Blender - An Automated Mesh Morphing Blending Tool to Extend Blend Limits for Inserted Blade and Bladed Rotors

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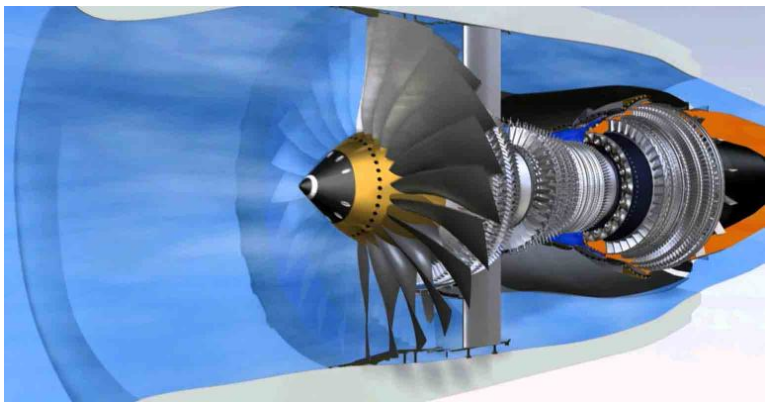
2019 PS&S CONFERENCE

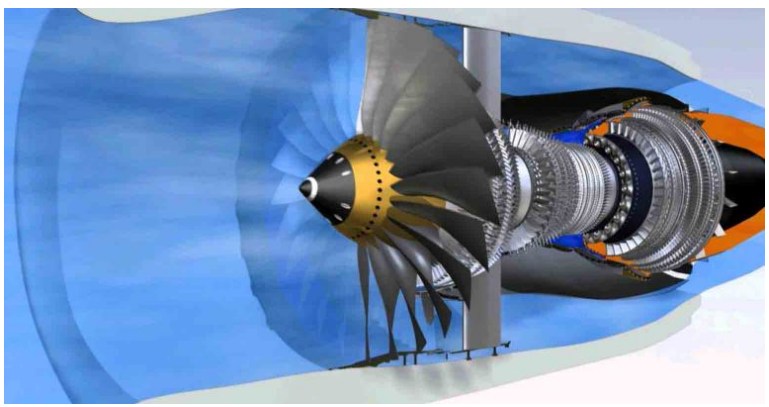
Overview

- RQTI in-house team developing methods to build validated as-manufactured component models
- Use large populations of components to quantify uncertainty
- Take advantage of this information to change durability criteria
- This work describes part specific airfoil blending analysis



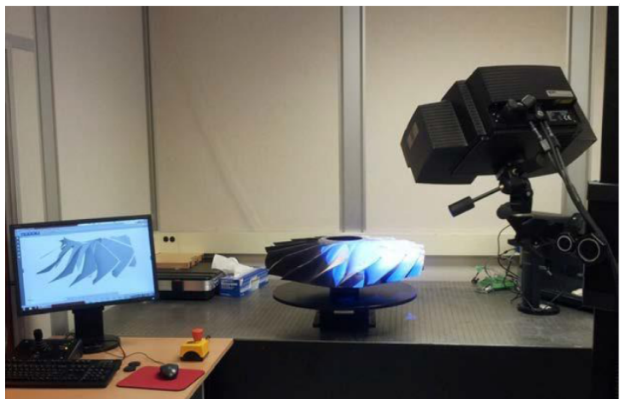
Blended Repairs

- Blends are an affordable method of repair
- On-wing blending capability increases ATOW
- A part specific approach can lead to extension in blend limits and significant cost savings



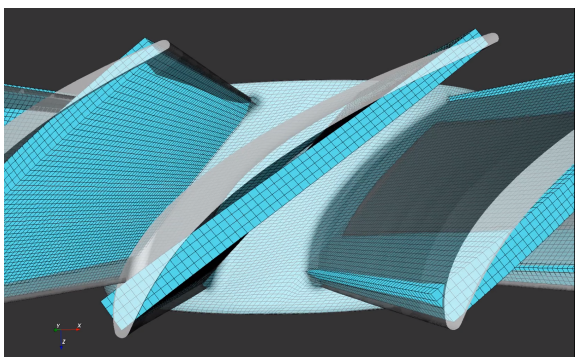
Enablers for Part-Specific Blend Analysis

- Increased understanding of variations in mechanical and aerodynamic behavior
- Rigorously validated analysis and test methodologies
- Advanced measurement systems for geometry, material properties, bench, and operational response
- Automated analysis work flows with robust computational grid permutation

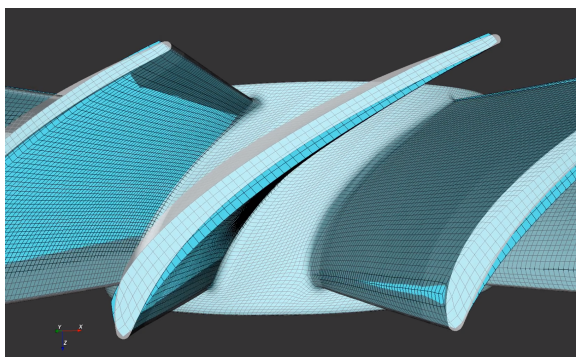


Automation and Permutation with FEMORPH, Blender, and PyIBR

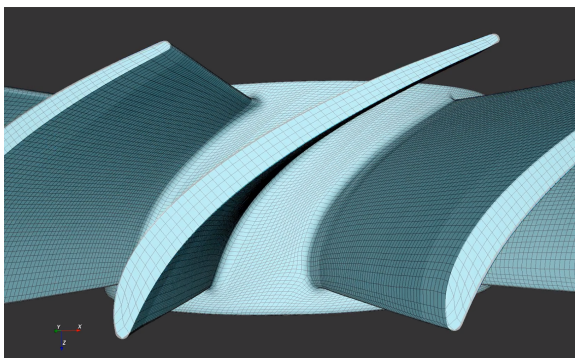
- FEMORPH maps exiting computational meshes to defined target surfaces (CMM points, point clouds, *.stl)
- Blender parametrically defines blends and modifies target surface
- PyIBR automates the use of FEMORPH, Blender, FEM solution, and post processing



Before Morphing



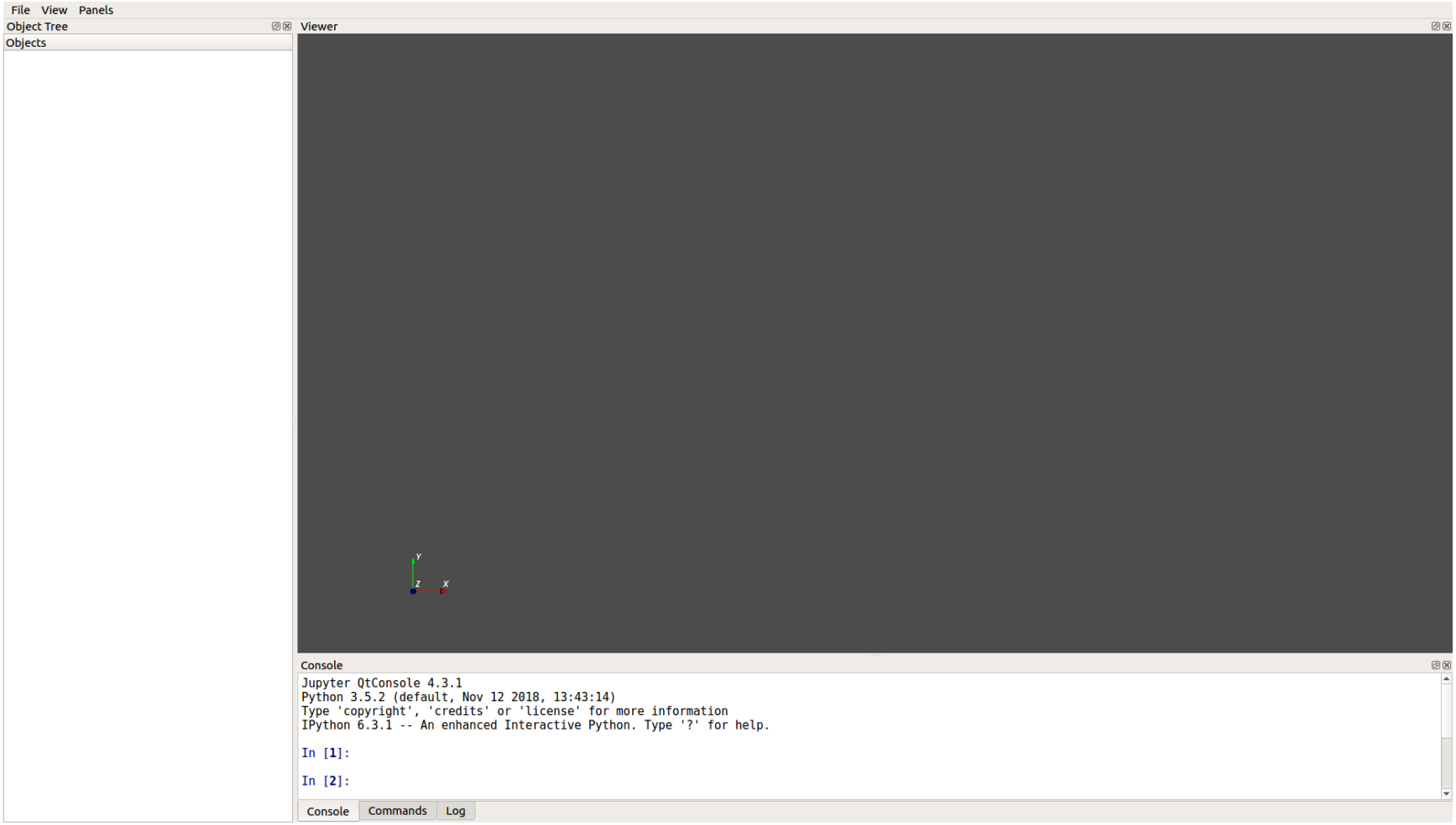
Mid Morphing



After Morphing

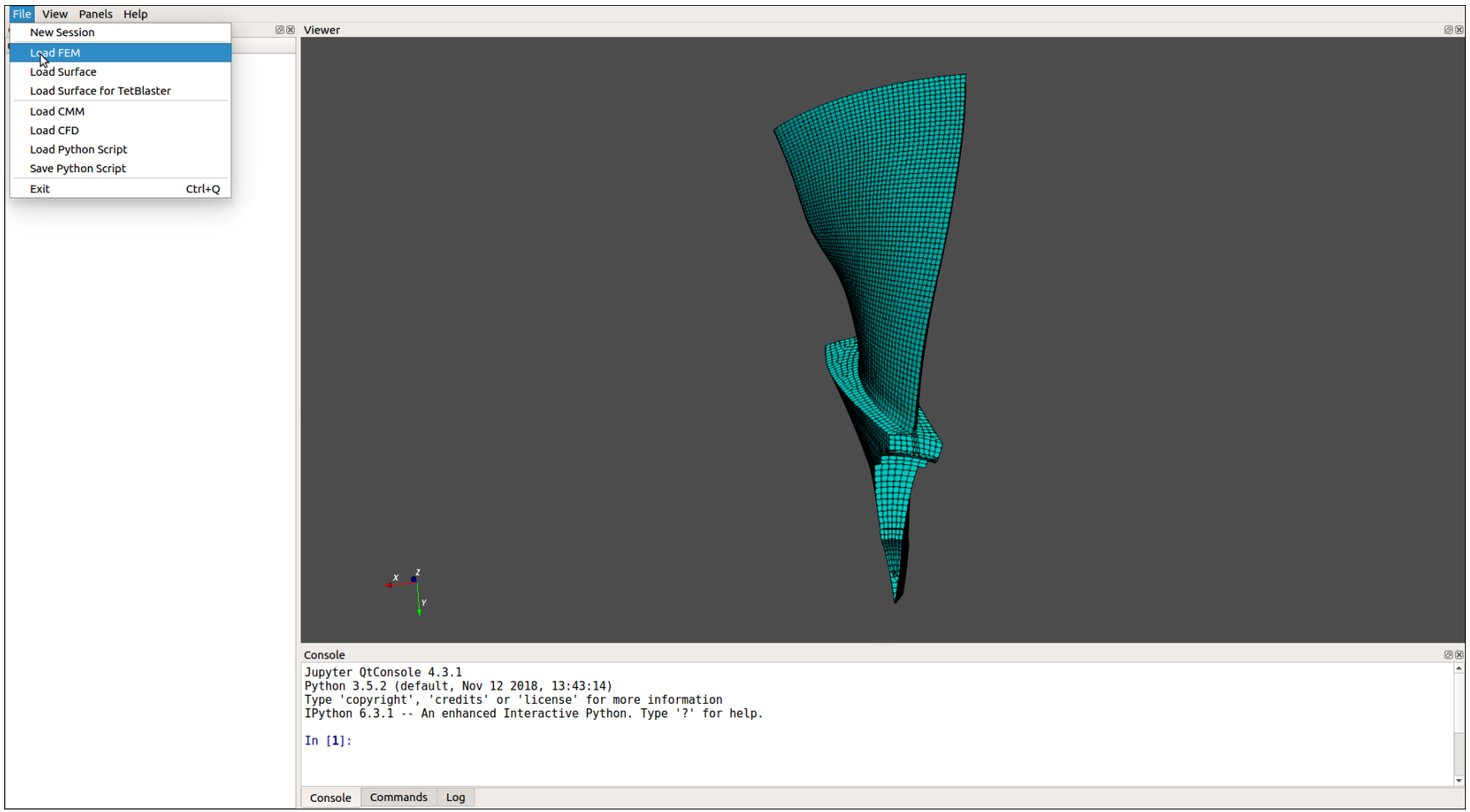
FEMORPH and Blender Process

FEMORPH Graphical Interface



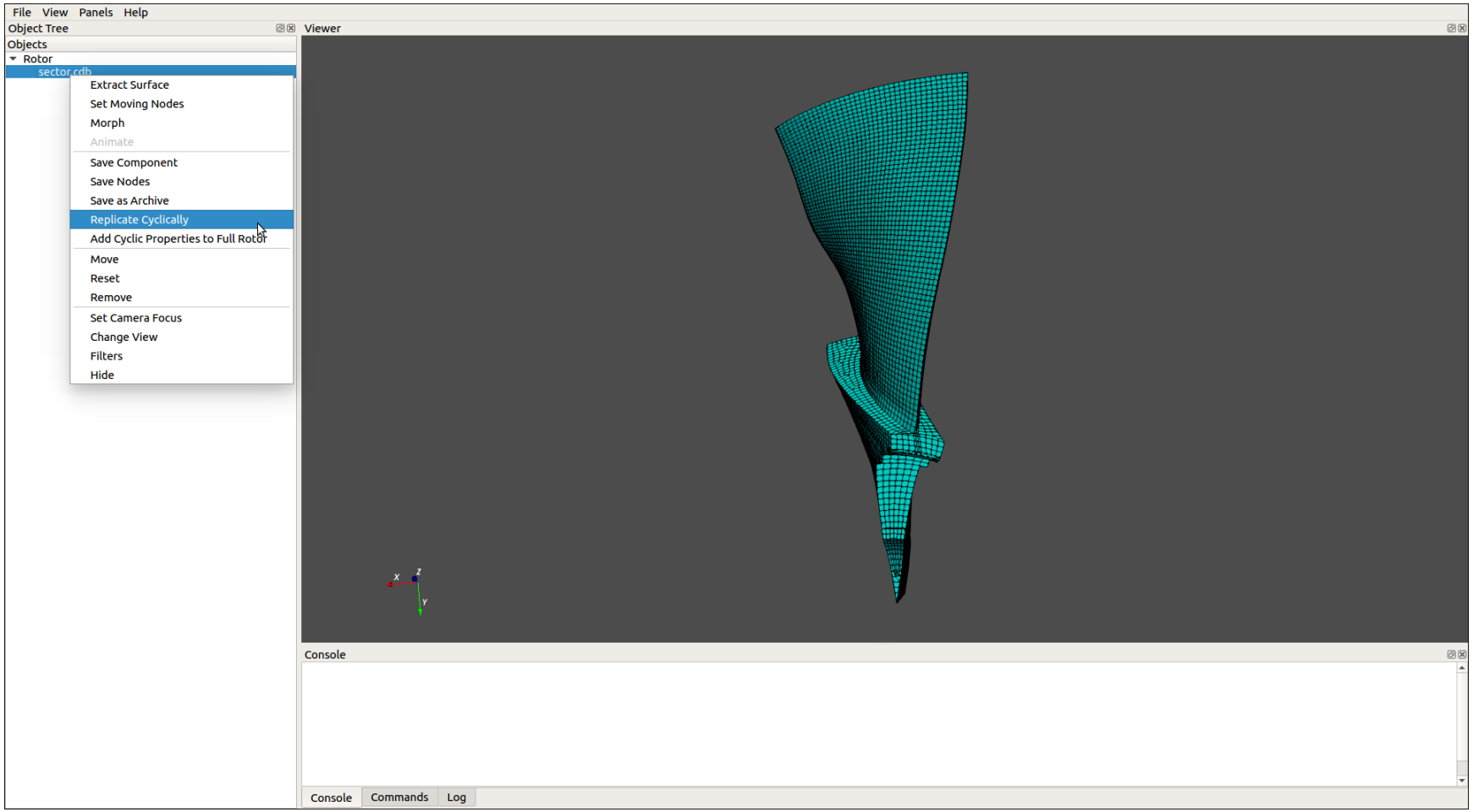
FEMORPH Graphical Interface

Load Cyclic ANSYS FEM (*.cdb)



