AI Agent-Driven Integrated Aerodynamic Design and Simulation for eVTOL Aircraft

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Beihang University

In collaboration with UNITOP AI

北京航空航天大學 BEIHANG UNIVERSITY

UNITOP AI 宇拓智源

Joint Development: Aerodynamics and Industrial AI



Yu Liang

Associate Research Professor, Beihang University

- Aircraft conceptual design and aerodynamic configuration
- Aerodynamic optimization and low-Reynolds-number flow
- VTOL, eVTOL, UAV and transport aircraft design

北京航空航天大學 BEIHANG UNIVERSITY

UNITOP AI 宇拓智源

Joint development

Beihang University and UNITOP AI jointly develop an agent system for rotor aerodynamic design. The system combines domain knowledge, variable-complexity simulation, CFD tools and an industrial agent platform, covering requirements, airfoil selection, 2D/3D modeling, rapid analysis, CFD verification and optimization.

Complementary expertise

Beihang contributes aircraft design theory, rotor aerodynamics and engineering validation. UNITOP AI provides agent orchestration, tool integration, workflow automation and deployment. Together, they support closed-loop rotor design and simulation optimization.

Rotor Performance in Low-Altitude Aviation

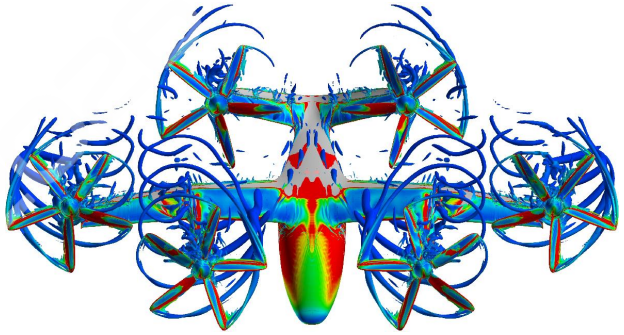
Diverse aircraft configurations, missions and operating environments






Rotor performance requirements

Hover efficiency	Cruise efficiency	Thrust and payload	Noise
Endurance	Wind tolerance	Safety margins	Handling and stability

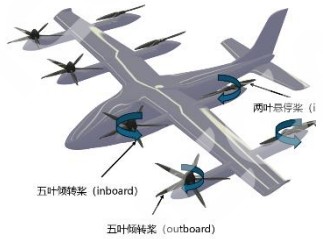


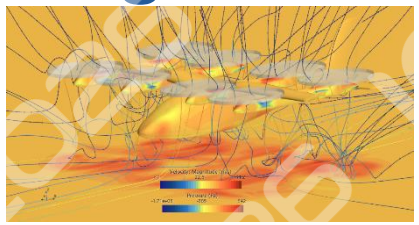
System-level optimization with multiple objectives and engineering constraints

Complexity of Rotor Aerodynamic Design

Configuration complexity

Single rotors, multirotors, tiltrotors and distributed propulsion differ in rotor count, placement, rotation direction, spacing and rotor-airframe coupling.



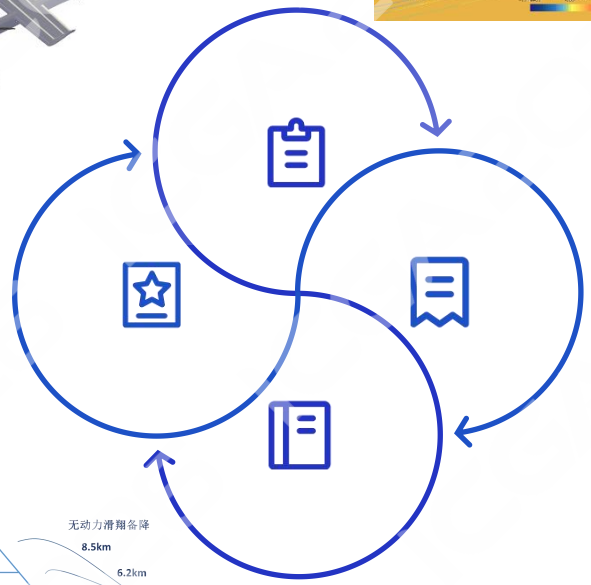


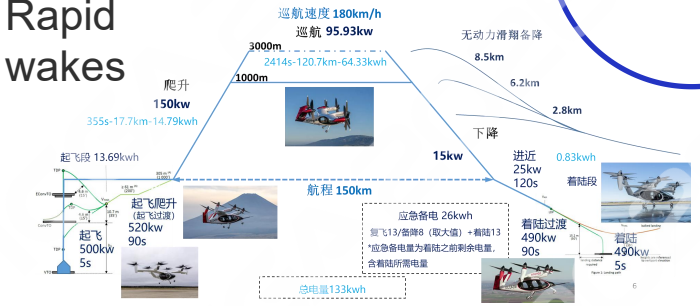
Complex flow physics

Low Reynolds numbers, strong 3D effects and unsteady wakes create separation, downwash, wake interaction and rotor-wing or rotor-fuselage interference.

Multiple operating conditions

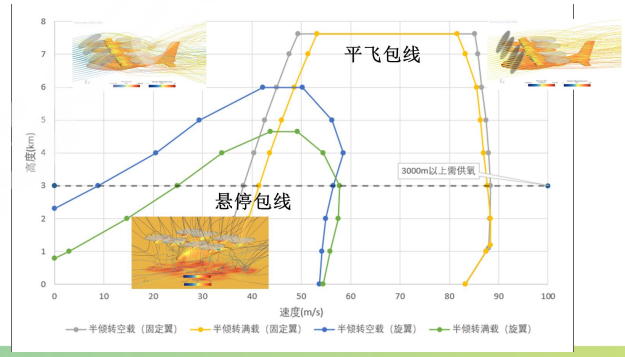
Hover, vertical takeoff and landing, forward flight, cruise and transition require consistent modeling. Rapid changes in inflow, loads and wakes complicate tiltrotor transition.





Coupled design objectives

Balance hover and cruise efficiency with thrust, power, noise, structural loads, safety margins, manufacturability and cost.



Engineering Challenges and Shorter Design Cycles

Long conventional workflows

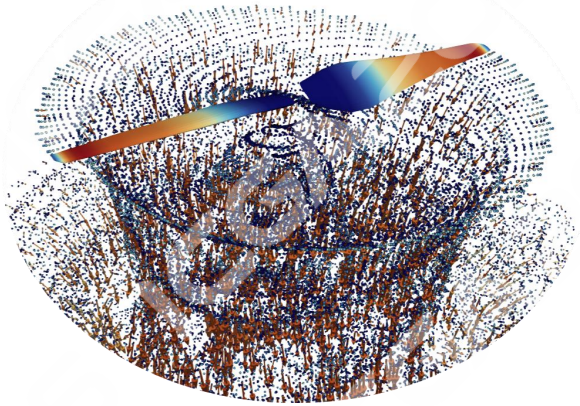
Requirements, airfoil selection, geometry, meshing, CFD and repeated optimization create many handoffs and slow feedback.

Strong multidisciplinary coupling

Aerodynamic efficiency interacts with loads, noise, propulsion, control stability, mass and manufacturing constraints.

Expensive simulation campaigns

Hover, cruise, transition and rotor–airframe interference require many evaluations across configurations.



Dependence on expert judgment

Airfoil selection, blade parameters, operating conditions and simulation credibility depend on experienced specialists.

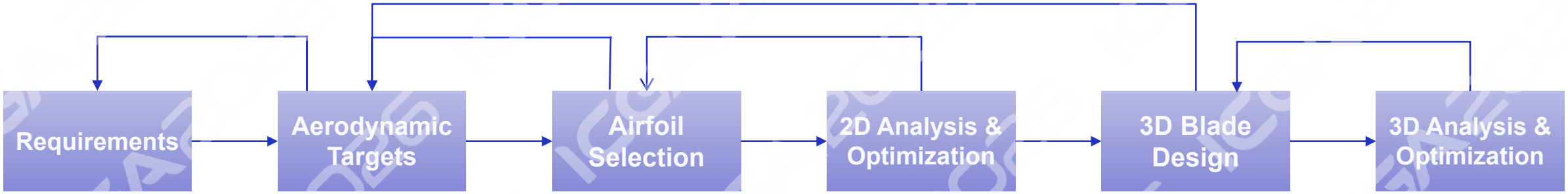
Fragmented engineering tools

Manual data transfer connects 2D analysis, CAD, meshing, CFD, post-processing and optimization.

Knowledge and data reuse

Design choices, simulation settings and unsuccessful trials remain scattered across project files and individual experience.

Conventional Rotor Design Workflow



- Mission, range and payload
- Rotor count, radius and configuration
- RPM and power limits
- Hover, climb, cruise and transition
- Safety, noise and structure

- Local Mach and Reynolds numbers
- Lift coefficients and angle-of-attack range
- Disk loading, solidity and induced velocity
- Thrust, power, efficiency and noise targets

- Screen candidate airfoils for each radial station
- Use airfoil databases and expert knowledge
- Check thickness, stall and structural space
- Assign root, midspan and tip sections

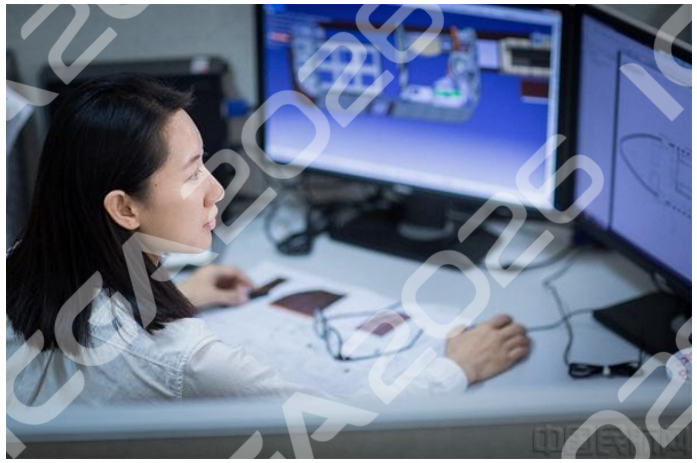
- Analyze with XFOIL, MSES or 2D CFD
- Generate lift, drag and moment polars
- Check stall and Reynolds sensitivity
- Optimize camber and thickness
- Export airfoil data tables

- Define chord, twist and thickness distributions
- Specify radius, sweep, tip and hub geometry
- Interpolate radial airfoil sections
- Check structure and manufacturing
- Build the 3D blade model

- Screen performance with QPROP or BEMT
- Resolve wake interaction with VPM
- Verify key cases with RANS CFD
- Assess performance, loads and noise
- Iterate the design

