Oral presentation | Industrial applications

Industrial applications-III

Tue. Jul 16, 2024 2:00 PM - 4:00 PM Room B

[5-B-01] Development of Multiobjective Aerodynamic Three-Dimensional Shape Optimization Method

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ICCFD12

Development of Multiobjective Aerodynamic Three-Dimensional Shape Optimization Method

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Process of aerodynamic design optimization

Design optimization problem definition

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Aerodynamic design optimization

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Analysis of the optimized designs

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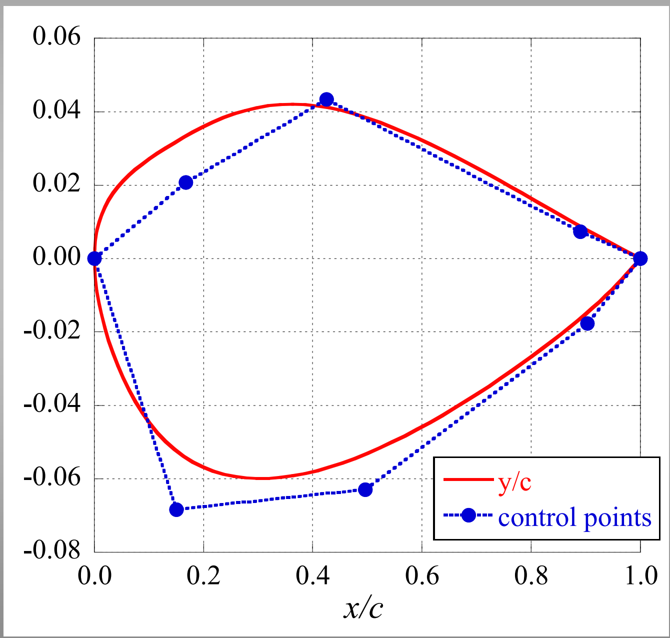
Knowledge about the optimization problem

Parameterization of shapes

Method for parameterizing 2D shapes and quasi-2D shapes has been established.



2D shape parameterization using Bezier curves

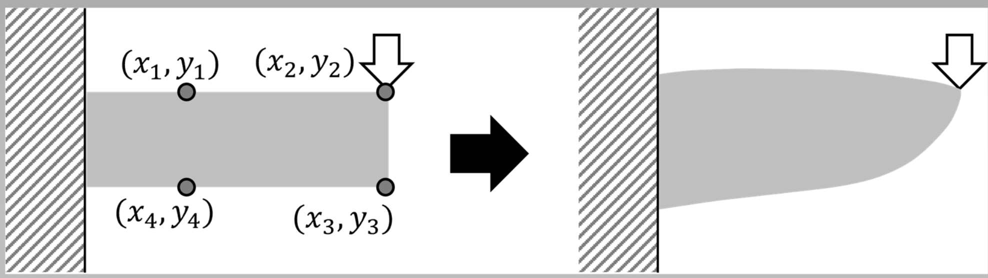
Quasi-2D shape parameterization by stacking 2D shapes

How to parameterize fully 3D shapes?

Two categories of design optimization methods

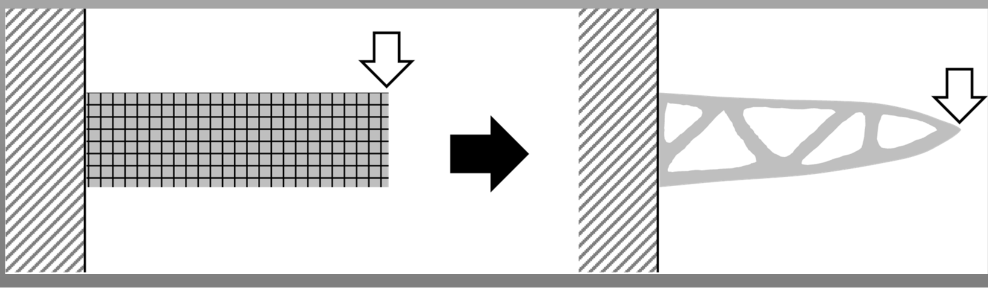
Shape optimization

Parameterization of a shape is required.
Degree of design freedom is limited by parameterization.

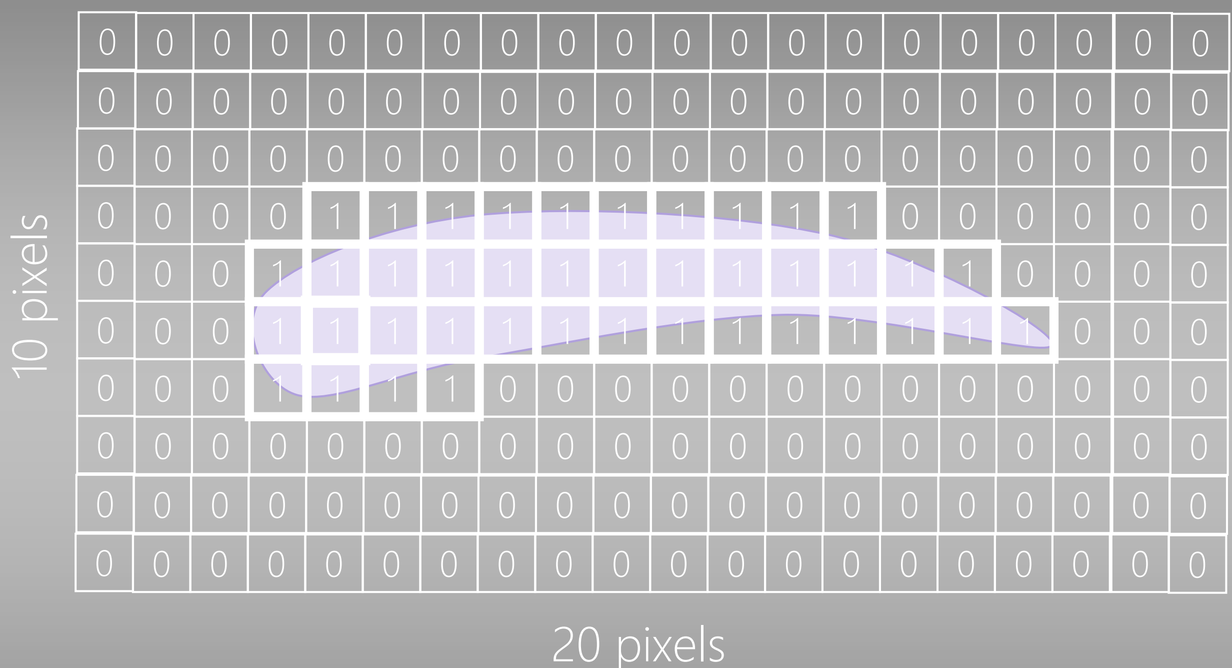


Topology optimization

Parameterization of a shape is NOT required.
It has a high degree of design freedom.



