BHE Progress Report

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Development of an Aero-Structural Optimization Tool for Aircraft

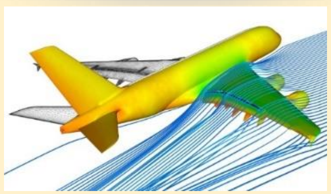
Department of Aerospace Engineering, Tohoku University

Masashi SODE

Introduction | Design Problem of CFRP Aircraft

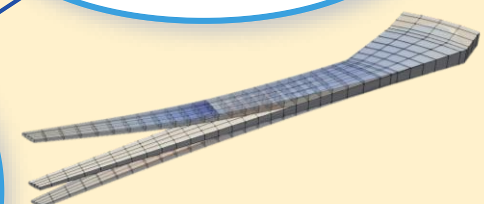
Integration problem of multi-disciplinary research fields

Aerodynamics Design

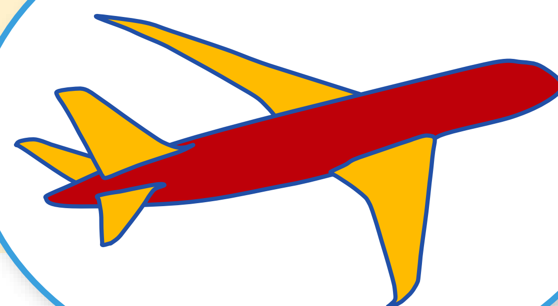


faster, longer range

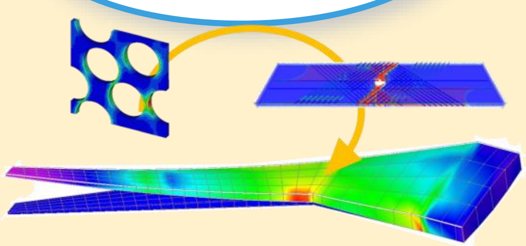
Structural Design



Light weight, efficient



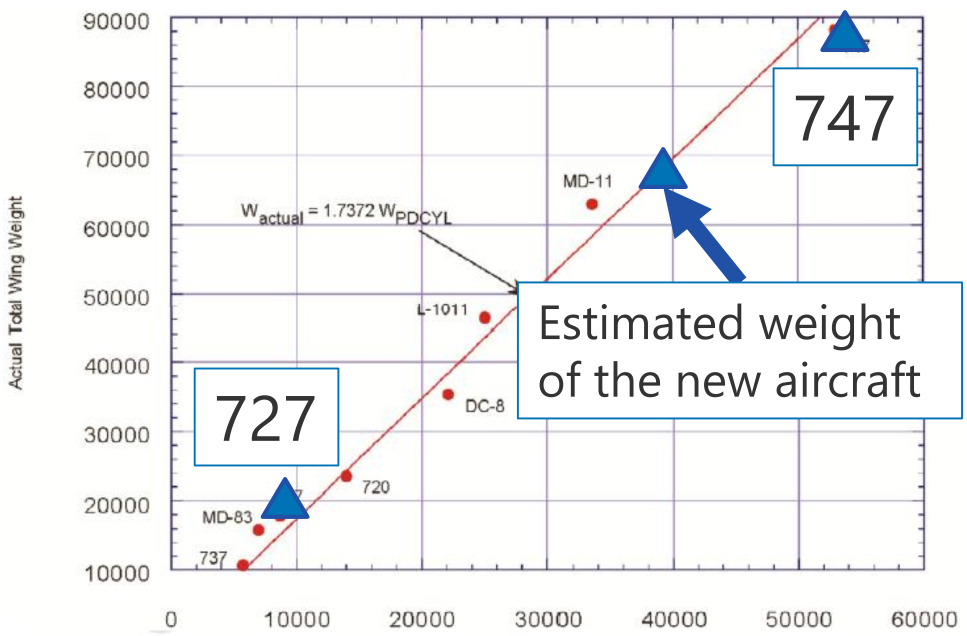
Materials Design



Light, strong, long life

Multi-scale design

- Multi-Disciplinary
- Multi-Objective
- Multi-Scale



Empirical design method

- Design by estimation formula obtained from statistical data
- It is effective for the design of the conventional aircraft.
- the problem is that the accuracy to the new concepts is low.
  ex) new materials (CFRP)

New design method is necessary for applying new materials

A review of aircraft wing mass estimation methods, Aerosp. Sci. Technol. (2017)

