Optimization of Structural Layout for Composite Aircraft Wings

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Background

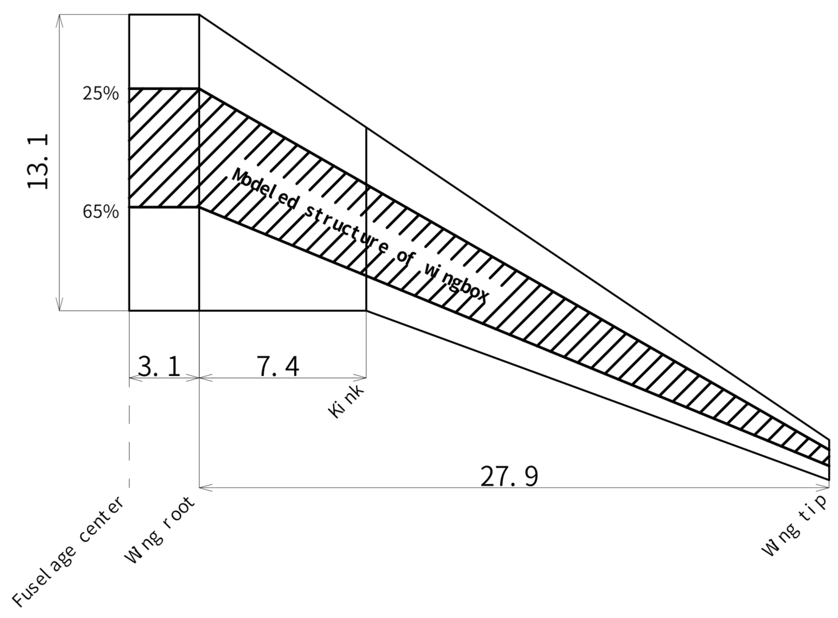
Future Aircrafts
- New structure
- Next-generation material
  Carbon Fiber Reinforced Plastics (CFRP)

Desired technology
- Computer Aided Engineering
- Optimization
  Multi-variable multi-purpose
  Search for global solution

In this study…
- Computational Fluid Dynamics (CFD) & Finite Elemental Analysis (FEA)
- Practical multi-variable & multi-purpose optimization
  : Structure layout of main wing
- Genetic Algorithm (GA) combined with Neural Network (NN)

Problem setting

Main wing model
- Based on Boeing 777
  Semispan : 28m   Receding angle 34°
- Material : CFRP
  Fiber : T800S   Resin : #3900-2B

