

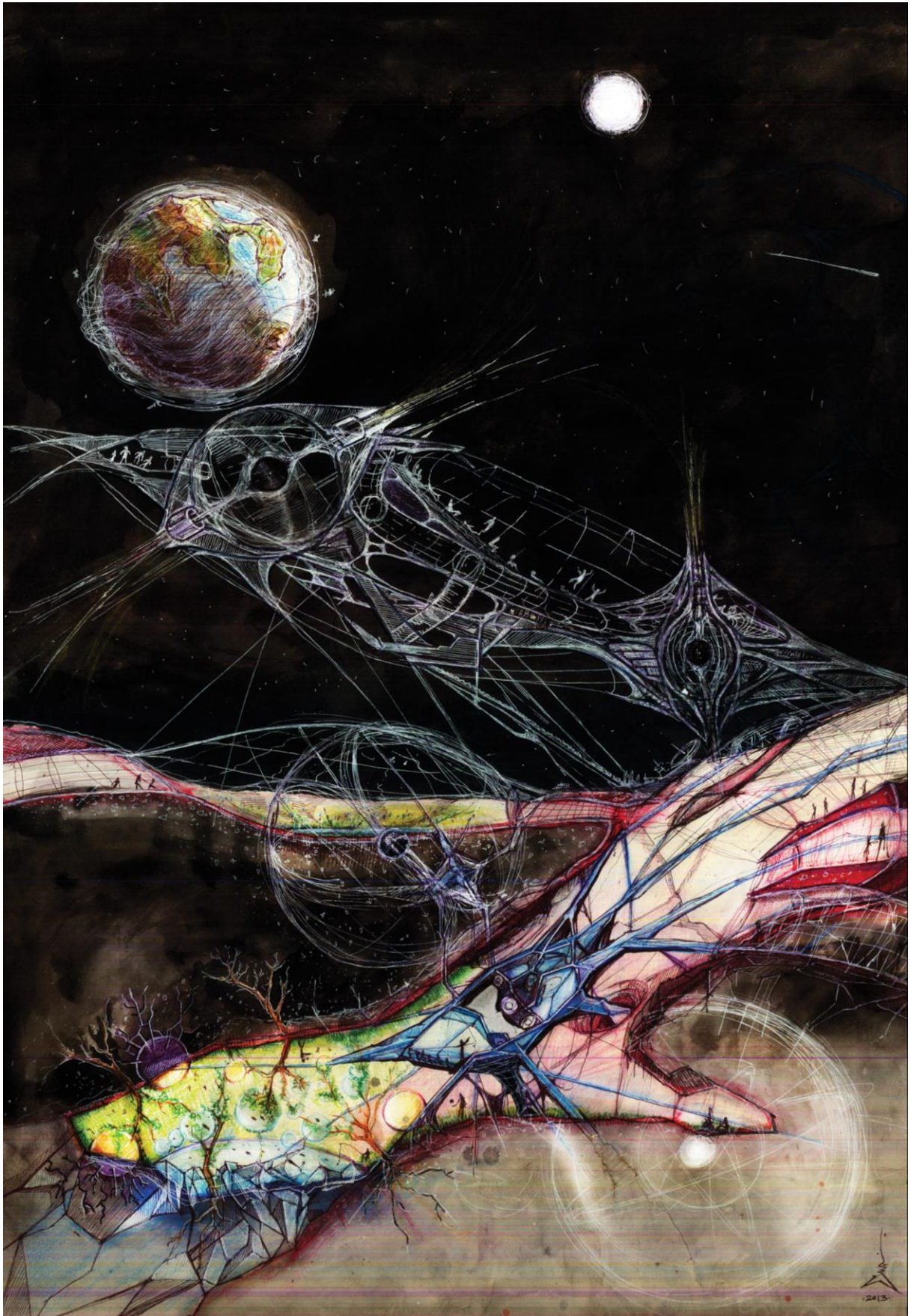
THESIS TITLE:

ANALYSIS AND SYNTHESIS OF SPATIAL QUALITY IN
1/6 GRAVITY OF EARTH – WITH RESPECT TO THE MOON –
WITH SPECIAL ATTENTION TO HUMAN PHYSIOLOGY
AND PSYCHOLOGICAL ESSENTIALS

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‘Listen to your Heart. Everything else will follow.’

- Theodore Emile, 2013.

ABSTRACT

“Three things cannot be long hidden: the Sun, the Moon, and the Truth.”

- BUDDHA

You are on a ship floating in the vast ocean of space. You can fly to the moon and back. And on the moon you sing to break the silence and dance with melodies of music and gaze upon the vastness of space. You find yourself in between the past and the future. Living within Earth Bound Dreams. For fortnights of Light and fortnights of Darkness you are floating inside the vast voids of the soul. With dreams of tomorrow drifting gently across of the universe.

Our dreams shape realities and our knowledge challenges space and time, with inspirations and exposures into the known and the unknown. Experiences define us and in turn are reflected in our actions. The human mind, the world of dreams – The Brain – drives cars, calculates complex math problems, draws comic fantasies, writes literary wonders, measures distances, cooks fancy dishes, dances with music and sings to make sense of it all; we remember and we forget; we forge the future, reconstruct the past and govern the present. We work collectively and display cognitive attitude. We reveal emotions and expose craziness. We transform with experiences. We are the bridge between the dream world and the reality of it all. We are Humane.

Nevertheless look at what we have achieved. We have analysed the globe and beyond in search of the blueprint of the universe to know about ourselves, why we are and who we are. We have found ways to mimic ourselves by constructing machines and enter other thresholds of existence, creating new layers of possibilities. That is, in an era where human population is growing in an exponential rate, and we are aided by technology for global, climatic, spiritual, political and individual transformations. The bridge, silver lining, between war and peace is hence forever constant and in contrast. We humans are the agent of order and change.

I started this project as a conceptual experimentation and evolution on self, investigating into ones core; important for the future generations to dream for themselves under the reflection of the moon, and unlock their creative potential; which will continue with top down, bottom up, qualitative and quantitative background study of Outer Space, Lunar Architectural Analysis, Human Anthropometry and Biomechanics in artificial gravity, Human Psychology, Geometric Analysis and Transformation of Form and Function. One must make great leaps to unlock oneself, of human nature and of one's creative potential. The results unfold through the course of time. Future design solutions can be prepared based on the studies made in this paper. Please refer to the bibliography for expanded information on this research. Should we return to the Moon, is a decision beyond one man's comprehension. But that doesn't stop one from dreaming.

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CHAPTER | 1

INTRODUCTION

Life is a fascinating thing, has a source of origin – birth, and an inevitable fate – death. And such is true for the entire universe. They say it all started with the Big Bang and will eventually expire with the Big Crunch. That is the base of our knowledge at the dawn of the 21st century.

We dwell on planet Earth, the third planet in our solar system, along with other planets orbiting around the 5 billion years old star – the Sun. The enormous mass of the Sun influences the gravitational fields of the planets and holds them in their distinct orbits. Our Earth is a work of art, a complex system made up of various interconnected processes that keep conditions stable and suitable for life. Diverse forms of life prosper on Earth, because of bizarre and spontaneous chemical reactions co-existing in every instant on the surface of the planet. But our Earth is a casualty of solar radiation and cosmic rays. Celestial radiations constantly cross Earth's orbit, threatening all life. Countless 'Extinction-Level Events' would have sterilized the surface of our planet had it not been for our constant companion and benefactor; a body which unintentionally wards away many of the ills that could befall us – the Moon.

The Moon is unique amongst other celestial bodies; there is no other satellite closer in size and composition to its mother-planet; the Earth–Moon system is the only tidally locked pair. Furthermore, it also happens to be the only moon in the solar system which is orbiting an intelligent civilization – a factor which may not be a mere coincidence. At the time Earth was formed 4.5 billion years ago, other smaller planetary bodies were also growing. One particularly promising young Proto-Planet, Thia, hit Earth late in its growth process, blowing out rocky debris. A fraction of that debris went into orbit around the Earth and aggregated into the Moon. This hypothesis is based on the findings by astrophysicist V. S. Safronov, and later by Hartmann and Davis. This theory verifies why Earth has a much larger iron core density than the Moon, and why the oxygen isotope composition of the Moon is exactly the same as the Earth. 'The Moon today is as it has been for about 3 billion years. Volcanism has ended. Meteorite impacts are rare. The quiet landscape awaits human intervention'. (William K. Hartmann)

Observations of the solar system show us that the Moon's birth was rather unusual. All of the other worlds either lack satellites or have captured them from other places. Of course the moon isn't Earth's only unusual resident; Earth's surface crawls with all manner of bizarre and delicate carbon-based life forms. The Rare Earth Theory hypothesizes that a large moon

such as ours is not merely a benefit for life, but essentially a requirement. The tidal fluctuations due to the gravitational attraction of the moon have been invaluable to the evolution of life on our planet; the regular shift of dry and wet ocean current, has given way for prehistoric life forms to reach out of the ocean and take advantage of this gradual change to adapt to the diverse environment outside the ocean.

In this unlikely set of circumstances brought forth by our moon, perhaps Earth is the only planetary system in the entire, vast universe, hospitable for life. But every once in a great while, when the time is right, two proto planets bump into each other and life can come together. Without the magical astronomical event we certainly would not be here.

The chapters in this thesis paper are revealed in the following layout.

Chapters 2 will continue with a brief study on the nature of our Universe, the Earth and the Moon, based on our current understanding of the space and time.

Chapter 3 consists of the study of Human Intervention in Outer Space, gathered information about Anthropometry and Biomechanics of Humans in space from International Space Agencies.

Chapter 4 deals with Architectural Considerations in Micro Gravity and essential guidelines required for space flight.

Chapter 5 contains a brief on current thoughts and resources about lunar discoveries, and future assumptions.

Chapter 6 ventures into outer space and the architectural implications in artificial gravity.

Chapter 7 consists of the synthesis and sketches drawn during the thesis timeline.

Chapter 8 is conclusion and future potentials of the research.

CHAPTER | 2

2.1 | THE BIG BANG AND THE UNIVERSE



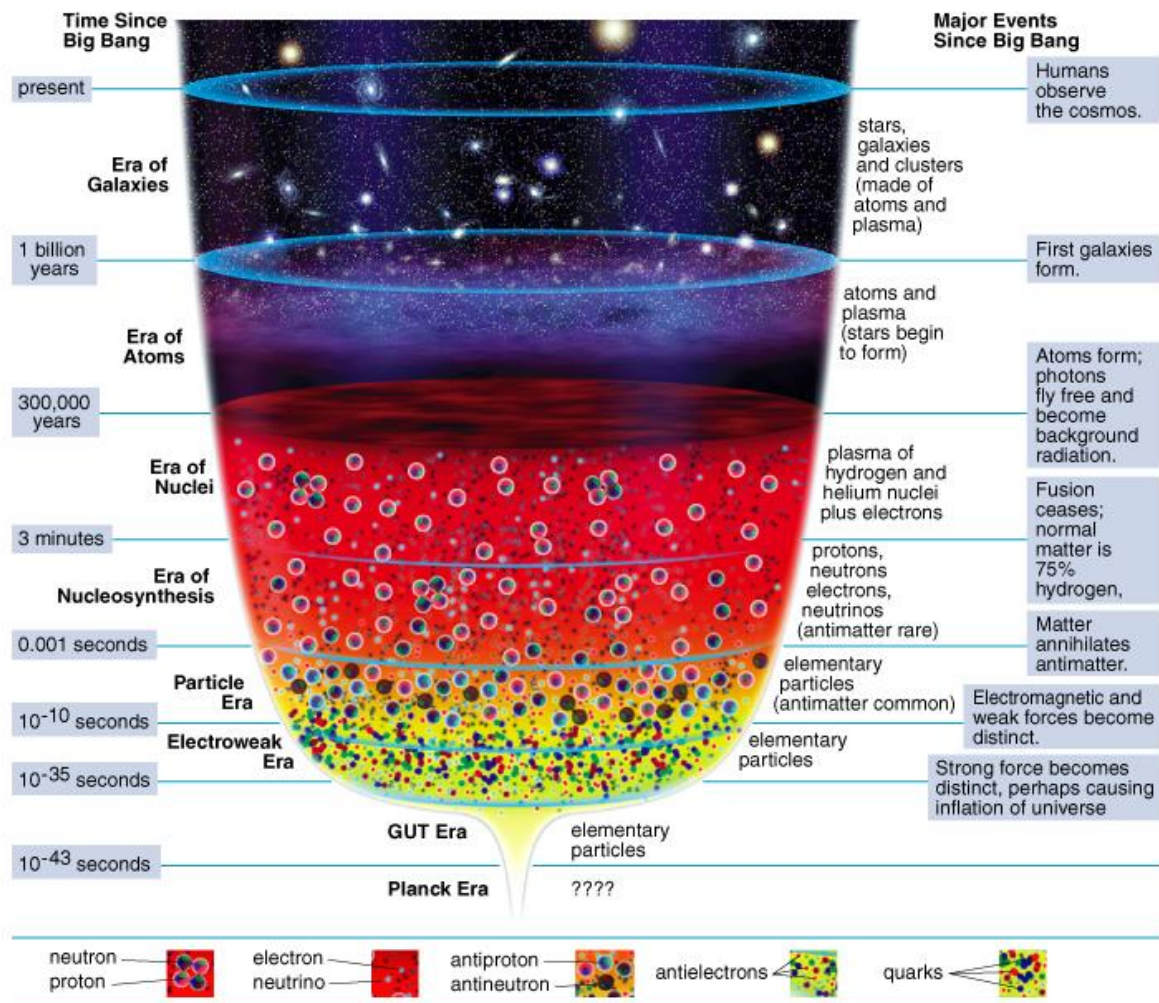
"I think that if it had been a religion that first maintained the notion that all the matter in the entire universe had once been contained in an area smaller than the point of a pin, scientists probably would have laughed at the idea."

Marilyn Vos Savant, February 1996,

In the beginning there was a Big Bang. Our Universe today is much different from the one it was few billions years ago. Scientists have yet to determine how it all begun, what we know now is that it started in an instant and it begun to expand rapidly from a singularity – The Big Bang. As of 2013, this expansion is estimated to have begun 13.798 ± 0.037 billion years ago. It is convenient to divide the evolution of the universe so far into few phases.

- PLANCK ERA - The time just before the Planck time ($1/10^{43}$ seconds). In this era, random energy fluctuations were so large that we cannot explain the physics at these high energies. Energy and mass are equivalent and so energy fluctuations cause changes in space and time. These fluctuations arise naturally out of the 'Heisenberg Uncertainty Principle'. So far, we do not know what happens during this time.
- GUT ERA - GUT stands for Grand Unified Theories. This is a theory that unites three of the four known forces. The four forces are Gravity, Electromagnetism, the Weak Force, and the Strong Force. GUT combines the strong force with the electroweak force (the combination of weak and electromagnetic force). The forces are separate but under high temperatures they come together. So the GUT era is when Gravity and GUT force

controlled the Universe. During the GUT Era is when we think INFLATION occurred - the point in which the Universe underwent a dramatic expansion. When the strong force froze out of the GUT force, caused an enormous release of energy. Inflation is an important aspect of the Big Bang since it explains the structure, the smoothness, and the fact that we are at the critical density.



© Addison-Wesley Longman

Image comment: Schematic showing the history of the Universe, according Big Bang theory.

Image source: maths.monash.edu

- **ELECTROWEAK ERA** - The electromagnetic and weak forces were still united. Conditions of this era were actually achieved in a particle accelerator in 1983.
- **PARTICLE ERA** - During this era the Universe was just the right temperature for particles to be created and destroyed continuously. What happens is the photons have the right energy to come together and annihilate each other to form matter and antimatter. And then the matter and antimatter smash together and form gamma-rays. This continues

until the Universe cools enough such that the photons do not have enough energy anymore to create particles, and we are then stuck with whatever was left at that point. At the end of the particle era, there were slightly more protons than antiprotons. For every billion antiprotons there were a billion and one protons. Another way to look at it is one billion protons were annihilated with one billion antiprotons to make a billion photons, which would result in leaving one proton in the end. It is this slight excess that makes up most of the matter in the Universe.

- **NUCLEOSYNTHESIS ERA** - Protons and Neutrons would come together for a short while before interactions broke them up again. Essentially, the Universe was a big continuous fusion reaction. This era ended when the Universe was 3 minutes old. It was at the end of this era that set the chemical composition of the Universe.
- **ERA of NUCLEI** - During this time, protons and neutrons were together in nuclei. Electrons would form an atom with this nucleus but would soon be ionized as a photon hit it. Thus, neither an atom could form nor could a photon travel very far. At the end of this era the Universe was cool enough that photons did not instantly destroy atoms and very quickly the electrons found the nuclei, and the photons were free to travel around. This is what makes the cosmic background radiation and it happened at a temperature of 3000 Kelvin (about the temperature on the surface of red giant stars).
- **ERA of ATOMS** - this era is marked by the first structures beginning to form and it blends in with the ERA of GALAXIES. This is about the time when astronomers take over from physicists in terms of trying to explain the Universe. The era of atoms lasts for a long time and is sometimes referred to as the **DARK AGES**: that point where we have essentially no information on what was going on. Galaxies had not formed yet and so we don't see bright objects. However, gamma-ray bursts may allow us to penetrate into this era. It is during this era that maybe black holes played a key role in terms of galaxy formation. Also, dark matter is crucial to understand as well. There are a few missions planned to observe the dark ages. Because it is at such a high red shift, the important features are shifted out of the normal wavelengths that we like to observe in (i.e., the optical). Through infrared observation we can gain information about this era.

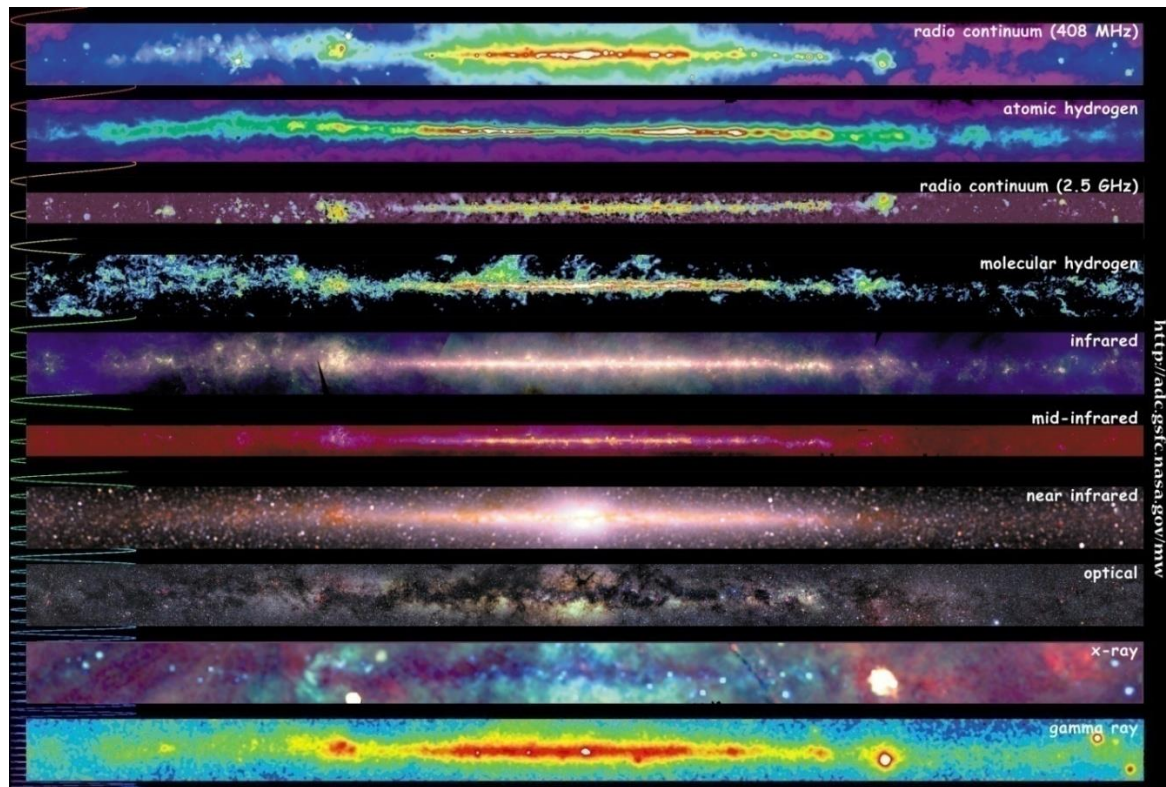


Image comment: Multi wavelength of the Milky Way

Image source: <http://adc.gsfc.nasa.gov/mw>

2.1.1 | STRUCTURE FORMATION

Structure formation in the big bang model proceeds hierarchically, with smaller structures forming before larger ones. The first structures to form are Quasars, which are thought to be bright, early active galaxies, and Population III stars. Before this epoch, the evolution of the universe could be understood through linear cosmological perturbation theory: that is, all structures could be understood as small deviations from a perfect homogeneous universe. This is computationally relatively easy to study. At this point non-linear structures begin to form, and the computational problem becomes much more difficult, involving, for example, N-body simulations with billions of particles. The first stars and quasars form from gravitational collapse. The intense radiation they emit Re-ionizes the surrounding universe. From this point on, most of the universe is composed of plasma.

