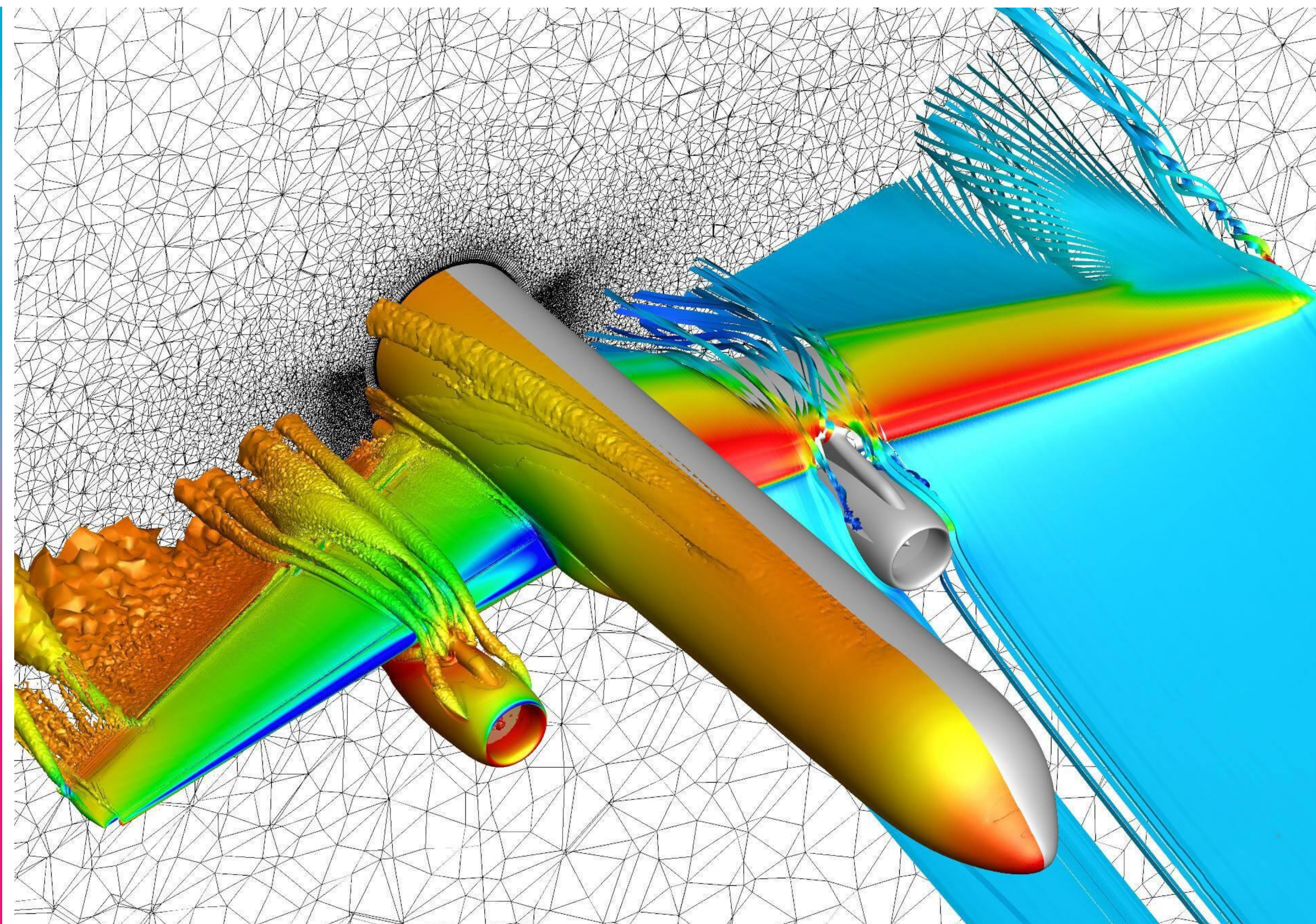


ToQuaFlics

Towards Quantum Fluid Dynamics

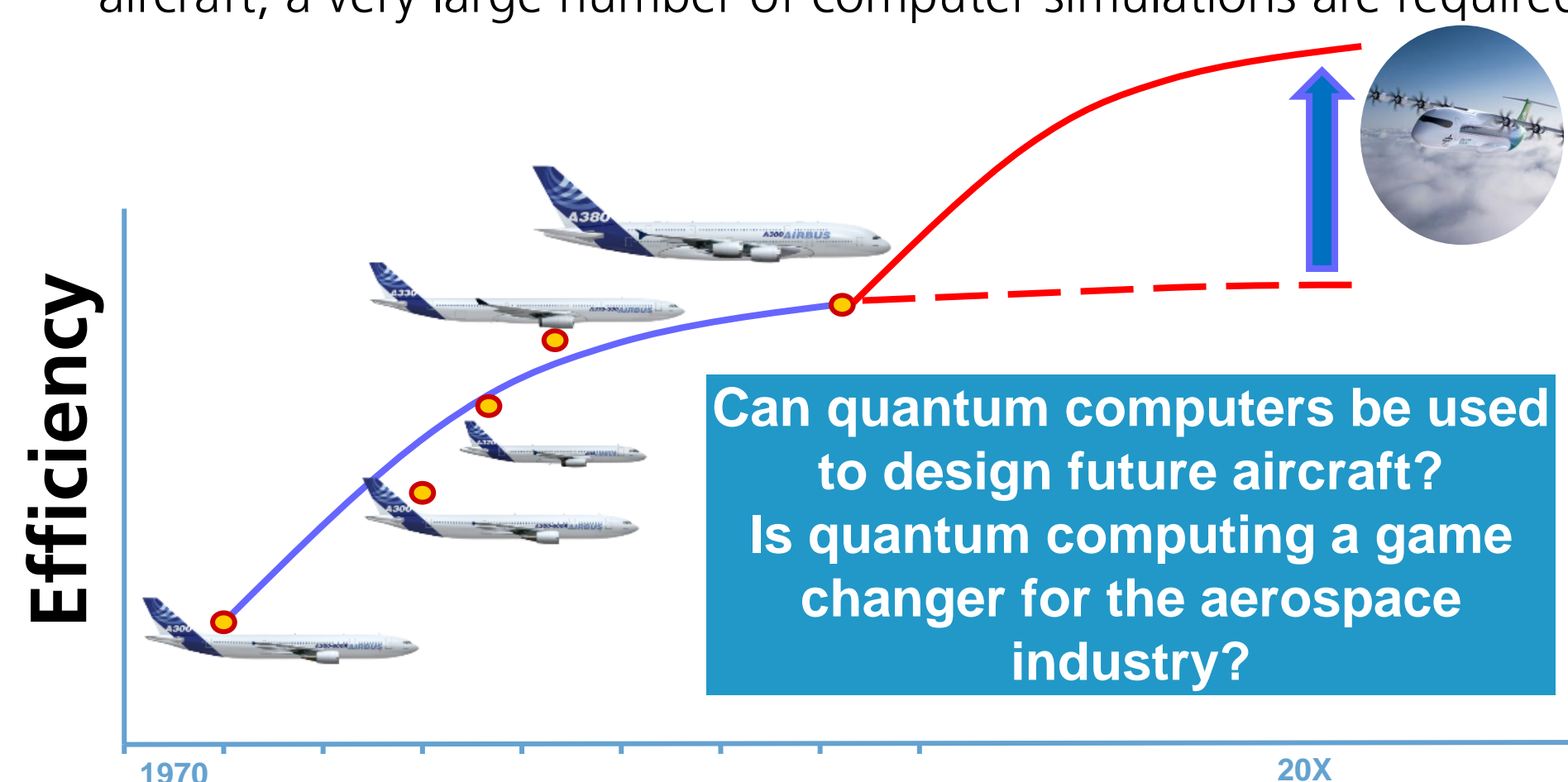
The simulation of aerodynamics during take-off, landing or cruise plays a fundamental role in the development of new environmentally friendly aircraft. In order to accelerate the introduction of innovative technologies a very large number of highly accurate simulations must be performed. These simulations are very time-consuming and expensive, even on today's supercomputers. It is the goal of this project to investigate in which way quantum computers can significantly accelerate such simulations to solve relevant problems in aerodynamics.

