32nd Annual INCOSE international symposium

hybrid event

Detroit, MI, USA
June 25 - 30, 2022

Space Habitats Should Be 1 g Shielded Space Platforms, Not on Low Gravity, Radiation Exposed Moon or MarS

Harry Jones, NASA Ames Research Center

Overview

- Previous missions have subjected astronauts to confined space, weightlessness, and increased radiation.
  - These impair astronaut comfort, performance, and future health.
- The exploration and settlement of space require space platforms where humans can live in health for many years.
  - They need adequate volume, gravity, and radiation shielding.
- This seems easier to do in deep space or Low Earth Orbit (LEO) than on the surface of the moon or Mars.

Introduction

- Previous human space missions required astronaut assistance.
  - All missions had small living space, 0 gravity, and high radiation.
  - The astronauts' comfort and health were necessarily somewhat compromised.
- A NASA objective is to establish a permanent human presence in space.
  - This requires a space platform where humans can live in health for many years.
  - It would provide sufficient habitable space, artificial 1 g gravity, and radiation shielding.
- The first fully habitable space station would probably be in LEO for convenience and lower cost.
  - Future human space platforms could expand into far Earth orbit or deep space.
  - They almost certainly would not be located on the moon or Mars.

Locations for human expansion into space

- Why have the first fully habitable space platform located in LEO?
  - Nearly all human activity occurs on the surface of the Earth.
  - Higher orbits require additional rocket boost, so the cost per kilogram is higher.
- Beyond the Van Allen belts the radiation protection of Earth's magnetic field is lost.
  - The radiation from solar flares and galactic cosmic rays is much greater.
  - More shielding would be needed for long term stays.
- Next step - platforms orbiting the sun at Earth distance.
  - They would receive the same solar intensity as Earth.
- But not - the surfaces of the moon or Mars.
  - These locations have partial gravity, high radiation, and extreme temperatures.

Surface areas

Planet location	Surface area, millions of square miles	Relative area
Earth	196.9	1.00
Earth water surface	139.7	0.71
Earth land surface	57.2	0.29
Mars	55.9	0.28
Earth habitable land	40.2	0.20
Asia	17.2	0.09
Earth barren land and glaciers	17.1	0.09
Moon	14.6	0.07

Moon and Mars are smaller than Earth

Sphere	Surface area, millions of square miles	Relative area
Earth	196.9	1.00
LEO, 200 miles above Earth's surface	217.3	1.10
GEO, 22,236 miles above Earth's surface	8,622.7	43.79
Earth-moon radius sphere, 240 thousand miles	7.17. E+05	3,642.47
Earth-sun radius sphere, 93 million miles	1.09E+11	5.52E+08

Spheres in space at GEO, Earth-moon radius, and Earth-sun radius have much more area

Surface resources

- The most important resource is solar radiation.
- Earth, the moon, and Mars rotate, having day and night.
  - Earth and Mars have roughly the same one-day rotation period.
  - Mars is about 1.5 times the Earth's distance from the sun and so is cooler.
  - The moon rotates once a month and has much greater temperature extremes.
- An Earth-sun radius sphere centered on the sun would capture all the sun's radiation. (A Dyson sphere)
- The surfaces of the Earth, moon, and Mars provide material resources.
  - Space platforms would require materials from Earth or other bodies.
- The moon has about 1/6 Earth gravity and Mars about 1/3.
  - Additional artificial gravity seems needed.

Is there enough mass and orbital clearance for a large Dyson sphere?

- Freeman Dyson stated, “The mass of Jupiter, if distributed in a spherical shell revolving around the sun at twice the Earth's distance from it, would have a thickness such that … it could be made comfortably habitable.”
- In addition to a solid sphere, Dyson also proposed a spherical shell of many human habitats independently orbiting around their star at the same distance.
  - If two orbits intersect, they can be adjusted by using solar sails, ion engines, etc.

