A Review of Quantum Computing for Space Exploration and Mars Colonization

Philip J. Andriola[1]
University of Florida, Gainesville, Florida, 32611, United States of America

Quantum computing holds the potential to revolutionize the space and rocket industries, offering groundbreaking advancements that will reshape space exploration and help achieve the long-term goal of Mars colonization. Quantum computing can overcome some of the biggest hurdles in modern space exploration, such as resource allocation, astronaut health, sustainable rocketry, life support systems, and dependable autonomous operations. Despite its promise, quantum computing faces significant obstacles, such as scalability, error correction ability, and the inherent sensitivity of quantum systems. This paper reviews the fundamental components of quantum computers and investigates its implications in multiple aspects of space exploration and Mars colonization. Numerous studies are examined, focusing on quantum computing for objectives such as trajectory optimization, environmental simulations for habitats on Mars, molecular simulations for pharmaceuticals in space, and adaptive machine learning and AI for autonomous operations. Past research suggests that while quantum computing does have promising implications for the future, its practical implementation and application remains a distant goal.

I. Nomenclature

H	=	Total energy of the system (Hamiltonian)
i	=	the imaginary unit.
m	=	mass of a particle
p	=	Momentum operator, related to the derivative concerning position
V	=	Potential energy as a function of position xxx
T	=	Kinetic energy operator of a particle
$\hbar$	=	Reduced Planck's constant
x	=	Position coordinate
V	=	the potential energy operator
QRL	=	Quantum-reinforced landing
$\psi(x)$	=	wave function of the system in space
E	=	energy eigenvalue of the system
α	=	alpha
β	=	beta
$\frac{\partial}{\partial t}$	=	represents the time derivative

II. Introduction

In a generational wave of AI and machine learning, quantum computing has emerged as a revolutionary concept that has implications for many facets of human life. Quantum computing can transform classical computing power to perform various complex tasks. Quantum-enhanced systems have become an increasingly important component of the future of the space industry. Multiple tech companies like D-Wave, Google, Microsoft, and IonQ are working to develop quantum technologies tailored explicitly for the space industry [5]. Quantum computers leverage the unique

[1] Student Member, Department of Mechanical and Aerospace Engineering, Open Topic: 1st Year.

principles of quantum mechanics to provide superior computational power, enabling them to perform complex optimization and simulation tasks with high accuracy and speed. Quantum computing could solve some of the leading obstacles in modern space exploration, including resource optimization, trajectory planning, rocket efficiency, unknown environment details, autonomous vehicle decision-making, and overwhelming data from space missions.

One of the most significant applications for quantum computing in the modern-day space industry is its potential role in Mars colonization. Human survival could depend on our ability to become an interplanetary species, as it would help mitigate deaths by potential extinction-level threats like asteroid impacts, global pandemics, and the depletion of resources. By diversifying our habitats, we can ensure the continuity of the human race. However, Mars colonization comes with numerous challenges, such as excessive costs, limited resources for survival, habitation issues, communication delays, rocketry limitations, and the dangers of radiation and atmospheric conditions.

Quantum computing provides the ability to overcome these challenges and makes the long-term and seemingly farfetched goal of colonizing Mars suddenly feasible. Quantum algorithms could optimize spacecraft navigation while considering fuel consumption and price [12]. Quantum technologies could also improve the designs of life support systems and help create efficient production systems for water, energy, and food on Mars [22]. We can better understand Mars's conditions and dynamics through quantum-enhanced simulations, AI, and sensor capabilities.

This paper investigates the theoretical applications of quantum computing based on past findings. The results suggest that, whereas quantum computing holds great promise for the future of space exploration, its current limitations—such as scalability, error correction, and vulnerability to environmental factors—render its widespread implementation unfeasible soon.

