QUANTUM COMPUTING FOR OPTIMIZATION APPLICATIONS

The Future in Focus

Honeywell

WHY HONEYWELL?

Commercial quantum computers did not exist a decade ago. However, in the last few years the conversation about quantum computers has shifted from *if* to *when*, with the "*when*" defined as the point at which quantum computers can perform calculations that today's computers cannot. Within Honeywell, a division called Honeywell Quantum Solutions (HQS) has been quietly developing the highest-performing quantum computers available. Recent commercial releases of the System Model H0 and System Model H1 have set industry records for performance. Honeywell's trapped-ion technology has inherent advantages, including higher fidelity gates and longer coherence times, which means that even at this early stage, H1 can run more complex calculations and produce more accurate results than other quantum computing systems.

For more than 100 years, Honeywell has provided technology-based solutions to meet customers' most challenging needs. Now, Honeywell is looking to the future and laying the foundation to incorporate our own quantum technology into solutions and product offerings for our customers. Combining our innovations in quantum capabilities with our deep domain expertise in our Aerospace, Building Technologies, Performance Materials and Technologies, and Safety and Productivity solutions, we are poised to be a leader for the next generation of quantum-enabled solutions.

Why Honeywell?

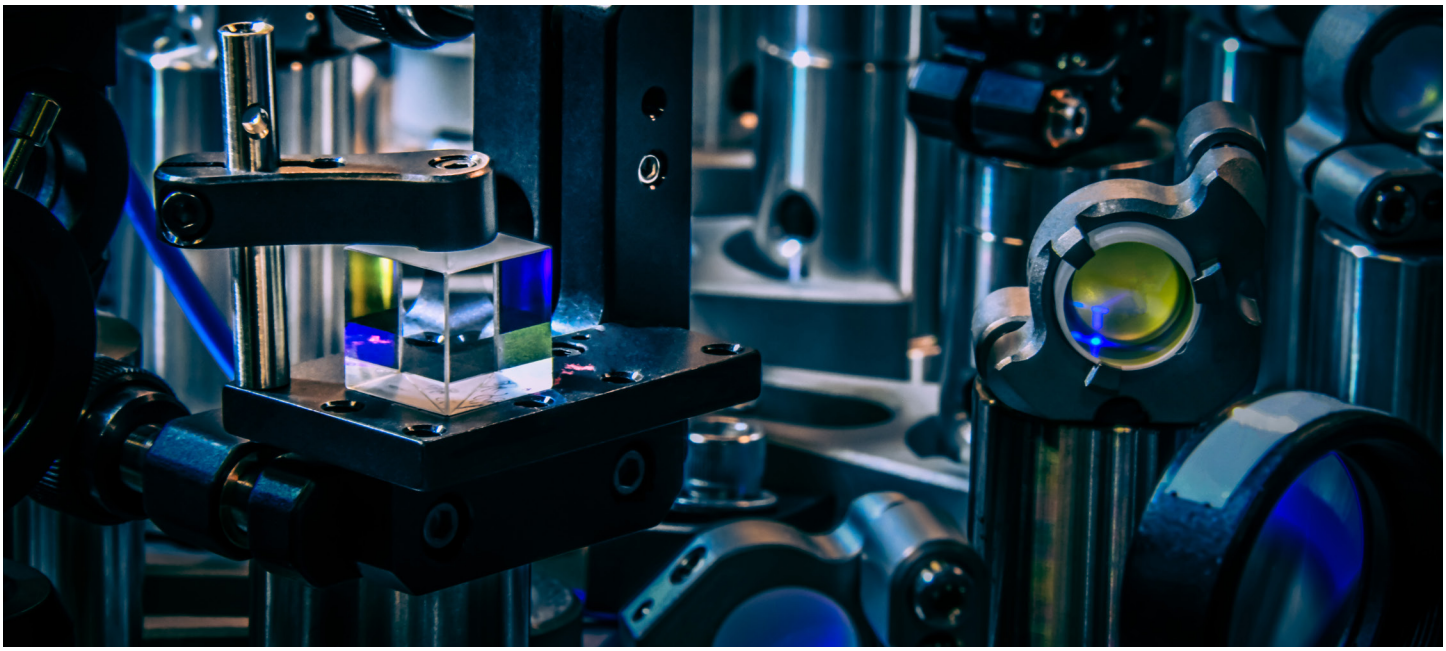
The only industrial with our own quantum technology, Honeywell is positioned to be a full-solution provider to bring quantum solutions to our customers.

