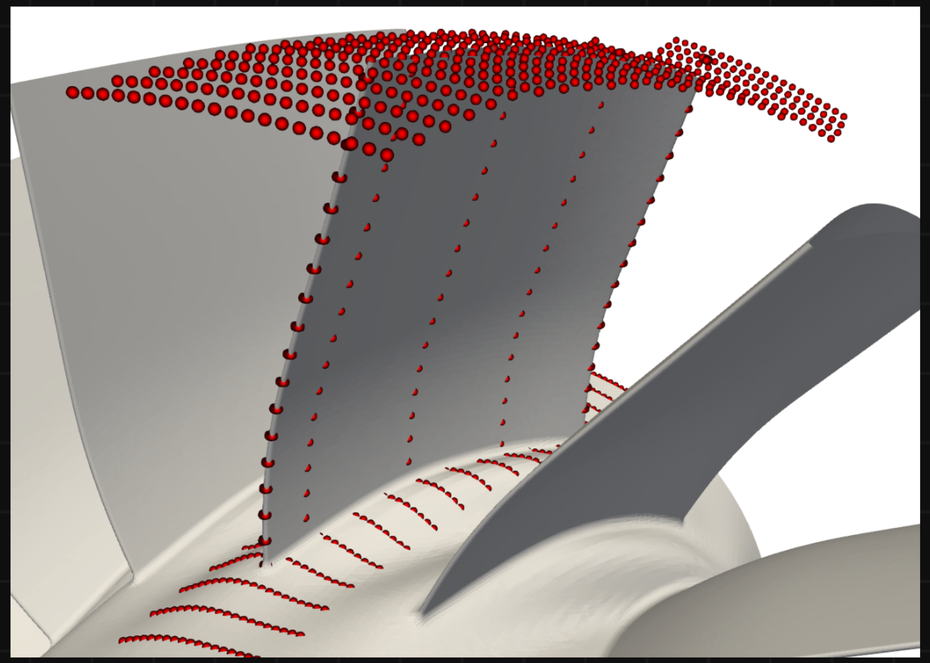
- Increase the robustness of the meshing automation- relying on topology did not take care of the movement of geometry outside of the specified blocking. The blocks faces on the geometry needed to repositioned more aptly for every change in geometry.
- To over come the above limitation, the topology faces of the blocking could be positioned far away to encompass all the variants but this leads to e poor initial condition for the smoother. A poor initial condition leads to longer smoothing time to create a good quality mesh. A better initial condition will enable the smoother to converge faster and create each mesh in few mins.

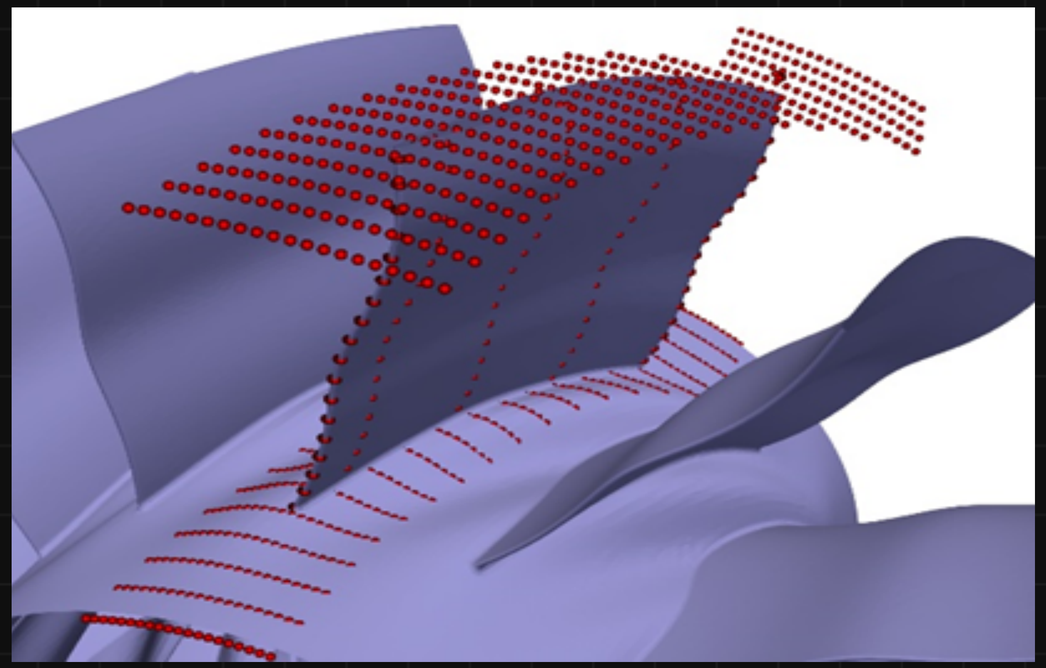
Point Cloud based block positioning approach

- CAESES generates points based on Surfaces in CAESES (Parameters in U-V space)
- Select surfaces which define the design space best.
- Baseline point data is stored in the project.
- For every New Design the baseline with the vector field is stored.



Point Cloud for Baseline and New Design Variant



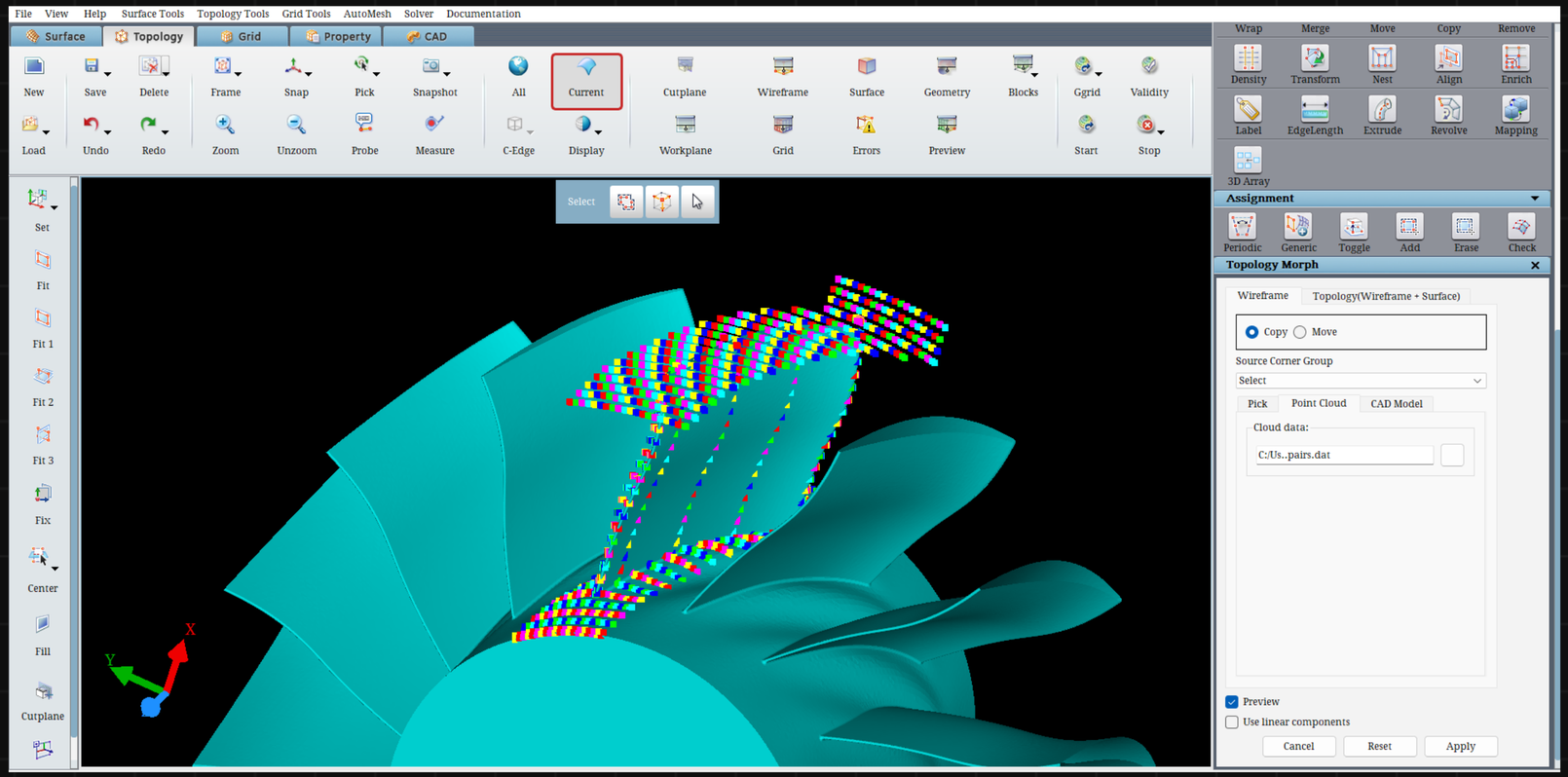


Methodology to Morph Blocks based on the point cloud

- **Spring Analogy**: Imaginary springs adjust topology blocks smoothly as the geometry deforms.

