



# AFRL FEMORPH

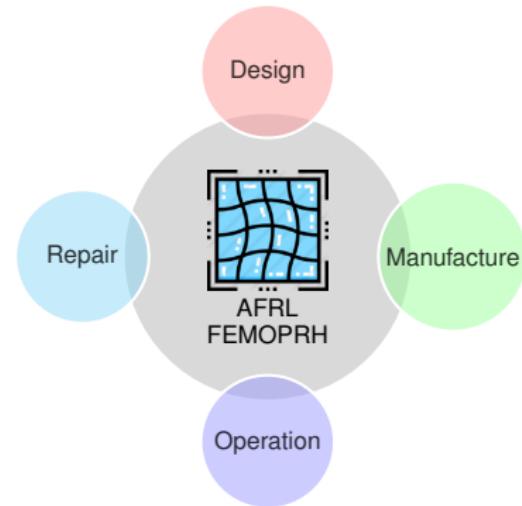
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**ENGINE INTEGRITY BRANCH  
TURBINE ENGINE DIVISION  
AEROSPACE SYSTEMS DIRECTORATE  
MARCH 10, 2021**

# AFRL FEMOPRH

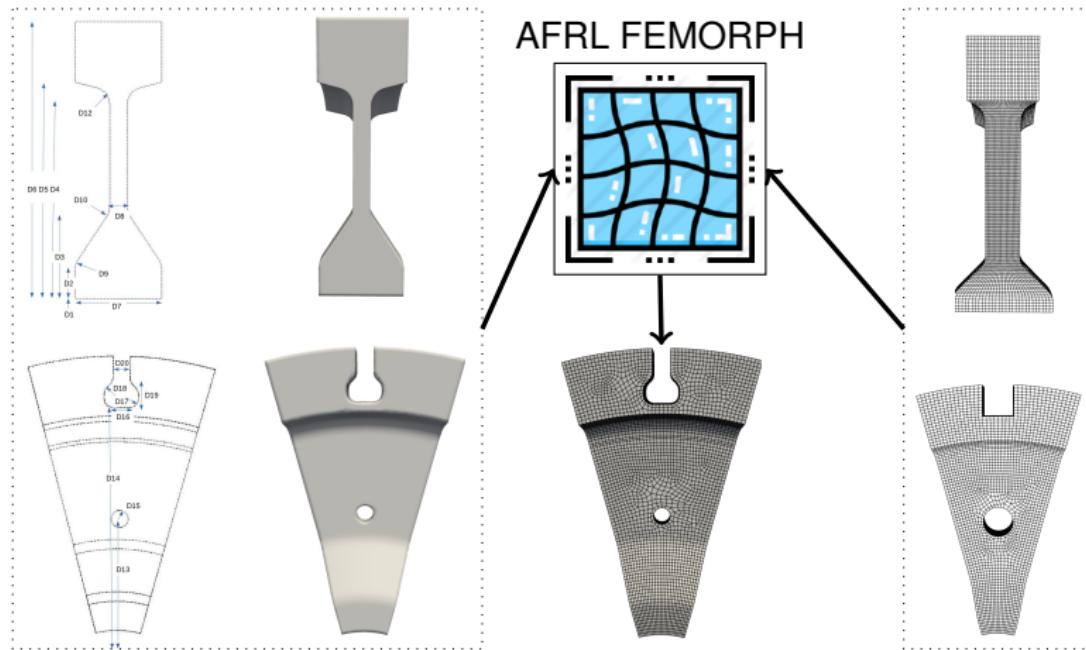
3D Mesh Morphing Software - FEM, CFD, .STL, CMM data, ...

- Simplify 2D and 3D shape optimization
- Robustly generate computer experiment designs
- Save design time by removing mesh generation bottlenecks
- Assess impacts of as-manufactured geometry on design intent
- Learn the effects of operational damage on continued use
- Design and validate the suitability of component repair
- And more...