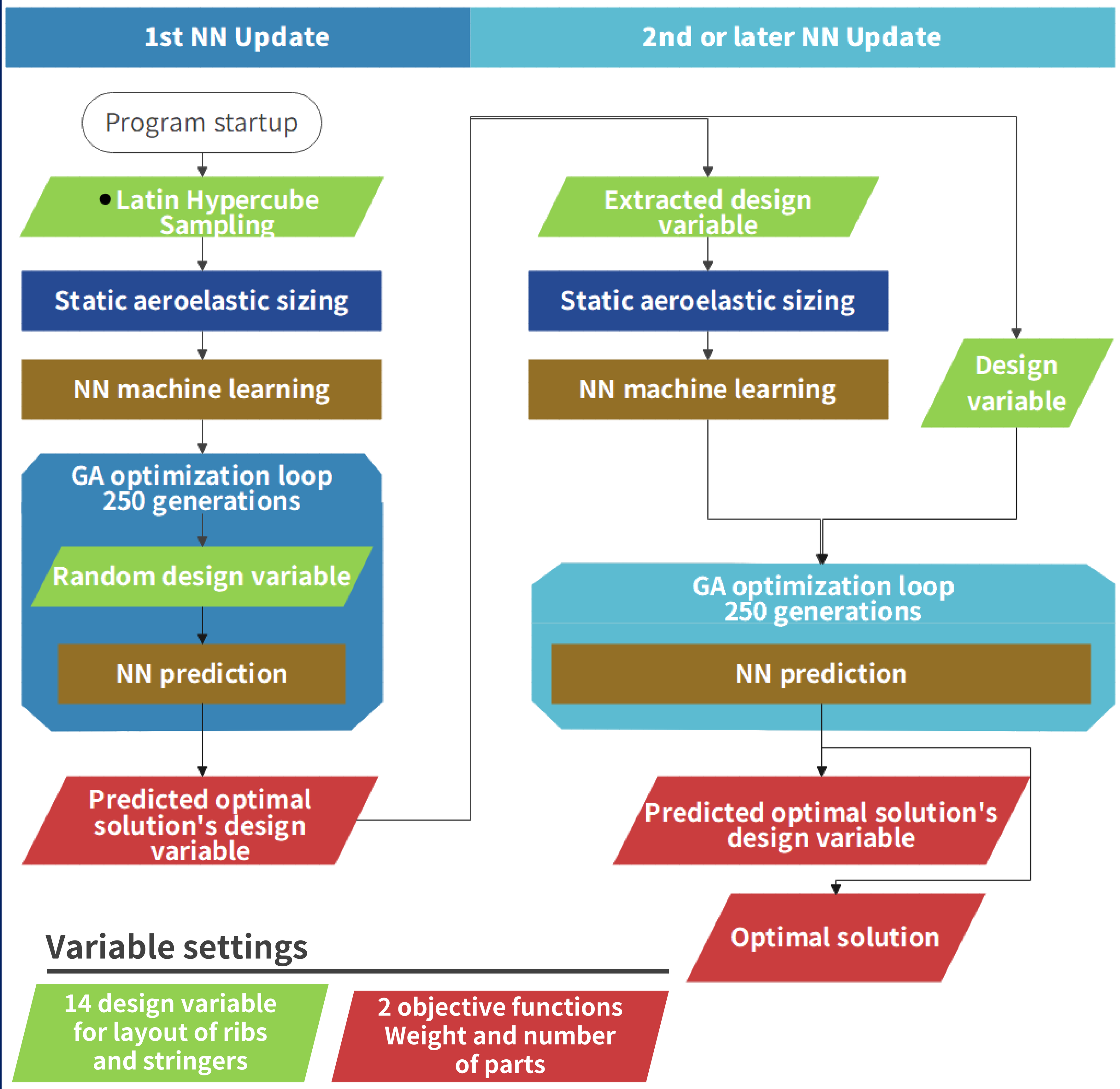


Flight Condition
Mach 0.84 C_L Target : 0.5

Optimization Settings
- Design variables
  Layout of ribs & stringers
- Objective functions
  Total weight & Number of parts
- GA
  250 generations × 50 individuals
- NN
  50 initial samples
  + 5 additional samples
  × 5 updates

GA+NN method

Optimization method
- GA combined with NN (GA+NN)
- Surrogate model using NN to reduce computational complexity



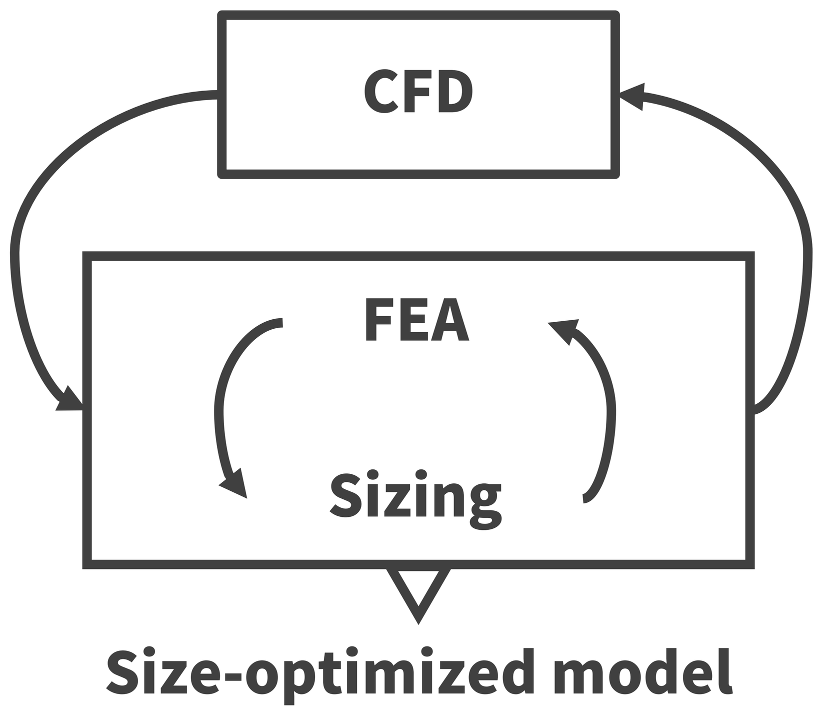
- **Simulate static aeroelastic sizing on all individuals of 1st updates**
- **Simulate on only 5 appropriately extracted individuals after 2nd updates**
- The computational complexity can be reduced by substituting NN inference for Static aeroelastic sizing which has a large complexity.
- Optimal solution obtained with GA+NN is often superior to one with pure GA because NN prediction is cheap evaluation and has a small computational complexity, therefore more generations can be executed.