- Aviation industry
- Computational Fluid Dynamics
- Aeroacoustics



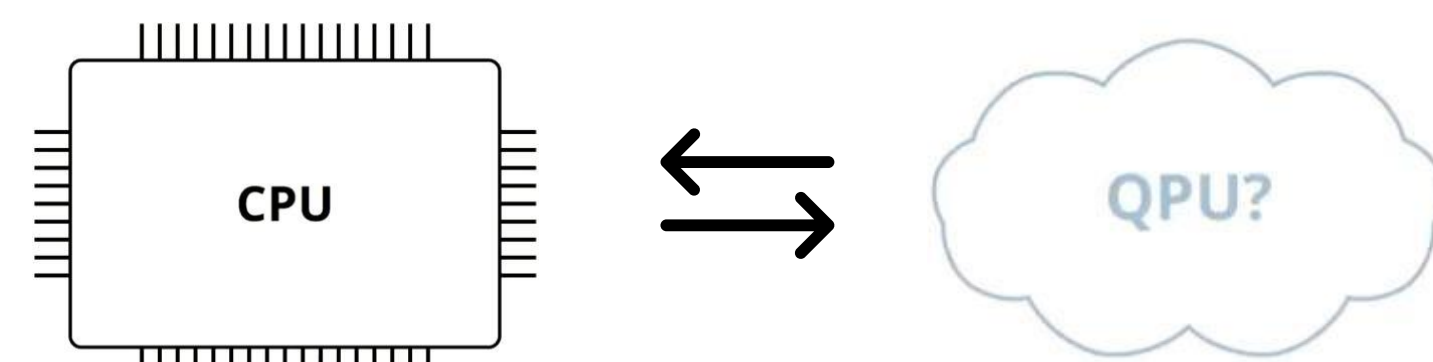
Motivation

The aviation industry faces the challenge of having to make significant contributions to achieving the ambitious global climate and environmental targets. To achieve this, the aircraft of the future will have to consume significantly less fuel than today's, use more environmentally friendly engines and also be quieter, especially during take-off and landing. In order to be able to assess these properties as early as possible in the development of a new aircraft, a very large number of computer simulations are required.



Approach

In order to use quantum computers to the benefit of applications in aerodynamics and fluid mechanics, one of the most important challenges is to identify specific problems in this field or to reformulate them in such a way that the potential of a quantum computer can be fully exploited.