# Design with AFRL FEMORPH

## Morph FEM to Parameterized CAD Model



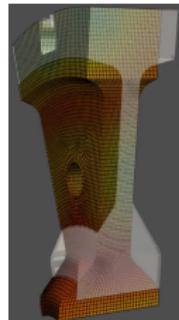
Parameterized CAD

Morphed FEM

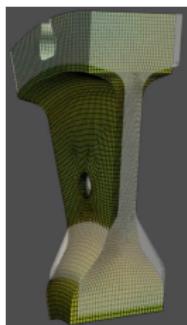
Initial FEM

# Design with AFRL FEMORPH

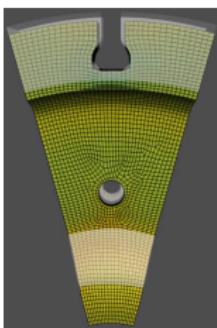
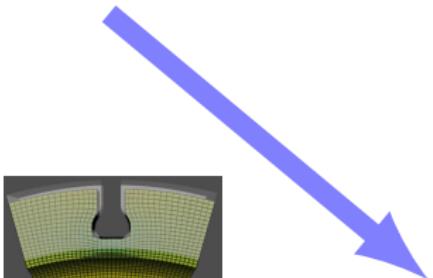
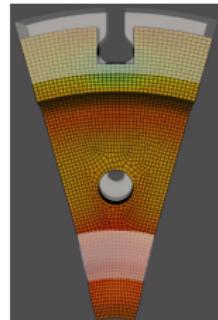
## Morphing FEM to CAD



