Nidus

Your Home in Space: The Habitat Layout Creator

NASA International Space Apps Challenge 2025

Monterrey, Nuevo León, México

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"How could an interactive visual tool enable the intuitive design, spatial optimization, and rapid testing of modular space habitats across different mission scenarios and environmental constraints?"

PROPOSAL

In the context of future space missions and human settlement beyond Earth, the design and spatial distribution of habitats are critical factors for survival and efficiency. The complexity of these systems demands intuitive and accessible tools that allow users to visualize, plan, and test different habitat configurations in varied environmental conditions.

This proposal focuses on the development of a visual and interactive platform designed to create and evaluate the distribution of space habitats. The tool aims to enable users to: design modular layouts with diverse components, determine the optimal allocation of functional areas within limited spatial constraints, and test multiple design approaches under different mission scenarios.

JUSTIFICATION

By integrating data visualization, human-centered design, and simulation principles, this tool would not only facilitate efficient planning but also foster creativity and innovation in habitat engineering. Exploring how humans might adapt living spaces beyond Earth contributes to our understanding of sustainable life systems and the future of interplanetary exploration.

OBJECTIVE

To develop an interactive visual tool that allows for the creation, evaluation, and optimization of space habitat layouts, facilitating functional design, efficient planning, and simulation of scenarios in space missions.

SPECIFIC OBJECTIVE

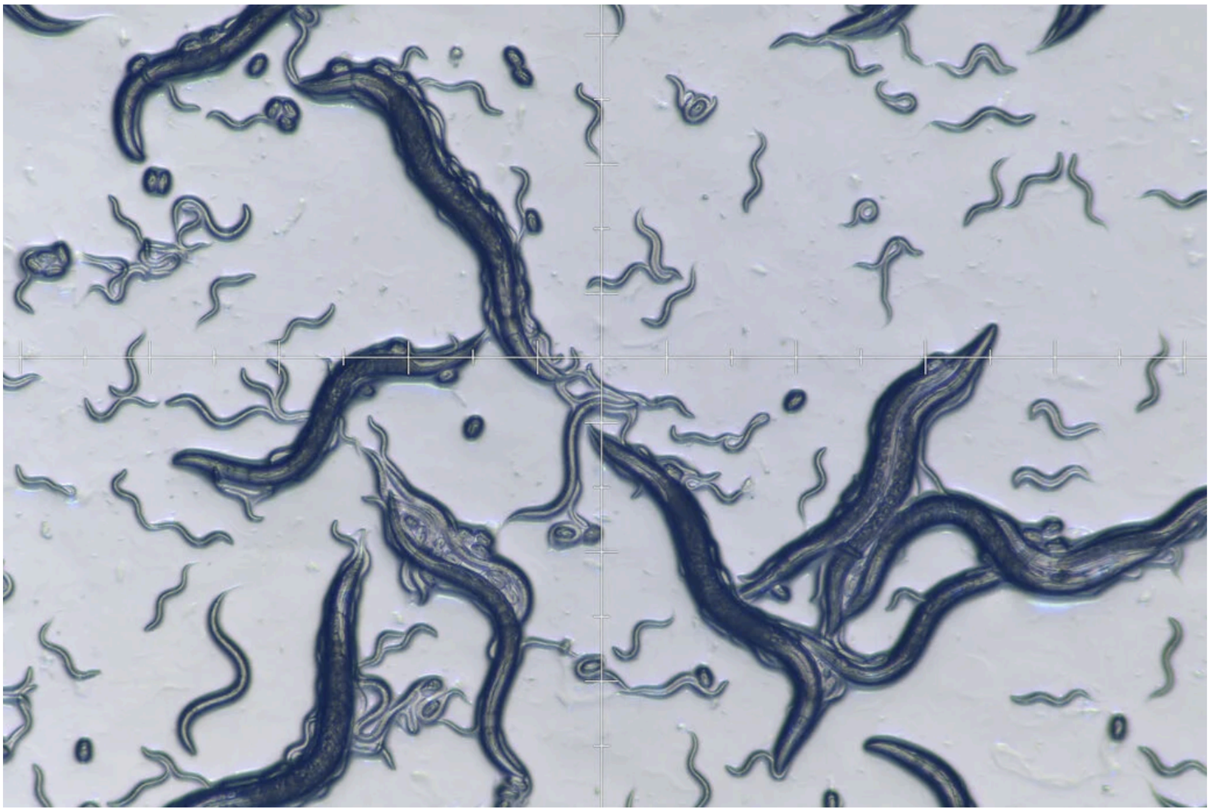
To design an accessible and intuitive interface that allows for the creation of modular habitat models, testing different configurations through simulations under various mission conditions, and fostering innovation in the development of sustainable and collaborative habitats for future space exploration.