Difficulty in topology optimization



Shape is represented by many pixels.

Number of design parameters is equal to number of pixels.

A huge number of binary design parameters should be optimized

Research Objectives

To propose a multiobjective evolutionary algorithm (MOEA) for topology optimization using

quadtree coding for two-dimensional shape optimization

and

octree coding for three-dimensional shape optimization

To verify the effectiveness of the proposed method by demonstrating

aerodynamic airfoil shape design optimization

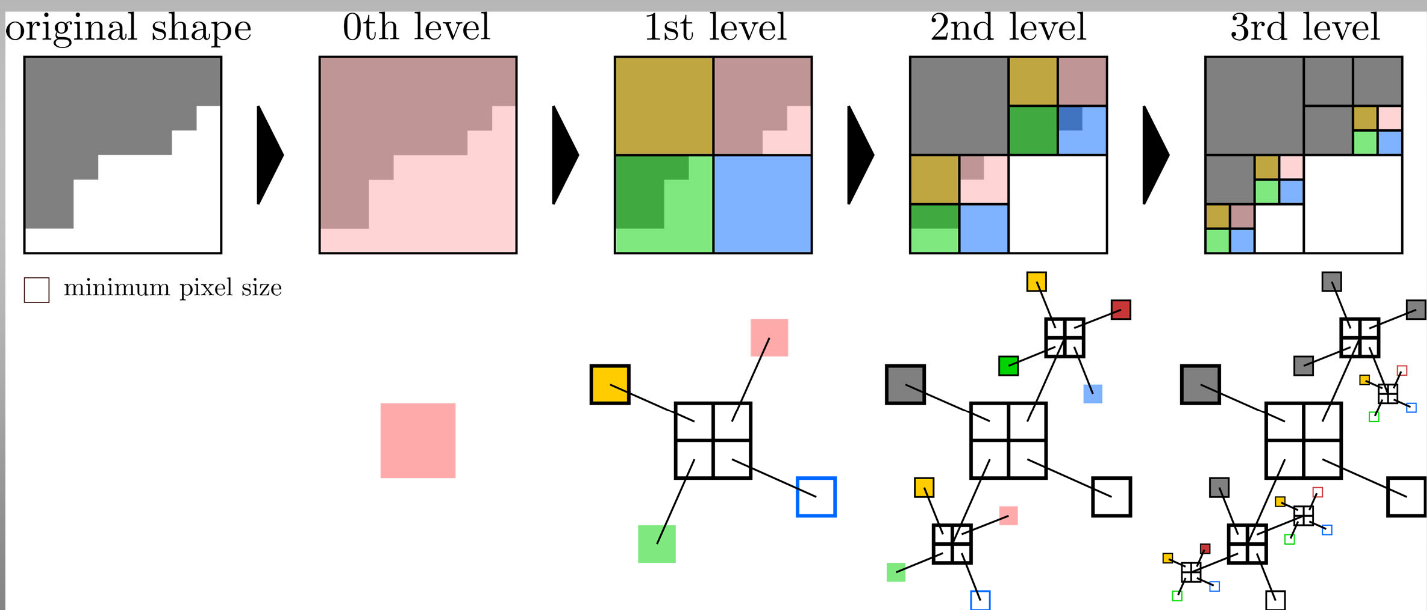
and

aerodynamic wingtip shape design optimization

MOEA using quadtree coding for 2D optimization

Shape is coded as a quadtree.

Multiobjective genetic programming is used to optimize quadtree.



aerodynamic airfoil shape design optimization

Design optimization problem

Flow condition

- Reynolds number of 1,000,000
- Mach number of 0.3
- Angle of attack of 7 degrees

Design objectives

- Lift coefficient (to be maximized)
- Drag coefficient (to be minimized)

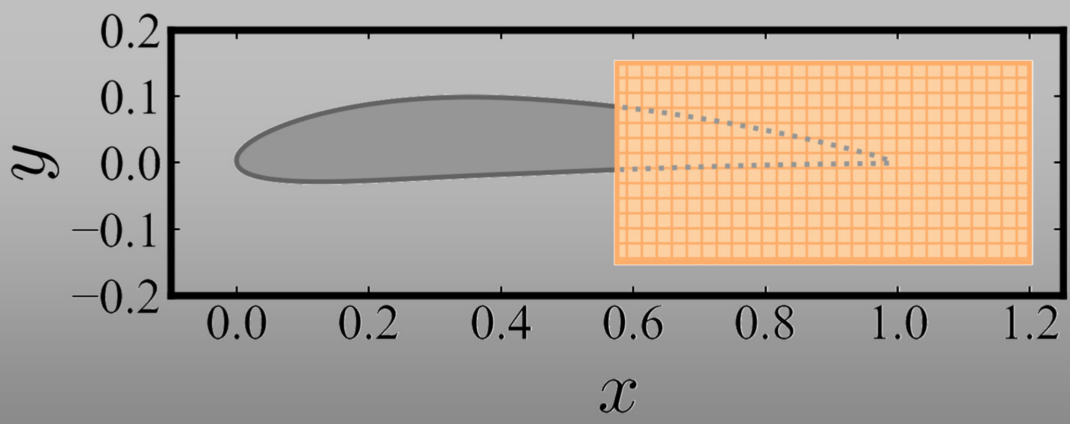
Design Constraint

- Cross sectional Area ≥ Cross sectional area of NACA4412

Design optimization problem

Shape representation

- Design domain is [0.575:1.2] in flow direction), [-0.15:0.15] in vertical direction
- 64 pixels (flow direction) x 64 pixels (vertical direction)