Why quantum?

It's not *if*, but *when* quantum computing will revolutionize computing, bringing tremendous business value.

When?

Quantum computers are still in the early stage of solving quantum problems, but algorithms, operating systems, and quantum hardware are progressing at record speed. Honeywell is engaging now with our customers to set the stage for quantum value.



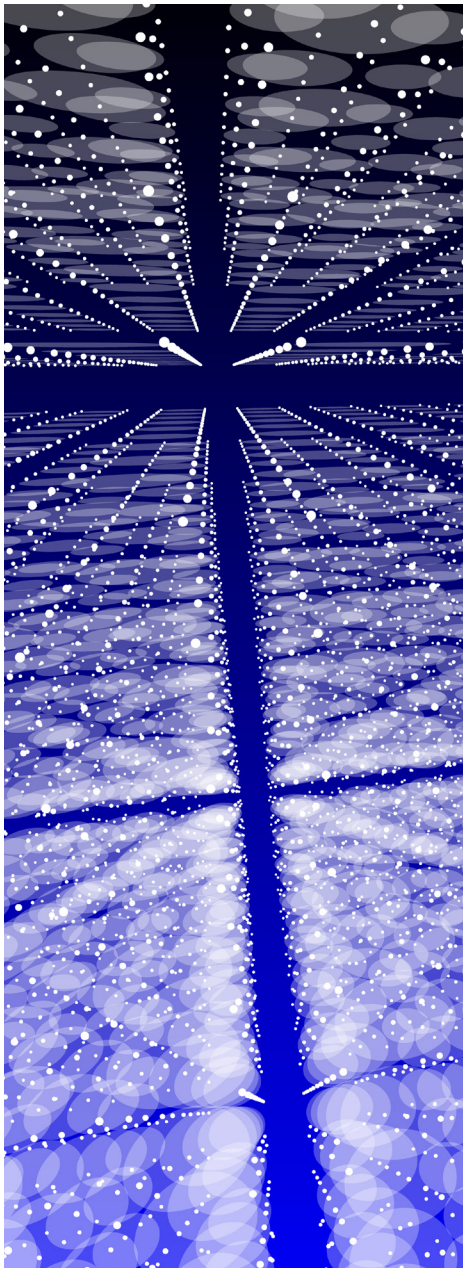
WHY QUANTUM? WHY NOW?

For more than 100 years, Honeywell has provided technology-based solutions to meet customers' most challenging needs. Now, Honeywell is looking to the future and laying the foundation to incorporate our own quantum technology into solutions and product offerings for our customers.

While there are still many unknowns, there is now little doubt that quantum computing will change the landscape of what problems are possible to solve. Quantum computers differ from conventional computers by leveraging the properties of quantum mechanics to store and process information. This key difference allows quantum computers to represent an exponentially larger state space than conventional computers.

Qubits are the fundamental building block of a quantum computer. Rather than representing 0s or 1s, qubits represent superposition states between 0 and 1. While the power of a classical computer can be approximately doubled by doubling its number of transistors, *a quantum computer's power doubles with each additional qubit*.

We are currently living through an important period of time for today's quantum computers. While the computational outcome of today's current quantum computers can largely be simulated by classical computers, there are a couple of things to understand. First, today's quantum computers are capable of generating *actual* quantum outcomes while classical computers are not. As a result, we are continuing to learn how these incredible systems really work, which will better set the industry up for near-term progress. Second, because we can classically simulate the computational outcomes of today's quantum computers, we have a mechanism to ensure these systems generate the outcomes we expect. That allows us to collectively build trust that as quantum computers scale, we will generate the correct computational outcomes. Harnessing the power and gaining the understanding of a quantum computer to bring business advantage is a journey that will take several years; users tempted to take a "wait-and-see" strategy could find themselves years behind the competition. With the advent of quantum computers and projected growth over the next decade, it is expected that early adopters will achieve breakthroughs that enable new business models. Hence, it is advantageous for organizations to act now and begin understanding quantum computing's possible use cases and begin putting a plan in place.

