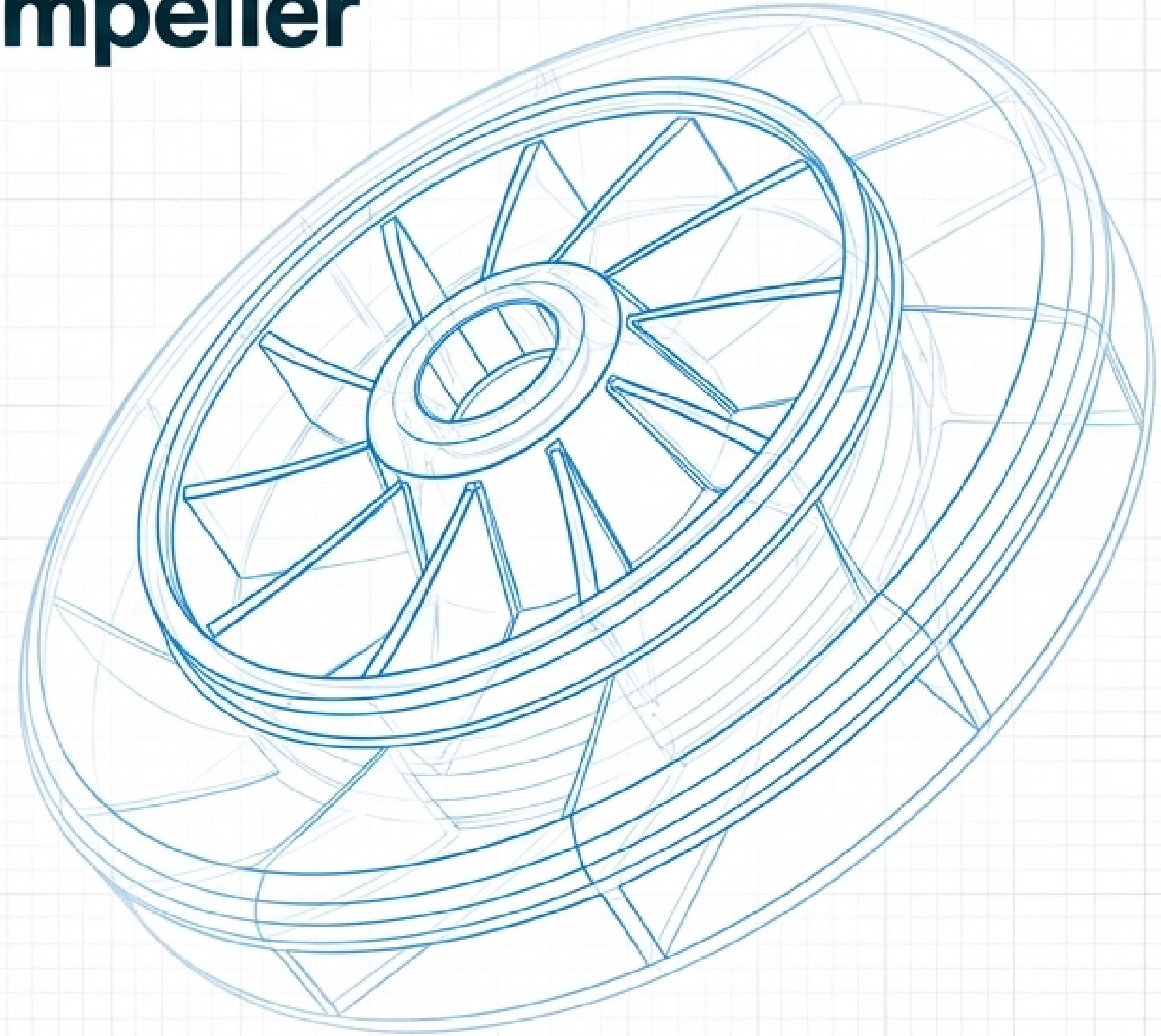
Optimising Centrifugal Impeller Meshing in Gmsh: An Experimental Study

From Basic Geometry to Advanced Field-Based Refinement



Internal Engineering Report

30/12/25 – 22/01/2026

Executive Summary & Project Timeline

Over a 4-week period, we investigated Gmsh as a viable open-source tool for meshing complex centrifugal impellers. Through 7 distinct experimental iterations, we identified that standard automation fails for turbomachinery. The optimal solution requires a hybrid approach: Field-based refinement on a single periodic sector, with rotation handled at the solver level.

Week 1: Basics

Geometry Modules, Kernel Basics, T1-T3 Tutorials.

Week 2: Advanced Control

Transfinite Meshing, Mesh Fields (Box, Cylinder, Threshold), T4-T10.

Week 3: Experiments

Iterations 1–3. Failure of Automesh; Success of Field Refinement.

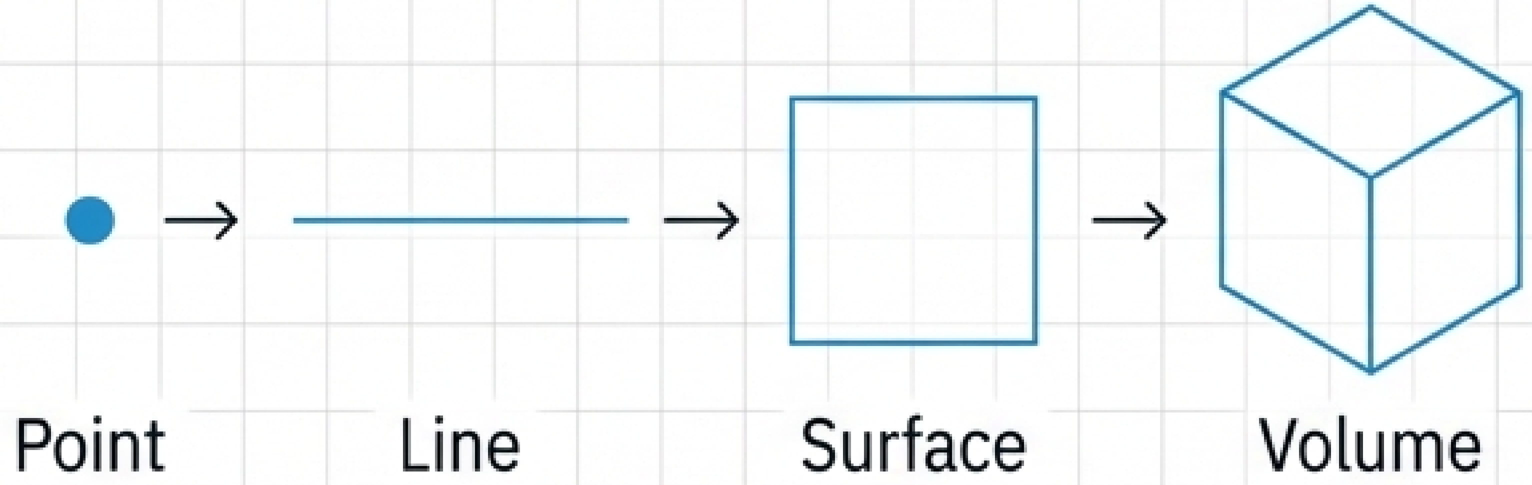
Week 4: Symmetry & Finalization

Iterations 4–7. Symmetry challenges, Ansys cross-validation, and final protocol.