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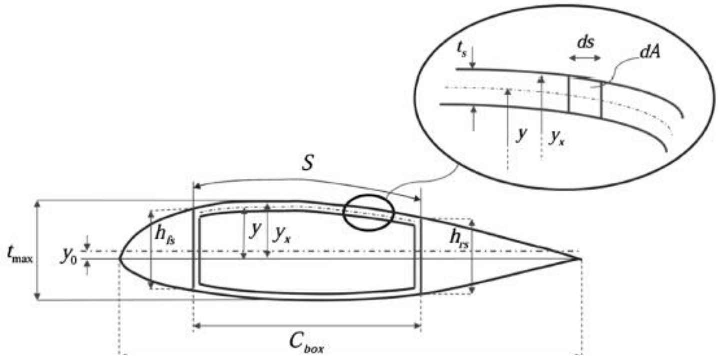
Analytical approach

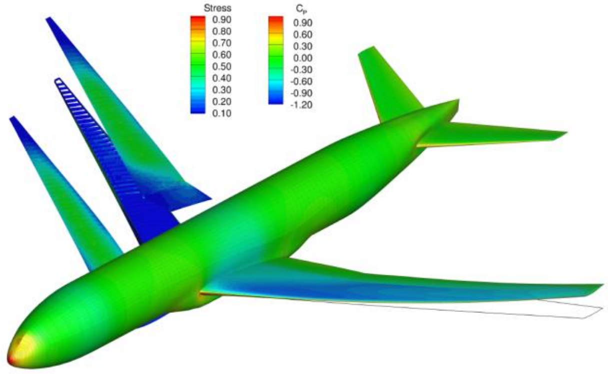
Weight estimation by semi-empirical structure design using theoretical equation



Elham et al., AIAA 2014

Numerical approach

Large scale optimization with simulations



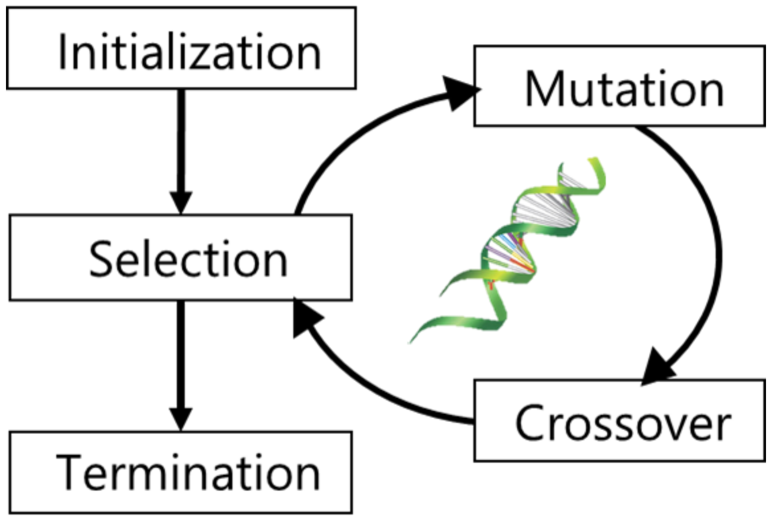
NASA-Michigan undeformed Common Research Model (uCRM)

Martins, Kenway et al., AIAA 2014

there are still no examples of aircraft design tools that can consider the multi-scale properties of CFRP.

construct an aircraft design tool that can take multi-scale properties of materials into account

Optimization Method | Genetic Algorithm (GA)



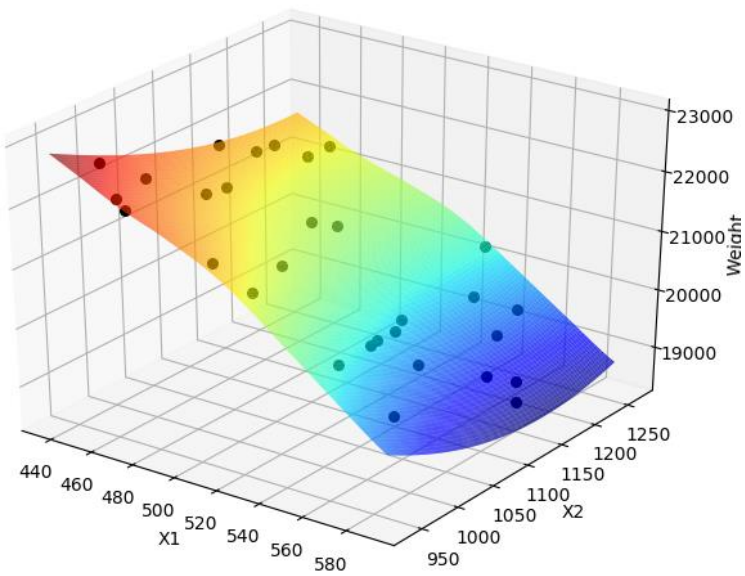
- Algorithm that mimics the process of evolution