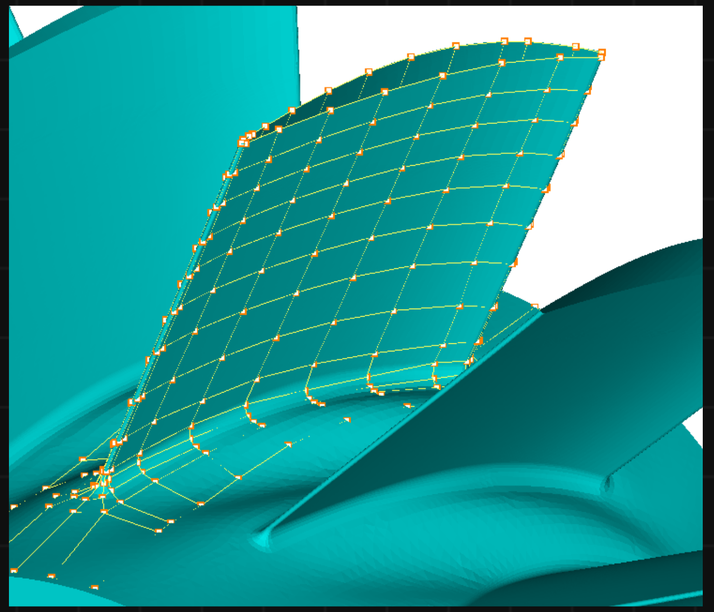
- **Radial Basis Function (RBF) Interpolation**: Fine-tunes node positioning to ensure precise conformity to deformed geometries.

- **Smoothing Algorithms**: Refine block quality after boundary node adjustments to maintain mesh integrity.

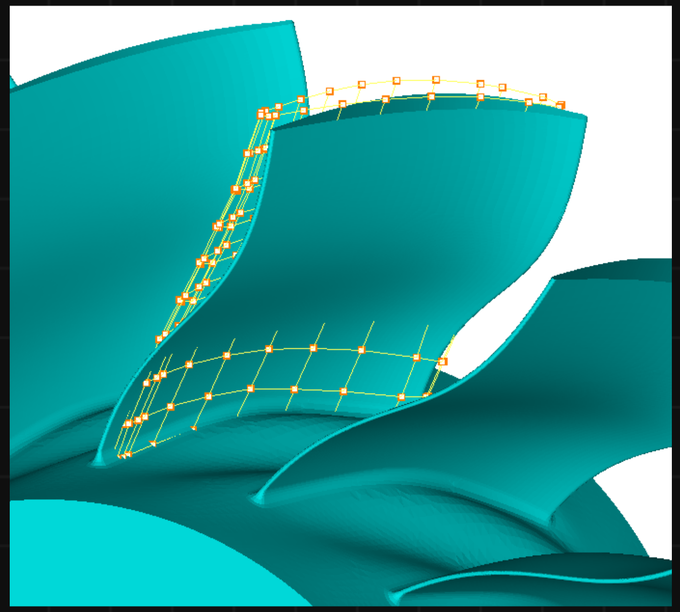


Point Cloud for Blade, hub and Shroud

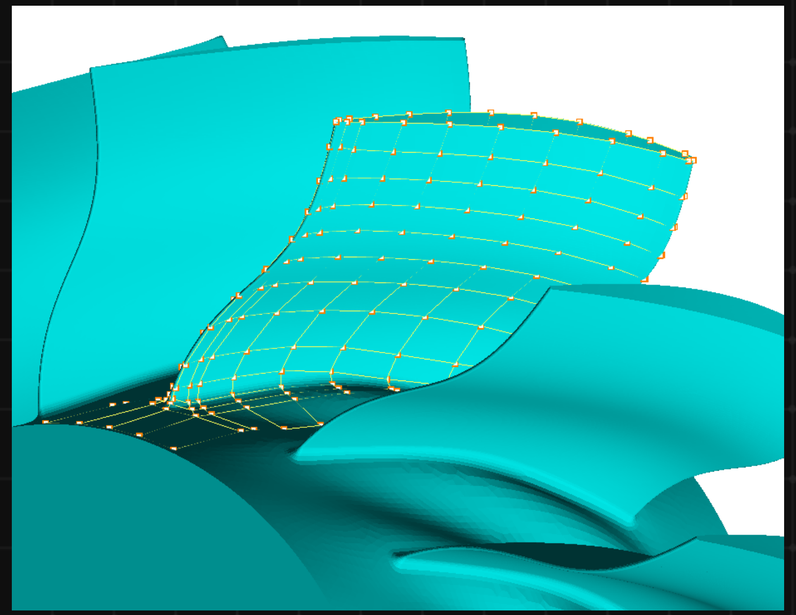
Result of the point cloud based Mappin and Morphing of Blocks



a. base topology.

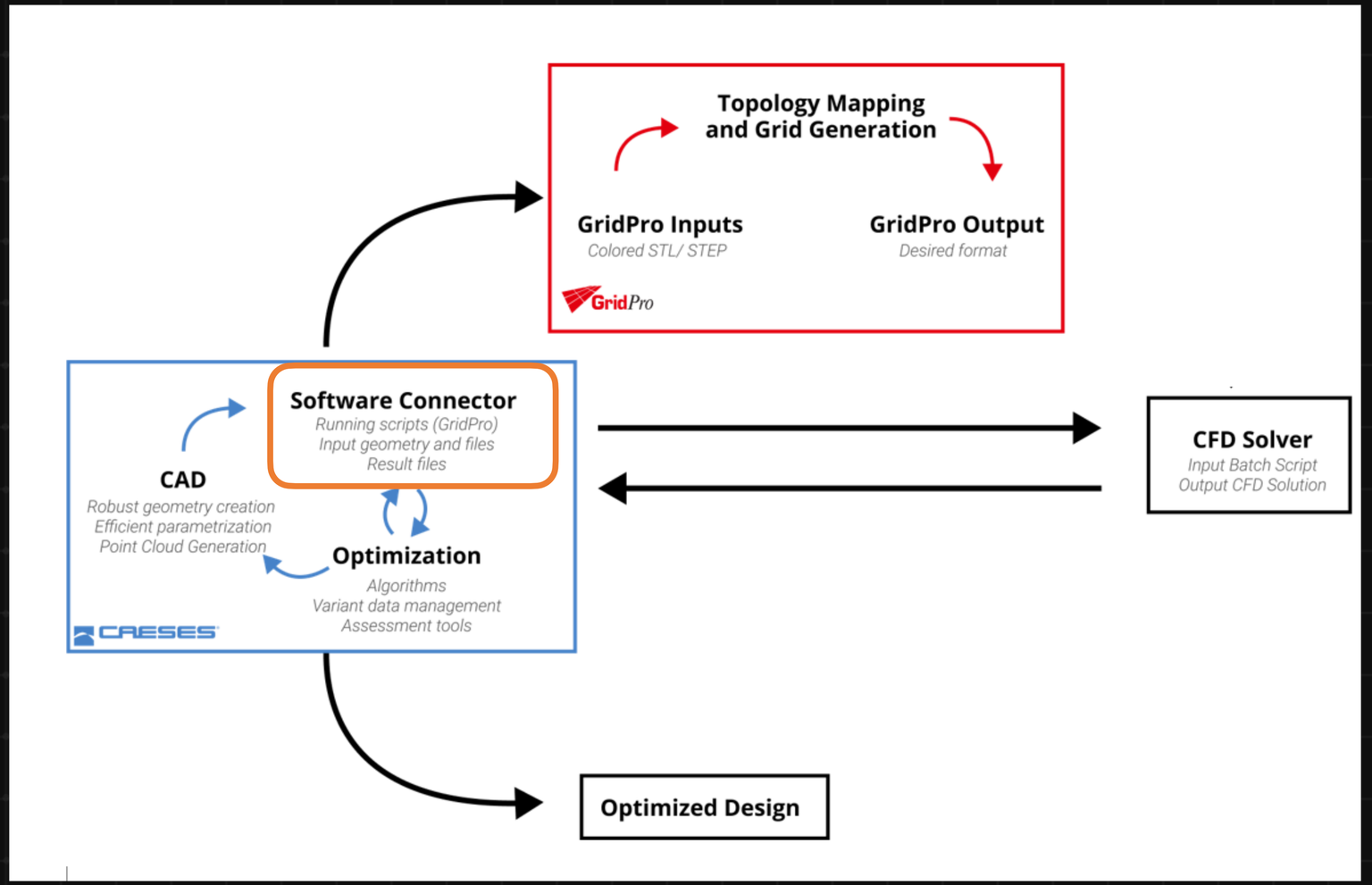


b. Topology without mapping.



c. Topology with point cloud mapping.

