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Long Term Human Presence in Space Requires Artificial Gravity and Radiation Shielding

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Introduction

Astronauts who spend months in microgravity suffer serious health problems:

muscle atrophy, cardiovascular deconditioning, bone calcium loss, impaired vision, and immune system changes.

Exercise countermeasures seem insufficient.

Similar problems are expected on the Moon and Mars.

Long-term human health in space requires providing artificial Earth level gravity.

Rotating habitats are needed.

Astronauts beyond Earth's magnetic field can suffer harm from cosmic radiation and occasional strong solar flares.

Long-term human health in space requires providing radiation shielding.

Shielding is also needed on the Moon and Mars.

Human habitation in pressurized domes on the Moon or Mars surface appears unrealistic because of partial gravity and radiation.

The damaging effects of microgravity

Bone Calcium Loss and Osteoporosis

Calcium is lost at 1% per month.

Calcium loss is not reduced by vigorous exercise.

Muscle Atrophy

Two weeks of zero gravity can atrophy muscles by 30%.

Exercise during spaceflight does not prevent muscle wasting.

Cardiovascular Deconditioning

Blood plasma and blood cells are lost, pulse duration and heart rate decrease.

Returning astronauts have reduced ability to work and exercise.

Sensory and Motor Deconditioning

Initial space motion sickness and continuing disorientation is common.

Returned astronauts experience imbalance, uncoordinated movement, and vertigo and nausea for months.

Regulatory Physiology Disruption

Changes occur in electrolyte balance, hormones, blood pressure, immune system, and circadian rhythms.

Will microgravity countermeasures or Moon/Mars gravity help?

Not much.

Exercise is suggested to prevent microgravity bone loss, muscle atrophy, and cardiovascular deconditioning.

- It does not work.
- After a long mission, crewmembers can’t lift their arms to remove their seat belts.
  - They must be helped to get out of the landing capsules.

Physiological deconditioning may be less severe in the partial gravity of the Moon or Mars.

- Heart rate, oxygen consumption, and metabolic rate seem correlated with simulated gravity from 0 to 1 g.
- Partial gravity seems insufficient to preserve body systems to a 1 g standard.

Artificial gravity can be provided by rotating spacecraft

Rotating spacecraft are the only way to provide artificial gravity in space.
Most past plans for space stations have suggested artificial gravity.

The main ideas are a wheel, a cylinder, and a habitat and mass joined by a tether.

- Konstantin Tsiolkovsky in 1903.
- Hermann Noordung in 1929 - a rotating wheel - 30-meter diameter.
- Werner von Braun in 1952 - a rotating wheel - 76-meter diameter for 0.3 g for Mars transit.
- Gerard O'Neil in 1977 - space colonies - a rotating cylinder - 5 mile diameter and 20 miles long.
- Johnson and Holbrow in 1977 - the Stanford torus - a rotating wheel - 1.1-mile diameter.
- Robert Zubrin in 1990 - a tethered rotating booster and habitat for Mars transit.

Rotating artificial gravity space habitats have not been built or planned in detail.
They have much greater mass and launch cost.
The recent great reduction in launch cost makes rotating habitats more feasible.

Spacecraft radius and spin rate

Artificial gravity should be Earth normal 1 g.

The force of artificial gravity increases with the rotation rate and the radius of rotation.

- Acceleration = radius * rpm

The maximum spin rate humans can tolerate is about 4 rotations per minute (rpm)

- The Coriolis effect produces disorientation and motion sickness.

A rotation of 4 rpm requires a habitat radius of 56 meters to produce 1 g.

- A very large diameter space habitat would rotate very slowly.

Advantages and disadvantages of rotating spacecraft

Key advantage - commonality between Earth and space hardware and processes.

- New systems needed for space can be developed and tested on Earth.
  - This avoids the high cost and risk of designing for zero gravity.
- Innovations developed on Earth can be directly used in space.

Disadvantages:

- Rotation will make external interaction and observation more difficult.
  - Propulsion, communication, solar power collection, and Earth and astronomical observation all require a fixed direction.
  - A split habitat with a rotating and non-rotating section would be difficult.
- Greater development cost and launch mass.

The damaging effects of space radiation

Solar and cosmic radiation can be harmful to humans in deep space and on the Moon and Mars.

- Earth is shielded by its magnetosphere.
- The Moon and Mars lack magnetic fields.

Solar flare particles are the major radiation hazard in space.

- Solar flares are unpredictable but occur more frequently near the sunspot maximum.
- They can build up in minutes and the radiation dose thousands or millions of times.
  - Dangerously large solar flares are rare but could cause radiation sickness.

Galactic cosmic rays are high energy particles emitted by distant stars.

- Cosmic rays cause less health damage than solar flares because of their lower particle flux density.
- Exposure to galactic **cosmic rays over a long period would greatly increase cancer** incidence and mortality.
  - Fatal cancer risk could increase by 1.5% to 2.8% per year of exposure.

Radiation shielding is required

Passive bulk material shielding is currently the only realistic approach.
- It requires high mass for adequate protection.

A safe haven from solar flares is doable.
- A 2-meter diameter aluminum sphere with 7.5 cm thick walls, weighing 2.5 metric tons.
- Volume is 4.2 m^3, room for one or two people.

Since galactic cosmic rays are omnidirectional, the entire living volume must be shielded.
- Shielding a volume of 100 m^3 for a single crewmember would require 78 metric tons to cut radiation by 3/4.
- But a large habitat with 1,000 crew is easier to shield, requiring only 6.5 metric tons per crewmember.

Mars bases also need artificial gravity and radiation shielding

The Martian atmosphere is thin but it does attenuate galactic cosmic rays.
- Solar flare and cosmic ray shielding are still needed.
  - One idea is to cover surface habitats with Martian regolith.

Mars gravity is probably insufficient to prevent the health problems caused by zero gravity.
- Some Mars habitat designs include artificial gravity.
  - One idea is to use a large rotating underground wheel.

A next step space habitat in low earth orbit

A near term rotating space habitat in LEO can avoid high radiation and the need for shielding.

Other advantages

- easier access from Earth
- a short communications delay
- close support for Earth surface and orbital systems

Its orbit would avoid the South Atlantic Anomaly

A high radiation area due to a gap the van Allen belts.

Human expansion into the solar system and galaxy

Humans may expand from Earth into the solar system.
- This will require the development of many permanent deep space habitats.

There is enough surface area at Earth's distance from the sun to allow one billion new Earths.
- There is sufficient mass and orbital space to allow that many space habitats.

Science, technology, and social systems seem to advance more rapidly as population increases.
- A solar-system-wide civilization would generate unimaginable progress.

Our galaxy contains about 300 billion stars.
- A disk about 100 thousand light years in diameter and one thousand light years thick.
- The typical distance between stars is a few light years.

Humans could travel to the stars using nuclear powered space habitats.

Conclusion

Establishing permanent human presence off Earth should begin by building space habitats with artificial gravity and radiation shielding.

- Weightlessness and radiation damage astronaut health.
- Artificial gravity and radiation shielding are needed so humans can live and raise families in space.

Permanently inhabited domes on the surface of the Moon and Mars are implausible.

- Bases on the Moon and Mars will require artificial gravity and radiation shielding.

The first rotating artificial gravity space habitat could be in LEO, where radiation shielding is not needed.

Permanent space habitats with artificial gravity and radiation shielding can enable human expansion into the solar system.

Nuclear powered space habitats can take us to the stars.


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