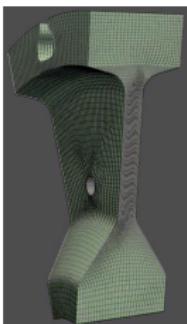
0% Morph



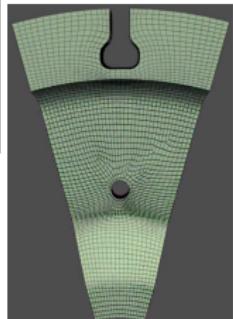
50% Morph



50% Morph

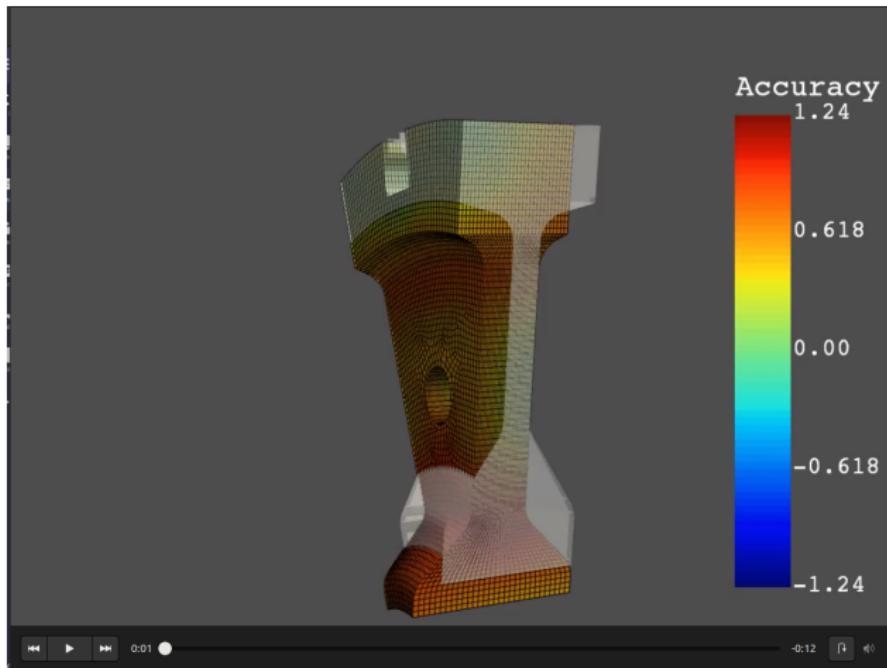


100% Morph

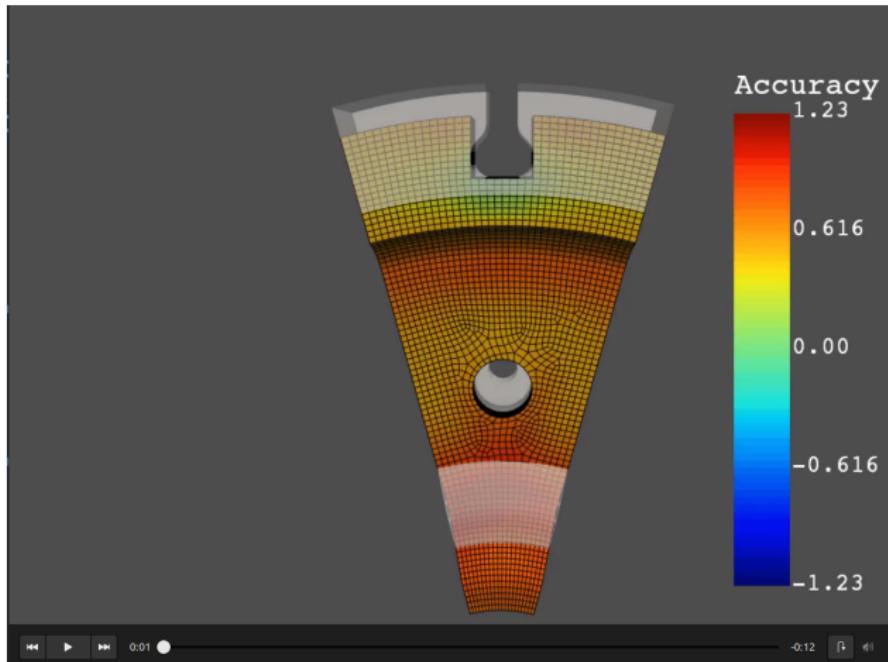


100% Morph