The Tool vs. The Challenge

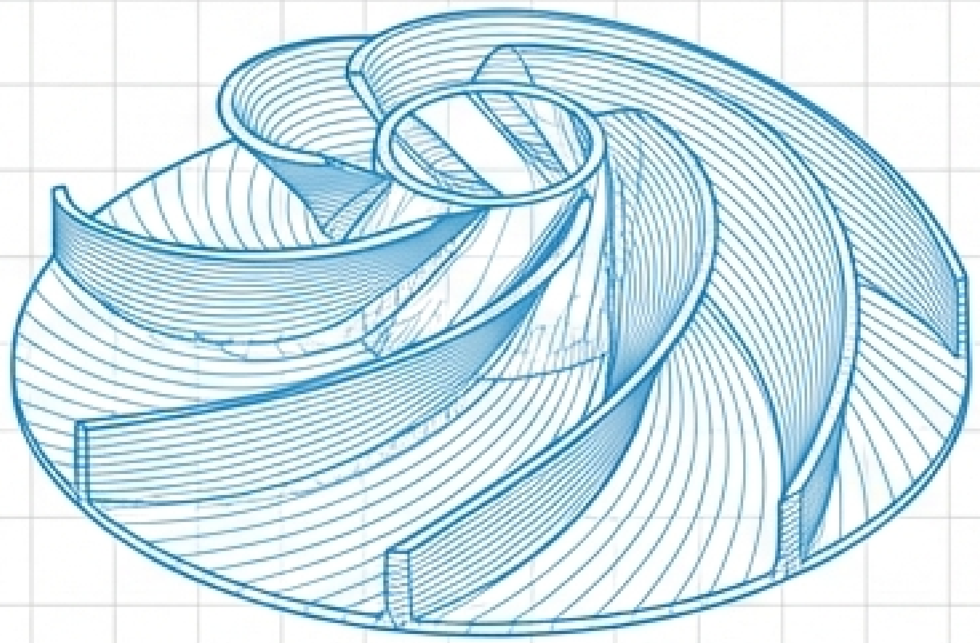
The Tool: Gmsh

- **Nature:** Open-source finite element mesh generator with built-in CAD kernel and OpenCASCADE support.
- **Hierarchy:** Strict bottom-up construction. Points → Lines → Curve Loops → Surfaces → Volumes.
- **Integration:** Bridge between CAD (STEP/STL) and Solvers (Elmer, OpenFOAM) via ONELAB.



The Challenge: Centrifugal Impeller

- **Geometry:** Complex curvature, twisted blades, and tight fluid gaps.
- **Requirement:** High-fidelity boundary layers to capture pressure gradients.
- **Constraint:** Requires structured or hybrid meshes; random tetrahedral generation is insufficient.



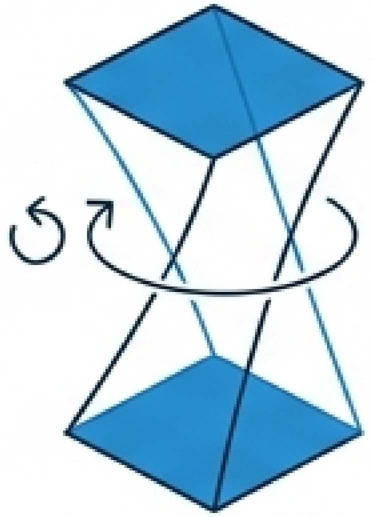
NotebookLM

Building the Toolbox: Core Geometric Functions

Key learnings from Tutorials T1–T6 that formed the foundation of our strategy.

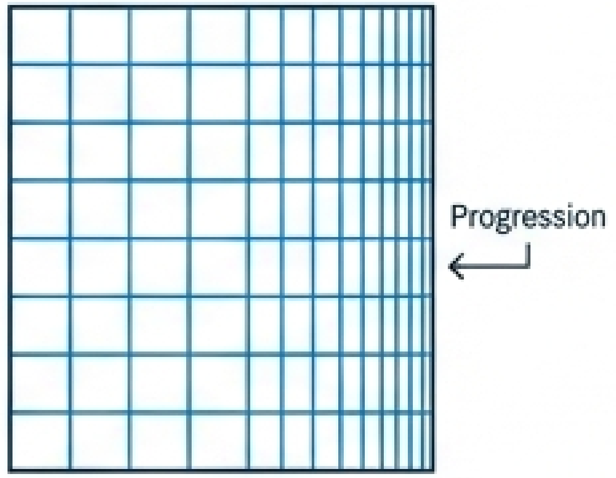
Extrusion (T2/T3)

Creating volume from surfaces. Critical for defining fluid domains. Learned 'Extrusion Rotation' for twisted geometries.



Transfinite Meshing (T6)

Forcing a 'Structured' mesh by explicitly defining node counts along a curve. Use of Progression to bias node distribution.

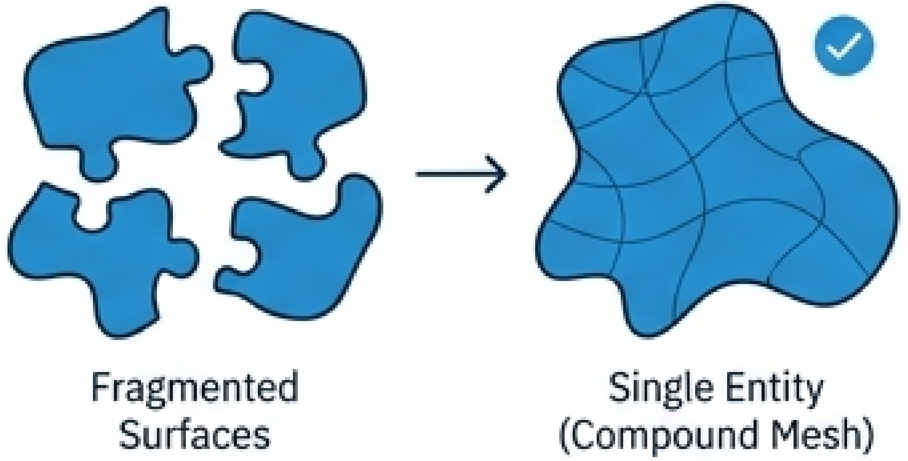


Compourd Meshing (T7)

Treating multiple fragmented surfaces as a single entity to ensure robust meshing on imported.

Compound Meshing (T12)

Treating multiple fragmented surfaces as a single entity to ensure robust meshing on imported STEP files.