Agent-Driven Rotor Design

Copilot / Agentic AI / Physical AI





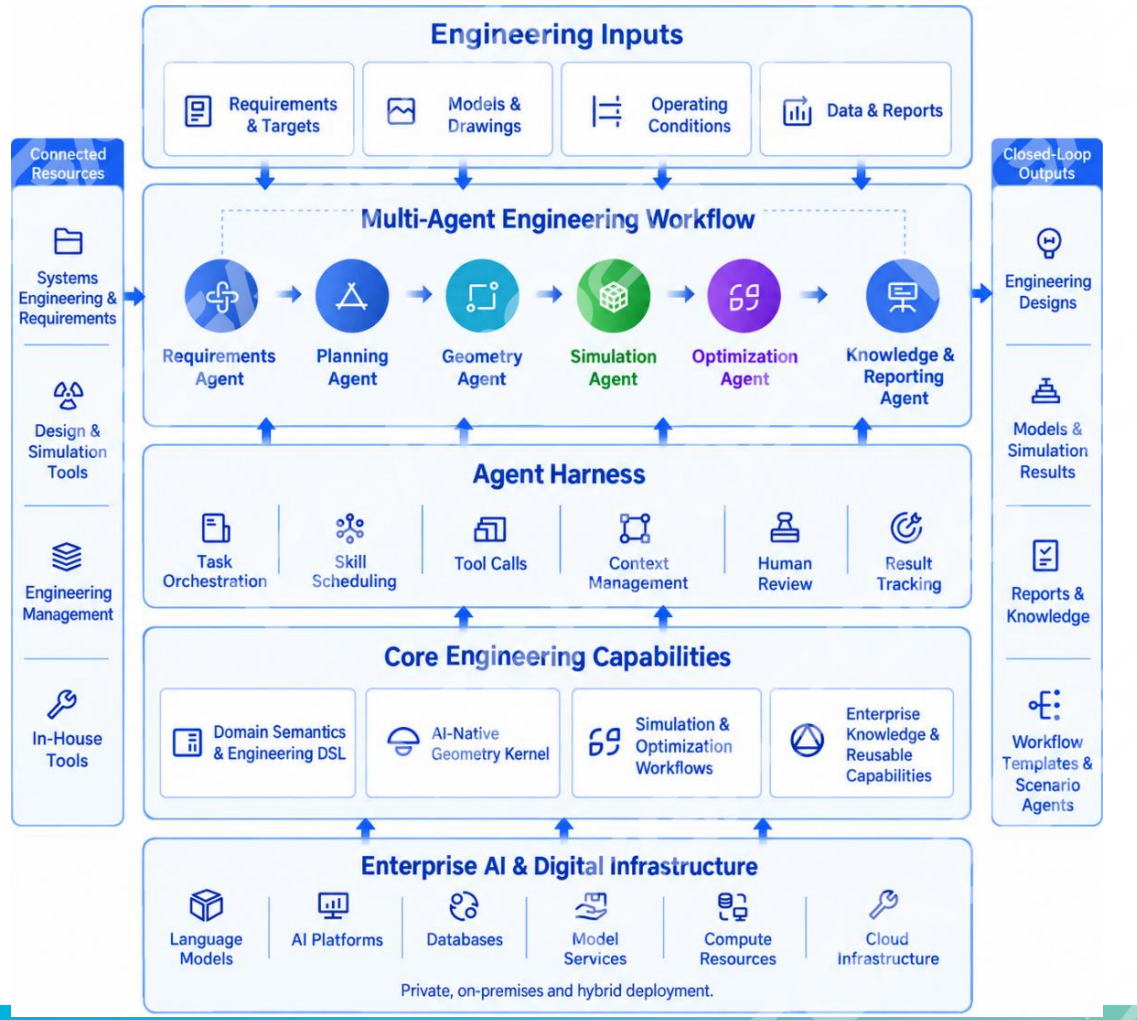
Conventional: engineers operate tools

- Experience-based decisions
- Sequential workflows and late simulation

Agent-driven engineering

- Explicit goals and constraints
- Knowledge, data and early simulation

Multi-Agent Design and Simulation Architecture



Engineering inputs

Requirements, performance targets, CAD models, drawings, operating conditions and historical reports support task planning, geometry design, simulation, optimization and reporting.

Agent Harness

Orchestrates tasks, skills, tool calls and context across agents. Human review and traceable results support reliable access to engineering software, enterprise data and optimization workflows.

Engineering kernels

Geometry kernels, simulation solvers, optimization workflows and reusable engineering knowledge.

Enterprise AI and infrastructure

Enterprise language models, data services, compute resources and cloud infrastructure.

Multi-Agent Collaboration



Reusable Engineering Assets

Capture task assets as reusable enterprise knowledge and capabilities.

Workflow Templates
Requirements breakdown, stage progression and task-state routing

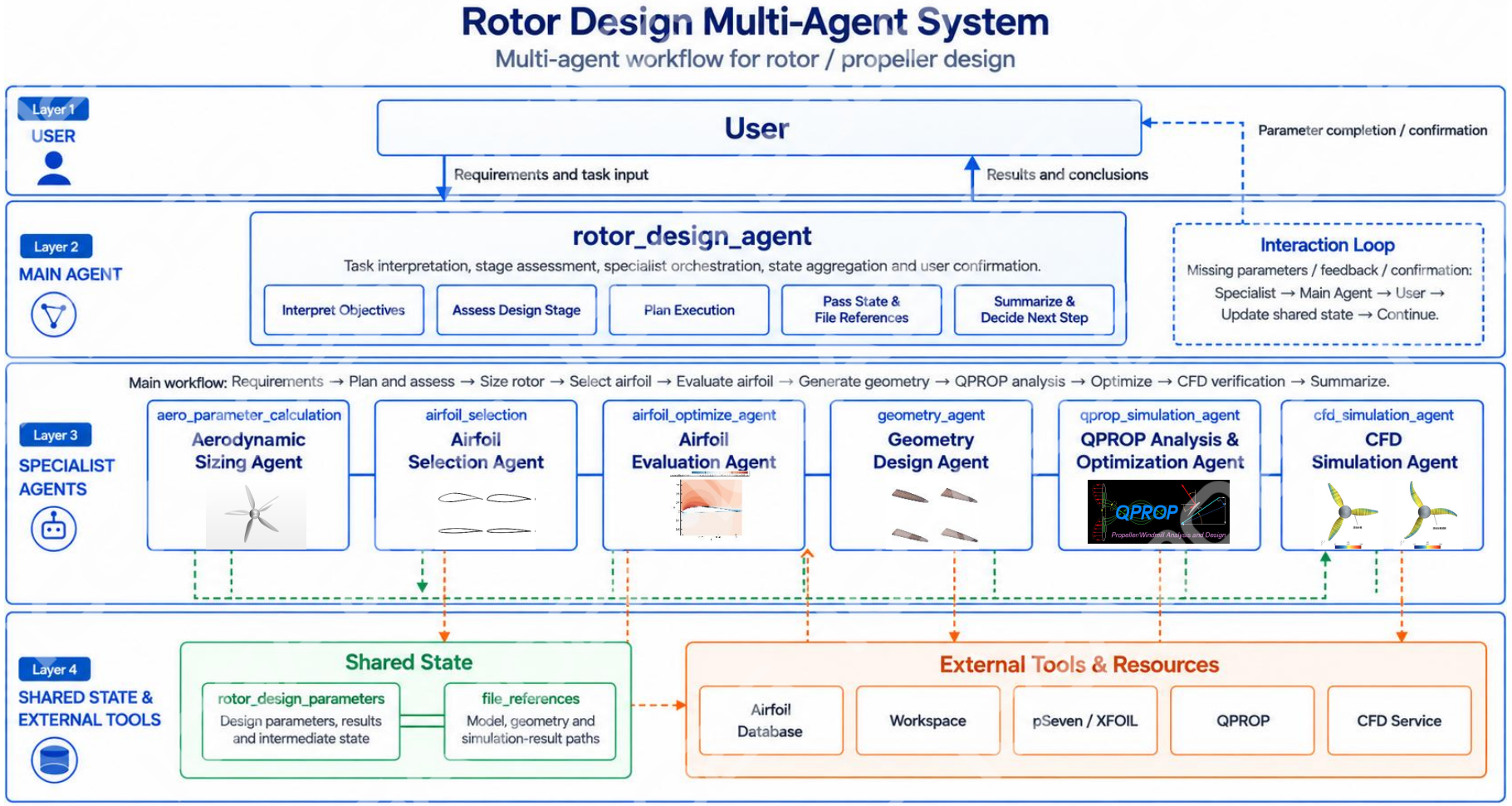
Tool Skills
Tool calls, script wrappers, parameter setup and capability reuse

File Context
Input files, intermediate results, history and context

Process Records
Tool logs, human review, execution traces and process tracking

Deliverables & Knowledge
Models, analysis reports and accumulated engineering experience

Closed-Loop Rotor Aerodynamic Design



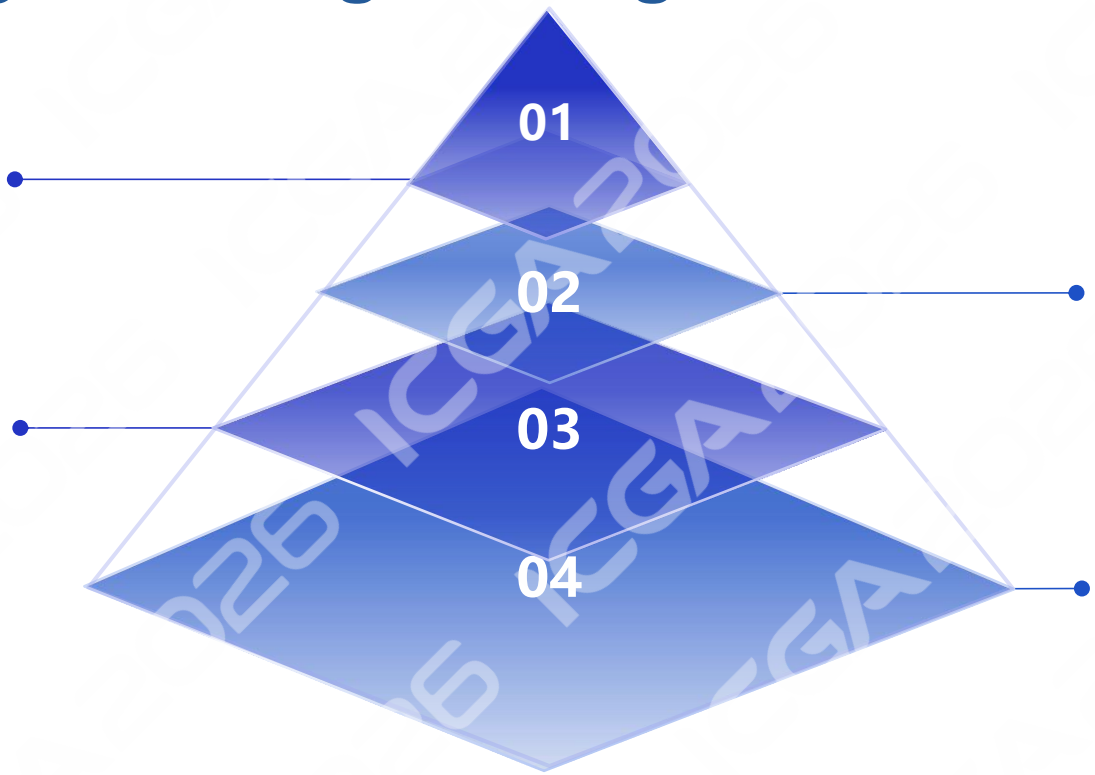
Domain Knowledge and Engineering Databases

Explainable Design Decisions

Engineering knowledge, data and simulation constraints guide design decisions.