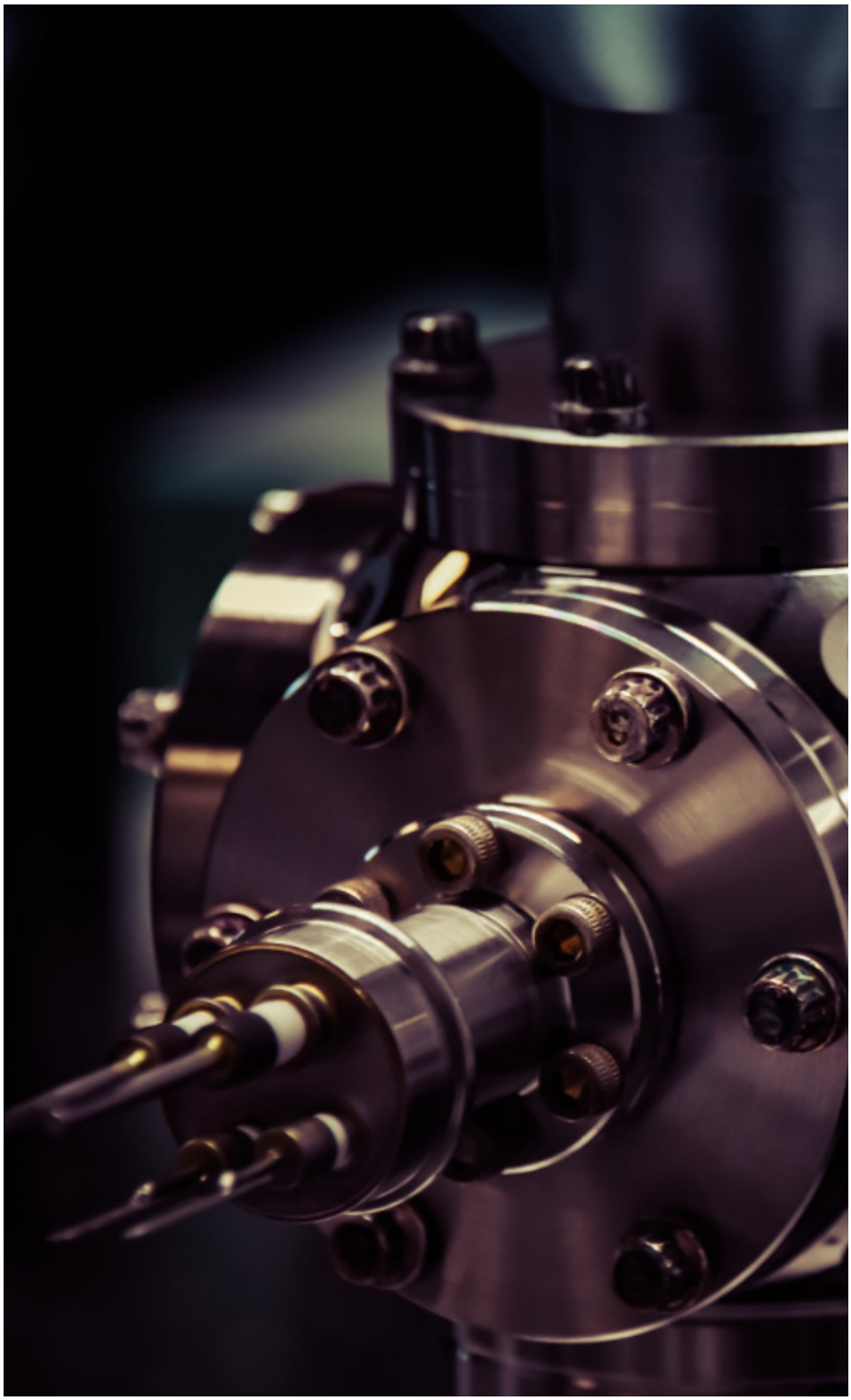


HONEYWELL'S BEST-KEPT SECRET

While quantum computing holds promise for a variety of applications, near-term devices will be limited both in the number of qubits and the complexity of circuit that can be executed. Increasing qubits while reducing errors is essential to realizing quantum advantage.

