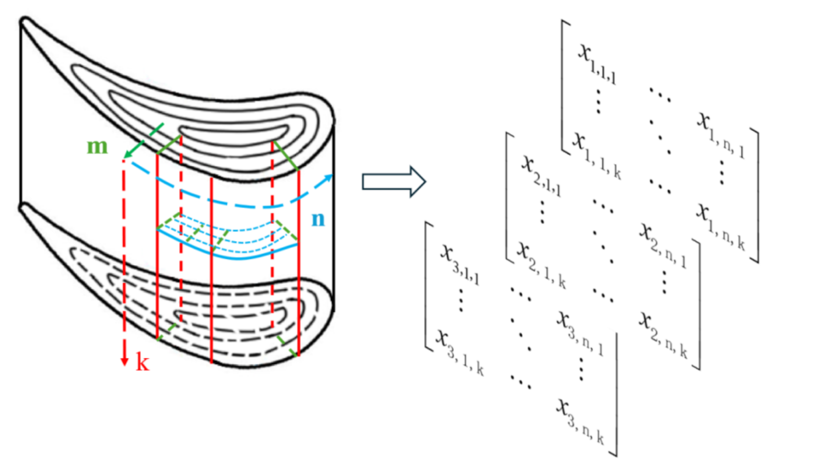
Turbine Blade Design and optimization

Jiazheng Fan, Jiawei Xu, Aneeb Siddiqui, Xurong Shi, Chuang Han, Shiqi Feng, Hongzhi Cheng, Penghao Duan

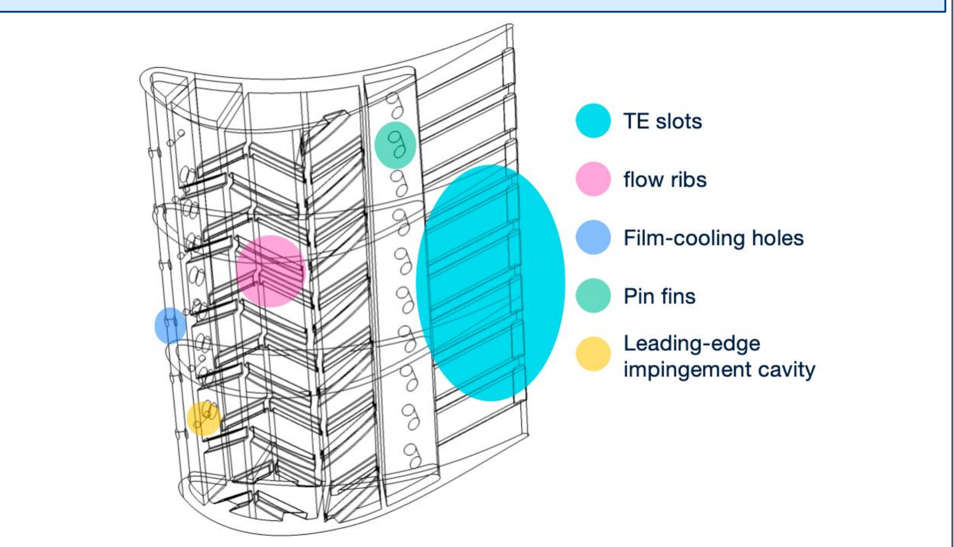
Department of Mechanical Engineering

Research 1: Turbine Blade Parameterization

From a blade profile, the framework builds 3D cooling geometry and high-quality FSI meshes for design iteration—handling complex geometry control, automatic fine-feature generation (impingement sleeves, flow ribs), robust Boolean operations, and stable curve insetting.

