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Theoretical Design and Overview of Steam Propelled and Nuclear Powered Interplanetary Transit Vehicle for Human Crewed Extraterrestrial Exploration

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Abstract: This article provides a theoretical overview of a spacecraft that utilizes extraterrestrial water resources and controlled nuclear fission to propel itself during interplanetary travel. The spacecraft is equipped with a water extraction module to supply water to a large water-boiler container, a small nuclear reactor, a nuclear heat coupler, and an exhaust nozzle for steam propulsion. When the reactor is activated, the water is transformed into steam through nuclear heat and is stored in a pressurized steam chamber. Once the steam reaches a specific pressure limit, it is released through the nozzle, resulting in steam propulsion and the movement of the spacecraft. The velocity of the spacecraft can be adjusted by controlling the injection of steam into the propulsion chamber. In this study, we have examined the feasibility, design overview, and constraints associated with constructing this type of spacecraft in Low Earth Orbit (LEO). The proposed spacecraft aims to provide faster and more reliable interplanetary transit beyond Mars, utilizing renewable energy resources. Since water resources can be found beyond Mars through asteroids, comets, and moons, the challenge lies not in finding water but in the extraction process. Furthermore, the scientific community requires faster transit vehicles for human exploration of Mars and Ceres. However, no architecture has been proposed for crewed exploration beyond this point. Ultimately, it is hoped that this type of spacecraft will enable future astronauts to undertake deep space exploration missions in the coming decades. The manuscript will delve into the design strategy, challenges, launch vehicles needed for deploying assembling instruments, and the assessment of dimensions and crew capability.

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1. Introduction

We acknowledge that the realization of an interplanetary expedition to Mars and beyond is highly probable within the coming decades. With the continuous progression and advancement of chemical, nuclear, and electric propulsion systems, the objective of mission planners is to successfully execute a human-crewed exploration mission to celestial bodies such as Ceres, Titan, and other interplanetary destinations, where potential resources for the sustenance of life in our solar system are harboured [1-5]. Subsequently, if the pursuit of future

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interplanetary travel were to materialize into a viable scenario, technological and economic challenges in transporting significant quantities of propellants from Earth to fuel the spacecraft would inevitably arise. Furthermore, the feasibility of constructing immense space vehicles equipped with powerful propulsion systems will become a paramount challenge for future astronauts and mission planners. Hence, given the aforementioned issues and challenges, we propose a ground-breaking space vehicle that utilizes extra-terrestrial water as the primary propellant, propelling it through nuclear reactors and steam. In this academic manuscript, we provide a concise overview of our conceptual approach toward designing the space vehicle, intending its potential application in future interplanetary missions.

2. Introduction to Steam and Water Propulsion Systems

Researchers worldwide have proposed various ideas for steam or water-propelled spacecraft to achieve sustainable operations and encourage the utilization of extraterrestrial resources. These concepts heavily rely on solar resources to generate heat, which subsequently boils the water and propels it through nozzles [6-8]. However, a major challenge associated with this heating method is the insufficient solar irradiation and heat required to boil the necessary amount of water aboard space vehicles. This limitation arises due to the gradual decrease in solar intensity and luminosity as we move further away from the center of the heliosphere [1].

As a result, the limited availability of solar resources may render the proposed space vehicles for interplanetary travel unusable. Similarly, the use of nuclear thermal or nuclear electric propulsion concepts also has drawbacks, including hyper delta-velocities, artificial nuclear radiation, and uncontrolled reactions. While these concepts offer faster transit, they are limited concerning crew safety. Therefore, in light of the challenges posed by both the earlier proposed steam propulsion and advanced nuclear propulsion systems, we have endeavored to expand our conceptual strategy by designing and proposing steam-propelled and nuclear-powered space vehicles. Our aim is to address all the challenges associated with sustainable operations. Furthermore, our space vehicle concepts have the potential to facilitate deep space or interplanetary travel in the near future by utilizing sustainable and renewable in-situ energy resources.