Advantage

- Multi-objective optimization is available
- A lot of solutions are obtained with one calculation.

- It is necessary to search a huge number of solutions.
- The calculation cost is generally high.
- Hard to combine with simulation.

Optimization Method | Response Surface Method



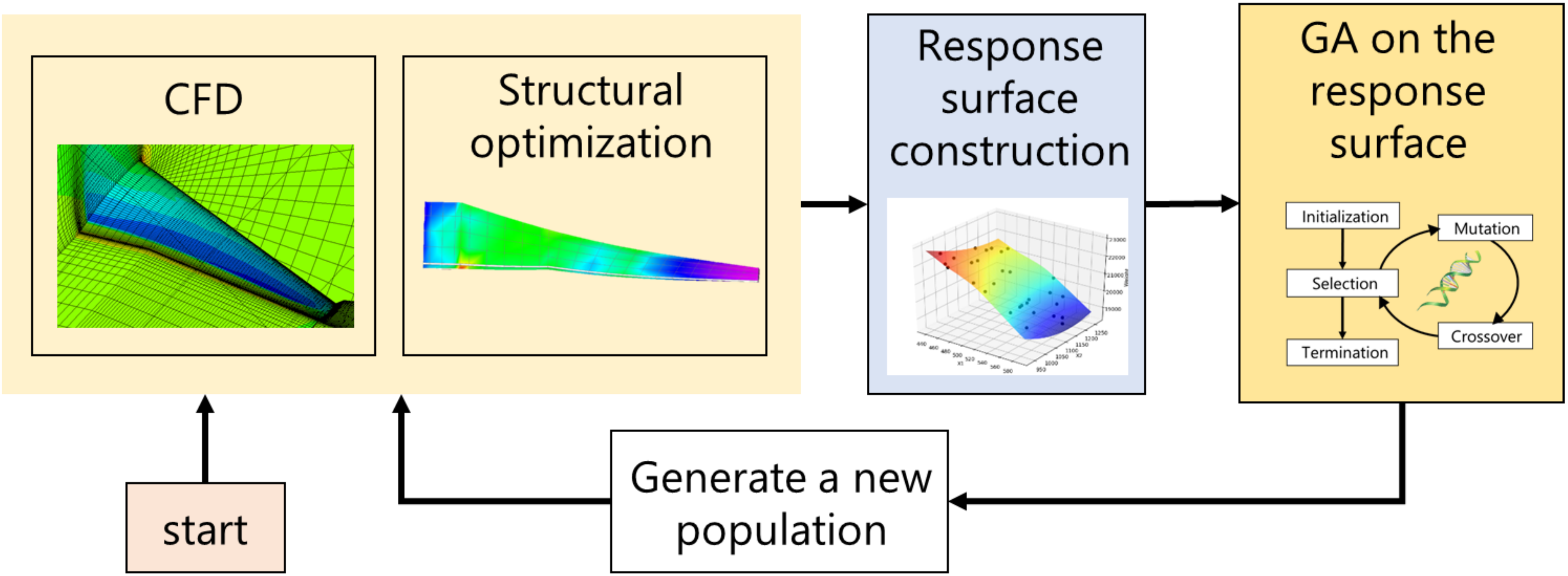
- A method to find an optimum solution by using a response surface with few measurement data
- a Kriging response surface is constructed from known samples.

$$\hat{f}(\boldsymbol{x}) = \mu + \boldsymbol{r}^{\mathrm{T}} \boldsymbol{R}^{-1}(\boldsymbol{f} - \boldsymbol{1}\mu)$$

- Using the EI value to find the next search point with GA.
  EI : Expected Improvement

By executing multi-objective optimization on the response surface,
It is possible to search Pareto solutions with realistic execution time.

Optimization Method | Framework



- 2 simulation methods are used for objective function evaluation to construct the response surface.
- The next search points on the response surface are acquired by GA.
- The response surface is updated sequentially.