BACKGROUND

Space and moon conditions

To realistically evaluate the effects of extraterrestrial environments on human physiology, it is crucial to understand how external stressors—such as temperature fluctuations, radiation, and microgravity—affect biological systems from the molecular to the organismal level. Insights from model organisms like *Caenorhabditis elegans* provide a valuable foundation for understanding these mechanisms, as they exhibit conserved genetic pathways involved in stress response and homeostasis.

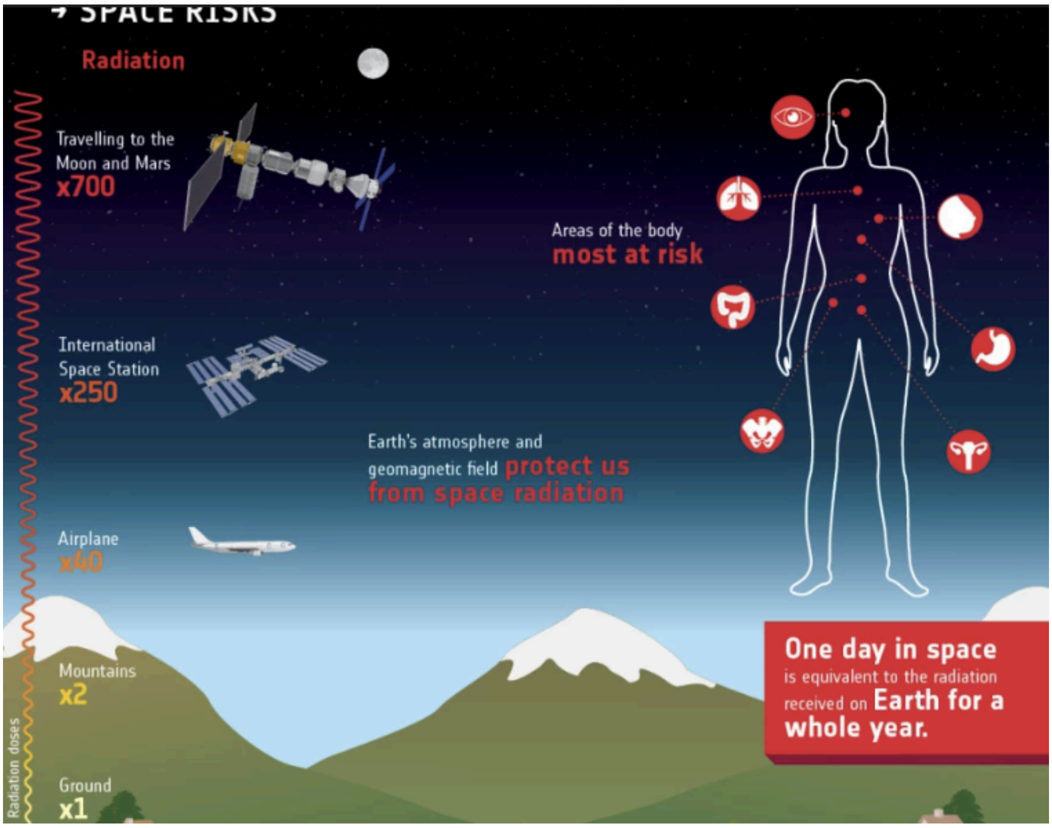
In previous studies, *C. elegans* exposed to low cultivation temperatures demonstrated significant alterations in gene expression, particularly in pathways associated with the cell cycle and TGF-β/insulin-like signaling. Out of 7,903 genes analyzed, differential expression was observed across multiple thermal conditions (10, 15, 20, and 25 °C), revealing activation of stress-related pathways under environmental changes. These findings suggest that similar molecular mechanisms could play a role in human adaptation to space habitats, where temperature, radiation, and limited resources impose continuous physiological stress.



On Earth, the magnetic field and atmosphere protect us from most space radiation, although we are exposed to low levels daily. In space, astronauts face much higher exposure from three main sources: particles trapped in Earth's magnetic field, solar energetic particles, and galactic cosmic rays.