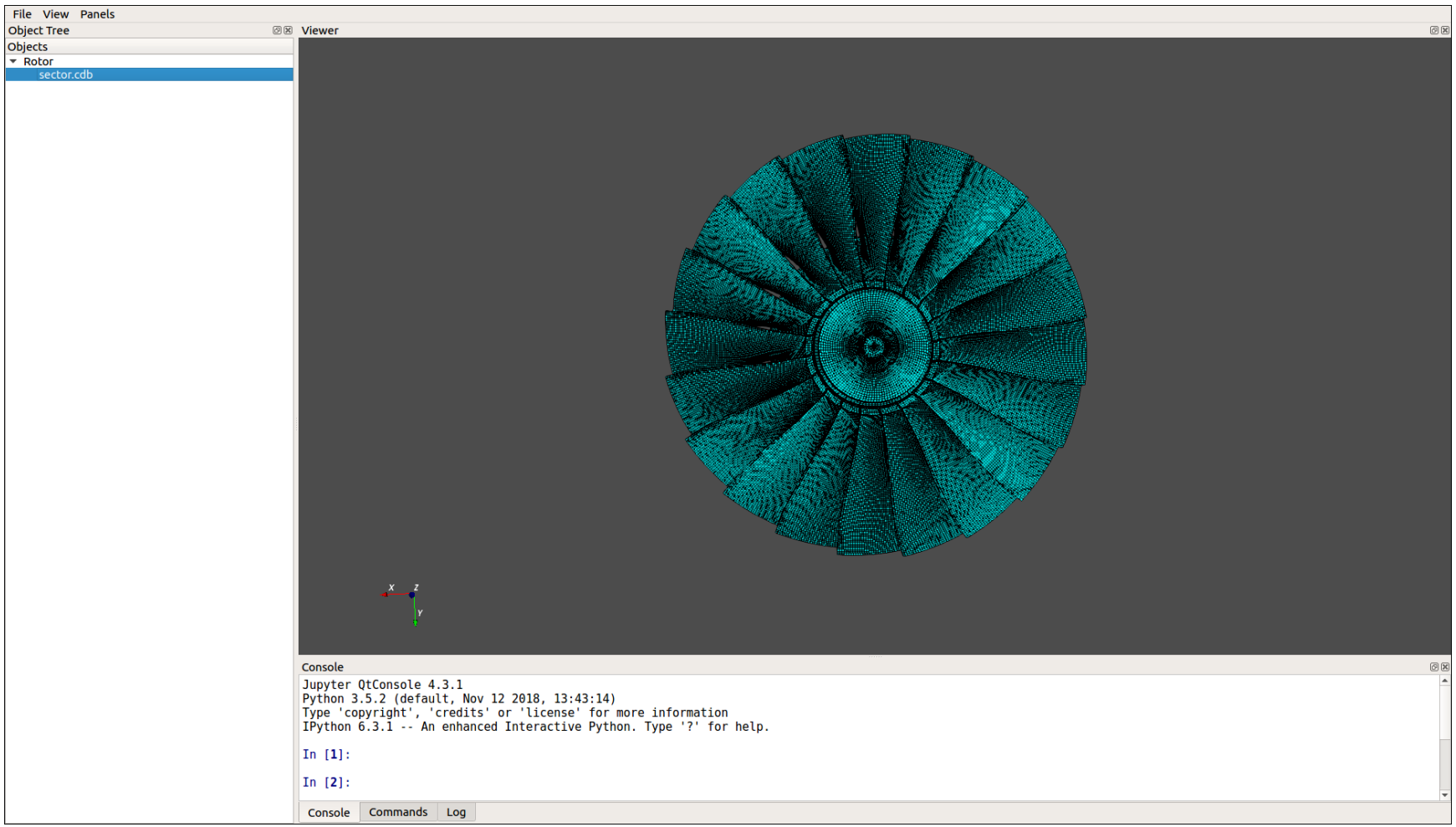
FEMORPH Graphical Interface

Replicate Sectors for Full Rotor



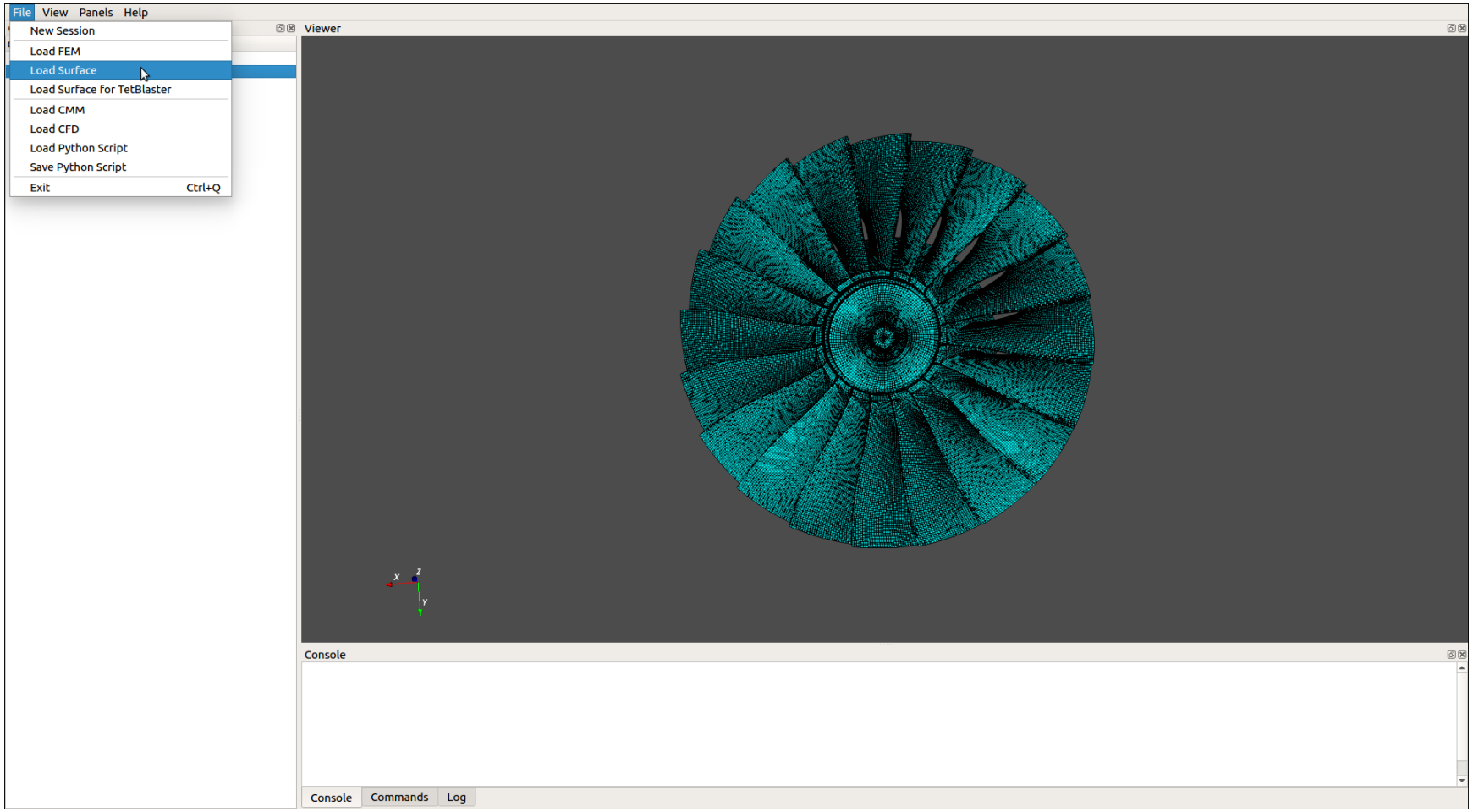
FEMORPH Graphical Interface

Full Rotor FEM



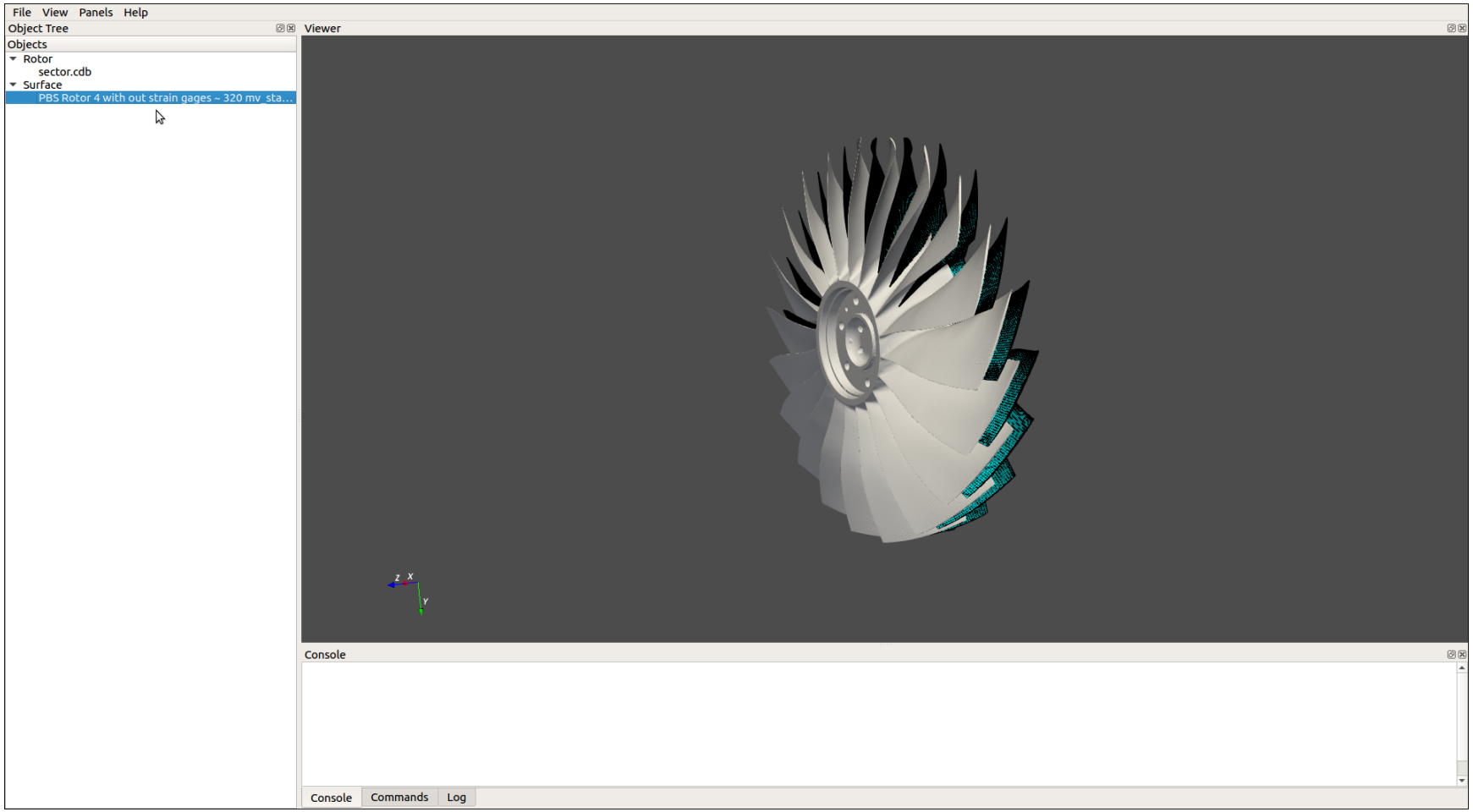
FEMORPH Graphical Interface

Import 3D Point Cloud *.stl



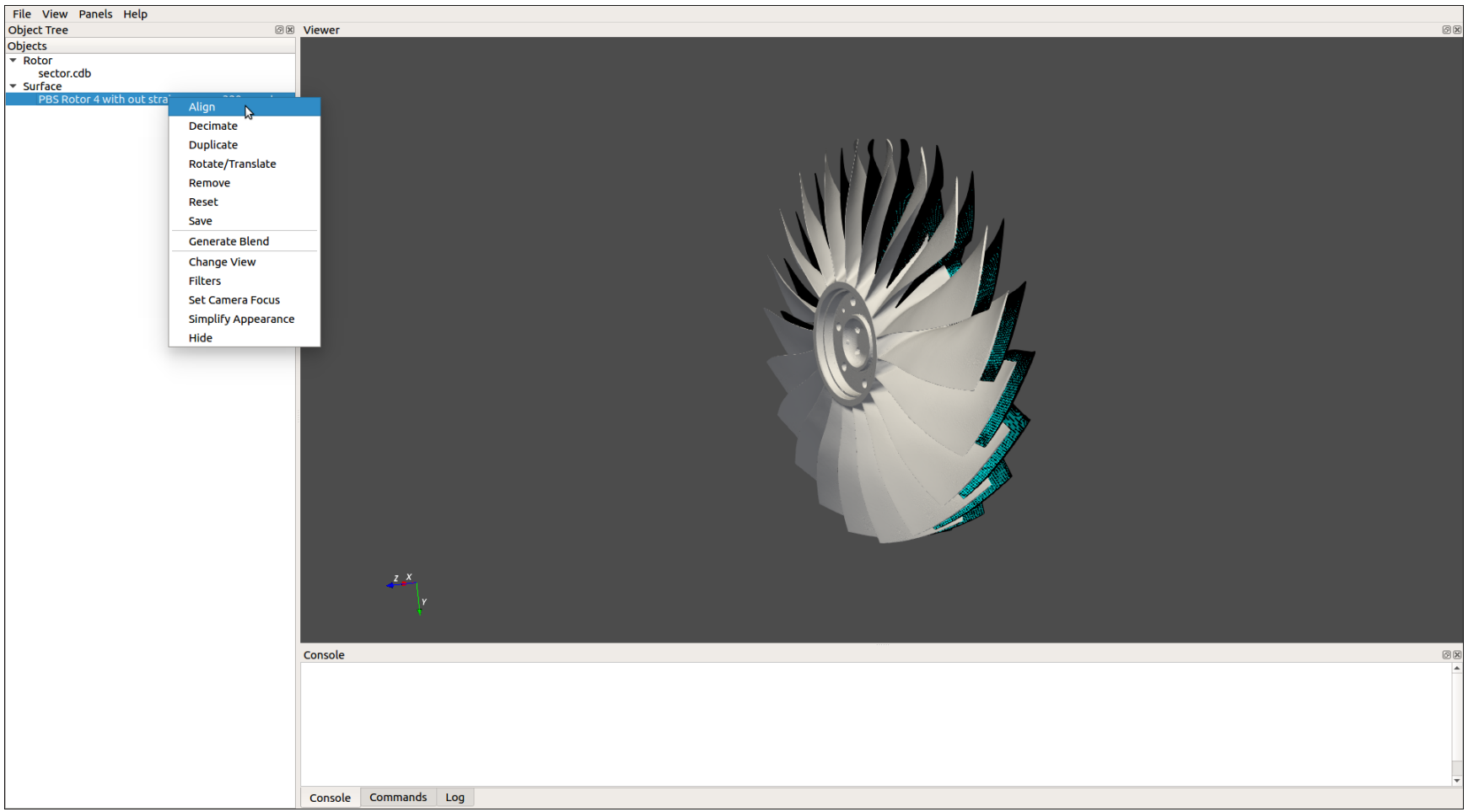
FEMORPH Graphical Interface

Imported 3D Point Cloud



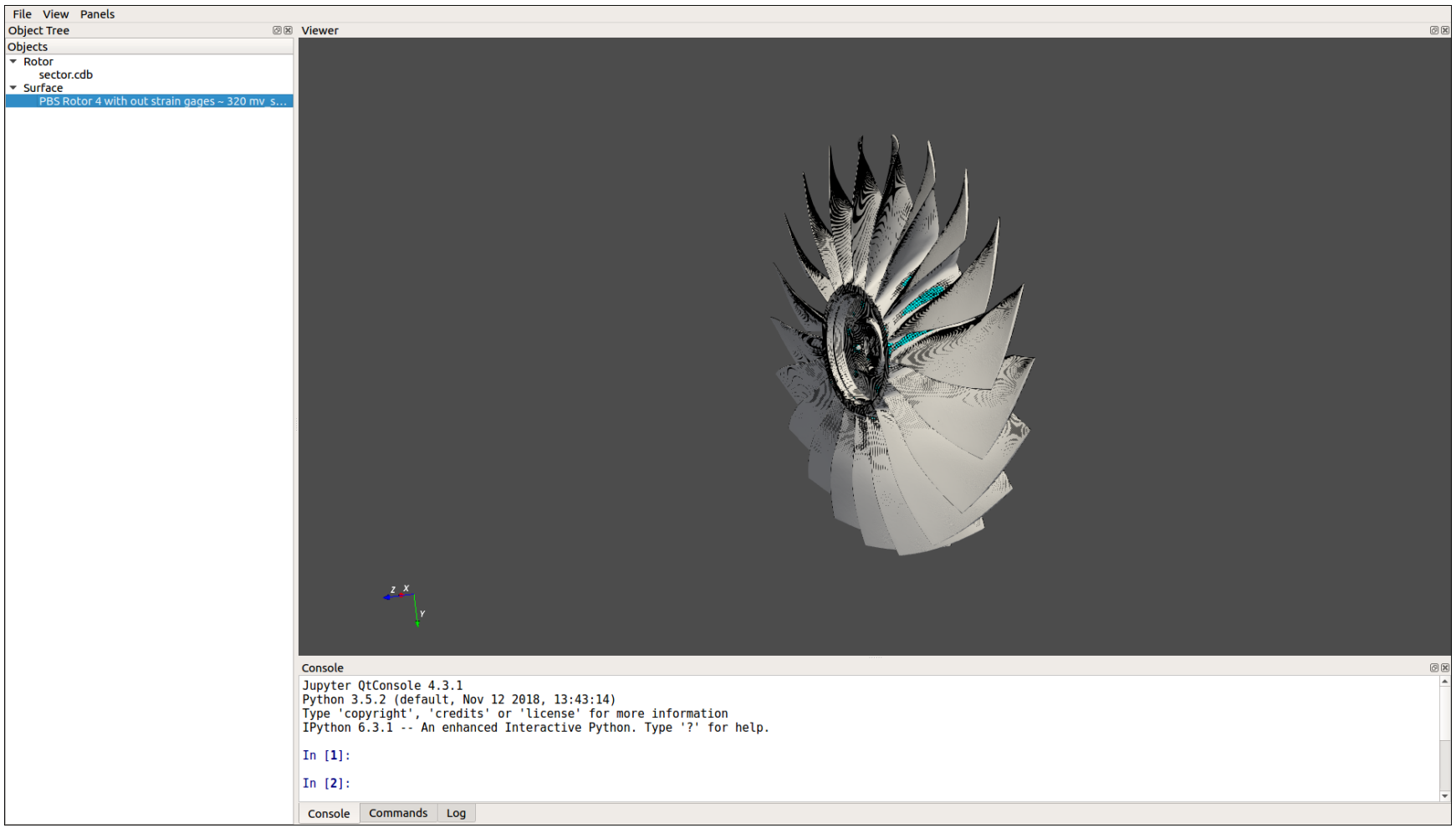
FEMORPH Graphical Interface

Align 3D Point Cloud with FEM



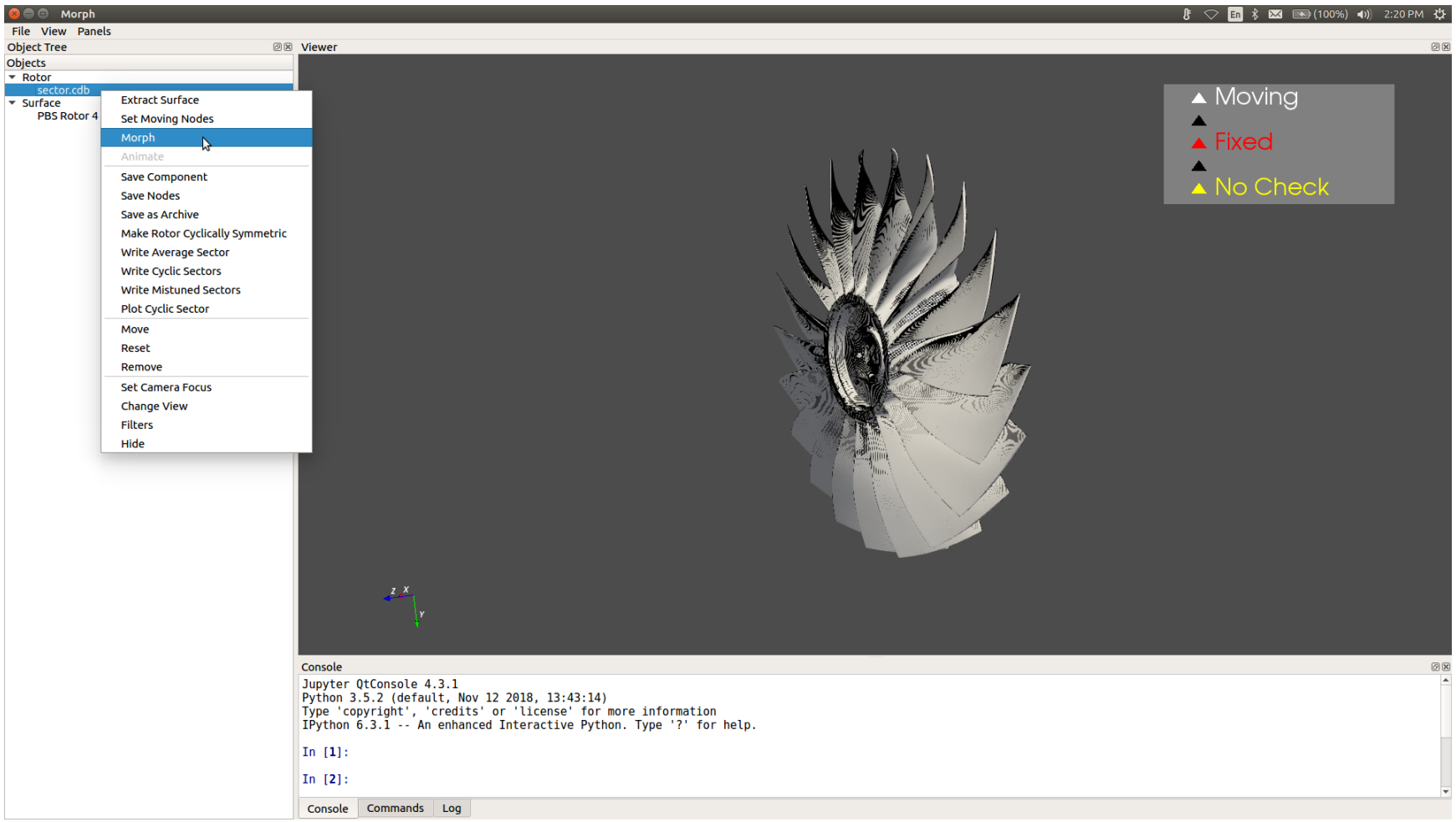
FEMORPH Graphical Interface

Aligned Data Sets



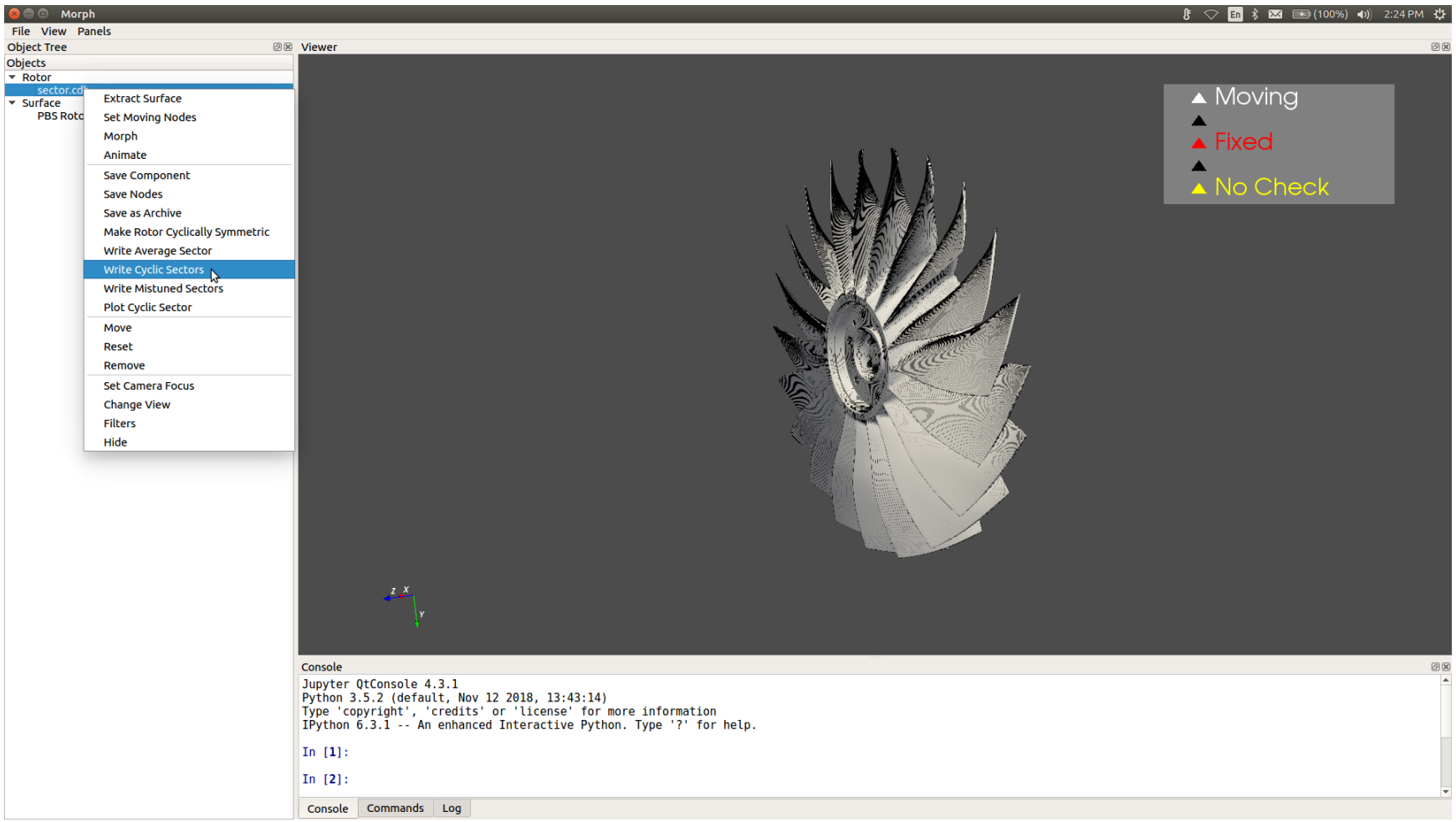
FEMORPH Graphical Interface

Morph - Transformation time: 65 seconds, 4 core i5-6300HQ @2.30Ghz, 8GB RAM



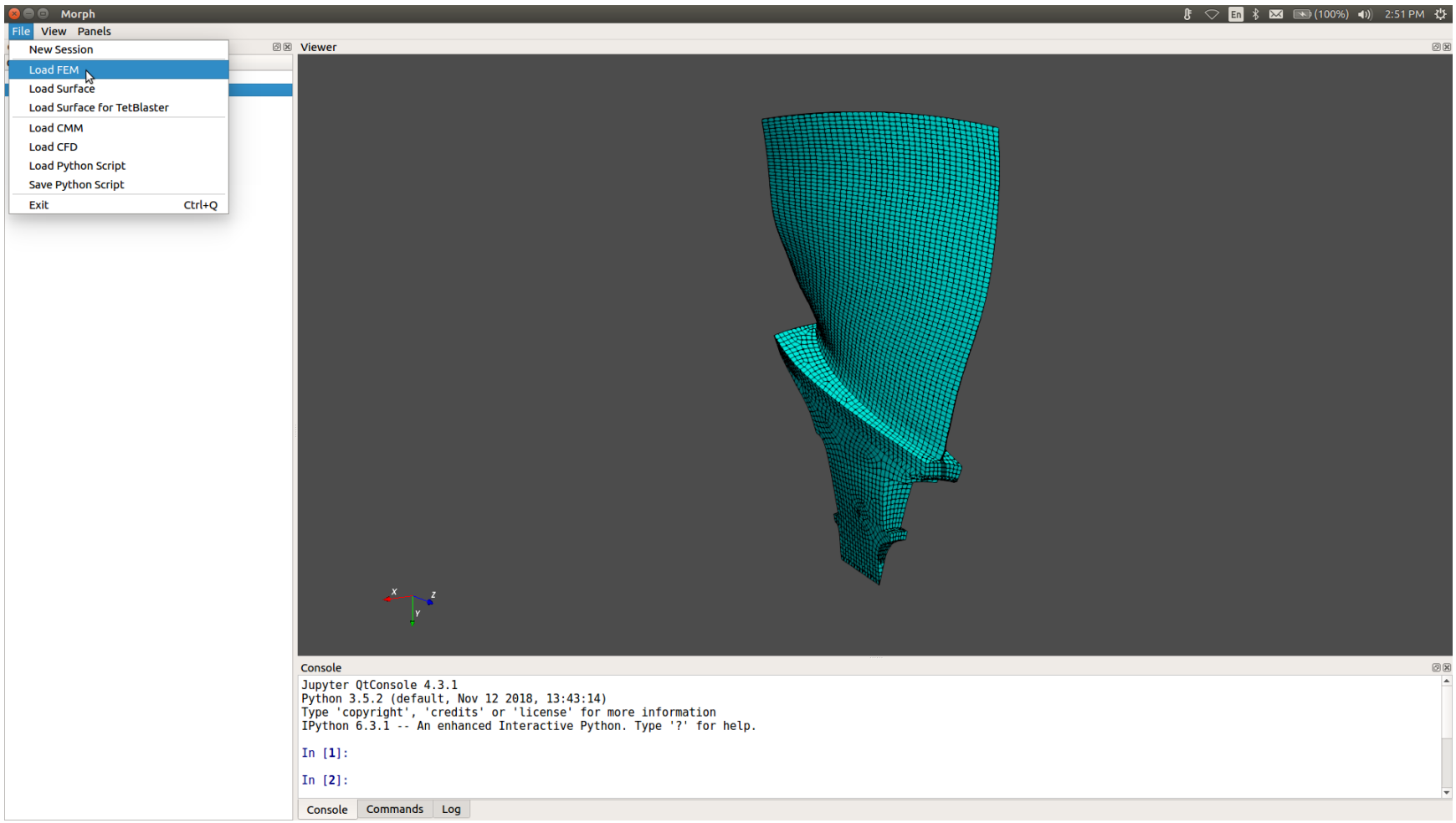
FEMORPH Graphical Interface

Write Average, Cyclic Sector, and Full Rotor .cdb or NBLOCK file



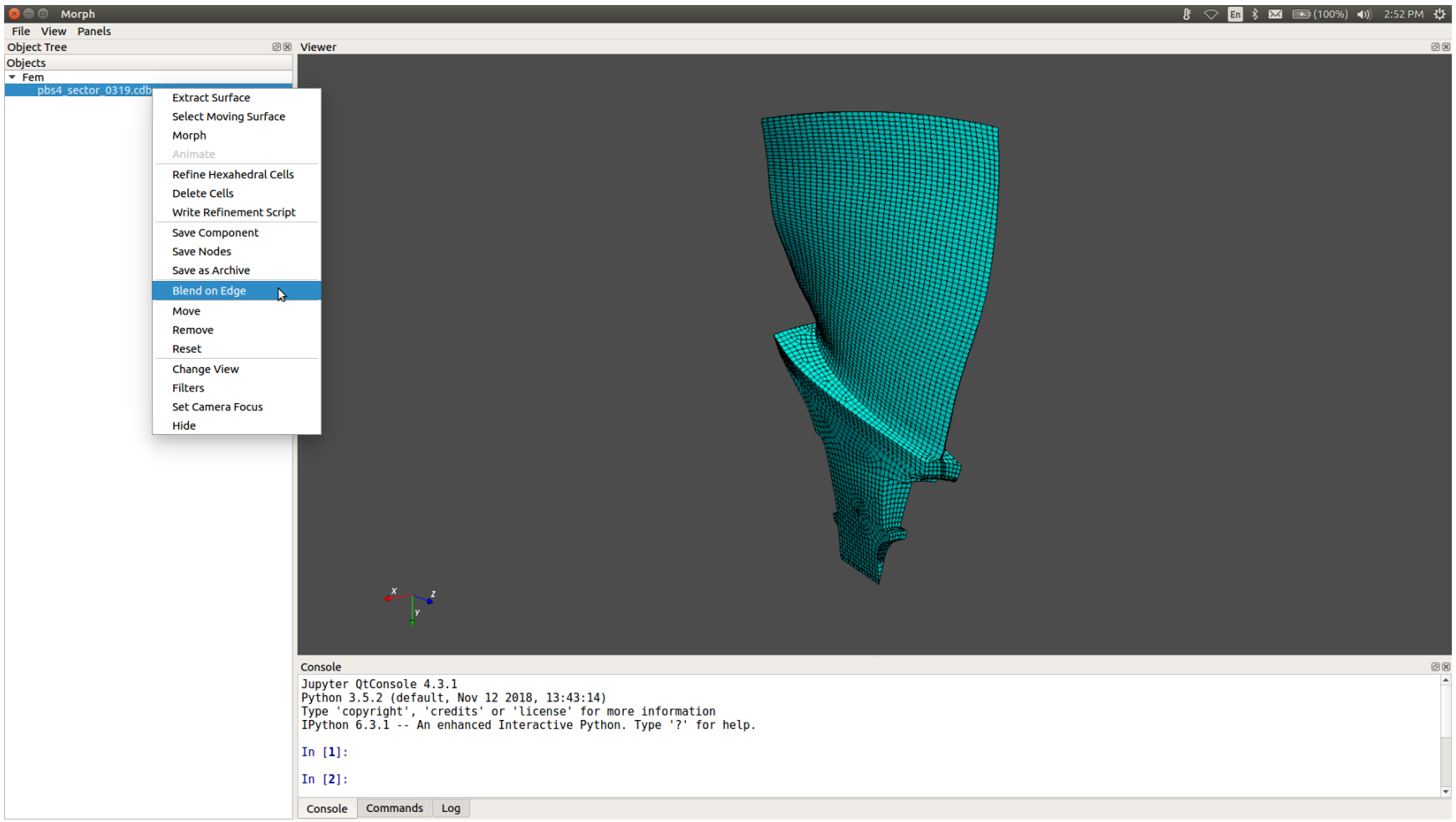
FEMORPH Graphical Interface

To blend a morphed sector, load a morphed sector .cdb File