Static aeroelastic sizing method

Sizing method
- Bidirectional fluid-structure coupling for Static aeroelastic analysis
- Structural sizing of main wing by the fully stressed design method as follows.

$$g_{k+1} = g_k \left(\frac{1.0+\overline{ms}}{1.0+ms_k}\right)^{\beta}$$

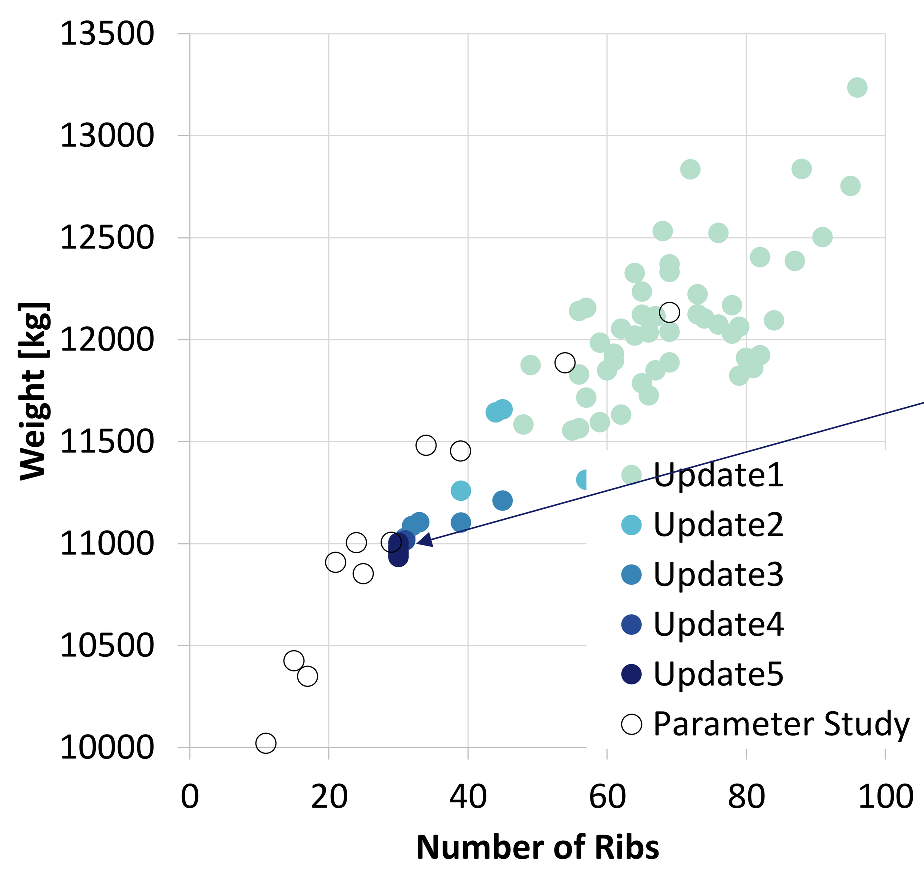
g: Thickness or cross-sectional area of each parts
k : Iteration
$\overline{ms}$: Target margin of safety ($\overline{ms}=0.05$)
ms_k : Margin of safety in the current iteration

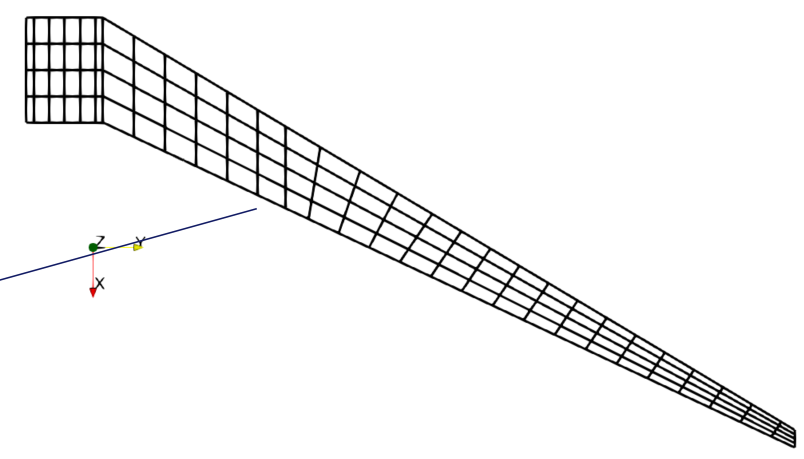


The lightest structure in the static aeroelastic equilibrium can be obtained with these loops.