Adequate habitable volume

- The International Space Station (ISS) pressurized volume is 916 cubic meters.
  - For six astronauts, this is 153 cubic meters each.
- The average volume of a new house is 637 cubic meters.
  - For 2.5 people, this is 255 cubic meters per person.
- NASA exploration missions require much less, 25 cubic meters per person.
- The Red Cross recommends 50 to 75 cubic meters per person for prisons.

Artificial gravity

- Rotating spacecraft producing artificial gravity have been proposed many times, beginning with Tsiolkovsky in 1903.
  - The von Braun wheel, the Stanford torus, the O'Neil cylinder, and Zubrin's Mars Direct
- Rotating spacecraft are the only way to provide artificial gravity in space.
  - They are necessary for permanent human habitation.
- Artificial gravity human spacecraft have not been built largely because of their much greater mass and launch cost.
  - 0 g is tolerable for short periods.
  - 0 g counter measures such as exercise have some credibility.
  - 0 g is interesting for scientific and engineering research.

Problems of zero and partial gravity

- Astronauts spending weeks or months in zero g suffer serious health problems.
  - Muscle atrophy, cardiovascular deconditioning, bone calcium loss, impaired vision, and immune system change.
  - Extensive exercise does not prevent these problems.
- Living in microgravity or partial gravity can disturb balance, orientation, locomotion, eye-hand coordination, and orthostatic tolerance.
  - Orthostatic tolerance is the ability to prevent low blood pressure and dizziness when standing up.
- Partial gravity exposure below 0.4 g seems to be insufficient to maintain musculoskeletal and cardiopulmonary properties in the long-term.
  - Some models predict a loss of 1% monthly loss in bone mineral densityon the moon and a more for Mars.

Different rotating spacecraft designs

- The simplest is a single cable with a mass at each end.
  - Two human habitats or one balancing module with storage and other support.
- The most well-known design is a wheel or torus.
  - A cylinder is probably the easiest to build and expand.
- Split designs with rotating and non-rotating sections have been suggested for transit missions.
  - Rotation is a problem for directionally fixed functions, such as propulsion, communications, and solar power arrays.
  - Split designs are complex, with large rotating joints to connect the sections and transfer people, material, power, and communications.
- A fully rotating cylinder is structurally simple and saves mass and reduces risk.

Proposed artificial gravity space habitats

Year	Author	Concept
1903	Konstantin Tsiolkovsky	Spinning space vehicle. Concept 1888, publication 1956.
1929	Hermann Noordung (Herman Potočnik)	Rotating wheel with 30-meter diameter.
1929	John Bernal	A hollow nonrotating spherical shell with a 10 mile diameter.
1952	Werner von Braun	Rotating wheel, 76-meter diameter, 0.3 g for Mars transit.
1977	Gerard O'Neil	Rotating Bernal sphere, 1,800-meter diameter. O'Neil rotating cylinder, five mile diameter, 20 miles long.
1977	Johnson and Holbrow	Stanford torus, 1.1 mile diameter rotating wheel. Larger version of von Braun wheel.
1990	Robert Zubrin	Rotating tethered booster and habitat for Mars transit.

- Noordung, von Braun, and Zubrin propose smaller habitats for interplanetary travel, the latter two specifically for Mars transit.
- Bernal, O'Neil, and Johnson and Holbrow with the Stanford torus propose larger habitats with dimensions of miles for permanent human habitation in space.

Required radius and spin rate

- Artificial gravity for long term human habitation should be Earth normal 1 g.
- Increasing artificial gravity produced by rotation requires increasing either the radius of rotation or the rotation rate.
  - The usually assumed maximum spin rate based on human tolerance is 4 rotations per minute (rpm), which determines a minimum habitat radius of 56 meters.
- The maximum rotation rate of 4 rpm is set to limit human susceptibility to the Coriolis effect, an apparent force felt in a rotating system.
  - The force acts on the inner ear and can produce disorientation and motion sickness.
- Research in artificial gravity for smaller spacecraft has found that spin rate can be increased to 10 rpm.
  - For 10 rpm, 1 g can be achieved with a radius of 8.9 meters.