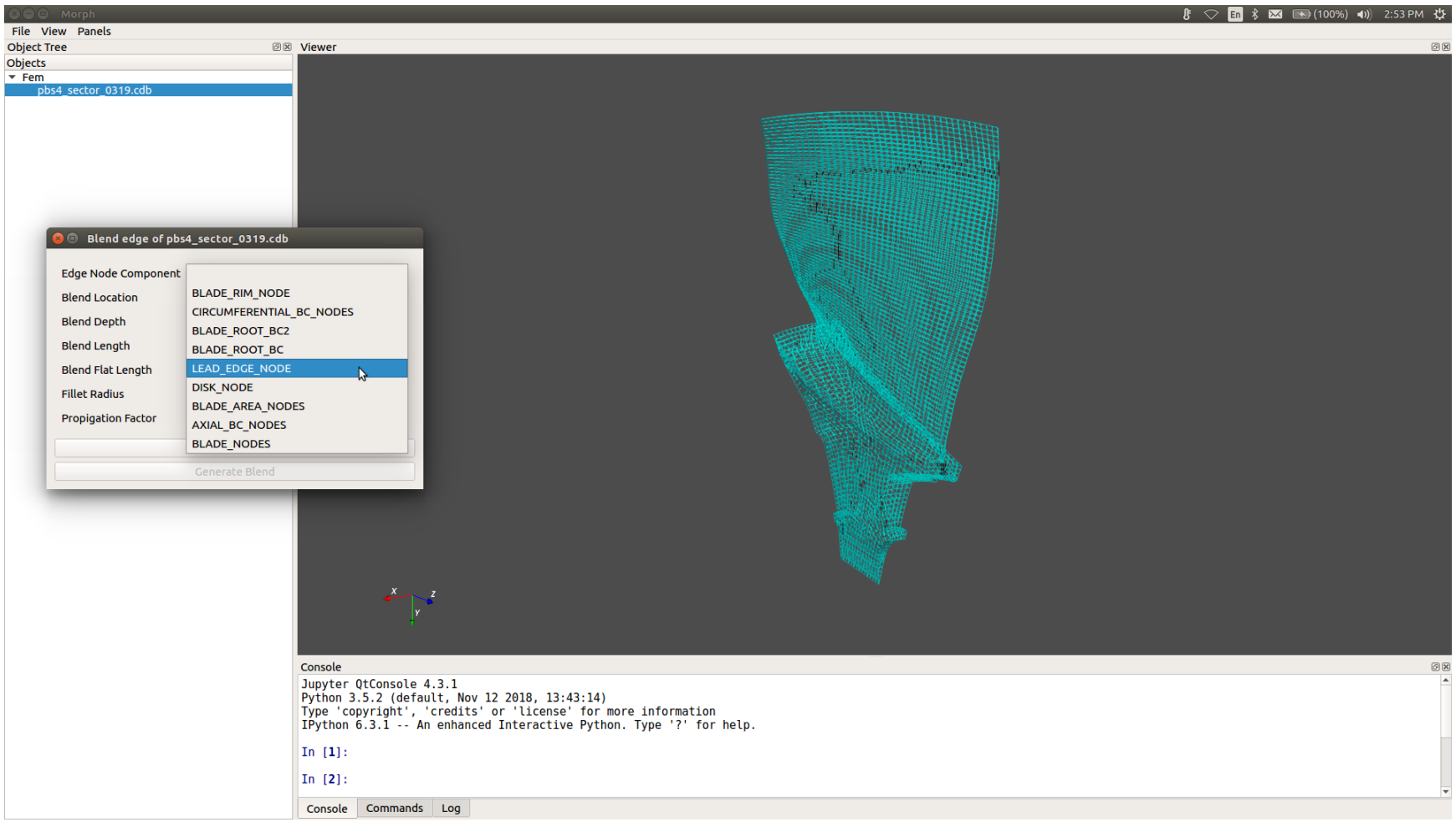
FEMORPH Graphical Interface

Select Blend on Edge



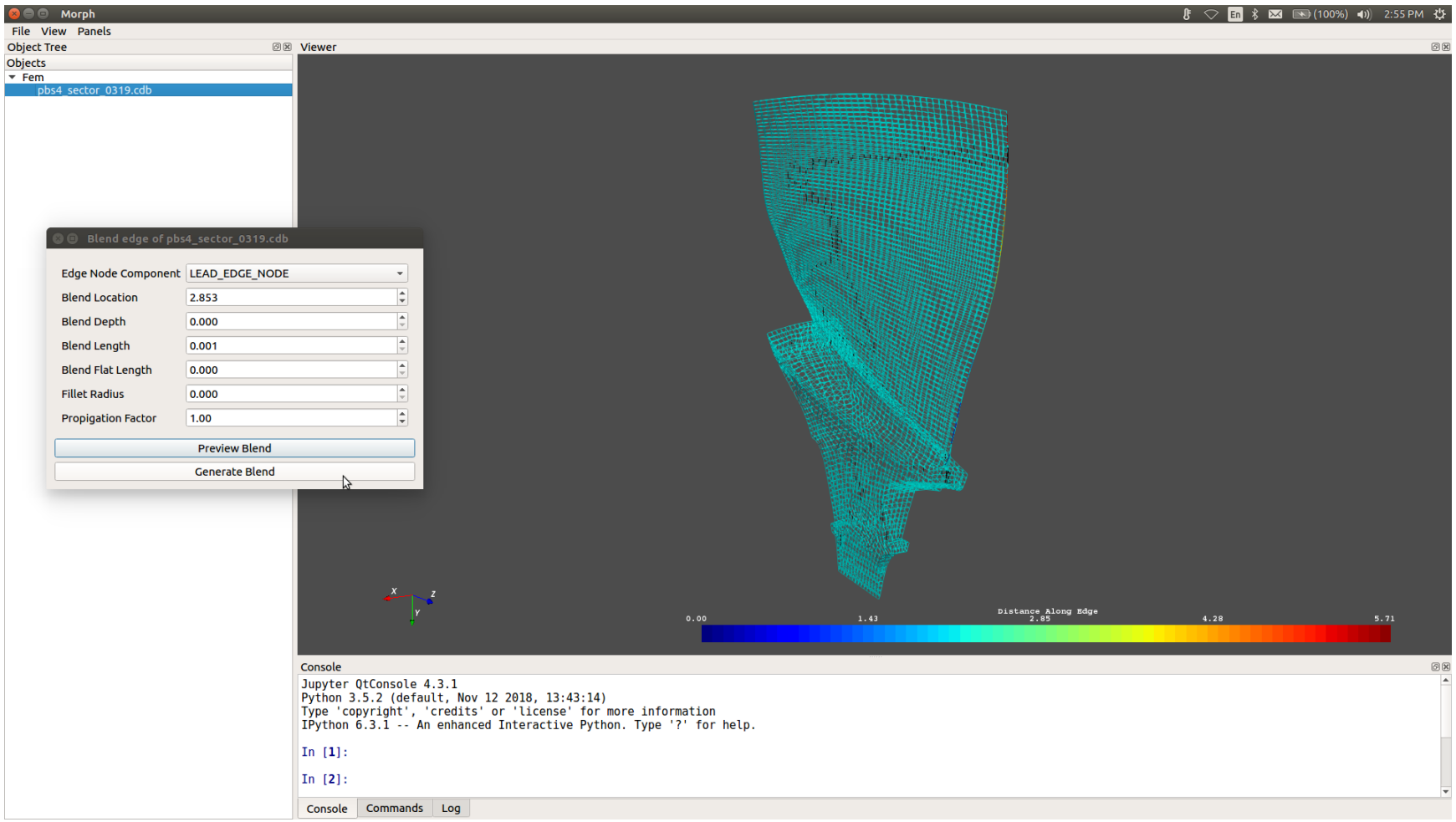
FEMORPH Graphical Interface

Select defined NODE component with leading edge nodes



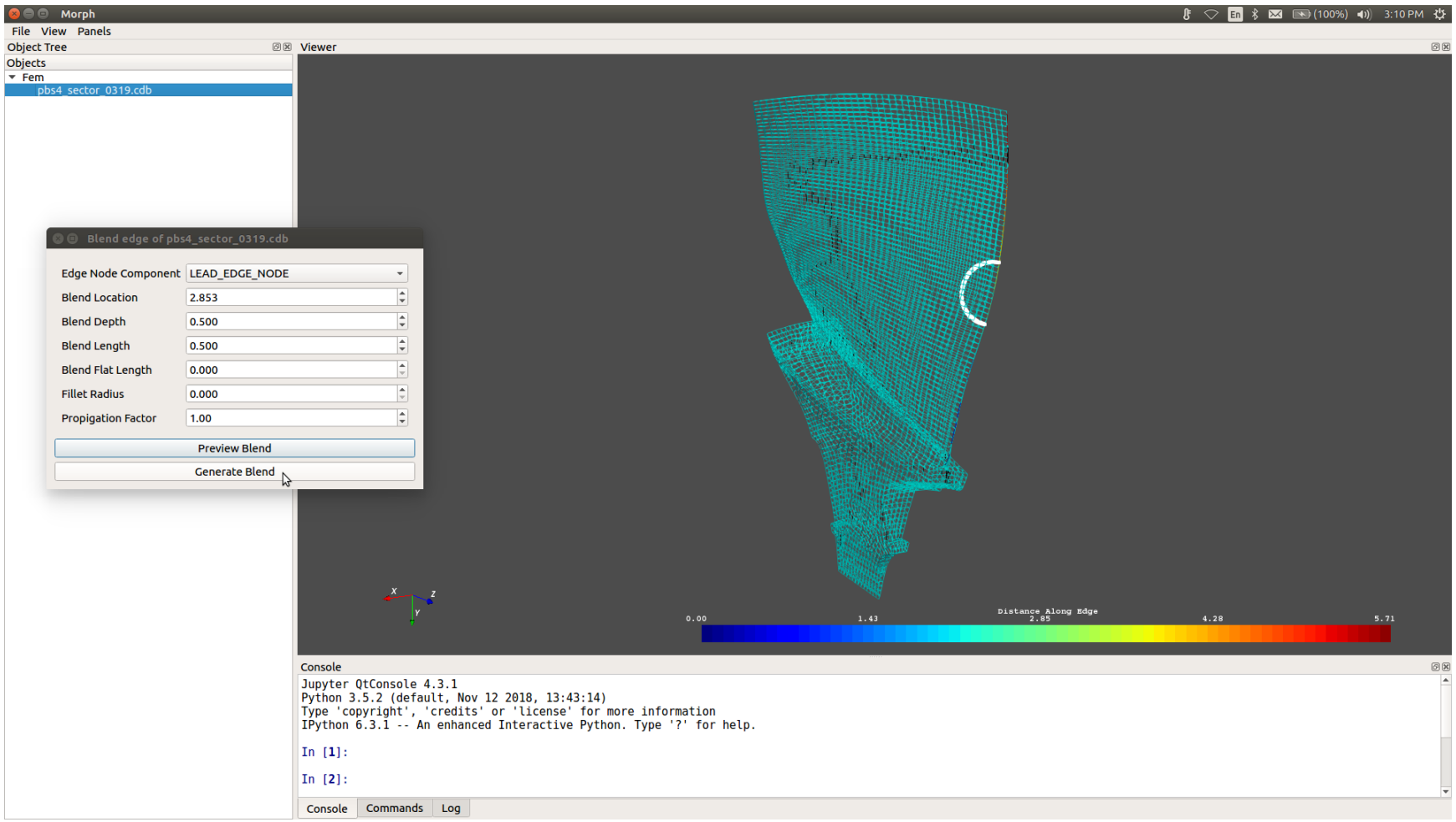
FEMORPH Graphical Interface

Define blend geometry parameters



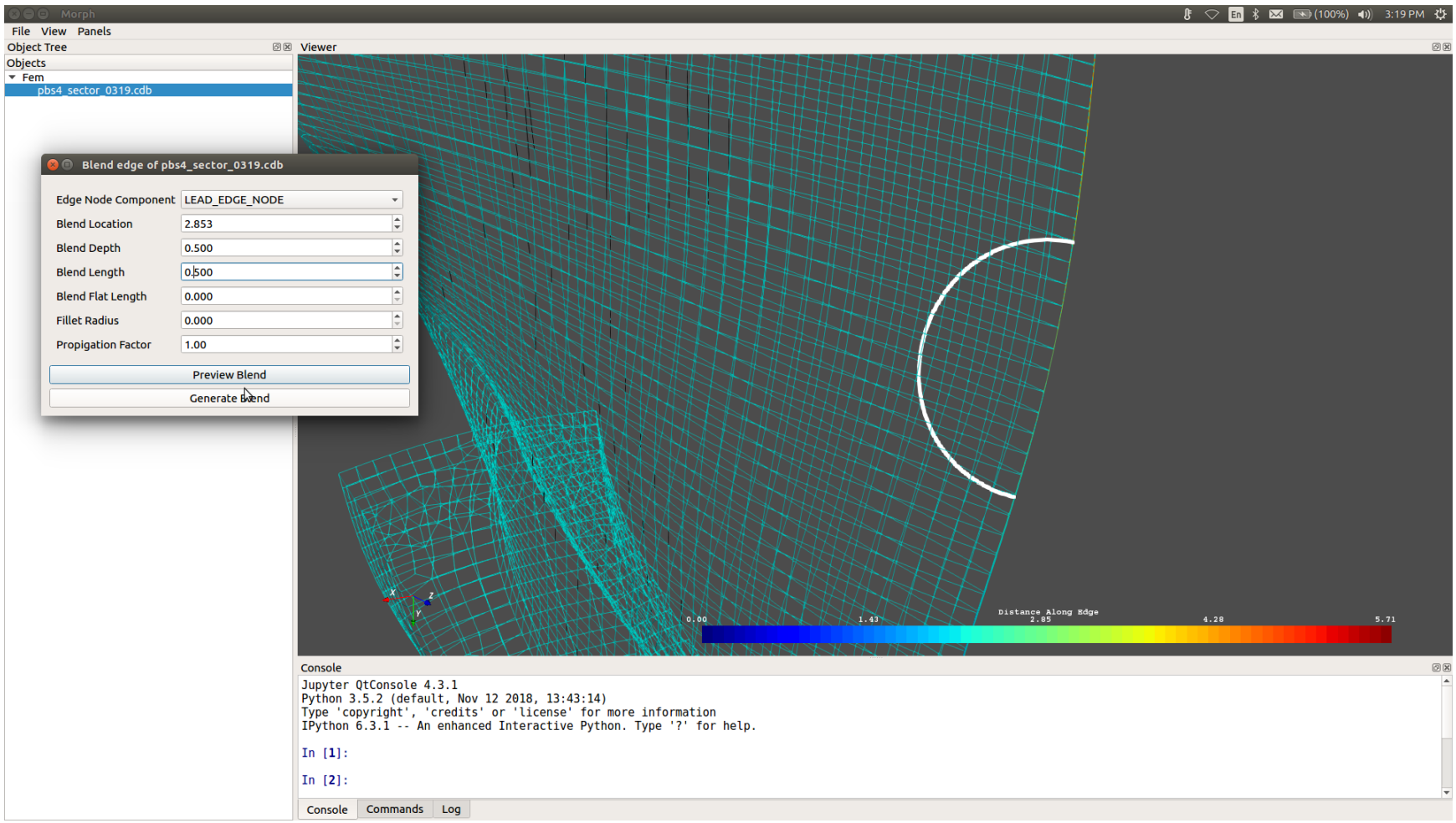
FEMORPH Graphical Interface

Visualize blend definition



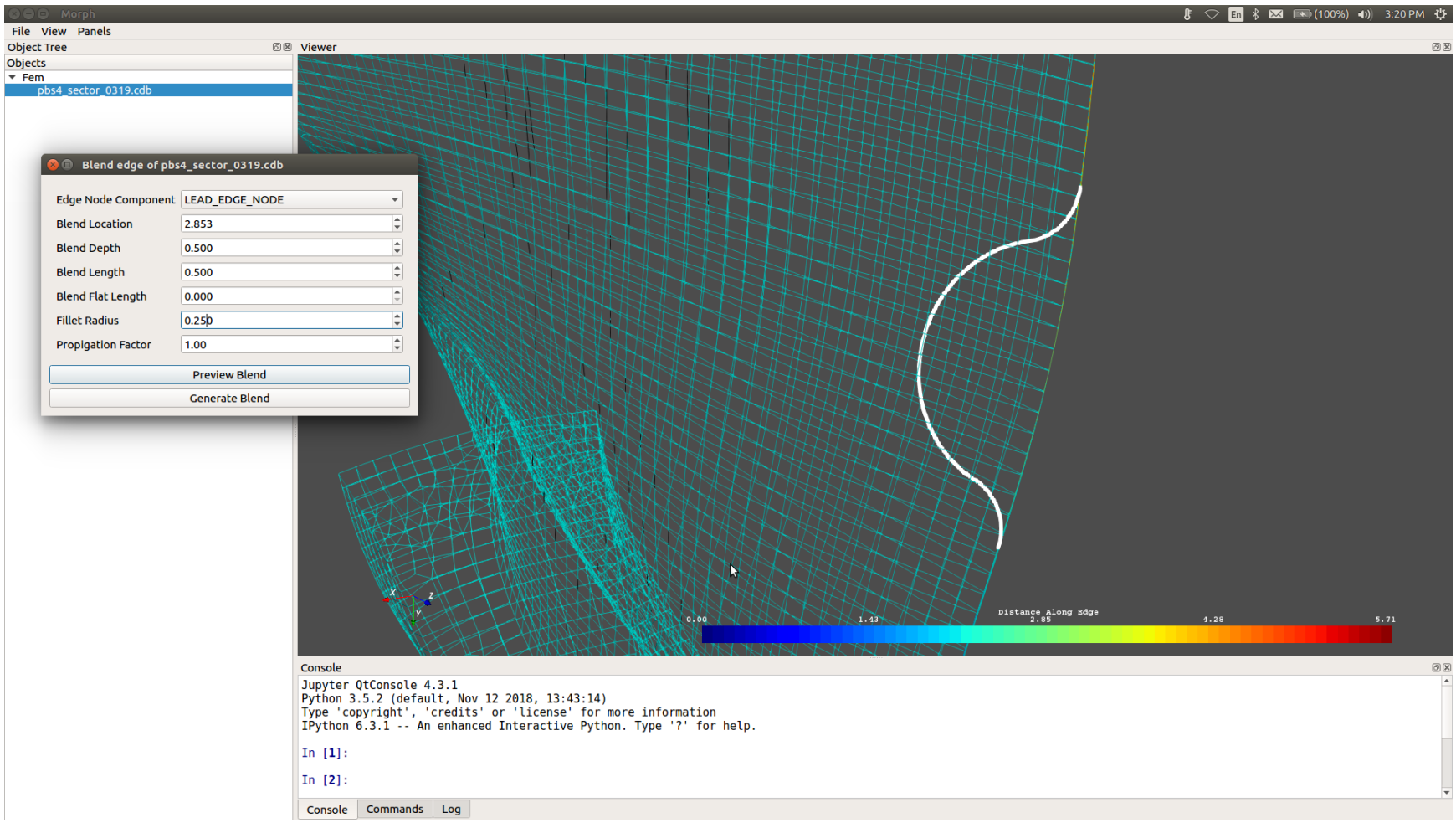
FEMORPH Graphical Interface

Zoom in



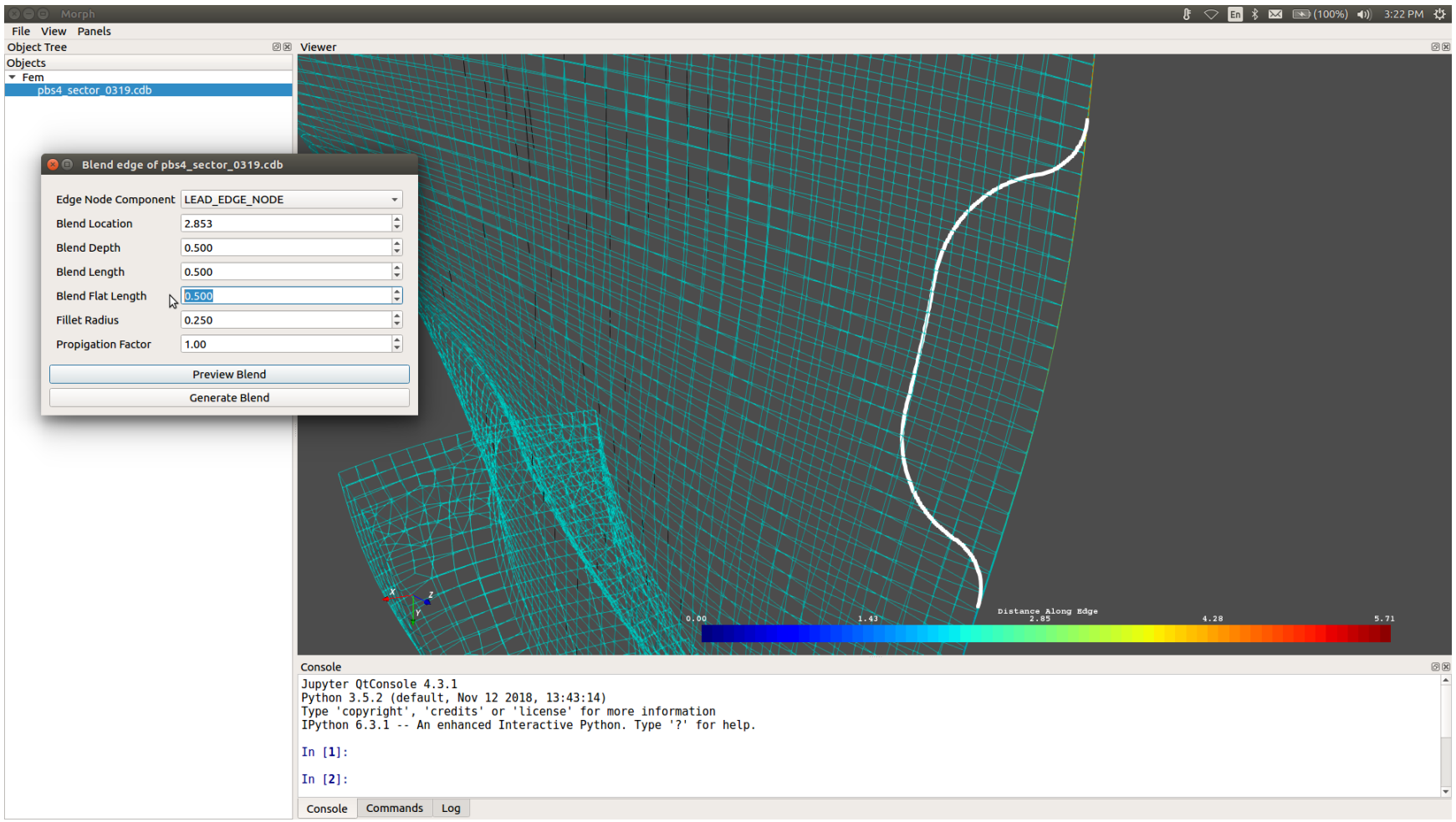
FEMORPH Graphical Interface

Add blend smoothing radius



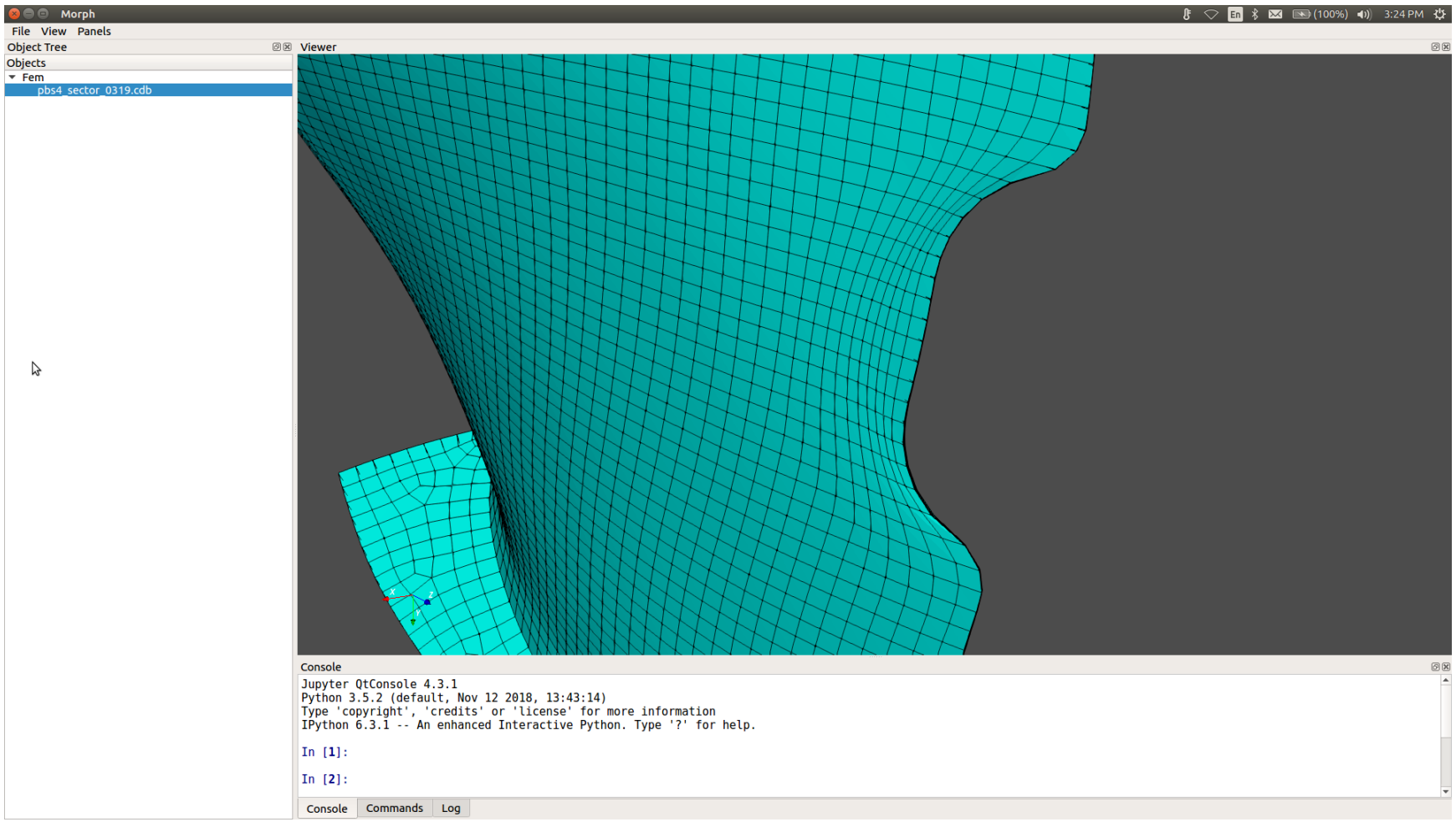
FEMORPH Graphical Interface

Add blend flat



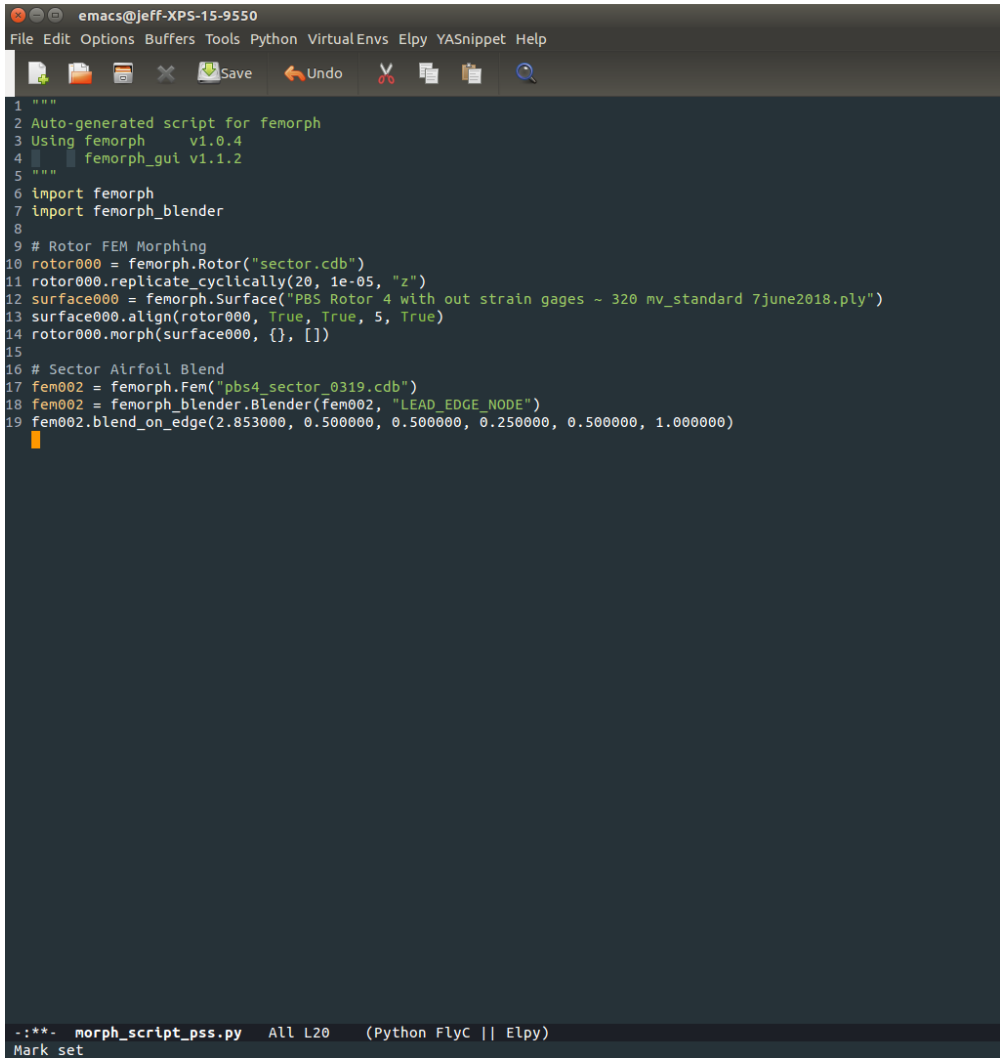
FEMORPH Graphical Interface

Morph to defined blend



FEMORPH Graphical Interface

Python Script of Process. 10 lines of code.



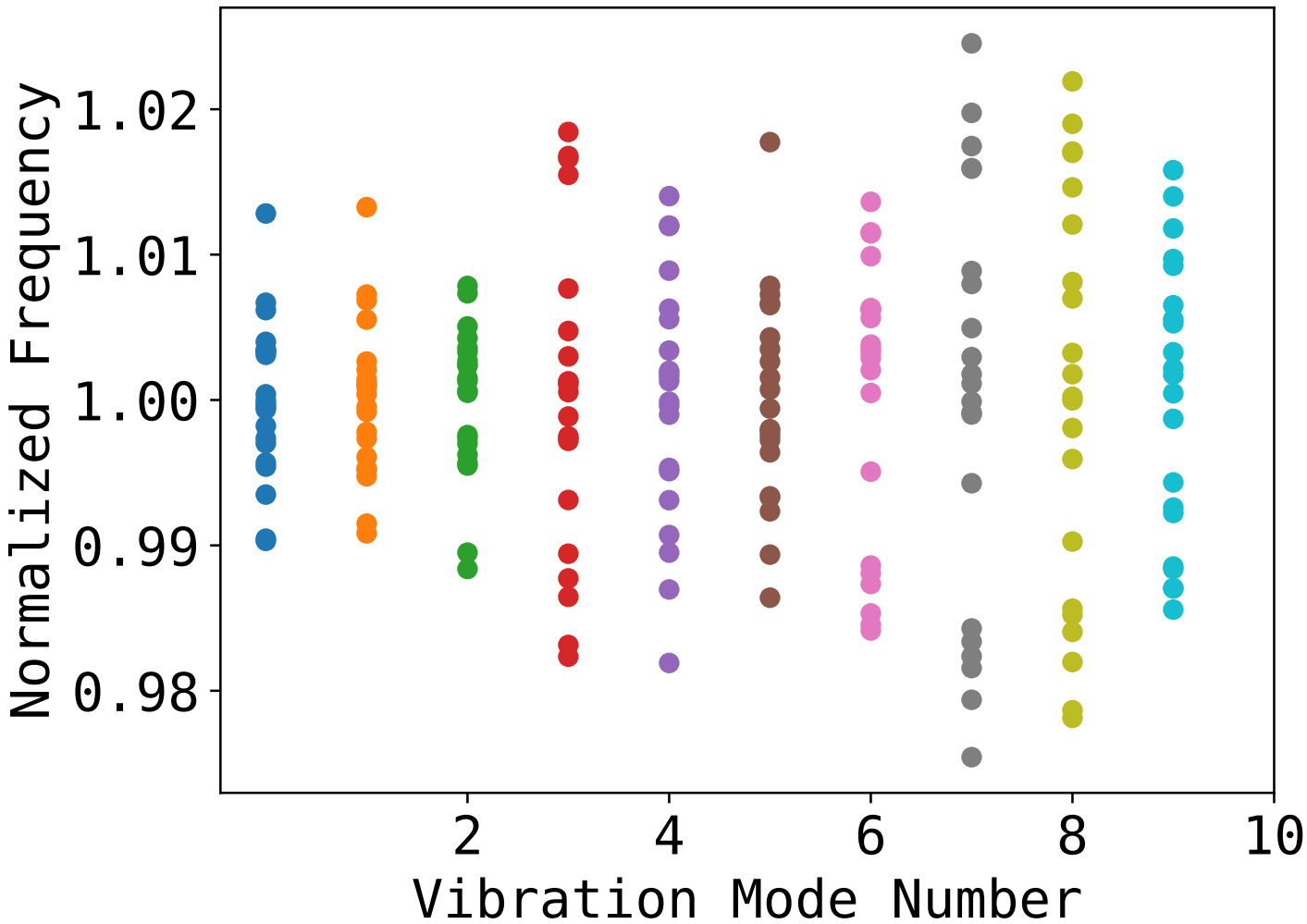
PyIBR Process Automation

- PyIBR.Blend
- PyIBR.Solve
- PyIBR.Post