3. Theoretical Design and Concept

3.1. Space Vehicle's Main Engine

The primary component of the space vehicle consists mainly of a compact fission reactor positioned centrally, surrounded by a water chamber with a substantial water retention capacity [9]. This fission reactor, working in conjunction with the water chamber, serves as the principal propulsive force of the space vehicle and is situated at the core of the vehicle, as depicted in Figure 1. Subsequently, the water chambers are interconnected with two steam tanks or chambers on either side of the vehicle. Furthermore, the steam tanks are linked to the steam-regulated valve, followed by the concerted action of powered thrusters on both sides of the thrust or nozzle section. It is worth noting that the water chamber, steam tanks, control valve, and nozzles are interconnected through resilient metallic conduits. Collectively, this entire configuration constitutes the main engine of the space vehicle.

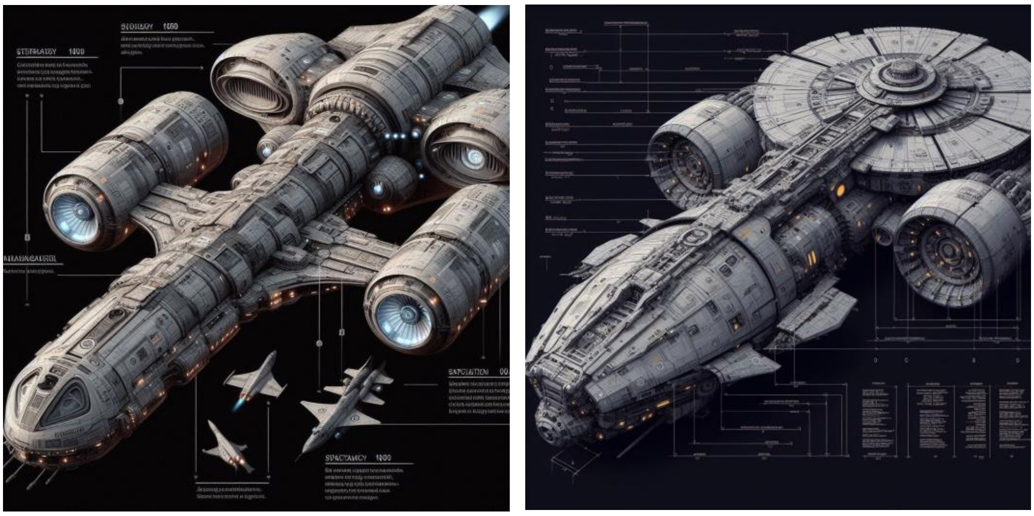

Figure-1 & 2 AI Modelled Design of Spaceship for Interplanetary Transit

3.2. Farming Module

The in-space farming module is positioned on either side of the primary engine and connected by means of docking or interlocking ports, as depicted in Figure 1. The incorporation of these farming modules serves to foster the practice of in-space agriculture and farming, thereby enhancing the mental well-being of the astronauts [10]. Additionally, the farming modules are safeguarded by bronze or hydrides to shield them from the effects of artificial radiation emanating from the main nuclear reactors. However, the majority of radiation and heat are mitigated through the utilization of water chambers and advanced cooling systems [11]. Consequently, with the safety of the crew in mind, we have situated the farming module adjacent to the core of the main nuclear reactor.

Figure-3 Cropping Plants and Edible Fruits aboard Spaceship [Image Courtesy: AI]

3.3. Habitation Module

The docking of the Habitation modules to the farming module occurs through interlocking ports, also known as docking ports, with the intention of facilitating easy access to the in-space farming module and its viable products. Additionally, this docking mechanism serves to protect the astronauts from exposure to artificial nuclear radiation. Our discussion has been limited to providing an overview of an interplanetary transit vehicle. Furthermore, to allow unimpeded movement for the astronauts aboard, who may be located in either of the habitation modules docked on opposite sides of the space vehicle, a crew passageway has been installed on the top of the vehicle, as depicted in Figure 1. It is worth noting, however, that this crew passageway is connected to the farming modules rather than the crewed or habitation modules.

3.4. Artificial Gravity Simulator

Since the space vehicle has been designed for deep space or interplanetary travel, the crew may encounter significant effects related to zero or microgravity. To ensure the crew's physical well-being in a microgravity environment, we propose the installation of two artificial gravity simulator wheels on both sides of the space vehicle. These wheels would be arranged in a rim configuration that is synchronized with either the farming or habitation module [12-13]. Additionally, each side of the space vehicle is equipped with a guidance and navigation module to facilitate navigation throughout the mission. The primary objective of incorporating these two modules is to eliminate the need for powered manoeuvres to alter the direction of the space vehicle during round-trip travel. Furthermore, if there is a need to install any additional modules, they can be launched and integrated between the habitation and guidance & navigation modules on either side.