CAESES-GridPro-Solver Workflow Overview



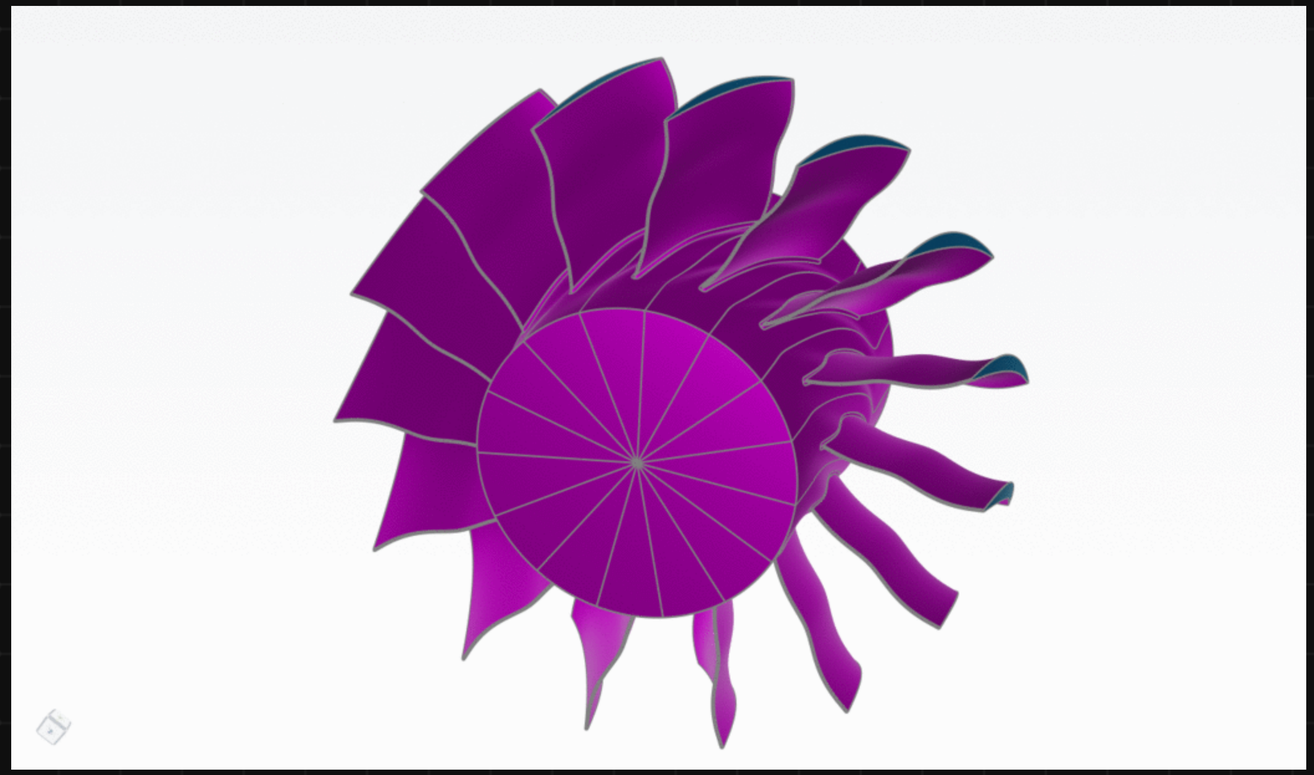
Axial Turbine - Large Design Variations

Test Case: Axial turbine with 50 geometric variants.

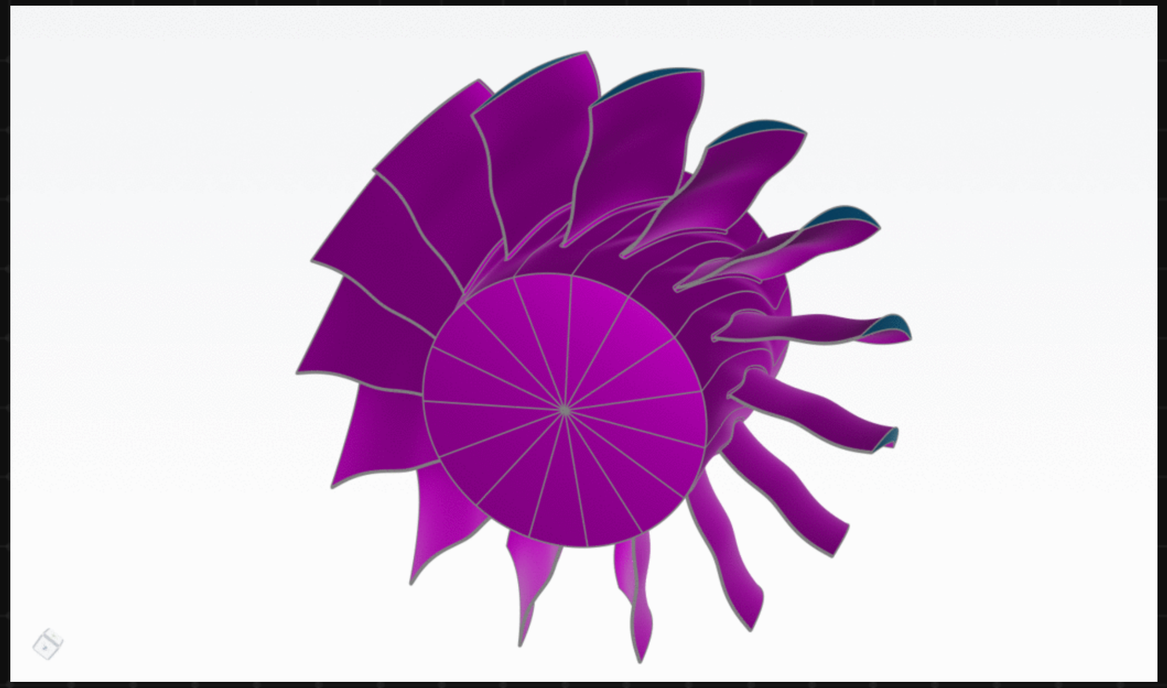
Parameters: 7 parametric variables were varied to create the variants.

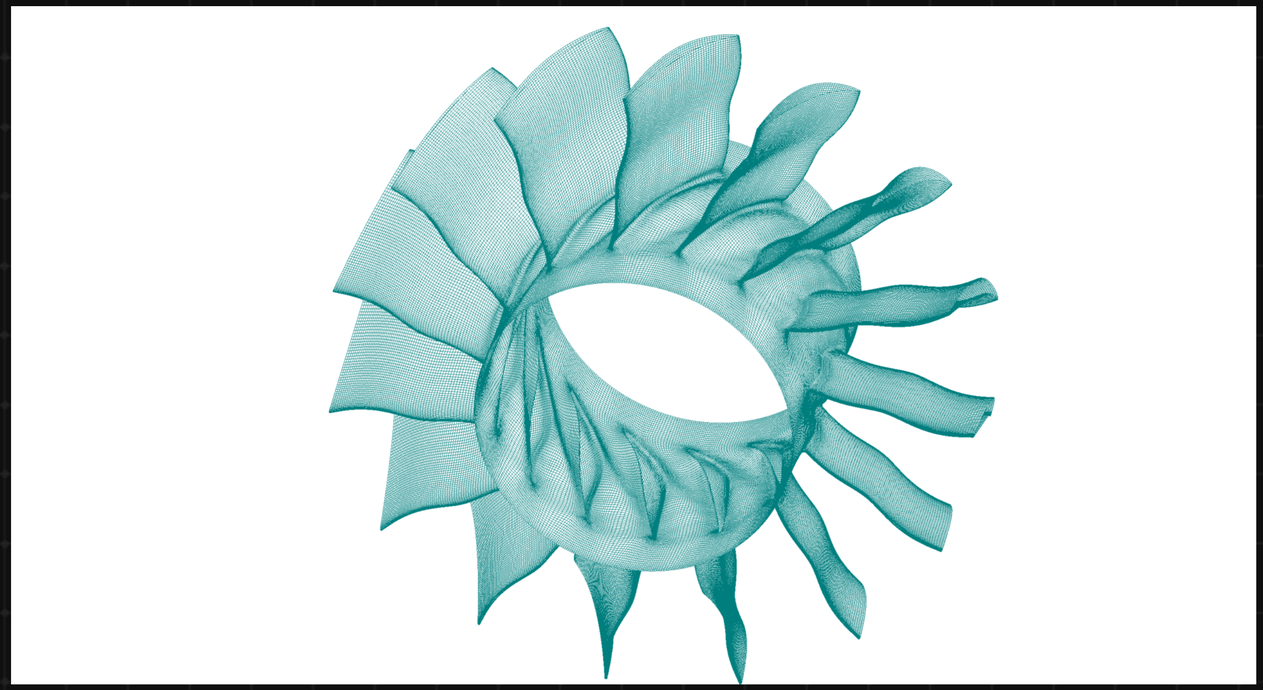
Baseline Topology: Manually created in 5 minutes and used as a template.