  - Frequency
  - MAC
  - Stress
  - Campbell
  - Goodman
  - LE Goodman
  - Modal Force
  - Mistuning
- PyIBR.Emulate
- PyIBR.ROM
- PyIBR.Validate

PBS 4 As-manufactured Airfoil Results

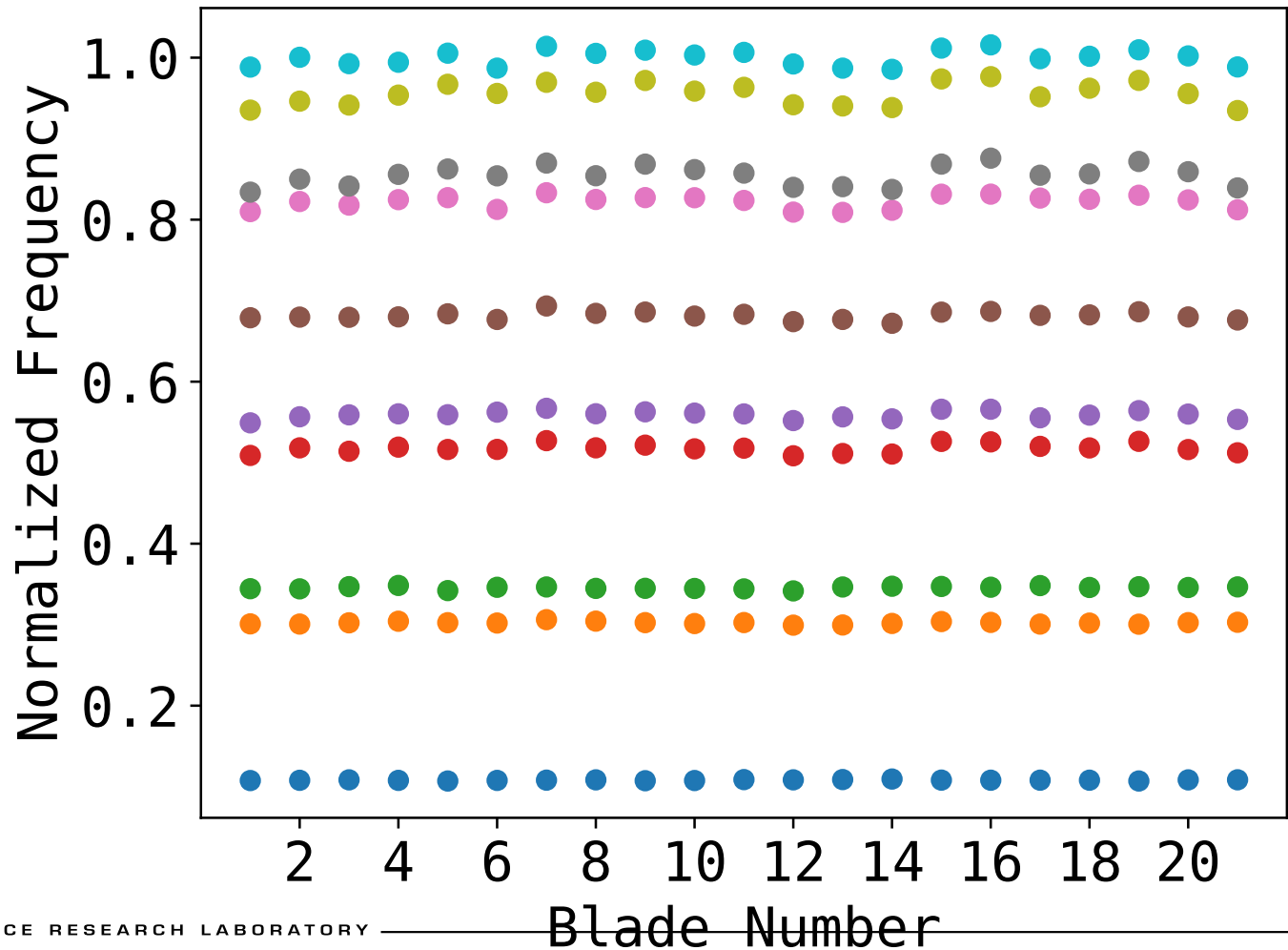
As-manufactured Frequency Results

Scatter of each mode frequency. Finding: typical blade frequency variation. Blended airfoil frequency limit can be based on part-specific frequency



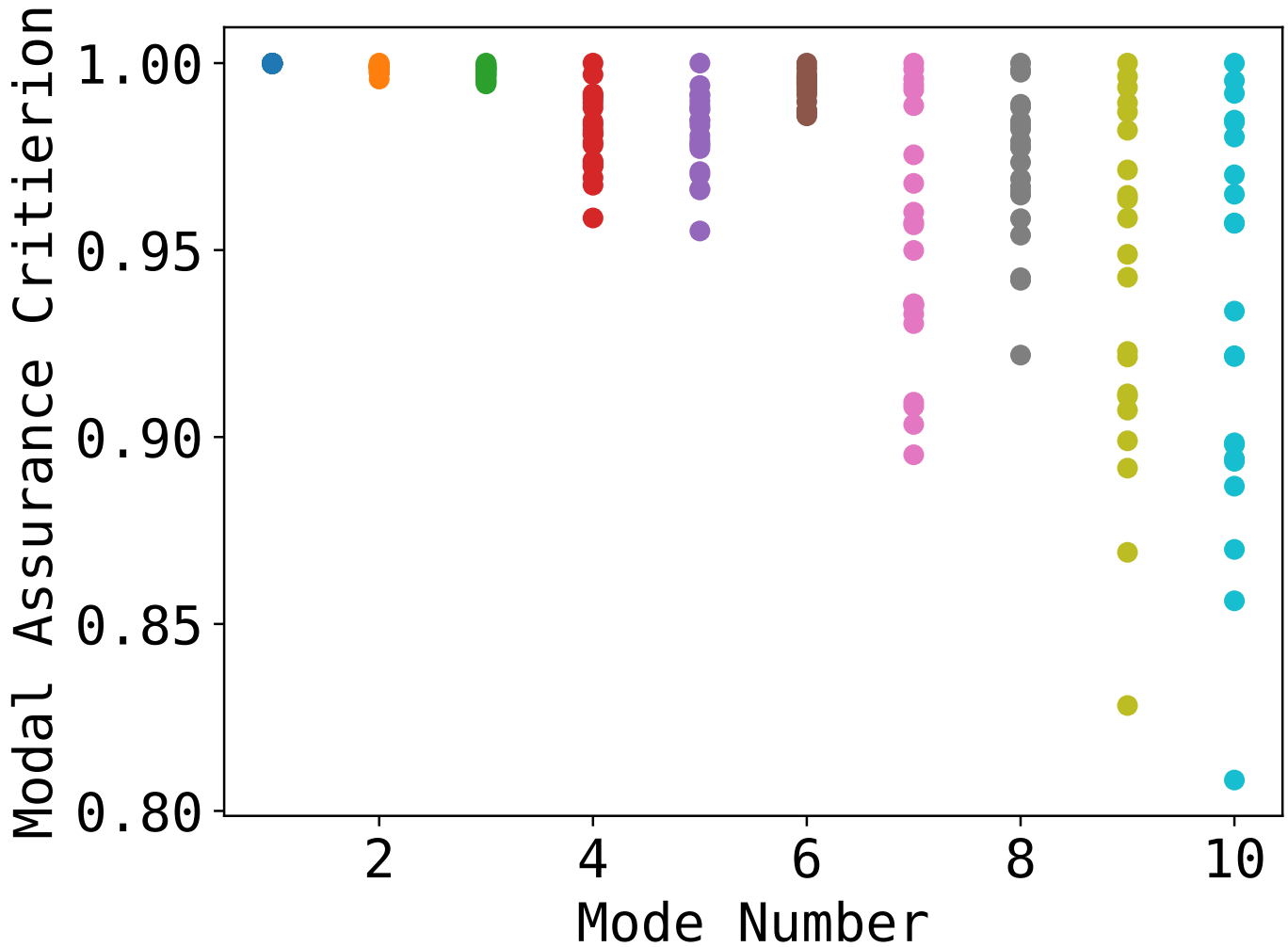
As-manufactured Frequency Results

Blade frequency variation. Finding:Closely spaced modes. Modes pairs (4,5), (7,8), (9,10) at risk for large mode shape variation.



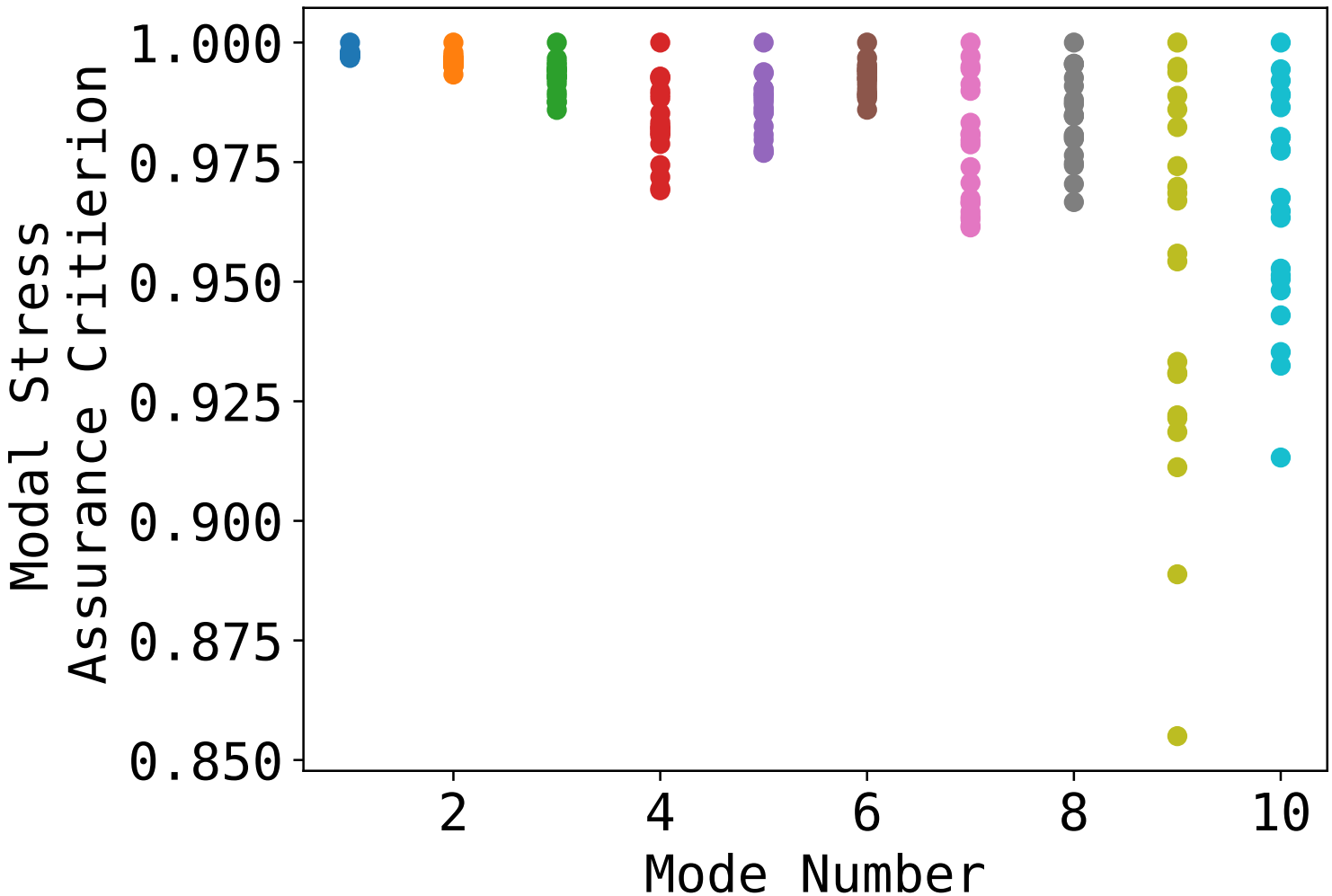
As-manufactured Mode Shape Results

Modal Assurance Criterion variation. Finding: Large mode shape variations confirmed. Airfoil blending should leverage this information.



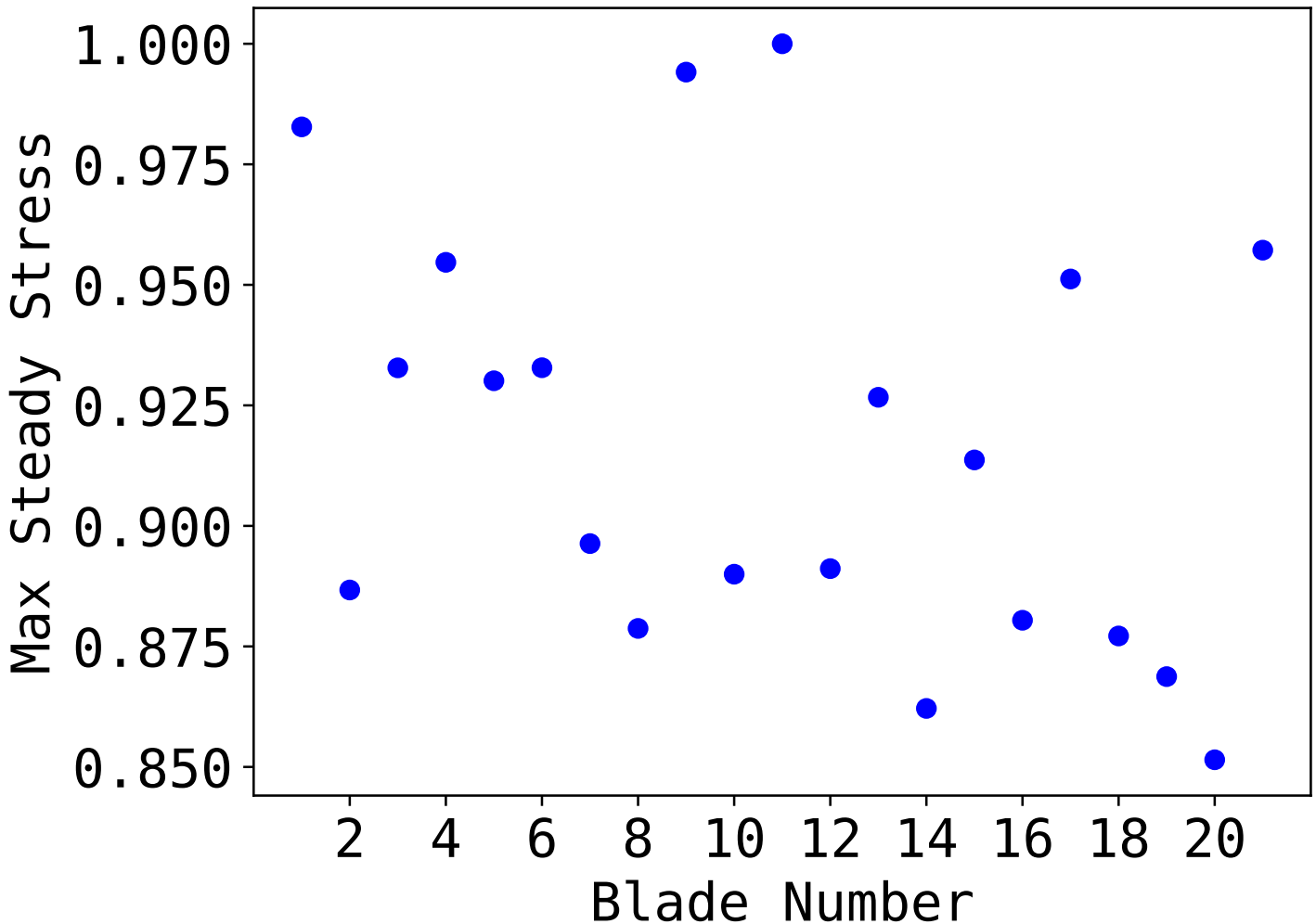
As-manufactured Modal Stress Results

For completeness...modal stress. Finding: Less modal stress shape variation.