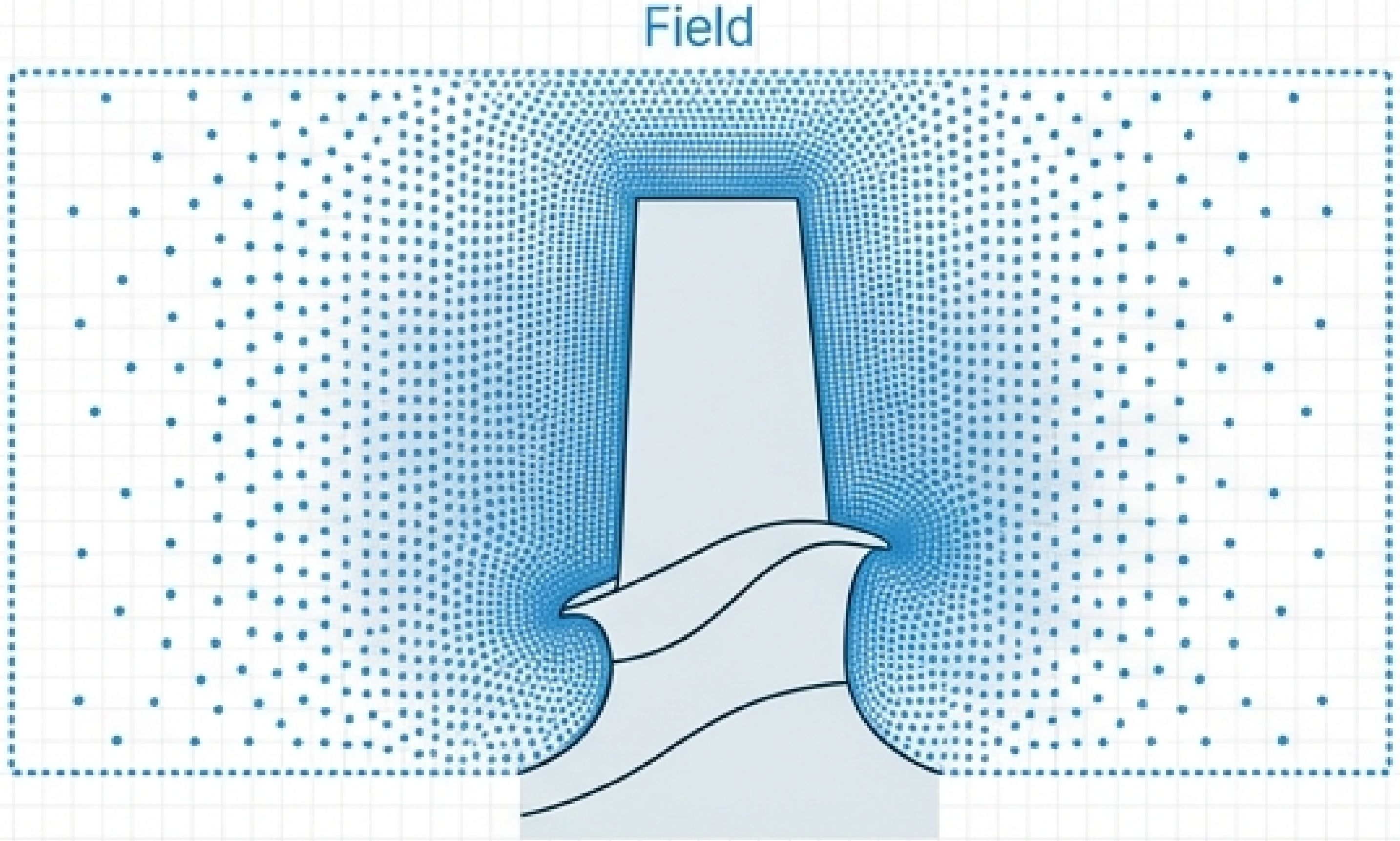
Advanced Arsenal: Smart Refinement & Periodicity

Advanced concepts from Tutorials T10–T21 tailored for turbomachinery.

Mesh Fields (T10)

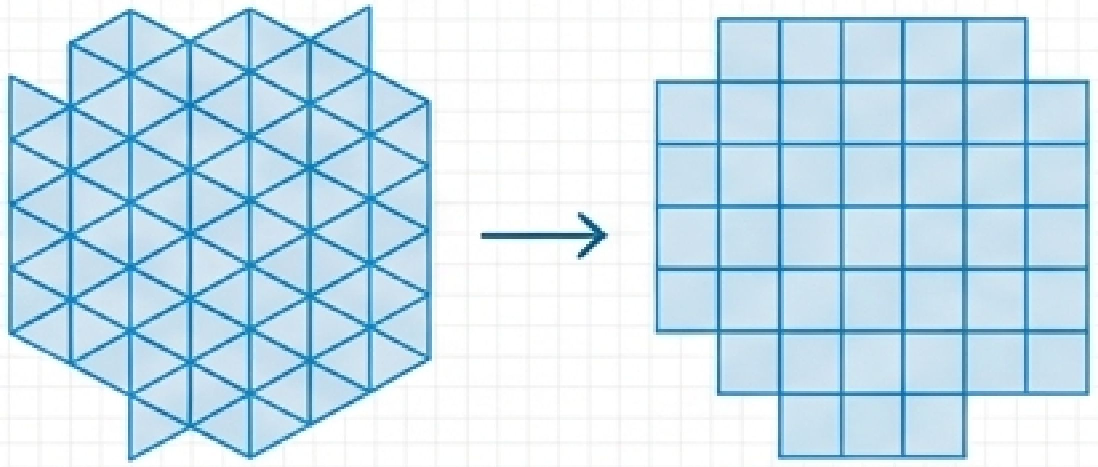
The most critical feature. Using mathematical fields to control mesh size without altering geometry.

- **Cylinder Field:** Refinement around rotational axes.
- **Distance & Threshold:** Automatic refinement based on proximity to blade surfaces.



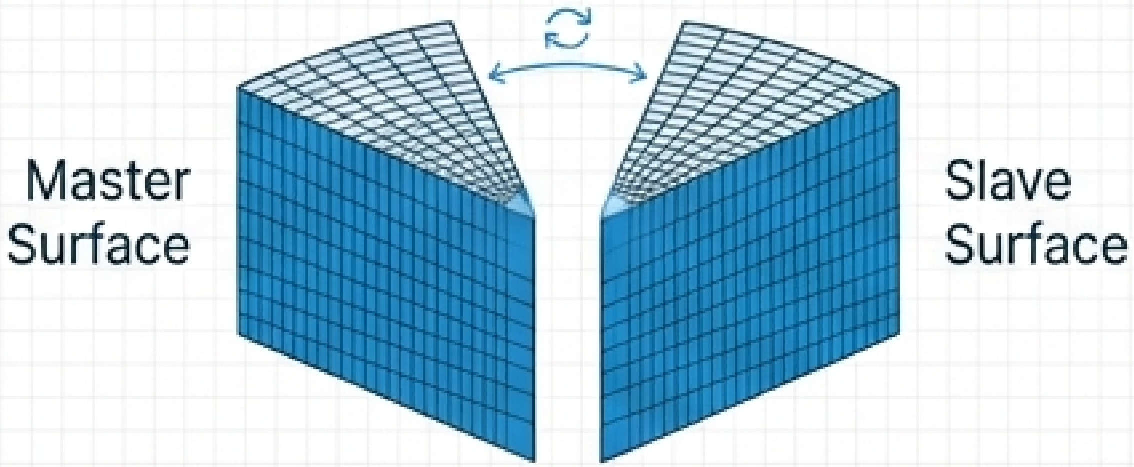
Recombination (T11)

Merging triangular elements into quadrilaterals (Quads) for cleaner numerical gradients in CFD.