2.1.1.1 | FORMATION OF STARS

The first stars, most likely Population III stars, form and start the process of turning the light elements that were formed in the Big Bang (hydrogen, helium and lithium) into heavier elements. However, as yet there have been no observed Population III stars, and understanding of them is currently based on computational models of their formation and evolution.

Large volumes of matter collapse to form a galaxy. The Hubble Ultra Deep Field shows a number of small galaxies merging to form larger ones, at 13 billion light years, when the Universe was only 5% its current age. Based upon the emerging science of Nucleo-Cosmo-Chronology, the Galactic thin disk of the Milky Way is estimated to have been formed 8.8 ± 1.7 billion years ago. Gravitational attraction pulls galaxies towards each other to form Groups, Clusters and Super Clusters.

2.1.1.2 | FORMATION OF THE SOLAR SYSTEM

The Solar System began forming about 4.6 billion years ago, or about 9 billion years after the Big Bang. A molecular cloud made mostly of hydrogen and traces of other elements began to collapse, forming a large sphere in the center which would become the Sun, as well as a surrounding disk. The surrounding accretion disk would coalesce into a multitude of smaller objects that would become planets, asteroids, and comets. The Sun is a late-generation star, and the Solar System incorporates matter created by previous generations of stars.

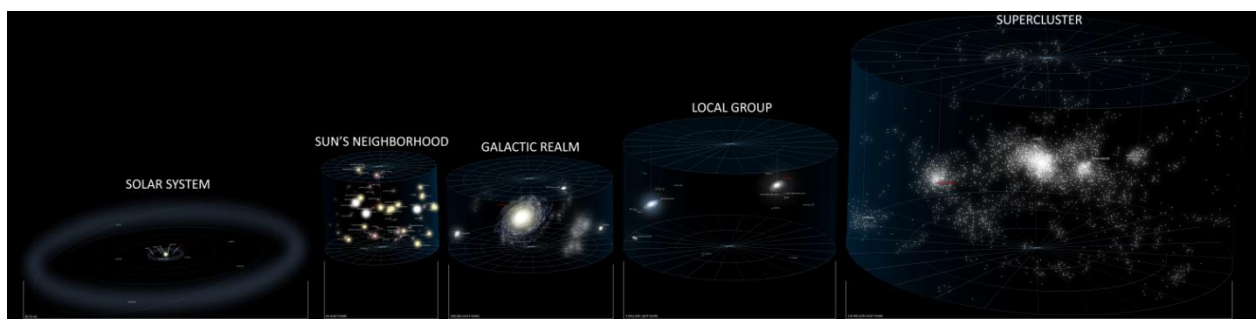


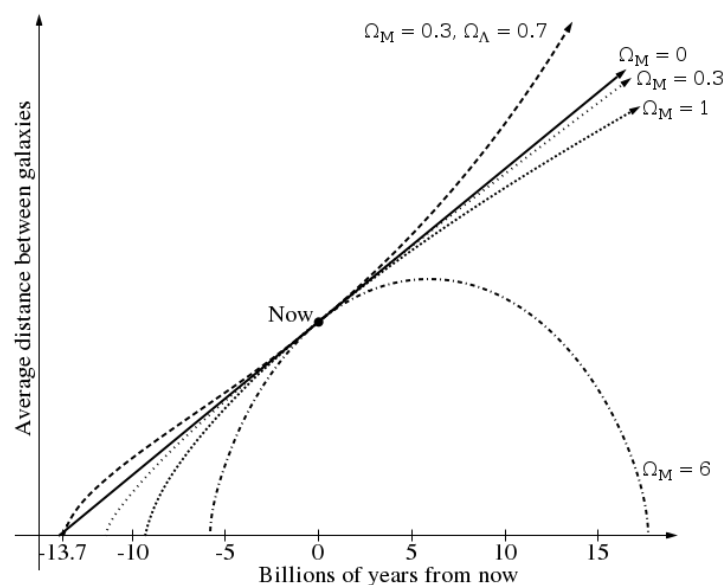
Image comment: Universe_Reference_Map

Image source: <http://upload.wikimedia.org/wikipedia/>

2.1.2 | FATE OF THE UNIVERSE

To understand what happened in the very early universe, advances in fundamental physics are required before it will be possible to know the ultimate fate of the universe with any certainty. Below are some of the major possibilities.

The current scientific consensus of most cosmologists is that the ultimate fate of the universe depends on its overall shape, how much dark energy it contains, and on the equation of state which determines how the dark energy density responds to the expansion of the universe. Recent observations have shown that, from 7.5 billion years after the Big Bang onwards, the expansion rate of the universe has actually been increasing, commensurate with the Open Universe theory. Recent measurements by Wilkinson Microwave Anisotropy Probe have confirmed that the universe is flat.



CLOSED UNIVERSE

If $\Omega > 1$, then the geometry of space is closed like the surface of a sphere. The sum of the angles of a triangle exceeds 180 degrees and there are no parallel lines; all lines eventually meet. The geometry of the universe is, at least on a very large scale, elliptic. In a closed universe lacking the repulsive effect of dark energy, gravity eventually stops the expansion of the universe, after which it starts to contract until all matter in the universe collapses to a point, a final singularity termed the "Big Crunch", by analogy with Big Bang. However, if the universe has a significant amount of dark energy then the expansion of the universe can continue forever—even if $\Omega > 1$.

OPEN UNIVERSE

If $\Omega < 1$, the geometry of space is open, i.e., negatively curved like the surface of a saddle. The angles of a triangle sum to less than 180 degrees, and lines that do not meet are never equidistant; they have a point of least distance and otherwise grow apart. The geometry of such a universe is hyperbolic. Even without dark energy, a negatively curved universe expands forever, with gravity barely slowing the rate of expansion. With dark energy, the expansion not only continues but accelerates. The ultimate fate of an open universe is either universal heat death, the "Big Freeze", or the "Big Rip", where the acceleration caused by dark energy eventually becomes so strong that it completely overwhelms the effects of the gravitational, electromagnetic and strong binding forces. Conversely, a negative cosmological constant, which would correspond to a negative energy density and positive pressure, would cause even an open universe to recollapse to a big crunch. This option has been ruled out by observations.

FLAT UNIVERSE

If the average density of the universe exactly equals the critical density so that $\Omega = 1$, then the geometry of the universe is flat: as in Euclidean geometry, the sum of the angles of a triangle is 180 degrees and parallel lines continuously maintain the same distance. Measurements from Wilkinson Microwave Anisotropy Probe have confirmed the universe is flat with only a 0.4% margin of error. Absent of dark energy, a flat universe expands forever but at a continually decelerating rate, with expansion asymptotically approaching zero. With dark energy, the expansion rate of the universe initially slows down, due to the effect of gravity, but eventually increases. The ultimate fate of the universe is the same as an open universe.

- FATE OF THE SOLAR SYSTEM: 1 TO 5 BILLION YEARS

Over a timescale of a billion years or more, the Earth and Solar System are unstable. Earth's existing biosphere is expected to vanish in about a billion years, as the Sun's heat production gradually increases to the point that liquid water and life are unlikely; the Earth's magnetic fields, axial tilt and atmosphere are subject to long term change; and the Solar System itself is chaotic over million- and billion-year timescales; Eventually in around 5.4 billion years from now, the core of the Sun will become hot enough to trigger hydrogen fusion in its surrounding shell. This will cause the outer layers of the star to expand greatly, and the star will enter a phase of its life in which it is called a red giant. Within 7.5 billion years, the Sun will have expanded to a radius of 1.2 AU—256 times its current size, and studies announced in 2008 show that due to tidal interaction between Sun and Earth, Earth would actually fall back into a lower orbit, and get engulfed and incorporated inside the Sun before the Sun reaches its largest size, despite the Sun losing about 38% of its mass. The Sun itself will continue to exist for many billions of years, passing through a number of phases, and eventually (if nothing else changes) ending up as a long-lived white dwarf. Eventually, after billions more years, the Sun will finally cease to shine altogether, becoming a black dwarf.

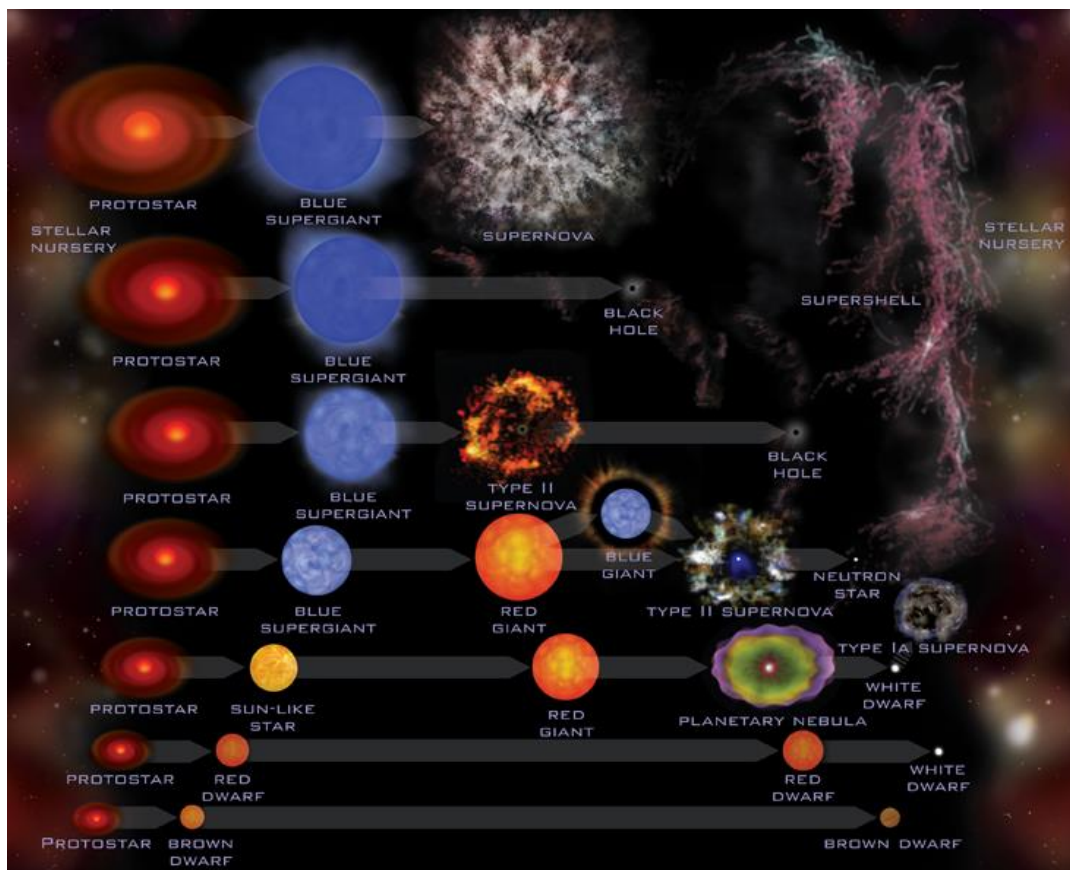


Image comment: Stellar Evolution

Image source: <http://web.jasper.k12.ga.us/~tharty/files/Extracurricular/ScienceOlympiad/2013/>

- **BIG FREEZE: 10^{14} YEARS AND BEYOND**

This scenario is generally considered to be the most likely, as it occurs if the universe continues expanding as it has been. Over a time scale on the order of 10^{14} years or less, existing stars burn out, stars cease to be created, and the universe goes dark. Over a much longer time scale in the eras following this, the galaxy evaporates as the stellar remnants comprising it escape into space, and black holes evaporate via Hawking radiation. In some grand unified theories, proton decay after at least 10^{34} years will convert the remaining interstellar gas and stellar remnants into leptons (such as positrons and electrons) and photons. Some positrons and electrons will then recombine into photons. In this case, the universe has reached a high-entropy state consisting of a bath of particles and low-energy radiation. It is not known however whether it eventually achieves thermodynamic equilibrium.

- **BIG CRUNCH: 100+ BILLION YEARS FROM NOW**

If the energy density of dark energy were negative or the universe were closed, then it would be possible that the expansion of the universe would reverse and the universe would contract towards a hot, dense state. This is a required element of oscillatory universe scenarios, such as the cyclic model, although a Big Crunch does not necessarily imply an oscillatory Universe. Current observations suggest that this model of the universe is unlikely to be correct, and the expansion will continue or even accelerate.

- **BIG RIP: 20+ BILLION YEARS FROM NOW**

This scenario is possible only if the energy density of dark energy actually increases without limit over time. Such dark energy is called phantom energy and is unlike any known kind of energy. In this case, the expansion rate of the universe will increase without limit. Gravitationally bound systems, such as clusters of galaxies, galaxies, and ultimately the Solar System will be torn apart. Eventually the expansion will be so rapid as to overcome the electromagnetic forces holding molecules and atoms together. Finally even atomic nuclei will be torn apart and the universe as we know it will end in an unusual kind of gravitational singularity. At the time of this singularity, the expansion rate of the universe will reach infinity, so that any and all forces (no matter how strong) that hold composite objects together (no matter how closely) will be overcome by this expansion, literally tearing everything apart.

- VACUUM METASTABILITY EVENT

If our universe is in a very long-lived false vacuum, it is possible that a small region of the universe will tunnel into a lower energy state, also known as Nucleation. If this happens, all structures within will be destroyed instantaneously and the region will expand at near light speed, bringing destruction without any forewarning.

- HEAT DEATH: $10^{150}+$ YEARS FROM NOW

The heat death is a possible final state of the universe, estimated at after 10^{150} years, in which it has "run down" to a state of no thermodynamic free energy to sustain motion or life. In physical terms, it has reached maximum entropy (because of this, the term "entropy" has often been confused with Heat Death, to the point of entropy being labeled as the "force killing the universe"). The hypothesis of a universal heat death stems from the 1850s ideas of William Thomson (Lord Kelvin) who extrapolated the theory of heat views of mechanical energy loss in nature, as embodied in the first two laws of thermodynamics, to universal operation.

Scientific understanding of the ultimate fate of life in the universe merges almost flawlessly into science fiction. Many works describe the end of the universe — rarely purely educational exercises describing theories of the day, more often exploiting its potential as the ultimate sense of wonder plot device, or mocking the pretensions of humanity in general and cosmologists in particular. Science fiction can try to suggest a scientific eschatology that searches for meaning in the face of the new knowledge. Countless sci-fi fantasy works use the threatened destruction of the universe as their plot device, usually with an evil super villain and/or the incompetence of humanity as the cause, and usually with human ingenuity saving the day.

Religion is not wholly excluded from science fiction's explorations of the end of our universe. Olaf Stapledon's 1937 science fiction novel 'Star Maker' describes intelligent life in the far future in each galaxy merging into hive mind-like Galactic Minds which themselves finally merge into a Cosmic Mind which, ascending into hyperspace, encounters God (the Star Maker). The "Star Maker" reveals to the "Cosmic Mind" a vision of the simpler Cosmoses He created in the past and of those more complex Cosmoses He will create in the future.

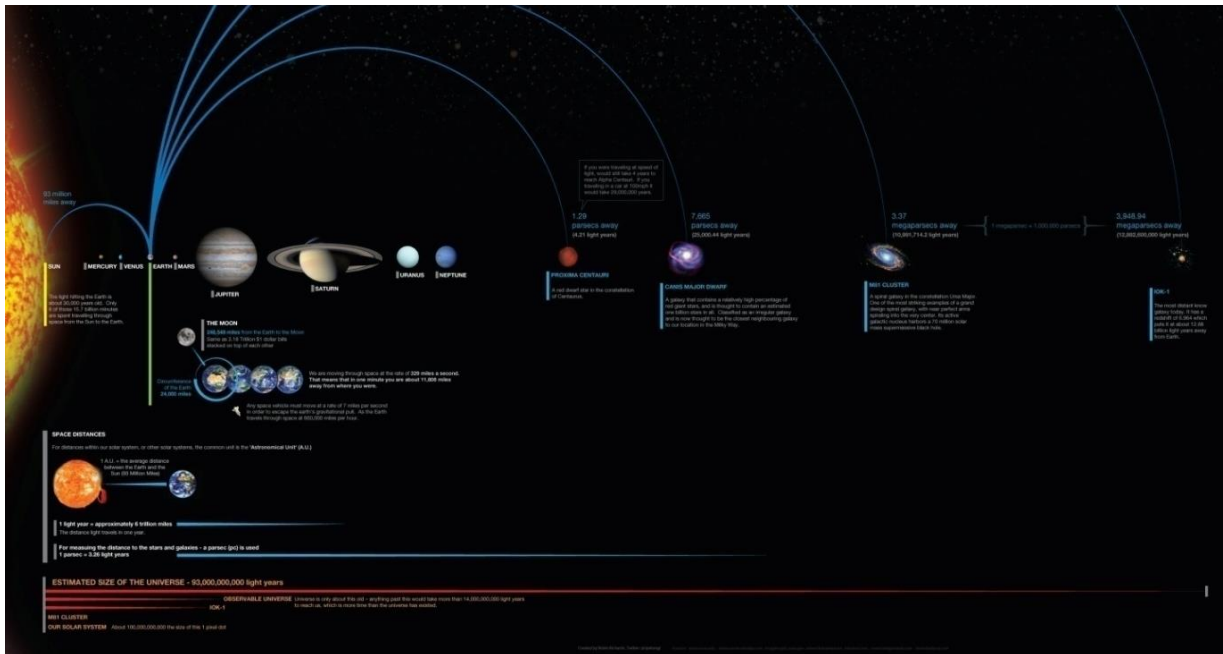


Image comment: The Size of the Universe

Image source: <http://ripetungi.com/the-size-of-the-universe/>

2.2 | THE SOLAR SYSTEM

When we gaze up upon the cosmic ocean, our existence seems so futile and empty. We often ask ourselves the question, are we alone? From our small world our decisions and choices make little or no change in the bigger picture, or do they? Our actions have a cause and effect on earth and the spaces we dwell in. The act of observation is changing the universe as it is; and as we are expanding our consciousness far beyond physical Earth, as well as deep into the matrix of Earth, we start to understand there are greater forces at work, a cosmological consciousness at play. Stargazers and astronomers in ancient times observed points of light that appeared to move among the stars. They called these objects Planets, meaning Wanderers, and named them after Roman deities - Jupiter, king of the gods; Mars, the god of war; Mercury, messenger of the gods; Venus, the goddess of love and beauty; and Saturn, father of Jupiter and god of agriculture.

A Solar System can be defined as a star and all the objects orbiting it as well as all the material in that system. Our solar system includes the Sun together with the eight planets and their moons as well as all other celestial bodies that orbit the Sun. Since the invention of the telescope, three more planets have been discovered in our solar system: Uranus (1781), Neptune (1846) and Pluto (1930). In addition, our solar system is populated by thousands of small bodies such as asteroids and comets. Most of the asteroids orbit in a region between the orbits of Mars and Jupiter, while the home of comets lies far beyond the orbit of the dwarf planet Pluto, in the Oort Cloud.

The four planets closest to the Sun -- Mercury, Venus, Earth, and Mars -- are called the terrestrial planets because they have solid rocky surfaces. The four large planets beyond the orbit of Mars -- Jupiter, Saturn, Uranus, and Neptune -- are called the gas giants. Beyond Neptune, on the edge of the Kuiper Belt, tiny, distant, dwarf planet Pluto has a solid but icier surface than the terrestrial planets.