Honeywell Quantum Solutions (HQS) has been developing quantum technology for over a decade and surprised the world in 2019 with announcement of our quantum roadmap and first commercial offering of the System Model H0. HQS uses trapped ions as qubits, and these devices have repeatedly set the record for quantum volume, a benchmark developed by IBM to quantify the computational power of a quantum computer. [1]

As the only industrial company developing a quantum computer, Honeywell is positioned to lead in the development and application of quantum computers to solve industrial-sized problems, performing internal study and analysis for approaches to solving industrial-sized problems as machine capabilities grow. This includes the exploration of tying classical and quantum approaches together to leverage quantum capabilities as they come online before the arrival of full fault-tolerant quantum computers.



HONEYWELL'S KEY APPLICATIONS FOR QUANTUM COMPUTING

How does Honeywell plan to utilize our internal game-changing capability to solve real customer problems? For starters, we've set our focus on two areas: large-scale optimization and chemical simulations.

OPTIMIZATION APPLICATIONS

Fueled by the digital transformation, analytical insights of connectivity, and cloud-based data management applications in Honeywell Forge, the opportunity to optimize end-to-end logistics and simplify operations is a recurring customer theme across all four of the Honeywell business verticals. Quantum computers have unique capabilities that lend themselves to possibly solving these complex types of optimization problems more efficiently: using the quantum property of *superposition* to represent all possible solutions while the quantum property of *interference* enables the identification of low-cost, high-value solutions. Classical methods for these problems tend to have either exponentially growing compute-times or sub-optimal performance. Quantum optimization algorithms such as the quantum approximate optimization algorithms (QAOA) hold the promise of finding the answers which improve on the sub-optimal solutions without incurring the cost of the exponentially longer compute times.

"Good, classical heuristics exist that solve variants of the vehicle routing problem within 2–3% of optimal, but even an additional improvement of 0.5% could translate to millions of dollars per year in savings..."

– MEGAN KOHAGEN,
HONEYWELL DATA SCIENTIST,
MATHEMATICIAN AND OPTIMIZATION THEORIST

SUPPLY CHAIN AND ROUTING OPTIMIZATION

Many common optimization problems seek to route assets in a network with minimum cost while fulfilling operational constraints. Good, classical heuristics exist that solve variants of many of these problems within 2–3% of optimal, but even an improvement of 0.5% could translate to millions of dollars per year in savings, thus the search continues for ever-improving methods to minimize operations cost. With increasing numbers of locations, products, and demand, comes increased complexity. The ability to do rapid optimization of product supply and delivery becomes increasingly difficult.

Exact classical optimization techniques will find the optimal solution to these larger problems—if given enough time and computational resources. Consider the well-known Traveling Salesman Problem (TSP), a single-vehicle routing problem in which a salesperson seeks to visit a set of cities by traveling the minimum distance possible. Problems with up to a few thousand cities can be easily solved on a laptop. One research group specialized in the TSP found the optimal answer to a 25k-city problem, but this took 10 months to solve; a later version of the problem with 49k cities took 1.5 years to solve.[2] These were academic exercises meant to push the limits of computing and what is known about exact classical approaches. Real problems involve multiple assets and constraints making industrial problems even more difficult.

Near-real-time optimization has challenges; companies must choose balancing performance and business constraint.

Near-term quantum devices will be limited in both scale and error rate levels. A natural way to map the TSP on a quantum computer means that as many qubits are required as there are binary variables. If a variable exists for each city-pair, it *optimistically* takes $n \times (n-1)/2$ variables to represent the problem, each of which map to 1 qubit. Many representations explored thus far on quantum computers require n^2 qubits. Therefore, to model the TSP with 10 cities directly on the quantum computer optimistically takes 45 qubits. More difficult problems require many more qubits as additional factors come into play. While a 10-city problem is nowhere near the limits of classical computers today for these problems, the possibility of utilizing quantum computers to solve these hard problems and bring near-term value has pushed Honeywell to begin exploring small-scale problems to discover the quantum algorithms and insights to eventually solve these problems more effectively. Academic and industry groups have undertaken the study of multi-scale classical-quantum algorithms, or hybrid computing (where hard subproblems are sent to the quantum computer), as well as quantum-inspired classical algorithms for solving complex optimization problems.[3] Given the rate of development in both the hardware and algorithms, we believe value creation in routing optimization applications is less than five years away and can be accelerated by concentrated efforts in development of multi-scale classical-quantum (hybrid) approaches and more efficient quantum algorithms.