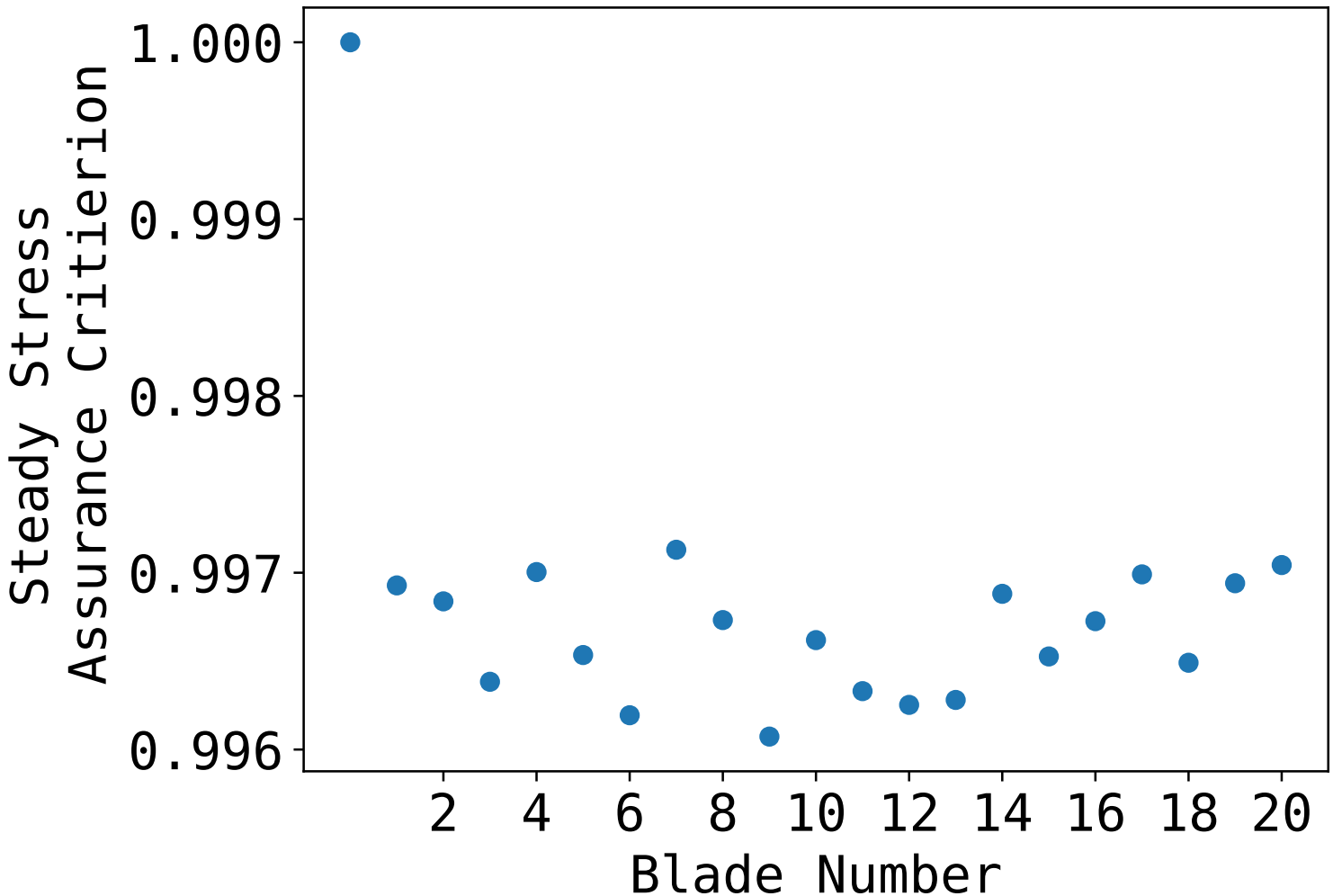
As-manufactured Steady Stress Results

Max stress variation normalized by blade of maximum stress



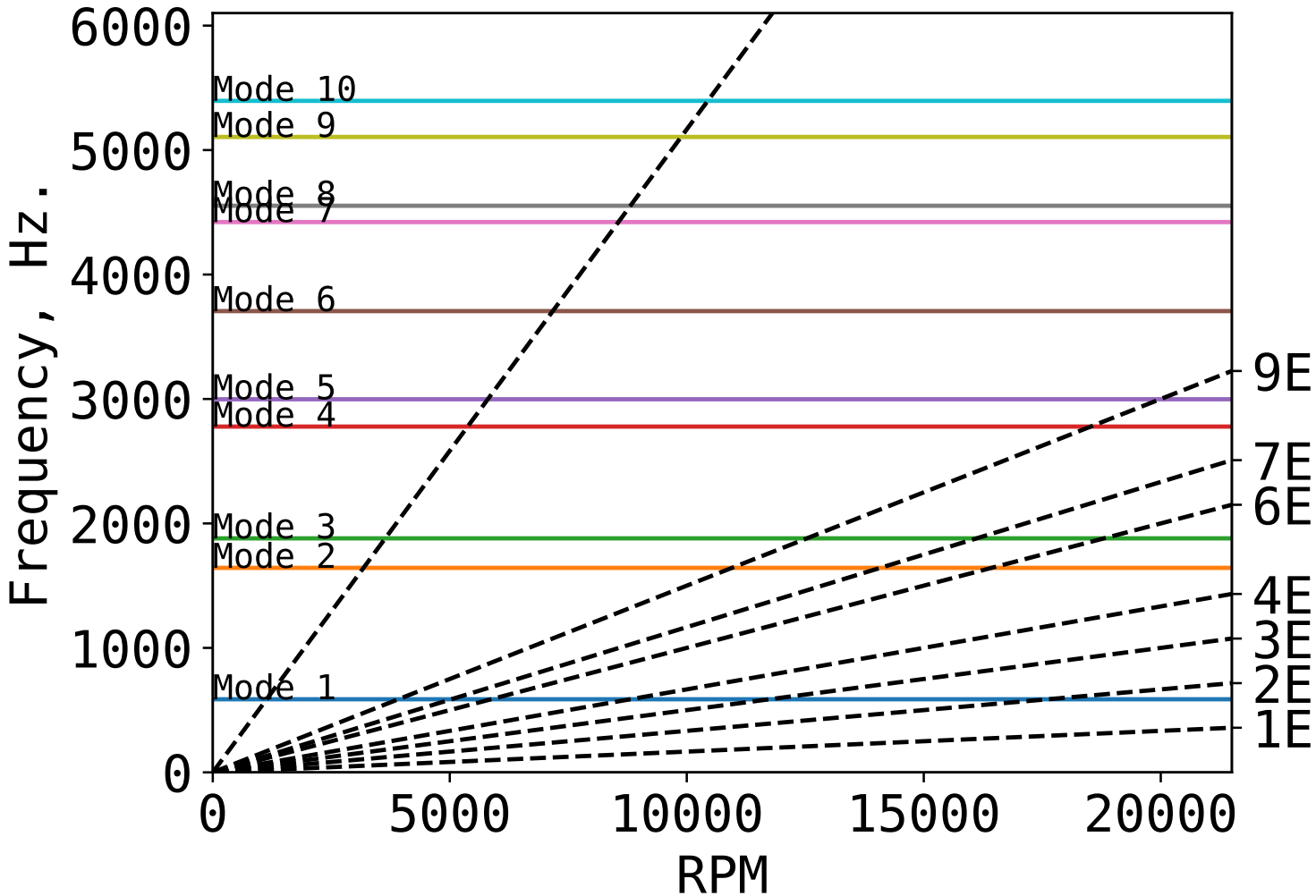
As-manufactured Steady Stress Results

Steady Stress Assurance Criterion shows small variation. SSAC versus nominal blade.



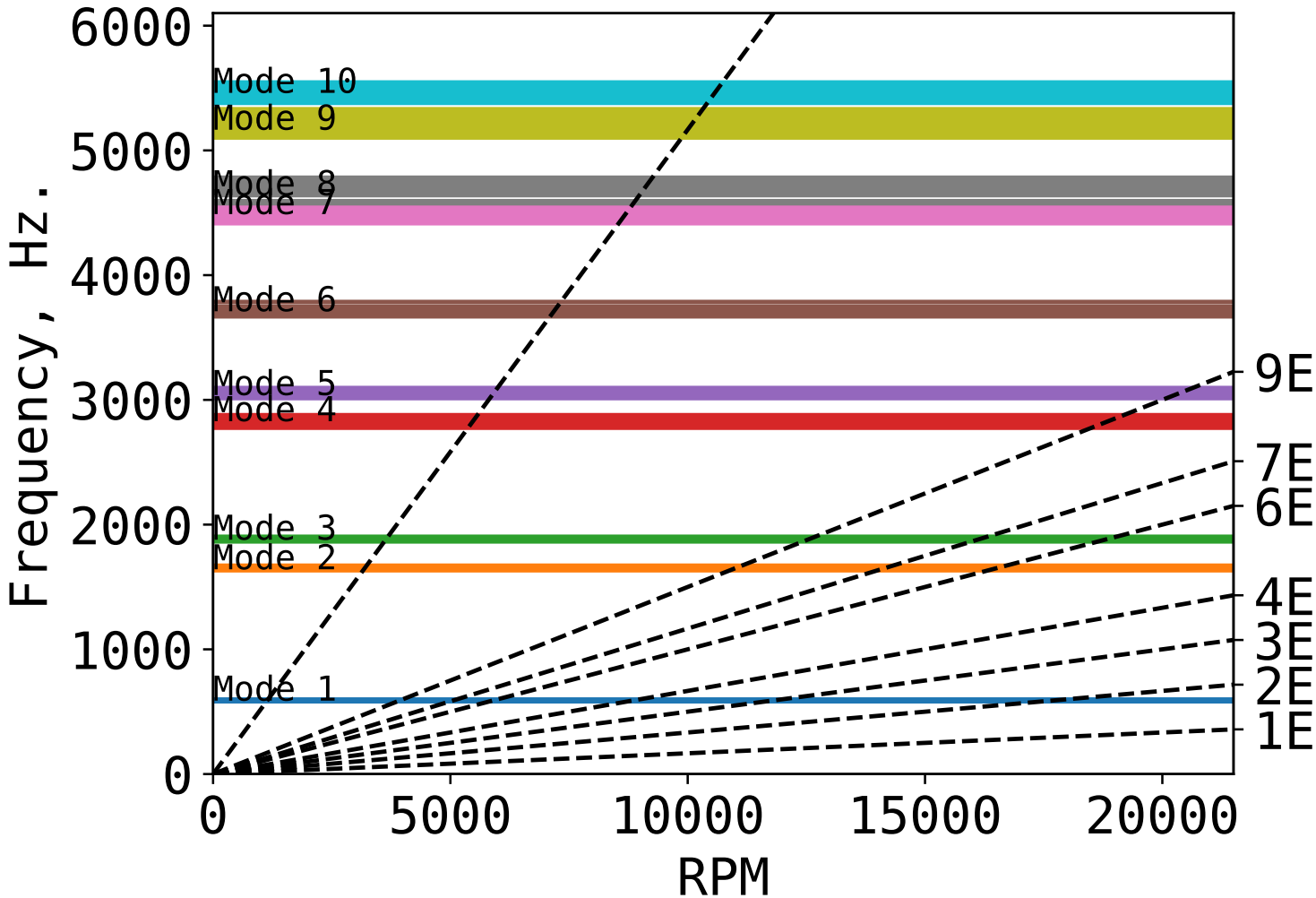
Nominal Airfoil Campbell Diagram

No crossings within 5% at 100% RPM



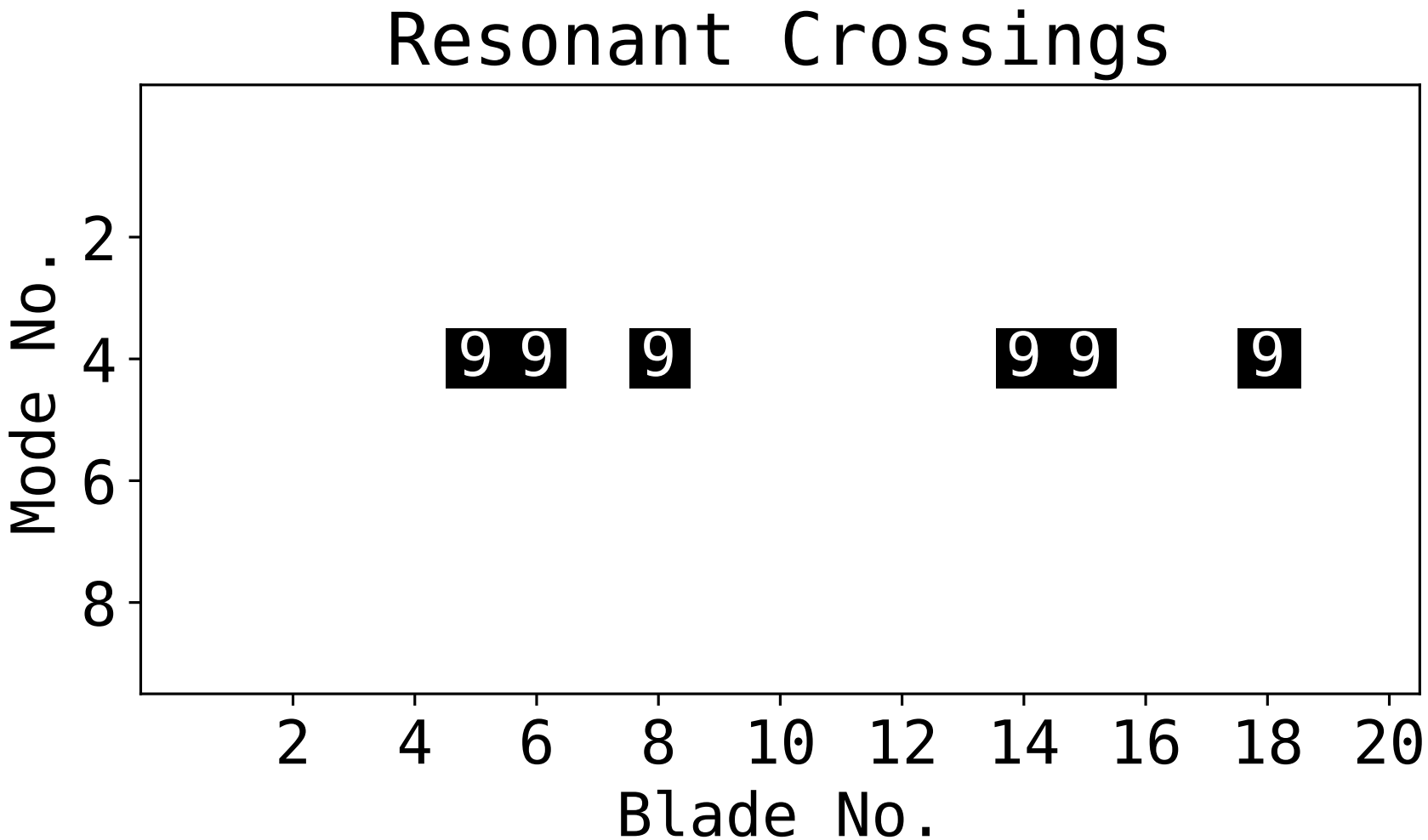
As-manufactured Airfoil Campbell Diagram

Mode 5 Crossings within 5% of 9EO driver at 100% RPM



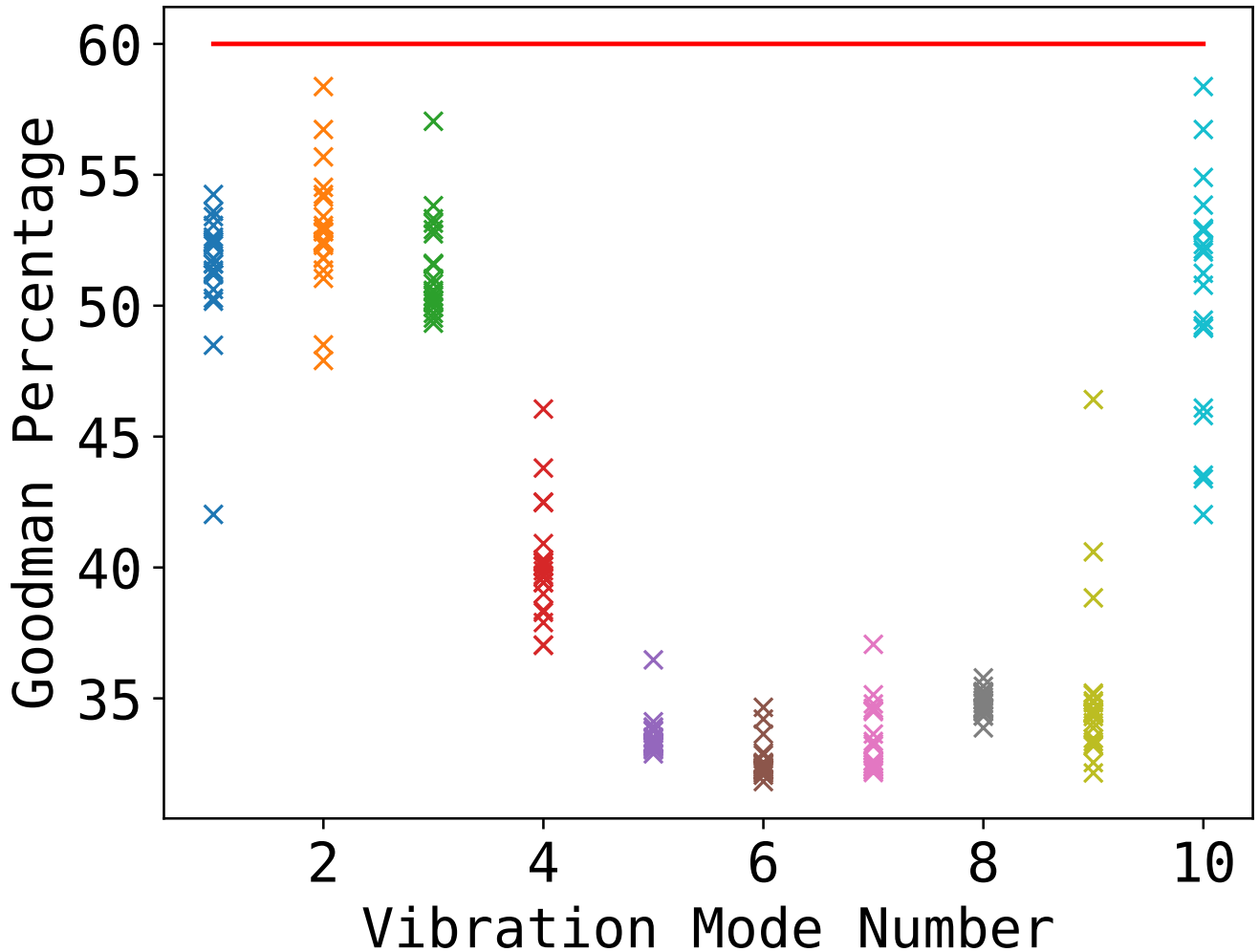
As-manufactured Frequency Margin at Max Speed

No resonant crossings within 5% of EO drivers



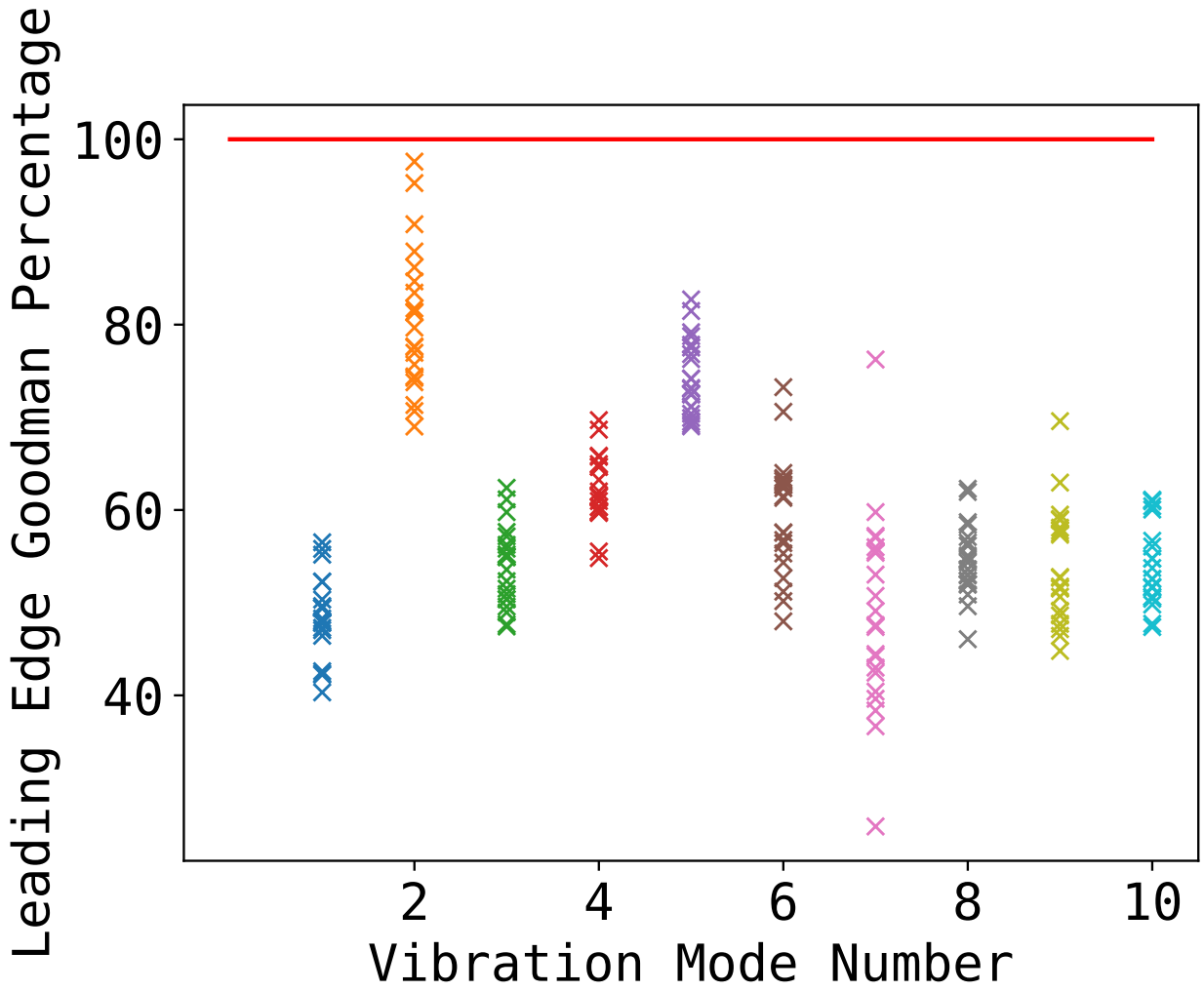
As-manufactured Goodman Percentage

Scaled modal stress to a maximum stress value. All airfoils below 60%



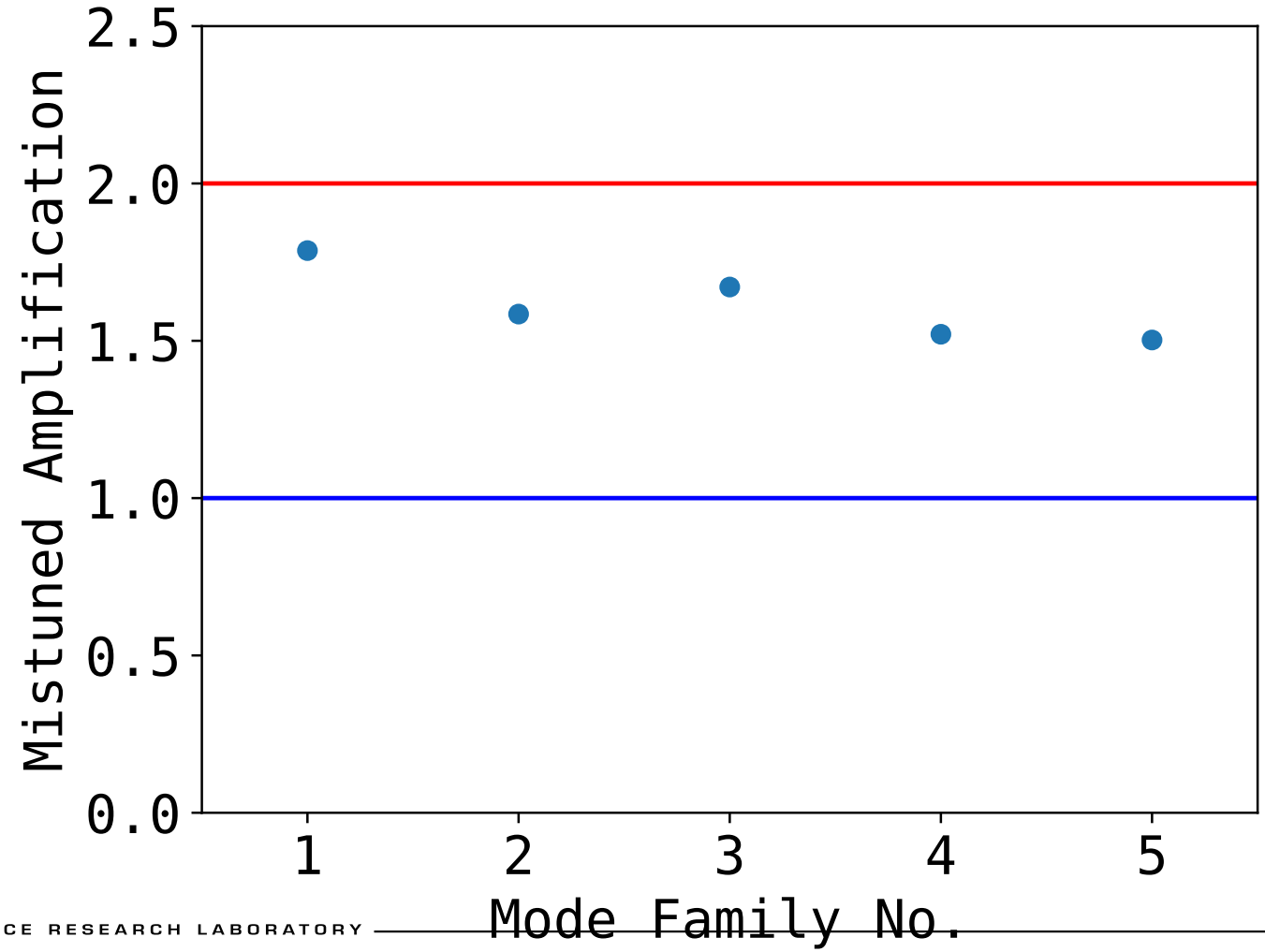
As-manufactured Leading Edge Goodman Percentage

Applied Kt to steady and alternating stress and allowed 100% capability



As-manufactured Rotor Mistuned Amplification

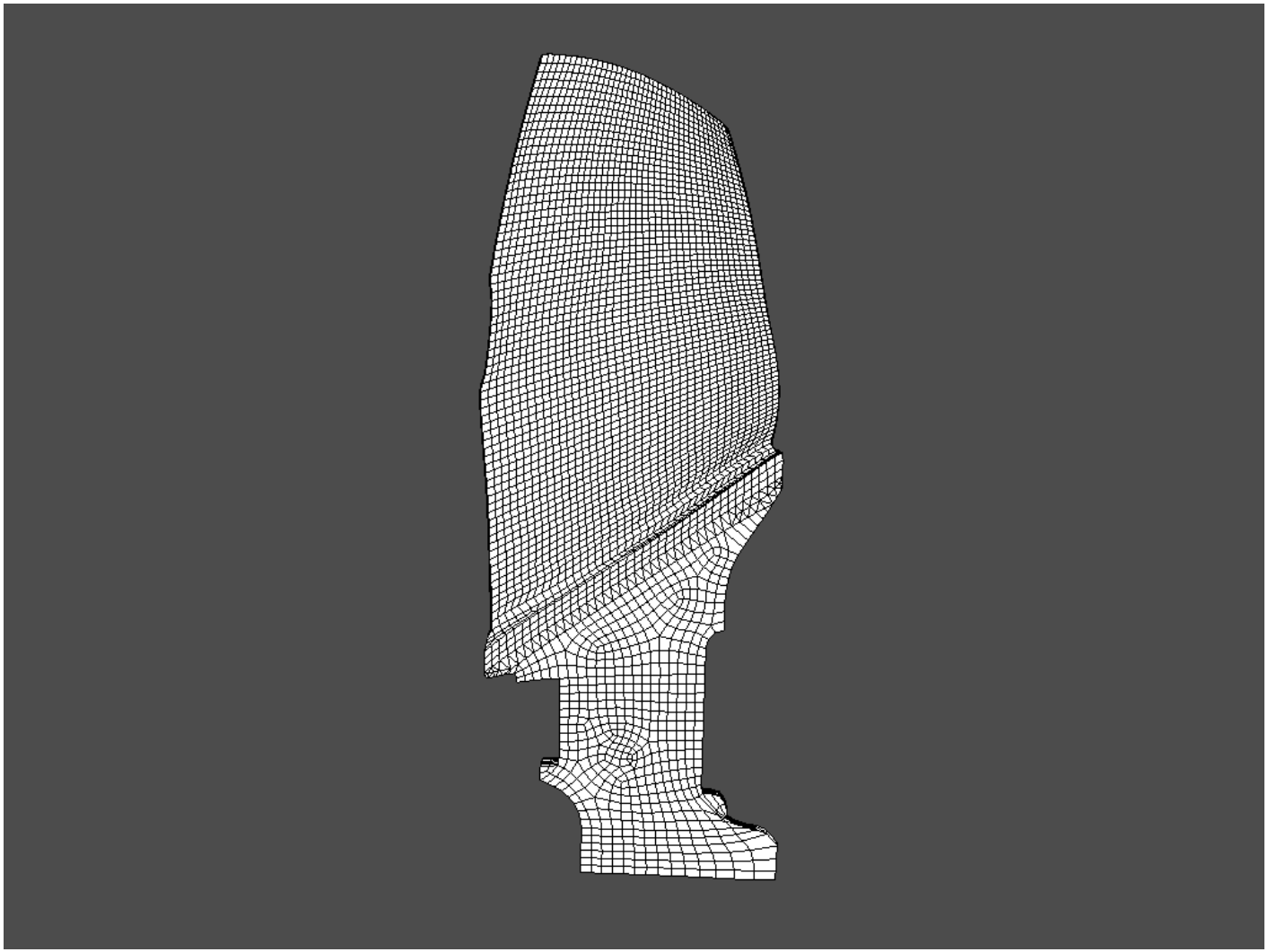
FMM predicted amplificaitons. Maximum amplification of 6 EO excitations. 2.0 set as limit.