2.2.1 | THE SUN

The centre of our solar system - the Sun - produces temperatures and densities in its core, high enough to sustain nuclear fusion, and mostly radiation into space as electromagnetic radiation. The Sun is a type G2 main-sequence star, a population I star; it was born in the later stages of the universe's evolution and thus contains more elements heavier than hydrogen and helium than the older population II stars. Elements heavier than hydrogen and helium were formed in the cores of ancient and exploding stars, so the first generation of stars had to die before the universe could be enriched with these atoms.

2.2.2 | INTERPLANETARY MEDIUM

The vast majority of the volume of the Solar System consists of a near-vacuum known as the interplanetary medium. However, along with light, the Sun radiates a continuous stream of charged particles (a plasma) known as the solar wind. This stream of particles spreads outwards at roughly 1.5 million kilometres (932 thousand miles) per hour, creating a tenuous atmosphere (the heliosphere) that permeates the interplanetary medium out to at least 100 AU. Activity on the Sun's surface, such as solar flares and coronal mass ejections, disturb the heliosphere, creating space weather and causing geomagnetic storms.

Earth's magnetic field stops its atmosphere from being stripped away by the solar wind. Venus and Mars do not have magnetic fields, and as a result, the solar wind causes their atmospheres to gradually bleed away into space. Coronal mass ejections and similar events blow a magnetic field and huge quantities of material from the surface of the Sun.

2.2.3 | INNER SOLAR SYSTEM

The inner Solar System is the traditional name for the region comprising the terrestrial planets and asteroids. Composed mainly of silicates and metals, the objects of the inner Solar System are relatively close to the Sun; the radius of this entire region is shorter than the distance between the orbits of Jupiter and Saturn.

The four inner or terrestrial planets have dense, rocky compositions, few or no moons, and no ring systems. They are composed largely of refractory minerals, such as the silicates, which form their crusts and mantles, and metals such as iron and nickel, which form their cores. Three of the four inner planets (Venus, Earth and Mars) have atmospheres substantial enough to generate weather; all have impact craters and tectonic surface features such as rift valleys and volcanoes. The term inner planet should not be confused with inferior planet, which designates those planets that are closer to the Sun than Earth is (i.e. Mercury and Venus).

Asteroids are small Solar System bodies composed mainly of refractory rocky and metallic minerals, with some ice. The asteroid belt occupies the orbit between Mars and Jupiter, between 2.3 and 3.3 AU from the Sun. It is thought to be remnants from the Solar System's formation that failed to coalesce because of the gravitational interference of Jupiter. Asteroids range in size from hundreds of kilometers across to microscopic. All asteroids except the largest, Ceres, are classified as small Solar System bodies.

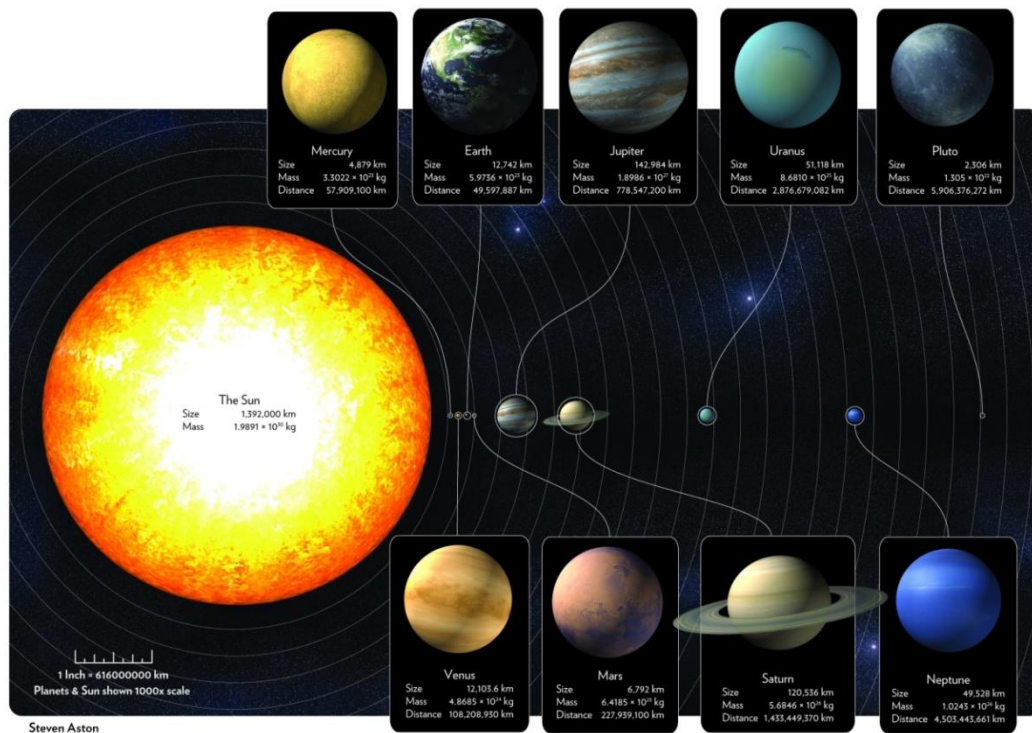


Image comment: Solar System Details

Image source: www.bestinfographics.info/solar-system/

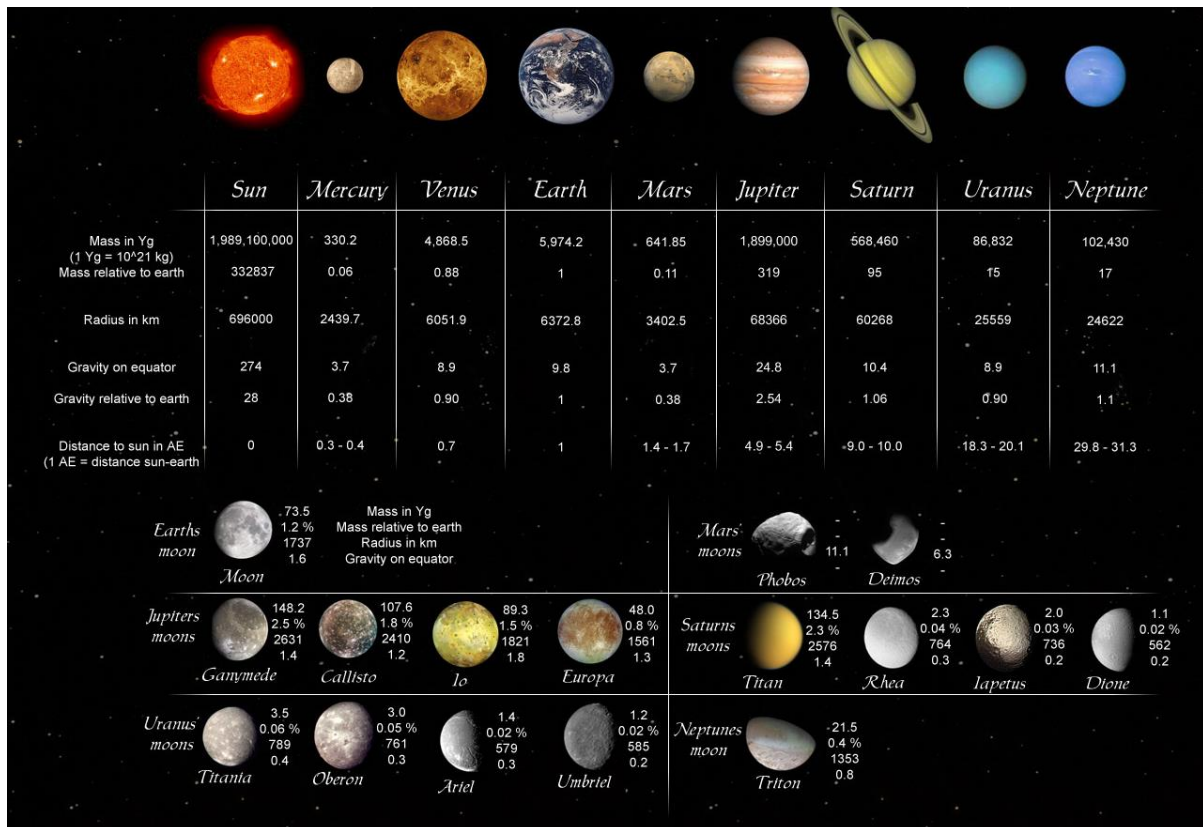


Image comment: The Solar System

Image credits: mail.colonial.net/~hkaiter/solarsysteminfo.html

2.2.4 | OUTER SOLAR SYSTEM

The outer region of the Solar System is home to the gas giants and their large moons. Many short-period comets, including the centaurs, also orbit in this region. Due to their greater distance from the Sun, the solid objects in the outer Solar System contain a higher proportion of volatiles, such as water, ammonia and methane, than the rocky denizens of the inner Solar System because the colder temperatures allow these compounds to remain solid.

The four outer planets, or gas giants collectively make up 99% of the mass known to orbit the Sun. Jupiter and Saturn are each many tens of times the mass of the Earth and consist overwhelmingly of hydrogen and helium; Uranus and Neptune are far less massive (<20 Earth masses) and possess more ices in their makeup. For these reasons, some astronomers suggest they belong in their own category, "Ice Giants". All four gas giants have rings, although only Saturn's ring system is easily observed from Earth. The term outer planet should not be confused with superior planet, which designates planets outside Earth's orbit and thus includes both the outer planets and Mars.

2.3 | THE SUN



Our solar system's central star - the Sun - has inspired mythological stories in cultures around the world, including those of the ancient Egyptians, the Aztecs of Mexico, Native American tribes of North America and Canada, the Chinese and many others. A number of ancient cultures built stone structures or modified natural rock formations to mark the motions of the sun and Earth's Moon - they charted the seasons, created calendars and monitored solar and lunar eclipses. These architectural sites show evidence of deliberate alignments to astronomical phenomena: sunrises, moonrises, moonsets, even stars or planets. Many cultures believed that the Earth was immovable and the sun, other planets, and stars revolved around it. Ancient Greek astronomers and philosophers knew this geocentric concept from as early as the 6th century B.C. The sun has many names in many cultures. The ancient Greeks called it Helios and the ancient Romans called it "Sol," which was translated into sun in modern English.

The sun is the closest star to Earth, at a mean distance from our planet of 149.60 million km (92.96 million miles). This distance is known as an astronomical unit (abbreviated AU), and sets the scale for measuring distances all across our solar system. The sun, a huge sphere of mostly ionized gas, supports life here on Earth. The connection and interactions between the sun and Earth drive the seasons, ocean currents, weather and climate.

About one million Earths could fit inside the sun. It is held together by gravitational attraction, producing immense pressure and temperature at its core. The sun has six regions -- the

core, the radiative zone, and the convective zone in the interior; the visible surface (the photosphere); the chromosphere; and the outermost region -- the corona.

At the core, the temperature is about 27 million degrees Fahrenheit (15 million degrees Celsius), which is sufficient to sustain thermonuclear fusion. The energy produced in the core powers the sun and produces essentially all the heat and light we receive on Earth. Energy from the core is carried outward by radiation, which bounces around the radiative zone, taking about 170,000 years to get from the core to the convective zone. The temperature drops below 3.5 million degrees Fahrenheit (2 million degrees Celsius) in the convective zone, where large bubbles of hot plasma (a soup of ionized atoms) move upwards.

The sun's surface -- the photosphere -- is a 500-km thick (300-mile-thick) region, from which most of the sun's radiation escapes outward and is detected as the sunlight we observe here on Earth about eight minutes after it leaves the sun. Sunspots in the photosphere are areas with strong magnetic fields that are cooler, and thus darker, than the surrounding region. The number of sunspots goes up and down every 11 years as part of the sun's magnetic activity cycle. Also connected to this cycle are bright solar flares and huge coronal mass ejections that blast off the sun.

The temperature of the photosphere is about 10,000 degrees Fahrenheit (5,500 degrees Celsius). Above the photosphere lie the tenuous chromosphere and the corona ("crown"). Visible light from these top regions is usually too weak to be seen against the brighter photosphere, but during total solar eclipses, when the Moon covers the photosphere, the chromosphere can be seen as a red rim around the sun while the corona forms a beautiful white crown with plasma streaming outward, forming the points of the crown.

The temperature increases with altitude, reaching temperatures as high as 3.5 million degrees Fahrenheit (2 million degrees Celsius). The source of coronal heating has been a scientific mystery for more than 50 years. Likely solutions have emerged from observations by the SOHO and TRACE missions, which found patches of magnetic field covering the entire solar surface. Scientists now think that this magnetic carpet is probably a source of the corona's intense heat. The corona cools rapidly, losing heat as radiation and in the form of the solar wind -- a stream of charged particles that flows to the edge of the solar system.

2.3.1 | FACTS AND FIGURES – THE SUN

Mean Radius	Metric: 695,508 km English: 432,168.6 miles Scientific Notation: 6.9551×10^5 km By Comparison: 109.2 x that of Earth
Equatorial Circumference	Metric: 4,370,005.6 km English: 2,715,395.6 miles Scientific Notation: 4.37001×10^6 km By Comparison: 109.2 x that of Earth
Volume	Metric: 1,409,272,569,059,860,000 km ³ English: 338,102,469,632,763,000 mi ³ Scientific Notation: 1.40927×10^{18} km ³ By Comparison: 1,301,018.805 Earths
Mass	Metric: 1,989,100,000,000,000,000,000,000,000 kg English: 4,385,214,857,119,400,000,000,000,000 lbs Scientific Notation: 1.989×10^{30} kg By Comparison: 333,060.402 x Earth's
Density	Metric: 1.409 g/cm ³ By Comparison: 0.256 that of Earth
Surface Area	Metric: 6,078,747,774,547 km ² English: 2,347,017,636,988 square miles Scientific Notation: 6.07877×10^{12} km ² By Comparison: 11,917.607 Earths
Surface Gravity	Metric: 274.0 m/s ² English: 899.0 ft/s ² Scientific Notation: 2.740×10^2 m/s ² By Comparison: 27.96 x Earth's surface gravity
Escape Velocity	Metric: 2,223,720 km/h English: 1,381,756 mph Scientific Notation: 6.177×10^5 m/s By Comparison: 55.20 x Earth
Sidereal Rotation Period (Length of Day)	25.38 Earth days 609.12 hours By Comparison: Rotation slows to about 35 days at the poles.
Minimum/Maximum Surface Temperature	Metric: 5,500 °C English: 10,000 °F
Effective Temperature	Metric: 5504 °C English: 9939 °F Scientific Notation: 5777 K

Source: <http://www.nasa.gov/home/index.html>

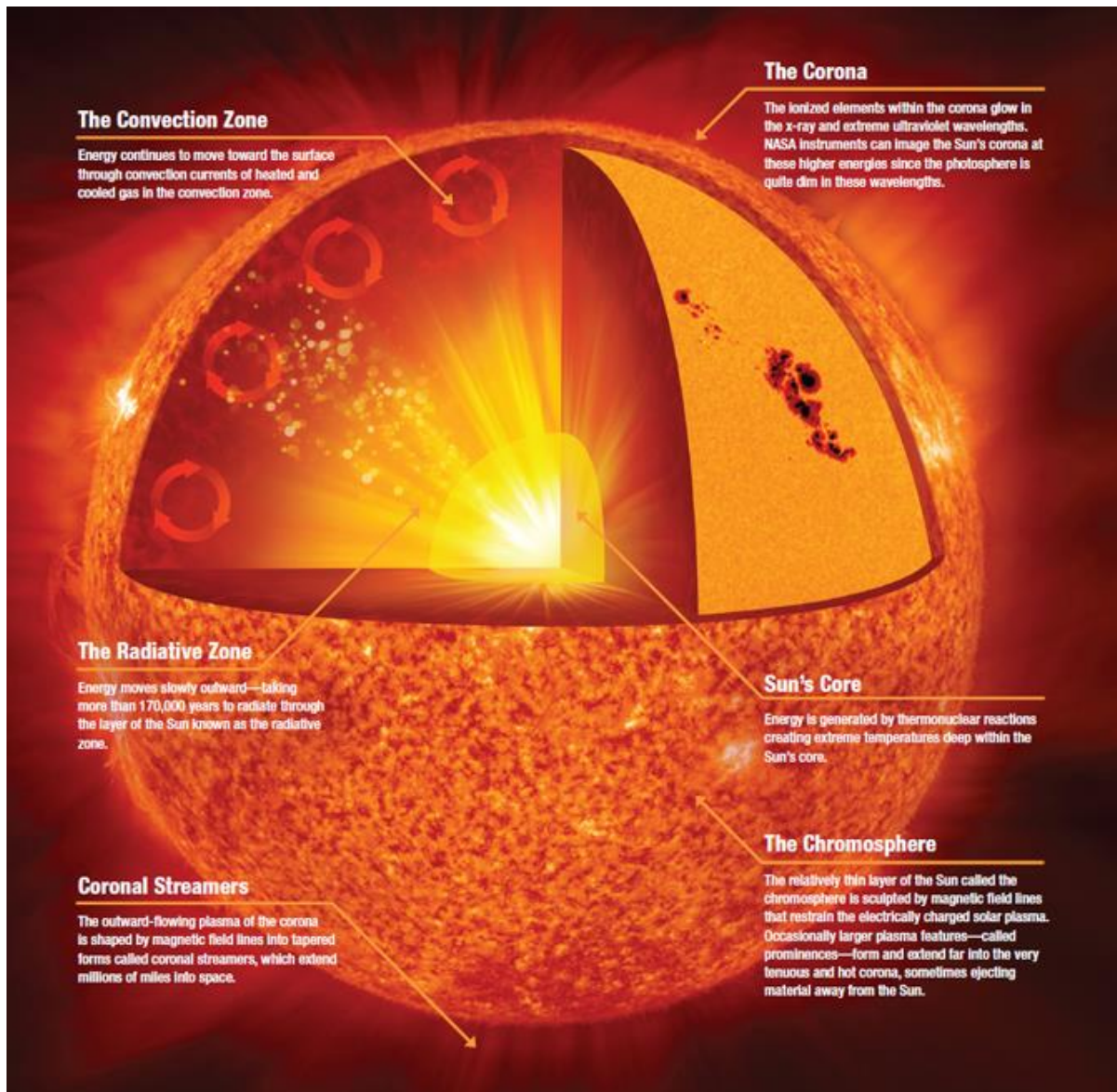


Image comment: Solar Anatomy

Image source: <http://www.nasa.gov/images/>

2.4 | THE EARTH AND THE MOON



The Blue marvel – Earth – the only planet where the magic exists, and it exists in varieties. Layers upon layers of ingredients have molded earth to its current form, with tectonic plates aligning continents and nations booming with cities, farmlands and forbidden landmasses, we are in the age where outer space is the next limit. Let us strip down all the political boundaries, the ethical dissimilarities, and multi-cultural philosophical insights, which wage war amongst ourselves and the coexistences of the copious systems. We are but children of the earth, and we share this planet with many living beings.

Once upon a time the micro bacteria prospered on sea beds, small single celled living organisms; sequentially came an age when sea creatures and giant reptiles, aka dinosaurs ruled over earth and ocean floors. Then came an age where mammals, warm blooded creatures, started ovulating offspring in themselves. It needed shelter and enclosure from its surroundings, to stay in a constant environment. Gradually some of them started understanding the idea of self and their existence as a thought.

In this day and age when humans rein superior; they find themselves building concrete systems and dazzled themselves with puzzling artifacts, new fashion trends and plastic knick-knacks. They have taken up the quest for reconnecting all that is seen and unseen. They have sent rockets into outer space to probe the galaxies and find celestial life, similar to our planet; and built Large Hadron Collider, expecting to address some of the still unsolved questions of science, advancing human understanding of the physical laws. God knows what they'll end up doing next.

And all this time, the Moon was rotating around Earth, nonchalantly.



The Moon - Where did that come from? Is it just the one, or were there more before that?

After years of research, studying gamma rays and rock samples from the Earth and the Moon, it is generally accepted that the ages of the Earth and the Moon are the same. There are several theories on its formation.