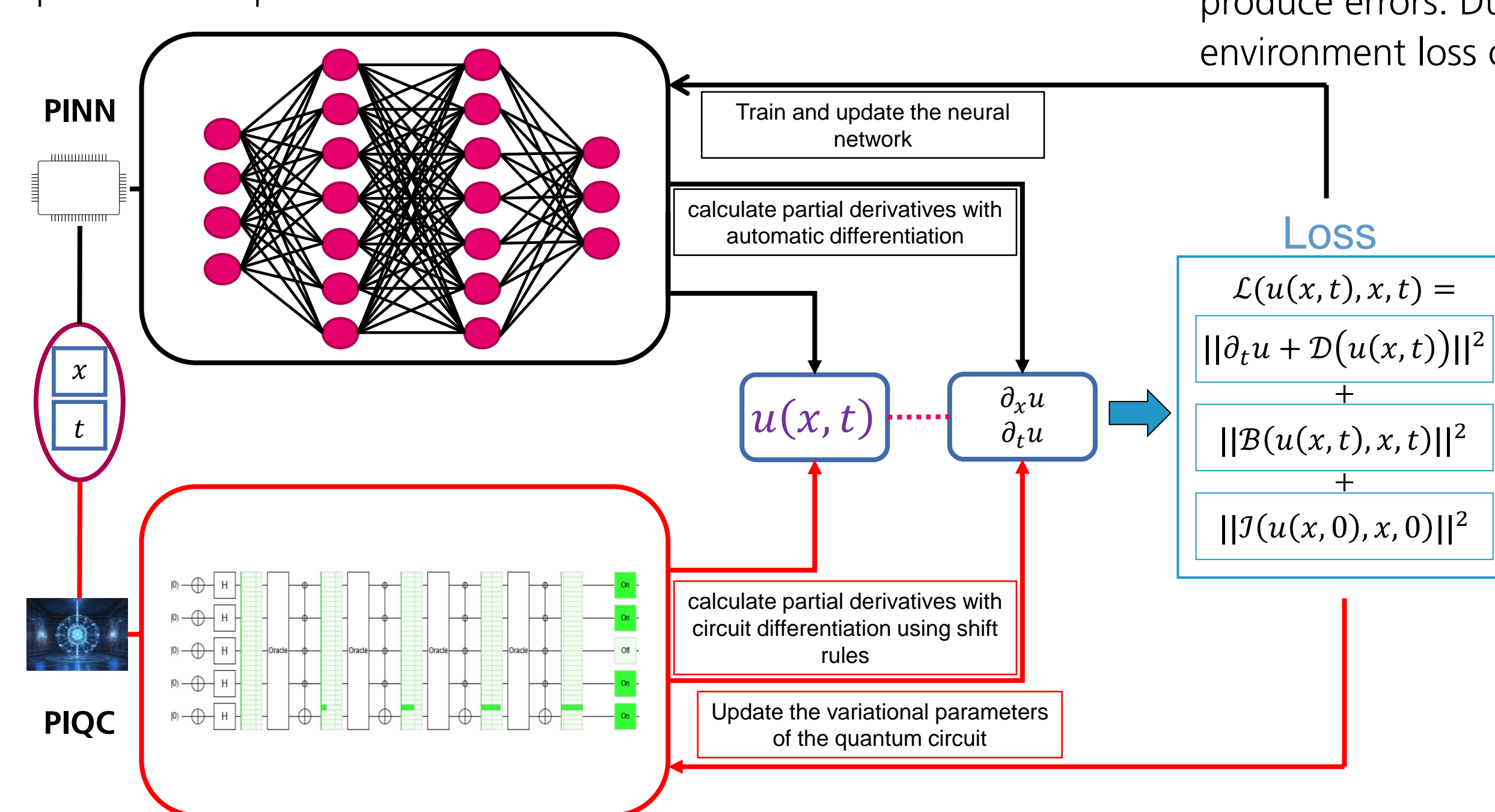
The following topics are addressed in the project to investigate the potential of quantum computers:

- Physics-Informed Neural Networks (PINNs) and Physics-Informed Quantum Circuits (PIQCs)
- Quantum-inspired algorithms
- Quantum Lattice-Boltzmann method
- Hybrid algorithms, e.g. Quantum Newton method
- Use of real and simulated quantum hardware
- Investigation of error propagation in quantum algorithms