III. Basics of Quantum Computation

A. Superposition, Entanglement, and Interference

At its core, quantum computing takes advantage of three fundamental principles of quantum mechanics: superposition, entanglement, and interference. Superposition is the property of quantum particles and systems that exist in multiple states simultaneously. This ability to process numerous possibilities simultaneously is a key advantage of quantum processing over classical computational models. It allows them to explore outcomes and solutions in parallel - an ability often called quantum parallelism. Quantum parallelism enables quantum computers to process data faster [5]. Interference is another unique property in which quantum states can act as wave functions, meaning they can be interpreted as amplitudes with crest and troughs that can cancel out the wrong outcomes and amplify the correct ones [2]. Combined with quantum parallelism from superposition, this ability allows a quantum system to provide accurate solutions at rapid speeds [5]. Entanglement enables the state of one quantum particle to be dependent on the state of another, meaning that the two particles are connected throughout space-time [21]. Given this phenomenon, when a quantum state is determined, one could immediately determine the quantum state of its entangled particle. These properties allow quantum processors to perform computations of a higher caliber than classical computing methods.

B. Classical Bits Versus Qubits

Classical computers use bits, a foundational unit of information, to process and convey data. Bits are binary, meaning they can be zero or 1. In classical processing, bits could be combined into complex strings of information used to represent images, text, and math. Each bit exists independently of one another, and computer programs utilize functions like AND, OR, or NOT to create relationships between sequences of bits [10].

On the other hand, Quantum bits (Qubits) are the base unit of information for quantum computers. Because of the unique properties of quantum mechanics, it could be handled in an entirely different way. Due to superposition, a qubit could simultaneously exist as 0 and 1. In quantum computing, qubits could be represented by the following equation:

$$|\psi\rangle=\alpha|0\rangle+\beta|1\rangle \tag{1}$$

α and β are complex numbers determining the probability amplitudes of being measured in the 0 or 1 state. The Ket vector and bra vector manipulate the states of the qubit to determine probabilities [5].

C. Algorithms, Quantum Methods, and Approaches

Shor's and Grover's algorithms are two commonly known algorithms in quantum computing that demonstrate the speed at which quantum computers can solve problems. Shor's algorithm is used for integer factorization of large numbers, a complicated computation for classical computers. Shor's algorithm solves a key problem in number theory and plays a crucial role in security encryption codes. It utilizes quantum Fourier transformations to find the period of a modular exponential function. On the other hand, classical computers have an exponential time complexity, making this task take longer. Grover's algorithm performs a quadratic speedup search through unstructured databases. It uses probability and quantum parallelism to speed up the time to find an item. These two algorithms display the potential for quantum computing and how it compares to classical computing.

When many qubits and interacting particles are incorporated into a system, it is referred to as a many-body system; in this complex system, multiple qubits interact in many ways, including entanglement, which makes it challenging to process its data correctly [2]. To digest this information correctly, quantum computers utilize Hamiltonians and T-gates. Hamiltonians are the total energy of systems operator and can be written for a single particle in one dimension as:

$$\mathrm{H} = \mathrm{T} + \mathrm{V} \tag{2}$$

Furthermore, the general form for a non-relativistic particle in one dimension could be represented as:

$$\mathrm{H} = \frac{p^2}{2m} + \mathrm{V(x)} \tag{3}$$

Additionally, Hamiltonians could be used in Schrodinger's equation to govern the evolution of a quantum, time-dependent system.

$$i\hbar\frac{\partial}{\partial t}\psi(x,t)=H\psi(x,t).$$
$$H\psi(x)=E\psi(x) \tag{4}$$

In this way, Hamiltonians dictate how the system behaves over time and represent the changes in the energy landscape associated with optimization tasks. T-gates are also utilized to handle these complex systems, as they are one-qubit gates that apply a phase shift of $\pi/4$ to the state of a qubit while the other remains unchanged [2]. While T-gates can be helpful in error mitigation, they require precise fault tolerance and error correction protocols that make them challenging to implement.

There are various approaches to using classical versus quantum computing, each with advantages. With proper combination and execution, classical conventions could be applied with quantum enhancements to yield greater processing power. For example, discrete Fourier Transformations are a classical method that could build upon quantum interference patterns to work as Quantum Fourier Transformations (QFT)[2]. Many other approaches highlight how algorithms, data, and mathematical interpretations could be best used in both quantum and classical conventions.

IV. Quantum Computing and Space Mission Design

A. Engine and Fuel Efficiency

Quantum computing could be used throughout various rocketry components, making them more energy efficient. Specifically, quantum engine cycles like Otto and Stirling can exceed classical rocket efficiency. Quantum-enhanced engine systems could exploit coherence and entanglement to intertwine thermodynamic principles with quantum and mechanical systems.