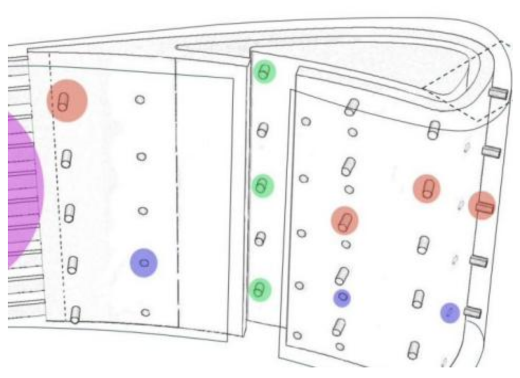


Geometry-to-Matrix Parameterization of Turbine Blade Cooling Features

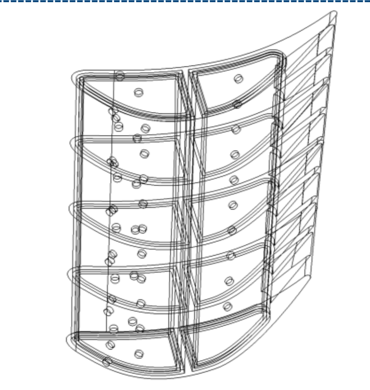


Serpentine channel & Cooling Feature Parameterization

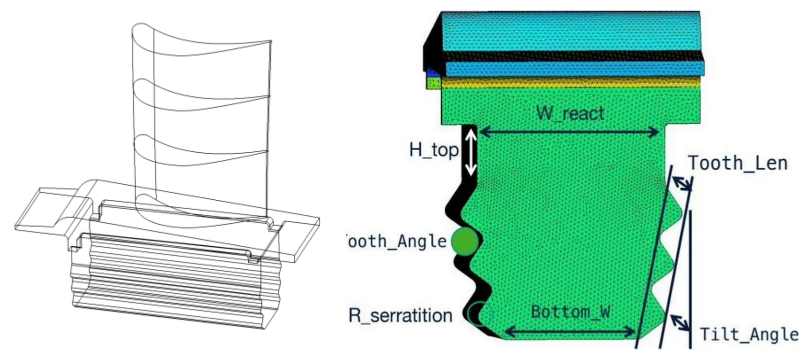
Cooling & Root Configurations: **double-wall · Impingement Sleeve · fir-tree blade root** — each fully parameterized and meshed in a unified framework.



Double-wall features



Impingement Sleeve



Blade Root Design (Platform + Fir-tree Root)

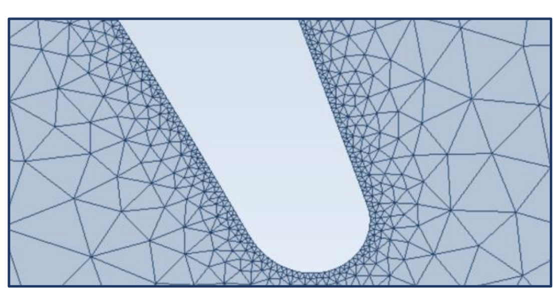
Research 2: Automatic Mesh Generation

Collision-aware hybrid mesh generation

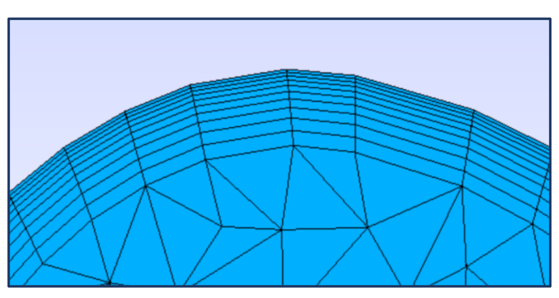
Boundary-layer prisms, transition cells and tetrahedra grown from a surface mesh.

Surface mesh →	Safe marching →	Prism + transition →	Tet-fill volume
surface input	per-point step	prisms + pyr/tet	fill interior