Computational methods

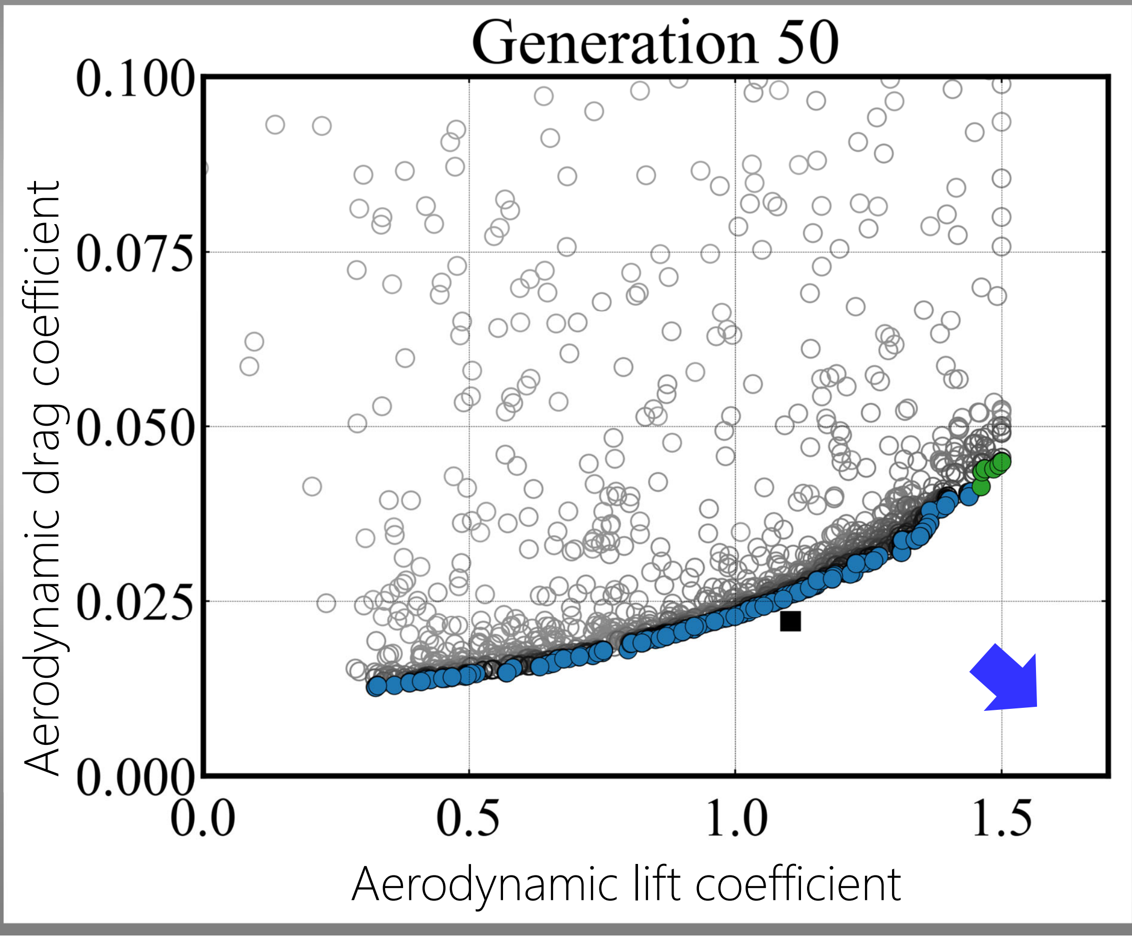
Optimization

- Multiobjective genetic programming
- Quadtree coding
- Population size 100 x number of generations 50