## Animation - Click image to Play (disk\_side.mp4)

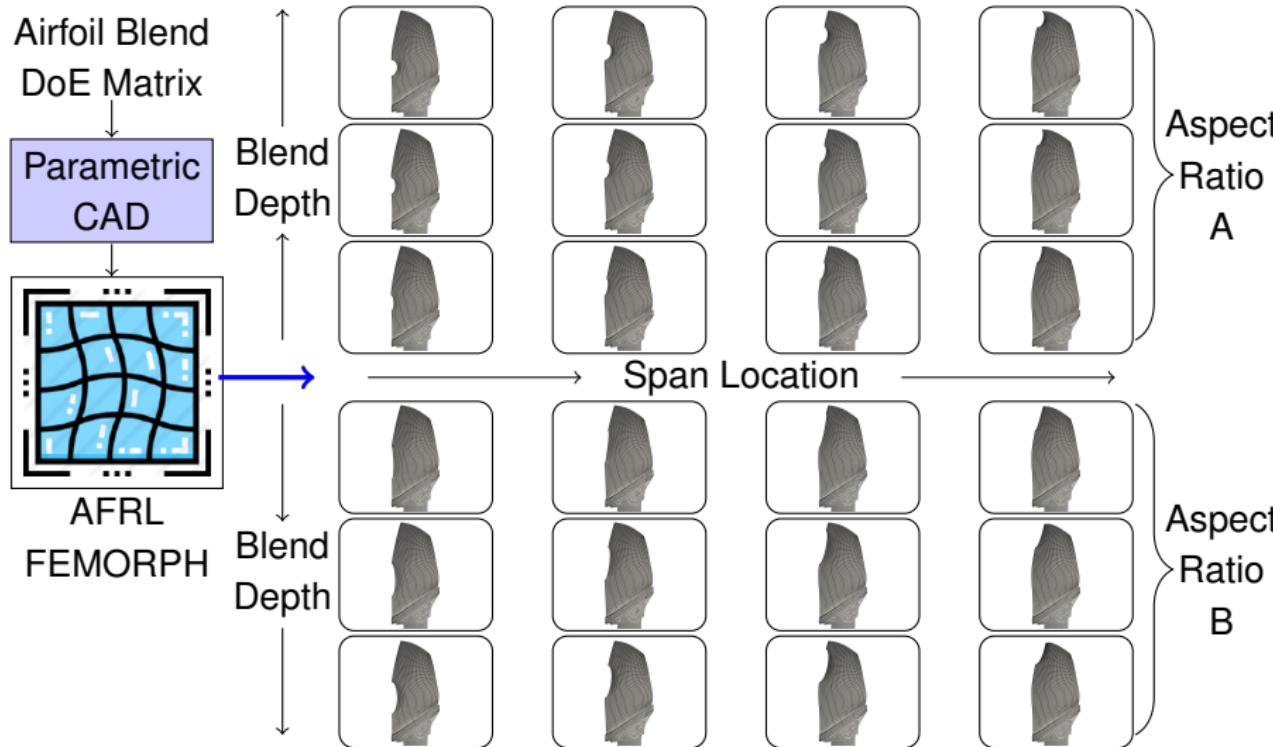


## Animation - Click image to Play (disk\_front.mp4)



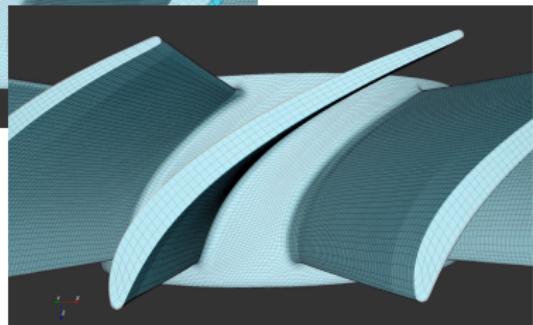
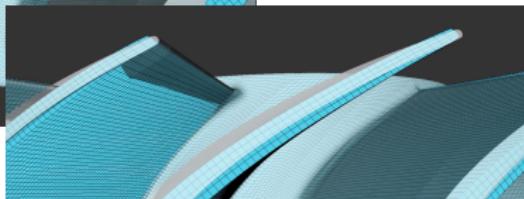
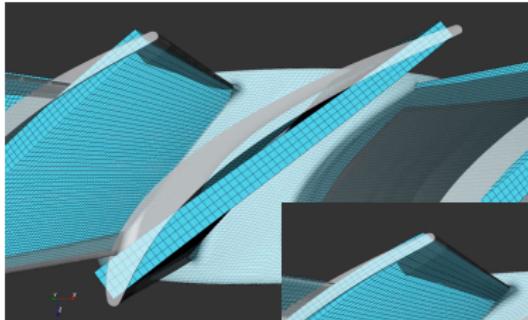
# Design with AFRL FEMORPH