This radiation poses a significant health risk, especially in the long term, as it can increase the likelihood of cancer, cardiovascular disease, and cataracts. Furthermore, this type of radiation has a more severe impact than terrestrial radiation.

Current strategies to mitigate these risks include shielding, constant monitoring, and safety protocols. However, longer missions, such as those to the Moon or Mars, will increase both total exposure and potential health effects for astronauts.



On the other hand, NASA research using Earth-based spaceflight analogs has shown that the duration and degree of isolation are critical factors for human mental health. Confined environments with little external contact increase the risk of behavioral, cognitive, and psychiatric disorders.

To counteract these effects, NASA has developed methods and technologies such as actigraphy, which records movement and ambient light to assess sleep and alertness. Furthermore, LED lighting on the space station helps align circadian rhythms, improving astronauts' sleep, attention, and performance.

Specifically, regarding environmental issues, NASA employs environmental monitoring technologies to ensure the space station's atmosphere is safe, controlling gases such as formaldehyde, ammonia, and carbon monoxide, and using thermal control systems to maintain astronaut comfort.

In addition, biological samples (blood and saliva) are analyzed to detect changes in the immune system and the reactivation of latent viruses. Molecular techniques are applied to assess microbial risks, with regular sampling of crew bodies and the environment, complemented by cleaning, air filtration, and water treatment. Preventative measures, such as flu vaccination and pre-launch quarantine, are also implemented to minimize illnesses during the mission.

By applying this understanding to human space habitation, it becomes possible to design environments that support biological equilibrium and reduce health risks associated with long-term missions. This integration of molecular biology, bioengineering, and environmental modeling could guide the creation of sustainable life-support systems that mimic optimal Earth-like conditions and promote resilience in extreme extraterrestrial settings.

Mars conditions and the effects on the human body

The journey to Mars involves a variety of extreme conditions that can significantly impact human health. Astronauts would face exposure to heightened levels of radiation, including solar and cosmic radiation, which are much more dangerous than what is encountered in low Earth orbit. They would also experience different gravitational fields, including microgravity during the journey, Martian gravity on the surface, and Earth's gravity upon return, making re-adaptation challenging.

On the surface of Mars, astronauts will be exposed to harmful Martian dust, which is abrasive, chemically reactive, and contains toxic substances like perchlorates, silicates, and heavy metals. This dust can enter the body and damage the lungs, immune system, and other organs. Additionally, the isolation and long communication delays with Earth will add psychological stress, impacting mental health and group dynamics.