Total Time: Geometry creation to grid generation for all 50 variants took approximately 4 hours.

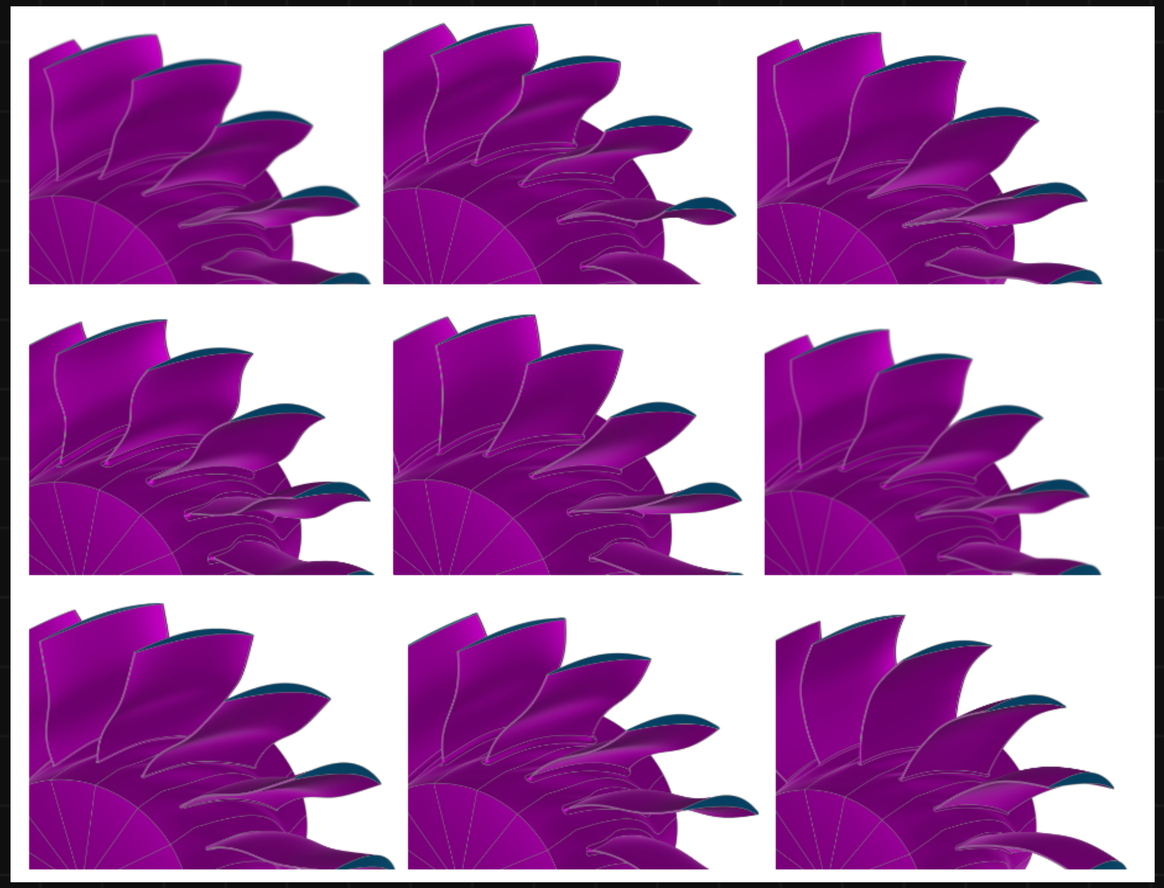


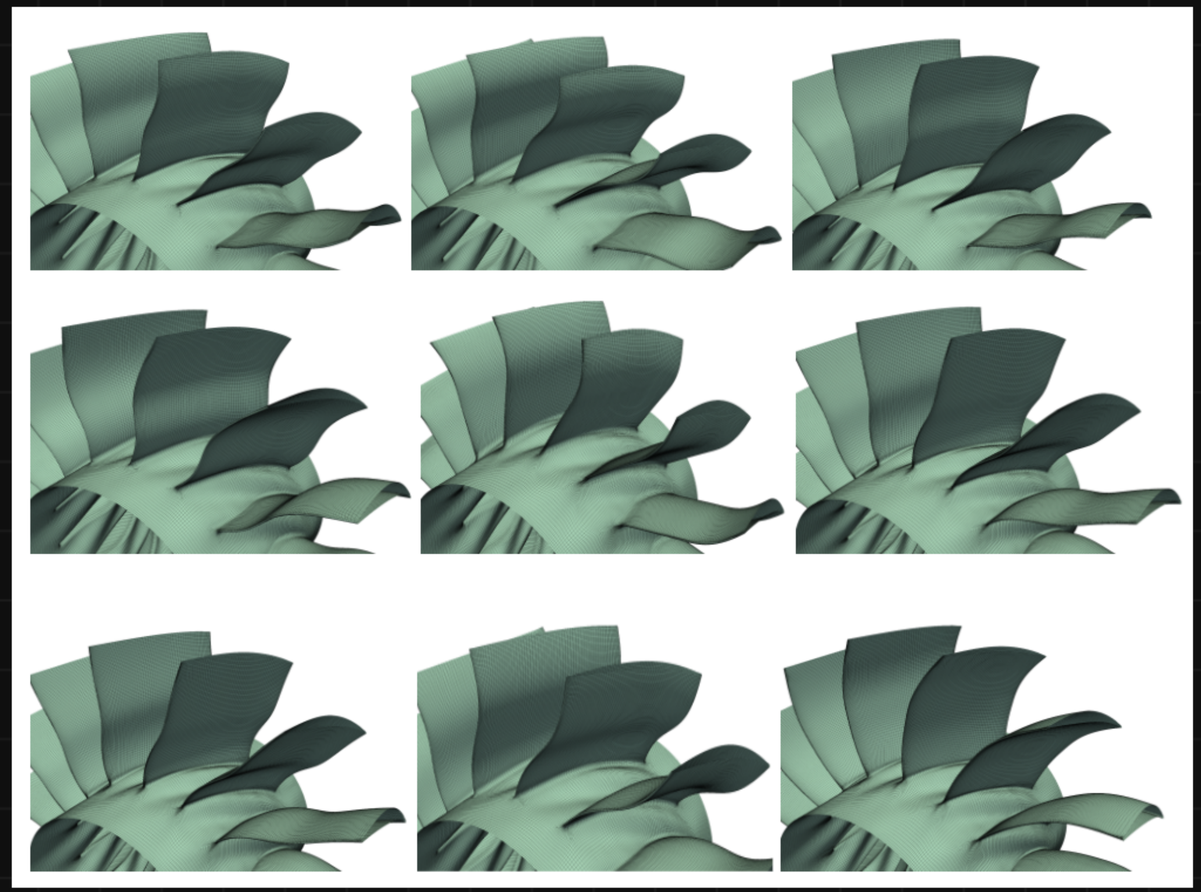
Axial Turbine - Large Design Variations (video)





Axial Turbine - Large Design Variations





Axial Turbine - Large Design Variations- Without point cloud mapping

Large Variations Without Point Cloud Based Mapping

For all variations where the geometry was outside of the blocking- the resultant grid has a folds and high skew.

