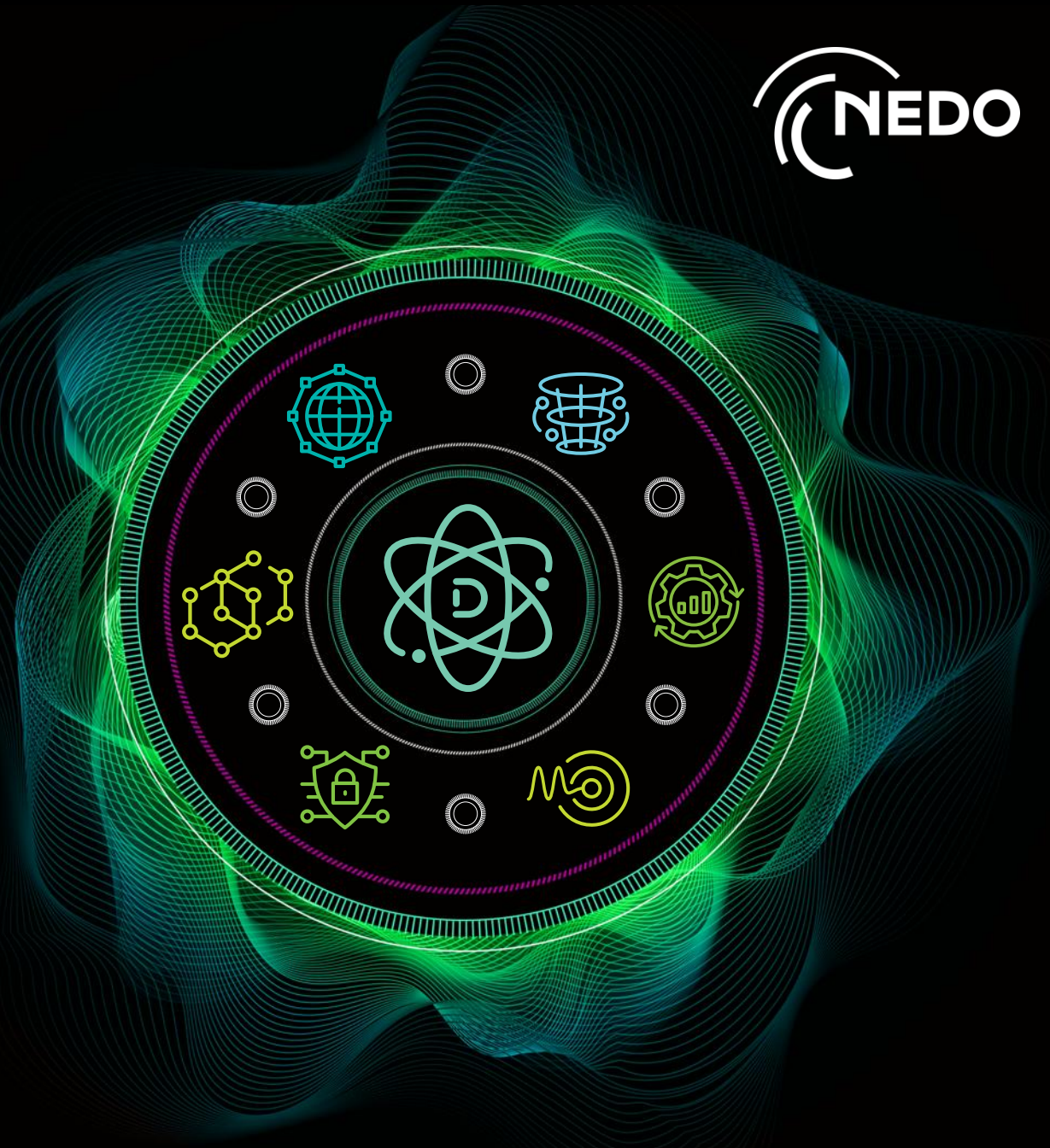
Quantum Computing Use Cases

# Optimization of aerodynamic characteristics in aircraft design

Airbus



New Energy and Industrial Technology Development Organization (NEDO)