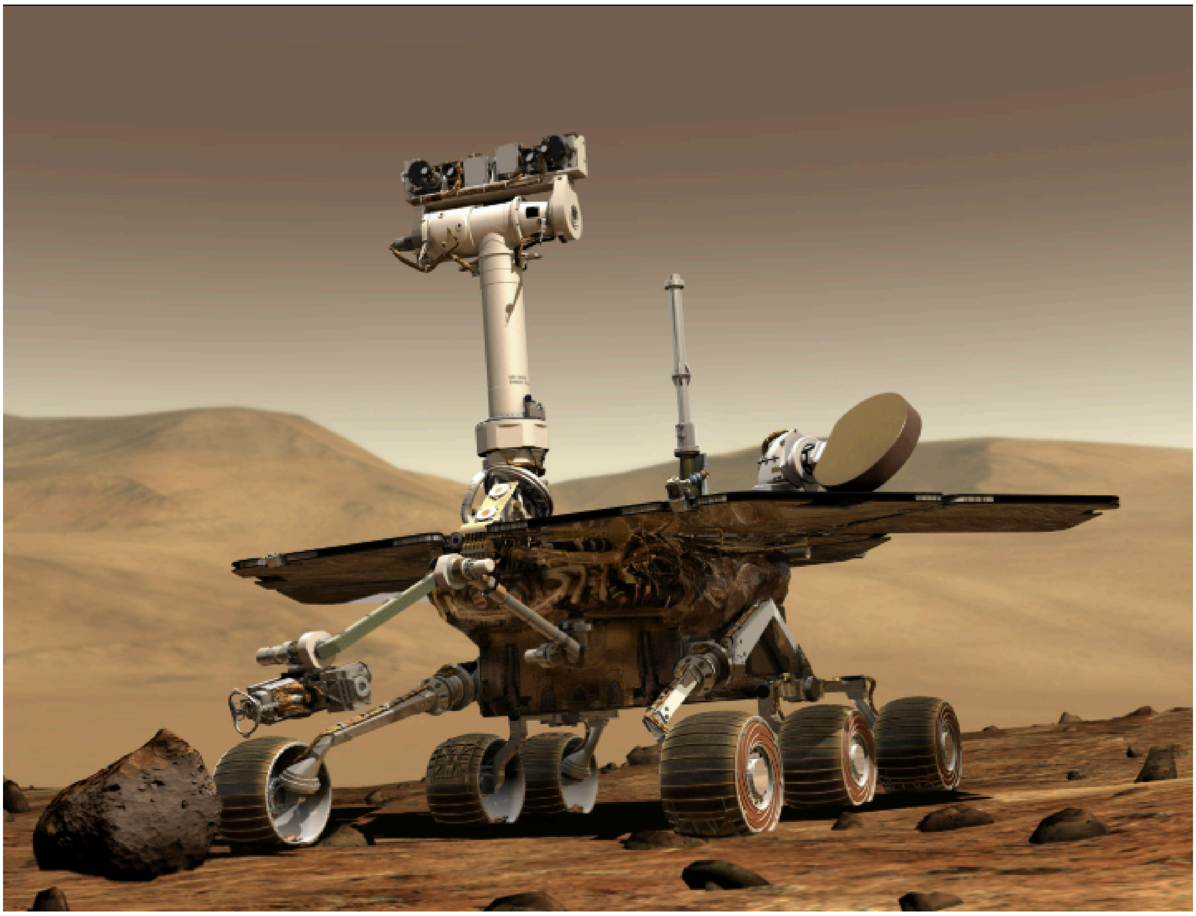
These harsh conditions will lead to several physiological effects. The lack of gravity causes bone loss and muscle atrophy, and astronauts are at higher risk for kidney stones due to calcium loss. Cardiovascular changes, such as fluid shifts in the body and weakened blood vessels, could pose long-term health risks. Radiation exposure can increase the likelihood of cancers, heart disease, and damage to vital organs. The dust and toxic metals on Mars can damage the lungs and organs, potentially leading to serious illnesses like silicosis or fibrosis.

The immune system will also be compromised, making astronauts more vulnerable to infections. Psychologically, the isolation and confinement may cause stress, fatigue, and cognitive or psychiatric issues, affecting overall mission performance.

In conclusion, the conditions on the journey to Mars and the Martian surface pose serious risks to astronaut health. These include radiation exposure, gravity changes, toxic dust, and psychological stress, all of which need to be addressed for the success of a long-term human mission to Mars.

Materials used for Mars’ exploration

NASA’s Mars exploration missions use a variety of specialized materials designed to withstand the extreme conditions of space and the Martian environment. For heat protection during atmospheric entry, spacecraft use Phenolic Impregnated Carbon Ablator (PICA), which can endure the intense heat. The structures of spacecraft and rovers are made from carbon fiber composites and titanium alloys, which provide strength while keeping the weight low. Rovers' wheels are crafted from aluminum alloys with specially designed treads to withstand Mars' rocky terrain and abrasive dust.



Power for the missions is provided by gallium arsenide (GaAs) solar cells, known for their high efficiency in the weak Martian sunlight. To handle the extreme temperature fluctuations on Mars, spacecraft are insulated using multi-layer insulation (MLI) and aerogels, materials that help retain heat during cold nights and dissipate it during the day.

Martian dust, known for its abrasiveness, is tackled with Teflon and silicone coatings, which prevent it from damaging moving parts and electronic systems. For future human missions, polyethylene and water-based shielding will be used to protect astronauts from harmful radiation in space. In terms of habitat construction, NASA is exploring 3D printing using Martian regolith, which could be used to build shelters and structures directly from the planet's surface material.

Lastly, electronic systems rely on gold and copper, chosen for their excellent conductivity and resistance to the harsh Martian environment. For life support, activated carbon is used in filtration systems, and MOXIE, an oxygen-generation system, is designed to convert Martian CO_2 into breathable oxygen for astronauts.

<u>Spacecraft components</u>

The Orion crew module is the pressurized capsule where four astronauts will live and work during missions of up to 21 days to the Moon. It is the only part of the craft that returns to Earth and features advances in life support, avionics, power, and manufacturing.