	hubRadius	thetaInt1	thetaInt2	thetaInt3	thetaShroud	f(x) eval_folds	f(x) eval_skewness
sobol_wo_rbf_11_des0000	137.5	2.5	-2.5	2.5	-2.5	8157	7257
sobol_wo_rbf_11_des0001	148.75	-3.75	3.75	3.75	-3.75	5524	5746
sobol_wo_rbf_11_des0002	133.75	1.25	-1.25	-1.25	1.25	8045	7095
sobol_wo_rbf_11_des0003	141.25	-1.25	-3.75	1.25	3.75	3488	3859
sobol_wo_rbf_11_des0004	156.25	3.75	1.25	-3.75	-1.25	4040	6361
sobol_wo_rbf_11_des0005	139.375	1.875	0.625	-3.125	-4.375	14080	12411
sobol_wo_rbf_11_des0006	154.375	-3.125	-4.375	1.875	0.625	0	0
sobol_wo_rbf_11_des0007	146.875	4.375	-1.875	-0.625	3.125	332	559
sobol_wo_rbf_11_des0008	131.875	-0.625	3.125	4.375	-1.875	9697	10818
sobol_wo_rbf_11_des0009	158.125	0.625	-0.625	3.125	-3.125	4331	5757
sobol_wo_rbf_11_des0010	143.125	-4.375	4.375	-1.875	1.875	0	0
sobol_wo_rbf_11_des0011	135.625	3.125	1.875	0.625	4.375	11668	13460
sobol_wo_rbf_11_des0012	150.625	-1.875	-3.125	-4.375	-0.625	7246	8248
sobol_wo_rbf_11_des0013	155.3125	-0.9375	-2.1875	-1.5625	0.3125	4899	6066
sobol_wo_rbf_11_des0014	140.3125	4.0625	2.8125	3.4375	-4.6875	5624	4993
sobol_wo_rbf_11_des0015	132.8125	-3.4375	0.3125	-4.0625	-2.1875	9927	10737
sobol_wo_rbf_11_des0016	147.8125	1.5625	-4.6875	0.9375	2.8125	0	714
sobol_wo_rbf_11_des0017	144.0625	-2.1875	1.5625	2.1875	1.5625	3116	3634
sobol_wo_rbf_11_des0018	159.0625	2.8125	-3.4375	-2.8125	-3.4375	4524	1830
sobol_wo_rbf_11_des0019	151.5625	-4.6875	-0.9375	4.6875	-0.9375	0	8
sobol_wo_rbf_11_des0020	136.5625	0.3125	4.0625	-0.3125	4.0625	8053	9053

Axial Turbine - Large Design Variations- With point cloud mapping

95% of the meshes created were of excellent quality with few failures.

Large Variations With Point Cloud Based Mapping

	chordLength	filletRadius	hubRadius	thetaInt1	thetaInt2	thetaInt3	thetaShroud	eval_folds	eval_skewness
sobol_09_des0000	80	2.75	52.5	2.5	2.5	2.5	2.5	0	0
sobol_09_des0001	60	5.25	37.5	2.5	2.5	2.5	2.5	0	0
sobol_09_des0002	65	3.625	48.75	3.75	3.75	3.75	3.75	0	0
sobol_09_des0003	85	7.125	33.75	1.25	1.25	1.25	1.25	0	0
sobol_09_des0004	75	1.875	41.25	1.25	3.75	1.25	3.75	0	0
sobol_09_des0005	55	5.375	56.25	3.75	1.25	3.75	1.25	0	0
sobol_09_des0007	77.5	5.6875	54.375	3.125	4.375	1.875	0.625	0	0
sobol_09_des0008	87.5	1.4375	46.875	4.375	1.875	0.625	3.125	0	0
sobol_09_des0009	67.5	4.9375	31.875	0.625	3.125	4.375	1.875	0	0
sobol_09_des0010	62.5	2.3125	58.125	0.625	0.625	3.125	3.125	0	0
sobol_09_des0011	82.5	5.8125	43.125	4.375	4.375	1.875	1.875	0	0
sobol_09_des0012	72.5	4.0625	35.625	3.125	1.875	0.625	4.375	64	200
sobol_09_des0013	52.5	7.5625	50.625	1.875	3.125	4.375	0.625	0	0
sobol_09_des0014	53.75	4.28125	55.3125	0.9375	2.1875	1.5625	0.3125	0	0
sobol_09_des0015	73.75	7.78125	40.3125	4.0625	2.8125	3.4375	4.6875	0	0
sobol_09_des0018	68.75	1.65625	44.0625	2.1875	1.5625	2.1875	1.5625	0	0
sobol_09_des0019	88.75	5.15625	59.0625	2.8125	3.4375	2.8125	3.4375	272	889
sobol_09_des0020	78.75	3.40625	51.5625	4.6875	0.9375	4.6875	0.9375	0	0

Results of Point cloud based Block mapping and morphing

Results on Exit Casing

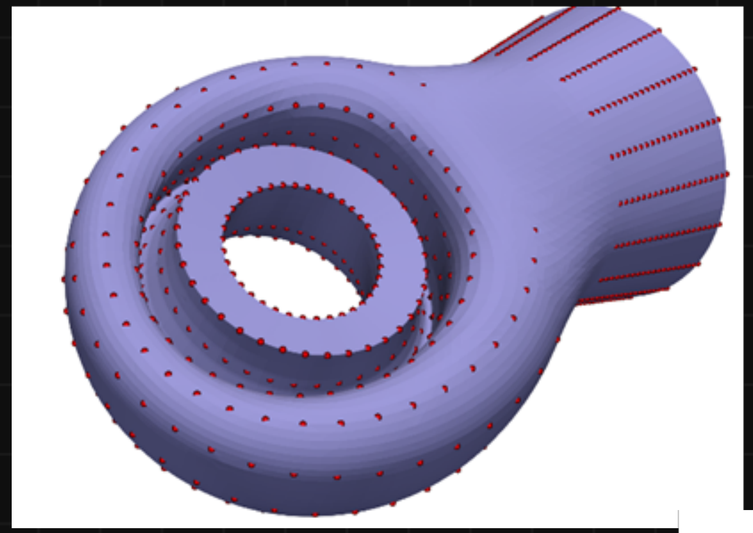
Test Case: Exit casing with 50 design variations.

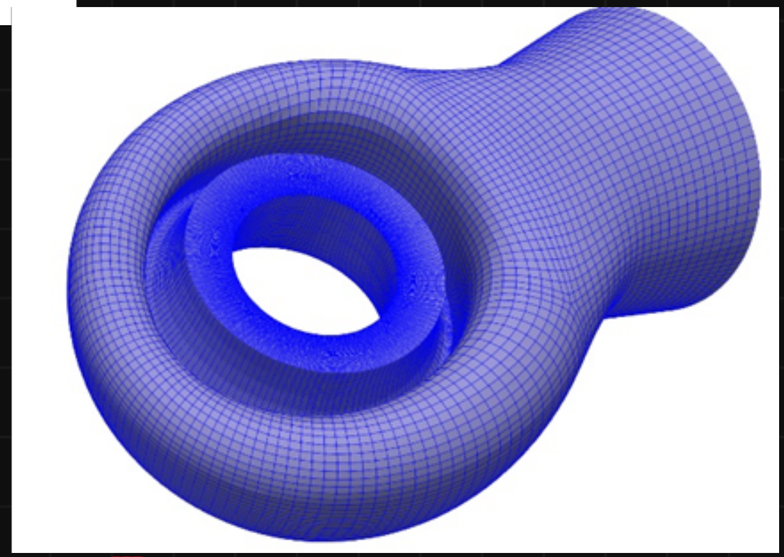
Parameters: 12 parametric variables.

Processing Time per Case: Average of 3 minutes.