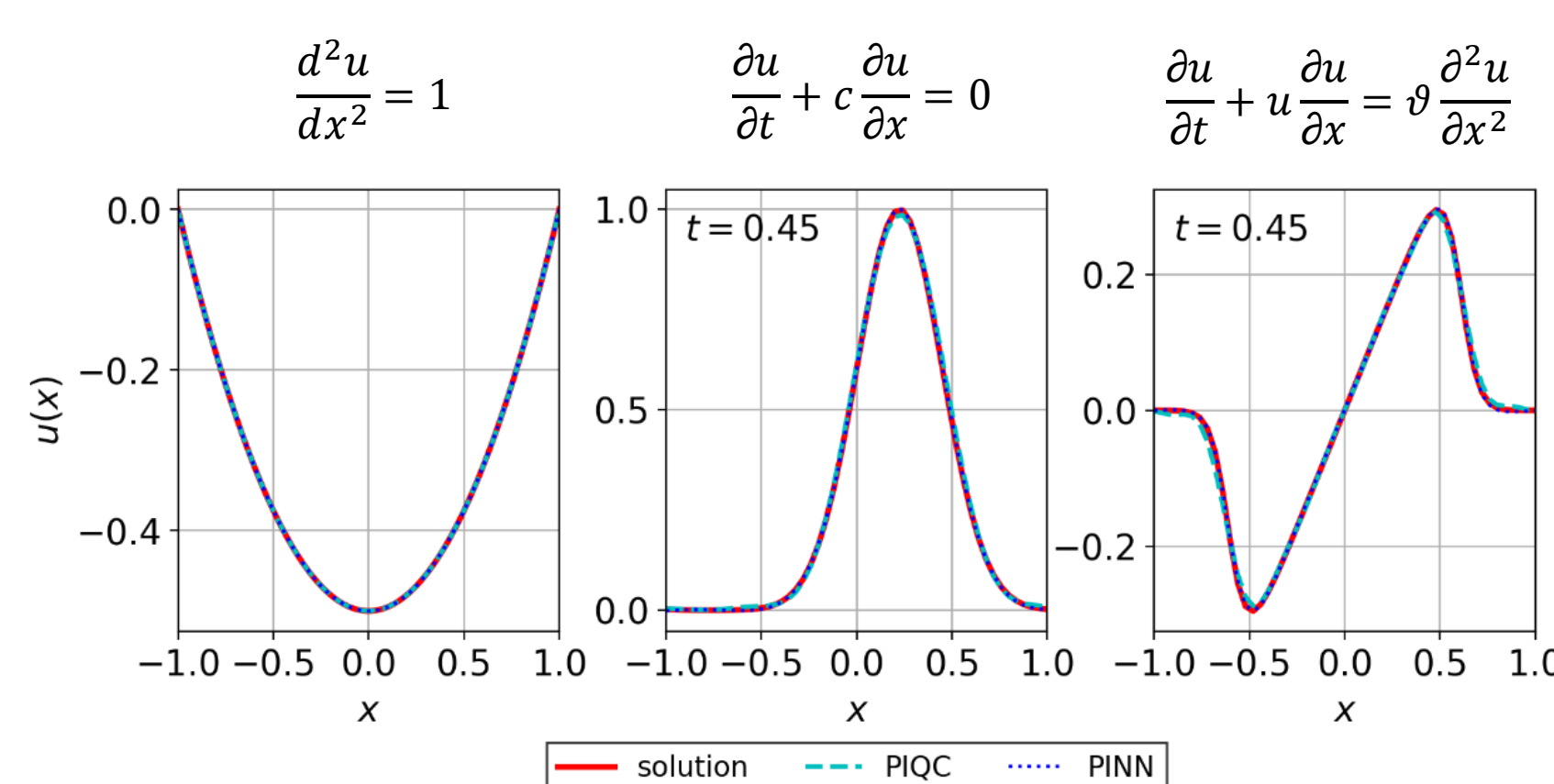
PINNs and PIQCs

Physics-Informed Neural Networks are emerging as an alternative method to solve partial differential equations based on machine learning ideas. A neural network is trained such that it satisfies a loss function corresponding to the set of governing equations.

The neural network can be replaced directly by a quantum circuit. This means that a significant part of the algorithm is executed on a quantum computer. This approach represents an interesting way of combining machine learning methods with the possibilities of quantum computers.