Blended Airfoil Results

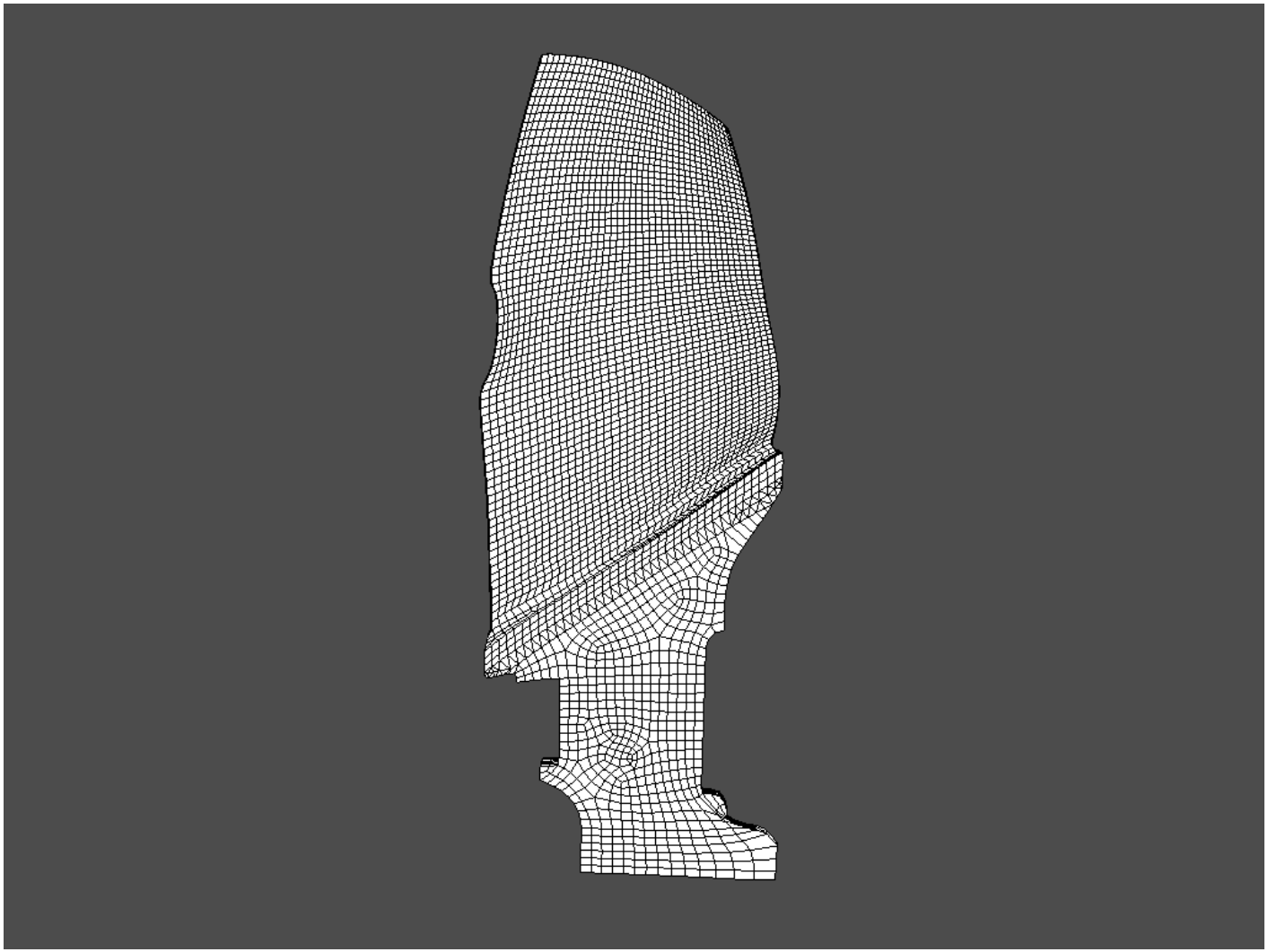
Blended Airfoil Models

Blade 1, Blend 1: loc=3.0”, len=0.5”, depth=0.1”, radius=0.25”, flat=0.0



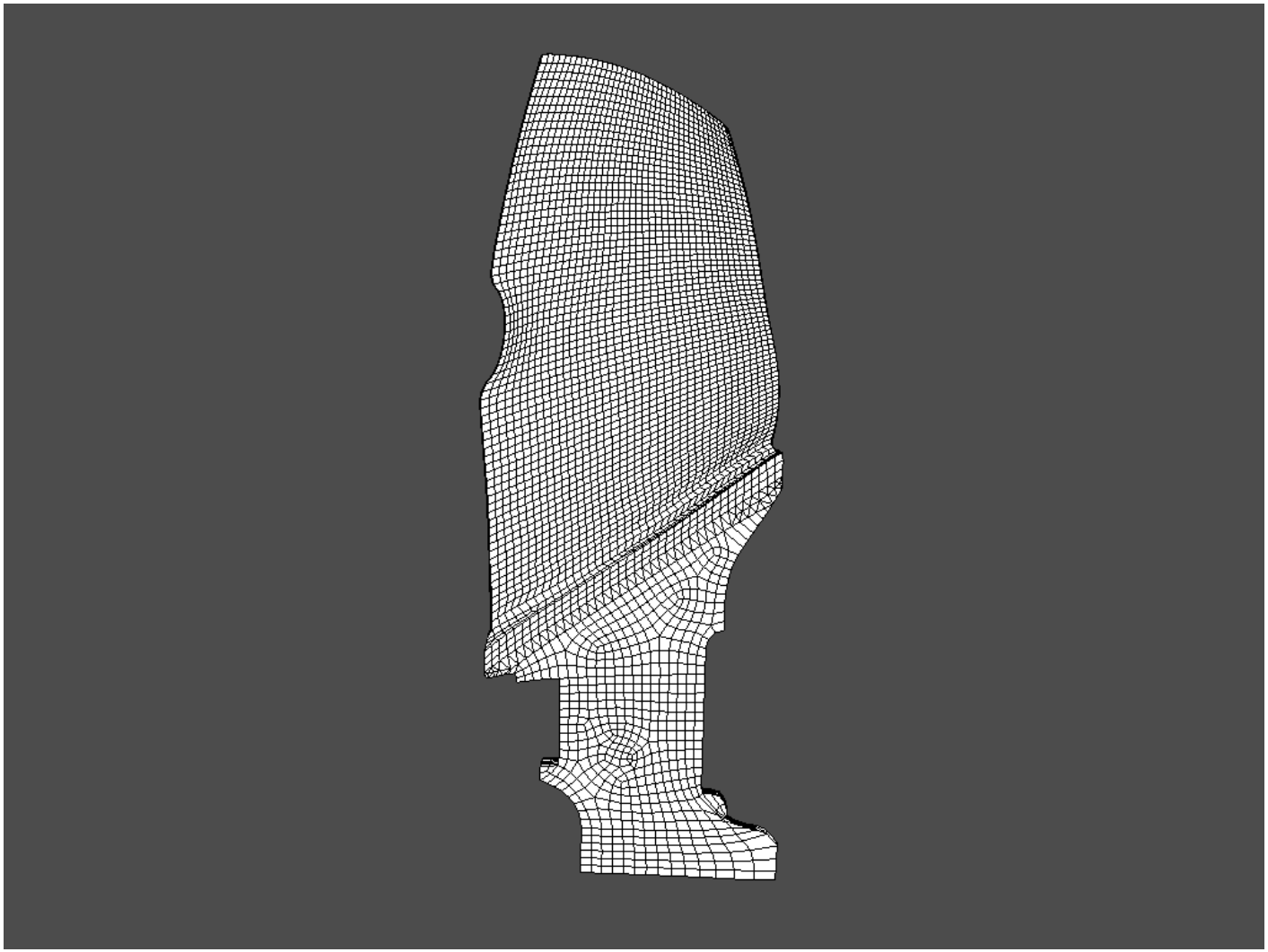
Blended Airfoil Models

Blade 1, Blend 2: loc=3.0”, len=0.5”, depth=0.2”, radius=0.25”, flat=0.0



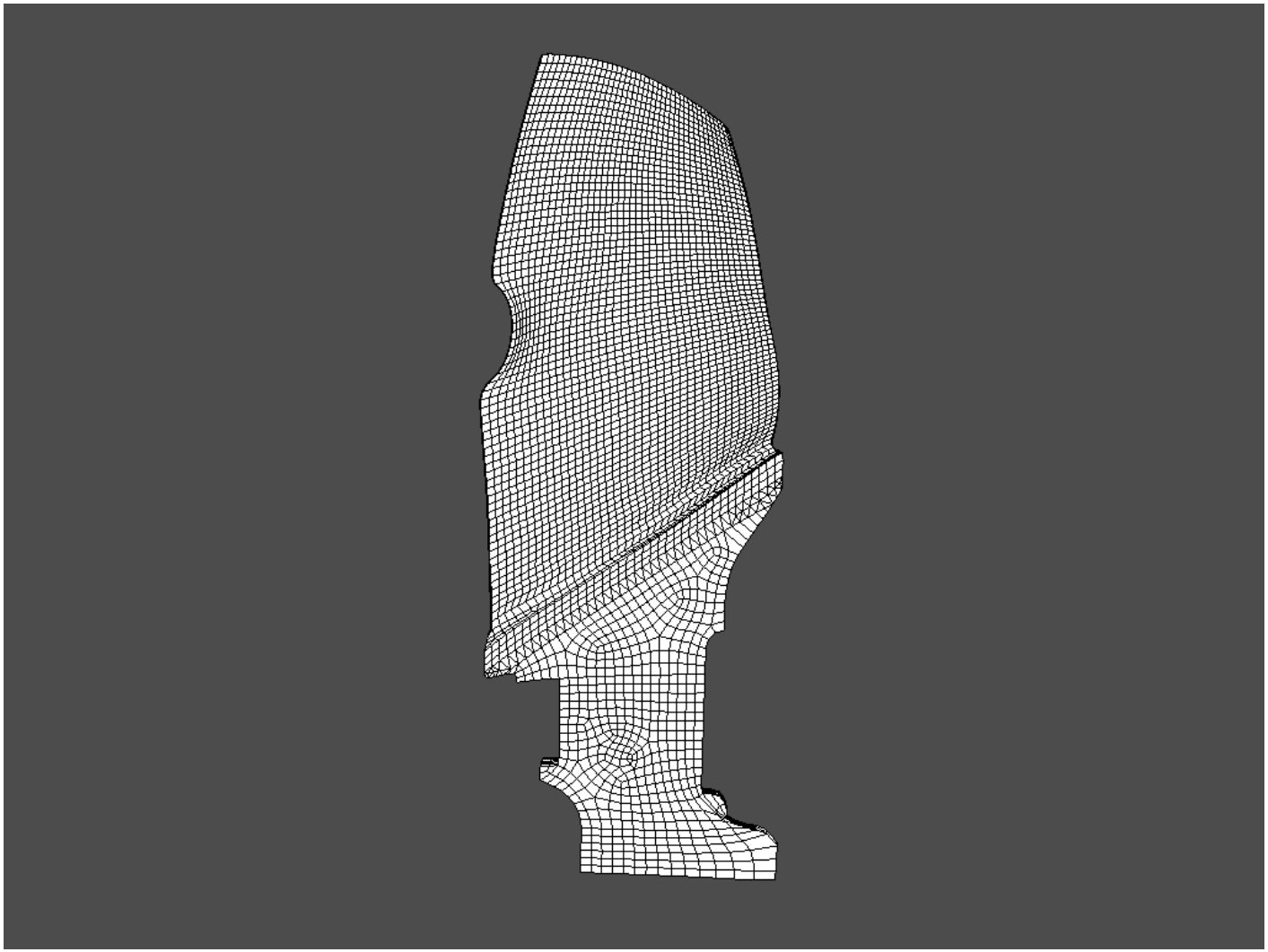
Blended Airfoil Models

Blade 1, Blend 3: loc=3.0”, len=0.5”, depth=0.3”, radius=0.25”, flat=0.0



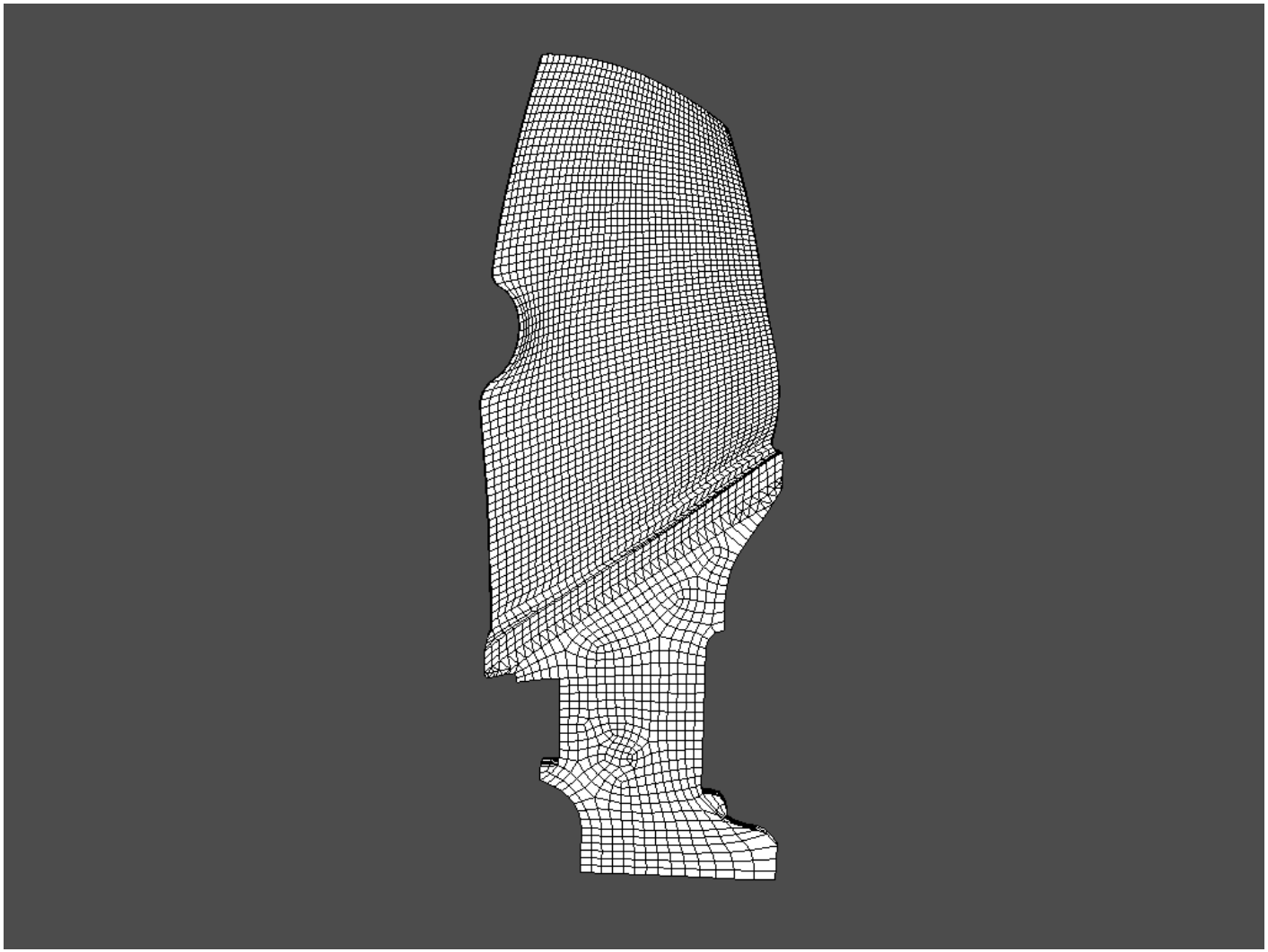
Blended Airfoil Models

Blade 1, Blend 4: loc=3.0”, len=0.5”, depth=0.4”, radius=0.25”, flat=0.0



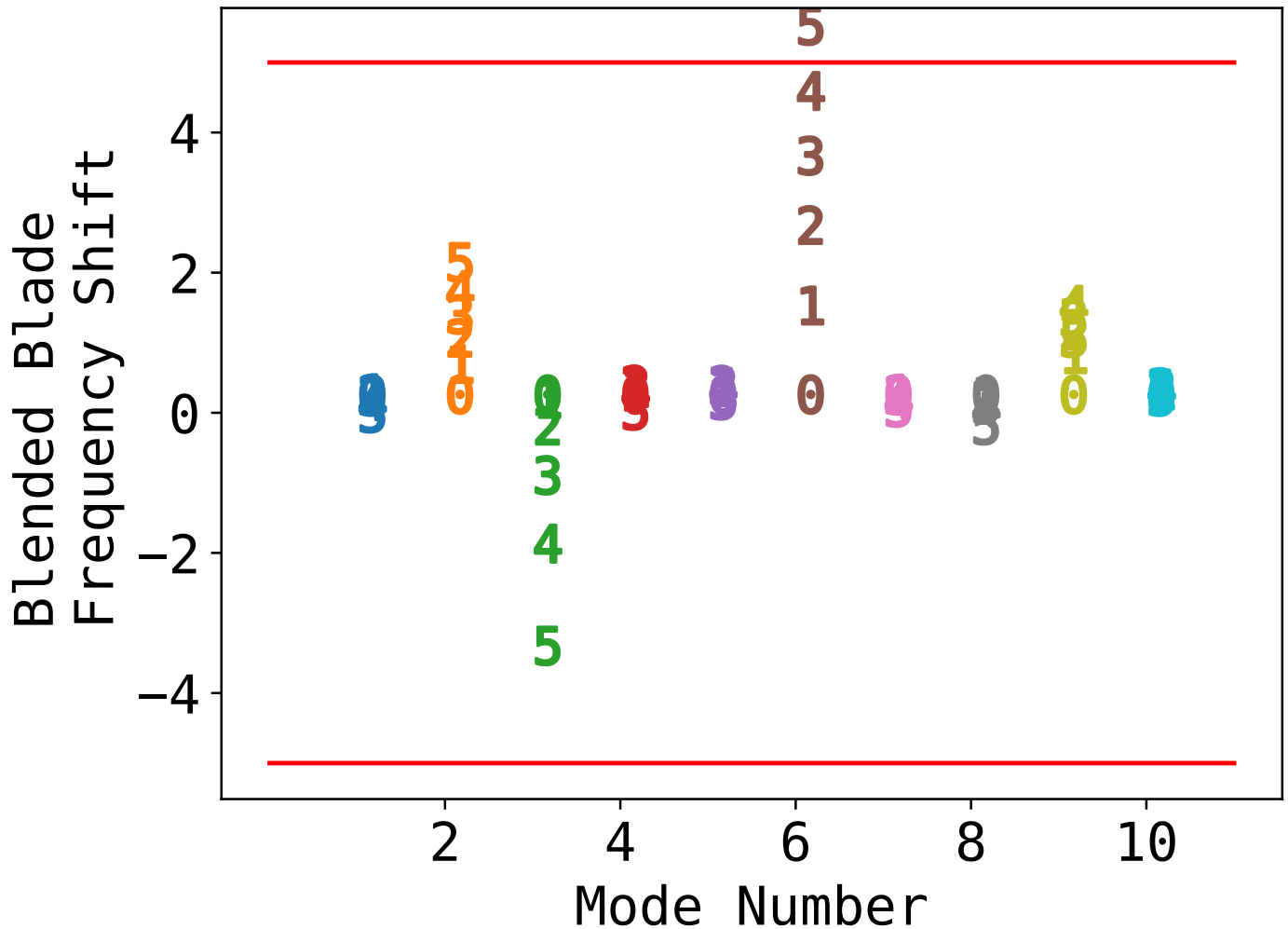
Blended Airfoil Models

Blade 1, Blend 5: loc=3.0”, len=0.5”, depth=0.5”, radius=0.25”, flat=0.0



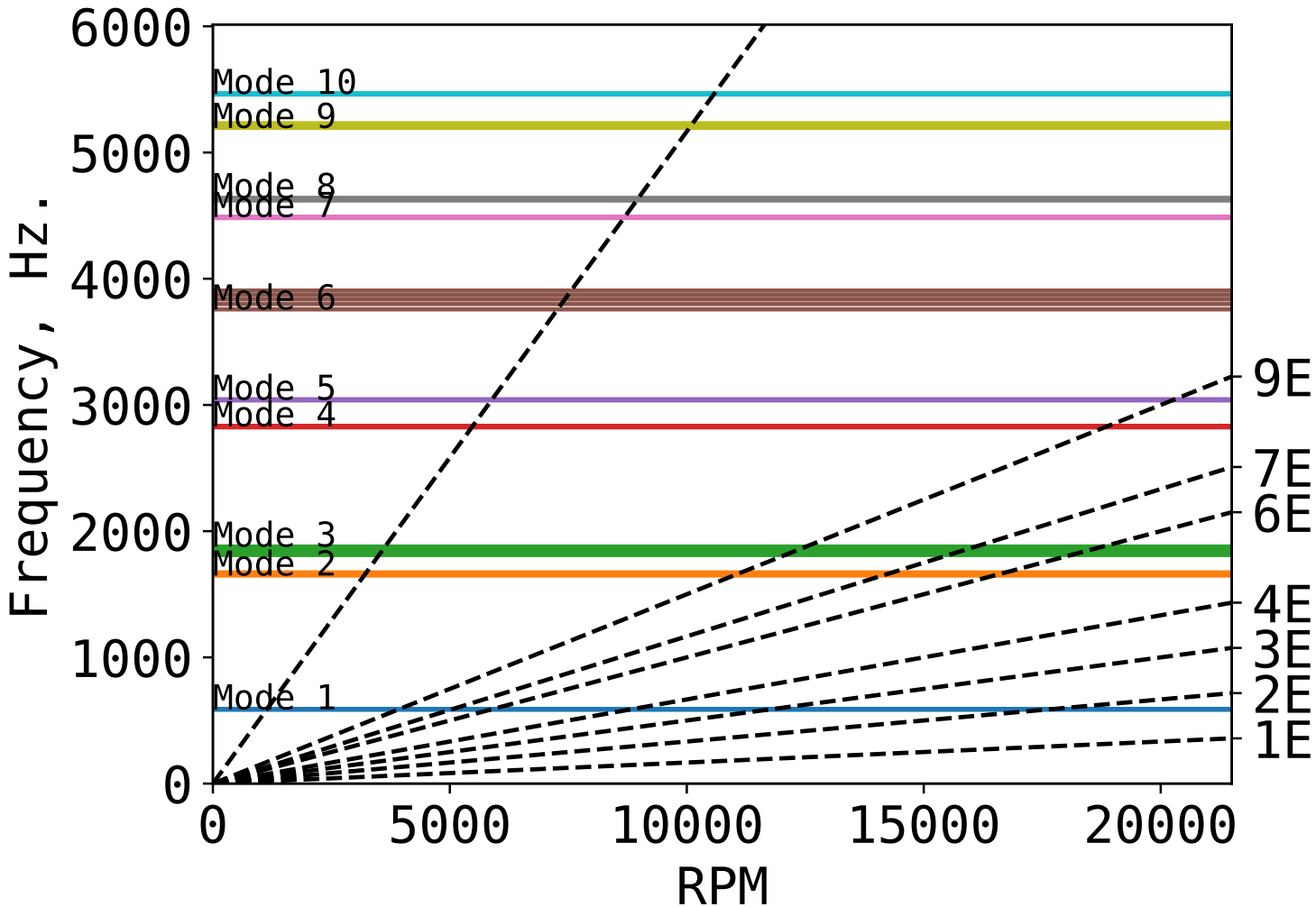
Sector 1 Blended Airfoil Frequency Delta

Defined 5% frequency limits. Mode 6 exceeds limit.