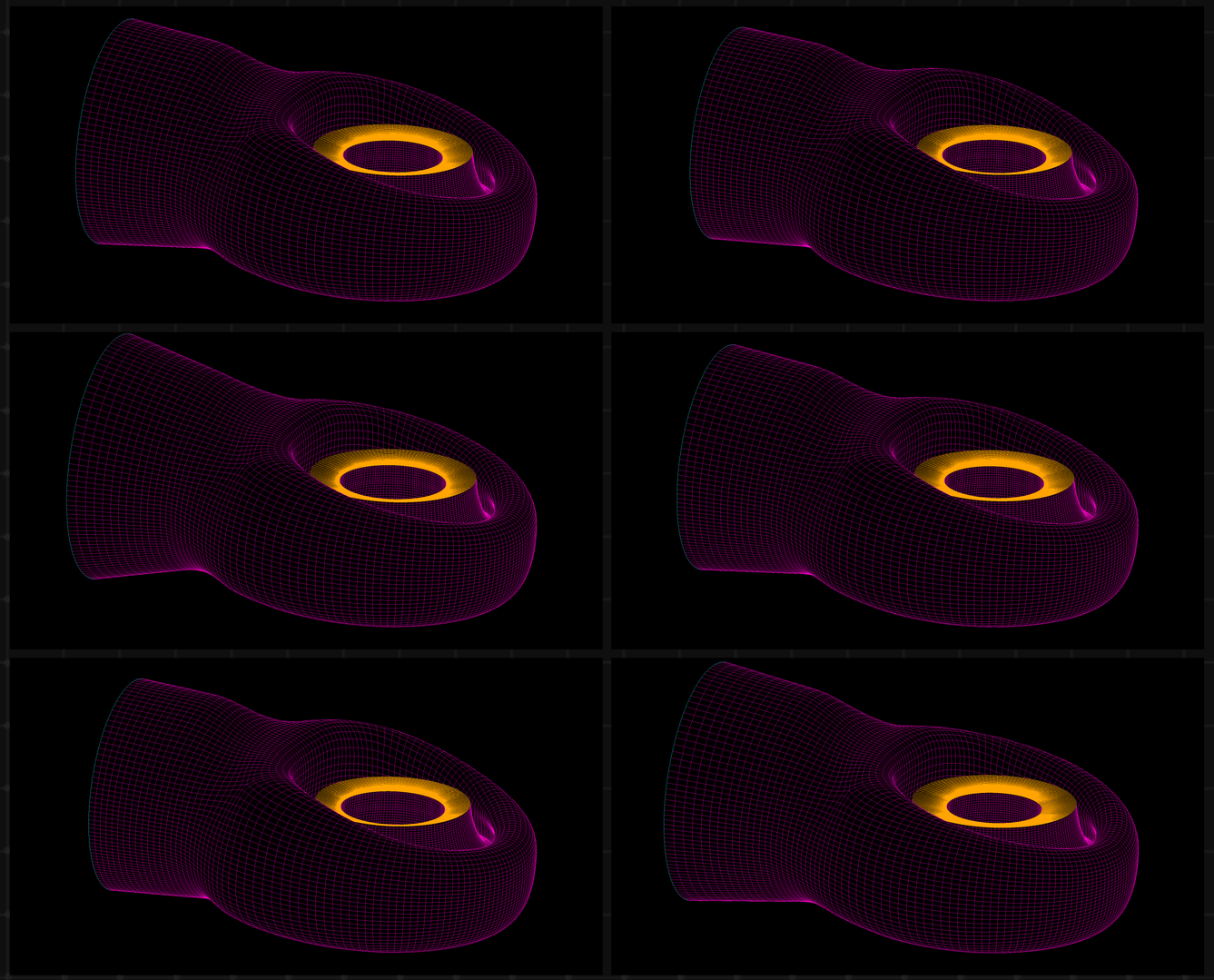
Baseline Topology Setup: Took about 30 minutes.

Total Processing Time: 2.5 hours for all 50 variants.





Results on Exit Casing



Results on Centrifugal Compressor

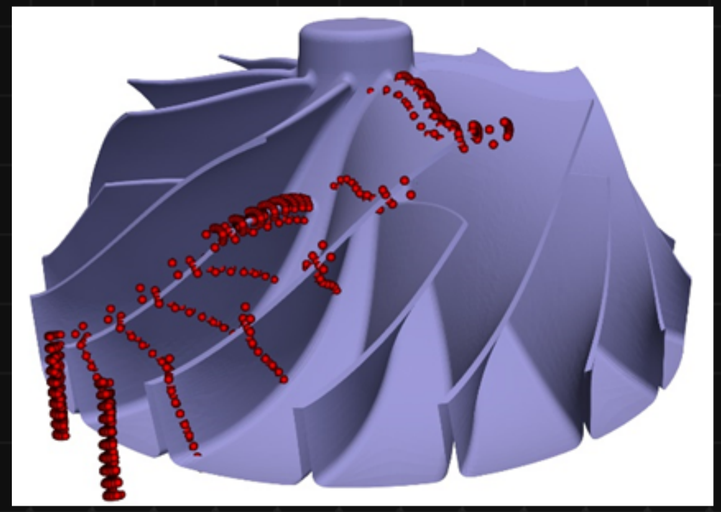
Test Case: Centrifugal compressor with 50 design variants.

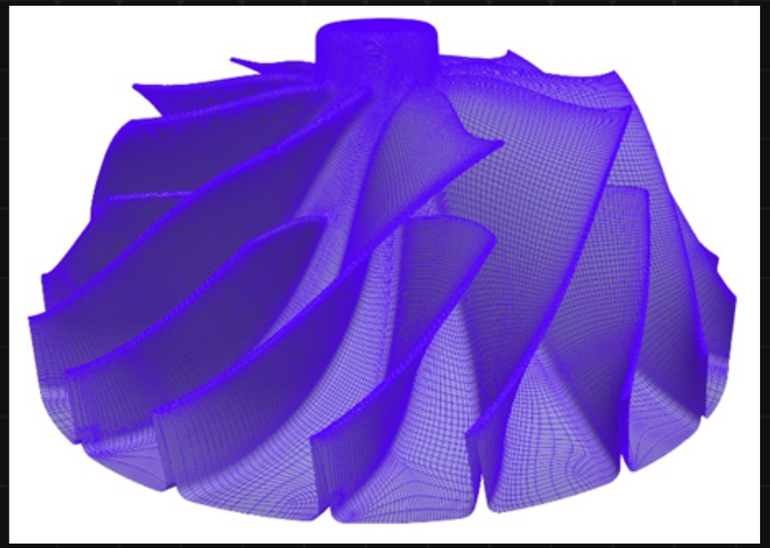
Parameters: 32 parametric variables.

Processing Time per Case: Average of 11 minutes.

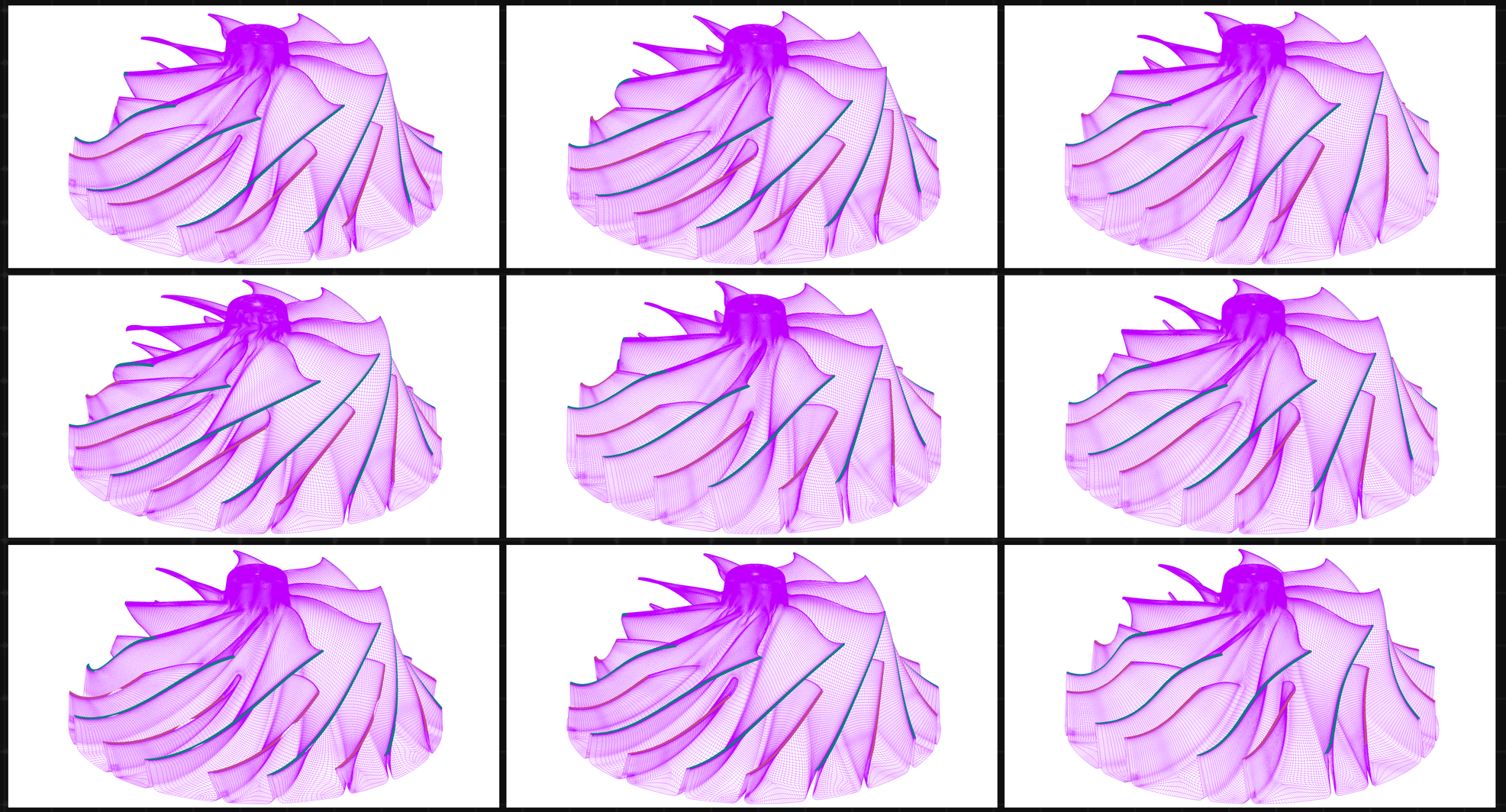
Baseline Topology Setup: Took approximately 30 mins.