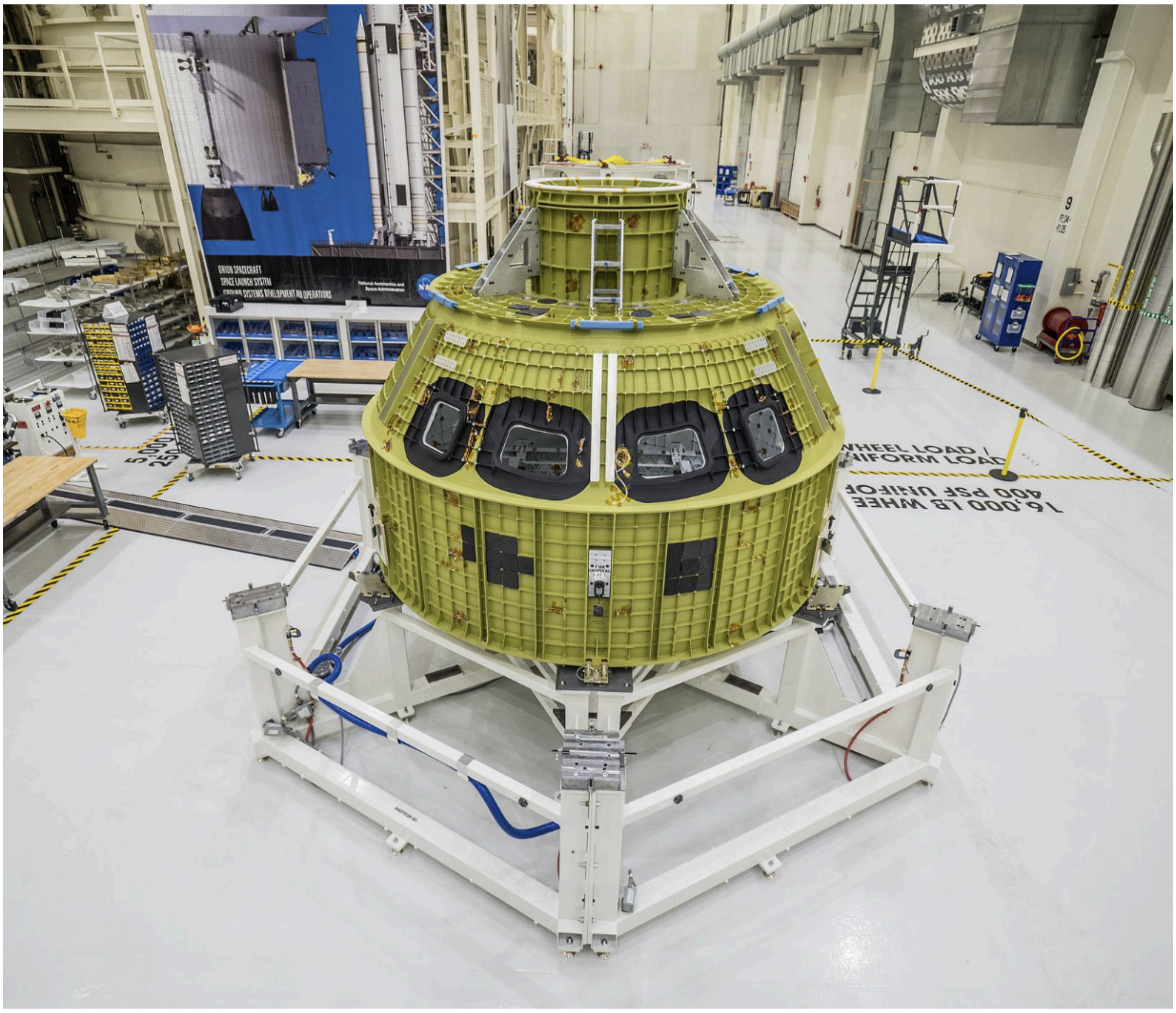
Inside, environmental systems control temperature, pressure, humidity, oxygen, and carbon dioxide, ensuring crew health and comfort. The cockpit with screens allows full control of Orion, while the capsule provides protection from cosmic radiation and micrometeoroids.

The module also includes a water supply, waste management system with private restrooms, aerobic and strength training facilities, and systems that remove heat, humidity, and odors, ensuring optimal conditions during multi-week missions.