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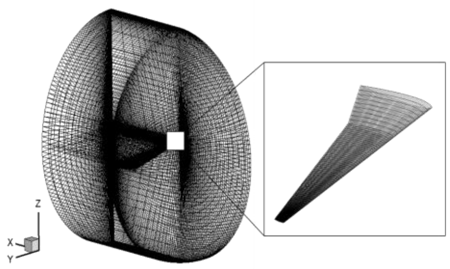
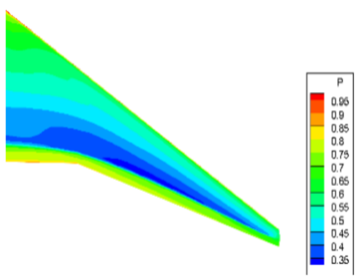
$$\frac{\partial \mathbf{Q}}{\partial t}+\frac{\partial \mathbf{E}}{\partial x}+\frac{\partial \mathbf{F}}{\partial y}+\frac{\partial \mathbf{G}}{\partial z}=\mathbf{0}$$





Calculate the pressure distribution around the wing using finite volume method with the Euler equation

$\boldsymbol{f}_{\mathrm{aero}}$ ⇩

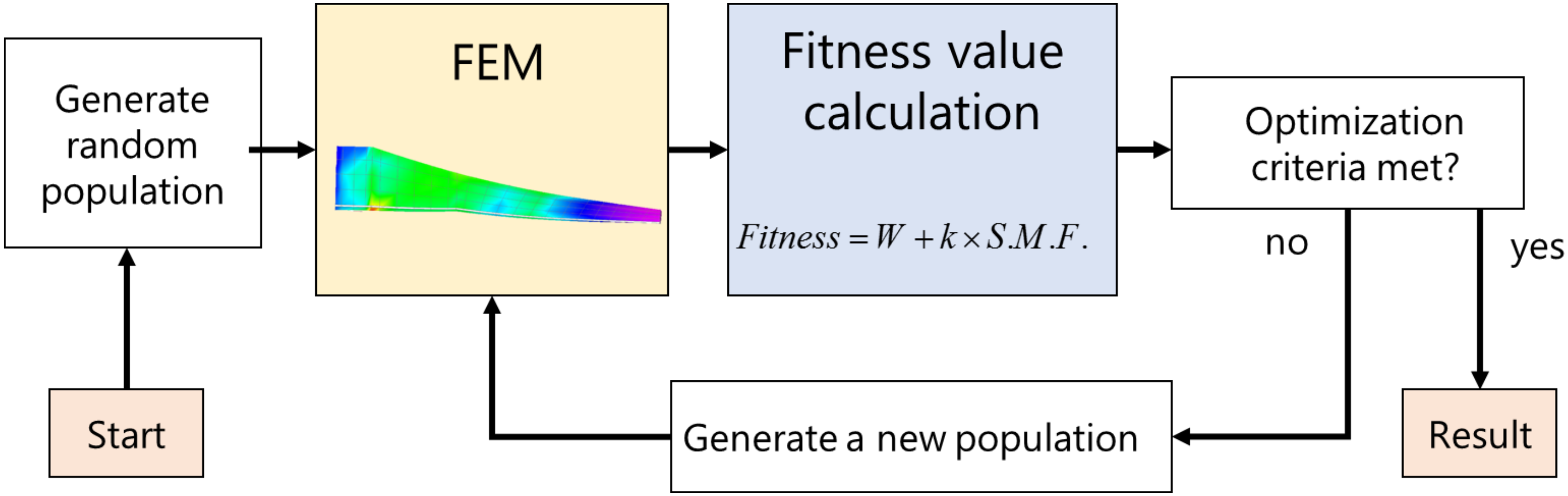
From the information of the pressure distribution, load distribution on the wing structure is calculated using CVT method