Periodic Meshing (T18)

Enforcing identical mesh topology on two corresponding surfaces (slave/master) to allow for cyclic symmetry.



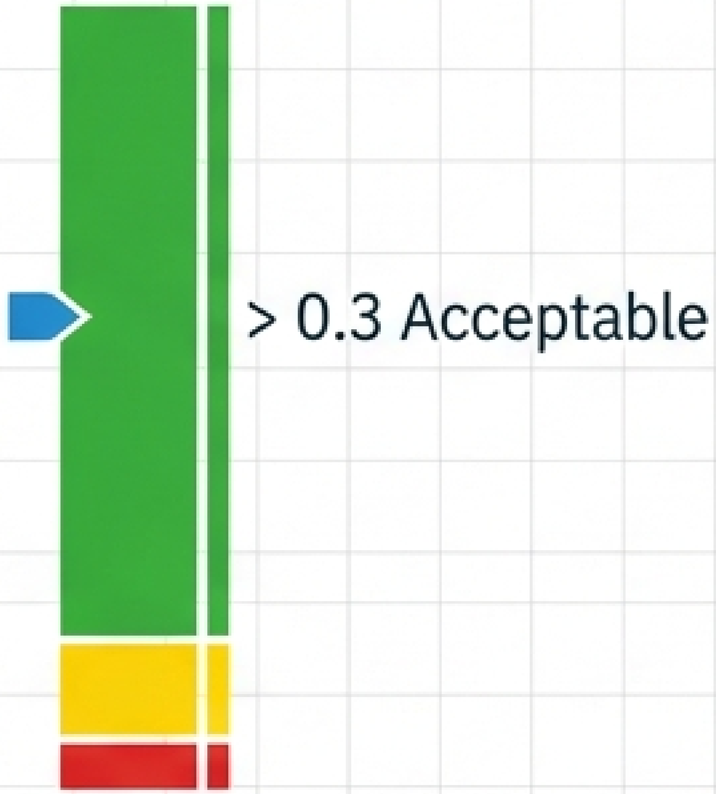
Metrics of Success: Validating Mesh Quality

SCIN (Signed Condition Number)

Measures element distortion/inversion.

SIG (Shape Index)

How close the element is to its ideal equilateral shape.



Gamma (Stretch)

Ratio of inscribed radius to longest edge.

EXP 1: The ‘Black Box’ Failure (Baseline Automesh)

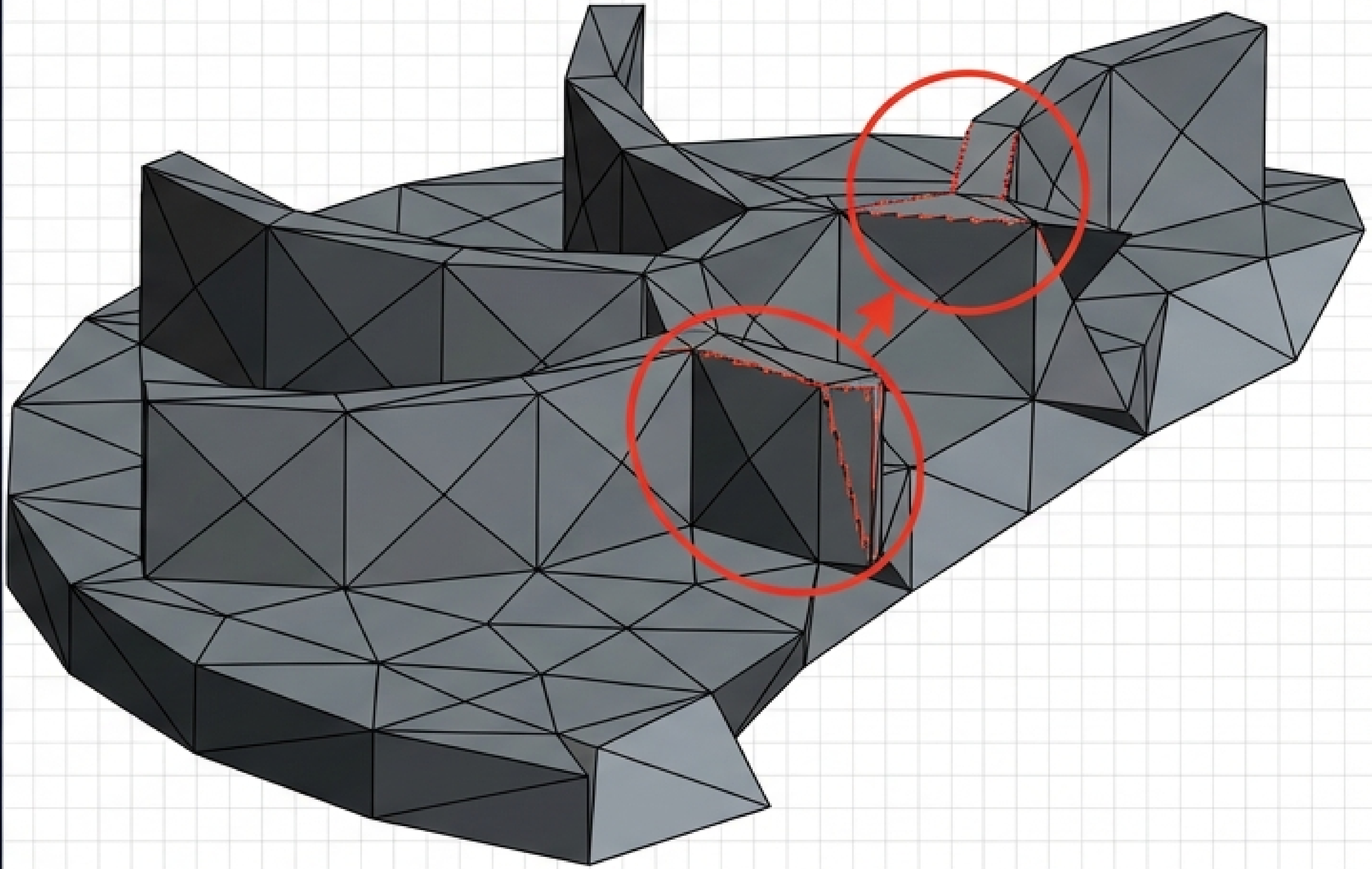
Objective: Test Gmsh’s default 3D kernel on a full impeller STEP file without manual sizing controls.

Outcome: **FAILURE.**

Geometric Decay: Leading edges represented by only 2–3 elements. Smooth aerodynamic curves became "stair-steps".

Volume Inefficiency: Massive, low-quality tetrahedra filled fluid gaps.

Insight: Automesh defaults to bounding-box scaling and cannot detect thin blade requirements.