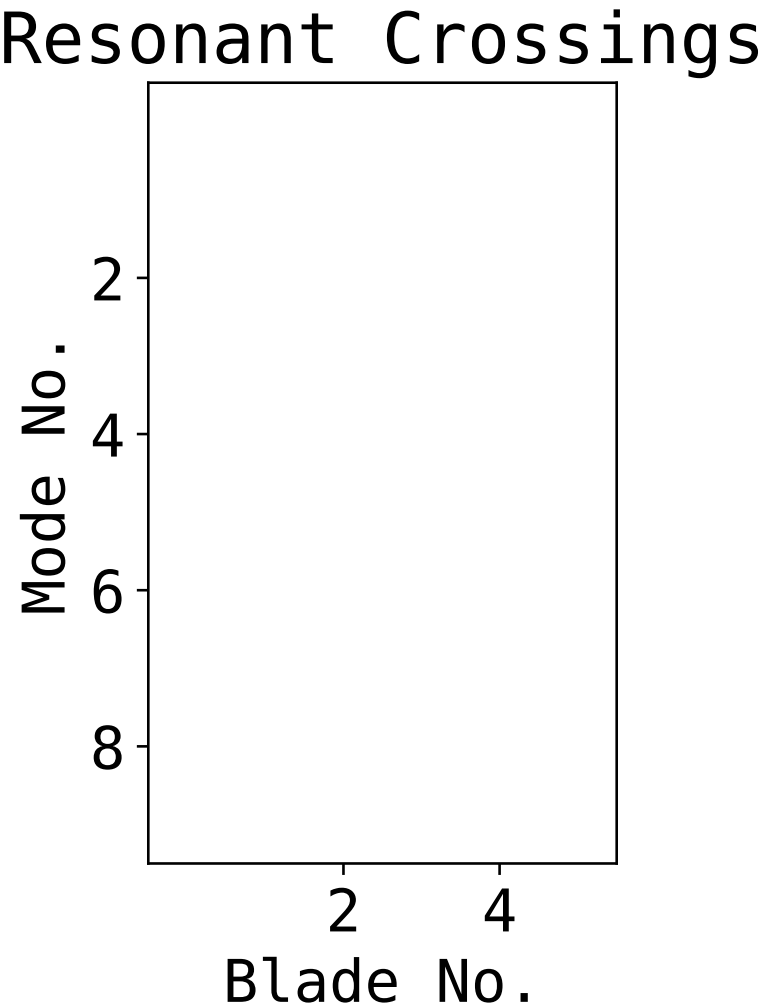


Blended Airfoil Campbell Results

Blended Mode 6 does not show crossing

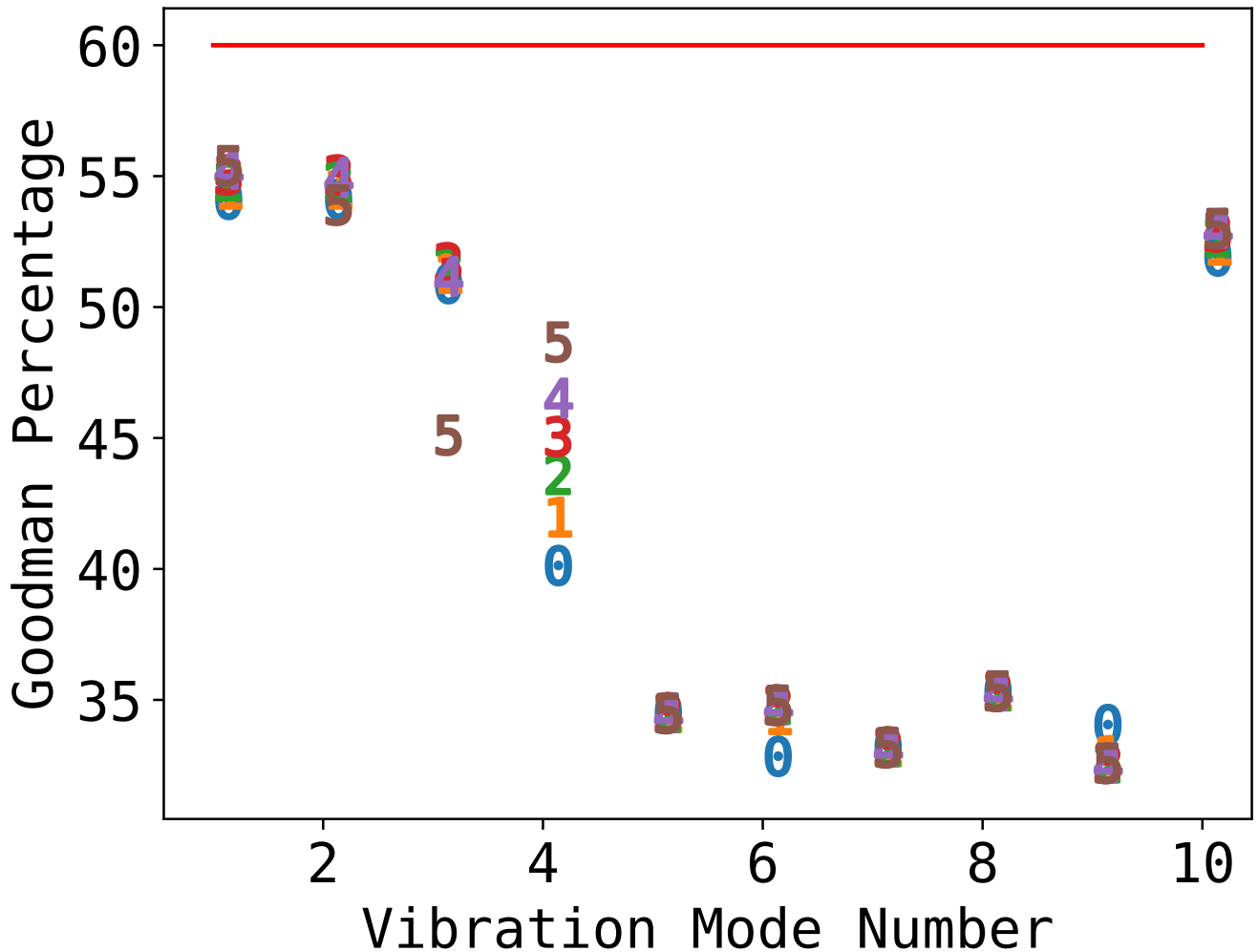


Blended Airfoil Crossing Check



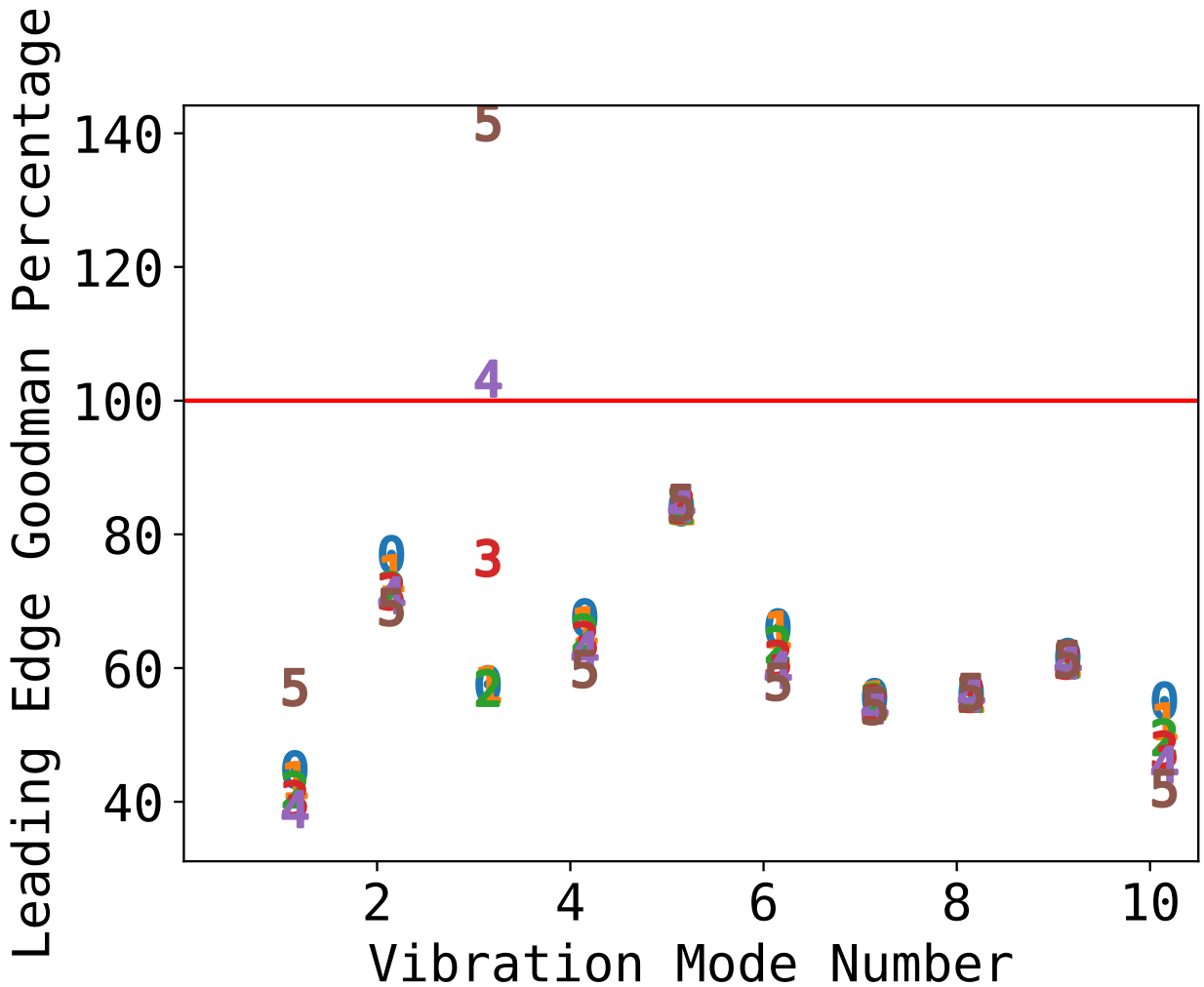
Blended Airfoil Goodman limits

Mode 4 shows greatest sensitivity



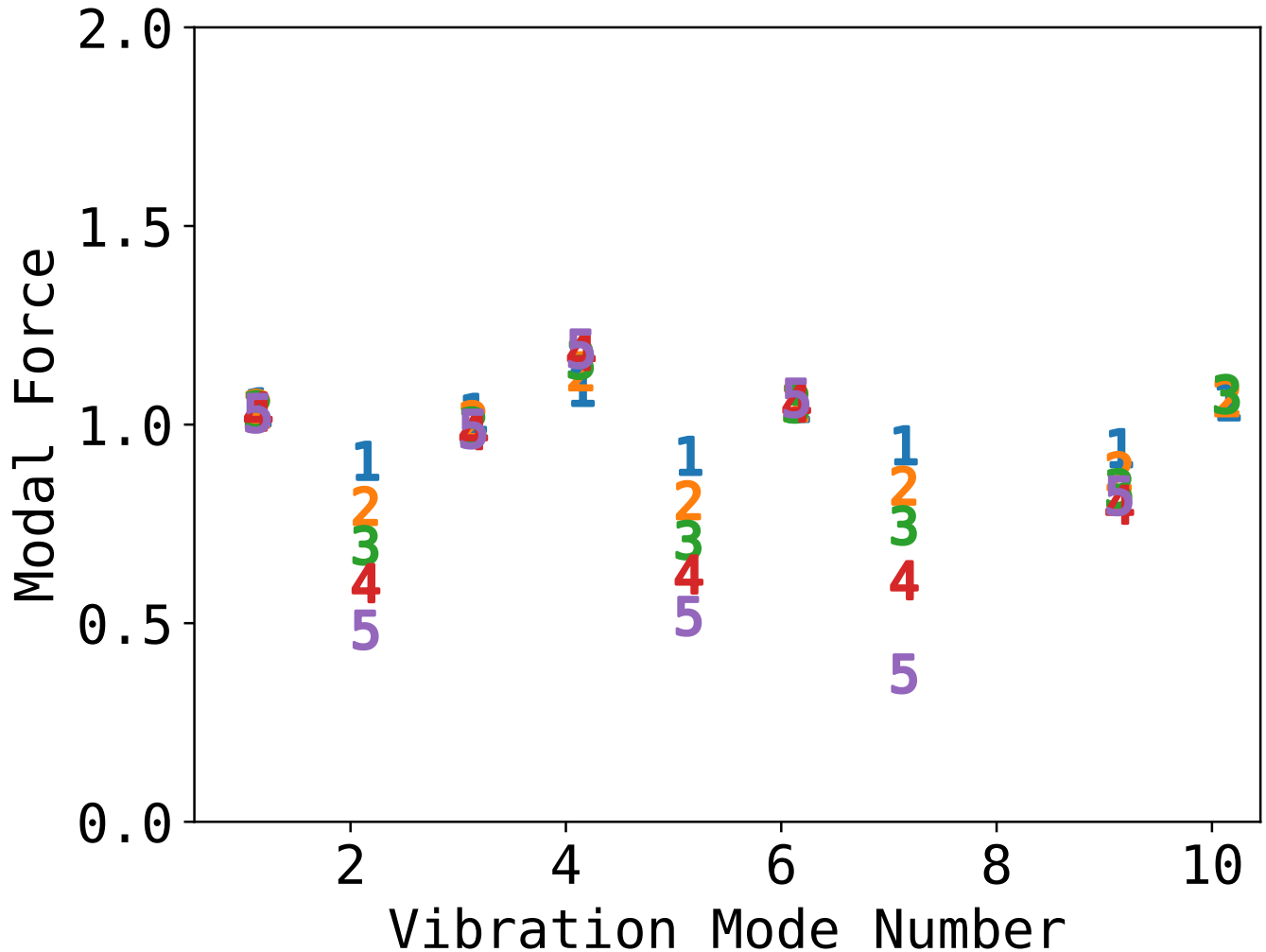
Blended Airfoil Leading Edge Goodman Assessment