Unlike the quantum Otto engine, which pairs adiabatic compression and expansion with isochoric heating and cooling, the Stirling cycle's isothermal processes enhance heat exchange efficiency. A study found that while Quantum Stirling cycles slightly increased engine efficiency, there was a decoherence, or a loss of quantum information from the system [1].

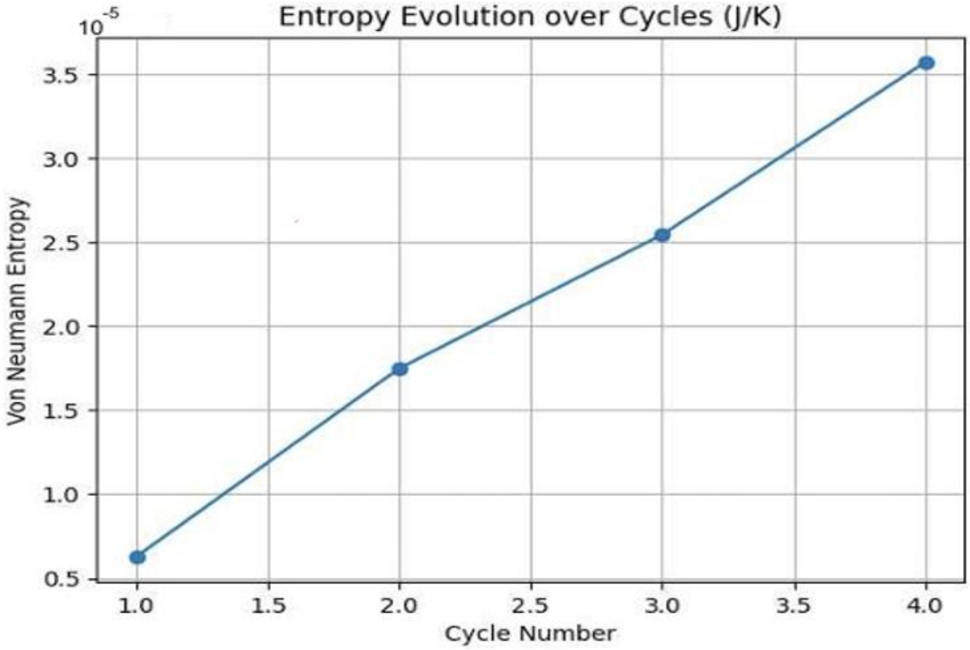

Fig. 1 Variation of system von Neumann entropy throughout the quantum Stirling cycles. Displays how the system becomes a mixture as it loses quantum information [1].

Pinheiro uses an integrated network of sensors for actuators that can adapt to a thermodynamic apparatus's identification and response properties [1]. Additionally, their study considers how their interactions, combined with harnessing entropy-gradient forces, can turn random motion into directed forces aiding an engine's thrust [1]. Quantum-enhanced systems could maximize heat conservation and engine production, yielding greater launch efficiency.

While quantum computing can optimize fuel consumption, it can also help explore potential fuel alternatives. Cyclic ozone is a high-energy, dense molecule that is highly reactive, making it hard to isolate and utilize. In theory, if cyclic ozone were to be used as a fuel source, it would significantly increase the specific impulse of a rocket by nearly 33%, allowing up to one-third more payload for a rocket launch. Quantum computing could utilize this substance by modeling how cyclic ozone would behave in a fullerene encapsulation- a carbon molecule stabilizing the cage [3]. Quantum simulations could simulate cycle ozone in these fullerene cages to discover if such a fuel alternative is feasible. These fuel and engine improvements would significantly improve the efficiency of space missions.