Rotor Case Library

More than 10 reference rotors, including lift rotors, propellers and tilting rotors.



Expert Design Workflow

Requirements, targets, airfoils, 2D analysis, 3D blade design, simulation and optimization.

Airfoil Database

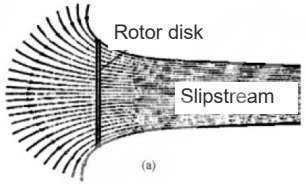
CFD data for dozens of airfoils across Mach number, Reynolds number and angle of attack.

Expert workflows, airfoil data, rotor cases and multi-fidelity verification constrain agent decisions.
Engineering knowledge, data and simulation become executable design capabilities.

Multi-Fidelity Aerodynamic Simulation

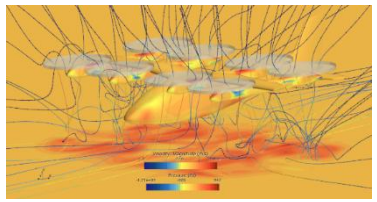
Empirical / Momentum Theory

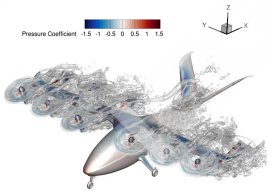
Estimate rotor size, disk loading, induced velocity, thrust, power, solidity and efficiency to bound airfoil and blade design.



BEM / RANS CFD

Detailed flow analysis verifies separation, viscous effects, interference, aerodynamic loads and performance limits of key designs.

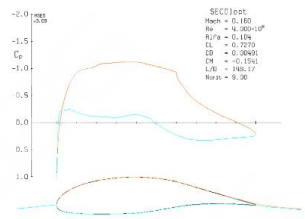


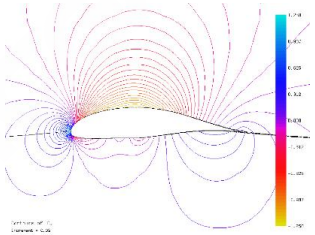




XFOIL / MSES

Rapid 2D analysis predicts lift, drag, pitching moments, maximum lift and stall characteristics.





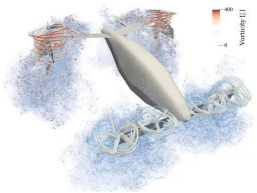
Blade-Element Analysis / QPROP

Evaluate chord, twist, RPM and flight conditions for thrust, power, efficiency and loads.



Vortex Methods / VPM

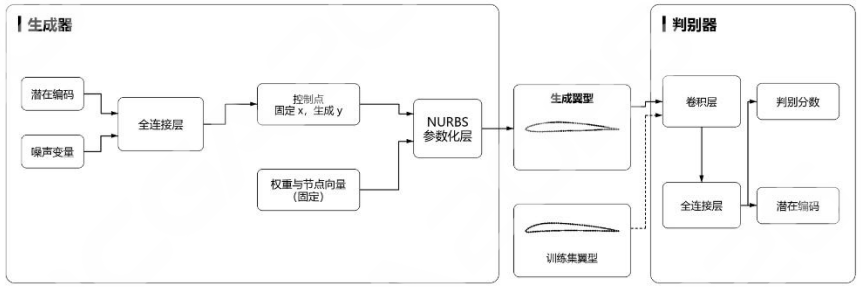
Resolve wakes, tip vortices and unsteady loads in multirotor interference, rotor-airframe coupling and tiltrotor transition.



NURBS-GAN: Deep Learning Rotor's Airfoil Geometry Correlations

A generative adversarial network learns airfoil-control correlations. A fixed NURBS layer outputs the geometry.

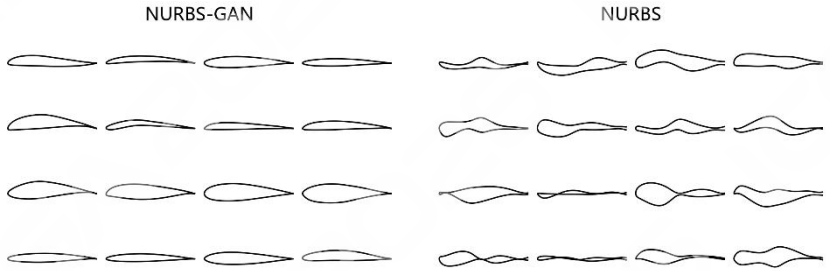
Generator, NURBS Layer and Discriminator



10D Latent Code + 10D Noise

Fixed x-coordinates, weights and knots. Learned control-point y-coordinates and trailing-edge gap.

Airfoil Samples at Matching Random Indices



99.90%

NURBS-GAN: No Self-geometry intersection

76.86%

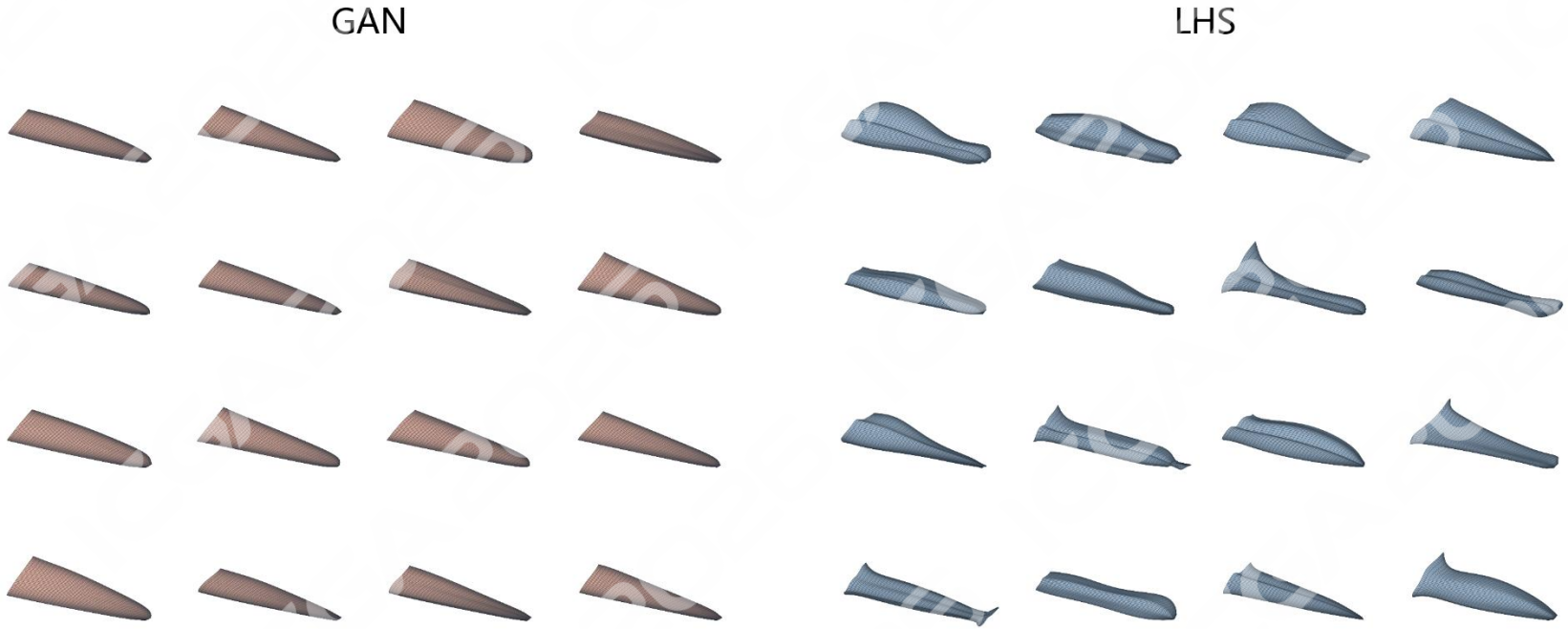
Direct NURBS: No Self-geometry intersection

1,024 samples per method. Direct NURBS uses LHS within prescribed control bounds. Each panel shows 16 unfiltered samples.

3D Blades from Radial Distributions and Airfoils

Combine generators for chord, twist and airfoil geometry to construct 3D blade candidates.