# Airbus: Optimization of aerodynamic characteristics in aircraft design [2020/11] 1/3

Concept

| | |
|---|---|
| Industry | Discrete Manufacturing |
| Process | R & D and product design |
| Method | Simulation |
| Category | Gate* |

## Background

- The shape and design of the entire airframe of an aircraft are important factors in airframe design because they affect energy efficiency.
- At present, **CFD**, *1, and **are utilized to determine an airframe shape with high efficiency**, and **aerodynamic characteristics evaluation to analyze the air flow around the airframe and elucidate the forces exerted on the airframe** are being conducted
  - ✓ Aircraft is considered to be a factor of global warming because it emits a large amount of carbon dioxide. Therefore, the aircraft industry is required to optimize airframe design and aircraft operation.

## Issues and motivation to be solved

- **A supercomputer is used to model the air flow around the airframe and evaluate the aerodynamic characteristics, but the processing time is long and it is difficult to improve the accuracy.**
- With the aim of utilizing quantum computers that can perform large-scale and high-speed calculations in aircraft design, Airbus held the **Quantum Computing Challenge** *2 and **NISQ** in 2019 to compete on tasks to improve aircraft design efficiency.
- In the Challenge, Origin Quantum, a Chinese quantum computer HW vendor, was selected as a finalist for the evaluation of aerodynamic characteristics using quantum computers.
- **Origin Quantum ran an aerodynamic evaluation model on a quantum computer to verify the possibility of fast computation**

*1: CFD is a numerical analysis and simulation method that observes the flow by solving equations related to the motion of a fluid (Euler equations, Navier-Stokes equations, or their derivatives) on a computer using the numerical solution of partial differential equations, etc.

*2: In the Quantum Computing Challenge, in addition to evaluating aerodynamic characteristics, five tasks were set, including optimization of aircraft cargo placement and wing structure, and finalists were selected for joint research with Airbus.

Reference: Airbus"Meet the Airbus Quantum Computing Challenge's five finalist teams" (https://www.airbus.com/en/newsroom/news/2020-10-meet-the-airbus-quantum-computing-challenges-five-finalist-teams)
*Gate（gate-based）: A computing approach in which operations are applied sequentially to qubits to perform calculations. Similar in concept to logic circuits in classical computers, it can address a wide range of problems.

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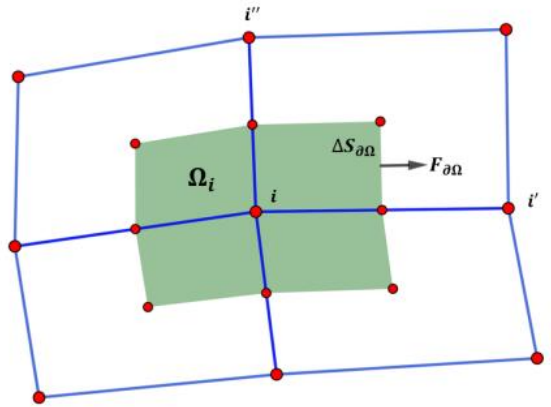
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## Problem setting as a quantum computer

- The finite volume method is used to approximately solve engineering problems that are mathematically **difficult to solve exactly** such as aerodynamic characterization of the airframe.
  - ✓ The finite volume method **divides the solution domain into a finite number of control volumes** and **replaces continuous partial differential equations with discontinuous linear algebraic equations**
  - ✓ However, **finer control volumes require more computing resources, making it difficult to perform calculations on a classical computer (supercomputer).**
- **Development of a quantum CFD solver that can quickly process input and output data of classical computers using quantum random access memory (QRAM *1)**
  - ✓ This method, based on the finite volume method and quantum computers, optimizes the CFD time integration process in aircraft design and can exponentially accelerate the computation time.
- Since the Airbus competition is designed to explore development techniques using NISQ quantum computers, **it seems to be taking advantage of gated quantum computers.**

*1: QRAM is equivalent to RAM in a classical computer, and when given a memory address, it outputs a quantum state from the corresponding quantum bit string.




Control volume with solution area gridded

(F is the flux value at the interface used in the discretization equation, S is the area, and Ω is the volume.)