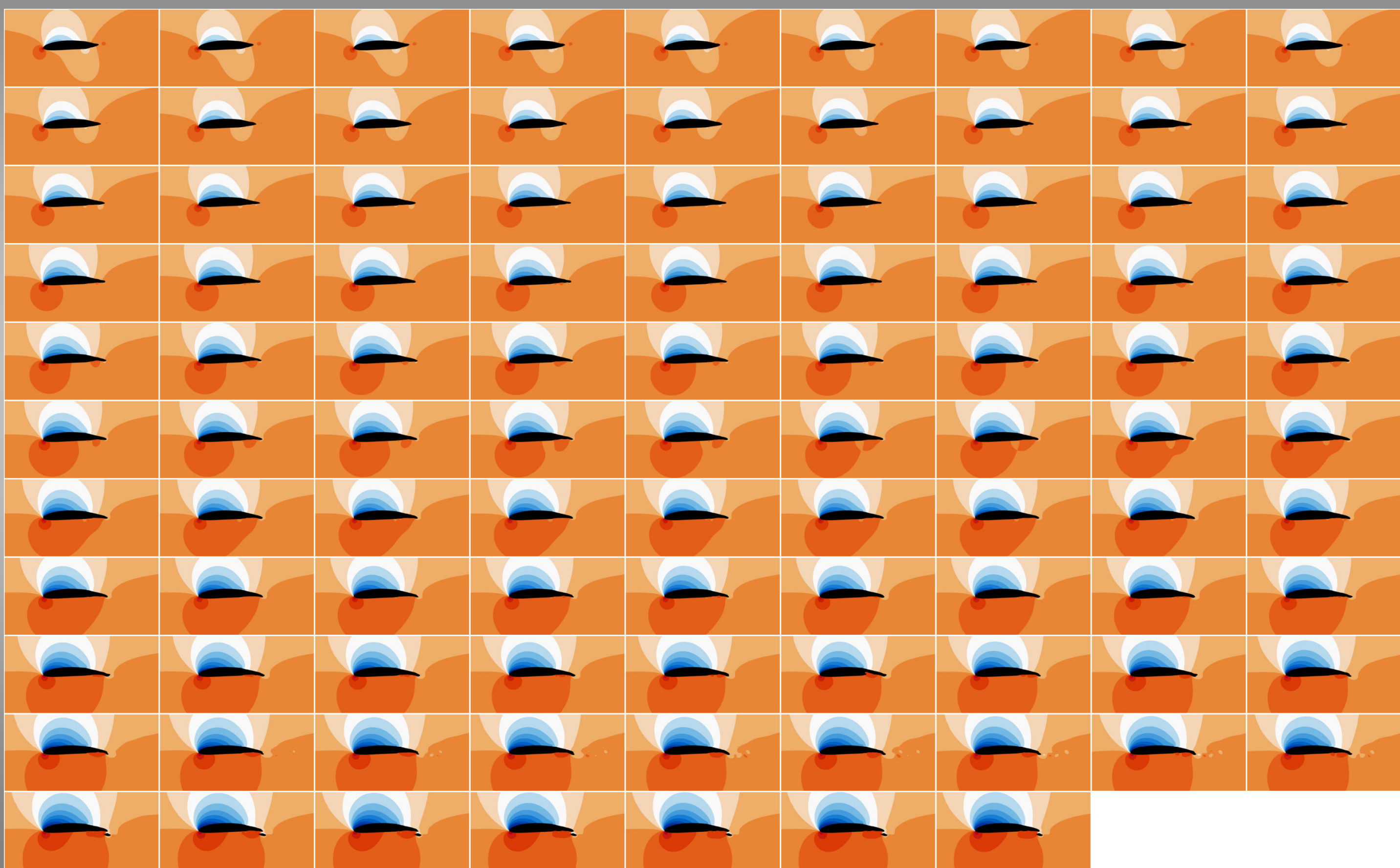
CFD simulation

- FaSTAR developed by JAXA (RANS simulation code)
  - HLLEW for convective term evaluation
  - LU-SGS for time integration
  - SST2003 for turbulent modeling
- HexaGrid developed by JAXA
  - Minimum distance from the wall 1.0 x 10^{-5}