3.5. Water Extraction Arms

Water extraction arms or configurations are installed on this space vehicle to facilitate the extraction of water and replenish its water chamber with water from extra-terrestrial sources. This allows for the utilization of water for the generation of steam and propulsion through steam during travel between planets. Furthermore, there is a significant abundance of water resources on moons and asteroids beyond the realms of Earth and Mars. Similarly, scientists have proposed numerous artificial methods for extracting water, making the extraction of extra-terrestrial water resources less problematic.

4. Working Mechanism

This section provides an overview of the pivotal function of nuclear fission in the propulsion mechanism of the space vehicle. It elucidates how the nuclear fission reaction, reminiscent of terrestrial nuclear power plants, gives rise to thermal energy and artificial radiation. The thermal energy generated is subsequently harnessed for the indispensable processes of steam generation and electricity production. The paragraph further expounds upon the process of steam generation, delineating how surplus thermal energy from the nuclear reactor is employed to vaporize water, and how the resultant steam is then stored. Furthermore, it outlines the storage of steam within a pressurized chamber and its subsequent controlled release for propulsion via the space vehicle's thrusters or nozzles. Moreover, the paragraph underscores the limitations and challenges associated with this groundbreaking approach, emphasizing the imperative of a resilient design and robust safety measures to ensure the sustainability of operations and the safety of the crew in the event of potential nuclear reactor incidents..

4.1. Nuclear Fission Reactor

The initiation of the nuclear fission reaction, akin to that of terrestrial nuclear power plants, is responsible for the generation of heat and synthetic radiation. This thermal energy is subsequently employed to induce the boiling of water within the designated chamber, thereby facilitating the production of steam for propulsion. Moreover, the surplus heat and radiation are effectively utilized for the generation of electricity, achieved through the utilization of Nuclear-Thermal Generators (NTG) and Radioisotope Thermoelectric Generators (RTG).

4.2. Steam Generation for Powerful Propulsion

The excess thermal energy generated by the nuclear reactor undergoes a process of heat transfer using a heat coupler to raise the temperature of the water contained in the water chambers. As a result of this heating, the water reaches its boiling point and transforms into steam. The steam is then collected and stored in a pressurized chamber located within the propulsion segment. Subsequently, this pressurized environment facilitates the generation of optimal propulsion force by means of steam nozzle devices or steam thrusters.

4.3. Steam Accumulation and Controlled Fusion

Steam is contained in the chamber in a concentrated manner and is overseen by a pressure gauge. When the pressure reaches its prescribed limits, the steam is discharged via the control valve, thereby enabling regulated propulsion through the thrusters or nozzles. This mechanism permits accurate management of delta-velocity and manoeuvring capabilities.

Figure-4 AI Modelled Space Transit Vehicle

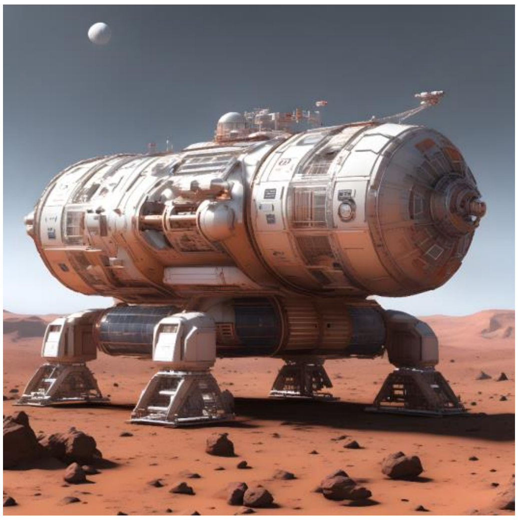

Figure-5 Spaceship on Mars

5. Limitation

The proposed space vehicle is presently a conceptual design that has not undergone practical demonstration. Concerns regarding its specific impulse indicate that the spacecraft thrusters may have a lower efficiency compared to other propulsion systems, potentially impacting delta-velocity during interplanetary travel. The extraction of water from asteroids and planetary bodies, while a key component of the vehicle's functionality, presents challenges and risks of contamination. Additionally, the utilization of water and steam propulsion methods raises the concern of releasing highly radioactive elements into interplanetary space, posing potential hazards for future space travelers. Furthermore, the inherent risk of nuclear reactor incidents during human spaceflight highlights the critical importance of a resilient design and stringent safety measures to mitigate potential crew fatalities and ensure the overall success and sustainability of interplanetary missions.