GA+NN analysis

- **Spars, skin and ribs are modeled** is optimized in order to reduce the number of elements in the model.
- Strength of the stringers is taken into account by setting the skin thickness to the effective cross-sectional area.





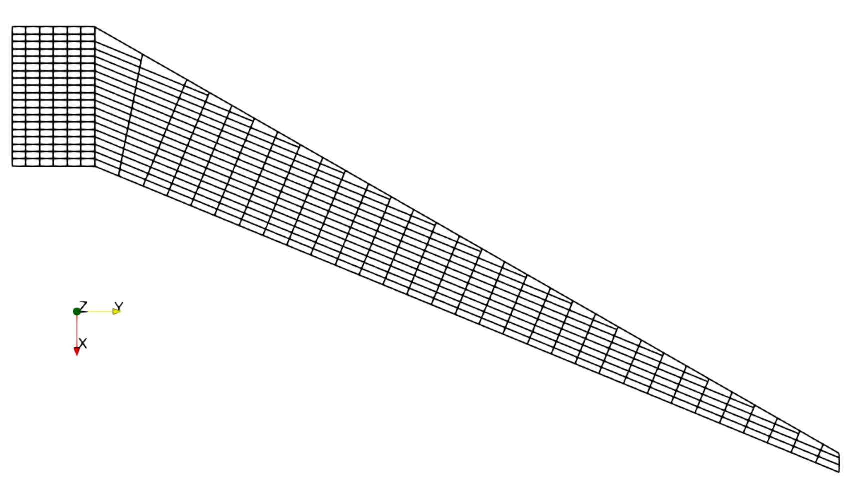
▲ "Optimal" rib layout
Each ribs are arranged at approximately equal intervals.

- **Limited design space to 25 or more ribs due to modeling problem**
- **No trade-off between weight and the number of parts**

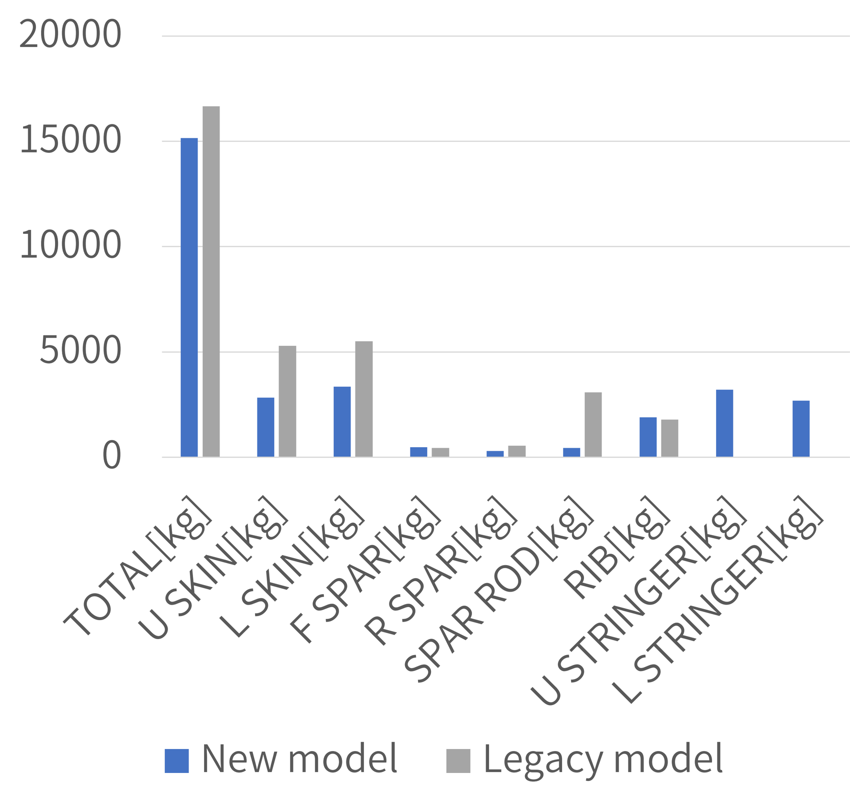
Need more accurate model and suitable objective function

Ongoing work

- **Stringers in addition to spars, skin and ribs are modeled**
- The number of elements of Finite Element Model is 2401 while it is 688 for the conventional model
- The skin weight of the legacy model is multiplied in consideration of the effective cross-sectional area described above.



▲ Structure model
All ribs are equally arranged and the stringers are parallel to the rear spar.



- **New model is slightly lighter than legacy model**
- **Weight of stringers has a large effect**
- **More accurate by modeling stringers**

We will optimize layout of ribs and stringers with this new model.