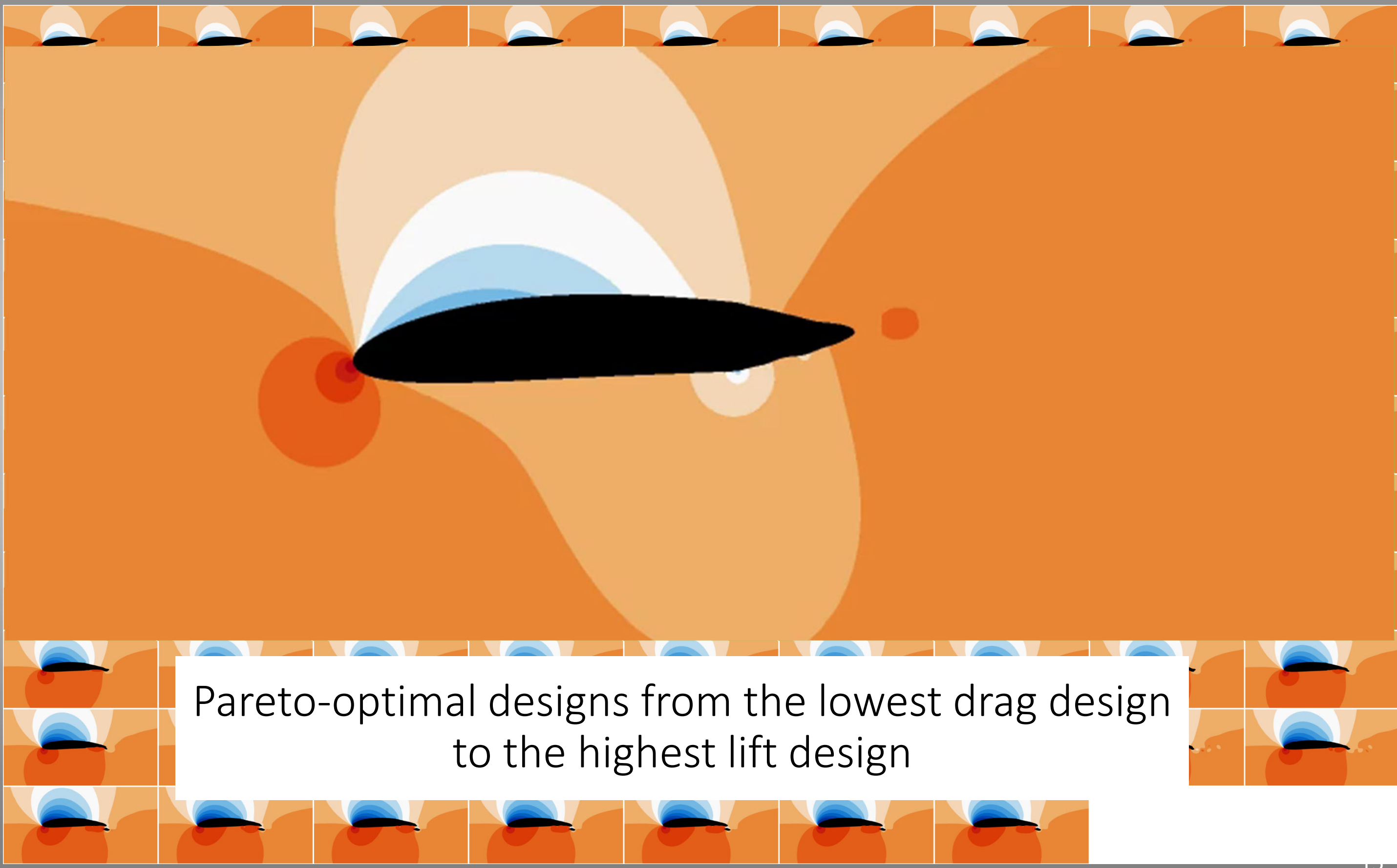
Distribution of Pareto-optimal designs



Shape of the obtained Pareto-optimal designs

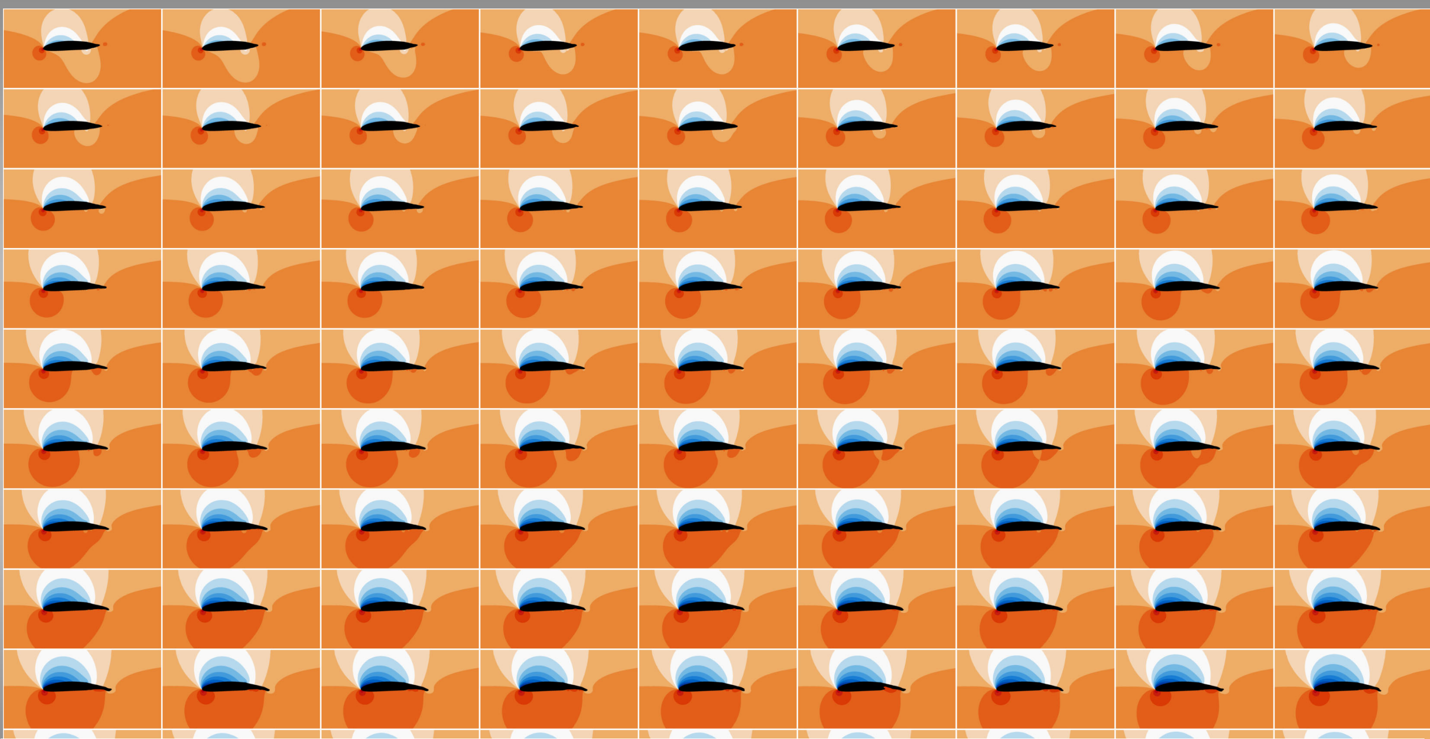


Shape of the obtained Pareto-optimal designs



Pareto-optimal designs from the lowest drag design to the highest lift design

Shape of the obtained Pareto-optimal designs



High lift airfoils shape with flap are rediscovered by MOEC.
(benefit of the topology optimization)

Aerodynamic wingtip shape design optimization

An example of wing tip shape

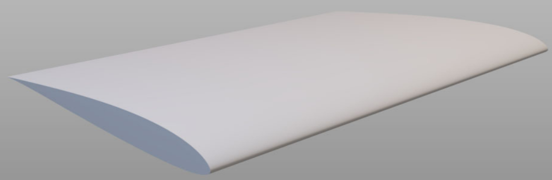
Design optimization problem

Flow conditions

- Reynolds number: 2.0×10^4
- Freestream Mach number: 0.2
- Angle of attack: $2°$

Baseline shape

Rectangular wing with SD7003 airfoil, *AR* = 1.5



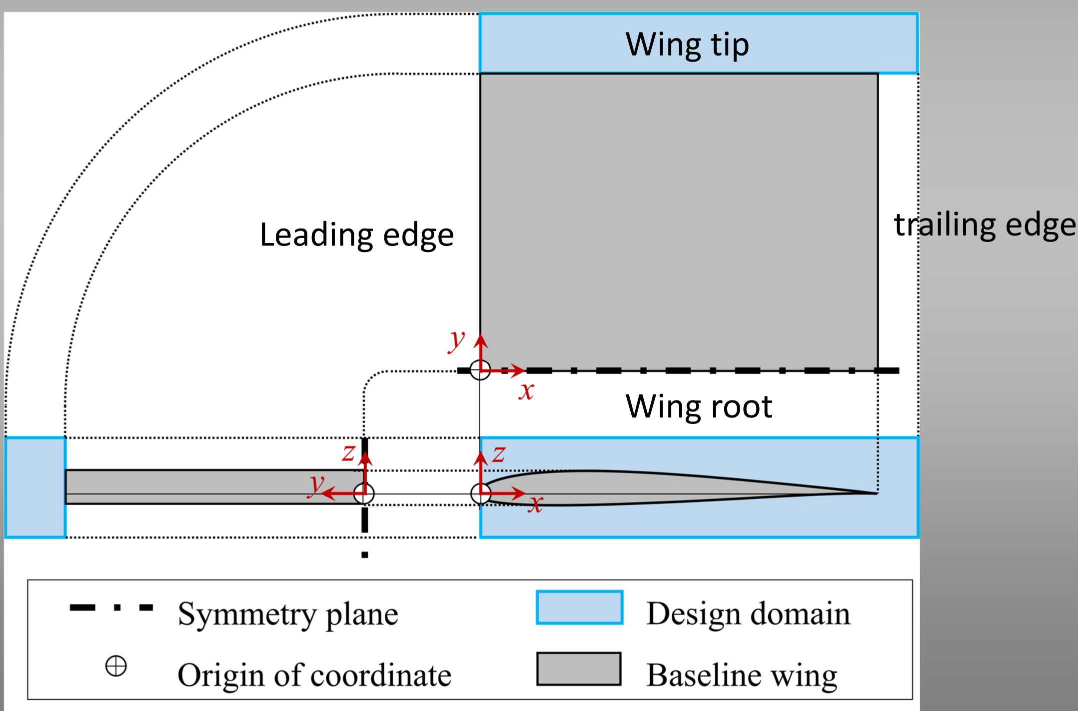
Objective functions

- Lift coefficient C_L (to be maximized)
- Drag coefficient C_D (to be minimized)