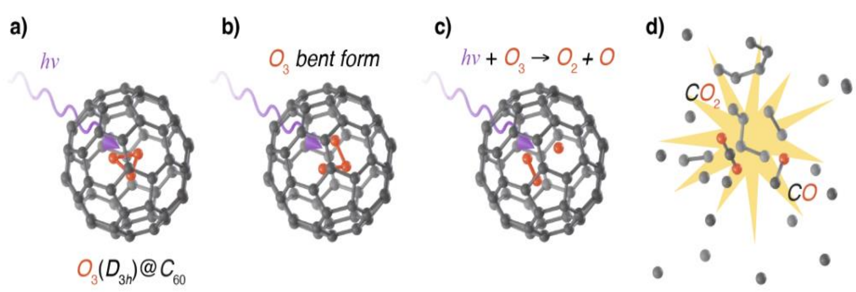

Fig. 2 Proposed fullerene–encapsulated cyclic ozone. (a) Cyclic ozone O3(D3h) in a fullerene matrix as C60; (b) single–photon excitation photoisomerizes O3(D3h) to the bent isomer O3(C2v); (d) combustion reactions create a sustained burn when numerous oxygen equivalents are present.

B. Quantum Reinforced Takeoff and Landing Procedures

There are far more reusable rockets in modern-day rocketry, making it much cheaper to launch missiles and conduct space missions. However, mission costs are still very high, and countless factors must be considered for a space mission. One research paper by Makhanov explores how quantum computing could optimize flight trajectories to achieve net carbon-neutral emissions for jets. They employ a classical Dijkstra's algorithm with quantum enhancements. This program considers flight path optimization in terms of the shortest trip with other ecological and economic considerations [6]. If a similar algorithm could be applied in rocket launches, it could significantly affect the efficiency of missions, optimizing time, money, and resources.

Reusable rockets like SpaceX's Starship or Blue Origin's New Glenn have proven relatively successful in accomplishing one of the biggest challenges in the current space industry. There have been several successful attempts to land rockets back on Earth, but landing them under various conditions on a planet like Mars is an entirely different situation, requiring flexible systems. Kim's research uses quantum-reinforced stabilization techniques so that a rocket could adapt to dynamic conditions like wind while landing. Quantum is advantageous over classical as it has increased efficiency, reduced memory requirements, and is more stable overall. Kim suggests a quantum reinforced landing (QRL) that could assist the vehicle's landing ability and help during other essential parts of the landing procedure, such as the flip maneuver and the backburn [11].

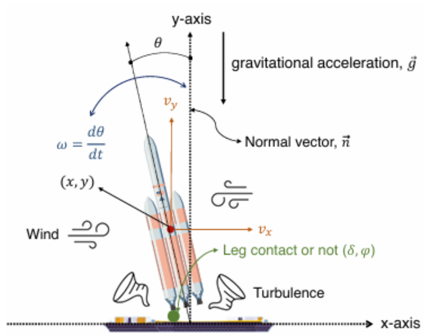

Fig. 3 Description of states in landing procedure [11].

C. Quantum-Enabled Communication Systems

With NASA's increasing push for explorations to new celestial bodies, classical communications may not withstand such long distances. Quantum communication capabilities offer an advantageous alternative. Quantum mechanics in communication involve sending single photons or entangled photon sources to a single photon detector. This enhancement will allow excellent communication abilities unlike classical radio frequencies or optical communication. One leading method in quantum communication is superdense coding, which uses pairs of entangled qubits to transmit information. Similar methods like hybrid states and hyperentanglement utilize quantum mechanics to send more data with fewer resources. One study explores superdense teleportation, which uses remote operations and hyperentangled photons to teleport multiple coherent phases [20]. Their findings demonstrated the potential for leveraging quantum mechanics for deep space communication; however, practical limitations require further research.

Quantum computing provides a new method of providing secure space communication. Quantum key distribution (QKD) is a communication technique used in quantum cryptography that leverages the laws of quantum mechanics to create secure networks. QKD exchanges quantum keys between two parties, and since quantum states are changed based on observation, any attempt to intercept the information will be detected as it will disrupt the system [18]. QKD is superior to classical cryptography in that classical security uses advanced algorithms to prevent intervention. These algorithms are complex math that is hard yet not impossible to solve.

Satellites are an essential part of providing reliable communication. The Satellite Mission Planning Problem (SMPP) is a significant issue that stems from a surge in requests and memory requirements, making it hard for satellites to operate effectively. Makarov discusses a potential solution: using quantum annealing and the Quantum Approximate Optimization Algorithm (QAOA). Quantum annealing utilizes quantum tunnelling to solve complex, combinatorial optimization problems. QAOA is a hybrid variational algorithm that combines gate-based quantum computing with classical parameter optimization. Makarov noticed that the quality of solutions decreased as the situation became more significant and more requests were made [9]. While this paper did show that quantum computing was not yet ready to attack such large tasks, it did display its potential for the future.