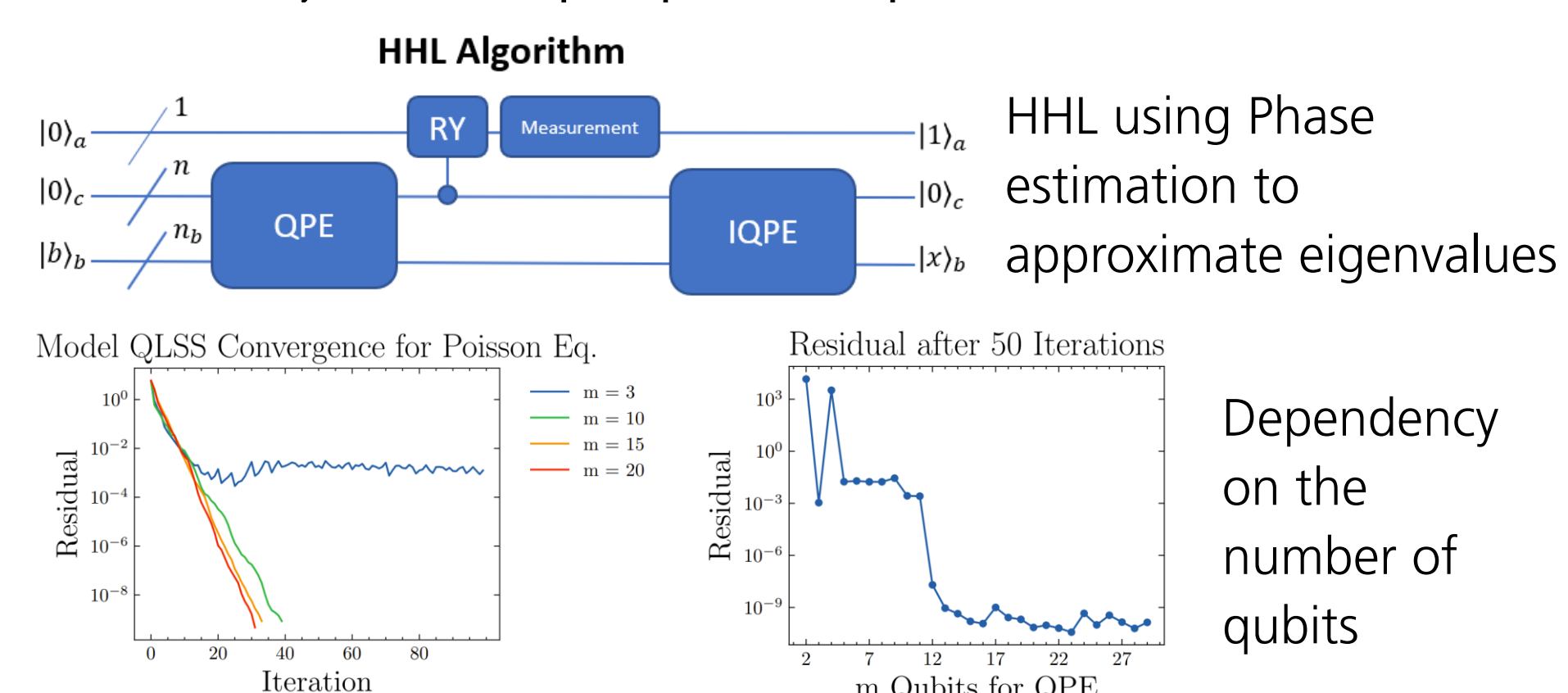


A comparison of PINNs and PIQCs for solving simplified differential equations shows that comparable results can be obtained. The aim is to transfer these approaches to more complex models of fluid dynamics.



Quantum Newton method

In CFD applications, linearization results in large-scale linear systems of equations that can take up to 90% of the computing time in an algorithm. Significant acceleration can therefore be achieved by outsourcing precisely this component to a QC. The **Harrow-Hassidim-Lloyd (HHL) algorithm**, which is based on the **Quantum Fourier transform** and **Quantum Phase Estimation**, offers the prospect of exponential acceleration.