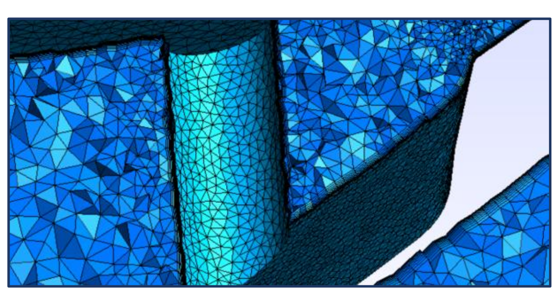
1 Mesh sections



Surface mesh refinement

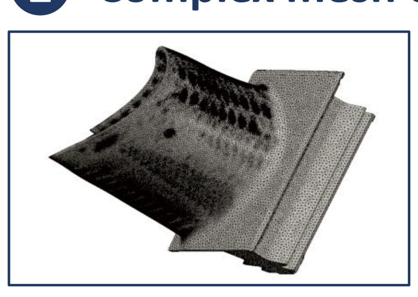


Layered volume section

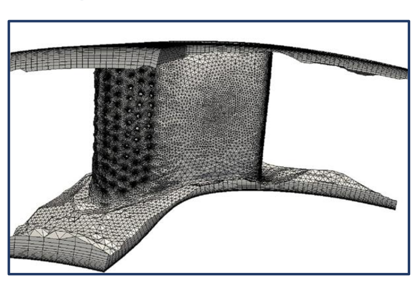


Cooling-channel section

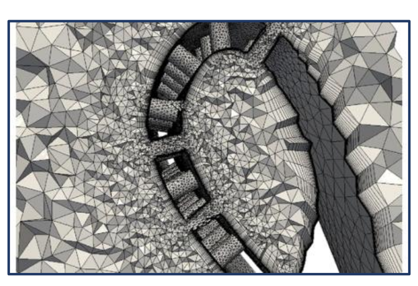
2 Complex mesh examples



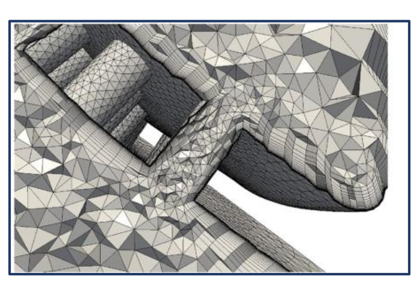
Film-cooled blade & platform



Blade mesh overview



Curved cooling-passage section



Local mesh refinement

FEATURES
- narrow gaps & sharp corners
- adaptive normal directions
- periodic boundaries
- fast collision detection

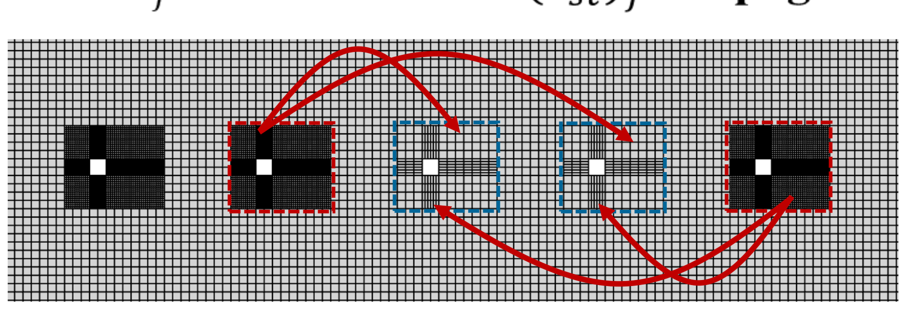
Research 3: Multi-scale Computation Algorithms

Inverse Mode in Fine Mesh: $\boxed{(S_s)_f} = R_C(\tilde{U}_f)$ **Solution $\tilde{U}_f$ or Source Term $(S_{st})_f$ Propagation**

Direct Mode in Coarse Mesh: $\frac{\partial U_C}{\partial t} + R_C(U_C) = \boxed{(S_s)_f}$

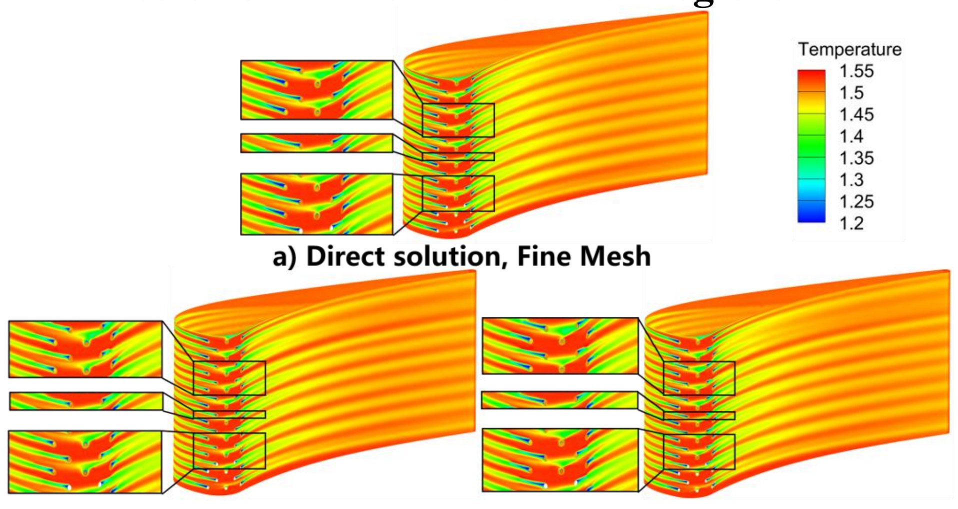
$$\boxed{R_C(U_c) = R_C(\tilde{U}_f)}$$

Recover the fine-mesh spatial averaged solution in the coarse mesh region.