D. Quantum in Space Exploration Data Analytics

Quantum computers can interpret data and use machine learning principles to create simulations that will give us a greater understanding of astrophysics and the universe. Classical computers have a difficult time simulating complex astrophysical systems and celestial interactions. These large systems often have complex internal interactions that exceed the capacity of classical computers. However, quantum computers can use entanglement to simulate these interactions. Thus, astrophysicists could gain more perspective on the gravitational interactions in a black hole or the orbital behaviors of celestial bodies [13].

Quantum sensor technology could also give more significant insights into planetary body dynamics, conditions, and measurements. These precise measurements can reveal data about the dynamics of planetary systems and put to test the fundamental laws of nature we currently know [14]. Overall, quantum computers can give precise data and simulate complex interactions in a way that classical computers cannot. Thus, it offers the potential to expand our modern conceptions about space and the universe exponentially.

E. Quantum-Enhanced AI and Machine Learning

AI and machine learning are emerging technologies that have radically changed how the world functions. Despite their recent success, quantum computation power can exponentially increase their functionalities and diversify their applications. AI in autonomous systems like drones and rovers requires extensive computational power. Most vehicles use reservoir computing, a classical computation framework capable of complex calculations. However, quantum reservoir computing (QRC) employs spin networks to optimize performance. Superconducting circuits and coherently coupled oscillators could achieve high accuracy with less memory and energy requirements [15]. These quantum systems allow AI and autonomous vehicles to operate much more efficiently. With these improvements, autonomous cars could be given more significant tasks in space exploration as they require less human intervention and have more longevity. Furthermore, data can overwhelm classical computation in autonomous vehicles for space, causing delayed reaction times. Quantum systems, on the other hand, are dynamic, with algorithms that can adapt and make real-time decision-making. This makes them computationally inexpensive to classical computers as they don’t need to be trained to handle these large datasets promptly [16].

V. Mars Colonization: Quantum Computing for Sustainable Presence

A. Food, Water, and Health

One of the significant challenges in establishing human presence on Mars is the need for life support systems. Establishing quality food, water, and energy sources is crucial to mission success. Planetary exploration has discovered sheets of ice under the Martian surface. Satellite images explored erosion scarps on the surface of Mars that reveal details about the planet’s ice-covered mantle. In situ tests and orbital observations allow researchers to predict the depth and extent of this ice. However, these ice sheets' purity, layering, and thickness remain unknown until potential in situ resource utilization (ISRU) efforts [19]. Quantum-enhanced autonomous vehicles could extract water, while other quantum methods could be used to optimize its distribution in a developing colony properly. Furthermore, quantum sensors could detect other potential water sources on the planet.