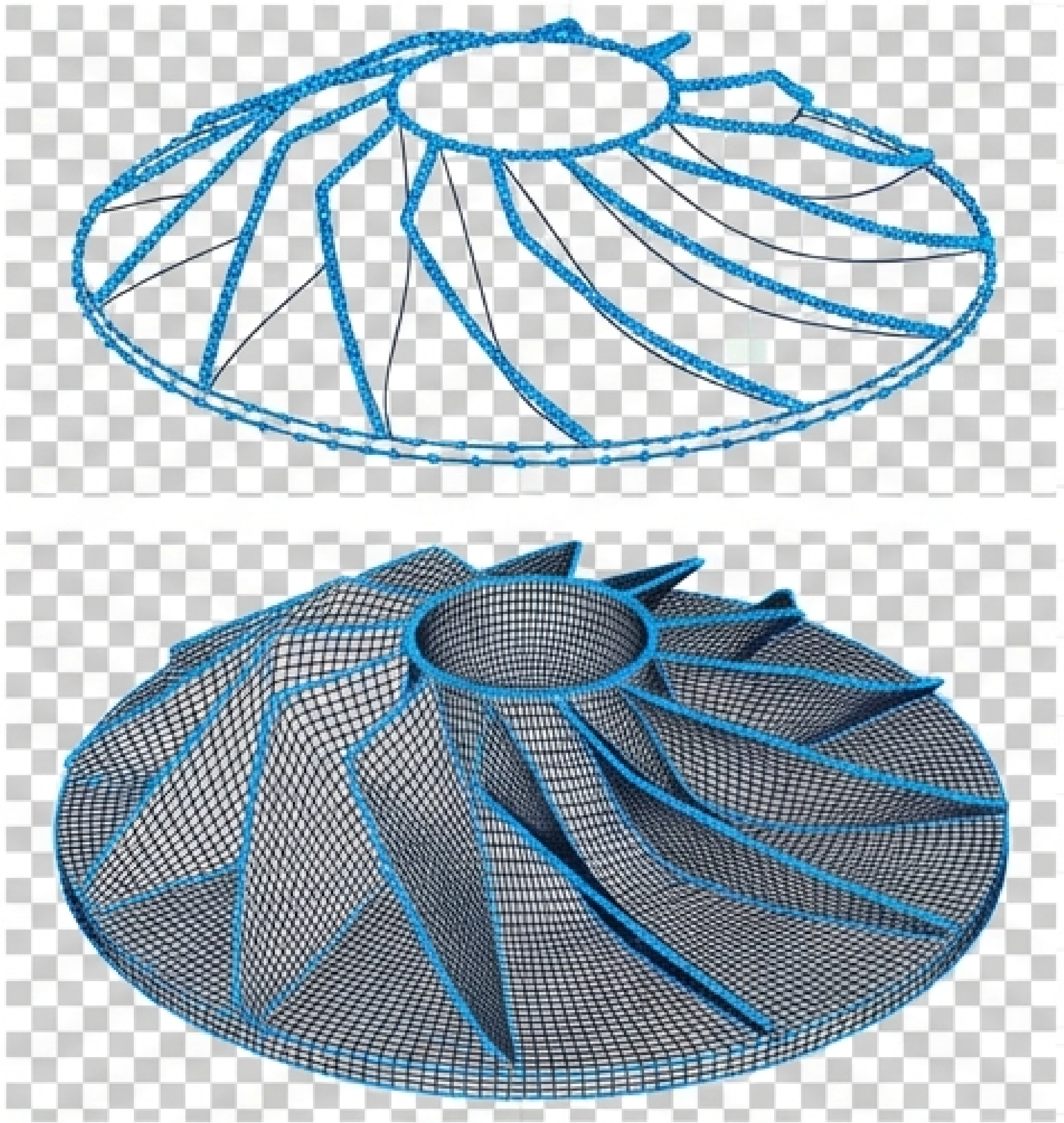
EXP 2: The ‘Rigid Skeleton’ (Global Transfinite)

Objective: Force high fidelity by applying Transfinite constraints (hard node counts) to every curve.

Outcome: **INEFFICIENT.**

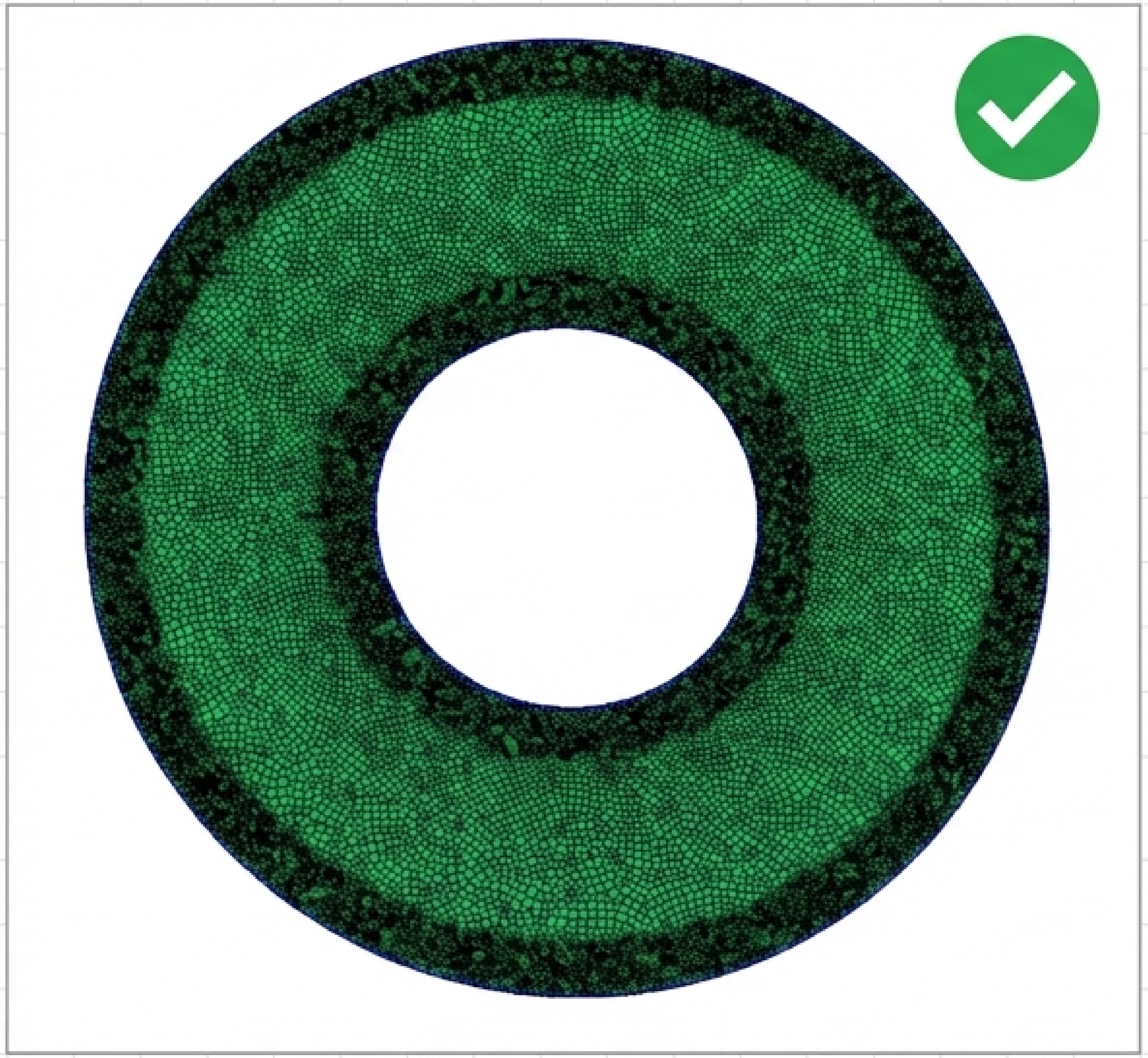
The Stiffness Problem:
The mesh became a rigid skeleton. While edges were detailed, the interior volume struggled to connect these dense borders.