Fine Mesh $\xrightarrow{\text{Upscale Solution}}$ **Coarse Mesh**

Fine Mesh $\xleftarrow{\text{Correct BCs}}$ **Coarse Mesh**

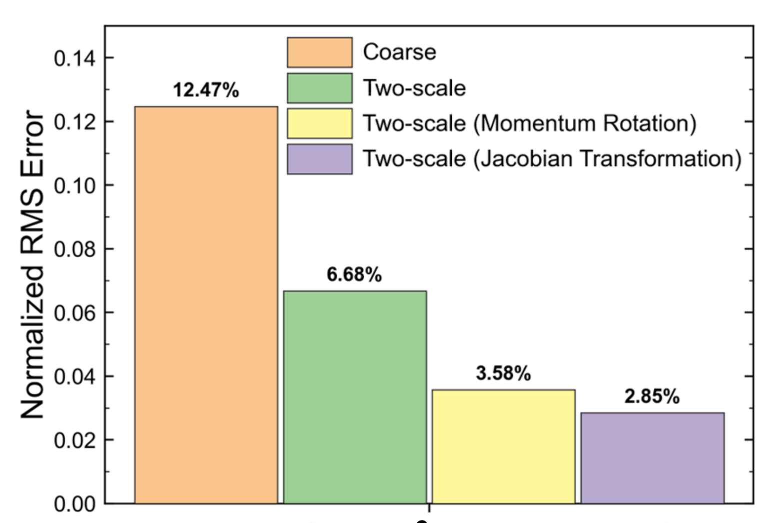


a) Direct solution, Fine Mesh

b) Direct solution, Coarse Mesh

c) Two-scale solution, Coarse Mesh

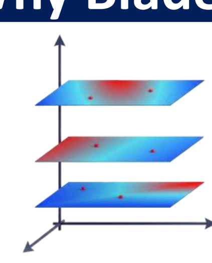
Practical case: film-cooled C3X vane



Accuracy: GE-E^3 pressure side

Research 4: BladeBench - Opensource Blade DataSet

Why BladeBench



- **AI-based blade design needs a large, diverse, standardized dataset.**
- **Existing datasets are narrow, not unified and rarely open-source.**
- **BladeBench is an open-source dataset featuring unified geometry parameterization and PI-theorem-guided boundary-condition generation.**

BladeBench Components

- **1000+ Geometries**
- **1000+ Performance data**
- **19 Parameters for Blade geometry**

Core Pipeline

1. **Blade from literature or 2D images**
2. **Extract and sample coordinates**
3. **Reverse-parameterize**
4. **Geometries and BCs variation**
5. **Performance data from SU2 simulation**