Mode 3 exceeds limits



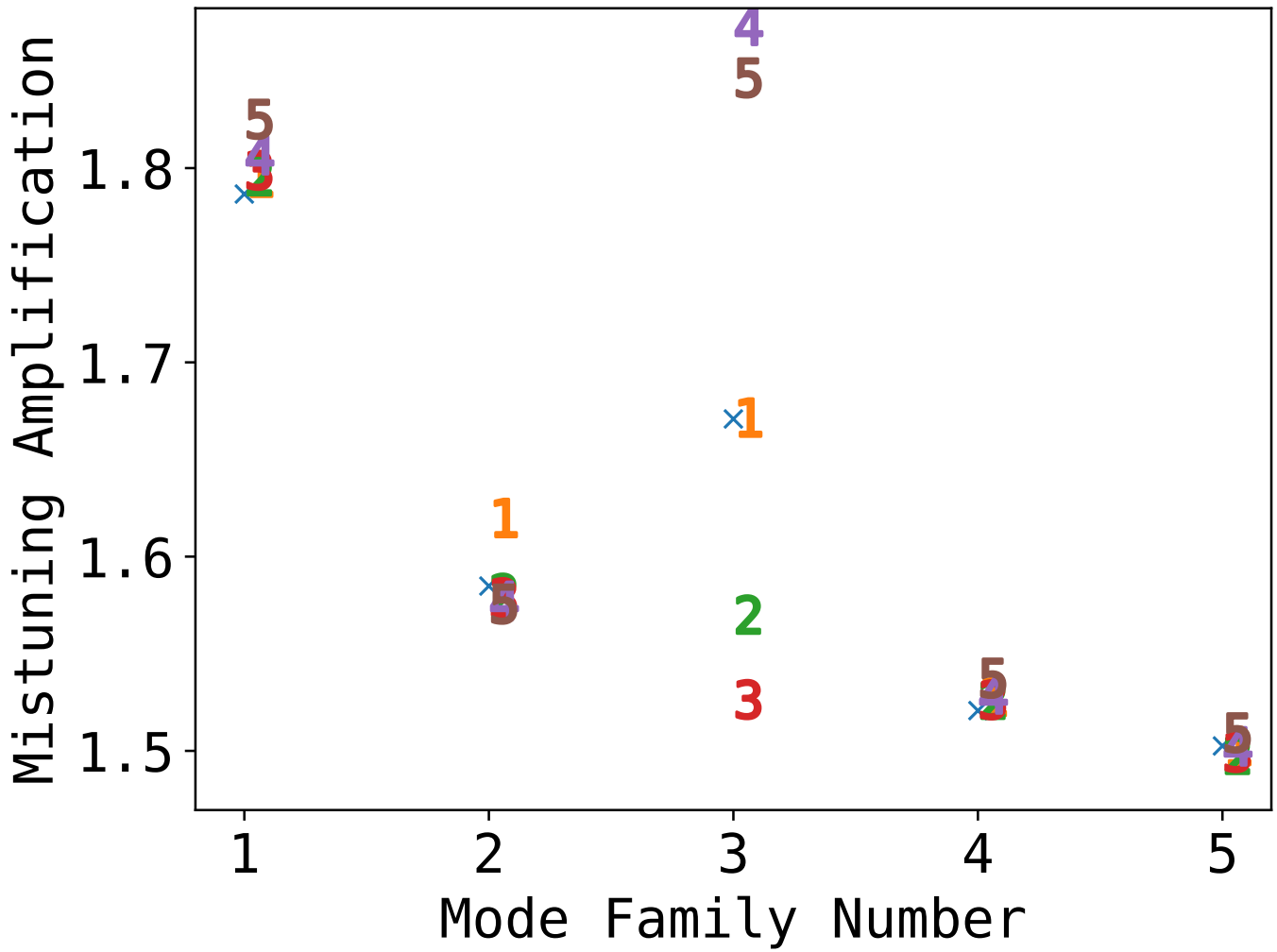
Blended Airfoil Modal Force Assessment

Modal Force drops for several modes as a function of blend depth



Mistuning Amplification Assessment

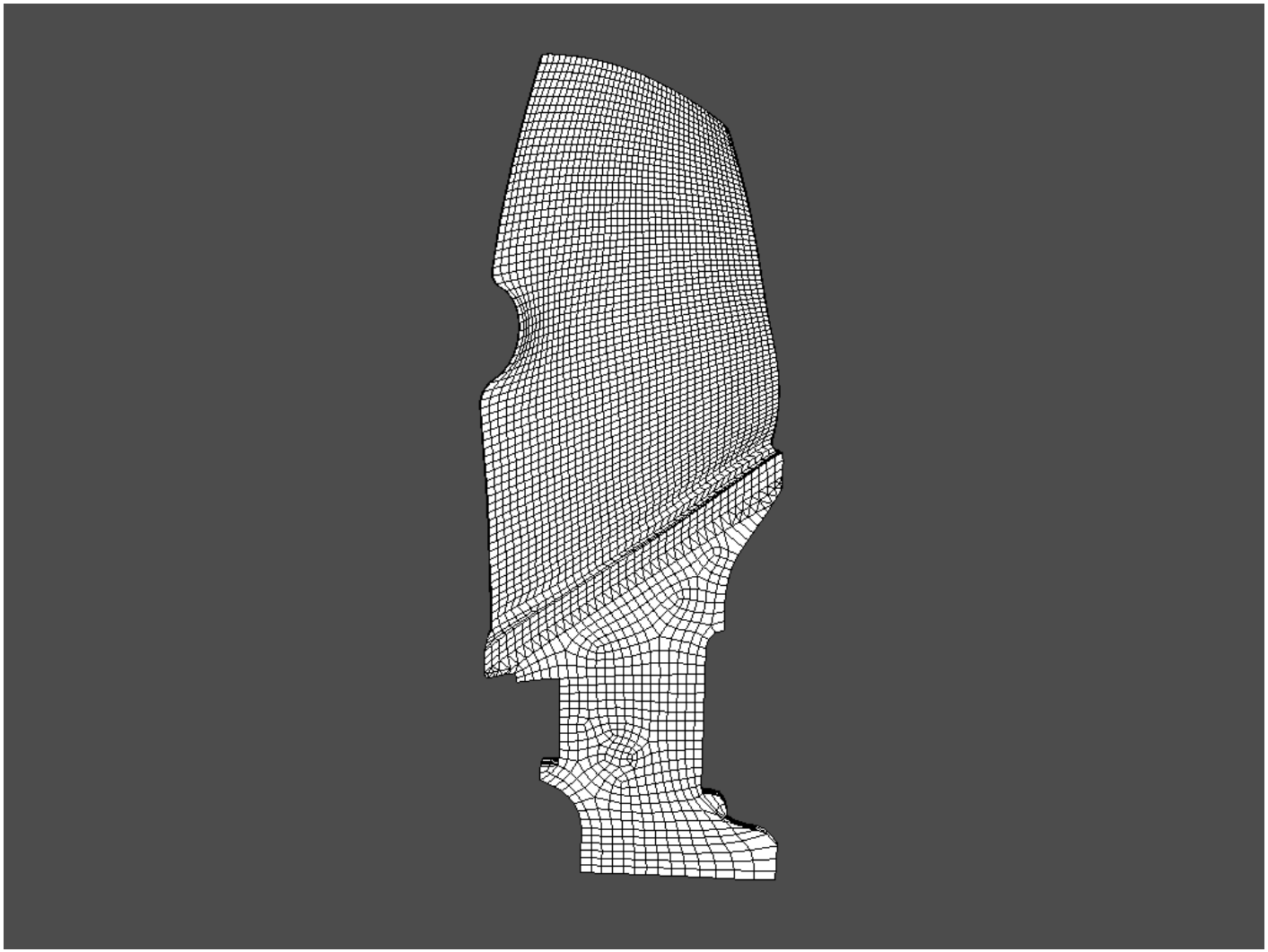
Mode 3 approaching mistuning limit



Blend Shape Optimization

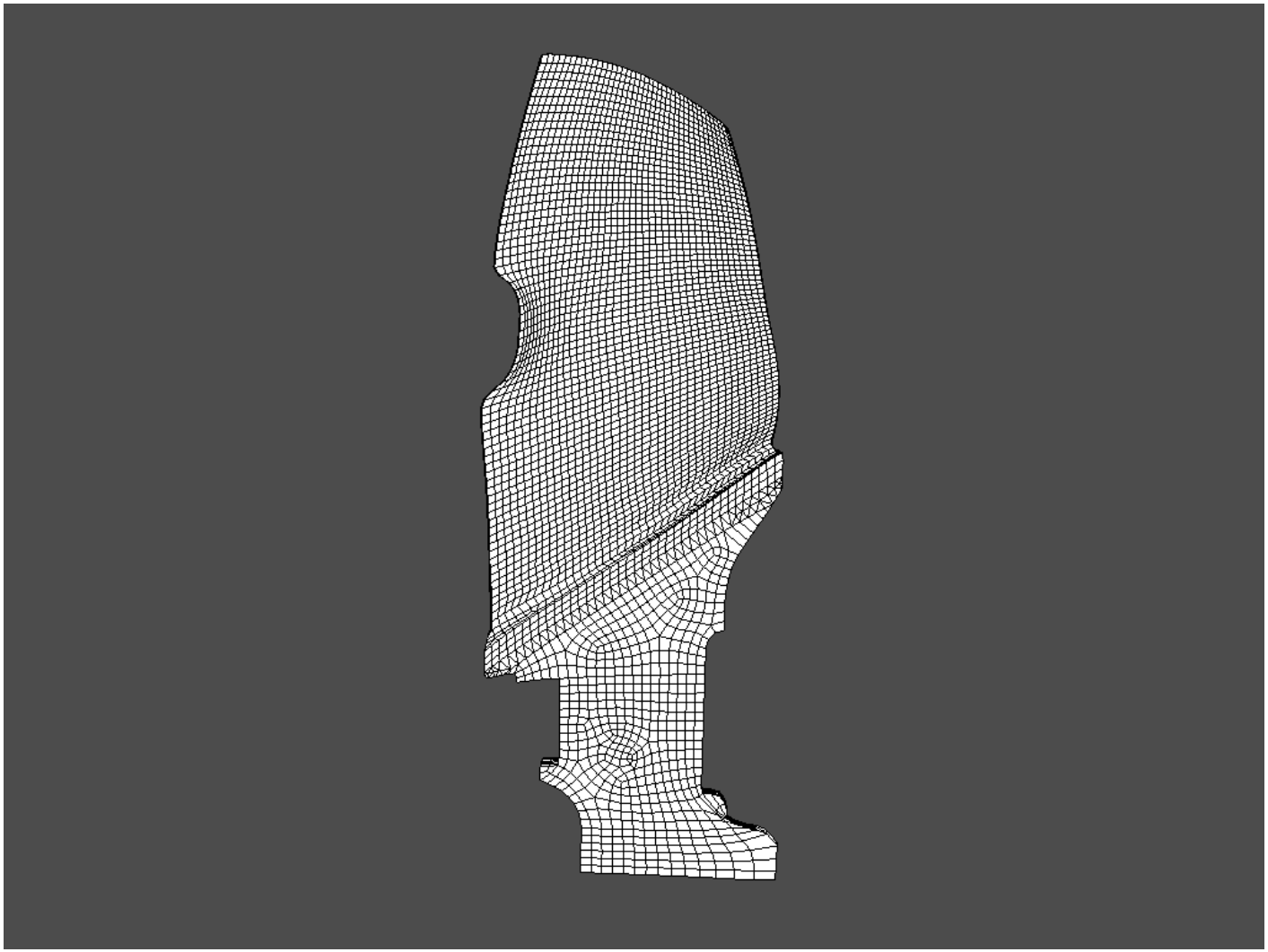
Blend Optimization

Opt 1 - Increased length



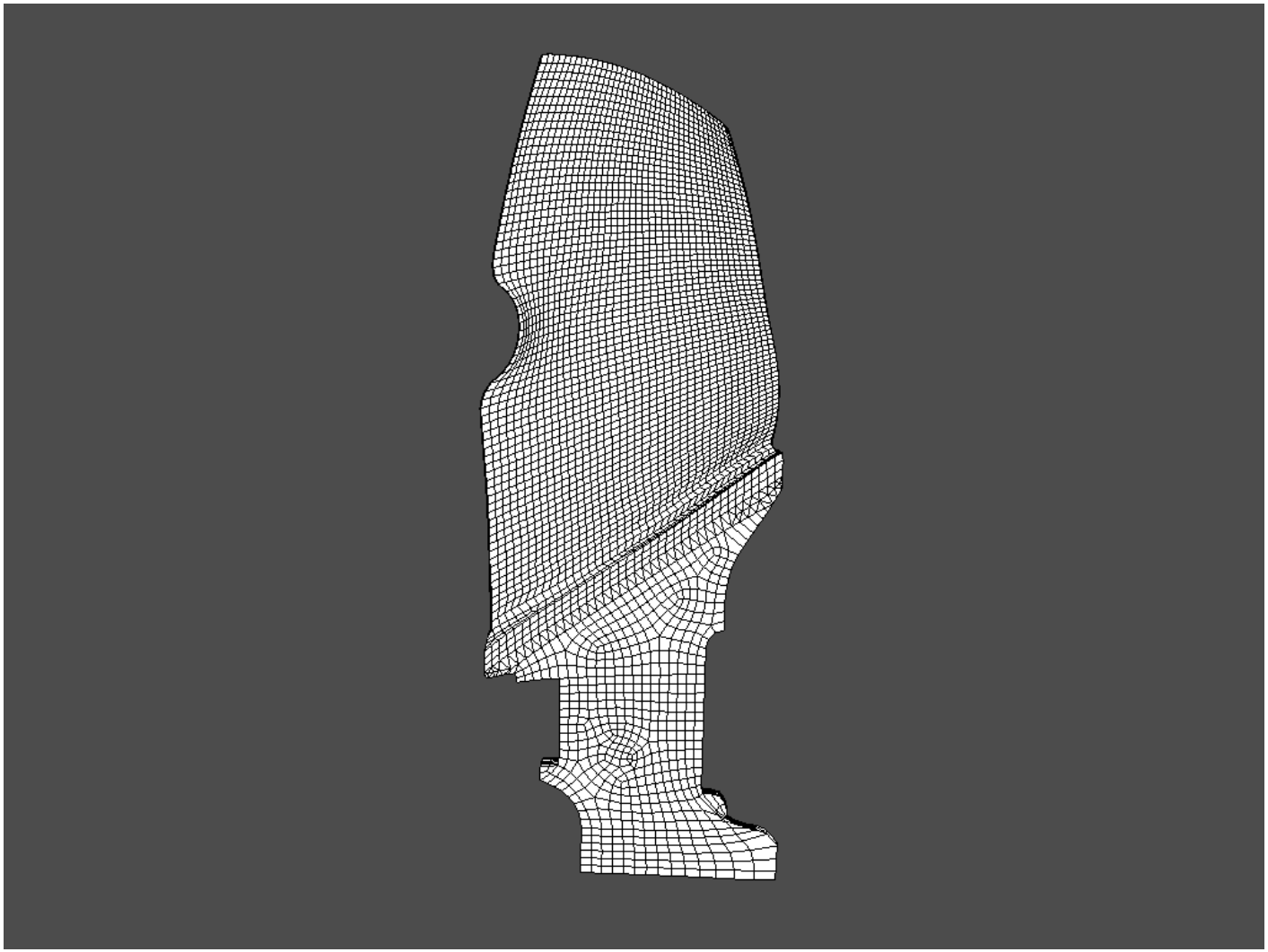
Blend Optimization

Opt 2 - Increased flat



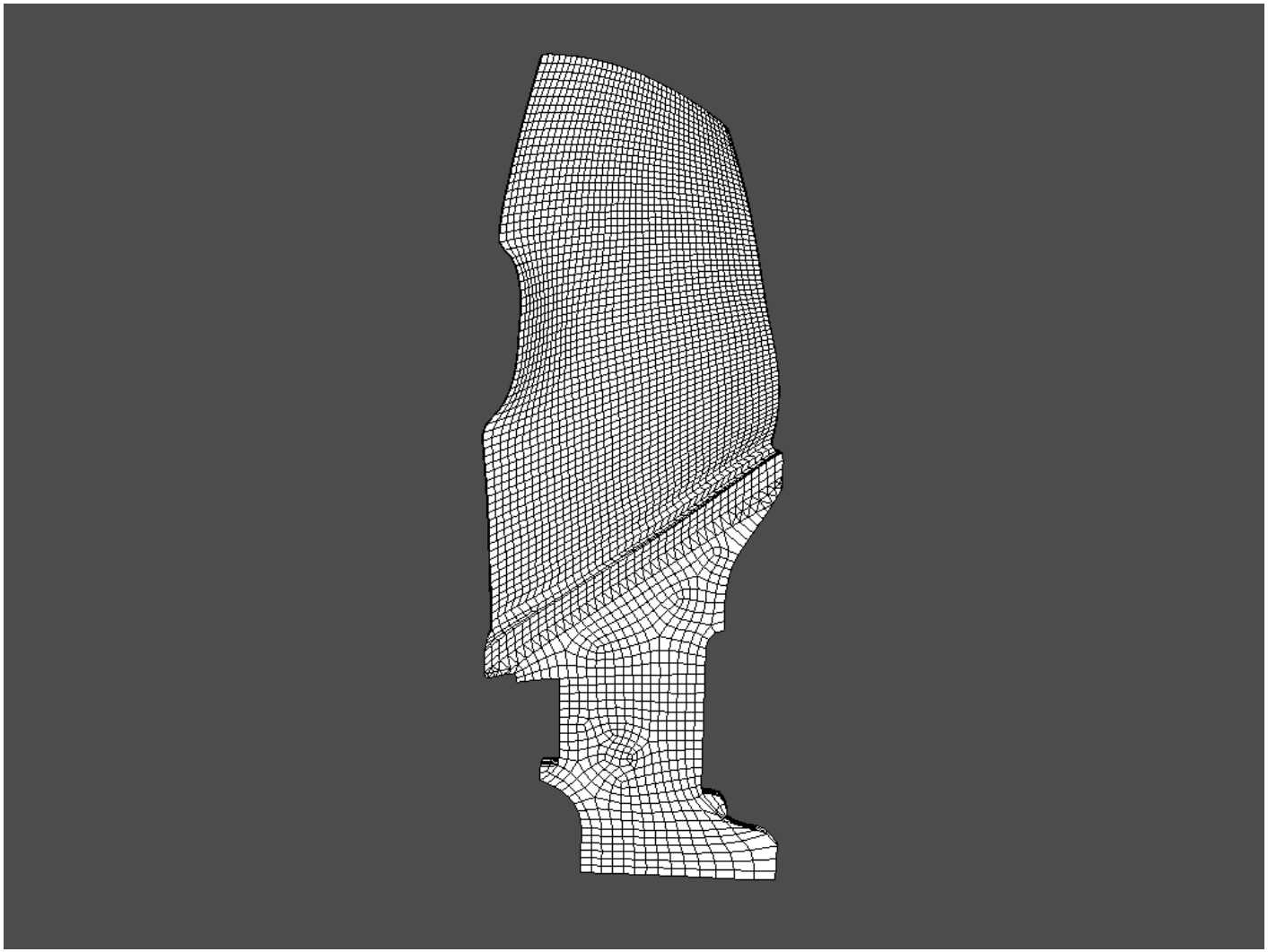
Blend Optimization

Opt 3 - Increased radius



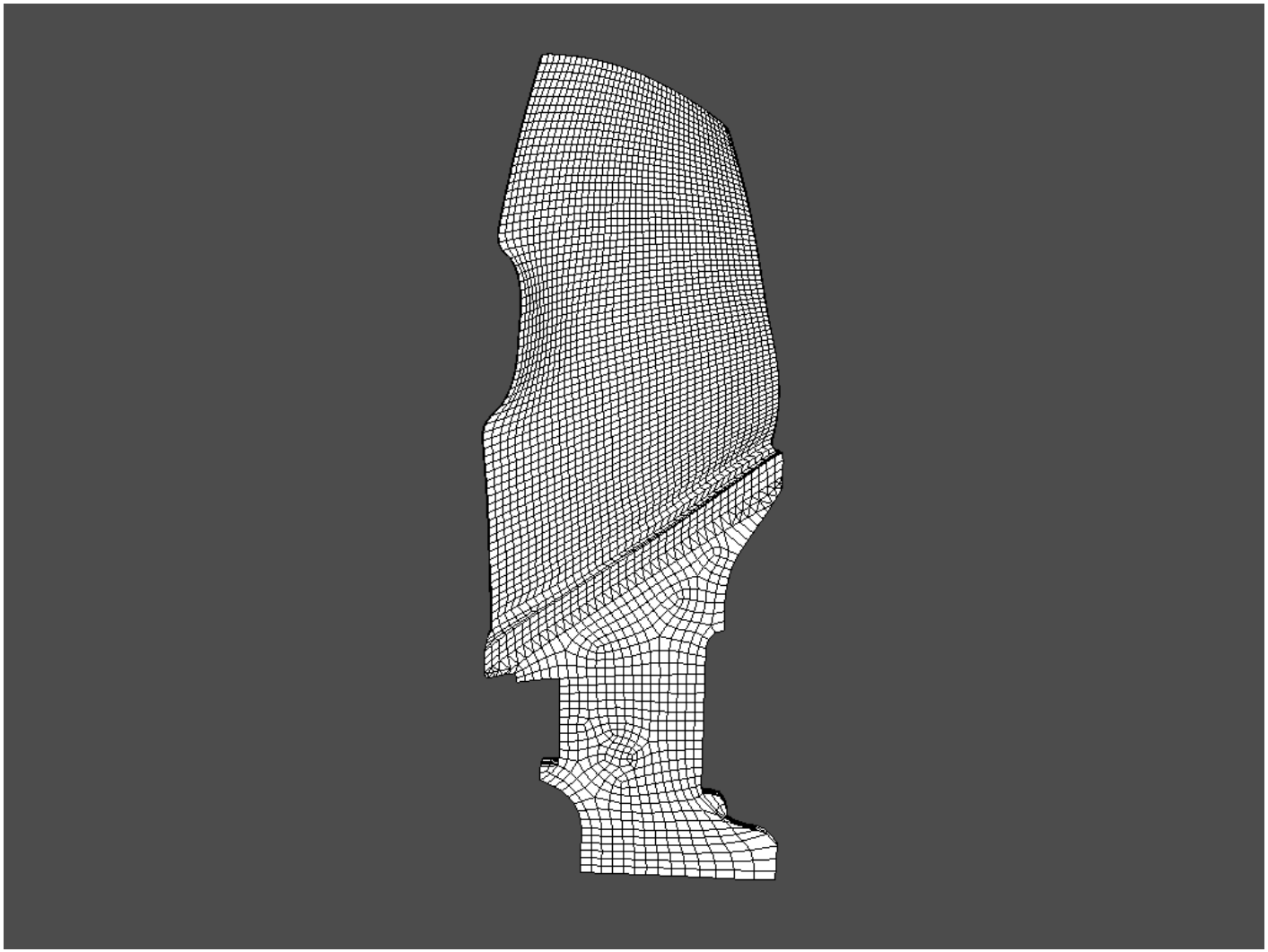
Blend Optimization

Opt 4 - Small increase in length, increase in flat



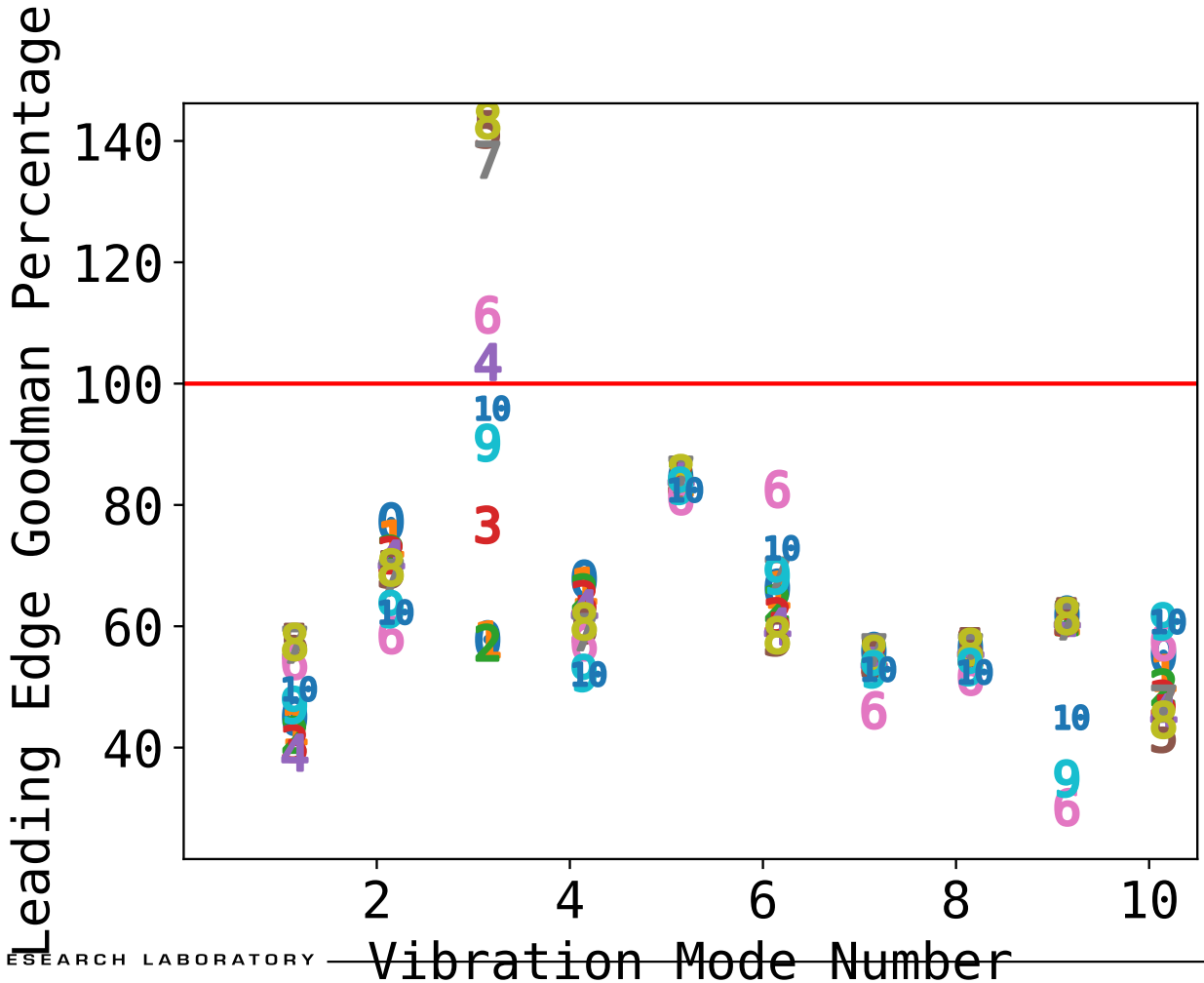
Blend Optimization

Opt 5 - Smaller increase in length, same increase in flat



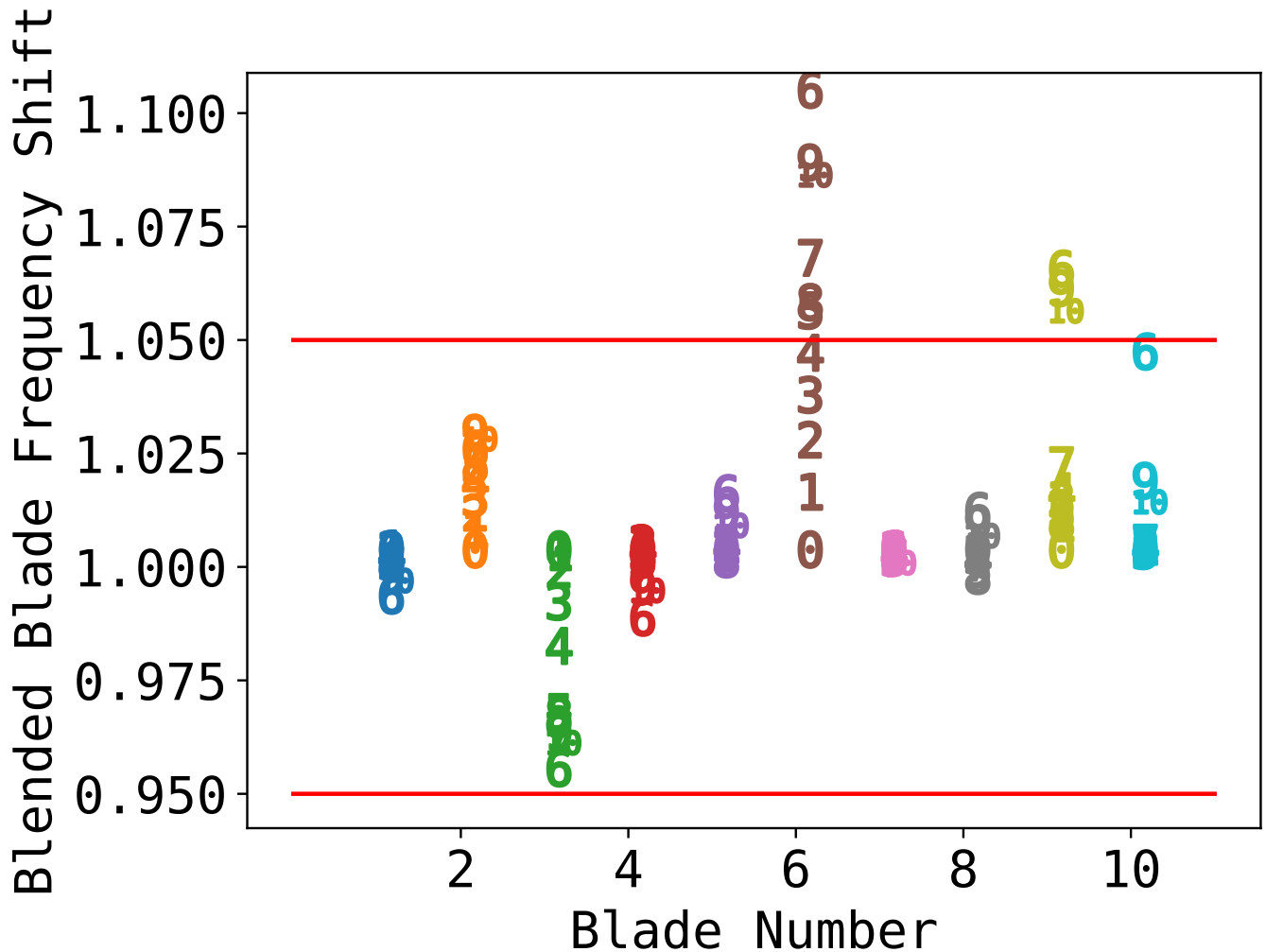
Blend Optimization

Leading edge Goodman results, optimum shapes are numbers 6-10. Blend #5, i.e. result #10, meets LE Goodman requirement



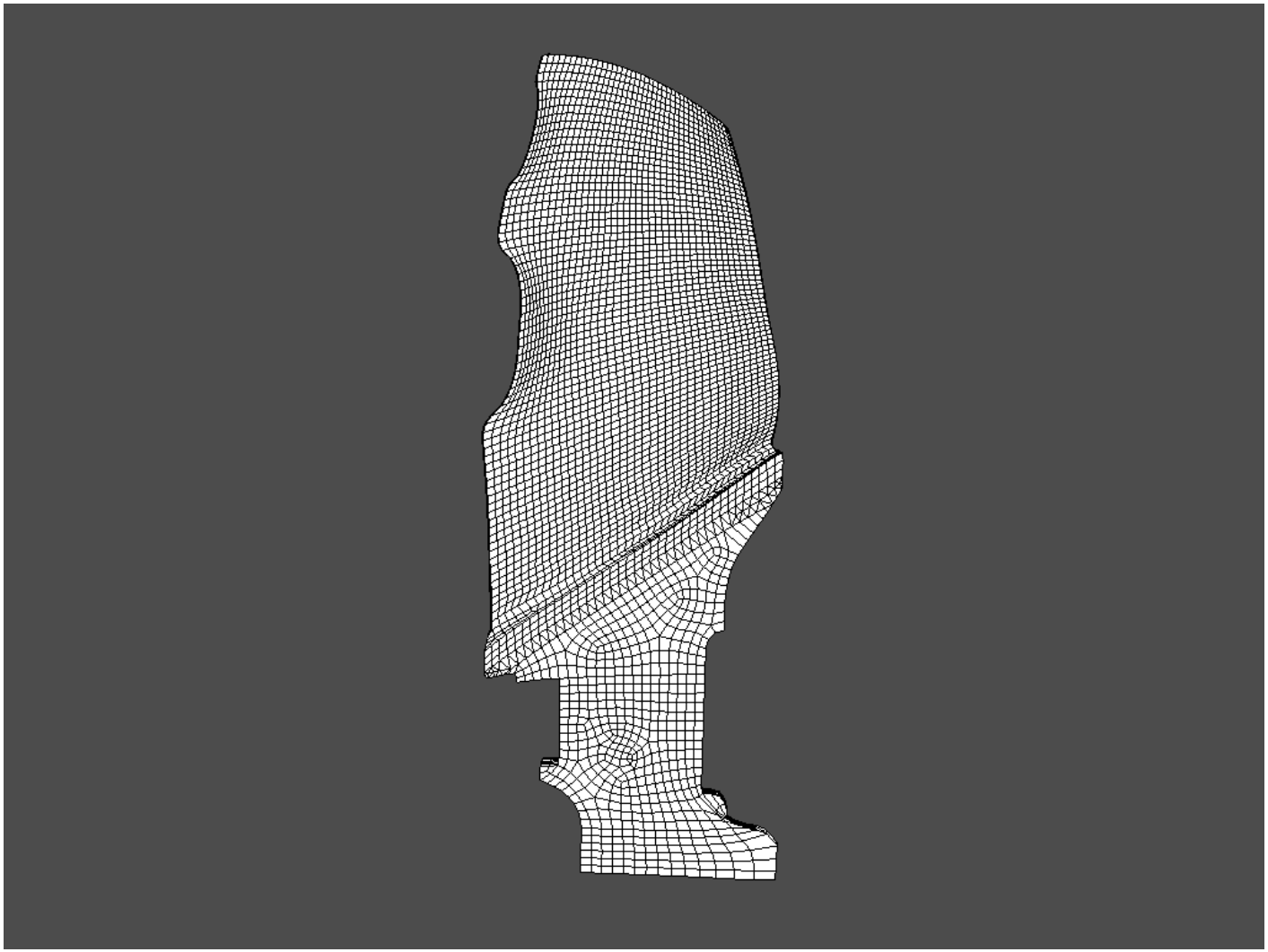
Blend Optimization

Frequency delta results, optimum shapes are #6-—#10. Optimized blends exceed Mode 6 frequency limit. However, Campbell shows no crossing within 10%.



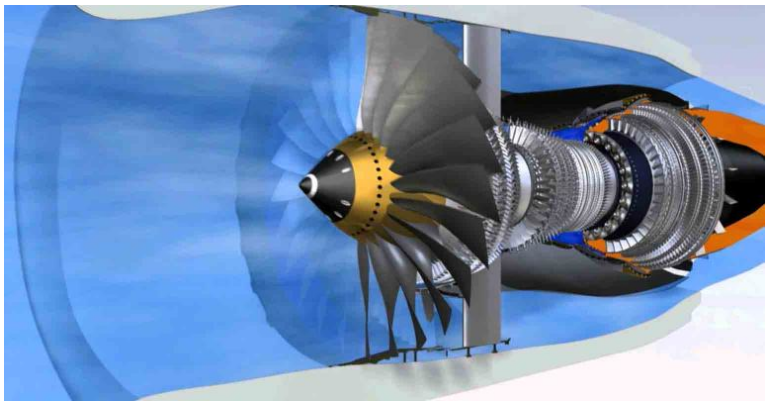
Even more blends options

N-number of blends can be applied



Conclusion

- Blends are an affordable method of repair and can be done on-wing
- Current limits based on assumptions that consider an entire fleet
- A part specific approach can lead to extension in blend limits and significant cost savings
- FEMORPH and Blender are capable of rapidly building models for this purpose

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