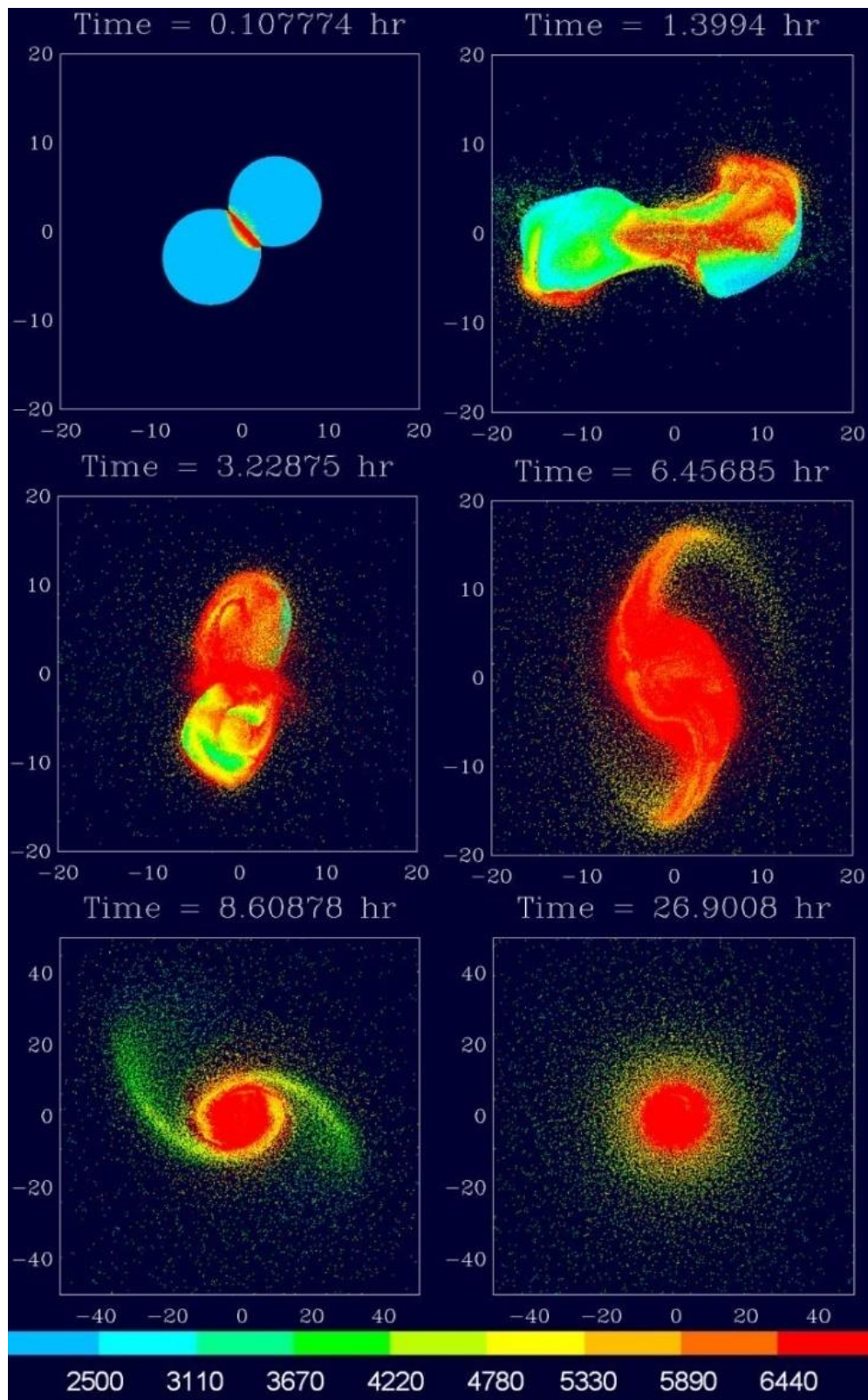
- **IMPACT:** One theory is that it was formed from the Earth's crust, following the impact of a large (Mars-sized) asteroid. A long string of rocky fragments were blown out from the Earth in the form of a trail, which coalesced into the Moon. Supporting this, the Earth has a large iron core but the Moon does not: the Earth's iron would have already sunken into the core by the time the giant impact happened.
- **COACCRETION:** Another theory, advocated by Edward Roche, is known as co accretion. It proposes the concurrent information of both the Earth and the Moon from clouds of space material. As a result the new Moon gets spun by the Earth's gravity field and starts to circle the Earth. The fact is that all smaller solar bodies appear to be irregularly shaped, but larger ones are nearly spherical.
- **FISSION:** The fission theory states that the Moon long ago split off from a fast-rotating Earth, like mud flung from a spinning bicycle wheel. The present Pacific Ocean basin is the most popular site for the part of the Earth from which the Moon may have come. This is not supported by evidence of higher rotational speed in the past.
- **CAPTURE:** If the Moon formed separately, it could have come close enough to the Earth's gravitational field to be trapped. The angle of orbital approach would have to be within narrow parameters in relationship to the moving centre of the orbiting Earth. The chance of this occurrence is very low without some other gravitational interaction.

The prevailing theory at present is some form of early impact, possibly by a co-orbiting object that fused with the Earth after the collision, but that blasted loose the material which later formed the Moon.

It is believed that the moon formed around 4.5 billion years ago and only a few hundred million years after the Earth. Today, based on the evidence, the most widely accepted scientific explanation for the formation of the Moon is called the Giant Impact Hypothesis. According to this model, the Moon formed from debris that was the result of a huge collision. Not long after Earth formed, a proto-planet about the size of Mars (often called Theia) smashed into it at a low angle and relatively low speed. The cataclysmic impact rendered the entire Earth molten, and caused significant amounts of its mantle and crust to be blown into space. The metallic core of the impactor sunk through the Earth's mantle to fuse with Earth's core, thereby depleting the Moon of metallic material and explaining its unusual composition. The force of the collision is also believed to have been responsible for tilting the Earth at angle of 23.5 degrees, allowing for seasons.

The debris from the collision began orbiting the Earth and gathered together through gravity to form a sphere: the Moon. The Moon formed surprisingly quickly, possibly in less than a month but no more than a century. It started out closer to the Earth than it is today, and must have caused massive tides. Slowly, due to conservation of angular momentum, it moved further and further out until it got to the familiar orbit it is now. Even today, the Moon is receding from Earth by an inch and a half every year, but it will take billions of years for the Moon to escape from Earth's gravity altogether.

There are still some problems with the Giant Impact hypothesis that need to be overcome. For example, the ratios of the Moon's volatile elements (such as water) are not explained by this model. Also, the moon's oxygen isotopic ratios are essentially identical to Earth's when they should be different. Regardless, the Giant Impact model is currently the best explanation scientists have based on the evidence that has been gathered, and holds more weight than the other theories for the Moon's formation. A detailed comparison of the properties of Lunar and Earth rock samples has placed very strong constraints on the possible validity of these hypotheses. For example, if the Moon came from material that once made up the Earth, then Lunar and Terrestrial rocks should be much more similar in composition than if the Moon was formed somewhere else and only later was captured by the Earth.



Shown is an off-center, low-velocity collision of two protoplanets containing 45 percent and 55 percent of the Earth's mass. Color scales with particle temperature in kelvin, with blue-to-red indicating temperatures from 2,000 K to in excess of 6,440 K. After the initial impact, the protoplanets re-collide, merge and form a rapidly spinning Earth-mass planet surrounded by an iron-poor protolunar disk containing about 3 lunar masses. The composition of the disk and the final planet's mantle differ by less than 1 percent. - Image credit: SwRI

Image comment: Formation of Earth – Moon System

Image source: http://moonandback.com/wp-content/uploads/2012/10/Canup_moonformation.jpg

These analyses indicate that the abundances of elements in Lunar and Terrestrial material are sufficiently different to make it unlikely that the Moon formed directly from the Earth. Generally, work over the last 10 years has essentially ruled out the first two explanations and made the third one rather unlikely. At present the fifth hypothesis, that the Moon was formed from a ring of matter ejected by collision of a large object with the Earth, is the favored hypothesis; however, the question is not completely settled and many details remain to be accounted for. The near symmetry of the collision causes the disk's composition to be extremely similar to that of the final planet's mantle over a relatively broad range of impact angles and speeds, consistent with the Earth-Moon compositional similarities. The new impacts produce an Earth that is rotating 2 to 2.5 times faster than implied by the current angular momentum of the Earth-Moon system, which is contained in both the Earth's rotation and the Moon's orbit.

However, in an accompanying paper in *Science*, Dr. Matija Ćuk, SETI Institute, and Dr. Sarah T. Stewart, Harvard University, show that a resonant interaction between the early Moon and the Sun — known as the evection resonance — could have decreased the angular momentum of the Earth-Moon system by this amount soon after the Moon-forming impact. In addition to the impacts identified in Canup's paper, Ćuk and Stewart show that impacts involving a much smaller, high-velocity impactor colliding into a target that is rotating very rapidly due to a prior impact can also produce a disk-planet system with similar compositions. After colliding once, the two similar-sized bodies re-collided and then merged briefly before separating into an early Earth surrounded by a disk of material that would coalesce into the Moon. The re-collision and merging left the two bodies with the similar chemical compositions seen today. One of the challenges to longstanding theory of the collision is that it likely would have left the Earth and Moon with different chemical compositions. The giant impact hypothesis has been a widely accepted theory for how the Earth-Moon system formed. In the giant impact scenario, the Moon forms from debris ejected into an Earth-orbiting disk by the collision of a smaller proto-planet with the early Earth. Earlier models found that most or much of the disk material would have originated from the Mars-sized impacting body, whose composition likely would have differed substantially from that of Earth.

2.4.1 | EARTH

The third planet from the Sun – Earth – is a marvel of its kind. This Blue Planet, Earth formed approximately 4.54 billion years ago, and the only planet where life prospers on its surface. Earth's biosphere then significantly altered the atmospheric and other basic physical conditions, which enabled the explosion of organisms as well as the formation of the ozone layer, which together with Earth's magnetic field blocked harmful solar radiation, and permitted formerly ocean-confined life to move safely to land. The physical properties of the Earth, as well as its geological history and orbit, have allowed life to persist. Estimates on how much longer the planet will be able to continue to support life range from 500 million

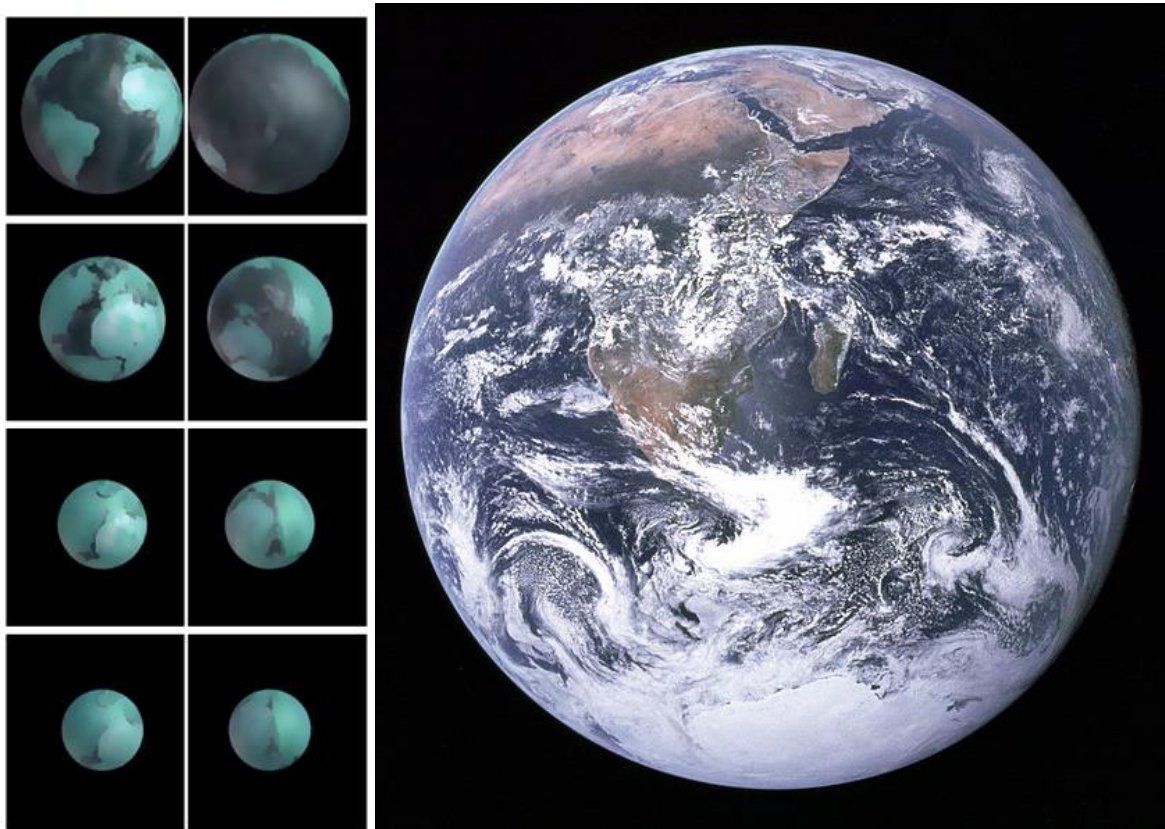


Image comment: Formation of Earth

Image source: www.skepticblog.org/tag/expanding-earth

Earth's lithosphere is divided into several rigid segments, or tectonic plates, that migrate across the surface over periods of many millions of years. About 71% of the surface is covered by salt water oceans, with the remainder consisting of continents and islands which together have many lakes and other sources of water that contribute to the hydrosphere. Earth's poles are mostly covered with ice that is the solid ice of the Antarctic ice sheet and the sea ice that is the polar ice packs. The planet's interior remains active, with a solid iron inner core, a liquid outer core that generates the magnetic field, and a thick layer of relatively solid mantle.

Earth gravitationally interacts with other objects in space, especially the Sun and the Moon. During one orbit around the Sun, the Earth rotates about its own axis 366.26 times, creating 365.26 solar days, or one sidereal year. The Earth's axis of rotation is tilted 23.4° away from the perpendicular of its orbital plane, producing seasonal variations on the planet's surface with a period of one tropical year (365.24 solar days).

Earth is a terrestrial planet, meaning that it is a rocky body, rather than a gas giant like Jupiter. It is the largest of the four terrestrial planets in size and mass. Of these four planets, Earth also has the highest density, the highest surface gravity, the strongest magnetic field, and fastest rotation, and is probably the only one with active plate tectonics.

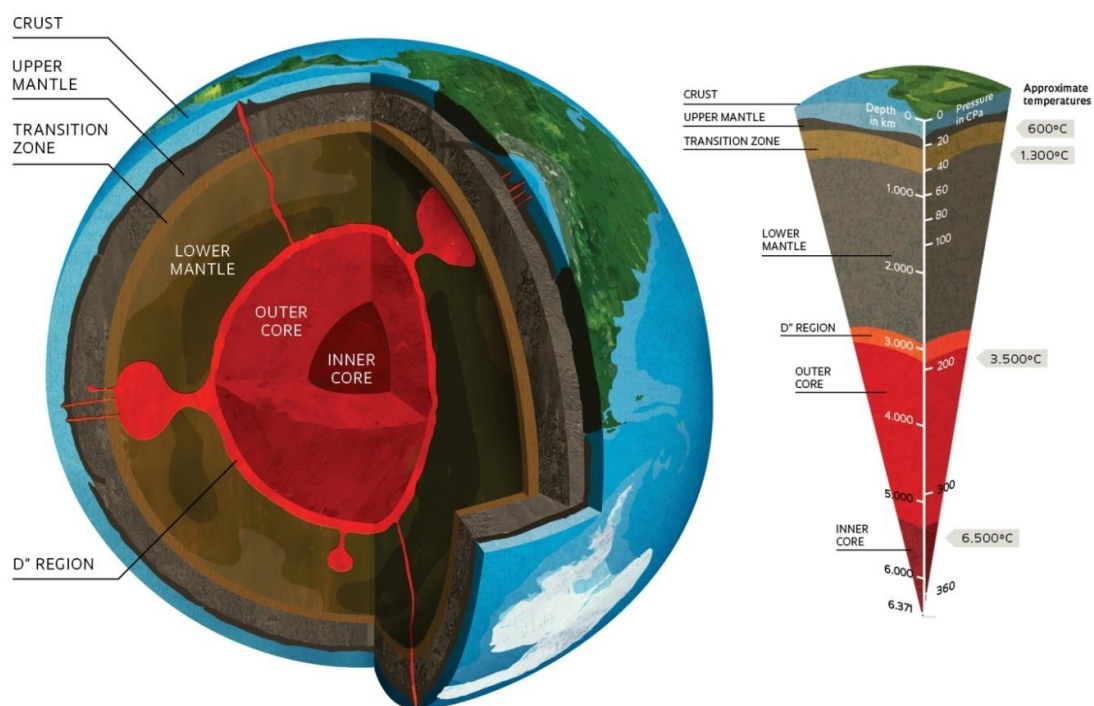


Image comment: Inside Earth

Image source: http://osprotetoresonline.blogspot.com/2012_11_01_archive.html

2.4.1.1 | SHAPE

The shape of the Earth approximates an oblate spheroid, a sphere flattened along the axis from pole to pole such that there is a bulge around the equator. This bulge results from the rotation of the Earth, and causes the diameter at the equator to be 43 km (kilometer) larger than the pole-to-pole diameter. For this reason the furthest point on the surface from the Earth's center of mass is the Chimborazo volcano in Ecuador. The average diameter of the reference spheroid is about 12,742 km, which is approximately $40,000 \text{ km}/\pi$, as the meter was originally defined as $1/10,000,000$ of the distance from the equator to the North Pole through Paris, France.

Local topography deviates from this idealized spheroid, although on a global scale, these deviations are small: Earth has a tolerance of about one part in about 584, or 0.17%, from the reference spheroid, which is less than the 0.22% tolerance allowed in billiard balls. The largest local deviations in the rocky surface of the Earth are Mount Everest (8,848 m above local sea level) and the Mariana Trench (10,911 m below local sea level). Due to the equatorial bulge, the surface locations farthest from the center of the Earth are the summits of Mount Chimborazo in Ecuador and Huascarán in Peru.

2.4.1.2 | CHEMICAL COMPOSITION

The mass of the Earth is approximately 5.98×10^{24} kg. It is composed mostly of iron (32.1%), oxygen (30.1%), silicon (15.1%), magnesium (13.9%), sulfur (2.9%), nickel (1.8%), calcium (1.5%), and aluminium (1.4%); with the remaining 1.2% consisting of trace amounts of other elements. Due to mass segregation, the core region is believed to be primarily composed of iron (88.8%), with smaller amounts of nickel (5.8%), sulfur (4.5%), and less than 1% trace elements.

The geochemist F. W. Clarke calculated that a little more than 47% of the Earth's crust consists of oxygen. The more common rock constituents of the Earth's crust are nearly all oxides; chlorine, sulfur and fluorine are the only important exceptions to this and their total amount in any rock is usually much less than 1%. The principal oxides are silica, alumina, iron oxides, lime, magnesia, potash and soda. The silica functions principally as an acid, forming silicates, and all the commonest minerals of igneous rocks are of this nature. From a computation based on 1,672 analyses of all kinds of rocks, Clarke deduced that 99.22% were composed of 11 oxides (see the table at right), with the other constituents occurring in minute quantities.

2.4.1.3 | INTERNAL STRUCTURE

The interior of the Earth, like that of the other terrestrial planets, is divided into layers by their chemical or physical (rheological) properties, but unlike the other terrestrial planets, it has a distinct outer and inner core. The outer layer of the Earth is a chemically distinct silicate solid crust, which is underlain by a highly viscous solid mantle. The crust is separated from the mantle by the Mohorovičić discontinuity, and the thickness of the crust varies: averaging 6 km(kilometers) under the oceans and 30-50 km on the continents. The crust and the cold, rigid, top of the upper mantle are collectively known as the lithosphere, and it is of the lithosphere that the tectonic plates are comprised. Beneath the lithosphere is the asthenosphere, a relatively low-viscosity layer on which the lithosphere rides. Important changes in crystal structure within the mantle occur at 410 and 660 km below the surface,

spanning a transition zone that separates the upper and lower mantle. Beneath the mantle, an extremely low viscosity liquid outer core lies above a solid inner core. The inner core may rotate at a slightly higher angular velocity than the remainder of the planet, advancing by 0.1–0.5° per year.