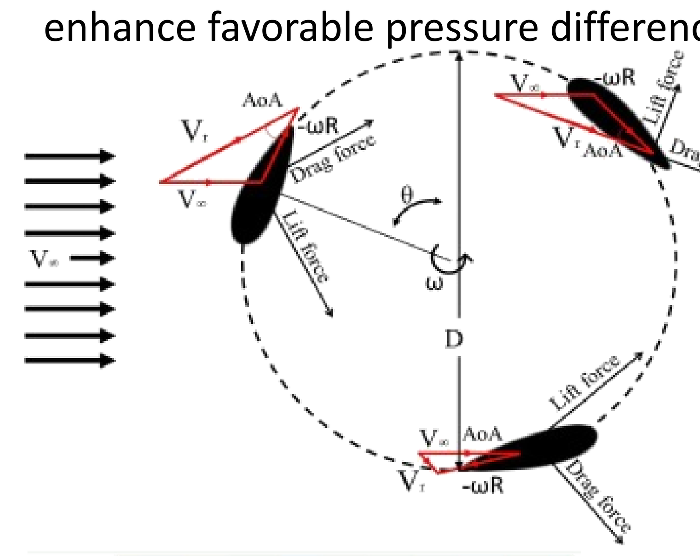
Reverse-parameterization MAE < 0.1%

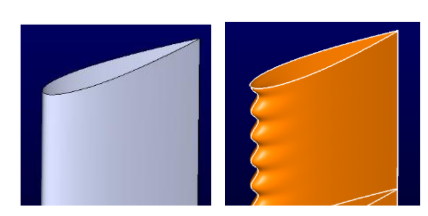
Open access: www.turbothing.com

Research 5: Vertical Axis Wind Turbine

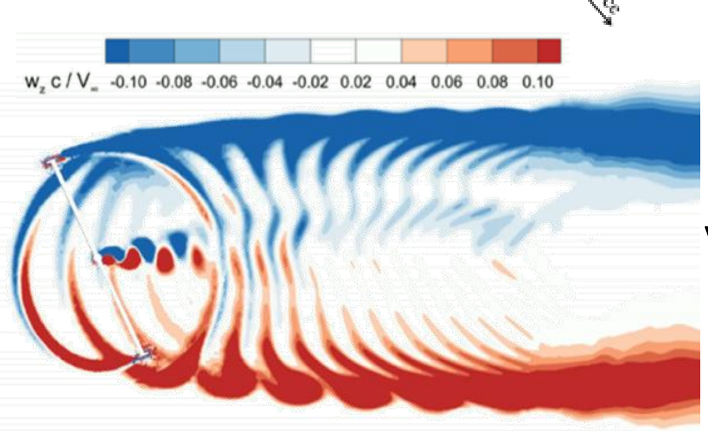
VAWT performance optimization using blade-geometry modification

- Passive and active flow-control strategies to mitigate dynamic stall and enhance favorable pressure differences

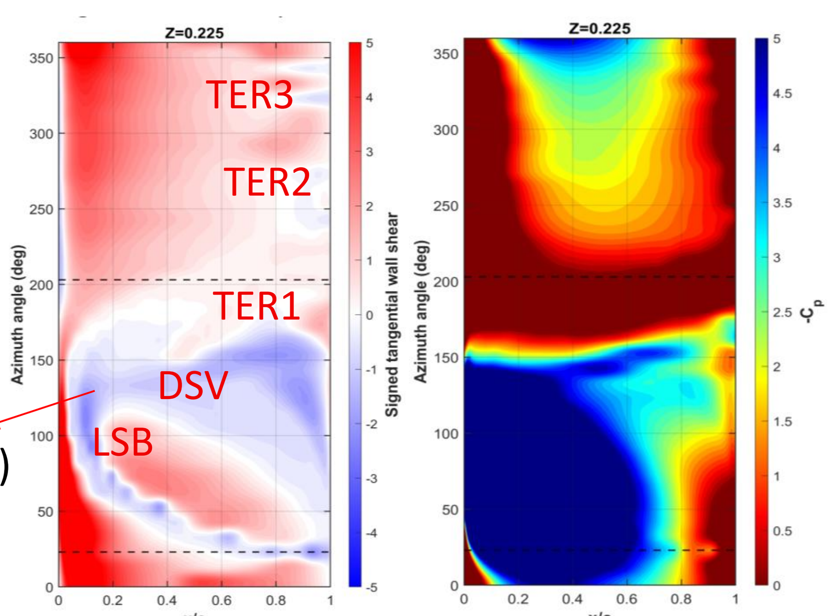




Blade Geometry Modifications



Dynamic stall vortex(DSV) formation & evolution



Spatiotemporal evolution of surface-flow parameters

- VAWTs have strong potential for wind-energy harvesting in complex urban wind environments. Understanding near-blade flow, wake interaction, and separation is essential for improving aerodynamic performance, structural reliability, and net energy extraction.

Controlling blade-scale flow separation is the key to improving VAWT power output and structural reliability.

Impact & Outlook

- **Industry Impact:** Collaborating with industrial partners to enable faster, more reliable design of advanced turbine blades through integrated parameterization, automated meshing, and multiscale simulation.
- **Design Revolution:** Establish a unified geometry-to-simulation workflow for complex cooling passages, blade roots, fine features, and fluid–structure interaction meshes, significantly reducing manual modelling effort.
- **AI & Open Data:** Expand BladeBench as an open, standardized dataset for AI-assisted blade design, surrogate modelling, performance prediction, and automated optimization.
- **Long-Term Vision:** Partner with industries and research institutes to validate, certify, and deploy next-generation blade technologies in gas turbines, aero-engines, and urban wind-energy systems.