## Sample Large Design Spaces Without Remeshing Challenges

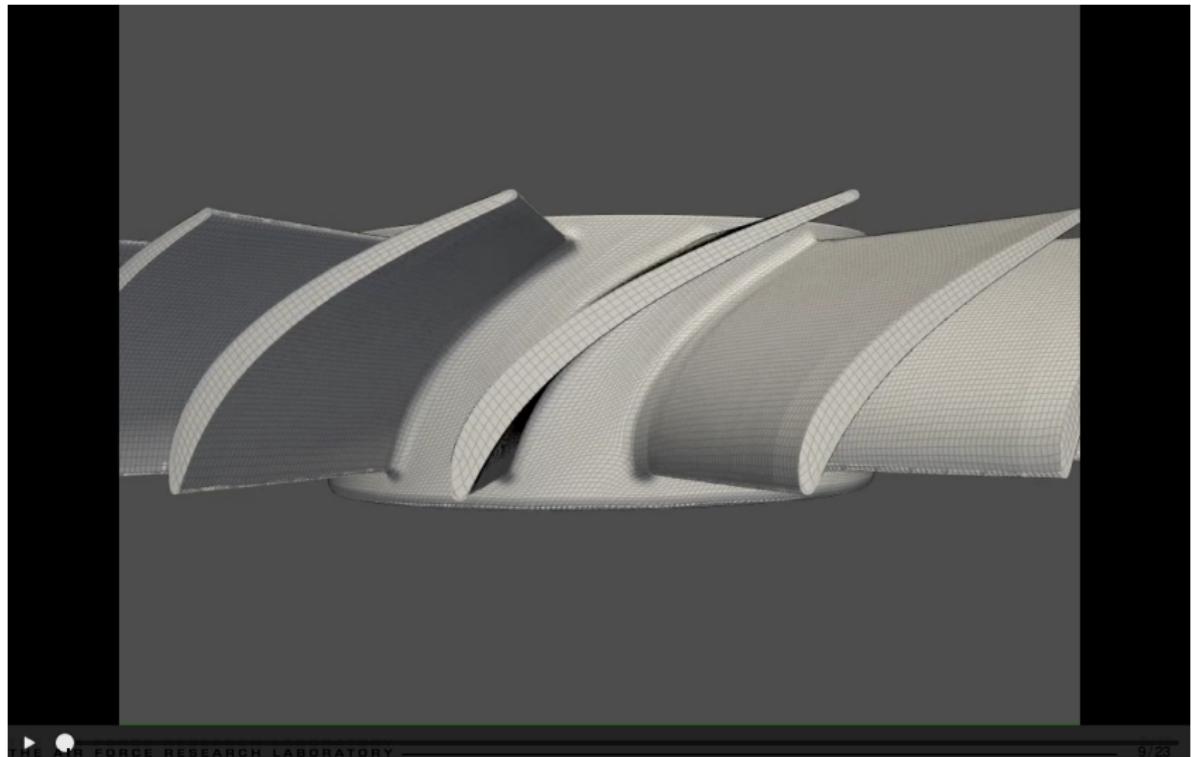


# Design with AFRL FEMORPH

Simplify Hex Mesh Generation - Morph defeatured FEM to Complex Surface



## Animation - Click image to Play (blade\_plate.mp4)

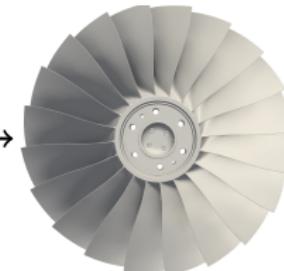


# Manufacturing with AFRL FEMORPH

It starts with measuring variation of a real part and comparing to Design Intent

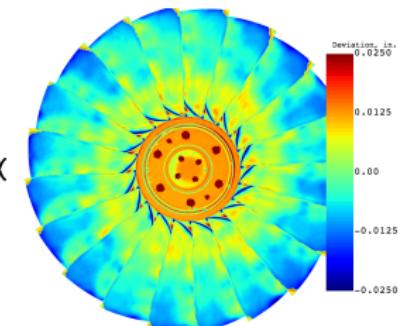


Geometry Measurement



STL Surface

Manufacturing Deviations



Deviation<sub>in.</sub>

0.0250

0.0125

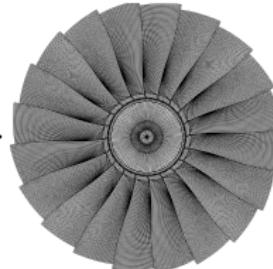
0.00

-0.0125

-0.0250



FEM Software



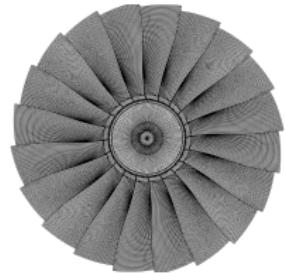
Design FEM

# Manufacturing with AFRL FEMORPH

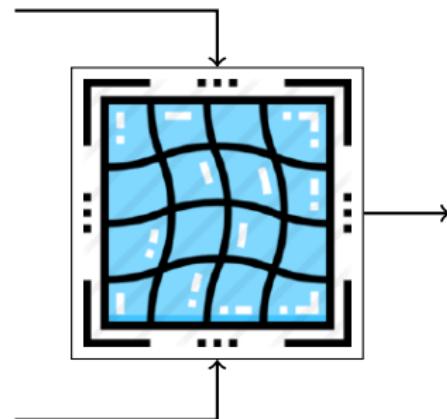
AFRL FEMORPH updates the Design FEM to match the STL surface within 0.001"



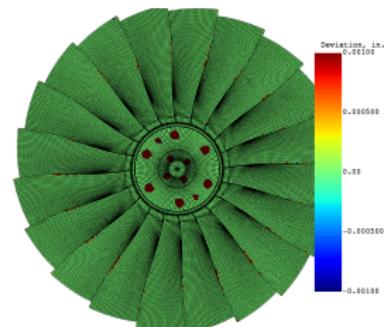
STL Surface



Design FEM

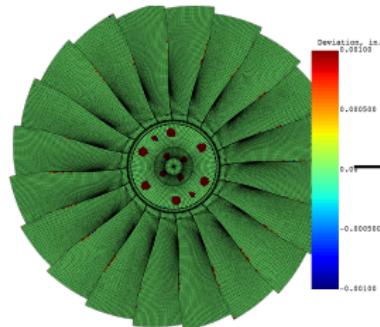


Morphed FEM  
Deviations from STL



# Manufacturing with AFRL FEMORPH

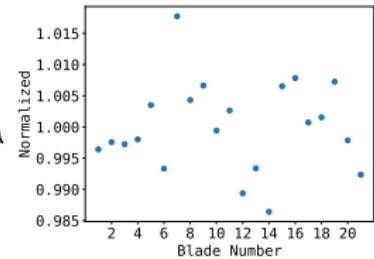
Morphed FEM is a Computational Replica of Physical Part