Insight:
We need functional refinement (physics-based), not just geometric refinement (edge-based).



Over-constrained edges lead to poor internal volume transitions.

EXP 3: The Breakthrough (Field-Based Refinement)



Objective: Implement a sizing function dependent on proximity to the blade, rather than hard-coded edges.

Methodology: Distance Field + Threshold Field.

Outcome: **SUCCESS.**

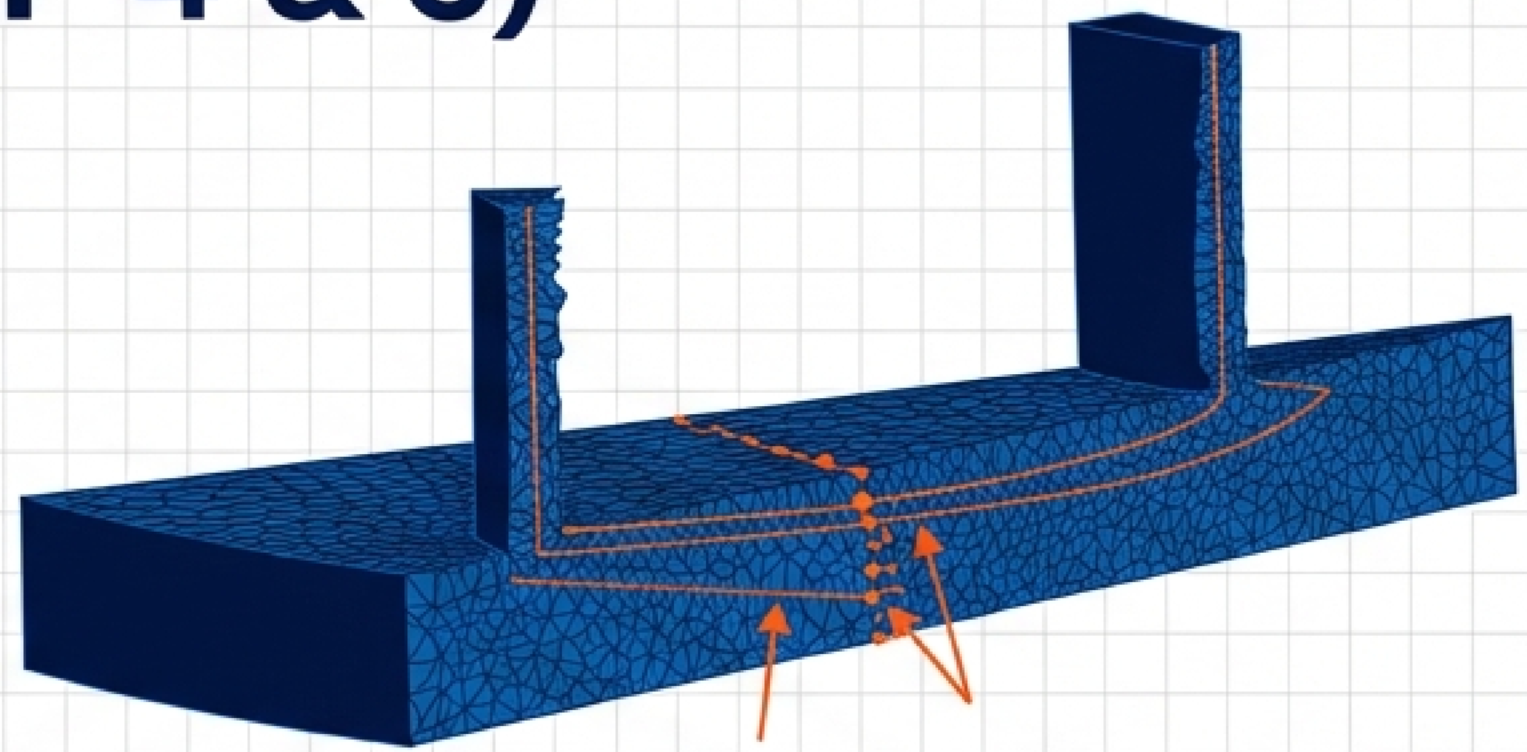
Achieved a ‘halo’ of high fidelity around the blade, transitioning smoothly to coarse elements.

```
Field[1] = Distance; Field[1].SurfacesList = {Blade_IDs};
Field[2] = Threshold; Field[2].IField = 1;
Field[2].LcMin = 0.5; Field[2].DistMin = 2;
```

The Symmetry Trap (EXP 4 & 5)