$\boldsymbol{f}_{\mathrm{st}}$ ⇩

Structural optimization

Carry out CFD and calculate the load on the structure

Optimization Method | Structural Optimization



Structural optimization using FEM and GA

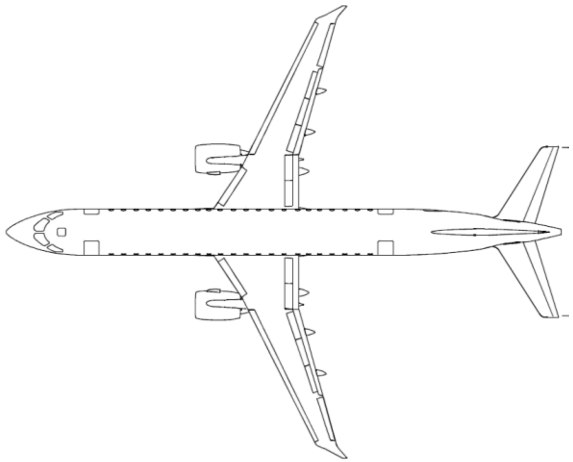
- Application to composite materials

with the original evaluation function,
any fracture criterion is available.

aiming to use multi-scale fracture criterion
which can deal with the difference
between resin type and fiber type in the optimization

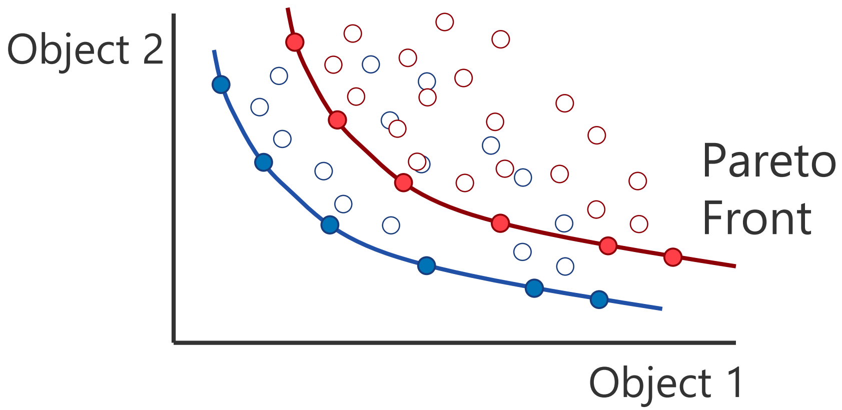
Perform structural optimization to obtain minimum weight.

Application | Optimization Target



- **90 passenger transonic jet**
  design range 2700km

When applying new materials, how much can we lighten the structure?



Pareto fronts between CFRP(T800s) and Duralumin(A7075) are compared

Application | Objective Function

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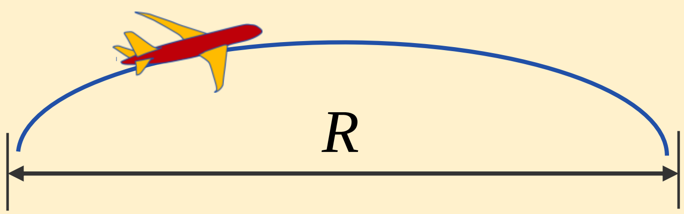
Range R [km]

$$R = \eta \frac{L}{D} \frac{V}{c} \ln\left(\frac{W_0}{W_1}\right)$$

(Breguet range equation)

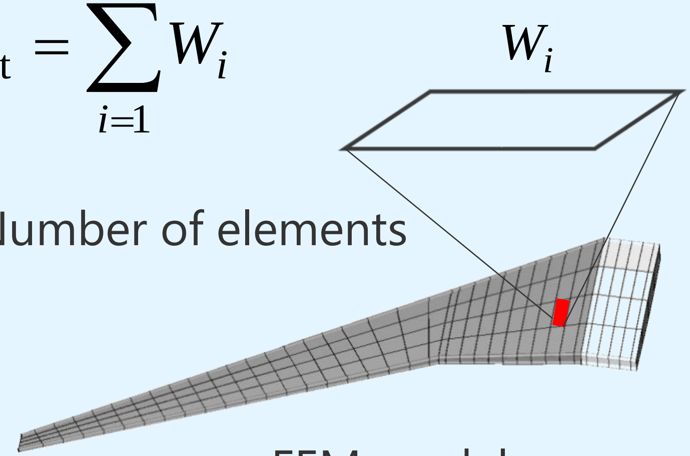


Weight W_{st} [kg]