References: Airbus"Meet the Airbus Quantum Computing Challenge's five finalist teams" (https://www.airbus.com/en/newsroom/news/2020-10-meet-the-airbus-quantum-computing-challenges-five-finalist-teams), arXiv"Quantum Finite Volume Method for Computational Fluid Dynamics with Classical Input and Output" (https://show.originqc.com.cn/prod/website/ResumeDelivery/2102.03557.pdf), CYBERNET (https://www.cybernet.co.jp/ansys/learning/glossary/yuugentaisekihou/)
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# Airbus: Optimization of aerodynamic characteristics in aircraft design [2020/11] 3/3

Concept

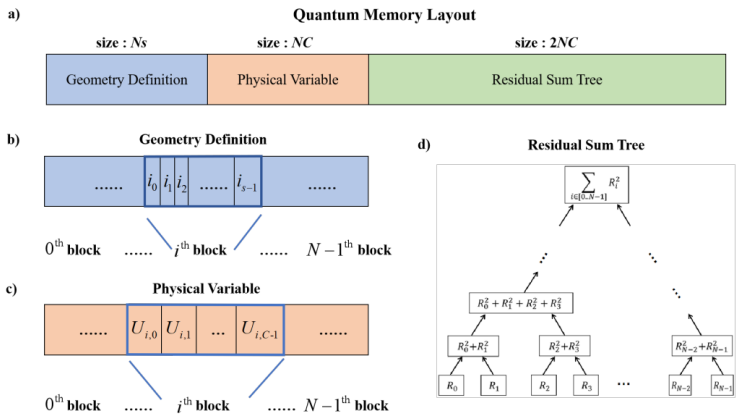
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## Expected business benefits

- **Each iteration step in the integration calculation is reduced from O (N) in classical computer to O (LogN), and the total calculation time by QCFD (CFD using quantum computer) is accelerated exponentially compared with classical computer.**
- **The quantum acceleration by QCFD is limited to the case where the problem size (N) is large enough.**
  - ✓ The conditions under which the fast performance of the QCFD algorithm is guaranteed depend on N and the computational accuracy (ε), and the conditions under which quantum acceleration is satisfied are N>>1/ε2.
- **We have created a large-scale computational fluid dynamics model for aerodynamic characterization of the fuselage shape, which is difficult to do with classical computers, and have increased the feasibility of using quantum computers to simulate energy-efficient fuselage designs.**
  - ✓ However, it is necessary to clarify the calculation accuracy and the convergence of calculation, which are the remaining issues of the above algorithm.



Airbus Airframe Design




Structure of QRAM (3 blocks)
Geometry Definition: preserving problem inputs
Physical Variable: keeps the physical variable of the discretized equation
Residual Sum Tree: Residual vector tree structure

Reference: Emerging Technology Review"Airbus uses quantum computers to design aircraft, NISQ starts developing quantum algorithms" (https://etechnologyreview.com/2019/11/08/%E3%82%A8%E3%82%A2%E3%83%90%E3%82%B9%E3%81%AF%E9%87%8F%E5%AD%90%E3%82%B3%E3%83%B3%E3%83%94%E3%83%A5%E3%83%BC%E3%82%BF%E3%81%A7%E8%88%AA%E7%A9%BA%E6%A9%9F%E3%82%92%E3%83%87%E3%82%B6%E3%82%A4%E3%83%B3/)

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**More use cases are available on our website. We invite you to explore them.**
**https://www.quantum-computing-use-cases.nedo.go.jp/english/**

More Use Cases

**New Energy and Industrial Technology Development Organization (NEDO)**
**AI and Robotics Department (e-mail: quantum_ai@ml.nedo.go.jp)**

**This collection of use cases was obtained as a result of the work commissioned by the New Energy and Industrial Technology Development Organization (NEDO) "Cyber-Physical Development Business of Quantum/Classical Hybrid Technology/Study of Use Case of Quantum Technology" and the "Post-5G Information and Communications System Infrastructure Reinforcement R & D Project (Quantum Industrialization)/Comprehensive Study for Promoting the Industrialization of Quantum Computers".**