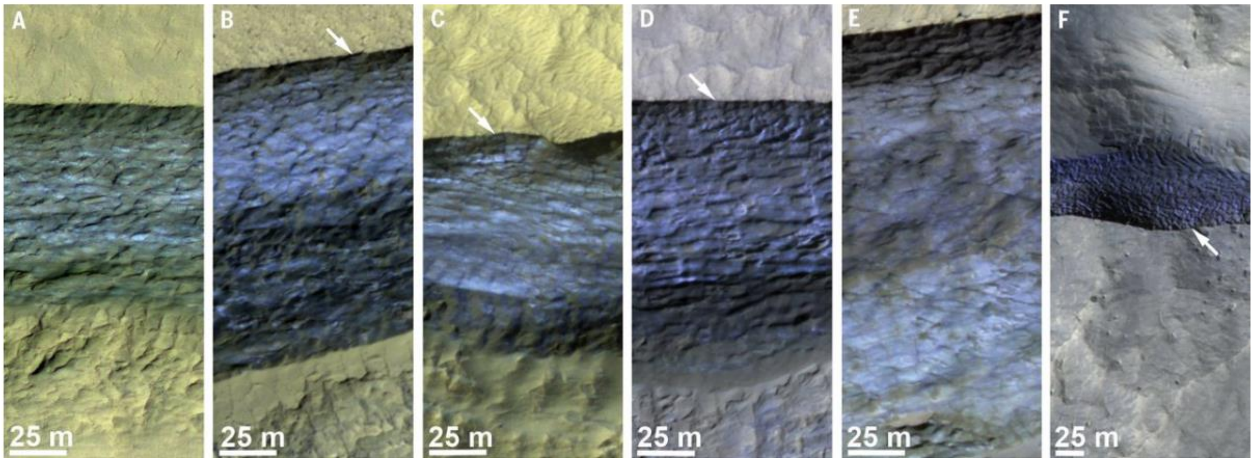

Fig. 4 Enhanced-color transverse sections of icy scarps in late spring/early summer. (A to F) Arrows indicate locations where relatively blue material is particularly close to the surface. Allow predictions for the depth of ice sheets and water [19].

Due to Mars's radiation, atmosphere conditions, and lower gravity, current farming traditions are not applicable, and to establish an agricultural network, innovations must be made to account for Mars's diverse conditions. Ensuring quality food is essential for colonization success as high-quality food has implicit physical and psychological benefits, increasing physical health while boosting morale. Current food models are impractical on Mars as they have little viability in a Martian environment. Quantum computing is a promising fix to this situation, leveraging quantum mechanics to create accurate molecular simulations for food sciences [22]. Quantum computing could create molecular analysis that can determine nutritional and digestible assessments with human biochemistry. Quantum computing could simulate foods fit for alien environments and use methods like cryopreservation and dehydration for food longevity. It could tailor meals to specific people, helping yield better health outcomes for individuals in space. Developing a farm system on Mars is also crucial to long-term colonization goals. By simulating regolith (Martian soil) with other Mars conditions, quantum computing could help create innovative approaches for cultivating an agricultural system on Mars.

In the long term, humans conducted space missions, and health and safety are quintessential concerns. Currently, drug discovery and disease treatment are time intensive with soaring costs. However, quantum computing has the potential to revolutionize pharmaceuticals. Quantum computers could create molecular simulations modeling how drugs behave and act under specific properties. Quantum chemistry for drug design could create accurate energy and affinity predictions for drug molecules and their targeted proteins and biomolecules. Quantum computers can investigate transition state analysis for reactions of enzymes or metabolic processes [8]. Quantum models could also expand the molecular simulations to model different environments, such as reactions in places of other atmospheric conditions.

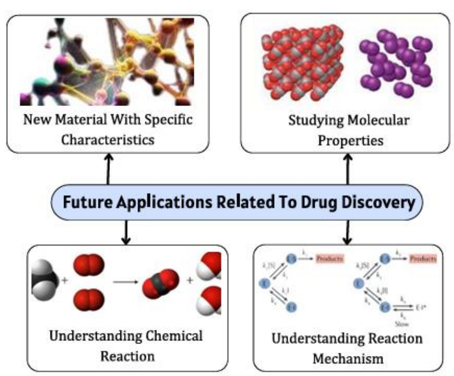

Fig. 5 Quantum simulations for drug discovery [8].

B. Habitat Systems

Habitation is also a crucial need to sustain life on Mars. Mars's radiation and atmospheric conditions make building a sustainable human habitat difficult. However, despite current technologies, many methods could overcome this obstacle. Bigelow Expandable Activity Modules (BEAM) already demonstrate the ability to operate internal human activity while protecting against harmful cosmic and UV radiation for above-ground habitat installments. On the other hand, underground installations are a prevalent idea, given Mars's topography in the Arsia Mons area. Past volcanoes and terrain show caverns and caves suitable for early human settlement [4]. With quantum-enhanced autonomous vehicles, we could explore underground structures and simulate potential infrastructure, making early development much quicker and more efficient.

As for breathable air, MOXIE systems already demonstrate the ability to take carbon dioxide from the Mars atmosphere, turn it into oxygen, and even help create water and fuel propellants. Solar panel installations have been reliable for energy in past rover Mars missions. However, the advent of KiloPower, units that generate energy for nuclear fission, is a promising supplement as it generates enough energy to last decades [17]. Quantum systems will help monitor oxygen and energy production as they can adequately allocate these resources and keep them in check.