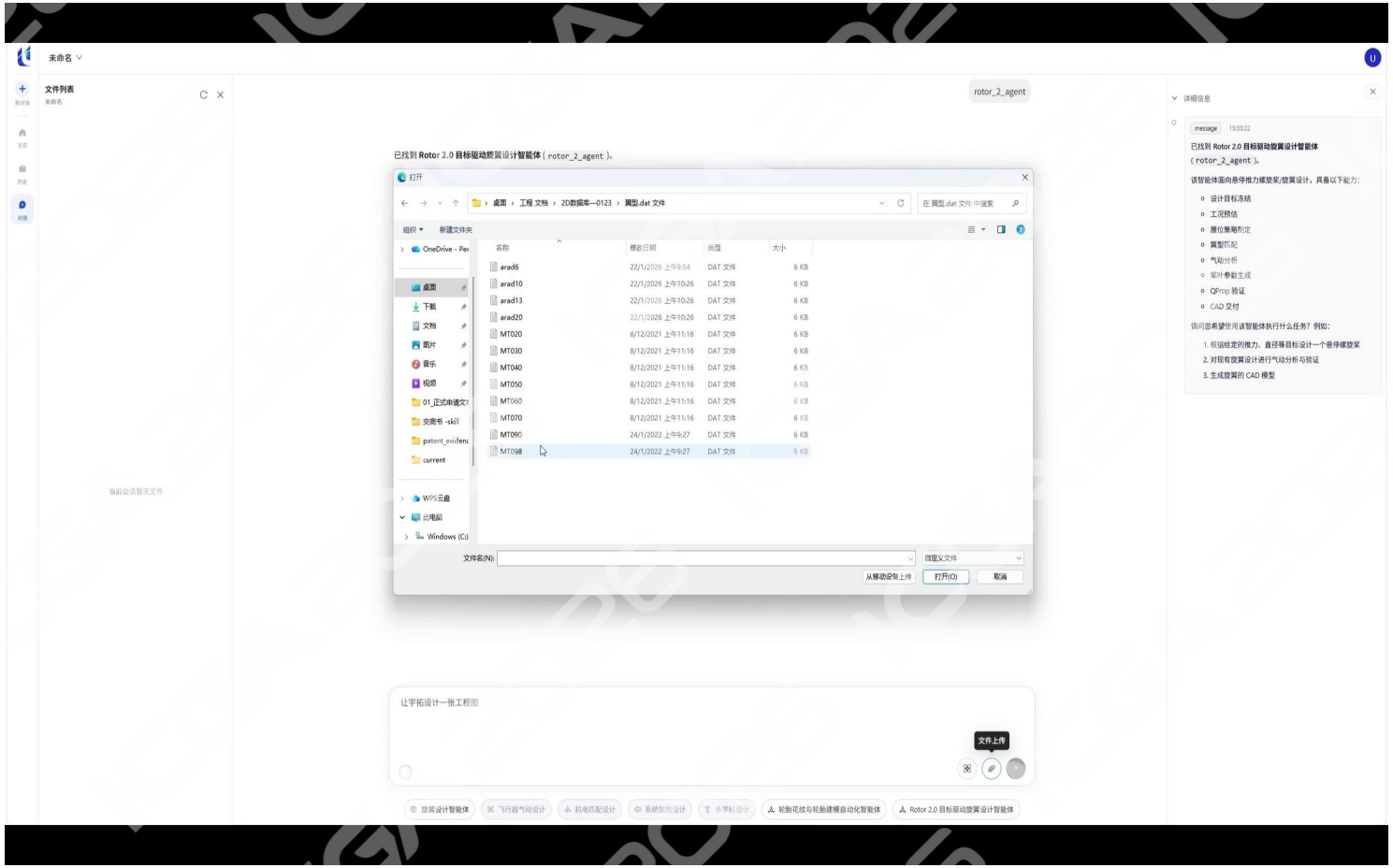
Radial Distributions + Normalized Airfoil: Scaling, Twist and Quarter-chord Stacking for 3D Surfaces



16 of 64 candidates per group, at matching random indices without shape filtering. Each blade uses one normalized airfoil along the span.

Automated Rotor Blade Geometry Generation

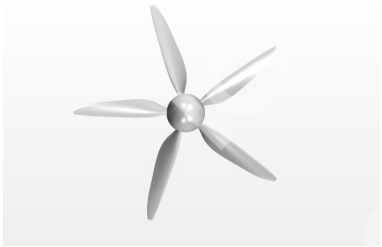
The geometry agent uses UNITOP AI's geometry kernel to generate 2D and 3D models directly.(Video)



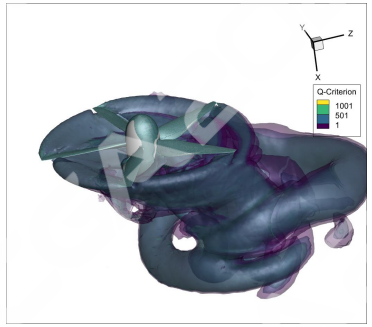
Multi-Point Blade Optimization



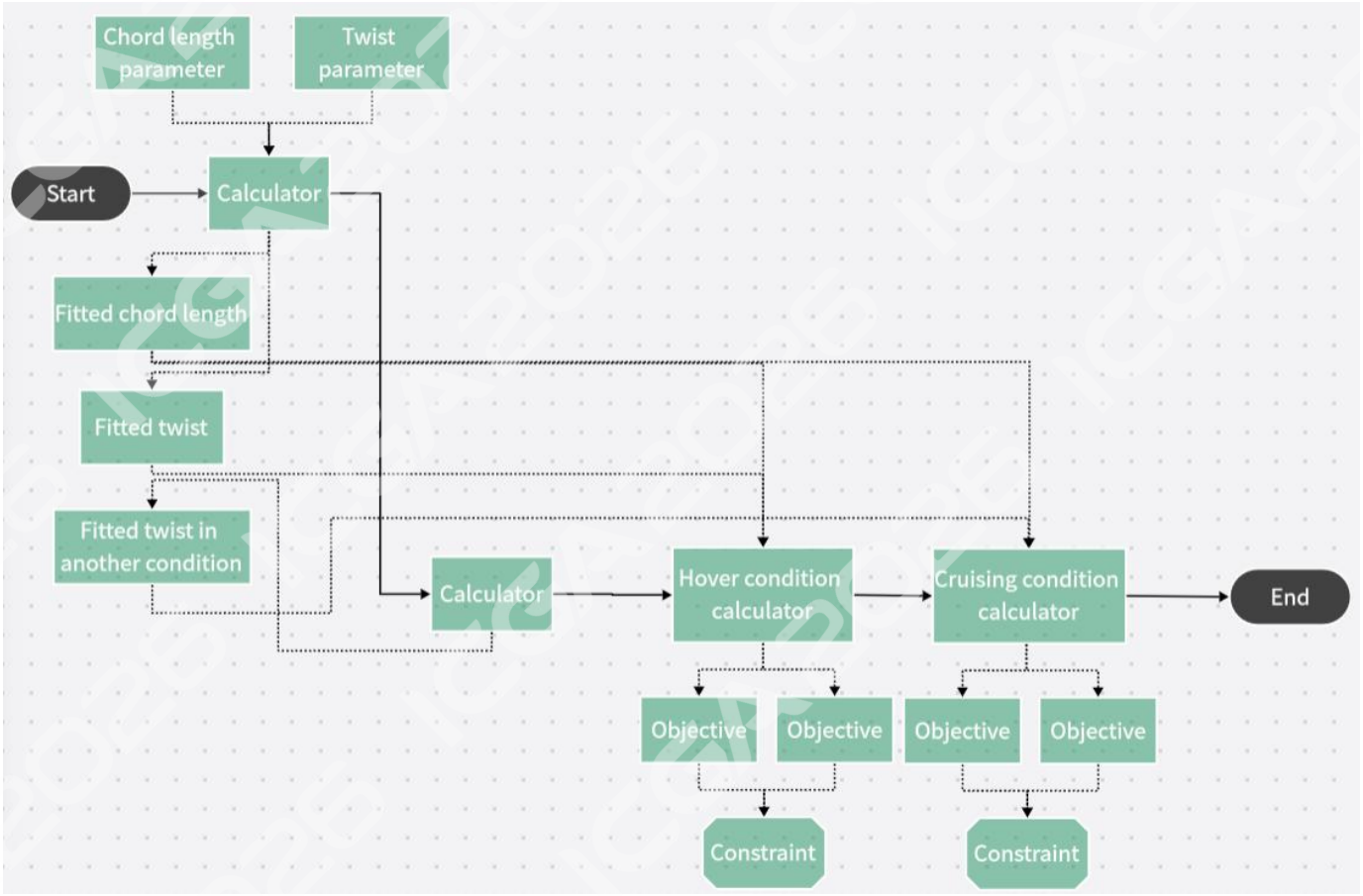
eVTOL rotor design



Blade geometry



Flow-field verification

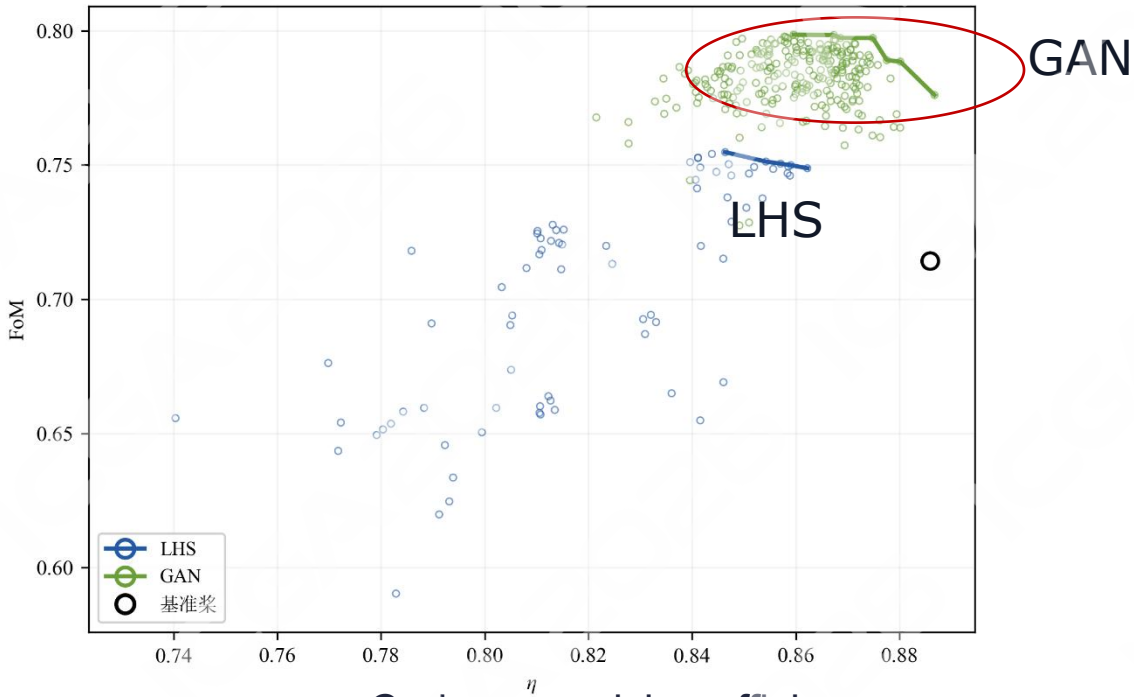


Chord, twist and pitch optimization for hover and cruise

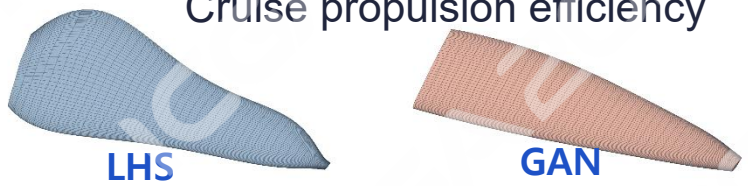
Cruise / Near-hover Optimization with Joint Parameterization

XFOIL/XROTOR compare both schemes under the same conditions, constraints and online budget.

Hover efficiency



Cruise propulsion efficiency



1200 s
Equal Online Optimization Computation Buget

Conditions and Thrust

Cruise: 50 m/s, 1350 rpm.
Near-hover: 1 m/s, 2000 rpm.

GAN Front Shifts Up and Right

Maximum cruise efficiency and near-hover FoM both exceed direct parameterization.