Quantum Lattice-Boltzmann method

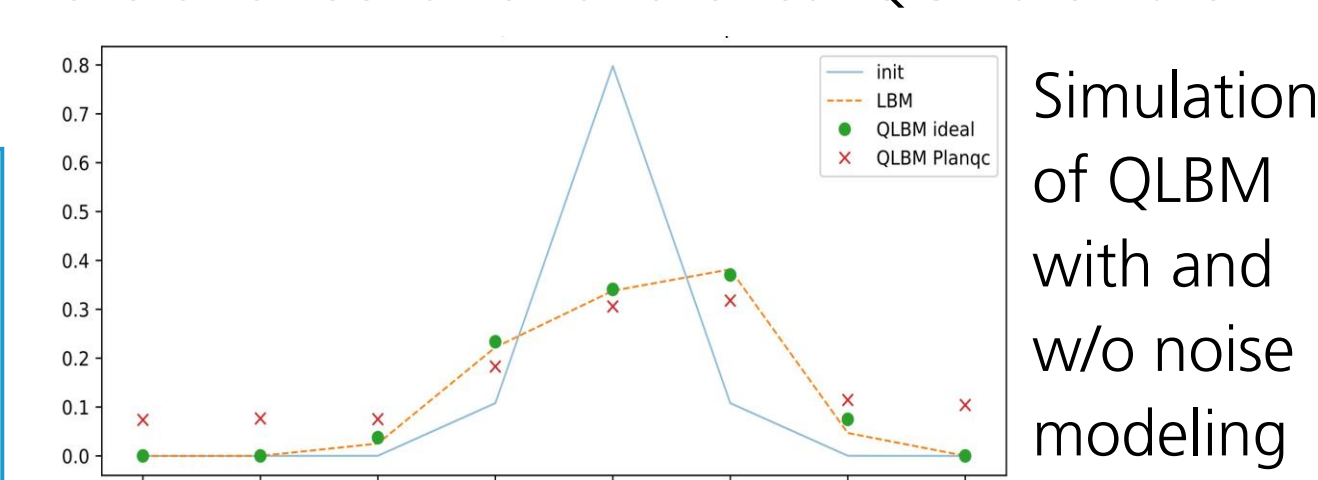
Compressible flows can be modeled by the Boltzmann equation

$$\frac{\partial f}{\partial t} + \xi \cdot \frac{\partial f}{\partial x} = \Omega(f)$$

with the Boltzmann collision operator $\Omega(f)$. Due to the statistical nature of these equations, it seems quite possible that they can be implemented more efficiently on a quantum computer than, for example, the Navier-Stokes equations. This approach may also enable more efficient approaches to aeroacoustics in order to significantly reduce noise from future aircraft.

Error propagation and its simulation

Existing quantum hardware is noisy, since gates and measurements produce errors. Due to interaction of the qubits with the environment loss of entanglement and decoherence is observed. A digital twin developed by planqc simulates the error behavior of the real QC hardware.