The crew module's pressure vessel is made up of seven large aluminum alloy pieces joined by friction stir welding, creating a lightweight, strong, and airtight capsule. This reduction in parts (from 33 to seven) improves manufacturing and saves more than 317 kg.

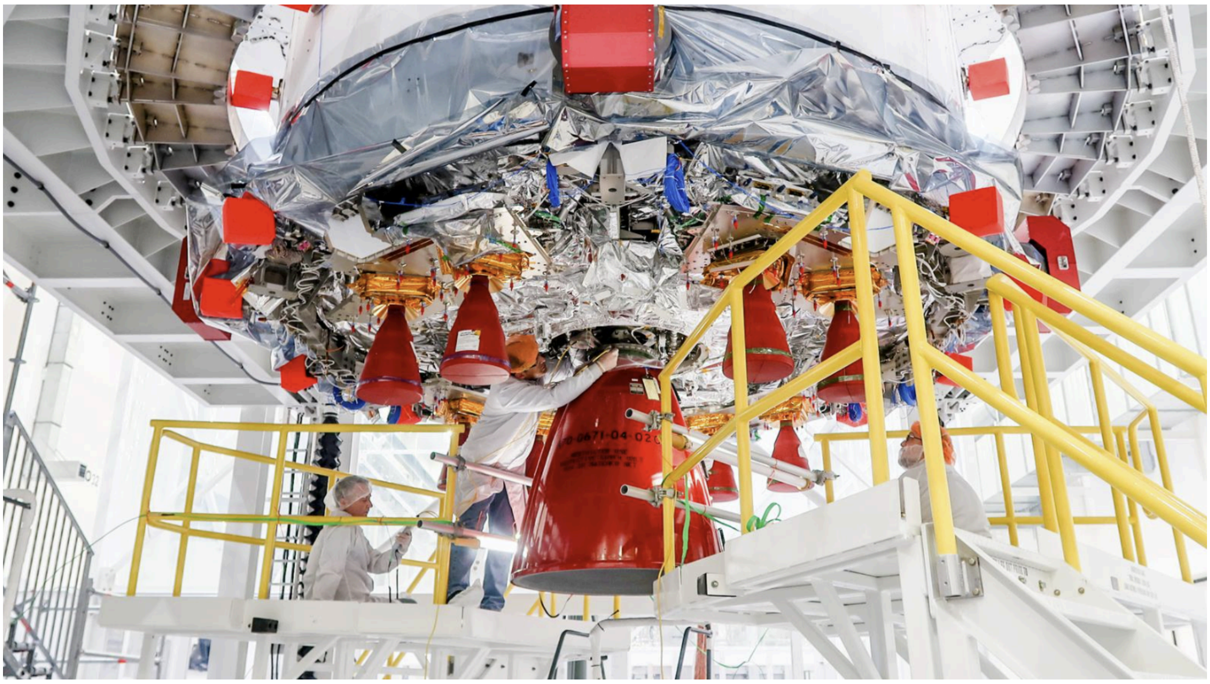
The backbone, a nine-piece structure bolted together with crossbeams, supports the crew seating and storage compartments, which include food, first-aid kits, emergency equipment, sleeping bags, and pressure suits.

The module is protected by the rear shell, composed of 1,300 silica fiber plates, which protect the craft from the cold of space and extreme heat during reentry into Earth's atmosphere.



While the service module serves as Orion's primary propulsion system, the crew module features a propulsion system composed of 12 small engines, called Reaction Control System (RCS) thrusters, which provide full control of the module's translation and rotation, both in orbit and during entry. When the crew module separates from the service module to re-enter Earth's atmosphere, the 12 RCS thrusters control the spacecraft's return.

To propel Orion to its destination, the service module is equipped with a total of 33 engines: one main engine (a NASA-provided refurbished Orbital Maneuvering System engine (OMS-E); eight auxiliary engines (NASA-provided Aerojet R4D-11); and 24 reaction control thrusters (ESA-provided engines that are the same model as those used on the Automated Transfer Vehicle (ATV). These three types of engines provide propulsion for lunar orbit injection and return to Earth, as well as attitude control for the crew module. The propulsion system can also be used, during some final phases of launch, for crew protection during potential abort scenarios.



The service module's electrical power system supplies electricity to the entire spacecraft, managing the power generated by four solar array wings, each with three 2 x 2 meter panels and a total of 15,000 gallium arsenide cells. The panels can rotate on two axes to maximize solar collection, and the control unit distributes power to the service module and crew module, protecting the power lines.