Design optimization problem

Design domain

[0.0, 1.1] in x direction × [0.75, 0.9] in y × [−0.1, 0.15] in z direction



Flow simulation method

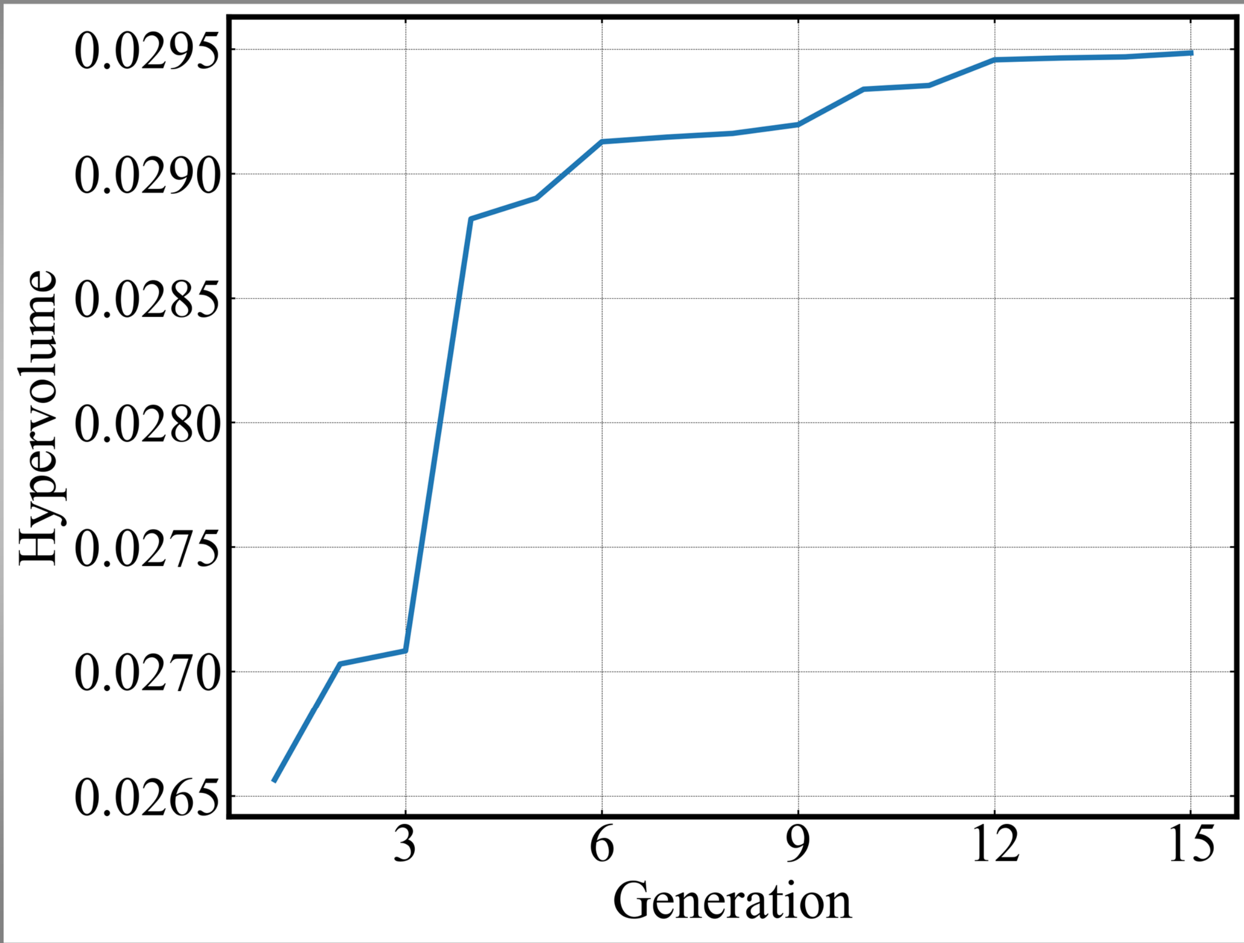
Solver	FaSTAR
Governing Equations	Compressible Navier-Stokes equations
Time integration	LU-SGS
Convection term	SLAU
Turbulence model	None

Grid generator	HexaGrid
Minimum distance from the wall	5.0×10^{-4}
Domain size	$51(x) \times 50(y) \times 50(z)$