VI. Conclusion

Quantum computing can revolutionize the space industry. It can be implemented in various areas to improve humans' ability to explore space and colonize Mars. In rocketry, quantum computing could introduce new methods, making rocket launches and space missions more efficient regarding energy, speed, and costs. Quantum computing could also revolutionize molecular simulations, offering new alternatives for health, food, and agriculture in space. Quantum optimization techniques will also expand resource allocation abilities, which can be applied in space missions and allocating water, minerals, and other Martian resources. Humans will also broaden our universe knowledge as quantum computers can better analyze telescope and satellite data, simulate extraterrestrial bodies, and enhance communication for autonomous vehicles. While quantum computing can create significant strides in the space industry, one common finding seen amongst research is that current quantum processing efforts fail to achieve scalability, error correction, and fragility of the quantum system. The experimental systems that have been researched have all experienced a similar issue when quantum computers were given more input to complete. As that happens, there is a loss of quantum information, which yields incorrect answers that multiply as it continues to compute. Additionally, while quantum systems' sensitivity makes them beneficial for processes like QKD, they make it extremely difficult to regulate the system successfully. A quantum computer has many temperatures and radiation requirements, making it challenging to utilize in space. While Mars colonization and space exploration may be possible without leveraging quantum mechanics, implementing quantum computers will fast-track development and exploration missions. More research and investment are needed to bring these theoretical concepts of quantum computing to life.

References

[1] Pinheiro, M. J., "Advances in Engine Efficiency: Nanomaterials, Surface Engineering, and Quantum-Based Propulsion," *Magnetochemistry*, Vol. 10, No. 3, 2024, pp. 17.
doi: 10.3390/magnetochemistry10030017

[2] Jordan, S. P., Shutty, N., Wootters, M., Zalcman, A., Schmidhuber, A., King, R., Isakov, S. V., & Babbush, R., "Optimization by Decoded Quantum Interferometry," *arXiv*, Google Quantum AI, Venice, CA, 2025 (unpublished).

[3] Watts, T. W., Otten, M., Necaise, J. T., Nguyen, N., Link, B., Williams, K. S., Sanders, Y. R., Elman, S. J., Kieferova, M., Bremner, M. J., Morrell, K. J., Elenewski, J. E., Johnson, S. D., Mathieson, L., Obenland, K. M., Sundareswara, R., & Holmes, A., "Fullerene-encapsulated Cyclic Ozone for the Next Generation of Nano-sized Propellants via Quantum Computation," *arXiv*, HRL Laboratories, LLC, Malibu, CA, 2024 (unpublished).

[4] Sheshpari, M., Fujii, Y., and Tani, T., "Underground Structures in Mars Excavated by Tunneling Methods for Sheltering Humans," *Tunnelling and Underground Space Technology*, Vol. 64, 2017, pp. 61-63.
doi: 10.1016/j.tust.2016.12.015

[5] Bhogal, A. S., Sinha, M., and Meshram, P., "NASA Nearest Earth Object Classification Using Quantum Machine Learning: A Survey," *Innovations in Electrical and Electronic Engineering, ICEEE 2023*, edited by R. N. Shaw, P. Siano, S. Makhilef, A. Ghosh, and S. L. Shimi, Lecture Notes in Electrical Engineering, Springer, Singapore, 2024, pp. 341-347.