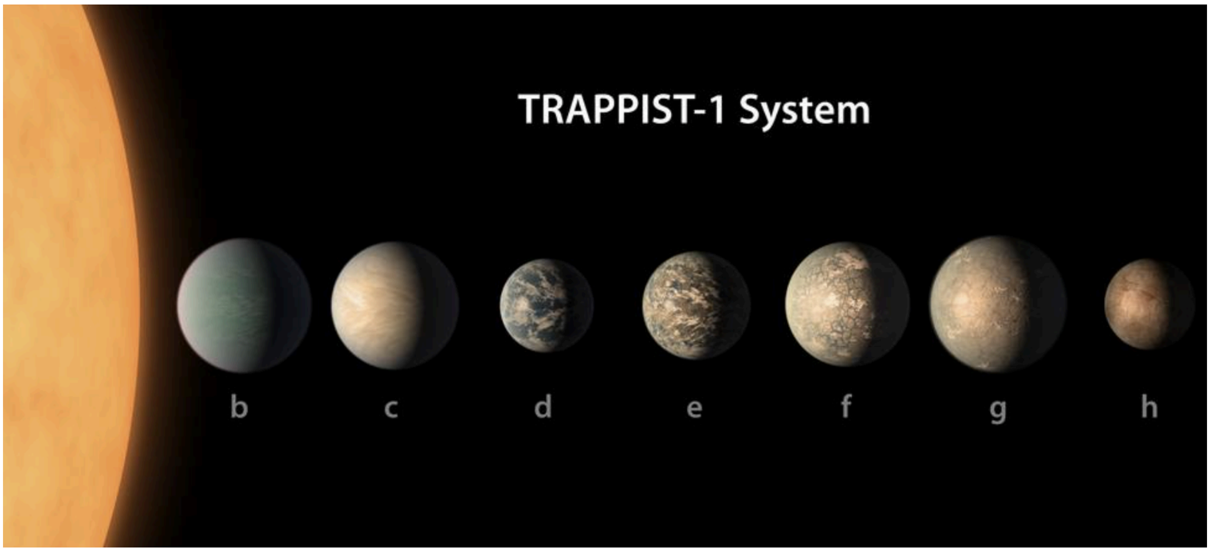
The thermal control system maintains comfortable temperatures for the crew and equipment using radiators and heat exchangers, combining active and passive methods.

The consumables storage system provides potable water, oxygen, and nitrogen, stored in dedicated tanks to meet the crew's needs during the mission, ensuring a safe and continuous supply.

Aquatic Exoplanets: Kepler System

An exoplanet, or extrasolar planet, is a celestial body that orbits a star outside our solar system. These planets can vary in size, composition, and environmental conditions and are classified based on various criteria.