(result of structural optimization)

$$W_{st} = \sum_{i=1}^{N} W_i$$

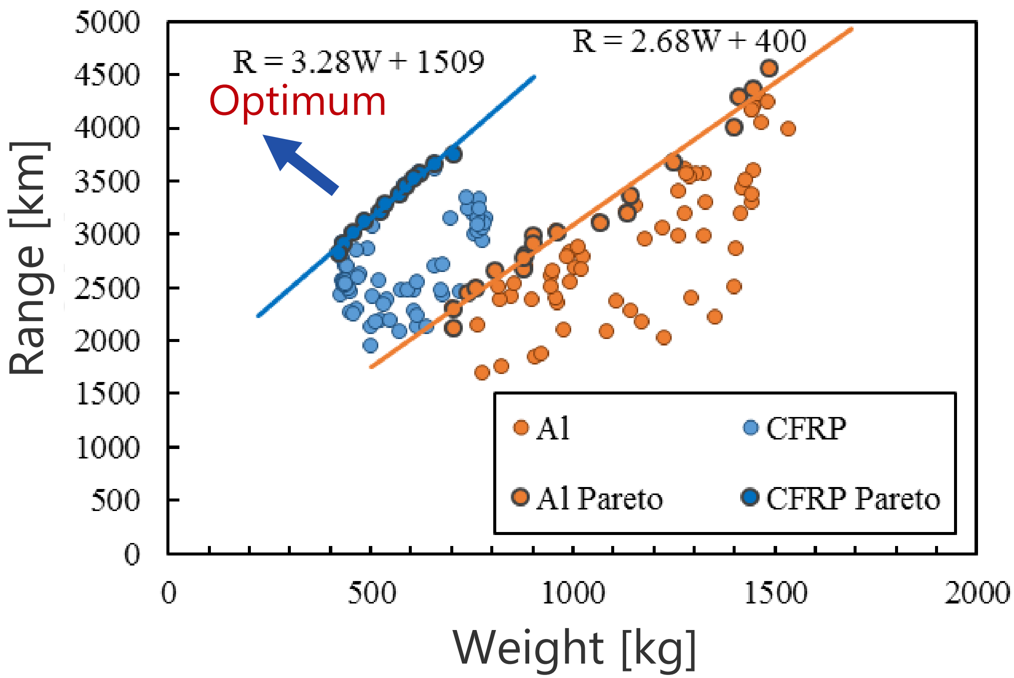
N : Number of elements



FEM model

	Optimum	objective
Range R	Maximum	Flight efficiency
Structural weight W_{st}	minimum	Light weight

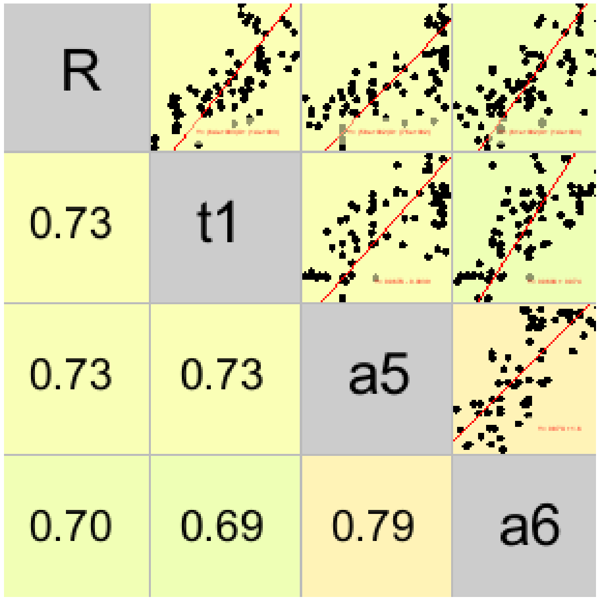
Results | Comparison between Pareto Fronts



- Weight-Range
- Pareto fronts show good approximation by linear interpolation
- From the comparison of these interpolation lines, the gradient of CFRP is higher

