The Promise and Limits of Quantum Fluid Dynamics

Can quantum computers simulate fluid flow? This project tested a quantum algorithm to model these complex dynamics, demonstrating promising breakthroughs for small-scale systems while uncovering critical bottlenecks for future up-scaling.

Designing aerodynamic aircraft, optimizing wind turbines, and predicting extreme weather events all rely on Computational Fluid Dynamics (CFD). However, as engineers demand higher resolutions for greater accuracy, even the world's most advanced supercomputers struggle to process the massive volume of calculations required in a reasonable time-frame. This project explored whether quantum computing could eventually offer a solution to this computational bottleneck.

The primary goal of this degree project was to investigate whether today's early-stage quantum algorithms could effectively manage the non-linear nature fundamental to fluid dynamics.

The findings highlighted both the theoretical capacities and the physical limitations of current quantum hardware. By mathematically translating a fluid simulation into a quantum state, three different systems of 2, 4, and 8 qubits (the quantum equivalent of bits) were tested. The 2 and 4 qubit versions were successfully implemented to accurately predict fluid motion and diffusion. Through a process called amplitude encoding, the distinct physical data points (4 and 16 nodes) were mapped directly onto the overlapping probability amplitudes of these two versions, demonstrating the exceptional data-compression capabilities of quantum technology.

However, attempting to double the system to 8 qubits (256 nodes) revealed significant scaling challenges. The quantum signals were severely disrupted by inherent hardware noise. Furthermore, the mathematical landscape used to guide the algorithm became exponentially flatter, stalling the optimization process and preventing the computer from converging successfully. Additionally, translating the quantum output back into the non-linear velocity domain was highly sensitive to error, with minor quantum inaccuracies creating massive, artificial spikes in the final data.

These results prove that while quantum computing holds promising potential for fluid engineering, classical methods cannot simply be ported over to quantum hardware. Achieving realistic quantum fluid dynamics will require the development of noise-resilient frameworks and the deployment of heavily error-corrected quantum processors.

To perform these experiments, a well-known fluid model (Burgers' equation) was mathematically transformed into a linear heat equation. The system was then solved using the "Variational Quantum Linear Solver", an algorithm that iteratively tunes its parameters to approximate the fluid's state without directly calculating the massive classical matrices.

The future of quantum fluid dynamics is promising, but this research shows that there is still a long way towards a deployable large-scale application of this technology in fluid dynamics.