doi: 10.1007/978-981-99-8289-9_34
[6] Makhanov, H., Setia, K., Liu, J., Gomez-Gonzalez, V., Jenaro-Rabadan, G., "Quantum Computing Applications for Flight Trajectory Optimization," arXiv, Univ. of Texas at Austin, Austin, TX, 2023 (unpublished).
[8] Kumar, G., GuiZani, M., Yadav, S., Mukherjee, A., and Hassija, V., "Recent Advances in Quantum Computing for Drug Discovery and Development," IEEE ACCESS, Vol. 12, 2024, pp. 1236-1239.
doi: 10.1109/ACCESS.2024.3376408.
[9] Makarov, A., Pérez-Herradón, C., Franceschetto, G., Taddei, M. M., Osaba, E., Del Barrio, P., Villar-Rodriguez, E., and Oregi, I., "Quantum Optimization Methods for Satellite Mission Planning," arXiv, GMV, Madrid, Spain, 2024 (unpublished).
[10] Shah, V., "Next-Generation Space Exploration: AI-Enhanced Autonomous Navigation Systems," *Journal of Environmental Sciences and Technology*, Vol. 03, No. 01, 2024, pp. 2-5.
doi: 10.5281/zenodo.10778451
[11] Kim, G. S., Chung, J., and Park, S., "Realizing Stabilized Landing for Computation-Limited Reusable Rockets: A Quantum Reinforcement Learning Approach," arXiv, 2023 (unpublished).
[12] Lalwani, J., and Jajodia, B., "Quantum Computing for Mars Exploration: Opportunities and Challenges," Quantum Computing Journal (to be published).
[13] Smith, R., "Quantum Computing in Astrophysics: Revolutionizing Simulation and Data Analysis," *Journal of Astrophysics & Aerospace Technology*, Vol. 12, No. 01, 2024.
[14] Kaltenbaek, R., Acin, A., Bacsardi, L., Bianco, P., Bouyer, P., Diamanti, E., Marquardt, C., Omar, Y., Pruneri, V., Rasel, E., Sang, B., Seidel, S., Ulbricht, H., Ursin, R., Villoresi, P., van den Bossche, M., von Klitzing, W., Zbinden, H., Paternostro, M., and Bassi, A., "Quantum technologies in space," *Experimental Astronomy*, Vol. 51, 25 June 2021, pp. 1677–1678.
doi: 10.1007/s10686-021-09748-7
[15] Abbas, A. H., Abdel-Ghani, H., and Maksymov, I. S., "Classical and Quantum Physical Reservoir Computing for Onboard Artificial Intelligence Systems: A Perspective," *Dynamics*, Vol. 4, No. 3, 12 Aug. 2024, pp. 643–644.
doi: 10.3390/dynamics4030033
[16] Landers, V. S., "Quantum Technologies for Space and Aerial Vehicles," in *Space Governance*, H. Jahankhani, S. Kendzierskyj, S. Pournouri, and M. A. Pozza, Eds., Space Law and Policy, Springer, Cham, 2024, pp. 8-10.
doi: 10.1007/978-3-031-62228-1_4
[17] Prestia, J. F., "The Future of Construction as It Applies to the Colonization of the Moon and Mars," M.S. Thesis, Dept. of Civil and Environmental Engineering and Construction, Univ. of Nevada, Las Vegas, Las Vegas, NV, May 2018.
[18] Unger, M., Heidler, N., Peschel, T., Damm, C., Jende, R., Weide, P., Kleinbauer, K., Steinkopf, R., Porwol, T., Müller, S., Rohde, M., Hartung, J., Jäger, C., Shestaeva, S., Schlegel, R., Schwinde, S., Goy, M., Steinlechner, F., Risse, S., "Design and manufacturing of a metallic telescope for ground-based quantum communication," *Proceedings of SPIE Optical Systems Design* 2024, Vol. 13021, SPIE, Strasbourg, France, 2024, pp. 1302105.
[19] Dundas, C. M., Bramson, A. M., Ojha, L., Wray, J. J., Mellon, M. T., Byrne, S., McEwen, A. S., Putzig, N. E., Viola, D., Sutton, S., Clark, E., and Holt, J. W., "Exposed Subsurface Ice Sheets in the Martian Mid-Latitudes," *Science*, Vol. 359, No. 6372, Jan. 12, 2018, pp. 199–201.
doi:10.1126/science.aao1619
[20] Kwiat, P., Bernstein, H., and Javadi, H., "Entanglement-assisted Communication System for NASA's Deep-Space Missions," NASA Grant/Cooperative Agreement NNX11AR33G, Final Summary of Research, University of Illinois, 2012.
[21] Bennett, C. H., and DiVincenzo, D. P., "Quantum Information and Computation," *Nature*, Vol. 404, No. 6775, 2000, pp. 253-255.
[22] Youvan, D. C., "Quantum Culinary Exploration: Unlocking the Potential of Extraterrestrial Food Systems Through Quantum Computing," *Preprint*, September 2024, URL:
https://www.researchgate.net/publication/384362107_Quantum_Culinary_Exploration_Unlocking_the_Potential_of_Extraterrestrial_Food_Systems_Through_Quantum_Computing