2.4.1.4 | HEAT

Earth's internal heat comes from a combination of residual heat from planetary accretion (about 20%) and heat produced through radioactive decay (80%). The major heat-producing isotopes in the Earth are potassium-40, uranium-238, uranium-235, and thorium-232. At the center of the planet, the temperature may be up to 6,000 °C (10,830 °F), and the pressure could reach 360 GPa. Because much of the heat is provided by radioactive decay, scientists believe that early in Earth history, before isotopes with short half-lives had been depleted, Earth's heat production would have been much higher. This extra heat production, twice present-day at approximately 3 byr, would have increased temperature gradients within the Earth, increasing the rates of mantle convection and plate tectonics, and allowing the production of igneous rocks such as komatiites that are not formed today.

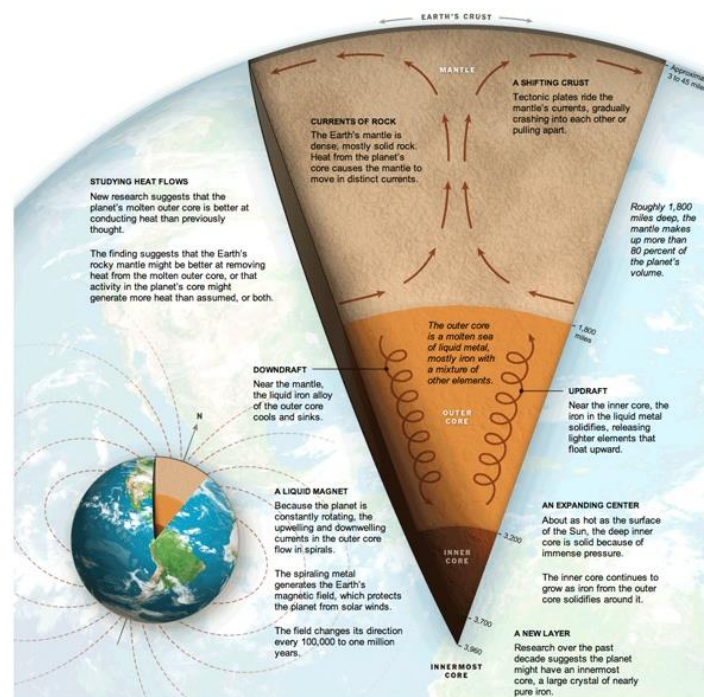


Image comment: The Earth's Core

Image source: <http://scientificillustration.tumblr.com/post/25350933578/rhaphotheca-earths-core-the-enigma-1-800>

The mechanically rigid outer layer of the Earth, the lithosphere, is broken into pieces called tectonic plates. These plates are rigid segments that move in relation to one another at one of three types of plate boundaries: Convergent boundaries, at which two plates come

together, Divergent boundaries, at which two plates are pulled apart, and Transform boundaries, in which two plates slide past one another laterally. Earthquakes, volcanic activity, mountain-building, and trench formation can occur along these plate boundaries. The tectonic plates ride on top of the asthenosphere, the solid but less-viscous part of the upper mantle that can flow and move along with the plates, and their motion is strongly coupled with convection patterns inside the Earth's mantle.

As the tectonic plates migrate across the planet, the ocean floor is subducted under the leading edges of the plates at convergent boundaries. At the same time, the upwelling of mantle material at divergent boundaries creates mid-ocean ridges. The combination of these processes continually recycles the oceanic crust back into the mantle. Due to this recycling, most of the ocean floor is less than 100 myr old in age. The oldest oceanic crust is located in the Western Pacific, and has an estimated age of about 200 myr. By comparison, the oldest dated continental crust is 4,030 myr.

The seven major plates are the Pacific, North American, Eurasian, African, Antarctic, Indo-Australian, and South American. Other notable plates include the Arabian Plate, the Caribbean Plate, the Nazca Plate off the west coast of South America and the Scotia Plate in the southern Atlantic Ocean. The Australian Plate fused with the Indian Plate between 50 and 55 mya. The fastest-moving plates are the oceanic plates, with the Cocos Plate advancing at a rate of 75 mm/year and the Pacific Plate moving 52–69 mm/year. At the other extreme, the slowest-moving plate is the Eurasian Plate, progressing at a typical rate of about 21 mm/year.

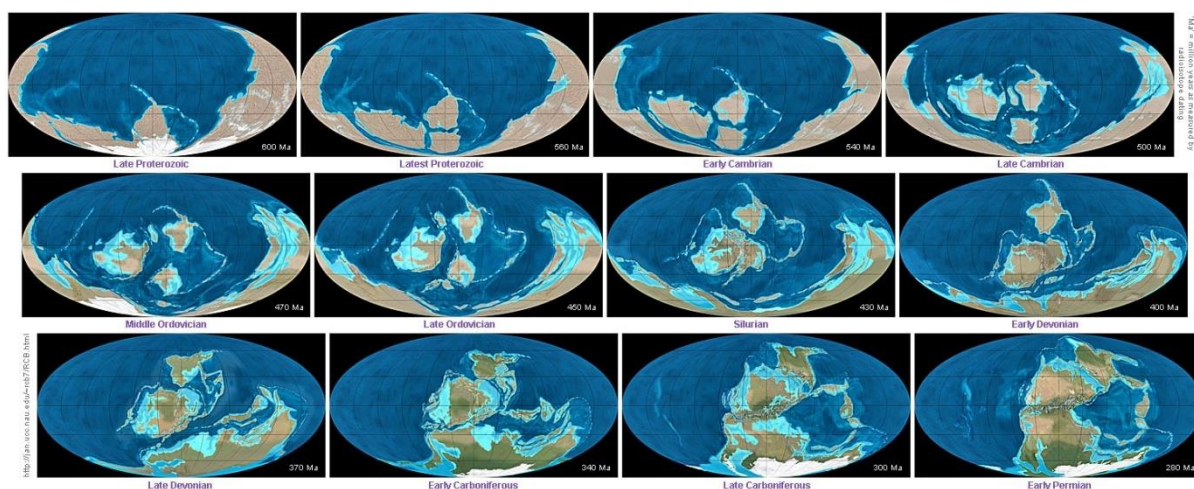


Image comment: Continental Plate Tectonic Movement

Image source: <http://www.earthhistory.org.uk/key-concepts/plate-tectonics-1>

2.4.1.5 | SURFACE

The Earth's terrain varies greatly from place to place. About 70.8% of the surface is covered by water, with much of the continental shelf below sea level. This equates to 361.132 million km² (139.43 million sq mi). The submerged surface has mountainous features, including a globe-spanning mid-ocean ridge system, as well as undersea volcanoes, oceanic trenches, submarine canyons, oceanic plateaus and abyssal plains. The remaining 29.2% (148.94 million km², or 57.51 million sq mi) not covered by water consists of mountains, deserts, plains, plateaus, and other geomorphologies.

The planetary surface undergoes reshaping over geological time periods due to tectonics and erosion. The surface features built up or deformed through plate tectonics are subject to steady weathering from precipitation, thermal cycles, and chemical effects. Glaciations, coastal erosion, the build-up of coral reefs, and large meteorite impacts also act to reshape the landscape.

The continental crust consists of lower density material such as the igneous rocks granite and andesite. Less common is basalt, a denser volcanic rock that is the primary constituent of the ocean floors. Sedimentary rock is formed from the accumulation of sediment that becomes compacted together. Nearly 75% of the continental surfaces are covered by sedimentary rocks, although they form only about 5% of the crust. The third form of rock material found on Earth is metamorphic rock, which is created from the transformation of pre-existing rock types through high pressures, high temperatures, or both. The most abundant silicate minerals on the Earth's surface include quartz, the feldspars, amphibole, mica, pyroxene and olivine. Common carbonate minerals include calcite (found in limestone) and dolomite.

The pedosphere is the outermost layer of the Earth that is composed of soil and subject to soil formation processes. It exists at the interface of the lithosphere, atmosphere, hydrosphere and biosphere. Currently the total arable land is 13.31% of the land surface, with only 4.71% supporting permanent crops. Close to 40% of the Earth's land surface is presently used for cropland and pasture, or an estimated 1.3×10^7 km² of cropland and 3.4×10^7 km² of pastureland.

The elevation of the land surface of the Earth varies from the low point of -418 m at the Dead Sea, to a 2005-estimated maximum altitude of 8,848 m at the top of Mount Everest. The mean height of land above sea level is 840 m.

Besides being divided logically into Northern and Southern Hemispheres centered on the earth's poles, the earth has been divided arbitrarily into Eastern and Western Hemispheres.

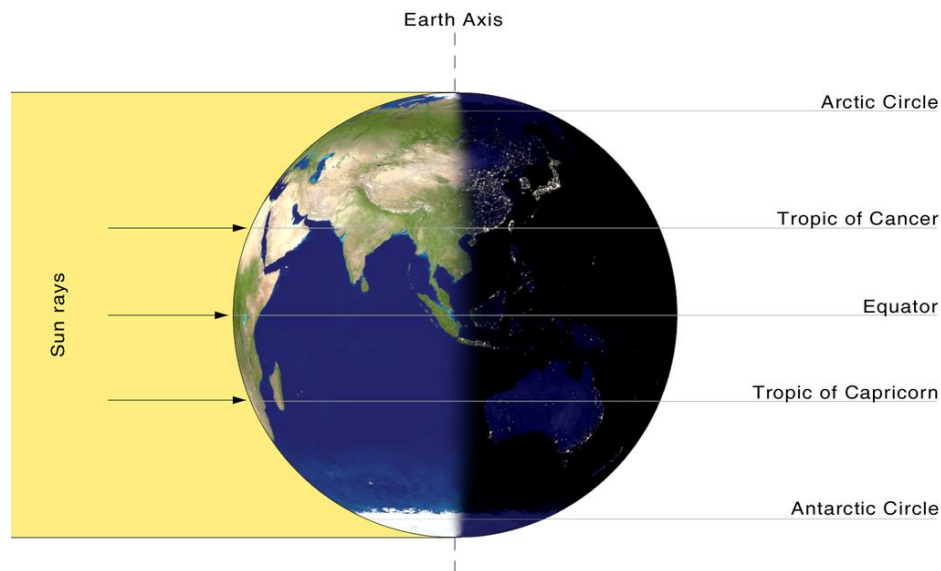


Image comment: Earth Lighting Equinox

Image credits: en.wikipedia.org/wiki/Equinox

2.4.1.6 | HYDROSPHERE

The abundance of water on Earth's surface is a unique feature that distinguishes the "Blue Planet" from others in the Solar System. The Earth's hydrosphere consists chiefly of the oceans, but technically includes all water surfaces in the world, including inland seas, lakes, rivers, and underground waters down to a depth of 2,000 m. The deepest underwater location is Challenger Deep of the Mariana Trench in the Pacific Ocean with a depth of −10,911.4 m.

The mass of the oceans is approximately 1.35×10^{18} metric tons, or about 1/4400 of the total mass of the Earth. The oceans cover an area of $3.618 \times 10^8 \text{ km}^2$ with a mean depth of 3,682 m, resulting in an estimated volume of $1.332 \times 10^9 \text{ km}^3$. If all the land on Earth were spread evenly, water would rise to an altitude of more than 2.7 km. About 97.5% of the water is saline, while the remaining 2.5% is fresh water. Most fresh water, about 68.7%, is currently ice.

The average salinity of the Earth's oceans is about 35 grams of salt per kilogram of sea water (35 ‰ salt). Most of this salt was released from volcanic activity or extracted from cool, igneous rocks. The oceans are also a reservoir of dissolved atmospheric gases, which are essential for the survival of many aquatic life forms. Sea water has an important influence on the world's climate, with the oceans acting as a large heat reservoir. Shifts in the oceanic temperature distribution can cause significant weather shifts, such as the El Niño-Southern Oscillation.

2.4.1.7 | WEATHER AND CLIMATE

The Earth's atmosphere has no definite boundary, slowly becoming thinner and fading into outer space. Three-quarters of the atmosphere's mass is contained within the first 11 km of the planet's surface. This lowest layer is called the troposphere. Energy from the Sun heats this layer, and the surface below, causing expansion of the air. This lower-density air then rises, and is replaced by cooler, higher-density air. The result is atmospheric circulation that drives the weather and climate through redistribution of thermal energy.

The primary atmospheric circulation bands consist of the trade winds in the equatorial region below 30° latitude and the westerlies in the mid-latitudes between 30° and 60°. Ocean currents are also important factors in determining climate, particularly the thermohaline circulation that distributes thermal energy from the equatorial oceans to the polar regions.

Water vapor generated through surface evaporation is transported by circulatory patterns in the atmosphere. When atmospheric conditions permit an uplift of warm, humid air, this water condenses and settles to the surface as precipitation. Most of the water is then transported to lower elevations by river systems and usually returned to the oceans or deposited into lakes. This water cycle is a vital mechanism for supporting life on land, and is a primary factor in the erosion of surface features over geological periods. Precipitation patterns vary widely, ranging from several meters of water per year to less than a millimeter. Atmospheric circulation, topological features and temperature differences determine the average precipitation that falls in each region.

The amount of solar energy reaching the Earth's decreases with increasing latitude. At higher latitudes the sunlight reaches the surface at lower angles and it must pass through thicker columns of the atmosphere. As a result, the mean annual air temperature at sea level decreases by about 0.4 °C per degree of latitude away from the equator. The Earth can be subdivided into specific latitudinal belts of approximately homogeneous climate. Ranging from the equator to the polar regions, these are the tropical (or equatorial), subtropical, temperate and polar climates. Climate can also be classified based on the temperature and precipitation, with the climate regions characterized by fairly uniform air masses. The commonly used Köppen climate classification system (as modified by Wladimir Köppen's student Rudolph Geiger) has five broad groups (humid tropics, arid, humid middle latitudes, continental and cold polar), which are further divided into more specific subtypes.

2.4.1.8 | UPPER ATMOSPHERE

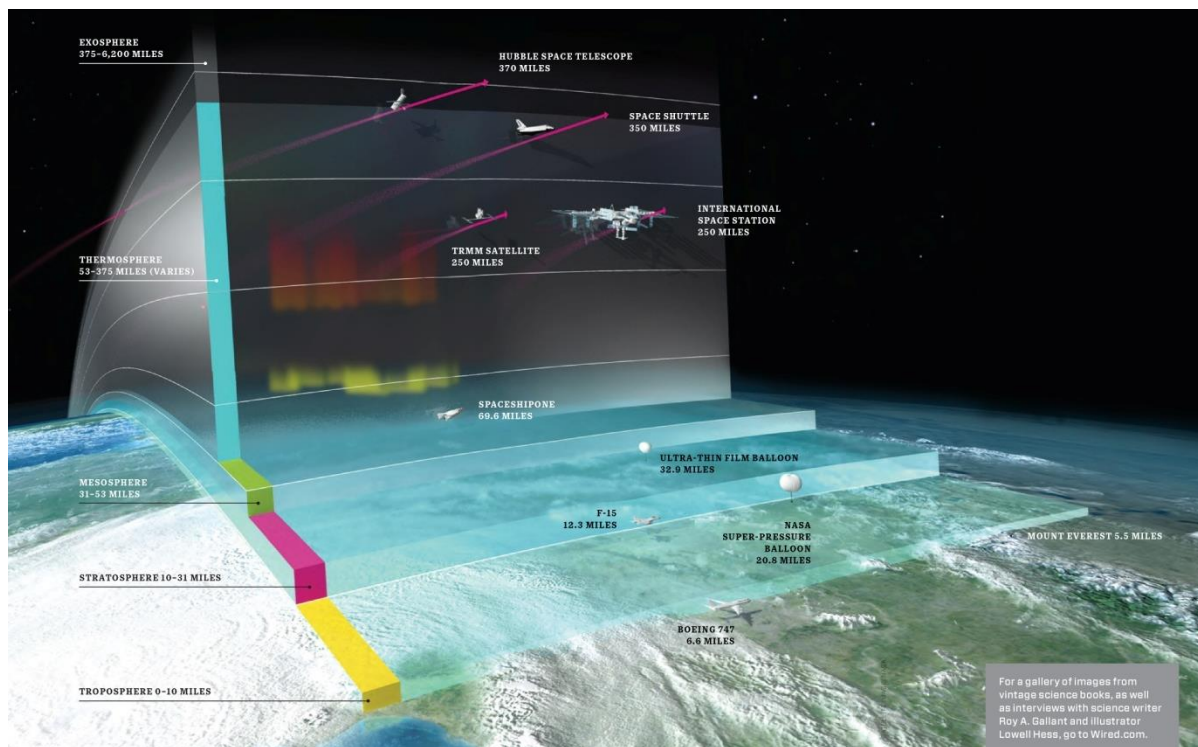


Image comment: The Upper Atmosphere

Image credits: <http://www.whatkatieDoes.net/2009/11/vintage-vs-modern-infographics.html>

Above the troposphere, the atmosphere is usually divided into the stratosphere, mesosphere and thermosphere. Each layer has a different lapse rate, defining the rate of change in temperature with height. Beyond these, the exosphere thins out into the magnetosphere, where the Earth's magnetic fields interact with the solar wind. Within the stratosphere is the ozone layer, a component that partially shields the surface from ultraviolet light and thus is important for life on Earth. The Kármán line, defined as 100 km above the Earth's surface, is a working definition for the boundary between atmosphere and space.

Thermal energy causes some of the molecules at the outer edge of the Earth's atmosphere to increase their velocity to the point where they can escape from the planet's gravity. This causes a slow but steady leakage of the atmosphere into space. Because unfixed hydrogen has a low molecular weight, it can achieve escape velocity more readily and it leaks into outer space at a greater rate than other gasses. The leakage of hydrogen into space contributes to the pushing of the Earth from an initially reducing state to its current oxidizing one. Photosynthesis provided a source of free oxygen, but the loss of reducing agents such as hydrogen is believed to have been a necessary precondition for the widespread accumulation of oxygen in the atmosphere. Hence the ability of hydrogen to escape from the Earth's atmosphere may have influenced the nature of life that developed

on the planet. In the current, oxygen-rich atmosphere most hydrogen is converted into water before it has an opportunity to escape. Instead, most of the hydrogen loss comes from the destruction of methane in the upper atmosphere.

2.4.1.9 | MAGNETIC FIELD



Image comment: Sun - Earth Magnetic Fields

Image credits: <http://www.whatkatiedoes.net/2009/magnet>

The Earth's magnetic field is shaped roughly as a magnetic dipole, with the poles currently located proximate to the planet's geographic poles. At the equator of the magnetic field, the magnetic field strength at the planet's surface is $3.05 \times 10^{-5} \text{ T}$, with global magnetic dipole moment of $7.91 \times 10^{15} \text{ T m}^3$. According to dynamo theory, the field is generated within the molten outer core region where heat creates convection motions of conducting materials, generating electric currents. These in turn produce the Earth's magnetic field. The convection movements in the core are chaotic; the magnetic poles drift and periodically change alignment. This causes field reversals at irregular intervals averaging a few times every million years. The most recent reversal occurred approximately 700,000 years ago.

The field forms the magnetosphere, which deflects particles in the solar wind. The sunward edge of the bow shock is located at about 13 times the radius of the Earth. The collision between the magnetic field and the solar wind forms the Van Allen radiation belts, a pair of concentric, torus-shaped regions of energetic charged particles. When the plasma enters the Earth's atmosphere at the magnetic poles, it forms the aurora.

2.4.1.10 | ROTATION

Earth's rotation period relative to the Sun—its mean solar day—is 86,400 seconds of mean solar time (86,400.0025 SI seconds). As the Earth's solar day is now slightly longer than it was during the 19th century due to tidal acceleration, each day varies between 0 and 2 SI ms longer.

Earth's rotation period relative to the fixed stars, called its stellar day by the International Earth Rotation and Reference Systems Service (IERS), is 86,164.098903691 seconds of mean solar time (UT1), or $23^{\text{h}} 56^{\text{m}} 4.098903691^{\text{s}}$. Earth's rotation period relative to the processing or moving mean vernal equinox, misnamed its sidereal day, is 86,164.09053083288 seconds of mean solar time (UT1) ($23^{\text{h}} 56^{\text{m}} 4.09053083288^{\text{s}}$) as of 1982. Thus the sidereal day is shorter than the stellar day by about 8.4 ms. The length of the mean solar day in SI seconds is available from the IERS for the periods 1623–2005 and 1962–2005.