Rotor Design Agent Demonstration(Video)



Design Cycle Comparison

Conventional blade design

~2 months

- Baseline blade and load distribution
- Airfoil design
- Chord and twist optimization
- Computational verification
- Design iterations
- Manual reporting

AI-assisted blade design

1–2 weeks

- LLM-assisted blade parameter selection
- AI-enabled airfoil database
- Automated geometry generation
- AI-driven analysis and surrogate prediction
- Automated design reports

Representative development-cycle comparison

Joint Development Outcomes and Applications

Engineering challenges

- Dependence on experienced specialists
- Manual geometry and simulation work
- Costly trial and error
- Long design cycles

Agent capabilities

- Knowledge-constrained decisions
- Requirements-to-verification automation
- Reusable design knowledge
- Compatibility with mainstream CAE tools

Reported performance

85%
Shorter design cycle

10×
Simulation verification efficiency

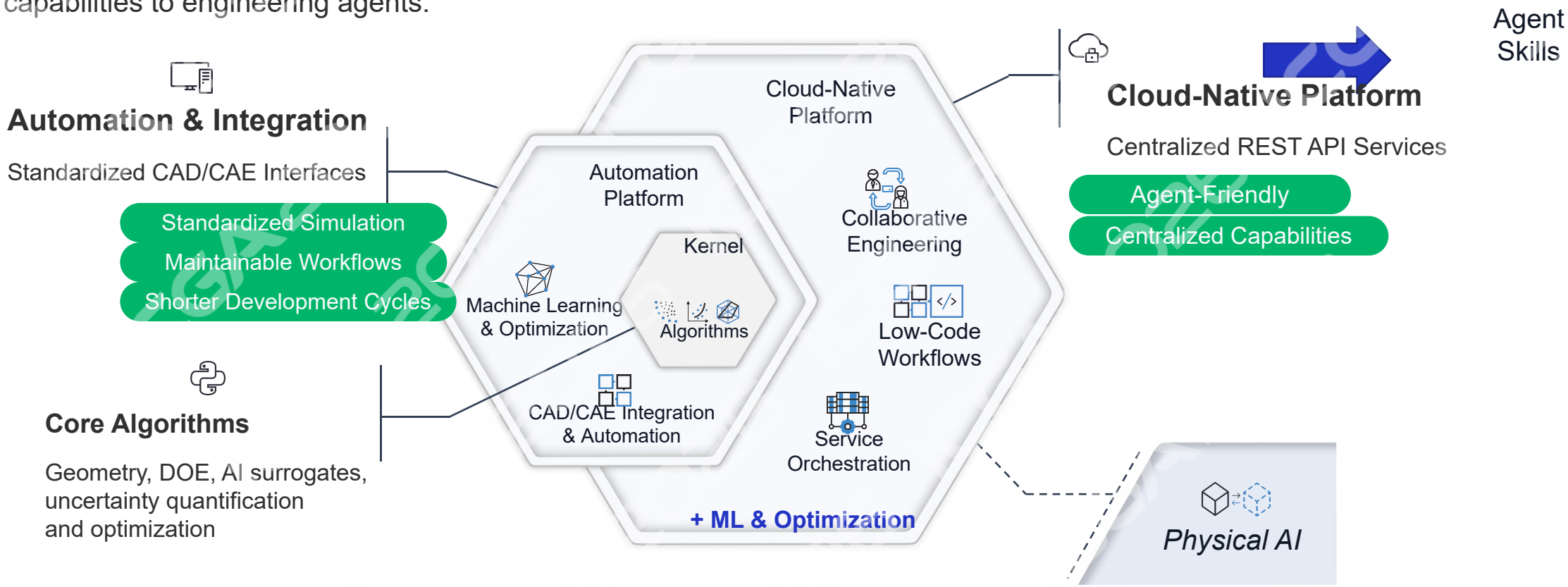
30%
Improvement in a key lift-to-drag metric

Applications: startup prototypes, aircraft variants, and supplier design services

Reported figures. Project scope and test conditions are unspecified.

Tool Integration and Workflow Automation

A unified platform standardizes industrial CAE tools, connects geometry and simulation workflows, and exposes reusable capabilities to engineering agents.

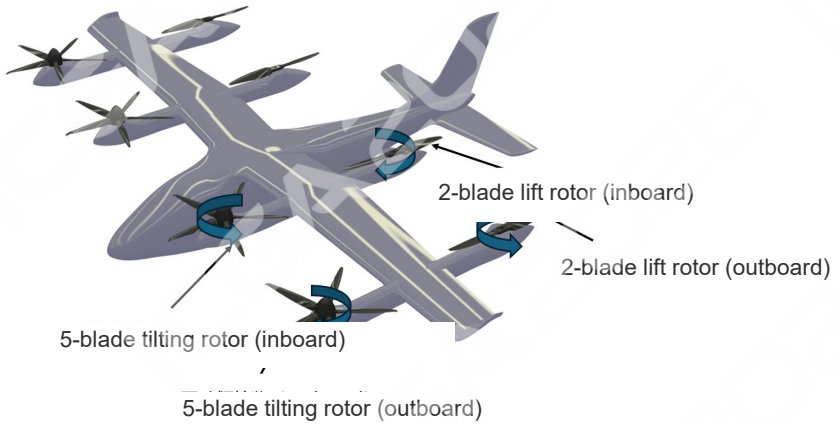




Tiltrotor eVTOL Transition: Multi-Fidelity Load Data by DNN

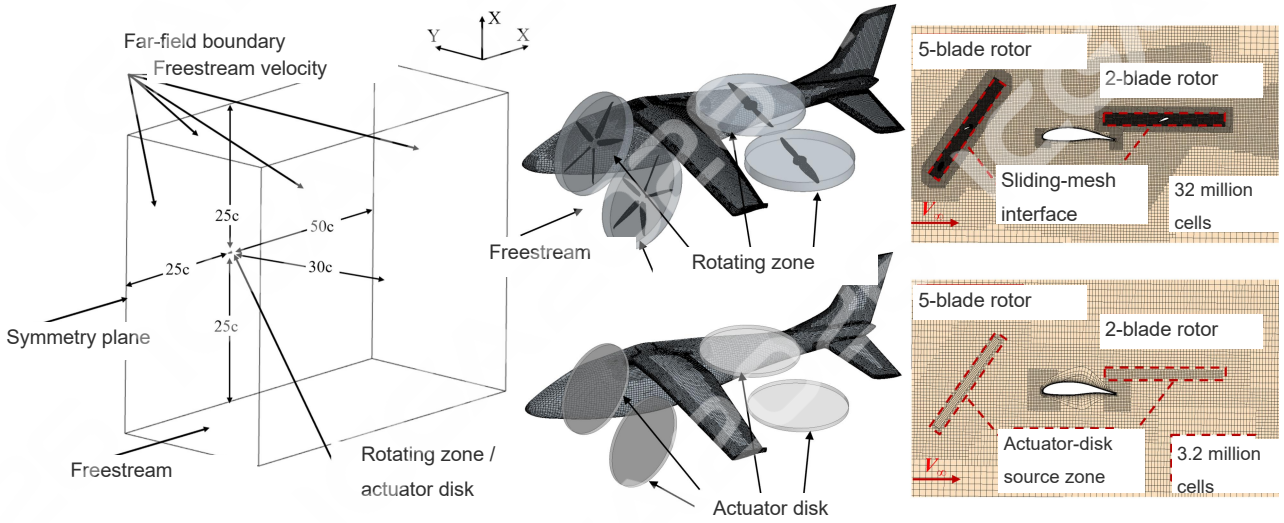
Predict wing pressure and rotor-disk loads using DNN(Deep Neural Network)while balancing interference-flow accuracy and data-generation cost.

Eight-rotor eVTOL with partial tilt



- Front five-bladed rotors: tilting, variable collective
- Rear two-bladed rotors: fixed, fixed pitch
- Half-model: wing and four rotors on one side

URANS and blade-element momentum sources



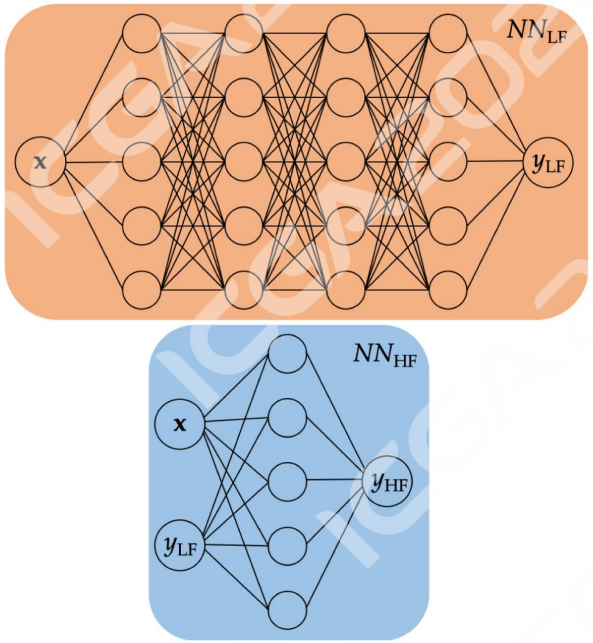
URANS: 32 million cells
3,280 core-h per condition

BEM: 3.2 million cells
20 core-h per condition

Multi-Fidelity Networks for Distributed Loads

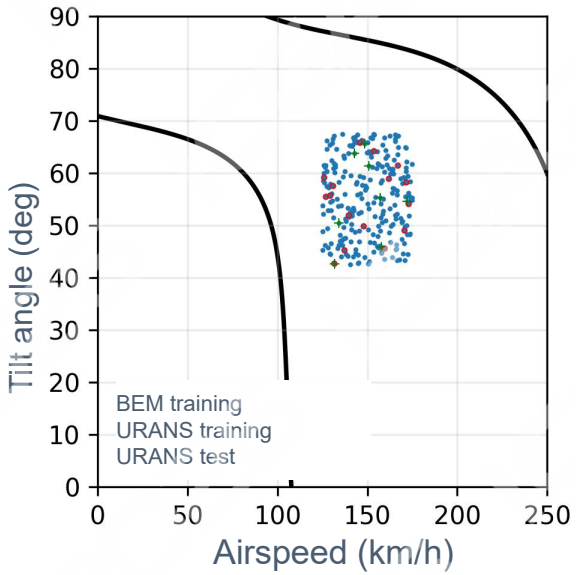
Learn response trends from many low-cost samples, then correct interference-related errors using a small high-fidelity dataset.