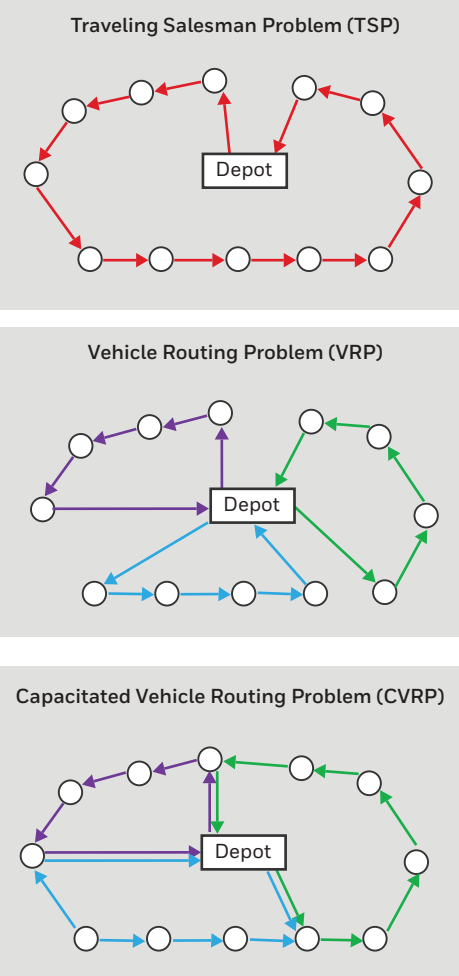


Figure 1: Example classical routing problems to which QAOA can be applied

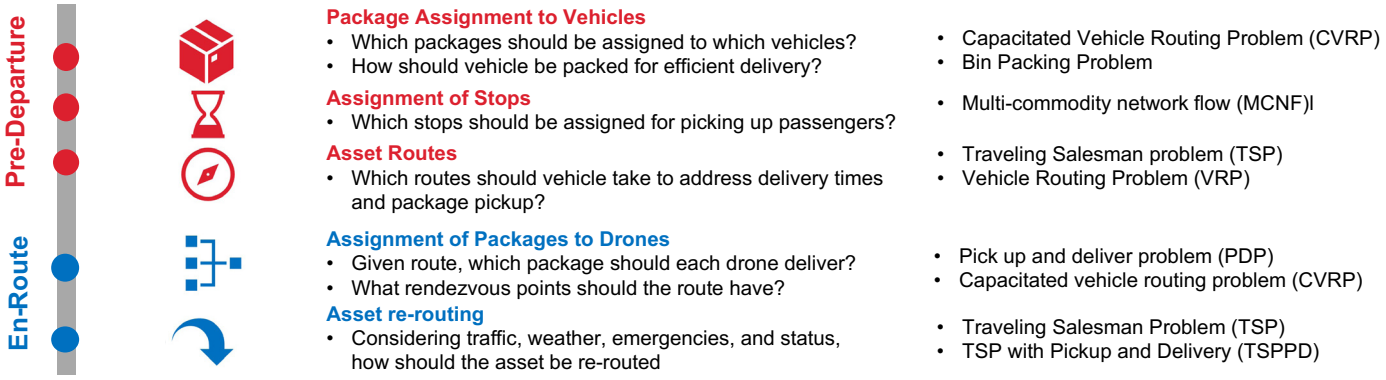


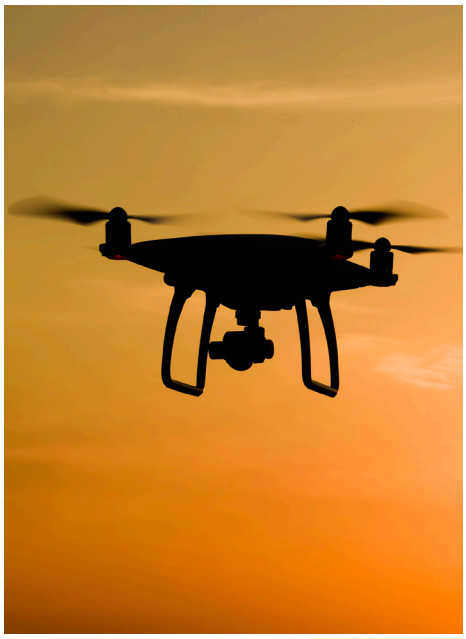
Figure 2: End-to-end Route Optimization

BUILDING QUANTUM OPTIMIZATION INTO EMERGING APPLICATIONS

ROUTE OPTIMIZATION FOR URBAN AIR MOBILITY (UAM), UNMANNED AIR VEHICLES (UAV), AND URBAN TRAFFIC MANAGEMENT (UTM)

Honeywell is preparing for the time when UAM is the preferred mode of travel for point-to-point urban destinations. UAV/UAM applications will include the need to send a vehicle to multiple destinations to complete its mission before returning to a common starting point, such as a warehouse, vertiport, or moving ground vehicle. Energy management is critical for electric UAM and UAVs, requiring optimizing both the cargo weight throughout the route and the point-to-point distance traveled.

These vehicle routing optimization problems are computationally difficult and are even more challenging when many destinations and UAVs/UAMs are considered. One such approach to address these routing problems in the context of mission planning is to utilize quantum computing. While the ability to use a quantum computer to solve dynamic, real-time problems will be limited, cloud-based-hybrid classical, cloud-based hybrid classic and quantum algorithms may be used pre-flight for route planning.



MOLECULAR SIMULATION

Modelling novel chemicals and materials can unlock new insights in chemistry, materials science, and healthcare. Currently, researchers must choose between slow, expensive methods that can accurately model small molecules or faster, less accurate methods that can be used on molecules at scale for materials and biology. Quantum computing opens the possibility to study chemicals and materials that are not well described by the faster methods, but are too large to consider with the slower, more accurate methods. Quantum-enabled machine learning will enable rapid screening of thousands of molecules to accurately predict their physicochemical behavior and interactions with materials or biological macromolecules. Modeling these materials could lead to more efficient chemical catalysts, new types of pharmaceuticals, and new exotic materials, such as novel magnetics.

Honeywell Quantum Solutions' low error rate and high connectivity enable high-quality simulations and our mid-circuit measurement capability allows simulation of large systems on a compact number of qubits.[4] These techniques can also simulate the dynamics of quantum materials giving insight into real-world, non-equilibrium properties that cannot be measured in the lowest energy state alone.