Apart from meteors within the atmosphere and low-orbiting satellites, the main apparent motion of celestial bodies in the Earth's sky is to the west at a rate of $15^{\circ}/\text{h} = 15'/\text{min}$. For bodies near the celestial equator, this is equivalent to an apparent diameter of the Sun or Moon every two minutes; from the planet's surface, the apparent sizes of the Sun and the Moon are approximately the same.

2.4.1.11 | ORBIT

Earth orbits the Sun at an average distance of about 150 million kilometers every 365.2564 mean solar days, or one sidereal year. From Earth, this gives an apparent movement of the Sun eastward with respect to the stars at a rate of about $1^{\circ}/\text{day}$, which is one apparent Sun or Moon diameter every 12 hours. Due to this motion, on average it takes 24 hours—a solar day—for Earth to complete a full rotation about its axis so that the Sun returns to the meridian. The orbital speed of the Earth averages about 29.8 km/s (107,000 km/h), which is fast enough to travel a distance equal to the planet's diameter, about 12,742 km, in seven minutes, and the distance to the Moon, 384,000 km, in about 3.5 hours.

The Moon revolves with the Earth around a common barycenter every 27.32 days relative to the background stars. When combined with the Earth–Moon system's common revolution around the Sun, the period of the synodic month, from new moon to new moon, is 29.53 days. Viewed from the celestial north pole, the motion of Earth, the Moon and their axial rotations are all counterclockwise. Viewed from a vantage point above the north poles

of both the Sun and the Earth, the Earth revolves in a counterclockwise direction about the Sun. The orbital and axial planes are not precisely aligned: Earth's axis is tilted some 23.4 degrees from the perpendicular to the Earth–Sun plane (the ecliptic), and the Earth–Moon plane is tilted up to ± 5.1 degrees against the Earth–Sun plane. Without this tilt, there would be an eclipse every two weeks, alternating between lunar eclipses and solar eclipses.^{[3][144]}

The Hill sphere, or gravitational sphere of influence, of the Earth is about 1.5 Gm or 1,500,000 km in radius. This is the maximum distance at which the Earth's gravitational influence is stronger than the more distant Sun and planets. Objects must orbit the Earth within this radius, or they can become unbound by the gravitational perturbation of the Sun.

Earth, along with the Solar System, is situated in the Milky Way galaxy and orbits about 28,000 light years from the center of the galaxy. It is currently about 20 light years above the galactic plane in the Orion spiral arm.

8 phases of the moon,

.....Each Lunar month

What causes the moon phases?

The moon appears in various phases, starts by the New Moon Phase, the Waxing Crescent going through the Full Moon and ends by the Waning Crescent.

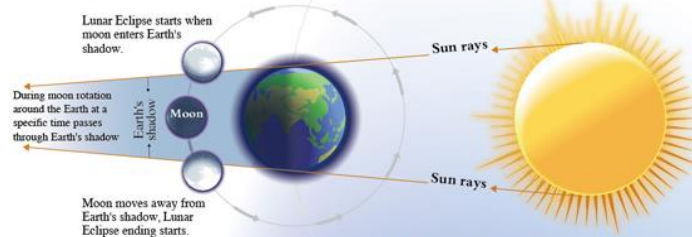
One half of the moon surface is always illuminated by the Sun rays as it faces the Sun and the other is always dark. However, people on Earth see the illuminated half from different viewing geometries depending on the moon's angle to the earth during its rotation, which generates the Moon phases.

Difference between Lunar eclipse and moon phases

It takes the moon a full Lunar month to show its various phases during its rotation around Earth. On the other hand, the lunar eclipse phenomenon shows the same shapes of the phases, but within a short period of time

represents the starting of the partial eclipse passing through the total Eclipse to the end of the eclipse. Today the whole Eclipse period lasts about three hours and thirty-two minutes.

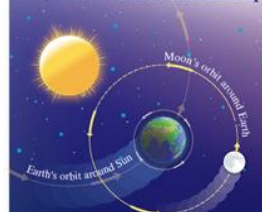
How lunar eclipse occurs



Steps of a Lunar Eclipse ..



Solar system (Earth & Moon Relationship)



In the solar system the eight planets orbit around the sun and the time each planet takes to complete cycle around the sun represents one year for this planet. Some planets have moons orbiting the planet itself while the planet orbits the sun. The earth has one moon rotates around and takes about one month (lunar month) to complete full cycle around. While the Earth takes one year (12 months) to complete one cycle around the sun, once the Earth completes one cycle around the sun, the moon revolves around the earth 12 times.

The Bigger Moon

Represents the phase of the moon as the observer on Earth view it.

The Smaller Moon

Represents the moon's position on its orbit (showing the always illuminated half).

3 First Quarter

The first quarter called a "half moon", happen when the moon is at a 90 degree angle with respect to the earth and sun. So we are seeing exactly half of the moon illuminated and half in shadow.

4 Waxing Gibbous

After the first quarter, the sunlit portion is still increasing, but now it is more than half, so it is waxing gibbous.

2 Waxing Crescent

The moon moves around the Earth, to be at a 45 degree angle with respect to the earth and sun, changing its previous alignment position. So we see a small part of the illuminated half.

1 New Moon

The new moon occurs when the moon is positioned between the earth and sun. The three objects are in approximate

Sun, moon & Earth alignment line. The entire illuminated portion of the moon is on the back side of the moon, the half that we cannot see.

5 Full Moon

At a full moon, the earth, moon, and sun are in approximate alignment, just as the new moon, but the moon is on the opposite side of the earth, so the entire sunlit part of the moon is facing us. The shadowed portion is entirely hidden from view.

Here a total eclipse could only occurs.

6 Waning Gibbous

After the full moon (maximum illumination), the light continually decreases. So the waning gibbous phase occurs next

7 Third Quarter

Called a "half moon" same as the First Quarter phase, happen when the moon is at a 90 degree angle with respect to the earth and sun.

8 Waning Crescent

Following the third quarter the moon at a 45 degree angle with respect to the earth and sun. Waning Crescent, which wanes until the light is completely gone, so a new moon starts again.

2.4.1.12 | AXIAL TILT AND SEASONS

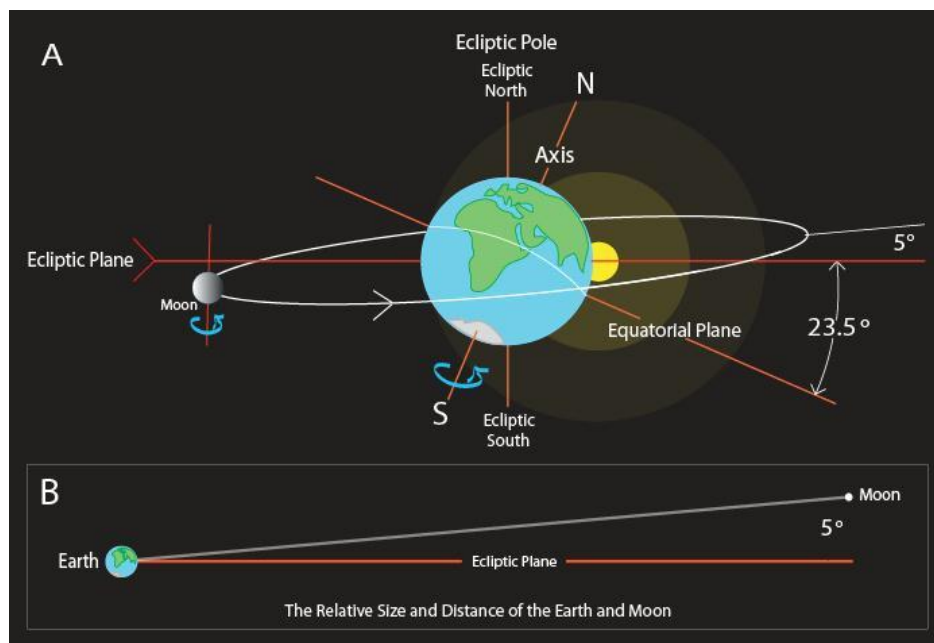


Image comment: Earth-Moon-Incline

Image credits: <http://www.dailykos.com/story/2012/02/13/1053999/-Getting-to-Know-Your-Solar-System-10-Luna>

Due to the axial tilt of the Earth, the amount of sunlight reaching any given point on the surface varies over the course of the year. This causes seasonal change in climate, with summer in the northern hemisphere occurring when the North Pole is pointing toward the Sun, and winter taking place when the pole is pointed away. During the summer, the day lasts longer and the Sun climbs higher in the sky. In winter, the climate becomes generally cooler and the days shorter. Above the Arctic Circle, an extreme case is reached where there is no daylight at all for part of the year—a polar night. In the southern hemisphere the situation is exactly reversed, with the South Pole oriented opposite the direction of the North Pole.

By astronomical convention, the four seasons are determined by the solstices—the point in the orbit of maximum axial tilt toward or away from the Sun—and the equinoxes, when the direction of the tilt and the direction to the Sun are perpendicular. In the northern hemisphere, Winter Solstice occurs on about December 21, Summer Solstice is near June 21, Spring Equinox is around March 20 and Autumnal Equinox is about September 23. In the Southern hemisphere, the situation is reversed, with the Summer and Winter Solstices exchanged and the Spring and Autumnal Equinox dates switched.

The angle of the Earth's tilt is relatively stable over long periods of time. The tilt does undergo nutation; a slight, irregular motion with a main period of 18.6 years.^[148] The orientation (rather than the angle) of the Earth's axis also changes over time, precessing around in a complete circle over each 25,800 year cycle; this precession is the

reason for the difference between a sidereal year and a tropical year. Both of these motions are caused by the varying attraction of the Sun and Moon on the Earth's equatorial bulge. From the perspective of the Earth, the poles also migrate a few meters across the surface. This polar motion has multiple, cyclical components, which collectively are termed quasiperiodic motion. In addition to an annual component to this motion, there is a 14-month cycle called the Chandler wobble. The rotational velocity of the Earth also varies in a phenomenon known as length of day variation.

In modern times, Earth's perihelion occurs around January 3, and the aphelion around July 4. These dates change over time due to precession and other orbital factors, which follow cyclical patterns known as Milankovitch cycles. The changing Earth–Sun distance causes an increase of about 6.9% in solar energy reaching the Earth at perihelion relative to aphelion. Since the southern hemisphere is tilted toward the Sun at about the same time that the Earth reaches the closest approach to the Sun, the southern hemisphere receives slightly more energy from the Sun than does the northern over the course of a year. This effect is much less significant than the total energy change due to the axial tilt, and most of the excess energy is absorbed by the higher proportion of water in the southern hemisphere.

2.4.1.13 | HABITABILITY

A planet that can sustain life is termed habitable, even if life did not originate there. The Earth provides liquid water—an environment where complex organic molecules can assemble and interact, and sufficient energy to sustain metabolism. The distance of the Earth from the Sun, as well as its orbital eccentricity, rate of rotation, axial tilt, geological history, sustaining atmosphere and protective magnetic field all contribute to the current climatic conditions at the surface.

2.4.1.14 | BIOSPHERE

A planet's life forms are sometimes said to form a "biosphere". The Earth's biosphere is generally believed to have begun evolving about 3.5 bya. The biosphere is divided into a number of biomes, inhabited by broadly similar plants and animals. On land, biomes are separated primarily by differences in latitude, height above sea level and humidity. Terrestrial biomes lying within the Arctic or Antarctic Circles, at high altitudes or in extremely arid areas are relatively barren of plant and animal life; species diversity reaches a peak in humid lowlands at equatorial latitudes.

The Earth provides resources that are exploitable by humans for useful purposes. Some of these are non-renewable resources, such as mineral fuels, that are difficult to replenish on a short time scale.

Large deposits of fossil fuels are obtained from the Earth's crust, consisting of coal, petroleum, natural gas and methane clathrate. These deposits are used by humans both for energy production and as feedstock for chemical production. Mineral ore bodies have also been formed in Earth's crust through a process of Ore genesis, resulting from actions of erosion and plate tectonics. These bodies form concentrated sources for many metals and other useful elements.

The Earth's biosphere produces many useful biological products for humans, including (but far from limited to) food, wood, pharmaceuticals, oxygen, and the recycling of many organic wastes. The land-based ecosystem depends upon topsoil and fresh water, and the oceanic ecosystem depends upon dissolved nutrients washed down from the land. In 1980, 5,053 Mha of the Earth's land surface consisted of forest and woodlands, 6,788 Mha were grasslands and pasture, and 1,501 Mha was cultivated as croplands. The estimated amount of irrigated land in 1993 was 2,481,250 square kilometres (958,020 sq mi). Humans also live on the land by using building materials to construct shelters.

2.4.1.15 | NATURAL AND ENVIRONMENTAL HAZARDS

Large areas of the Earth's surface are subject to extreme weather such as tropical cyclones, hurricanes, or typhoons that dominate life in those areas. From 1980 to 2000, these events caused an average of 11,800 deaths per year. Many places are subject to earthquakes, landslides, tsunamis, volcanic eruptions, tornadoes, sinkholes, blizzards, floods, droughts, wildfires, and other calamities and disasters.

Many localized areas are subject to human-made pollution of the air and water, acid rain and toxic substances, loss of vegetation (overgrazing, deforestation, desertification), loss of wildlife, species extinction, soil degradation, soil depletion, erosion, and introduction of invasive species.

According to the United Nations, a scientific consensus exists linking human activities to global warming due to industrial carbon dioxide emissions. This is predicted to produce changes such as the melting of glaciers and ice sheets, more extreme temperature ranges, significant changes in weather and a global rise in average sea levels.

2.4.1.16 | HUMAN GEOGRAPHY

Cartography, the study and practice of map making, and vicariously geography, have historically been the disciplines devoted to depicting the Earth. Surveying, the determination of locations and distances, and to a lesser extent navigation, the determination of position and direction, have developed alongside cartography and geography, providing and suitably quantifying the requisite information.

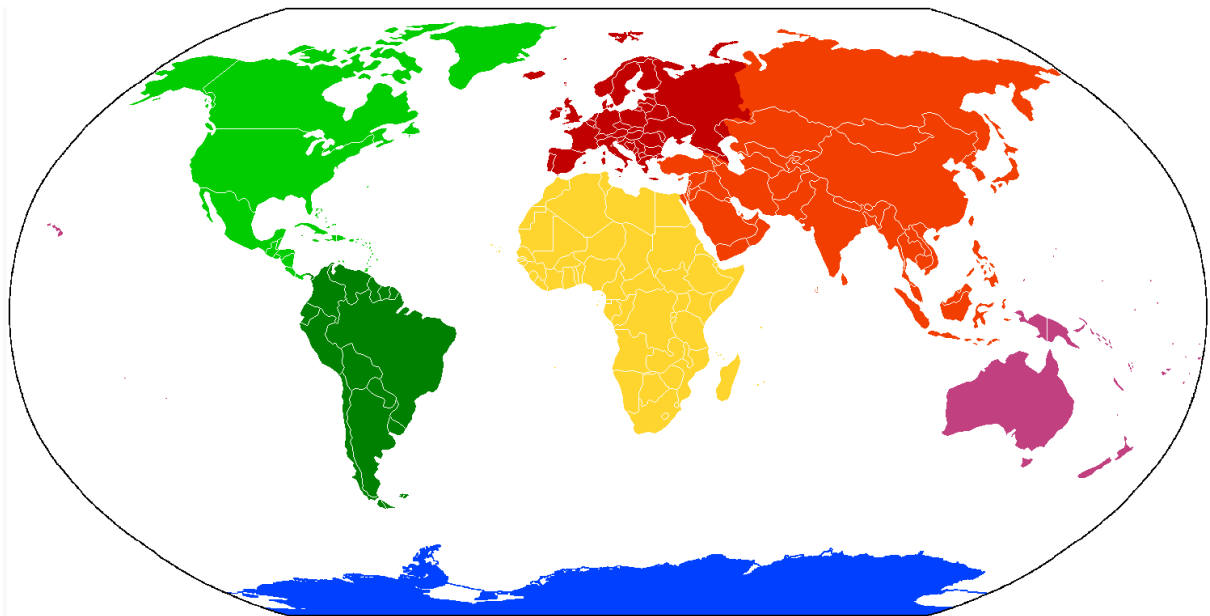
Earth has reached approximately 7,000,000,000 human inhabitants as of October 31, 2011. Projections indicate that the world's human population will reach 9.2 billion in 2050. Most of the growth is expected to take place in developing nations. Human population density varies widely around the world, but a majority live in Asia. By 2020, 60% of the world's population is expected to be living in urban, rather than rural, areas.

It is estimated that only one-eighth of the surface of the Earth is suitable for humans to live on—three-quarters is covered by oceans, and half of the land area is either desert (14%), high mountains (27%), or other less suitable terrain. The northernmost permanent settlement in the world is Alert, on Ellesmere Island in Nunavut, Canada. (82°28'N) The southernmost is the Amundsen-Scott South Pole Station, in Antarctica, almost exactly at the South Pole. (90°S)

Independent sovereign nations claim the planet's entire land surface, except for some parts of Antarctica and the odd unclaimed area of Bir Tawil between Egypt and Sudan. As of 2013, there are 206 sovereign states, including the 193 United Nations member states. In addition, there are 59 dependent territories, and a number of autonomous areas, territories under dispute and other entities. Historically, Earth has never had a sovereign government with authority over the entire globe, although a number of nation-states have striven for world domination and failed.

The United Nations is a worldwide intergovernmental organization that was created with the goal of intervening in the disputes between nations, thereby avoiding armed conflict. The U.N. serves primarily as a forum for international diplomacy and international law. When the consensus of the membership permits, it provides a mechanism for armed intervention.

The first human to orbit the Earth was Yuri Gagarin on April 12, 1961. In total, about 487 people have visited outer space and reached Earth orbit as of July 30, 2010, and, of these, twelve have walked on the Moon. Normally the only humans in space are those on the International Space Station. The station's crew, currently six people, is usually replaced every six months. The furthest humans have travelled from Earth is 400,171 km, achieved during the 1970 Apollo 13 mission.



The 7 continents: ■ North America, ■ South America, ■ Antarctica, ■ Africa, ■ Europe, ■ Asia, ■ Australia

Image comment: 7 continents of Earth

Image credits: expattutor.wordpress.com/tag/how-many-continents-are-there/

2.4.1.17 | CULTURAL AND HISTORICAL VIEWPOINT

The standard astronomical symbol of the Earth consists of a cross circumscribed by a circle.

Unlike the rest of the planets in the Solar System, humankind did not begin to view the Earth as a moving object in orbit around the Sun until the 16th century. Earth has often been personified as a deity, in particular a goddess. In many cultures a mother goddess is also portrayed as a fertility deity. Creation myths in many religions recall a story involving the creation of the Earth by a supernatural deity or deities. A variety of religious groups, often associated with fundamentalist branches of Protestantism or Islam, assert that their interpretations of these creation myths in sacred texts are literal truth and should be considered alongside or replace conventional scientific accounts of the formation of the Earth and the origin and development of life. Such assertions are opposed by the scientific community and by other religious groups. A prominent example is the creation–evolution controversy.

In the past, there were varying levels of belief in a flat Earth, but this was displaced by spherical Earth, a concept that has been credited to Pythagoras (6th century BC). The human perspective regarding the Earth has changed following the advent of spaceflight, and the biosphere is now widely viewed from a globally integrated perspective. This is reflected in a growing environmental movement that is concerned about humankind's effects on the planet.

The planet is home to millions of species of life, including humans.^[29] Both the mineral resources of the planet and the products of the biosphere contribute resources that are used to support a global human population. These inhabitants are grouped into about 200 independent sovereign states, which interact through diplomacy, travel, trade, and military action. Human cultures have developed many views of the planet, including its personification as a planetary deity, its shape as flat, its position as the center of the universe, and in the modern Gaia Principle, as a single, self-regulating organism in its own right.