Total Processing Time: About 4 hoursfor all 50 variants.





Results on Centrifugal Compressor



Results on Radial Turbine

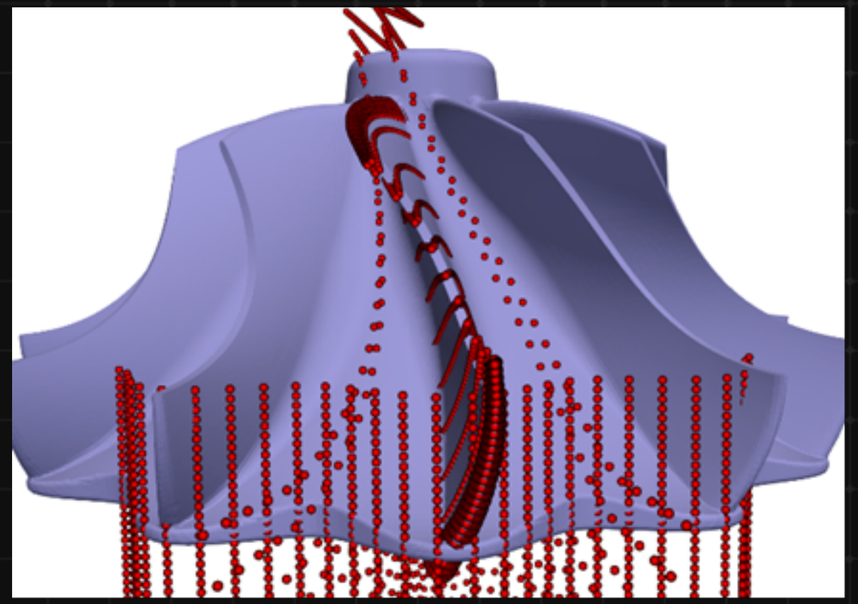
Test Case: Radial turbine with 50 design variations.

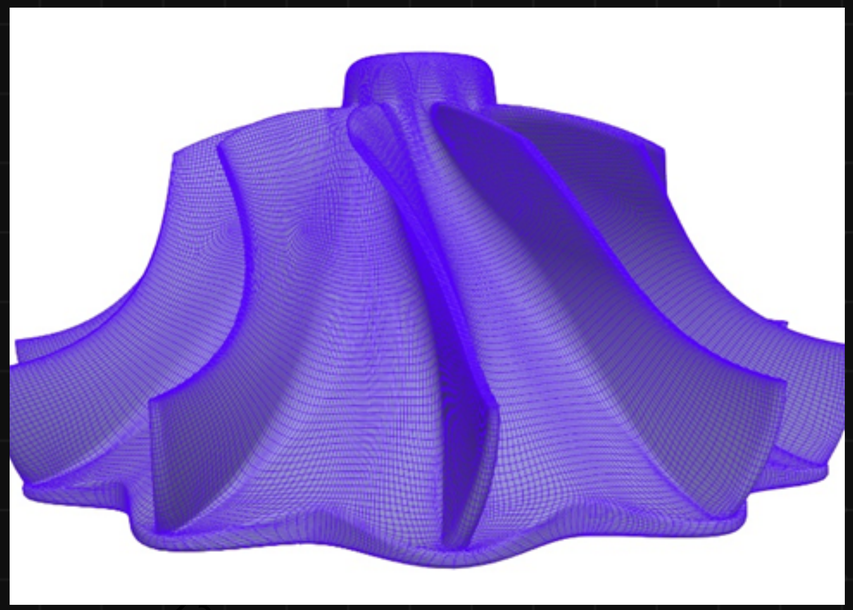
Parameters: 15 parametric variables.

Processing Time per Case: Average of 7 minutes.

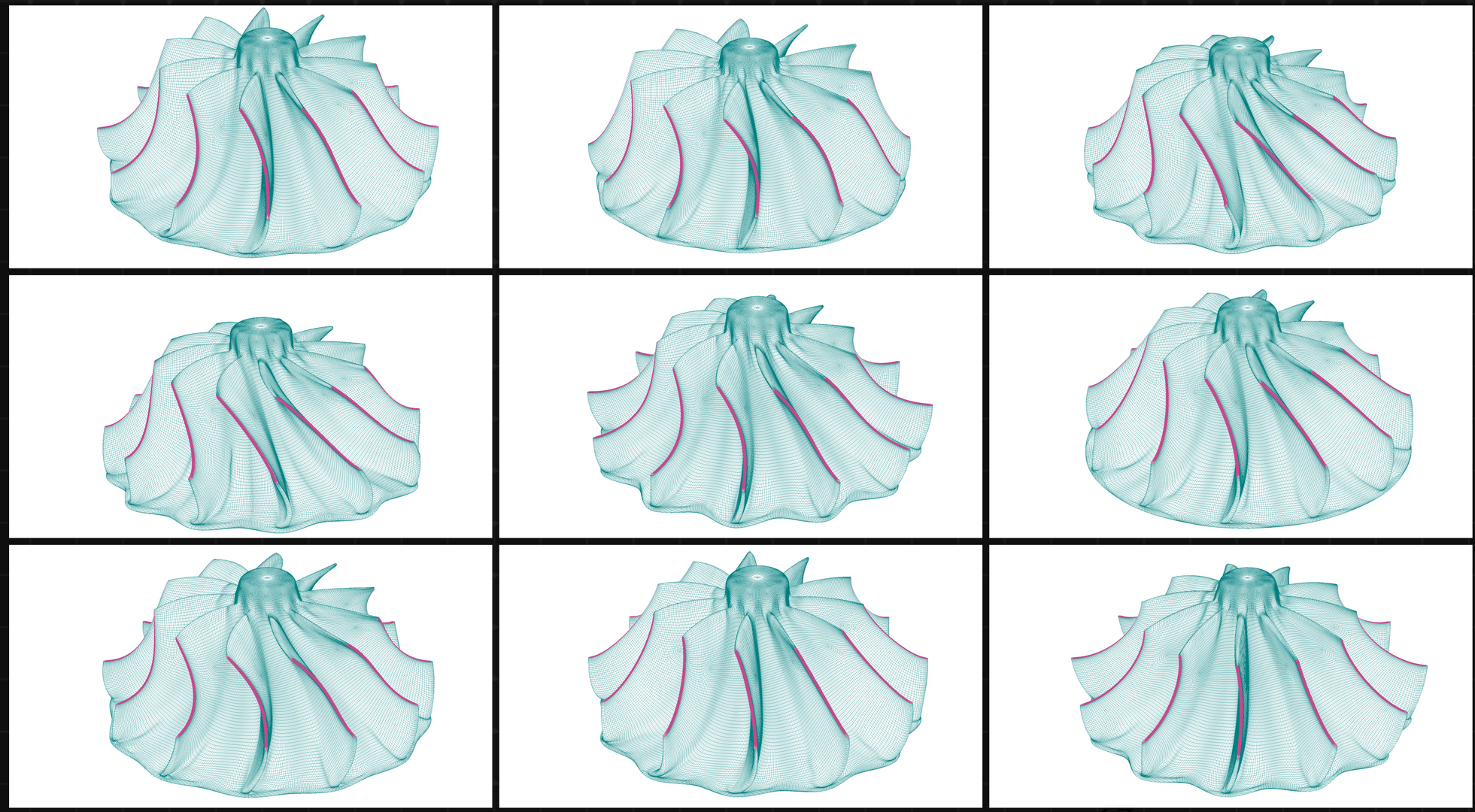
Baseline Topology Setup: Took approximately 2 hours and 30 minutes.

Total Processing Time: 350 minutes (6 hours) for all 50 variants.