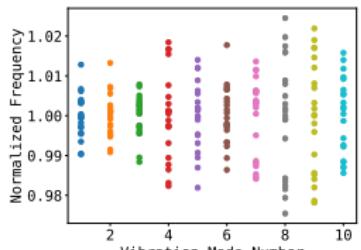
Morphed FEM  
Computational Replica

Ansys

FEM Software

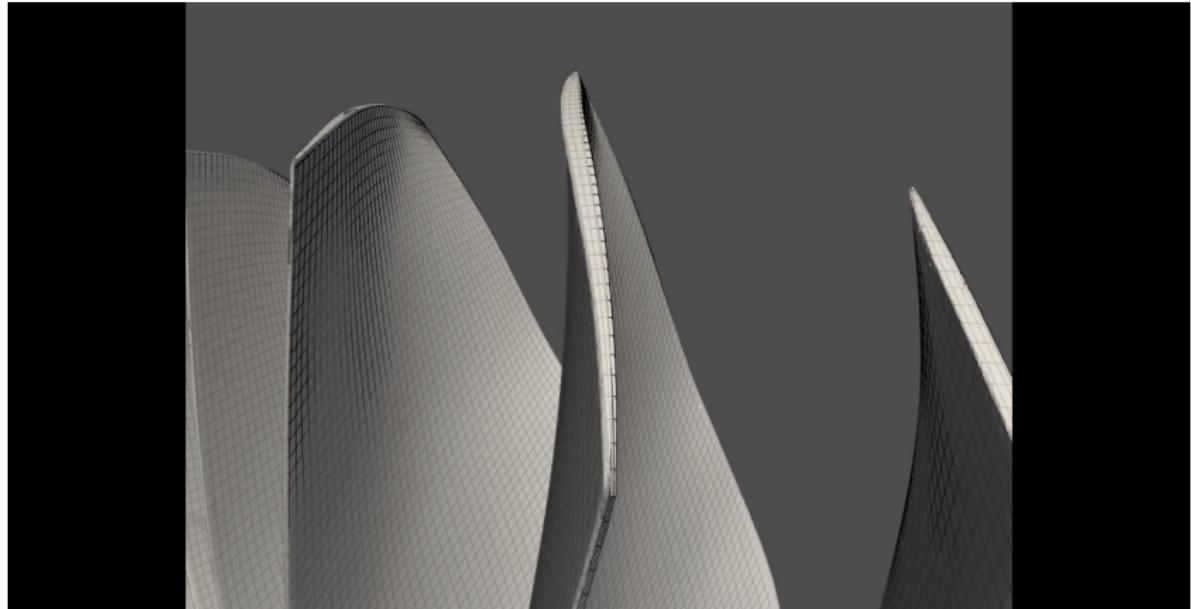


Blade to Blade  
Variation



Rotor to Rotor  
Variation

## Animation - Click image to Play (blade\_morphvid.mp4)

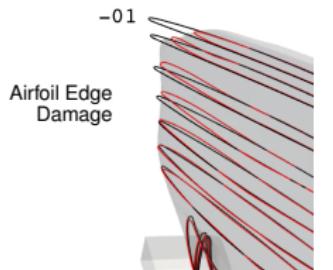


# Operations with AFRL FEMORPH

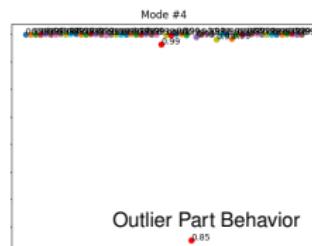
## Integrating with Maintenance, Repair, and Operations with FEMORPH