Radiation shielding is needed for SPEs

- Earth is largely shielded from radiation by its magnetosphere.
- Cosmic background radiation and solar flares can be harmful to humans in deep space and on the moon and Mars, which lack magnetic fields.
- The major radiation hazard in space is a Solar Particle Event (SPE) or solar flare.
  - SPEs produce radiation at frequencies from radio to X-rays and particles including electrons, protons, and heavy nuclei.
  - SPEs can build up in minutes and last for hours.
  - Solar flares are unpredictable but dangerously large flares are rare.
- A well shielded storm cellar is needed for solar flares.

Galactic cosmic ray shielding would be nice

- Galactic cosmic rays are emitted by distant stars and galaxies and come uniformly from all directions.
  - They consist of extremely high energy particles including electrons, protons, and heavy nuclei.
  - They have low flux density and so cause little damage compared to solar flares.
- Nevertheless, minimally shielded galactic cosmic rays over a long period would greatly increase cancer mortality.
  - Men in the US have a 40% chance of developing cancer and a 22% chance of dying from it.
  - Deep space cosmic rays could increase risk of dying by 2 or 3% per year.

Shielding mass and cost

- Passive bulk shielding is currently the only realistic approach, but it requires high mass for adequate protection.
- A solar flare safe haven for a few people would be a 2-meter diameter aluminum sphere with 7.5 cm walls, 20 g/cm, weighing 2.5 metric tons (MT).
  - At the current projected low launch cost of $1 k/kg, or $1 M/MT to LEO, this safe haven would cost $2.5 M to launch to LEO, $1M/person.
- Since galactic cosmic rays are omnidirectional, all habitation volume must be shielded.
- Reducing the galactic radiation to about half requires an 8 g/cm^2 shield and reducing it to one-quarter requires 50 g/cm^2.
  - The masses per crewmember would be 13 MT and 82 MT.
  - At launch cost of $1 M/MT to LEO, these shields would cost $13 M and $82 M per crew member to launch to LEO.

Long term expansion into the solar system using permanent deep space stations

- It is hoped that humans can expand from Earth into the solar system, capturing much of the sun's energy to support a solar civilization.
  - This will require permanent deep space habitats with artificial gravity and radiation shielding.
  - The metal for rotating habitat construction could be obtained from planets and asteroids, while hydrogen, oxygen, and carbon for shielding, propulsion, and life support could be obtained from comets and the outer gas giant planets and their satellites.
- Scientific and technical productivity seems to increase with the number of interacting individuals and their ability to cooperate and specialize.
  - Human expansion into the solar system would make possible scientific, technical, economic, political, and social advances that are now unimaginable.

Settling the moon or Mars is less feasible

- The moon and Mars have surface area less than the Earth.
- The moon lacks an atmosphere and magnetic field and requires radiation shielding.
- The Mars atmosphere attenuates galactic cosmic rays with a shielding value of about 16 - 22 g/cm2, but more shielding is required.
  - Underground habitats are suggested for moon and Mars.
- The moon’s 1/6 gravity and Mars 1/3 gravity seem insufficient to eliminate the problems of zero gravity, and artificial gravity is needed.
  - Rotating underground wheels are suggested.
- The moon’s month-long solar cycle and consequent extreme temperatures are problems not found in deep space.
- Solar light radiation is lower by half at Mars’ distance from the sun and temperatures are much colder.

Conclusion

- Large rotating artificial gravity space platforms were proposed long ago and radiation shielding has been added.
- But the “von Braun paradigm,” a space station in LEO, next visiting and colonizing the moon, and then on to Mars has been generally accepted since the 1950’s.
  - The von Braun paradigm” has met major difficulties, partial gravity and radiation.
- Artificial gravity shielded space platforms seem more feasible since they address these problems.

32nd Annual **INCOSE**
international symposium

hybrid event

Detroit, MI, USA
June 25 - 30, 2022

www.incose.org/symp2022