Two-stage machine learning



Low-fidelity model + high-fidelity correction

Sampling and test conditions



Airspeed (km/h) and tilt angle (deg)
eVTOL Transition corridor

Six operating-condition inputs

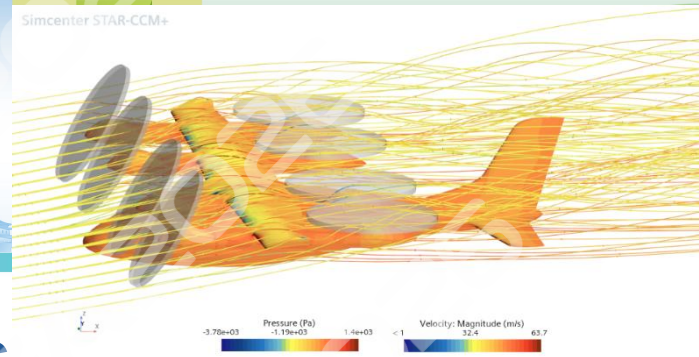
Airspeed, angle of attack, tilt angle, two rotor speeds and five-bladed rotor collective-pitch increment

256 BEM + 16 URANS samples

Stage 1 learns low-fidelity load distributions. Stage 2 combines an affine baseline with nonlinear residual correction.

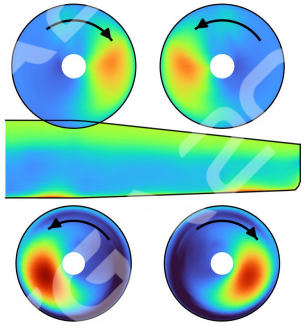
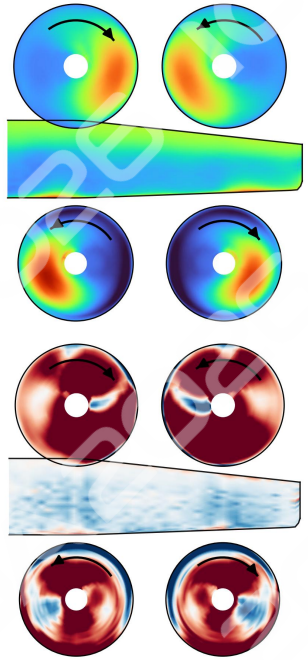
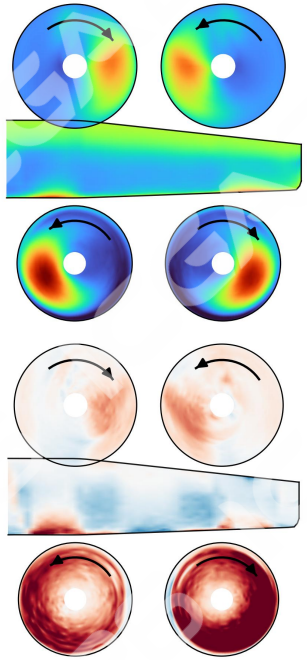
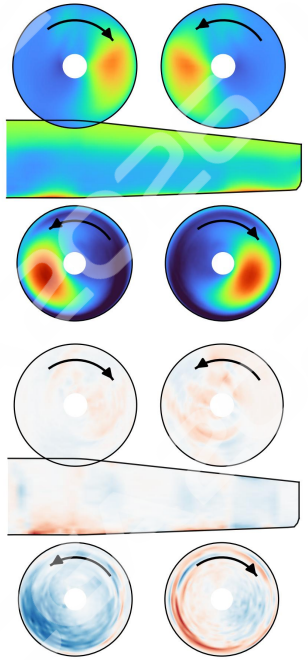
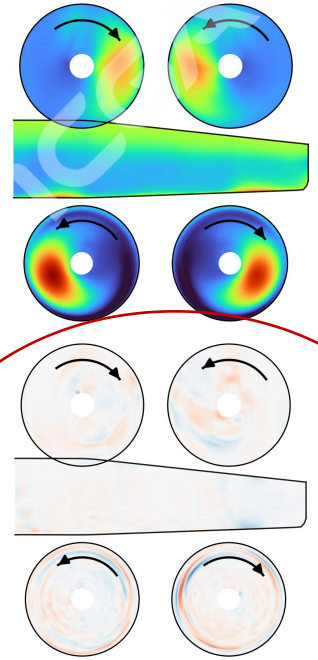
9 tasks, 9,195 outputs

- Wing Cp: 2,475 values
- Four rotors: Fz and Fθ, 840 values per task



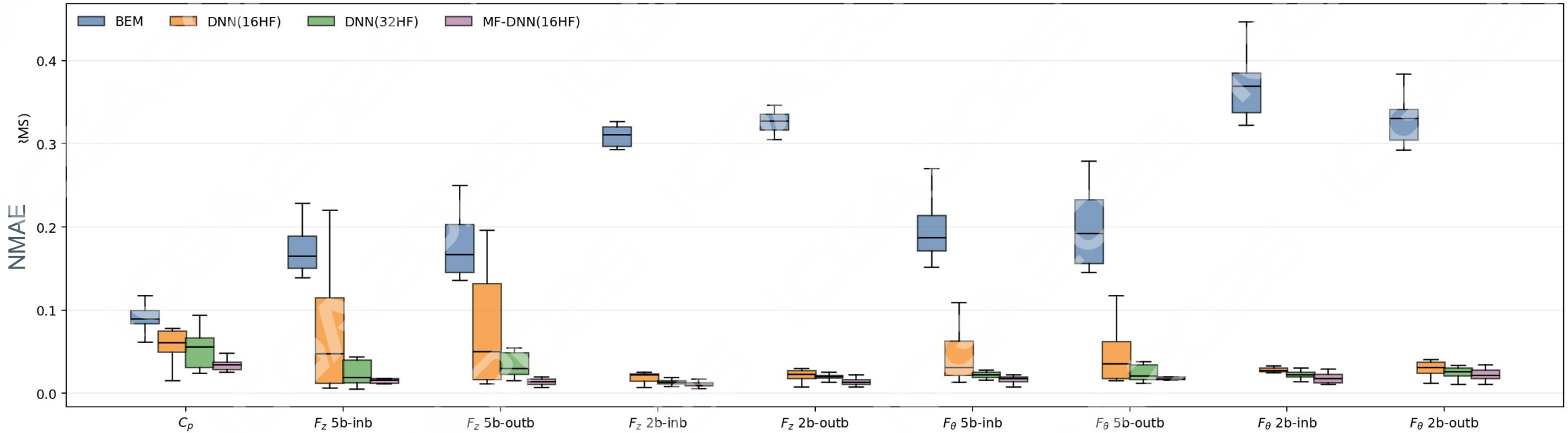
Wing Pressure and Rotor-Disk Load Distributions

Test case 1: 172 km/h, angle of attack 0.54°, tilt 54.56°. MF-DNN better reproduces the URANS load fields.

	URANS	BEM	DNN (16HF)	DNN (32HF)	MF-DNN (16HF)
Load fields					
Error vs. URANS	High-fidelity reference Difference = prediction − URANS Disk tilt angles are omitted				smallest error

Load Prediction Accuracy Across Operating Conditions

Across 8 held-out URANS conditions and 9 tasks, MF-DNN (16HF) has the lowest mean NMAE for every task.



NMAE = pointwise MAE / RMS of the URANS field for the same condition. Rotor metrics below average the four rotor tasks equally.

3.26%
Wing pressure, Cp

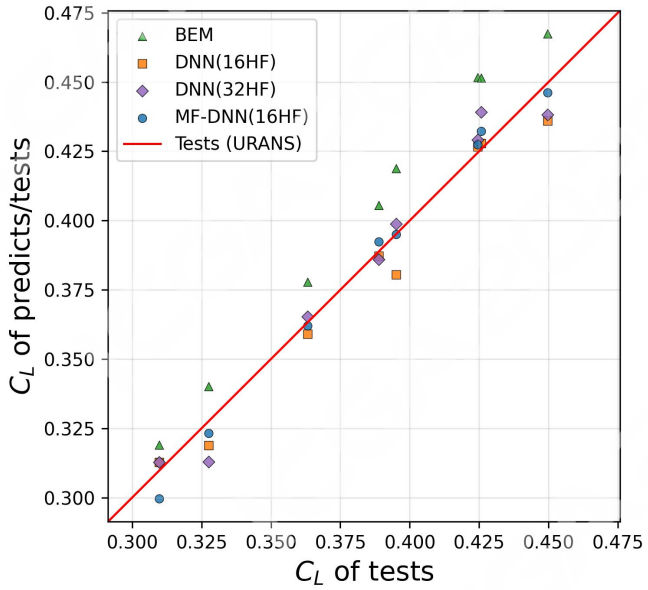
1.59%
Axial Fz, four-rotor mean

2.13%
Tangential Fθ, four-rotor mean

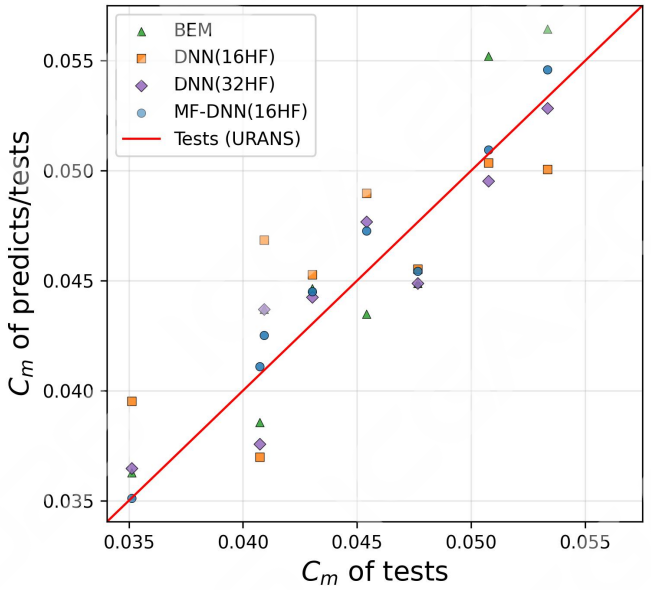
Prediction of Integrated Aerodynamic Performance

Integrating predicted wing pressure yields wing lift and pitching moment.