Airfoil Leading Edge Blend Repair

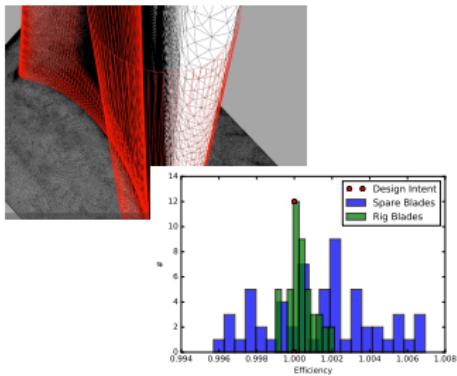


Assess Damage

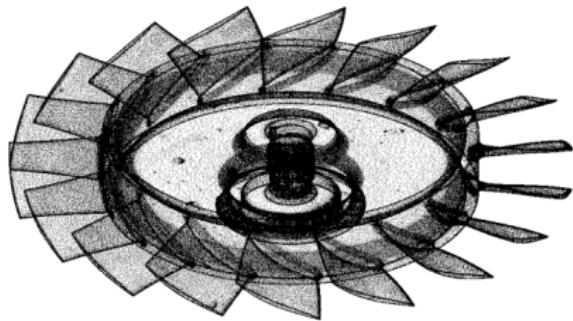


Safety Review Board

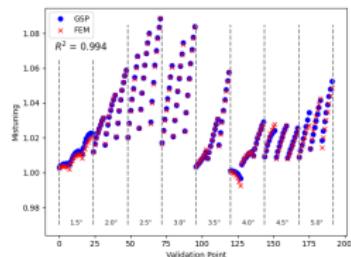
## More with AFRL FEMORPH



Turbine CFD Mesh Morphing

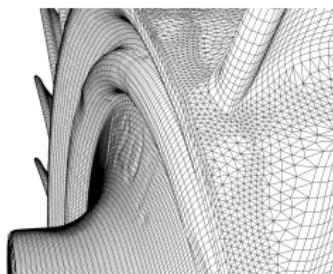


First Article Analysis



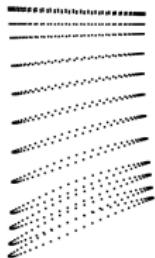
ML/AI Training Data Generator

THE AIR FORCE RESEARCH LABORATORY



Additive Part Models

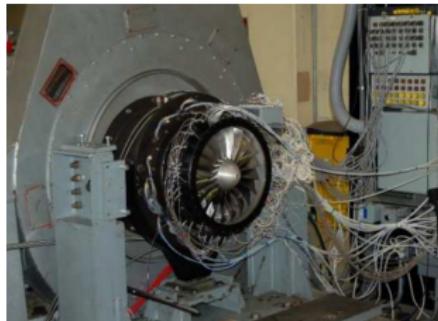
## Even more with AFRL FEMORPH



CMM Data Capable



Improved Instrumentation



Improved Model Validation

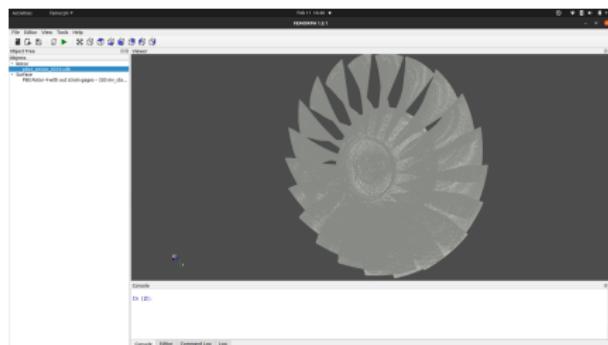


Adaptive Toolpath Generation

# AFRL FEMORPH Interface

## Python API for automated workflows and GUI for user experience

```
File Edit Options Buffers Tools Python Virtual Envs Elpy YASnippet
1 import femorph
2 import femorph_blender
3
4 jetcat_surf = 'jetcat_scan.ply'
5 jetcat_cdb = 'jetcat_sector.cdb'
6
7 surf = femorph.Surface(jetcat_surf)
8 fem = femorph.Rotor(jetcat_cdb)
9 fem.replicate_cyclically()
10 fem.align(surf)
11 fem.morph(surf, settings=set_morph)
12 fem.write_cyclic_sectors()
13
14 blend = femorph_blender.Blender(fem)
15 blend.define_edge('LEAD_EDGE_NODE')
16 span = 2.5
17 aspect = 2.0
18 depth = 0.2
19 blend.blend_on_edge(spans, aspect, depth, 0.0, 0.0, 100)
20 blend.write_archive()
```