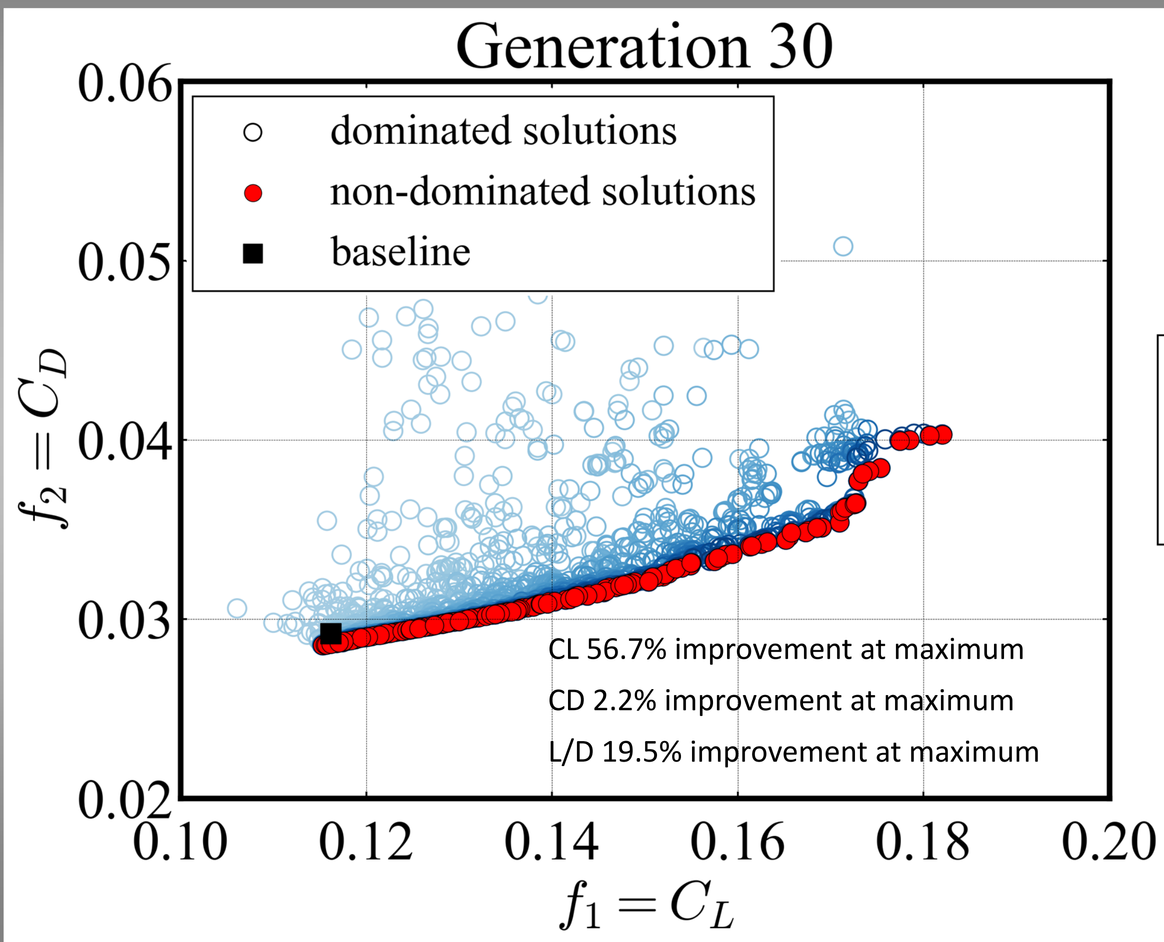
Optimization method

Algorithm	Octree encoded NSGA-II
Population size	160
Maximum number of generation	15
Node exchange rate in crossover	0.3
Node mutation rate in mutation	0.0003
Maximum depth of octree	5 （$32 \times 32 \times 32$ voxels）
Regularization filter	Morphology operations