6. Conclusion

In conclusion, the proposed space vehicle represents an innovative conceptual design with the potential to revolutionize interplanetary travel. However, several critical considerations and challenges need to be addressed before its implementation. The specific impulse limitations and potential delta-velocity impact should be thoroughly examined to optimize the spacecraft's propulsion efficiency. Moreover, the extraction of water from extraterrestrial sources requires meticulous planning to mitigate contamination risks. The use of water and steam propulsion introduces concerns about releasing radioactive elements into space, necessitating careful evaluation of environmental consequences. Lastly, the inherent risks associated with nuclear reactor incidents during human spaceflight underline the paramount importance of robust design and stringent safety measures to safeguard the well-being of future space travelers and ensure the success of deep-space exploration missions. Finally, the Acceleron Aerospace Sciences Private Limited is actively engaged in the preliminary design, concept development, and feasibility study for this spaceship. Subsequent updates and advancements in this proposal will be published as separate papers, reflecting the continuous efforts to refine and enhance the spacecraft's capabilities for safe and sustainable interplanetary exploration.

7. References

[1] Biswal M, M. K., & Annavarapu, R. N. (2021). Human Mars Exploration and Expedition Challenges. In AIAA Scitech 2021 Forum (p. 0628). **https://doi.org/10.2514/6.2021-0628**.

[2] Drake, B. G., Hoffman, S. J., & Beaty, D. W. (2010, March). Human exploration of Mars, design reference architecture 5.0. In 2010 IEEE Aerospace Conference (pp. 1-24). IEEE. **https://doi.org/10.1109/AERO.2010.5446736**.

[3] Cichan, T., Bailey, S. A., Norris, S. D., Chambers, R. P., Jolly, S. D., & Ehrlich, J. W. (2017, March). Mars base camp: An architecture for sending humans to mars by 2028. In 2017 IEEE Aerospace Conference (pp. 1-18). IEEE. **https://doi.org/10.1109/AERO.2017.7943981**.

[4] Musk, E. (2017). Making humans a multi-planetary species. New Space, 5(2), 46-61. **https://doi.org/10.1089/space.2017.29009.emu**.

[5] Biswal M, M. K, R. Kumar V, N.B. Das. (2021). Human Crewed Interplanetary Transport Architecture for a Roundtrip Exploration of Mars and Ceres: Research Study. In 2021 AIAA ASCEND Forum. **https://doi.org/10.2514/6.2021-4195**.

[6] Rabade, S., Barba, N., Garvie, L., & Thangavelautham, J. (2016, January). The case for solar thermal steam propulsion system for interplanetary travel: Enabling simplified ISRU utilizing NEOs and small bodies. In Proceedings of the 67th International Astronautical Congress.

[7] Adirim, H., Lo, R., Pilz, N., & Kreil, M. (2006). Hot water propulsion development status for earth and space applications. In 42nd AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit (p. 4566). **https://doi.org/10.2514/6.2006-4566**.

[8] Powell, J., Maise, G., & Paniagua, J. (2003, March). SUSEE-ultra light nuclear space power using the steam cycle. In 2003 IEEE Aerospace Conference Proceedings (Cat. No. 03TH8652) (Vol. 1, pp. 1-507). IEEE. **https://doi.org/10.1109/AERO.2003.1235078**.

[9] Ingersoll, D. T., & Carelli, M. D. (Eds.). (2020). Handbook of small modular nuclear reactors. Woodhead Publishing.

[10] Biswal M, M. K., Basanta Das, N., & Naidu Annavarapu, R. (2021). Biological Risks and its Implications for Crewed Interplanetary Missions. LPI Contributions, 2103, P8. **https://doi.org/10.2514/6.2021-4133**.

[11] Žohar, A., & Snoj, L. (2019). On the dose fields due to activated cooling water in nuclear facilities. Progress in Nuclear Energy, 117, 103042. **https://doi.org/10.1016/j.pnucene.2019.103042**.