Results on Radial Turbine



Results on Compressor Volute

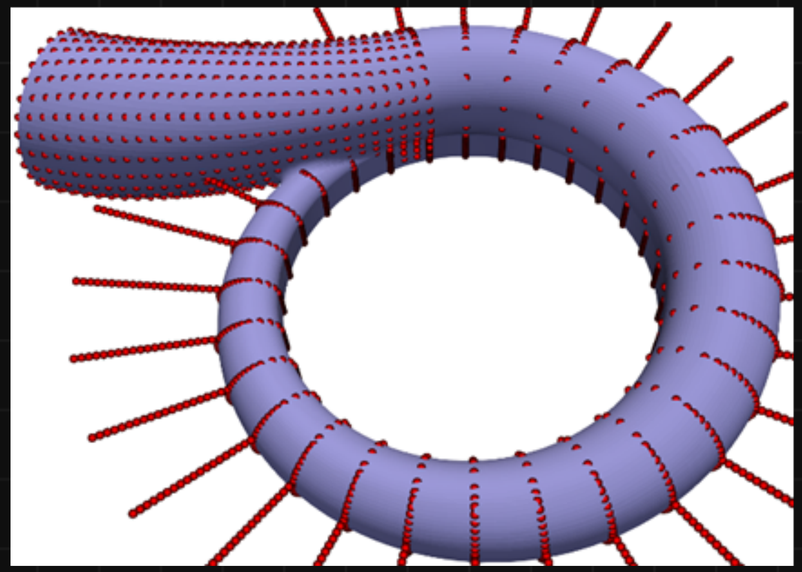
Test Case: Compressor volute with 50 geometric variants.

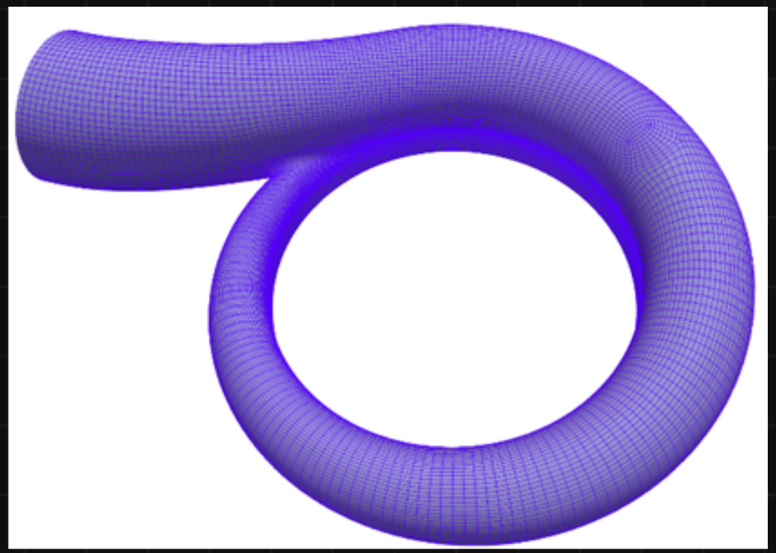
Parameters: 15 parametric variables.

Processing Time per Case: Average of 3 minutes.

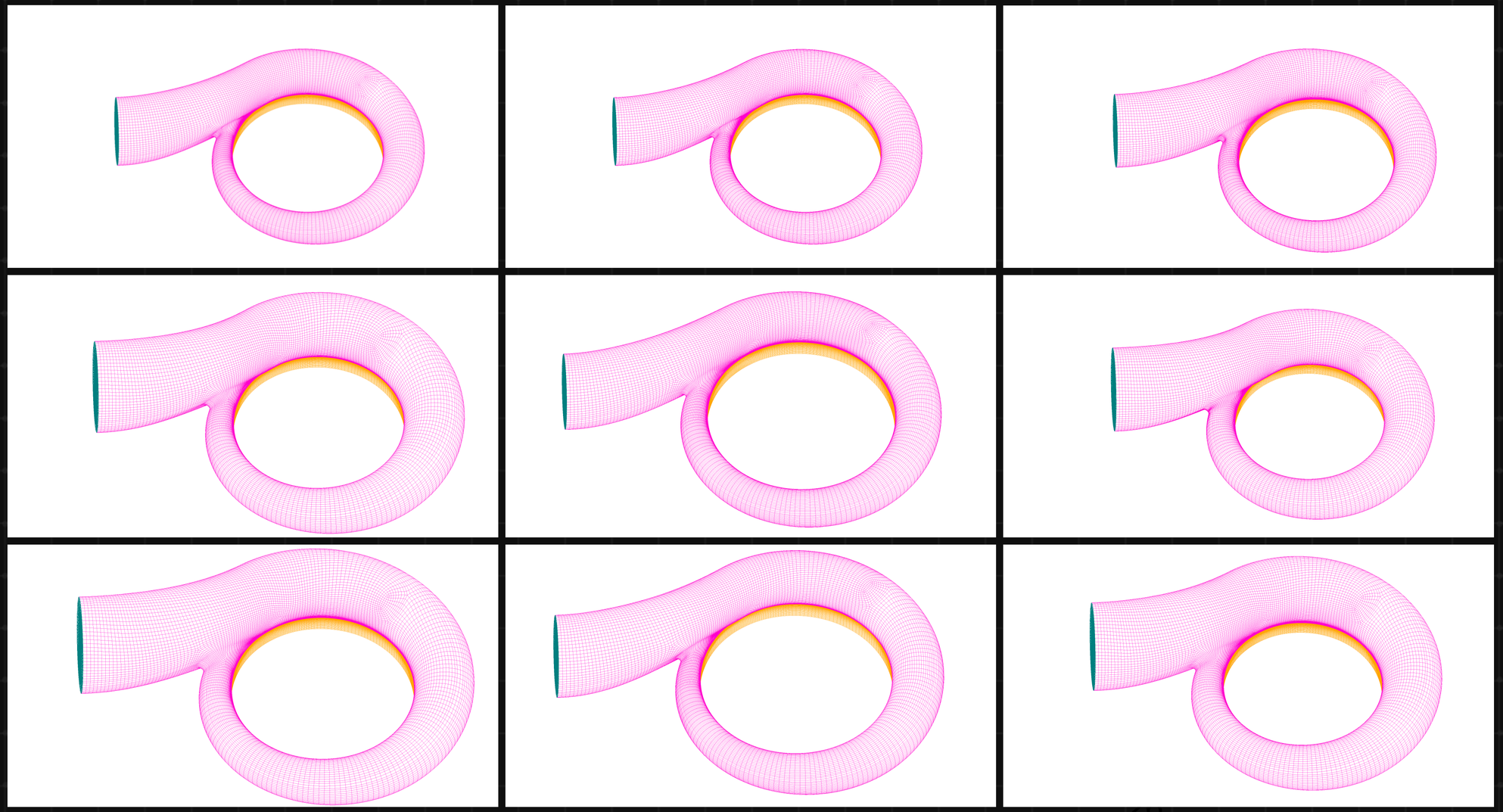
Baseline Topology Setup: Took approximately 15 mins.

Total Processing Time: 2 hours for all 50 variants



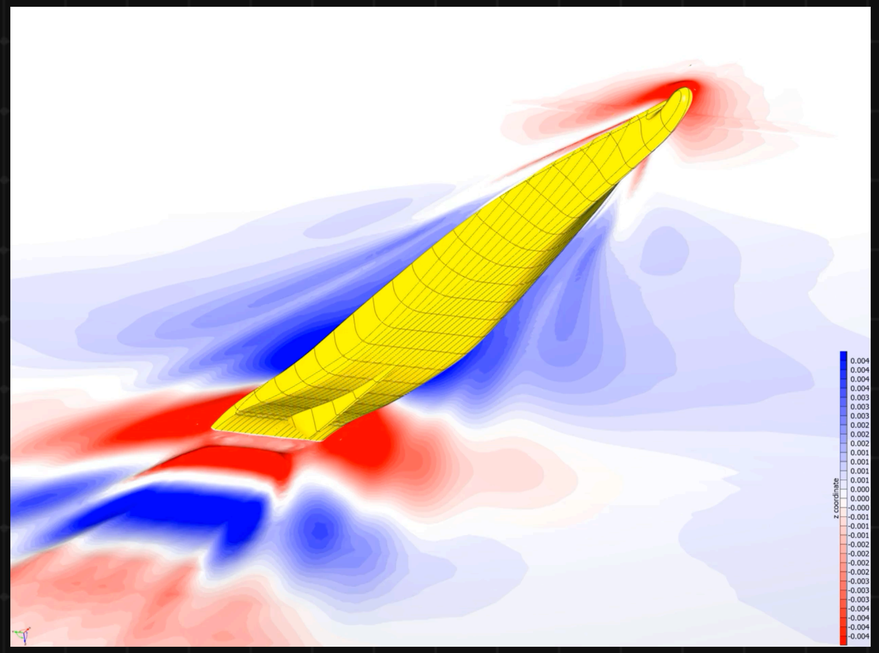


Results on Compressor Volute



Concluding Remarks

- **Tighter Integration between GridPro and CAESES for Generation Hexahedral Meshes**
- **Fast and Robust Setup to Generate meshes**
- **Can handle large changes in design variations**
- **Future work: To test on different geometries like propellers, Ship Hull with more design changes.**



Thank You for Your Patience!

If you would like to know more about why meshing is important and how to automate it!

Reach out to us!

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