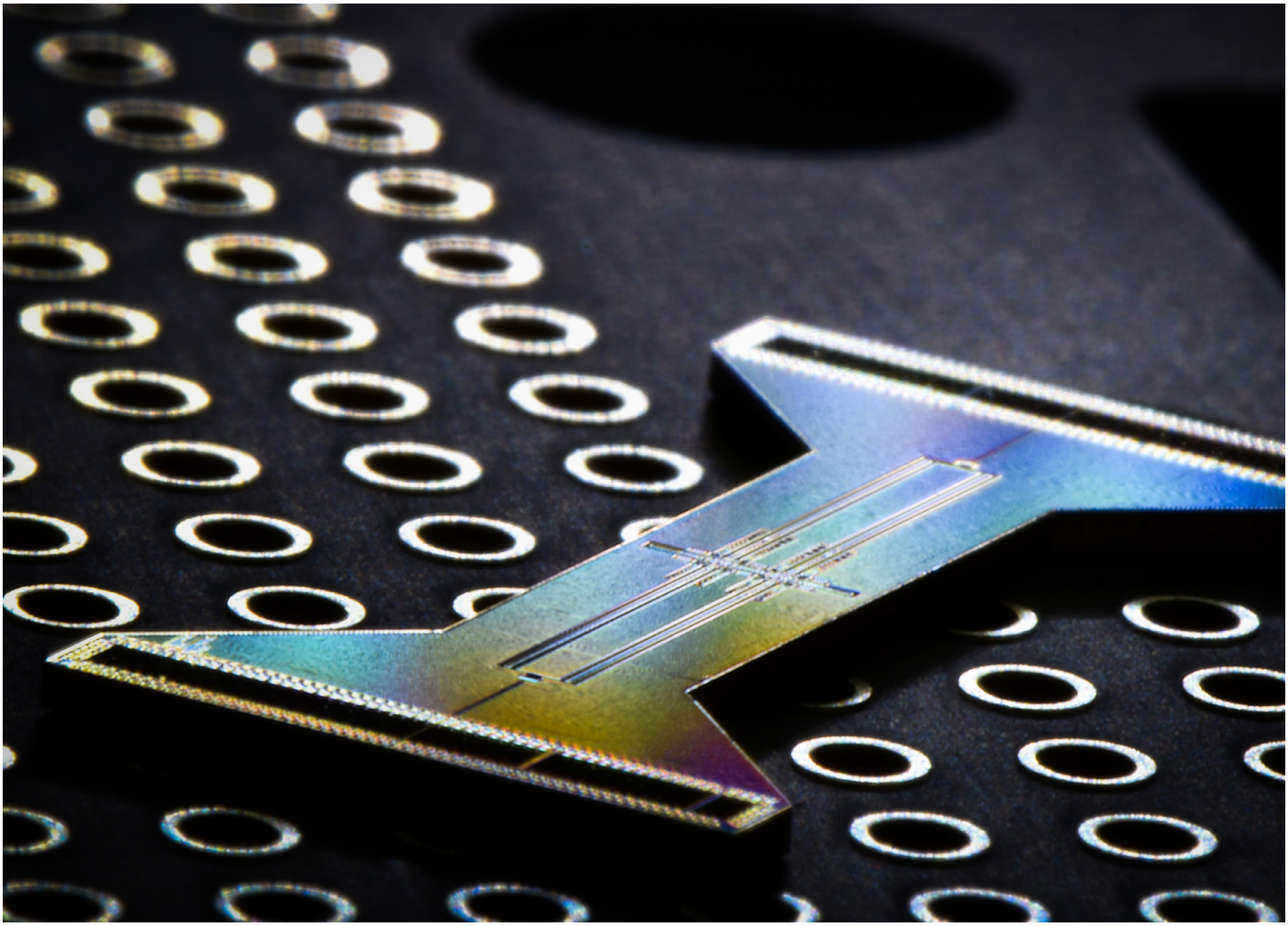
BEYOND ROUTE OPTIMIZATION AND MOLECULAR SIMULATIONS

Honeywell also is looking at other applications for applying our quantum solutions that could bring value on a longer horizon.