Wing lift coefficient, CL



Wing pitching moment, Cm



1.28%
Relative RMSE of CL

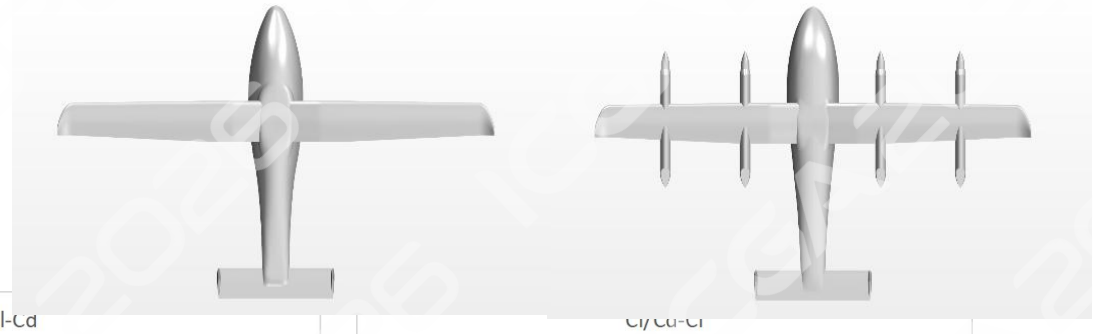
3.03%
Relative RMSE of Cm

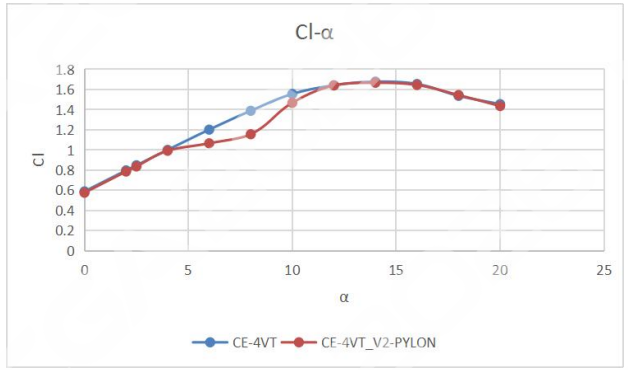
45%
Lower data-generation cost

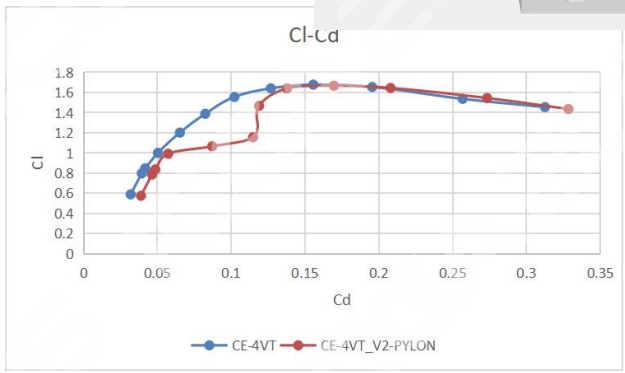
104,960 to 57,600 core-h
DNN (32HF) to MF-DNN (16HF)

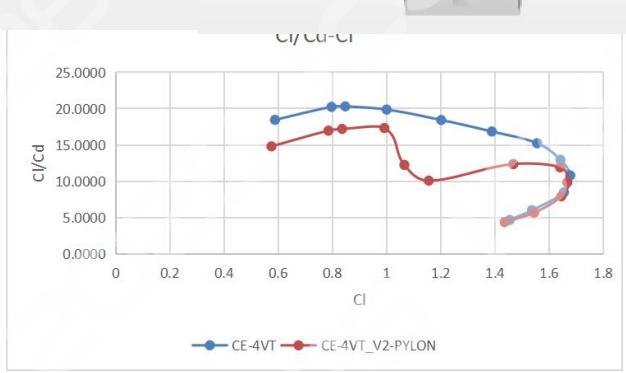
MF-DNN (16HF) uses 16 URANS + 256 BEM samples and achieves lower mean error than DNN (32HF) for all nine distribution tasks.

Problems of propeller pylon and wing integration





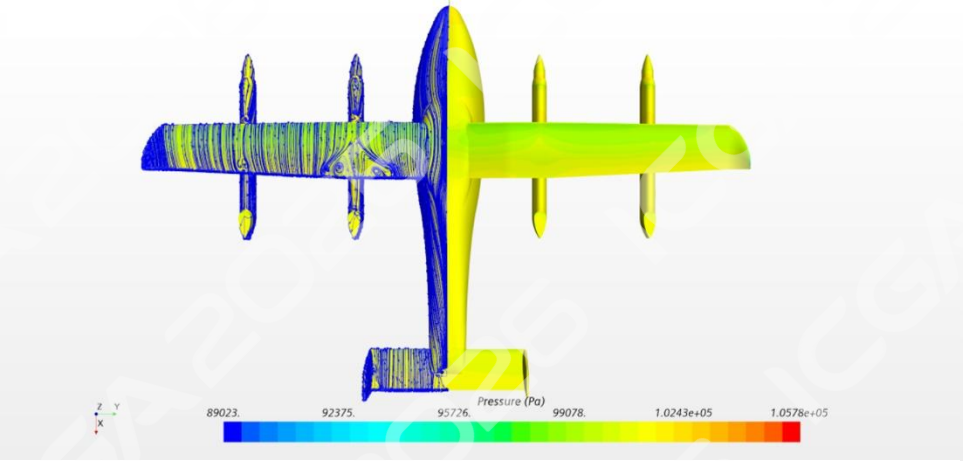




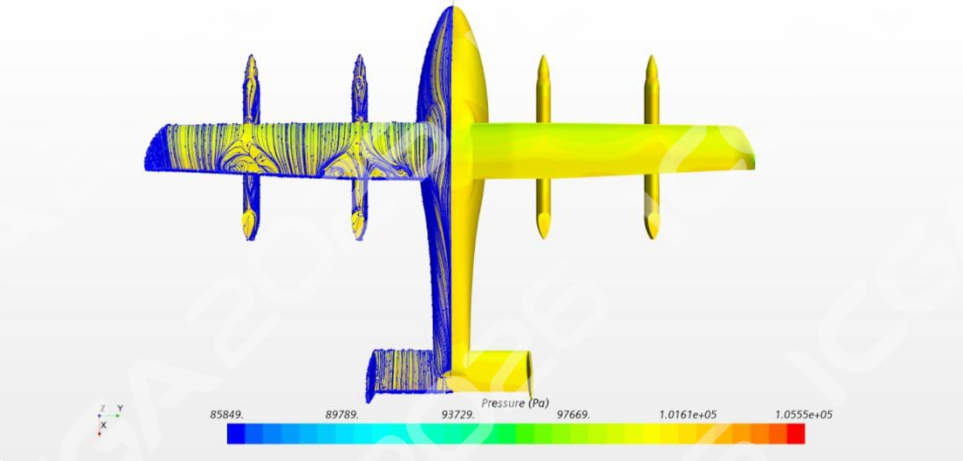
Simulation results with and without mounting pylon

- **AOA=6deg Cl↓ Cd↑**
- **AOA=12deg** Lift coefficient recovers to be similar to that of the unmounted pylon configuration, but the drag coefficient is still relatively increased.