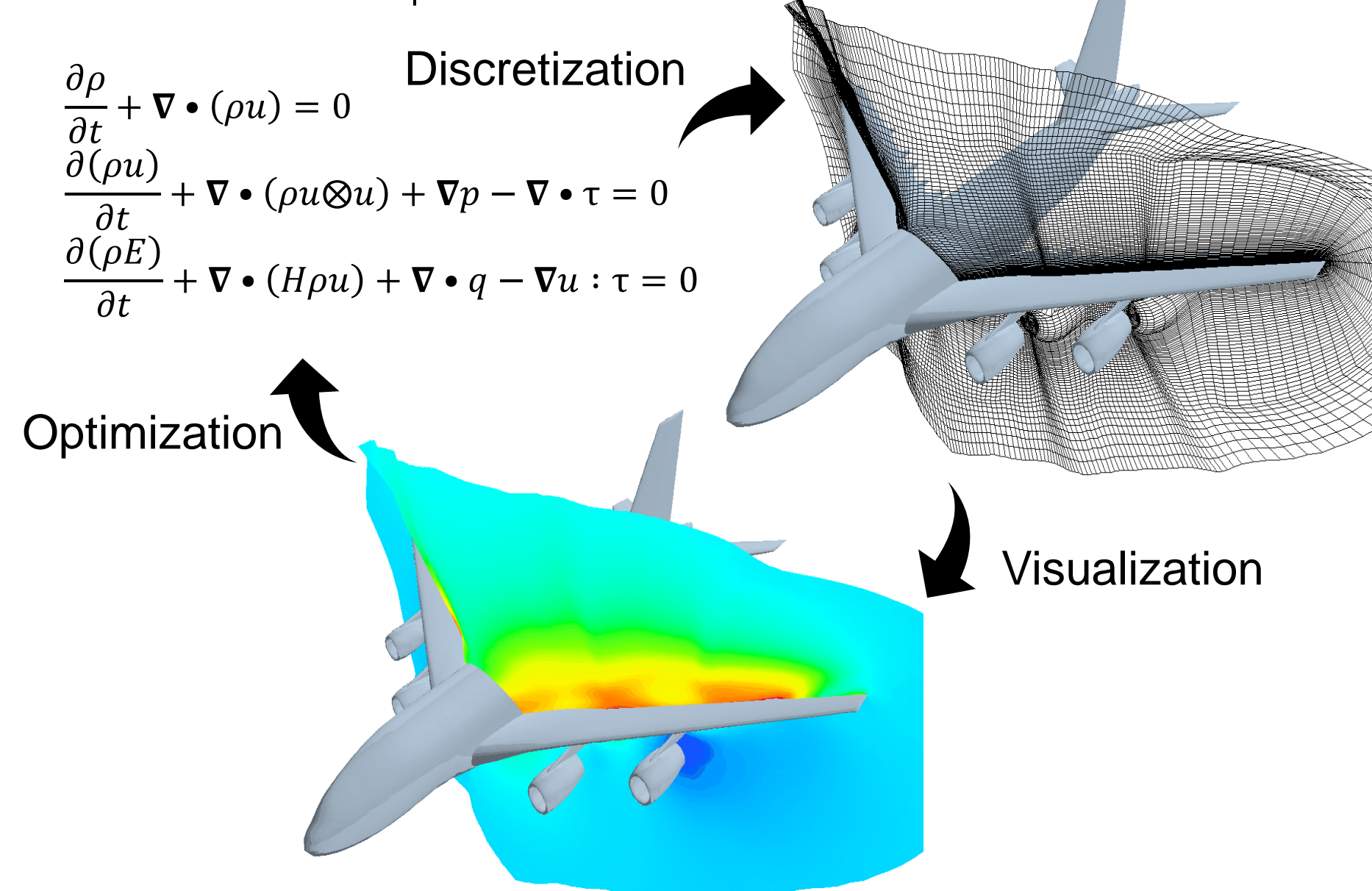


Goals of the project

- Perspective how to exploit potential of quantum computers for applications in aerodynamics and aeroacoustics
- Classification if certain equations are better suited than others
- Identification which parts of a solution algorithm can gain from bringing them on a quantum computer
- Perspective of implementing iterative time stepping on quantum computers
- Estimate how many Qubits are required to solve relevant test cases representing industrial problems
- Investigation of error propagation in Quantum algorithms to formulate requirements on accuracy on hardware
- Implementation of interfaces for data transportation

Computational Fluid Dynamics (CFD)

CFD is based on discretizing and solving the governing equations of fluid mechanics, the Navier-Stokes equations, on computational grids. By evaluating and solving these equations, important knowledge about the properties of aircraft is gained and enables the aircraft to be optimized.



Quantum Computing: A game changer for CFD?

The number of simulations and their costs to calculate the entire flight envelope of an aircraft are almost impossible to manage, even with today's high-performance computers. Accelerating these simulations, thanks to the use of quantum computers (QC), promises to close this gap in the future. For example, with n Qubits a vector of size 2^n can be encoded on a quantum computer. For a Direct Numerical Simulation (DNS) about $N = \text{Re}^{9/4}$ degrees of freedom are required, where the Reynolds number for an aircraft can be on the order of tens of millions. Hence, a quantum computer with only around 50 Qubits can be used to model flows for a Reynolds number of around 10^7 . This illustrates the potential of quantum computers in this field of applications.

As a consequence, expected characteristics of an aircraft that would only become evident later in flight testing can be uncovered in advance through a large number of scale-resolving simulations and remedied during the design process.



Artist's impression of aircraft simulation on quantum computer

You can find more information about the project on our website



A project of



Contractor



Contact

Stefan Langer (DLR)
Stefan Görtz (DLR)
Martin Kiffner (planqc)
Nikolaus Adams (TUM)
Thomas Schumacher (engys)
Moriz Scharpenberg (Airbus)



Get in touch. We enable quantum!