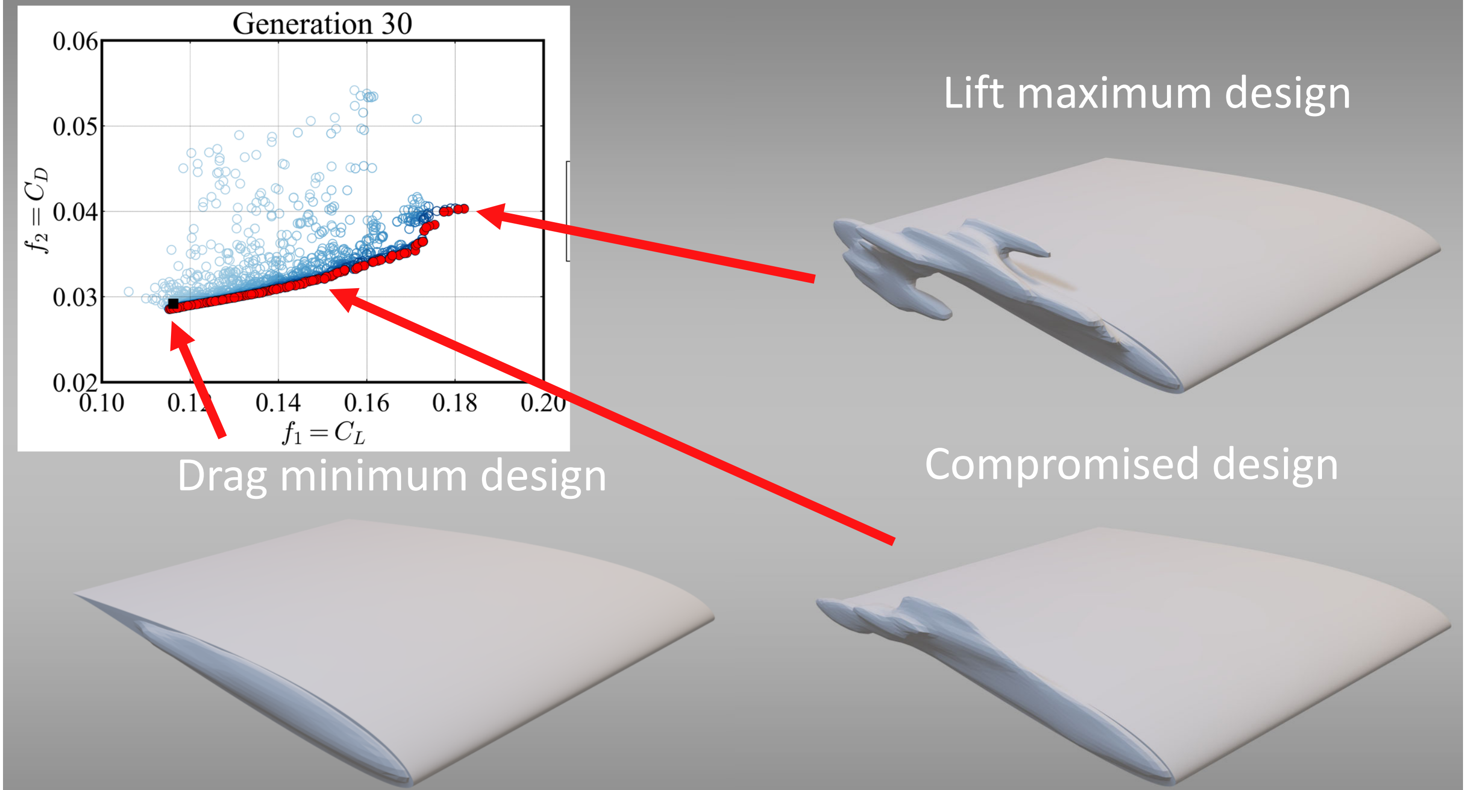
Optimization history



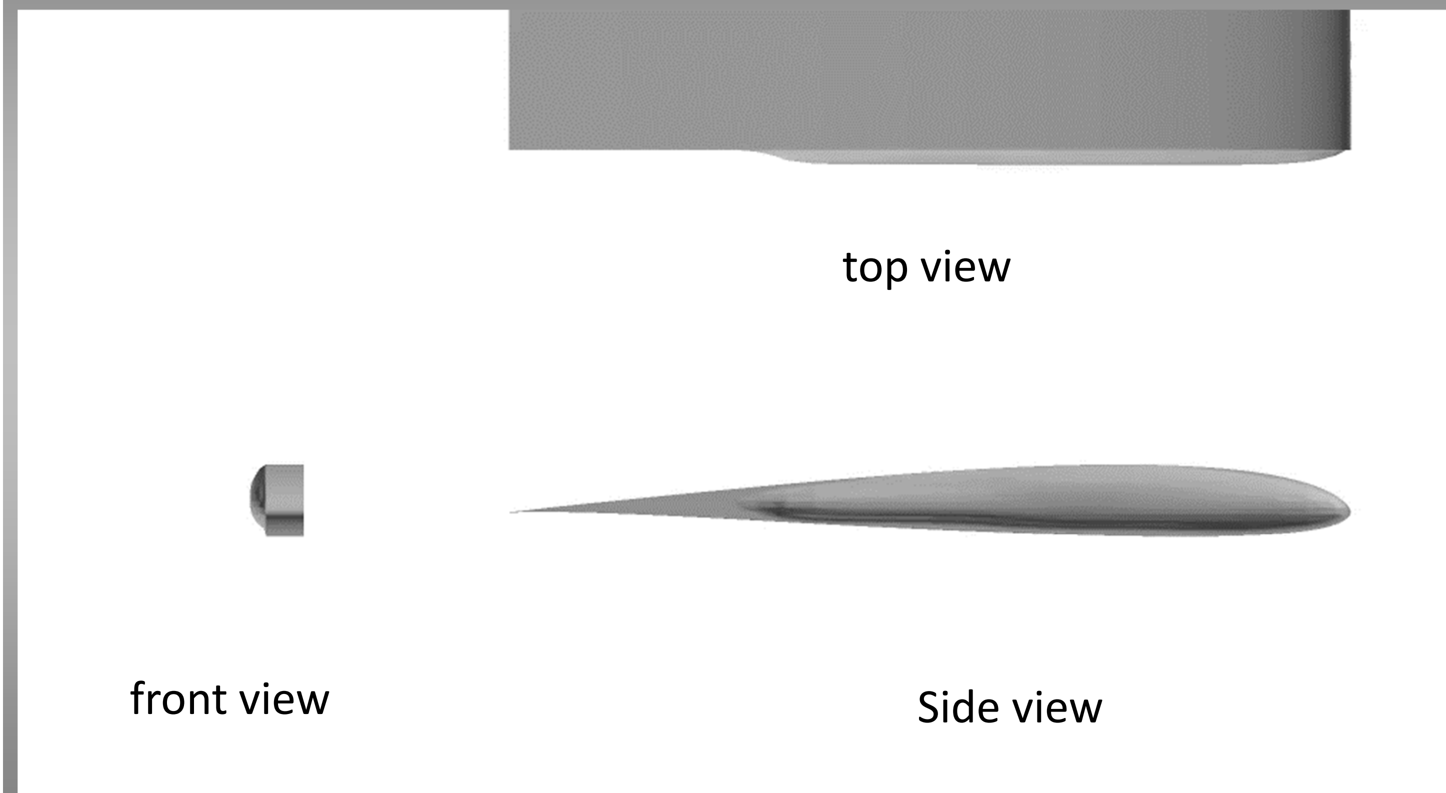
Optimization result



Optimization result

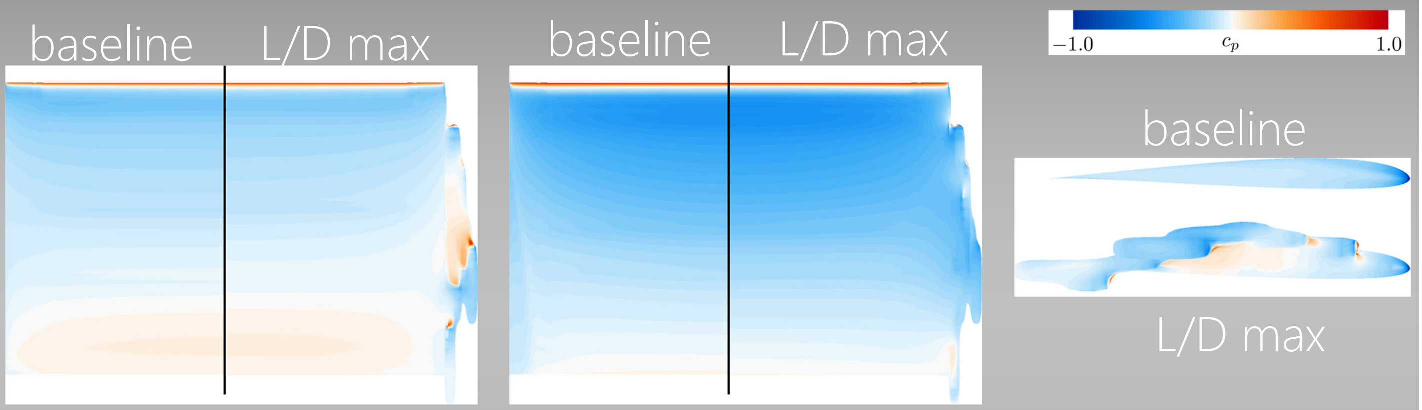


Obtained Pareto-optimal designs from minimum drag design to maximum lift design



Winglet shape is rediscovered by MOEC.

Surface pressure distribution of the L/D maximum design



Lower surface Upper surface wingtip side

Upper surface c_p near the wingtip become lower

Lower surface c_p near the wingtip become higher

Summary

MOEA for topology optimization using

quadtree coding for two-dimensional shape optimization

and

octree coding for three-dimensional shape optimization

Is proposed.

Effectiveness of the proposed method is verified by demonstrating

aerodynamic airfoil shape design optimization

and

aerodynamic wingtip shape design optimization

References

1. Naruhiko Nimura and Akira Oyama, “Multiobjective Evolutionary Topology Optimization Algorithm Using Quadtree Encoding,” IEEE Access, Vol. 12, pp. 73839-73848, DOI: 10.1109/ACCESS.2024.3404594, 2024.
2. Naruhiko Nimura and Akira Oyama, “Global Multiobjective Aerodynamic Optimization of Wingtip Design for Micro Aerial Vehicle,” AIAA SCITECH 2024 Forum, https://doi.org/10.2514/6.2024-2504, 8-12 January, 2024.
3. Naruhiko Nimura and Akira Oyama, “Multiobjective Aerodynamic Topology Optimization using Quadtree Genetic Programming,” 2023 AIAA Aviation and Aeronautics Forum and Exposition, San Diego & Online, USA, 12-16 June, 2023.