Baseline configuration



CE-4VT_V2-PYLON
AOA=6deg streamline

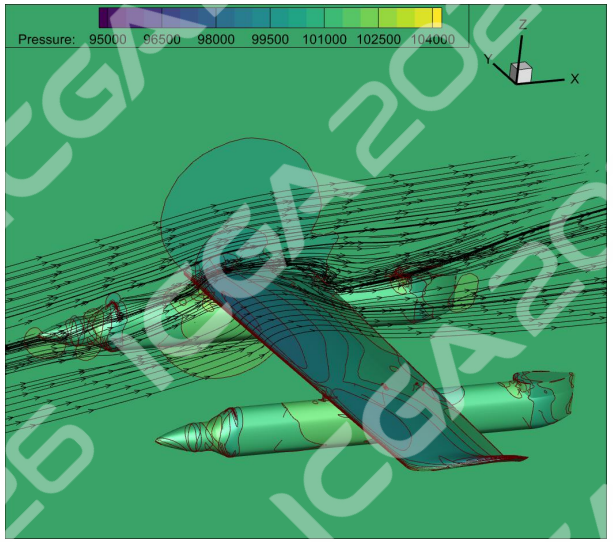


CE-4VT_V2-PYLON
AOA=8deg streamline

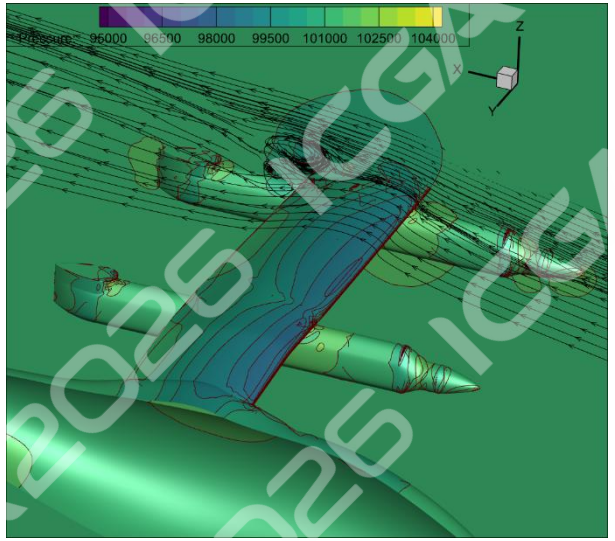
Baseline configuration



Pylon_**inner**
AOA=6deg

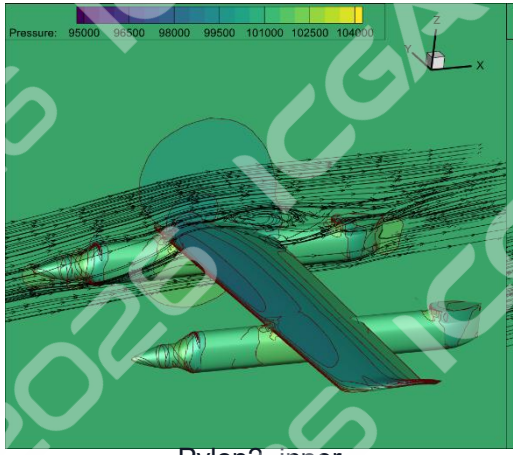


Pylon_**inner**
AOA=8deg

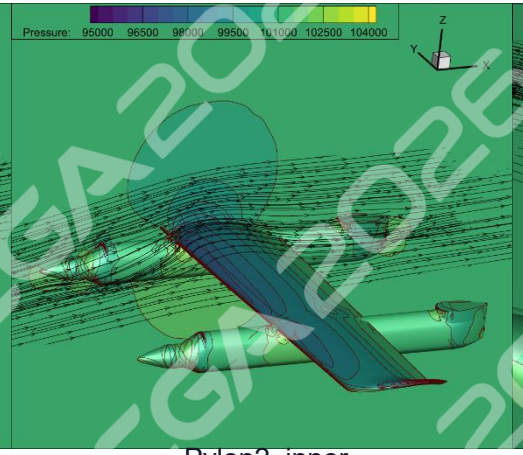


Pylon_**outer**
AOA=8deg

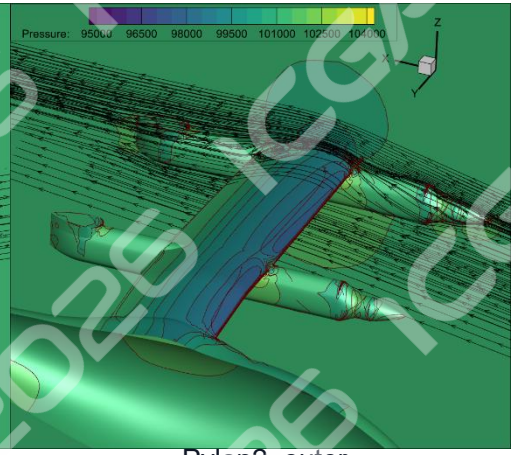
Pylon installation tradeoff



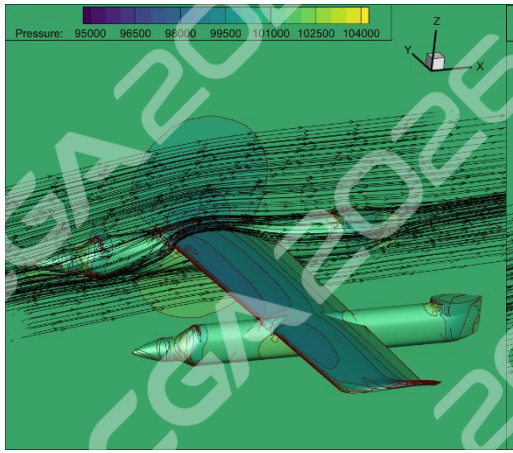
Pylon2_inner
AOA=6deg



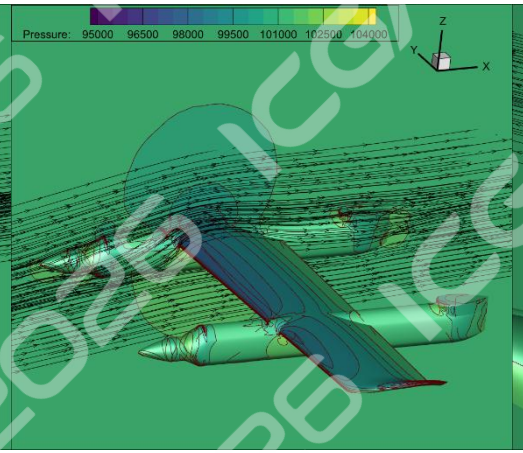
Pylon2_inner
AOA=8deg



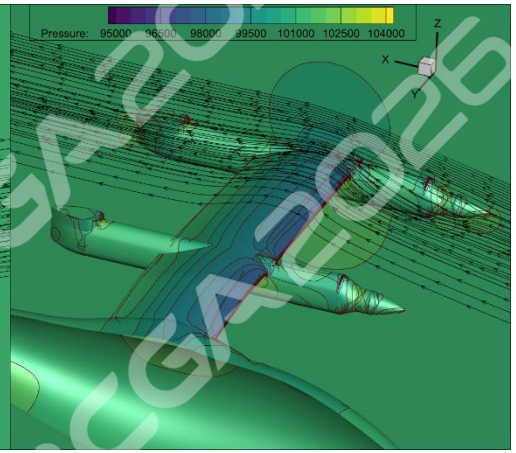
Pylon2_outer
AOA=8deg



Pylon3_inner
AOA=6deg



Pylon3_inner
AOA=8deg



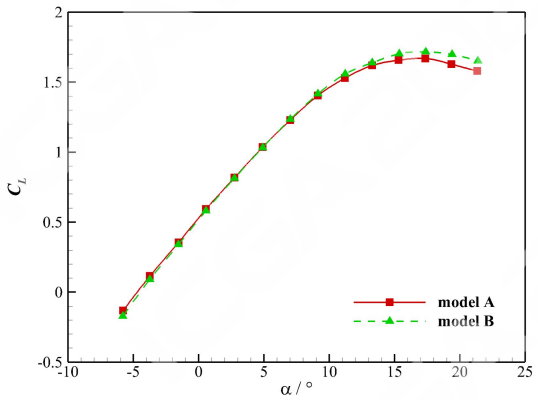
Pylon3_outer
AOA=8deg

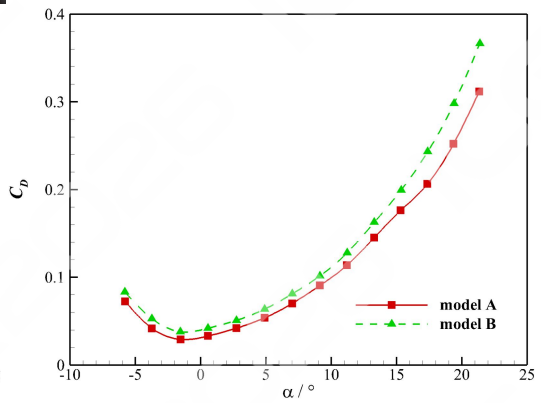
Lift-drag performance of different pylon configurations

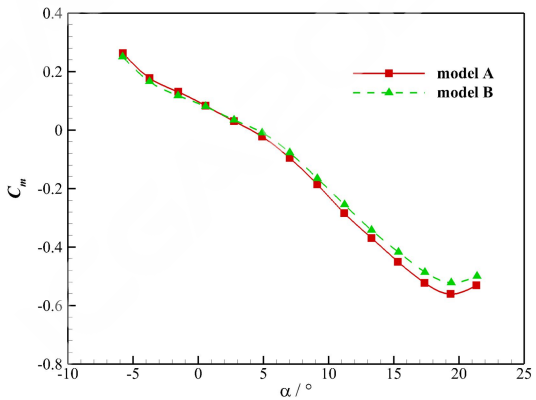
- Pylon3 configuration(purple line) is close to that of unmounted configuration(blue line) At low AOA
- Although lift-drag ratio reduced (compared to blue line) → existence of pylon
- Aerodynamic performance recovery (compared to red line) → coupling problem solved











Future Development

Agent Collaboration for Aircraft Development

Structures, Loads & Strength

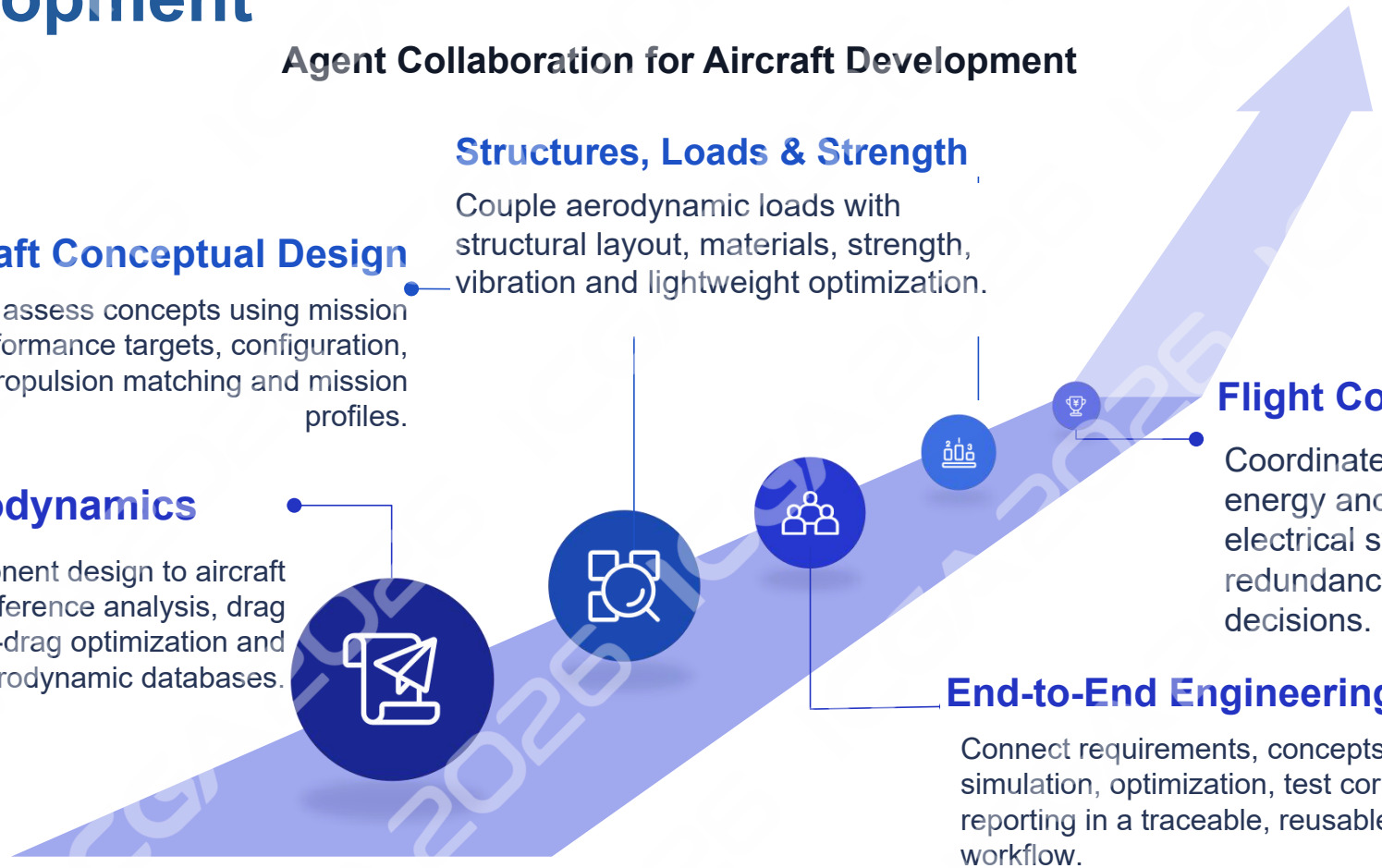
Couple aerodynamic loads with structural layout, materials, strength, vibration and lightweight optimization.

Aircraft Conceptual Design

Generate and assess concepts using mission requirements, performance targets, configuration, mass estimates, propulsion matching and mission profiles.

Whole-Aircraft Aerodynamics

Extend component design to aircraft configuration, interference analysis, drag breakdown, lift-to-drag optimization and aerodynamic databases.



Flight Control & Systems

Coordinate flight control, propulsion, energy and thermal management, electrical systems and safety redundancy in system-level design decisions.

End-to-End Engineering

Connect requirements, concepts, modeling, simulation, optimization, test correlation and reporting in a traceable, reusable engineering workflow.

Summary

01 Aerodynamics and industrial AI

Joint expertise connects rotor design methods with an engineering agent platform.

02 Knowledge-constrained design

Airfoil data, rotor cases and expert workflows guide agent decisions.

03 Multi-fidelity simulation

Rapid models, VPM and CFD support design exploration and verification.

04 Integrated development

Multi-agent workflows connect geometry, analysis, optimization and reporting.

Thank you

Questions and discussion

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