[12] Houghton, N. M., Fulton, J., Mazarr, A., Park, S., & Williams, P. A. (2020). Utilizing in-space assembly to add artificial gravity capabilities to Mars exploration mission vehicles. In AIAA Scitech 2020 Forum (p. 2016). **https://doi.org/10.2514/6.2020-2016**.

[13] Chen, M., Goyal, R., Majji, M., & Skelton, R. E. (2020). Design and analysis of a growable artificial gravity space habitat. Aerospace Science and Technology, 106, 106147. **https://doi.org/10.1016/j.ast.2020.106147**.

[14] Calla, P., Fries, D., & Welch, C. (2018). Asteroid mining with small spacecraft and its economic feasibility. arXiv preprint arXiv:1808.05099. **https://doi.org/10.48550/arXiv.1808.05099**.

[15] Ho, K. L. (2021). THE TECHNOLOGICAL AND ECONOMIC FEASIBILITY OF ASTEROID MINING (Doctoral dissertation, Monterey, CA; Naval Postgraduate School).

[16] Metzger, P. T., Zacny, K., & Morrison, P. (2020). Thermal extraction of volatiles from lunar and asteroid regolith in axisymmetric Crank–Nicolson modeling. Journal of Aerospace Engineering, 33(6), 04020075. **https://doi.org/10.1061/(ASCE)AS.1943-5525.0001165**.

[17] Biswal M, M. K., & Kumar V, R. (2021). Power Options for Human Mars Mission. In AIAA Propulsion and Energy 2021 Forum (p. 3260). **https://doi.org/10.2514/6.2021-3260**.

[18] Biswal M, M. K., Kumar, R., & V, P. (2022). Human Crewed Interplanetary Transport Architecture for Roundtrip Exploration of Mars and Ceres: Trajectory Paths and Communication Systems. In AIAA SCITECH 2022 Forum (p. 2587). **https://doi.org/10.2514/6.2022-2587**.

[19] Biswal M, M. K., Kumar, R., & Basanta Das, N. (2022). A Review on Human Interplanetary Exploration Challenges. In AIAA SCITECH 2022 Forum (p. 2585). **https://doi.org/10.2514/6.2022-2585**.

[20] Biswal M, M. K., Basanta Das, N., & Annavarapu, R. N. (2021). Orbital and Planetary Challenges for Human Mars Exploration. arXiv e-prints, arXiv-2101. Advances in the Astronautical Sciences, Volume 178, pp-11. **https://doi.org/10.48550/arXiv.2101.04725**.

[21] Biswal M, M. K., & Annavarapu, R. N. (2021). Interplanetary Challenges Encountered by the Crew During their Interplanetary Transit from Earth to Mars. arXiv e-prints, arXiv-2101. Advances in the Astronautical Sciences, Volume 178, pp-12. **https://doi.org/10.48550/arXiv.2101.04723**.

8. Biography

Malaya Kumar Biswal M: Malaya Kumar Biswal is the Founder & CEO of Acceleron Aerospace in Bangalore, India. He is a renowned entrepreneur and scientist in aerospace engineering, specializing in space exploration. After earning his bachelor's degree in Aerospace Engineering, he worked as a Senior Research Scientist at Grahaa Space, focusing on satellite reliability, aerospace design, and space science research. With a visionary mindset, Biswal founded Acceleron Aerospace and now leads the company in revolutionizing the aerospace industry. He is particularly interested in human Mars exploration and envisions ambitious missions to Mars and Ceres. Biswal's achievements have earned him respect in the scientific community, and he actively mentors aspiring scientists, inspiring future space pioneers.

Ilavazhagi G: Ilavazhagi G, with a Masters in English and a Bachelor's in Education, serves as the Director of Acceleron Aerospace in Bangalore, India. Notably contributing to "A Comprehensive Overview of ISRO's Ambitious Space Station Project," she blends literary insight with aerospace leadership. Ilavazhagi G is dedicated to advancing space education and empowering women in STEM. Her role as a women entrepreneur underscores her commitment to breaking barriers in the aerospace industry, making her a dynamic force at the intersection of literature, education, and space exploration.

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10. Conflict of Interest

The author have no conflict of interest to report.

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