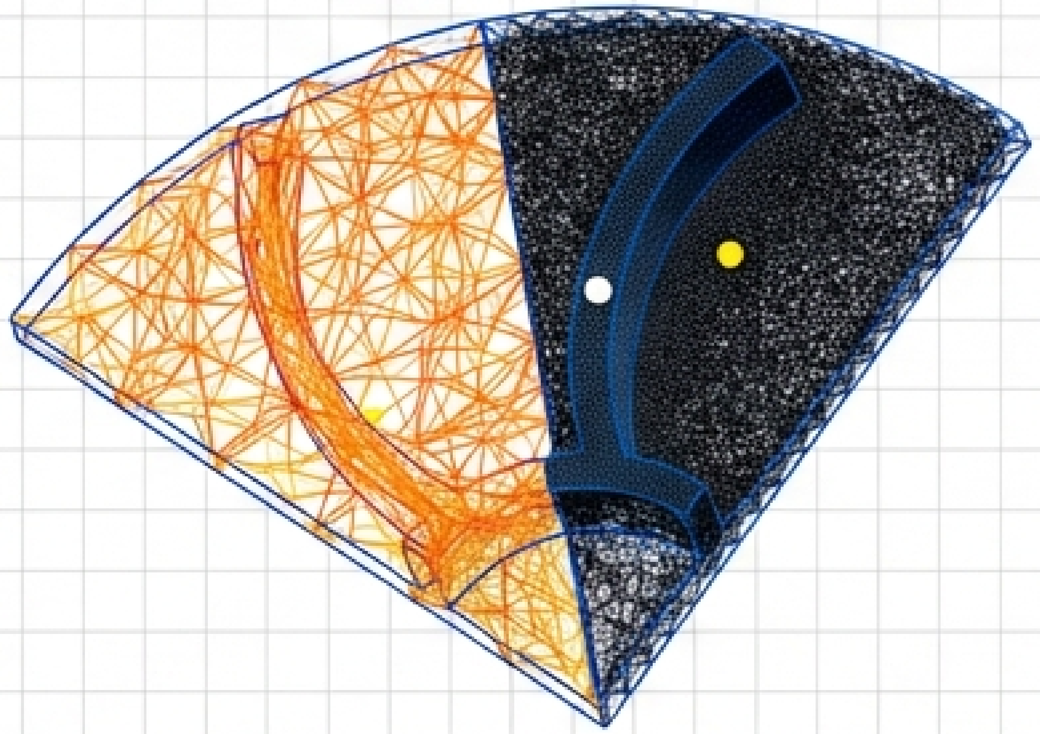
EXP 4: Partitioning Failure ⚠

Sliced geometry in FreeCAD ->
→ Resulted in Non-conformal nodes.
Left face mesh did not match right face mesh.



EXP 5: Transformation Limits

Used Gmsh Rotate command ->
Geometry rotated, but Mesh did not.
Gmsh re-meshed every sector randomly, destroying symmetry.



Insight: Gmsh architecture does not support direct mesh transformation (copy/paste of elements).

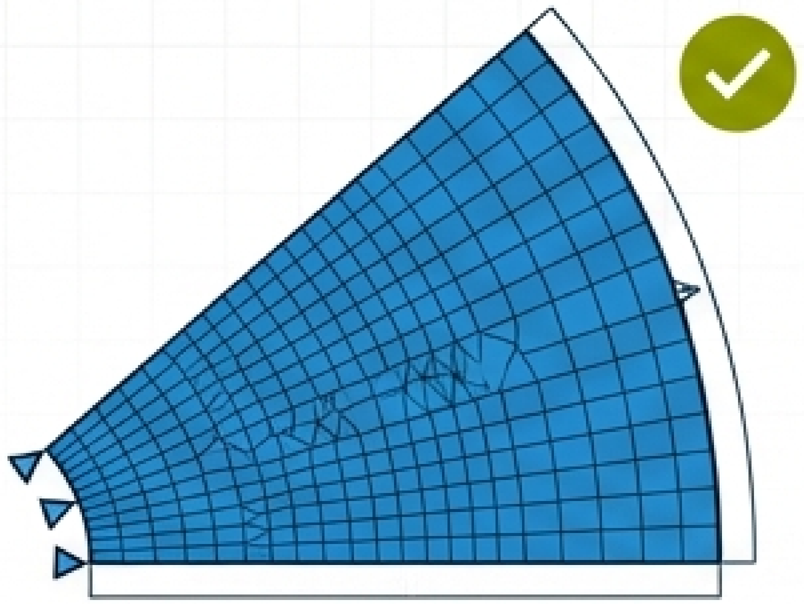
Bridging the Gap: Periodicity & Cross-Platform Analysis

EXP 6: Periodic Linking (Partial Success)

Helvetica Now Display Medium

Used "Periodic Surface" command to force node-identity between Master and Slave faces.

Ideally connected sector, but Gmsh still could not generate full 360-degree mesh as a single file.

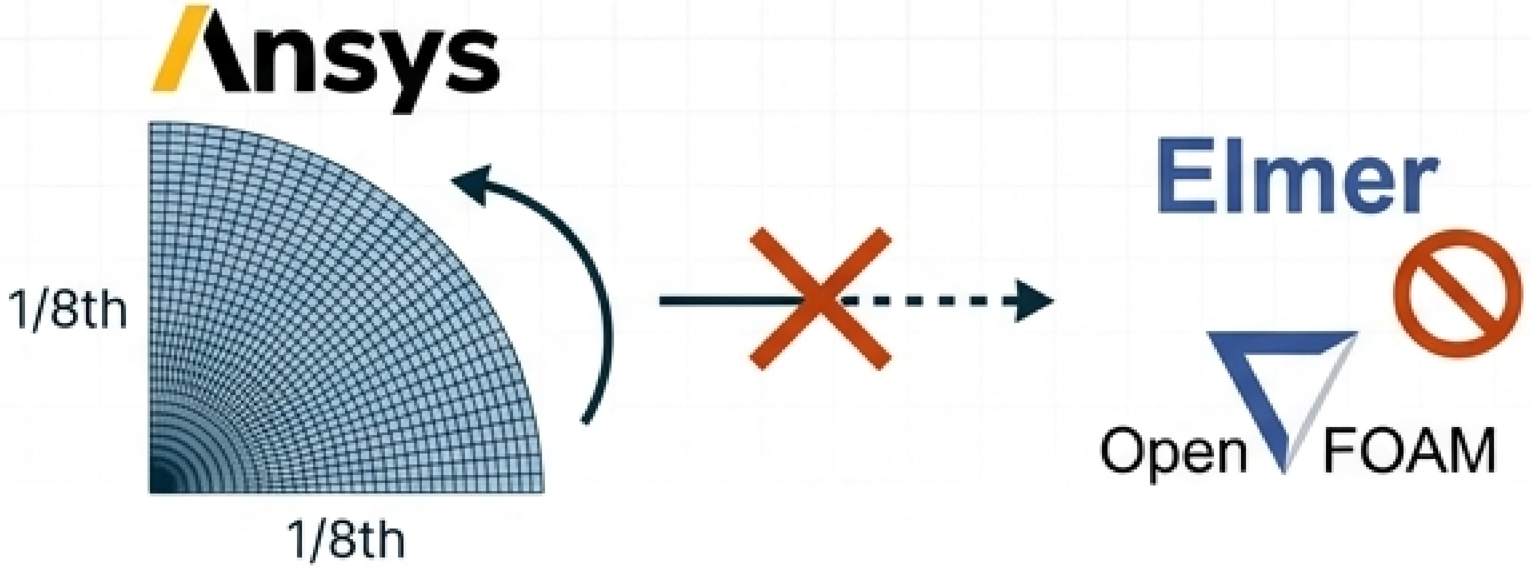


EXP 7: The Ansys Pivot (Dead End)

Helvetica Now Display Medium

Imported 1/8th mesh into Ansys ICEM CFD.

Successfully rotated mesh, but **FAILED** to export back to open-source formats (Elmer/OpenFOAM) without losing tags.



Proprietary tools are a dead end for this open-source workflow.

The Final Verdict: Recommended Workflow

Isolate Sector

Create 1/8th geometry.

Field Refinement

Apply Distance/ Threshold fields.

Periodic Constraints

Define Master/Slave boundaries.