2.4.1.18 | FACTS AND FIGURES – EARTH

Orbit Size Around Sun (semi-major axis)	Metric: 149,598,262 km English: 92,956,050 miles Scientific Notation: 1.4959826×10^8 km (1.000 A.U.)
Perihelion (closest)	Metric: 147,098,291 km English: 91,402,640 miles Scientific Notation: 1.47098×10^8 km (9.833×10^{-1} A.U.)
Aphelion (farthest)	Metric: 152,098,233 km English: 94,509,460 miles Scientific Notation: 1.52098×10^8 km (1.017 A.U.)
Sidereal Orbit Period (Length of Year)	1.0000174 Earth days 365.26 Earth hours
Orbit Circumference	Metric: 939,887,974 km English: 584,019,311 miles Scientific Notation: 9.399×10^8 km
Average Orbit Velocity	Metric: 107,218 km/h English: 66,622 mph Scientific Notation: 2.9783×10^4 m/s
Orbit Eccentricity	0.01671123
Orbit Inclination	0.00005 degrees
Equatorial Inclination to Orbit	23.4393 degrees
Mean Radius	Metric: 6,371.00 km English: 3,958.8 miles Scientific Notation: 6.3710×10^3 km
Equatorial Circumference	Metric: 40,030.2 km English: 24,873.6 miles Scientific Notation: 4.00302×10^4 km

Volume	Metric: 1,083,206,916,846 km ³ English: 259,875,159,532 mi ³ Scientific Notation: 1.08321 x 10 ¹² km ³
Mass	Metric: 5,972,190,000,000,000,000,000 kg Scientific Notation: 5.9722 x 10 ²⁴ kg
Density	Metric: 5.513 g/cm ³
Surface Area	Metric: 510,064,472 km ² English: 196,936,994 square miles Scientific Notation: 5.1006 x 10 ⁸ km ²
Surface Gravity	Metric: 9.80665 m/s ² English: 32.041 ft/s ²
Escape Velocity	Metric: 40,284 km/h English: 25,031 mph Scientific Notation: 1.119 x 10 ⁴ m/s
Sidereal Rotation Period (Length of Day)	0.99726968 Earth days 23.934 hours
Minimum/Maximum Surface Temperature	Metric: -88/58 (min/max) °C English: -126/136 (min/max) °F Scientific Notation: 185/331 (min/max) K
Atmospheric Constituents	Nitrogen, Oxygen Scientific Notation: N ₂ , O ₂

Source: <http://www.nasa.gov/home/index.html>

We think of ourselves as living on a single planet, but in reality, we live in a system of two worlds. Our sister world, the Moon, is easily visible in our sky, and we can see its daily effects on ocean tides. The relationship between the two bodies was first appreciated in 1968, when humans started to explore the other half of our system.

The Moon affects the Earth in several observable ways. Consider the monthly movement of the Moon around our planet – we see the phases of the Moon cycle daily, as different parts of the Earth-facing side of the Moon are illuminated by the Sun. Many people superstitiously believe that the Moon influences human behavior by some unknown force, causing people to act strangely during a full Moon. However, this has never been convincingly proven. (Though there may be some tendency for more people to be out on full Moon nights and hence for more interesting events to happen.)

2.4.2 | THE MOON

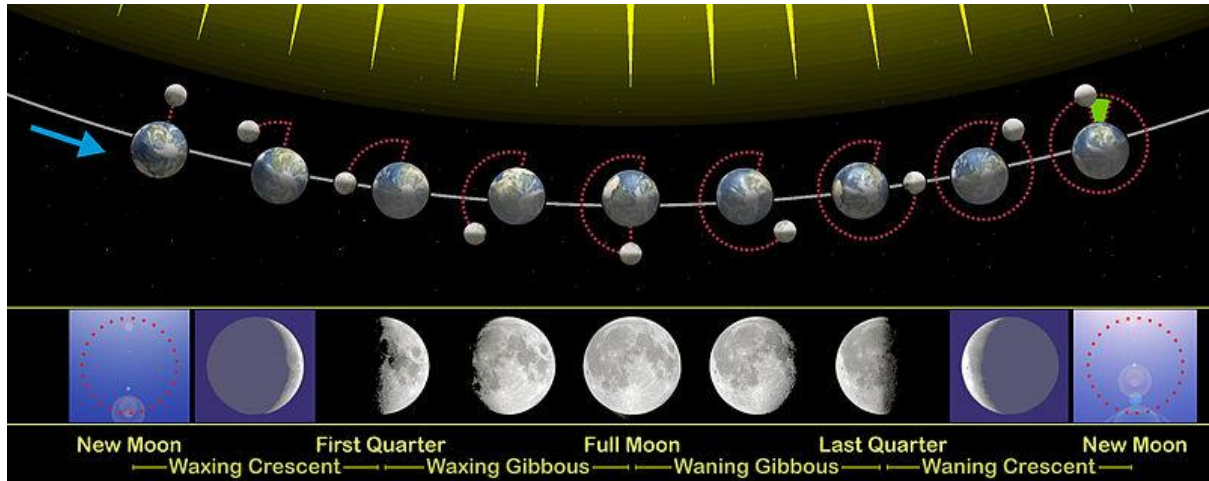


Image comment: Lunar Phases

Image credits: <http://3.bp.blogspot.com/-F1HQsufc4Qg/UFiBzjswAJI/AAAAAAAAAU/2jdZMWLIR00/s1600/fases+lunares.png>

As Newton discovered, Earth's gravity attracts the Moon toward the Earth, and keeps it in orbit around the Earth. But gravity is a mutually attractive force. So the Moon is attracting the Earth, too. Since the force of gravity depends on the inverse square of the distance, the side of the Earth facing the Moon has a stronger force pulling toward the Moon than the opposite side, because it is closer to the Moon. The two unequal forces cause a net stretching force along the Earth-Moon axis, called a tidal force. Tidal forces occur any time there is a difference between the gravity on the two sides of a celestial body caused by the attraction of another body. The actual effect is to stretch the whole planet into a slightly football-like shape. This elongation of the solid Earth is actually very subtle – it results in a difference in the radii at the poles and the equator of only about 20 centimeters!

The liquid ocean can move much more freely in response to tidal forces than the solid rocks inside the Earth. Water flows until it “piles up” in tidal bulges on each side of the Earth. You may wonder about the fact that tides occur on both sides of the Earth. Why doesn't the attraction of gravity just cause the water to pile up on the side closest to the Earth? Just as the force of gravity is strongest on the side of the Earth facing the Moon, the force is weakest on the side away from the Moon. Less gravitational force on the far side means the water is not attracted as strongly, and it moves away from the center of gravity. Think of a spring as an analogy. When the spring is stretched, the distance between all parts of the spring increases. In the same way, the tidal stretching force applies to the oceans on both sides of the Earth. Since there are tides on opposite sides of the Earth, and the Earth rotates once per day, a given spot on the rotating Earth passes through two high-tide zones in one day.

If the tug of the Moon were the only thing causing tides, high tides would occur whenever the Moon is overhead, and then exactly 12 hours later. In fact, three effects complicate ocean tides. First, the Earth's rotation drags the tidal bulges out of line with the direction to the Moon. Second, coastlines complicate the flow of water, so that actual high tides occur in a complex rhythmic pattern. Third, the Sun contributes its own tidal forces.

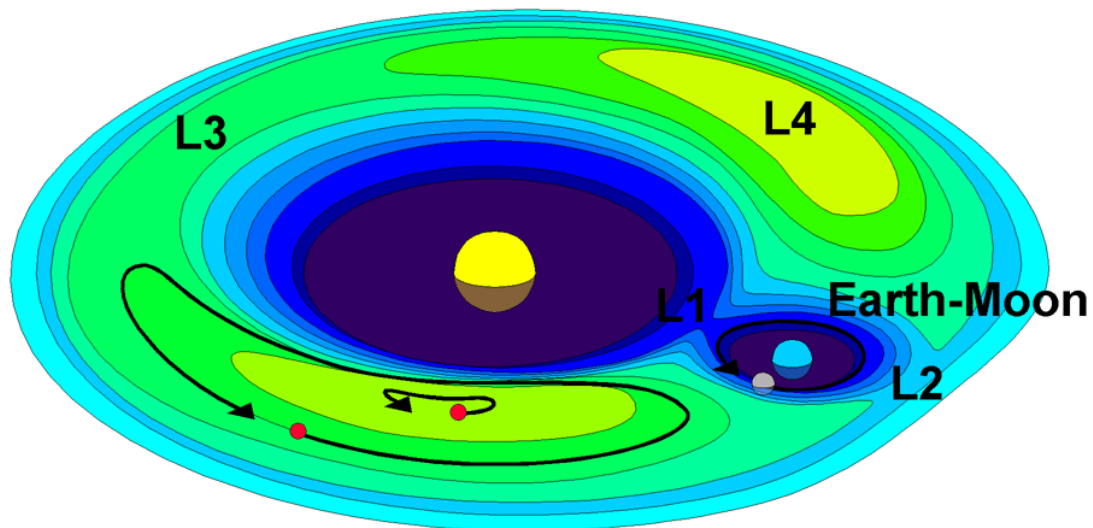


Image comment: Lagrange_points

Image credits: davesbrain.ca/art/science_illos/

The Sun is much more massive than the Moon, but it's also a lot farther away. When you calculate the resulting gravitational forces, the Sun's gravitational force on the Earth is much stronger than the Moon's gravitational force on the Earth. This is how the Sun keeps the Earth in orbit around it. However, because the Moon is so much closer, the differential force caused by the Moon is larger than the differential force caused by the Sun. So the Moon's tidal force is larger. The Sun has some tidal force on the Earth, too – but solar tides are only about half as high as lunar ones. When the Sun and Moon line up (new Moon and full Moon), the tides on Earth are especially high (spring tides). When they are 90° in opposition, the tides partially cancel each other out, and the resulting lower tides are called neap tides.

The liquid oceans can move easily to respond to the Moon's influence. But the rocky mass of the Earth feels the same tidal forces, and it can't alleviate the stress by flowing freely. Land tides put extra stresses on the brittle rocks of the lithosphere. This can lead to earthquakes. Geologists have found that earthquakes do not occur randomly over time. There is a slightly higher chance of earthquakes near full Moon or new Moon, when the tidal forces are largest. You've probably noticed that the features of the Moon always appear the same – the Moon actually orbits the Earth in such a way that the same side always points towards the Earth. This is because the force of gravity is working both ways – the Moon is slightly elongated by

its own tides, caused by the gravity of the Earth. Earth's gravity has forced the long axis of the Moon to face the planet, so that the Moon is tidally locked in synchronous rotation. Through a complex interplay of gravity, tidal forces are also slowing down the rotation of Earth. At the same time, the Moon is slowly spiraling further away from Earth. This is yet another example of the conservation of energy. As the Earth loses rotational kinetic energy by spinning more slowly, the gravitational potential energy increases as the Moon moves to a larger distance from the Earth. The total energy in the Earth-Moon system is conserved. If we follow these changes in reverse, backwards in time, we find that the Earth rotated faster. The Moon was closer to the Earth, so it orbited the Earth in fewer days.

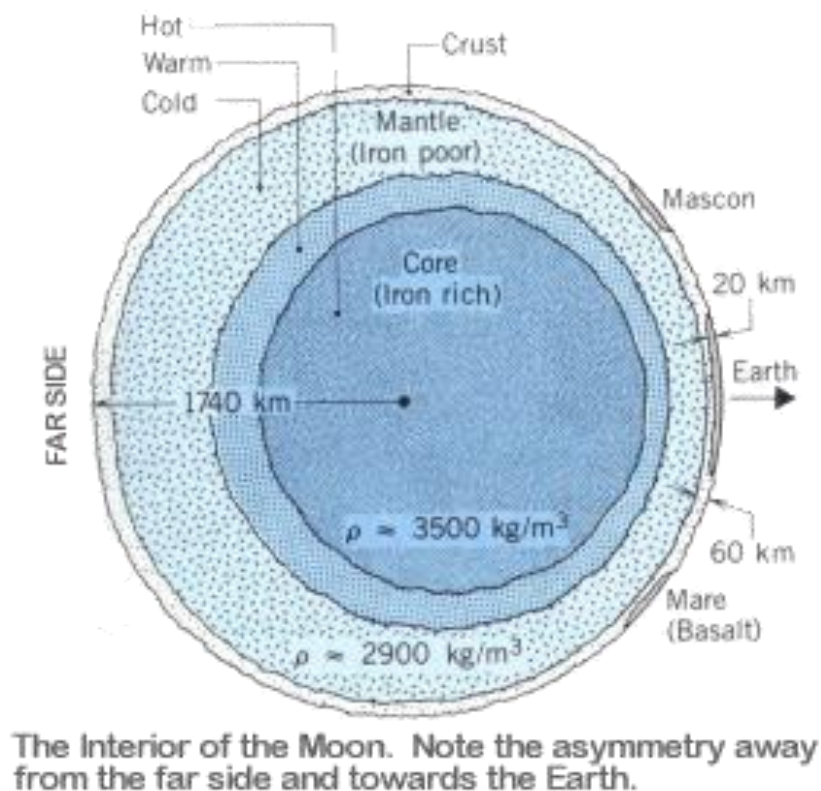
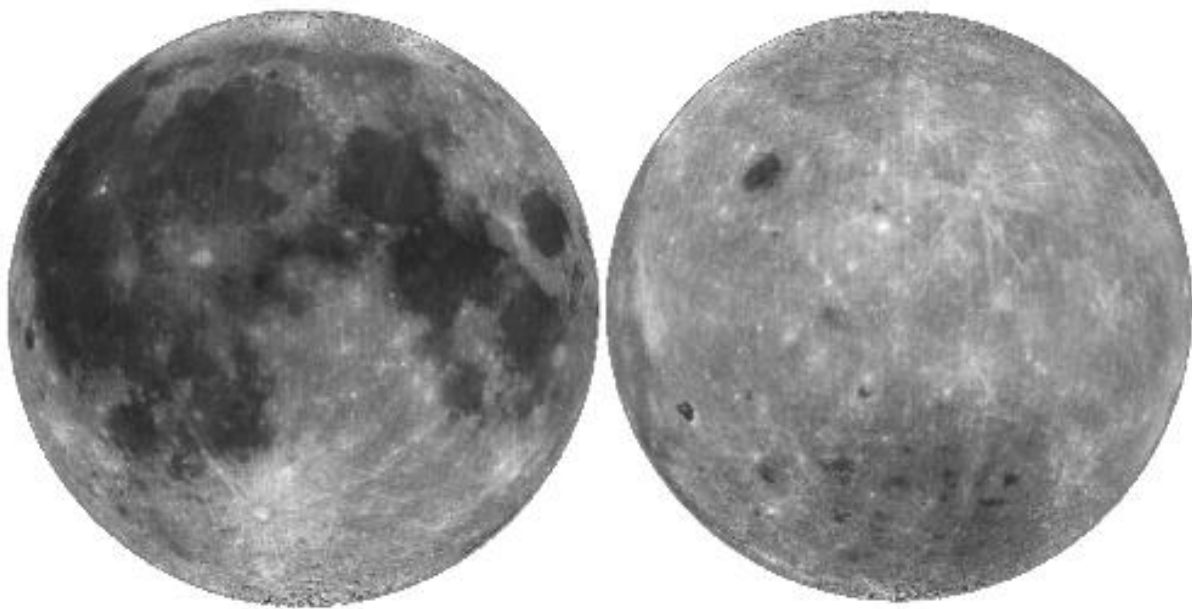


Image comment: Interior of the Moon

Image credits: zebu.uoregon.edu/~imamura/121/nov10/nov10.html

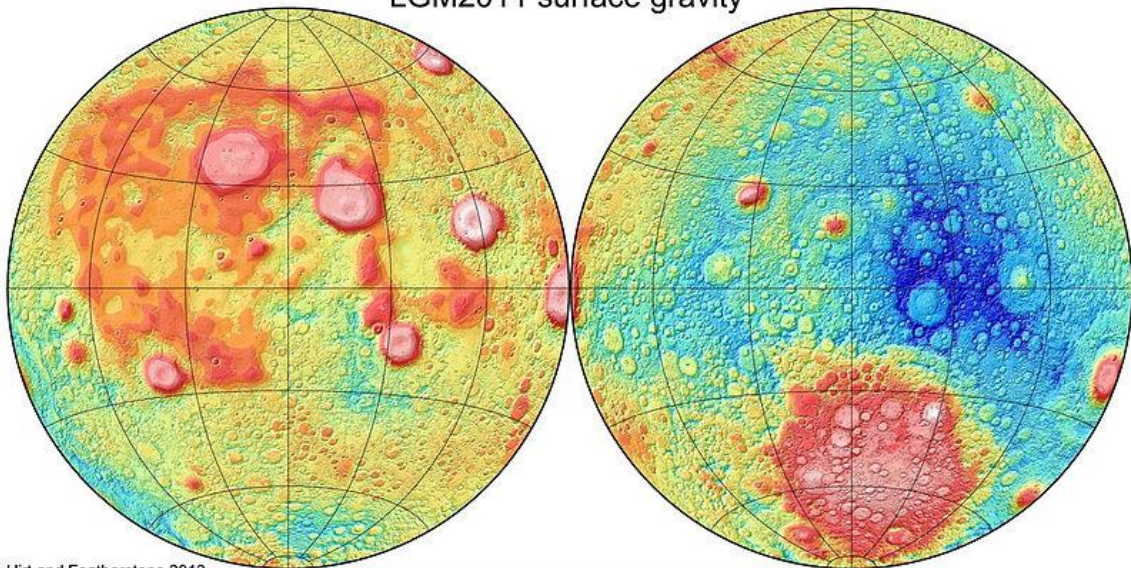
What evidence do we have to support the theory that the spin of the Earth is slowing down? The Apollo astronauts placed laser reflectors on the Moon in order to measure lunar motions precisely. These measurements confirm that the Moon is moving very slowly away from the Earth, as predicted. In addition, paleontologists have studied the daily and monthly growth rings in fossilized coral and other organisms. The results show that one billion years ago, the Moon took only 23 days to go around the Earth, and the Earth rotated in only 18 hours! Somewhat controversial fossil data from 2.8 billion years ago suggest that the lunar month was as short as 17 days!



Near Side

Far Side

LGM2011 surface gravity



Hirt and Featherstone 2012
Earth Plan Sci Lett 329-330, 22-30
doi:10.1016/j.epsl.2012.02.012

1.611 1.616 1.621 1.626 1.631 1.636 [m/s²]

Image comment: Moon gravity acceleration Map

Image credits: <http://ottawa-rasc.ca/wiki/index.php?title=Hanmer-Articles-Moon-Two-Faces>

2.4.2.1 | FACTS AND FIGURES – MOON

Orbit Size Around Earth (semi-major axis)	Metric: 384,400 km English: 238,855 miles Scientific Notation: 3.84400×10^5 km (0.00257 A.U.) By Comparison: 0.00257 x Earth's Distance from the Sun
Average Distance from Earth	Metric: 384,400 km English: 238,855 miles Scientific Notation: 3.844×10^5 km (2.570×10^{-3} A.U.) By Comparison: 0.00257 x Earth's distance from the Sun
Perigee (closest)	Metric: 363,104 km English: 225,623 miles Scientific Notation: 3.631×10^5 km (2.427×10^{-3} A.U.) By Comparison: 0.00243 x Earth's distance from the Sun
Apogee (farthest)	Metric: 405,696 km English: 252,088 miles Scientific Notation: 4.051×10^5 km (2.712×10^{-3} A.U.) By Comparison: 0.00271 x Earth's distance from the Sun
Sidereal Orbit Period (Length of Year)	0.074803559 Earth days 27.322 Earth hours
Orbit Circumference	Metric: 2,413,402.16 km English: 1,499,618.58 miles Scientific Notation: 2.413×10^6 km
Average Orbit Velocity	Metric: 3,680.5 km/h English: 2,287.0 mph Scientific Notation: 1,022 m/s By Comparison: 0.034 x Earth
Orbit Eccentricity	0.0554 By Comparison: 3.315 x Earth
Orbit Inclination	5.16 degrees By Comparison: Oscillates roughly 0.15 degrees in 173 days.
Equatorial Inclination to Orbit	6.68 degrees
Mean Radius	Metric: 1737.5 km English: 1079.6 miles Scientific Notation: 1.738×10^3 km By Comparison: 0.2727 x Earth
Equatorial Circumference	Metric: 10,917.0 km English: 6,783.5 miles Scientific Notation: 1.0917×10^4 km
Volume	Metric: 21,971,669,064 km ³ Scientific Notation: 2.197×10^{10} km ³

	By Comparison: 0.020 x Earth
Mass	Metric: 73,476,730,924,573,500,000,000 kg Scientific Notation: 7.3477×10^{22} kg By Comparison: 0.0123 x Earth
Density	Metric: 3.344 g/cm ³ By Comparison: 0.607 x Earth
Surface Area	Metric: 37,936,694.79 km ² English: 14,647,439.75 square miles Scientific Notation: 3.793669×10^7 km ² By Comparison: 0.074 x Earth
Surface Gravity	Metric: 1.624 m/s ² English: 5.328 ft/s ² Scientific Notation: 1.624 m/s ² By Comparison: 0.166 x Earth
Escape Velocity	Metric: 8,552 km/h English: 5,314 mph Scientific Notation: 2,376 m/s By Comparison: 0.212 x Earth
Sidereal Rotation Period (Length of Day)	27.322 Earth days 655.73 hours By Comparison: Synchronous with Orbital Period
Minimum/Maximum Surface Temperature	Metric: -233/123 °C English: -387/253 °F Scientific Notation: 40/396 K

<http://www.nasa.gov/home/index.html>

By studying the Earth and the Moon, scientists have been able to piece together their linked histories. Our planet and its satellite are a double system that formed 4.6 billion years ago. The Moon probably originated during a gigantic collision in the late stages of planetary formation, after the Earth's iron core formed. The Moon formed close to the Earth from the ejected material, and it has been slowly moving outward in its orbit ever since, due to tidal forces. The age of the Earth-Moon system and the chronology of the Earth's history are measured using the technique of radioactive decay. This well-understood physical process also provides the energy that drives most of the Earth's geological evolution.