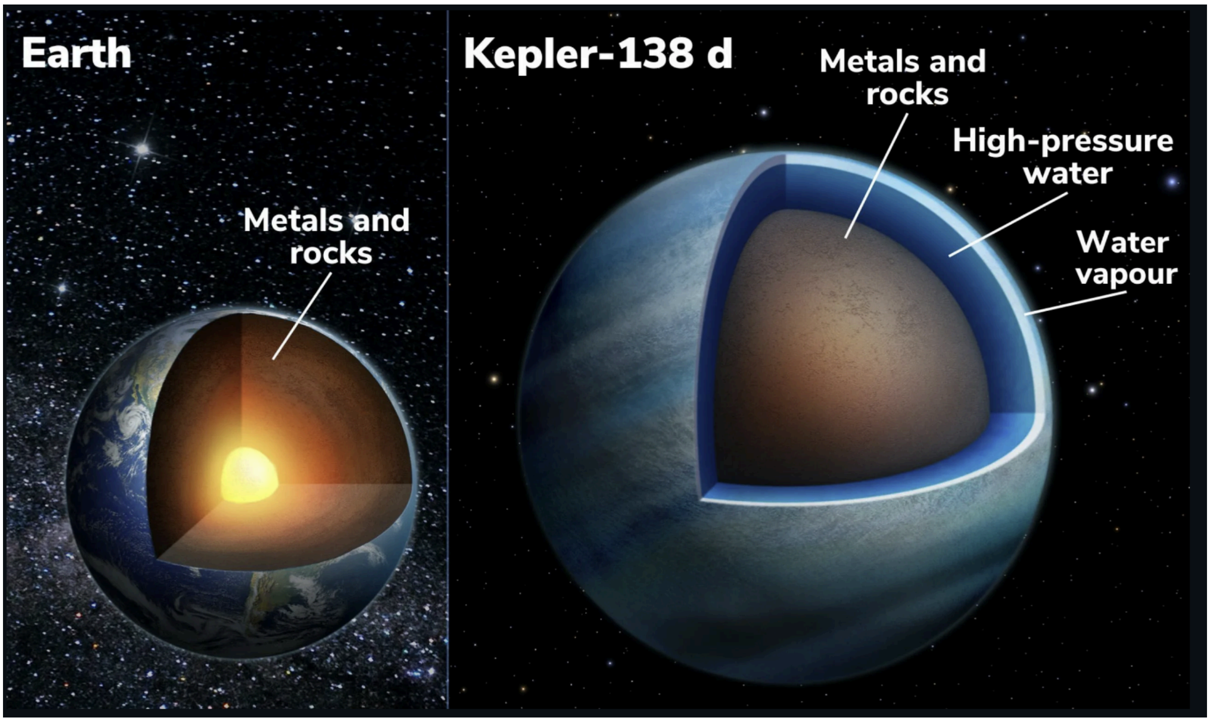
Scientist Lynnae Quick from NASA's Goddard Space Flight Center in Greenbelt, Maryland, discovered that more than a quarter of a dozen exoplanets she was studying, including those in the nearby TRAPPIST-1 system, show a high likelihood of being oceanic beneath various layers of surface ice, similar to the cases of Europa and Enceladus.



To determine this, one would need to measure the heat emitted by an exoplanet or detect volcanic eruptions within it, which would be caused by liquid or vaporized molten rock. Thus, life could exist, as the heat from hydrothermal vents might be found on the ocean floor. Moreover, sharing similarities with Earth, such as size, could indicate that the planet is more solid than gaseous, making it more likely to have water on its surface

A team of researchers from the University of Montreal found evidence that the planets in the Kepler-138 system could be aquatic planets.

The Kepler-138 system consists of three confirmed exoplanets, Kepler-138 b, Kepler-138 c, and Kepler-138 d, each with its own characteristics, with Kepler-138 b being the closest to the star, while Kepler-138 c and Kepler-138 d are basically “twin” planets, meaning they are nearly the same size and mass. In the initial investigation, the water surface of these two planets was not directly detected, but it was concluded that a large fraction of their volume was made up of lighter materials than rock and heavier than hydrogen or helium, leading astronomers to conclude that they are composed of water. This theory was later confirmed by another study conducted using NASA's Hubble and Spitzer space telescopes, comparing these planets to the icy moons of our solar system, Europa and Enceladus, which are also largely composed of water surrounding a rocky core. Caroline Paulet, who leads the research at the University of Montreal, stated, “Imagine larger versions of Europa or Enceladus, the water-rich moons orbiting Jupiter and Saturn, but much closer to their star.” Instead of having an icy surface like the moons of our solar system, researchers warn that the planets would not have oceans or a layer of ice directly, but due to the high temperatures found on Kepler-138 d and Kepler-138 c, which exceed the boiling point of water, the planets are expected to have a dense vapor atmosphere, and beneath this atmosphere, there could be liquid water at high pressure, making these worlds potentially habitable.



In the same research with the Hubble and Spitzer telescopes, researchers also found evidence of a fourth planet in the system, named Kepler-138 e. This newly discovered planet is small and orbits farther from its star than the other three planets, taking only 38 days to complete an orbit. Unlike its neighboring planets, the nature of this new planet remains unknown, but it lies within the habitable zone of its star.

Interstellar planets, also known as rogue or solitary planets, are characterized by not experiencing sunrises and sunsets, as they do not belong to any solar system nor orbit close to a star. Without sunlight, they remain in perpetual darkness. This phenomenon occurs when, in the early stages of solar system formation, gravitational forces can expel one or more planets, moving them away from their stars.

A lesser-known characteristic of many interstellar planets is that they may have a molten core while their surface remains completely frozen. Due to these conditions, it is possible that some of them contain oceans of liquid water beneath their icy crust. “Rogue planets have molten cores, even though the surface is completely frozen. Between these extremes, there may exist oceans of liquid water,” states Neil DeGrasse.