Export Sector

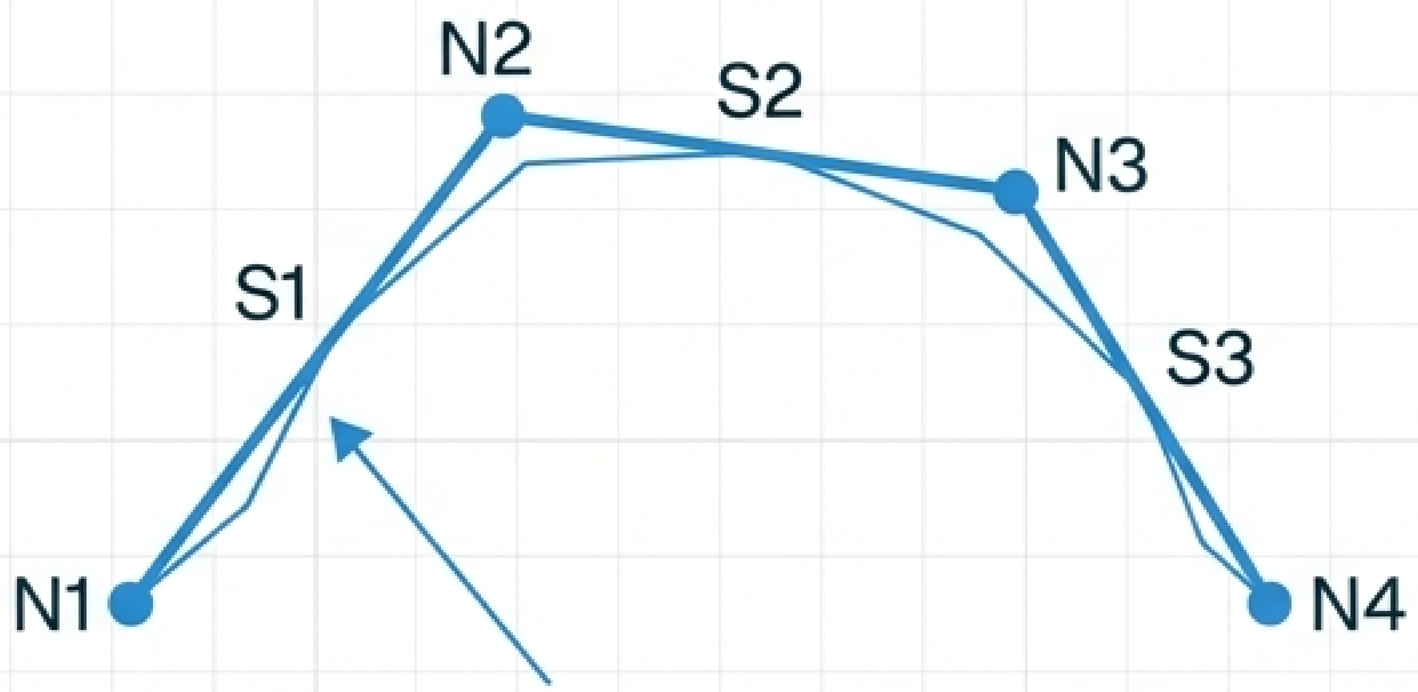
Export .msh/.unv (Do not rotate in Gmsh).

Solver Duplication

Config Solver (OpenFOAM/ Elmer) for 360° rotation.

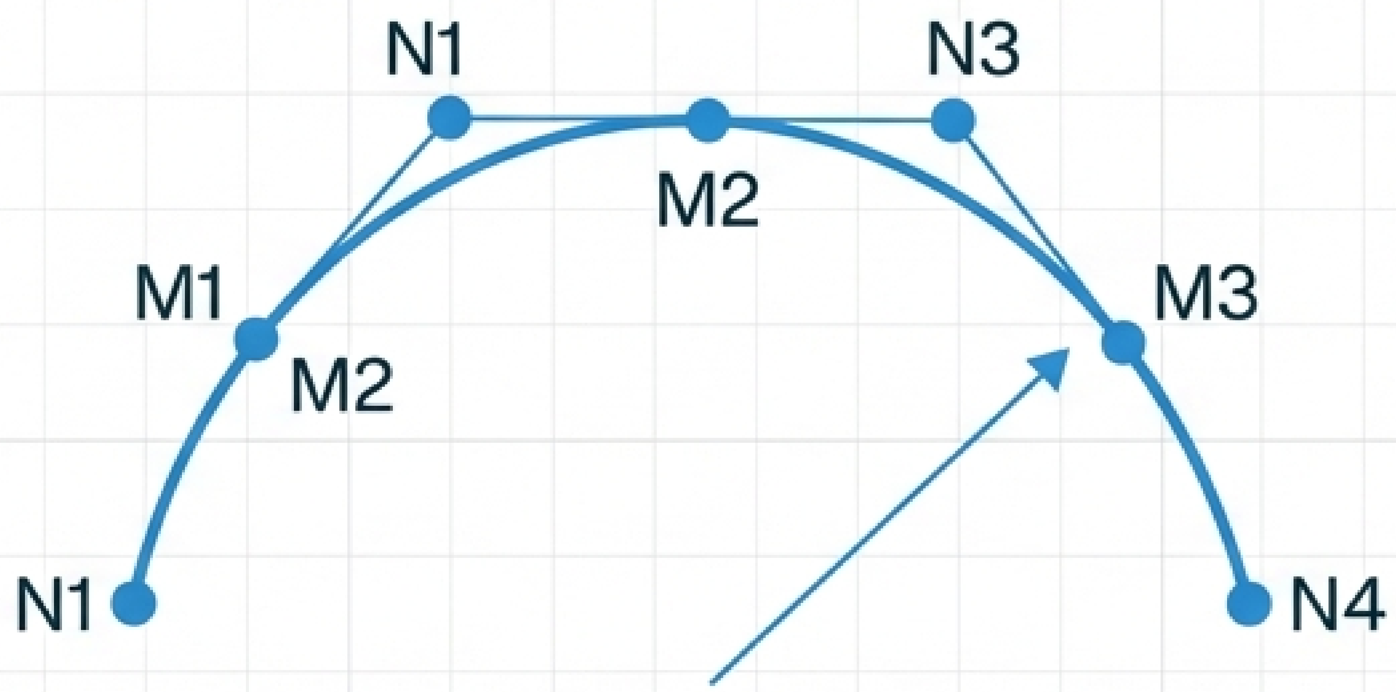
Technical Deep Dive: Why 2nd Order Elements?

Linear (1st Order)



Straight edges. Faceted representation. Creates artificial turbulence.

Quadratic (2nd Order)



Curved edges. Captures true geometry. Preserves surface normals for accurate lift/pressure.

```
Set Polynomial Order -> 2
```

Gallery of Results: The Optimized Mesh

Final Output: Structured-like quality using unstructured algorithms. Fully compliant with periodic solver requirements.

Conclusion & Future Outlook

Key Takeaways

- **Control:** Gmsh is powerful only when controlled via Fields, not global defaults.
- **Symmetry:** Mesh periodicity belongs in the Solver, not the Mesher.
- **Platform:** Established a robust, open-source pipeline rivaling proprietary tools.

Next Steps

→ Import periodic sector into Elmer/OpenFOAM.

→ Configure Cyclic Boundary Conditions.

→ Run full CFD validation.