Quantum algorithms for structural analysis

Presenting Author: Krisztian BENYO
Co-Authors: Antoine MALLET, Marianne SOUAIBY

Capgemini Engineering Research and Development France, Paris, France

krisztian.benyo@capgemini.com

The conception, development, and production of current airplanes is the result of decades of multidisciplinary investigation and countless improvements. From a shape and structure optimization point of view, the granularity of the problem and the extensive number of backend numerical and structural computations push even the highest performing classical machines to their limits [2]. To address this emerging issue, quantum technology has been identified as a potential candidate to bring about solutions [5].

Given the current technological state of quantum computing, the most viable route for considering such a complex and potentially high-dimensional problem is by means of hybrid algorithms [1]. Our work aims to utilise specifically such methods for finding the optimal design of the wings of an airplane.

Our wingbox optimization process can be summarized in the following 5 steps:

1. Model definition and data preparation: discretization of the wingbox model, description of the physical model of the current wingbox design, identification of the physical parameter space
2. Structural analysis of a given design: it comes down to solving the linear system of static equilibrium, a process that we implemented in a quantum computer via a novel VQE reinforced Harrow-Hassidim-Lloyd (HHL) algorithm [3]
3. Classification of the given design based on the structural integrity criteria
4. Exploring the parameter space by means of a trained quantum-enhanced support vector machine (QSVM) [6] to identify structurally sound designs
5. Searching for the minimal weight among successful designs

As of today, hybrid algorithms are relatively underrepresented in the scientific literature. Our preliminary investigations and performance analysis on the implementation of the two key quantum algorithms (HHL and QSVM) have already highlighted some key factors. An a priori eigenvalue analysis (by means of a Variational Quantum Eigensolver, VQE) allows for a close to optimal parametrization of the Quantum Phase Estimation necessary for the HHL algorithm [4], thus improving considerably its performance. It has been observed on multiple data structures that a certain degree of entanglement in the quantum circuit is positively beneficial to the training performance of a QSVM.

References

[1] Endo et. al. JPS Journal, 90 (2021)
[2] França-Garcia-Patron, Nature Physics, 17 (2021) 1221-1227.
[3] Harrow-Hassidim-Lloyd, Phys. Rev. Lett. 103 (2009)
[4] Lee et. al. Nature Scientific Reports, 9 (2019)
[5] Luckow et. al. Digitale Welt, 5 (2021), 38-45
[6] Vojtech et. al. Nature, 567 (2019), 209-212

Figures

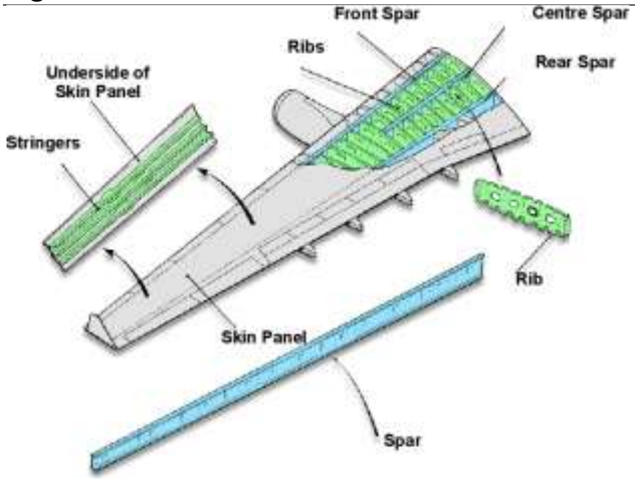

Figure 1: Illustration of problem complexity in designing the wingbox of a commercial aircraft