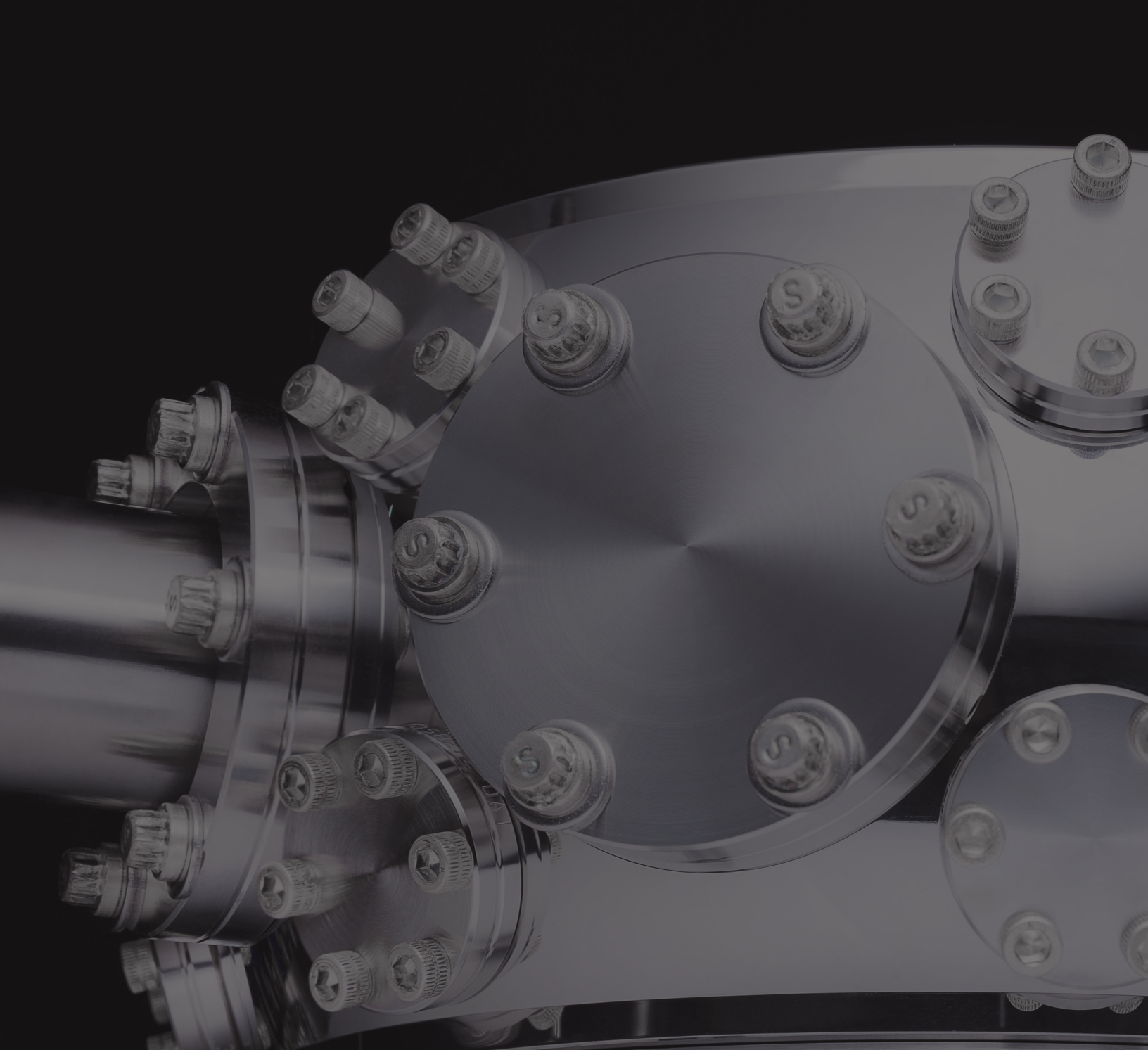
- Quantum-enabled artificial intelligence to gather new insight for our enterprise management software solutions.
- Quantum-enabled multi-physics simulations to perform simulations and calculations on computational fluid dynamics for better engine design and optimized heating/cooling solutions.

THE FUTURE

Quantum computing promises to revolutionize the world of computing and break through limitations with today's technology. While quantum computing will solve small-scale problems to start, capabilities are developing quickly and will change the way business is done in every industry. The future doesn't make itself; the future is what we make it. At Honeywell, we're doubly involved in making the future of quantum: developing in-house, state-of-the-art quantum computing and arming our internal business units with the techniques and abilities to drive quantum-enabled solutions to solve the challenges of the future.



[1]Validating quantum computers using randomized model circuits, Quantum Milestone: How We Quadrupled Performance
[2]UK Pub Crawl with 24,727 cities , UK Pub Crawl of 49,687 cities
[3]Quantum Computing based Hybrid Solution Strategies for Large-scale Discrete-Continuous Optimization Problems, Quantum Impact: Optimization Solutions (Microsoft)
[4]Holographic quantum algorithms for simulating correlated spin systems



For more information

With any new technology, there is a lot of hype and misinformation. Honeywell stands by to collaborate with our customers in seeking the best quantum-enabled solutions for your needs.

To speak with someone about how Honeywell can use quantum-enabled solutions for your business, contact: Quantum.Solutions@honeywell.com

You can read more about Honeywell's quantum computer at: https://www.honeywell.com/us/en/company/quantum

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THE FUTURE IS WHAT WE MAKE IT

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