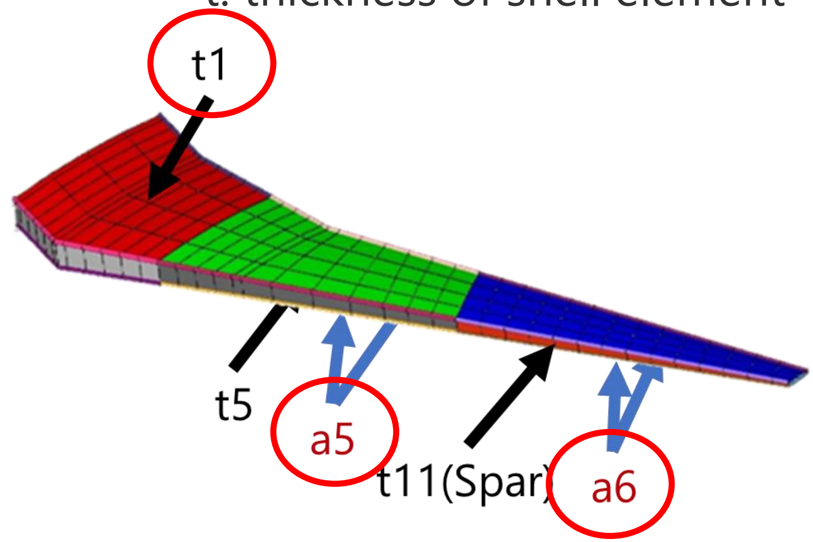
- The Pareto front of CFRP has the higher sensitivity of range to weight.
- Aircraft with a larger range have advantage of weight reduction, when applying CFRP

Results | Correlation Matrix of Duralumin



Relationship between
Range and Structural parameters
(Duralumin)

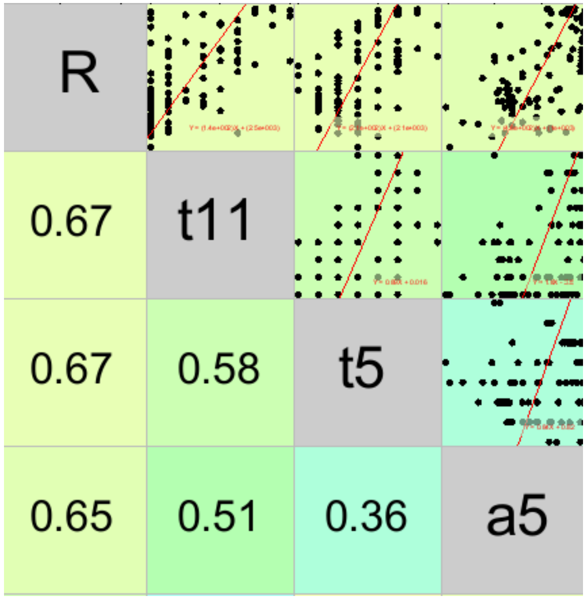
a: cross section area of rod element
t: thickness of shell element



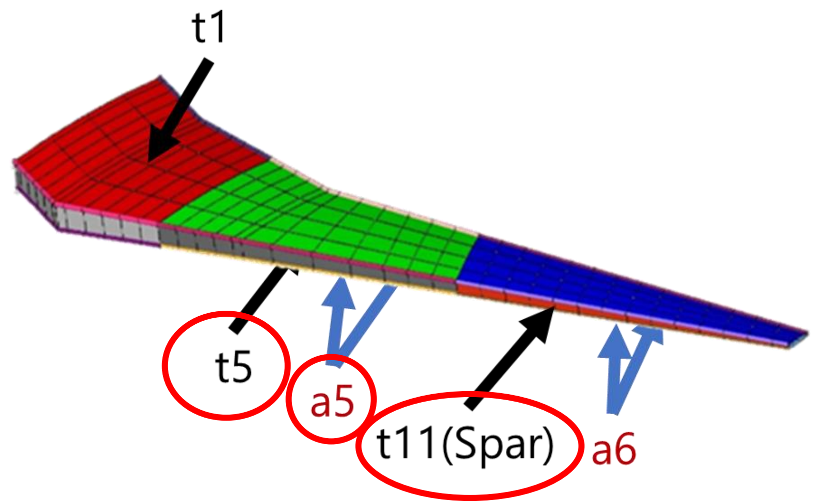
- Longer range wing has
  thicker skin on the upper skin.
  larger flange area on the lower wing.

Results | Correlation Matrix of CFRP

a: cross section area of rod element
t: thickness of shell element



Relationship between
Range and Structural parameters
(CFRP)



- Longer range wing has
  thicker skin on the front spar.
  larger flange area and thicker skin on the lower wing.

Conclusion

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Method

- Aero-structural optimization tool
  by genetic algorithm using response surface method is constructed.

- Aero-structural optimization capable
  of multiscale evaluation was constructed by using
  original evaluation function.

- By performing optimization on duralumin and CFRP,
  Pareto Fronts was acquired and compared.

Results

- Aircraft with a larger range have advantage of weight reduction,
  when applying CFRP

- Differences of structural design are confirmed.

Thank you for your attention.