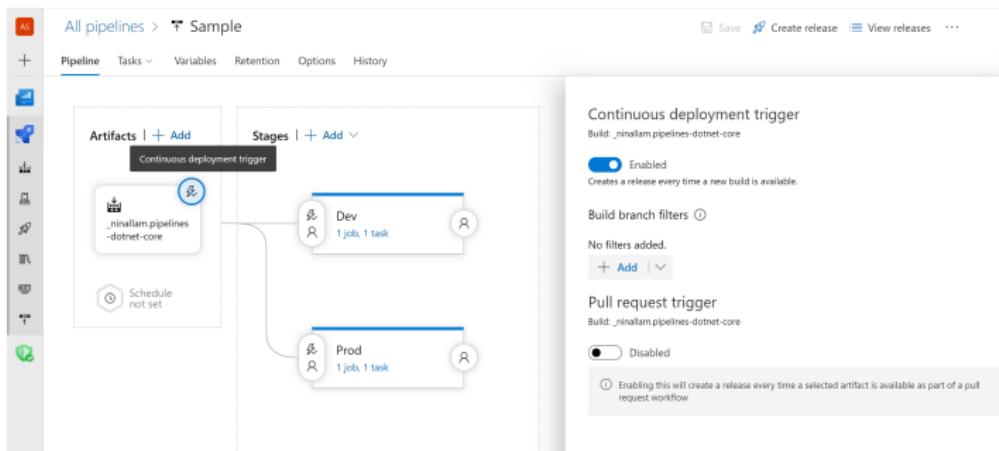
## AFRL FEMORPH Background

- Developed in Python, C, and C++ for 8+ years
- Compatible with Linux, Windows, and Mac OS
- Beta tested by Pratt & Whitney for two years
- In fourth year of 10 year non-exclusive license with Pratt & Whitney
- P&W provides licensing fees for use and support
- Utilized by large P&W user base for wide range of applications
- Applied pervasively in AFRL research and customer support activities

# AFRL FEMORPH Background

## Software Development Process Enhances Robustness

- Software tested rigorously in continuous development and deployment (CI/CD) pipelines
- Leverages automated testing in a secure environment
- Enables high code coverage and stability testing through regression testing.



# AFRL FEMORPH Background

## Software Testing

- AFRL FEMORPH follows standard software development practices.
- Unit and regression tests ensure new features are added without breaking existing ones.
- Code coverage of  $\geq 95\%$  required for all modules, and  $\geq 98\%$  for core modules

```
tests/test_surface.py::test_surface_blend SKIPPED (Requires femorph_blender) [ 91%]
tests/test_surface.py::test_boolean PASSED [ 92%]
tests/test_surface.py::test_load_g3d PASSED [ 92%]
tests/test_tree.py::test1d PASSED [ 93%]
tests/test_tree.py::test3d PASSED [ 93%]
tests/test_tree.py::test3d_float32 PASSED [ 94%]
tests/test_tree.py::test3d_float32_mismatch PASSED [ 94%]
tests/test_tree.py::test3d_float32_mismatch2 PASSED [ 95%]
tests/test_tree.py::test3d_8n PASSED [ 95%]
tests/test_tree.py::test3d_8n_ub PASSED [ 96%]
tests/test_tree.py::test3d_8n_ub_leaf20 PASSED [ 96%]
tests/test_tree.py::test3d_8n_ub_eps PASSED [ 97%]
tests/test_tree.py::test3d_large_query PASSED [ 97%]
tests/test_tree.py::test_scipy_comp PASSED [ 98%]
tests/test_tree.py::test1d_mask PASSED [ 98%]
tests/test_tree.py::test1d_all_masked PASSED [ 99%]
tests/test_tree.py::test3d_mask PASSED [ 99%]
tests/test_tree.py::test6d PASSED [ 100%]

=====
===== 210 passed, 2 skipped in 88.92s (0:01:28) =====
```

# AFRL FEMORPH Background

## Software Design: Modularity

- Software is a non-monolithic, modular, and composed of several packages.  
Includes both GUI and batch packages.
- Designed to be expandable, adaptive, and compatible with modern Python 3.6 - 3.8 environments on Windows, Mac, and Linux.
- Compatible with standalone virtual environments, Jupyterlab webpages, or standard Python.



femorph

Version 1.2.1



femorph-blender

Version 0.5.0



femorph-cfd

Version 0.2.4



femorph-gui

Version 1.5.1



femorph-remesh

Version 0.2.4

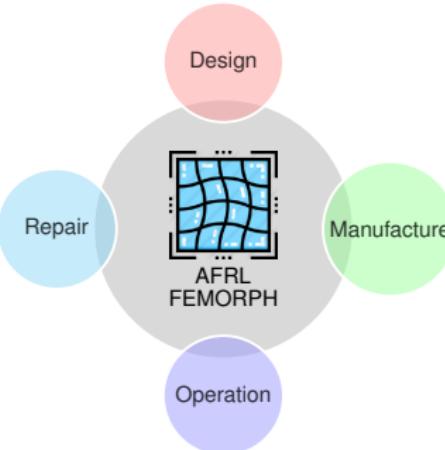


femorph-tetblaster

Version 0.2.3

## Closing Remarks

- AFRL FEMORPH adds value across the life cycle, from design, to manufacture, and through operations
- Rigorous software development practices have enabled rapid development and successful deployment
- Windows demo software available and licensing opportunities





**AFRL**