Both the Earth and the Moon at one time had molten or partially molten interiors. This allowed differentiation – the gravitational separation of rocks by their density within a planet. This process explains the overall compositional structure of the Earth and the Moon, with a dense core at the center and lighter rocks forming a crust at the surface.

Unlike the Moon, the Earth is large enough to have retained a large part of that original internal heat for the past 4.5 billion years, and it is also experiencing continued heating from the radioactive decay of materials in its crust. Only the thin outer lithosphere is rigid. Much of its mantle is hot and plastic, with a slow circulation of molten rock that create stresses in the lithosphere, causing earthquakes and plate tectonic activity. Plate tectonics describe the constant shifting and reformation of plates, including continents, on the Earth's surface. This geological activity explains why most of the Earth's surface is relatively young, most of it being no more than a few hundred million years old.

By contrast, the neighboring Moon's surface is three to four billion years old, and heavily cratered. Because it's so small, the Moon cooled off more rapidly, and now it has a relatively dead interior and a thick lithosphere. It shows fewer signs of surface sculpting from below, and those date from its early history, when it was still warm inside. The dominant process that has sculpted the Moon's surface in the last three billion years comes from outside, not from inside. Eons of asteroids and comets have slammed into the Moon, creating its characteristic cratered surface. The granular soil the Apollo astronauts walked on is the result of small meteorites pulverizing the surface. No internal processes exist to "recycle" the surface. Earth is subject to the same onslaught of asteroids and comets, but the atmosphere burns up the smaller projectiles before they land. Tectonics, volcanism, and erosion by wind and rain have obscured most of the remaining cratering record.

Combining studies of rock strata, the fossil record, and radioactive ages, yields a chronology of the Earth, known as the geological time scale. The layers of the Earth reveal a succession of prehistoric species, generally from less complex to more complex, with distinct breaks in the fossil record. The vast majority of these fossil species are now extinct. The impact of an interplanetary body 65 million years ago caused one of these breaks, or mass extinctions. The largest mass extinction was about 250 million years ago, and its cause is uncertain. The evolution of life on Earth has been punctuated by catastrophes caused by space debris. The Earth's history doesn't occur in a closed environment, but is subject to cosmic influences.

Most of the Earth's environmental changes have occurred slowly, over many millions of years. This includes the buildup of oxygen in the atmosphere due to the respiration of tiny organisms several billion years ago. Environmental changes continue, some caused by human activity on a very short time scale (compared to longer time scales that allow biological evolution to respond). Human activity has depleted the ozone layer and increased the carbon dioxide content of the atmosphere, which may lead to global warming.

Mass explains most of the difference between the Earth and the Moon. The Earth is so massive that a lot of energy is released by radioactive decay within the interior rocks. This heats and liquefies the rock, which then drives the activity of the crust. The Moon is 80 times less massive, so it has proportionately less energy from radioactive decay. The heat generated within the Moon is insufficient to melt rocks and drive geological activity. This simple difference illustrates the fundamental contest between internal and external forces in determining the surface conditions on planets. In general, a massive planet is more likely to retain a hot interior, and internal geological forces win the contest to shape the surface. Smaller worlds lose their heat and have little internal geological activity, so external impacts play the dominant role in shaping surface features.

2.5 | HUMANS AND SPACE TRAVEL



Image comment: Nasa Apollo Mission

Image source: <http://www.space.com/12771-nasa-apollo-missions-photo-countdown.html>

The people who used to investigate space were called Astronomers and Astrologers, who saw the moving but unchanging patterns of stars as clues to how the world worked. Until the invention of the telescope, all they knew were gross delineations: wandering stars (planets), fixed stars, nebulae, and comets. The Moon and Sun were of particular interest because the two marked the passage of days, of months, and of years. Their relationship to the weather, to the tides, and to the seasons, made them important to civilization.

The serious development of rocketry in the 20th century made direct exploration of space possible. Jules Verne and others had examined it in fiction, but advances in metallurgy, chemistry, and mechanical systems made it feasible in reality. The German V-2 rockets of the early 1940s were a major step, and both the Soviet Union and the United States made use of captured specimens to augment their own technology. The political dichotomy after World War II, communism versus democracy, spurred an arms race that soon included space. So the purely scientific inquiries were studied hand-in-hand with the development of advanced weapons systems. The Soviets had the first artificial satellite, and the first man in space, but their technology soon lagged behind the US juggernaut that put men on the Moon.

By the 1970s, the satellite had become an integral part of life on Earth, and civilian uses soon outnumbered the military ones. Governments and businesses cooperatively utilized space for communications, weather, and the study of resources on Earth.

Once the Moon was reached, the impetus for competition waned, and the Russians and Americans were soon assisting each other in building space stations, and sending probes to the planets. On the ground and in orbit, there were new means of observing the universe, and new mathematical concepts of how it worked. Scientists and astronauts from around the world continue to study space, but the major reason is to understand life here on Earth.

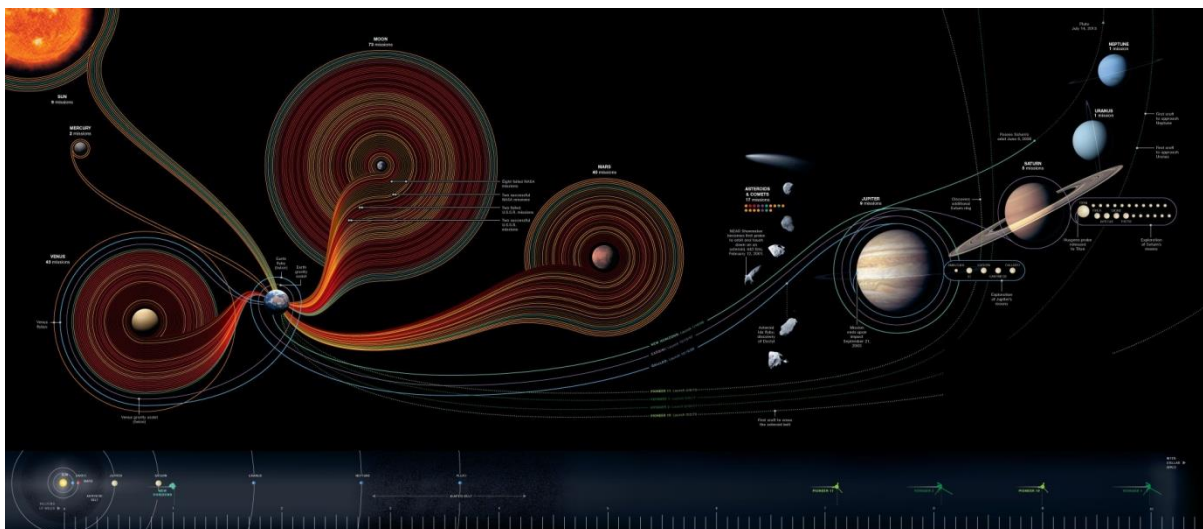


Image comment: 50 years of space exploration

Image source: <http://www.edudemic.com/2012/08/50-years-of-space-exploration-explained-in-one-visualization/>

Humans have been continually present in space for 12 years and 270 days on the International Space Station. The first manned spaceflight was launched by the Soviet Union on April 12, 1961 as a part of the Vostok program, with cosmonaut Yuri Gagarin aboard. Currently, only Russia and China maintain human spaceflight capability independent of

international cooperation. As of 2013, human spaceflights are only launched by the Soyuz program conducted by the Russian Federal Space Agency and the Shenzhou program conducted by the China National Space Administration. The United States lost human spaceflight launch capability upon retirement of the space shuttle in 2011.

In recent years there has been a gradual movement towards more commercial means of spaceflight. The first private human spaceflight took place on June 21, 2004, when Space Ship One conducted a suborbital flight. A number of non-governmental startup companies have sprung up, hoping to create a space tourism industry. NASA has also tried to stimulate private spaceflight through programs such as Commercial Crew Development (CCDev) and Commercial Orbital Transportation Services (COTS).

SPACE LAUNCHES (payloads by country and purpose, annually)

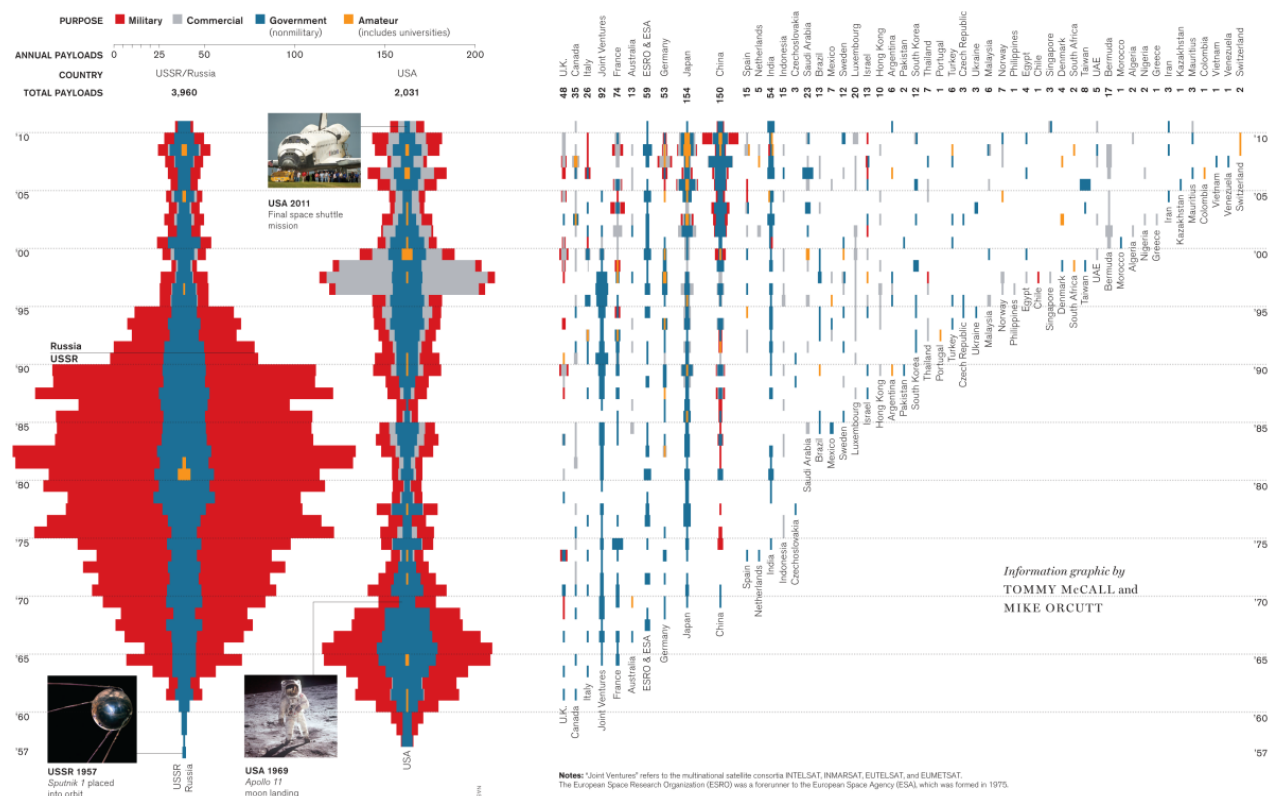


Image comment: Space Launches

Image source: visual.ly/space-launches

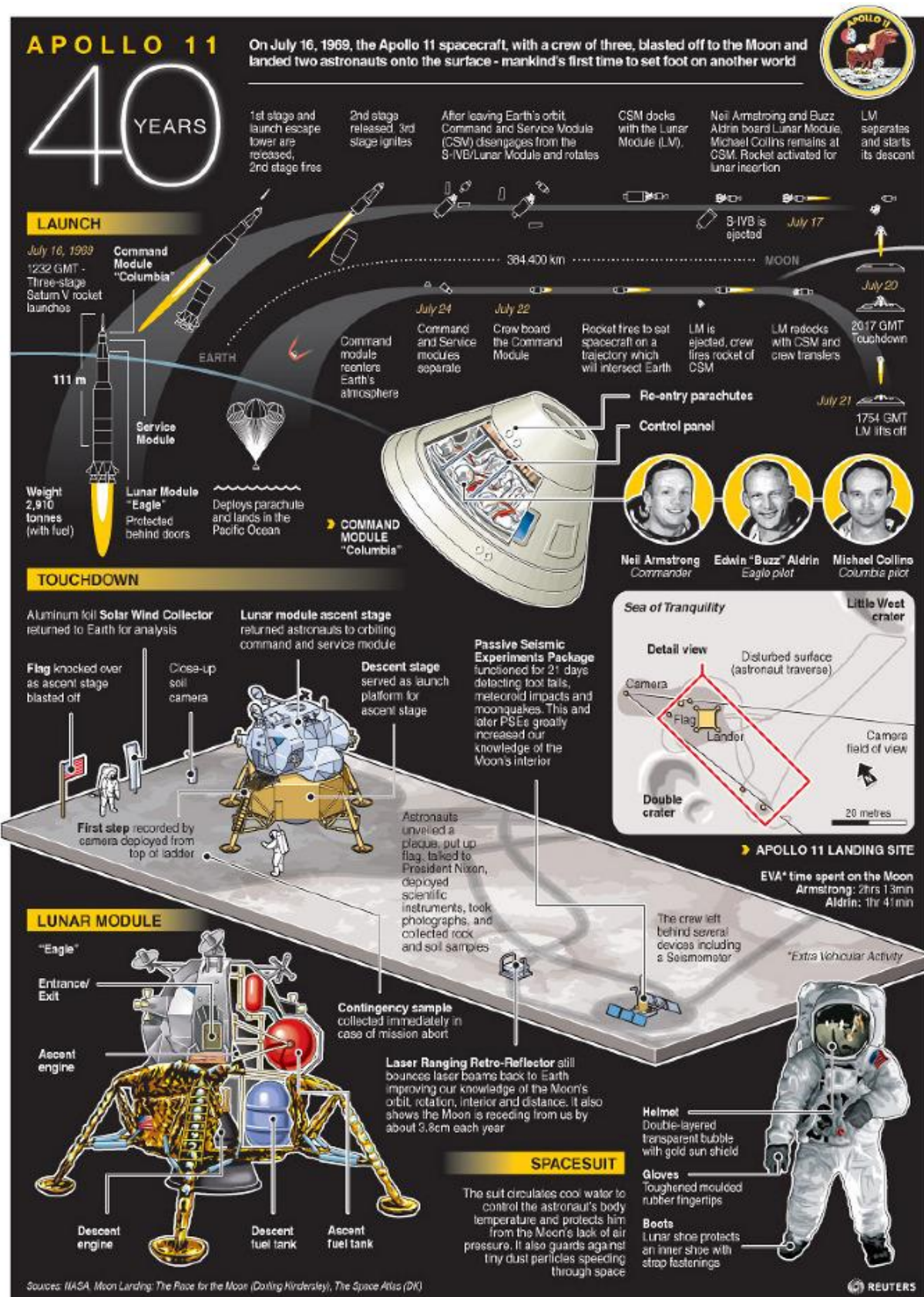


Image comment: 40years of Apollo 11

Image source: ouniversodegian.blogspot.com/2012/08/homem-na-lua.html

CHAPTER | 3

HUMAN AND OUTER SPACE

3.1 | HUMAN AND OUTER SPACE



Image comment: Human in space

Image credits: en.wikipedia.org/wiki/Outer_space

We humans are physiologically well-adapted to life on Earth. Consequently, spaceflight has many negative effects on the body. The most significant adverse effects of long-term weightlessness are muscle atrophy and deterioration of the skeleton. Other significant effects include a slowing of cardiovascular system functions, decreased production of red blood cells, balance disorders, and a weakening of the immune system. Lesser symptoms include fluid redistribution (causing the "moon-face" appearance typical in pictures of astronauts experiencing weightlessness), loss of body mass, nasal congestion, sleep disturbance, and excess flatulence. Most of these effects begin to reverse quickly upon return to Earth.

The engineering problems associated with leaving Earth and developing space propulsion systems have been examined for over a century, and millions of man-hours of research have been spent on them. In recent years there has been an increase in research on the issue of how humans can survive and work in space for extended and possibly indefinite periods of time. This question requires input from the physical and biological sciences and has now become the greatest challenge (other than funding) facing human space exploration. A fundamental step in overcoming this challenge is trying to understand the effects and impact of long-term space travel on the human body.

What motivates an astronaut, an outer space explorer, to spend a lot of time under water in an underwater habitat? The answer is, it's a great way to simulate many aspects of zero gravity living and long term confinement that are experienced in space vehicles and stations.

For decades, NASA has been studying astronaut's physiological responses to being exposed to zero gravity, to living in outer space and to staying in a space vehicles and space stations for extended periods of time. Researchers William Toscano and Pat Cowing have been doing this kind of research for several decades. Some of their most interesting work has involved researching the problem of Zero Gravity illness, which is sort of like car or sea-sickness. It's a common problem among astronauts.

New, microminiaturization technologies have enabled the NASA researchers to use commercially produced biomedical devices like the FlexComp Infiniti™ to do what used to take a wall full of equipment easily weighing over 1000 pounds. Now, the device, manufactured by Thought Technology, weighs less than a pound and has built-in data storage using flash memory cards.

3.1.1 | THE EFFECTS OF SPACE ON HUMAN PHYSIOLOGY

Space medicine is a developing medical practice that studies the health of astronauts living in outer space. The main purpose of this academic pursuit is to discover how well and for how long people can survive the extreme conditions in space, and how fast they can re-adapt to the Earth's environment after returning from space. Space medicine also seeks to develop preventative and palliative measures to ease the suffering caused by living in an environment to which humans are not well adapted.

Many of the environmental conditions experienced by humans during spaceflight are very different from those in which humans evolved; however, technology is able to shield people from the harshest conditions, such as that offered by a spaceship or spacesuit. The immediate needs for breathable air and drinkable water are addressed by a life support system, a group of devices that allow human beings to survive in outer space. The life support system supplies air, water and food. It must also maintain temperature and pressure within acceptable limits and deal with the body's waste products. Shielding against harmful external influences such as radiation and micro-meteorites is also necessary.

Of course, it is not possible to remove all hazards; the most important factor affecting human physical well-being in space is weightlessness, more accurately defined as microgravity.

Living in this type of environment impacts the body in three important ways: loss of proprioception, changes in fluid distribution, and deterioration of the musculoskeletal system.

The environment of space is lethal without appropriate protection: the greatest threat in the vacuum of space derives from the lack of oxygen and pressure, although temperature and radiation also pose risks.

3.1.2 | THE VACUUM OF SPACE

Human physiology is adapted to living within the atmosphere of Earth, and a certain amount of oxygen is required in the air we breathe. The minimum concentration, or partial pressure, of oxygen that can be tolerated is 16 kPa. Below this, the astronaut is at risk of becoming unconscious and dying from hypoxia. In the vacuum of space, gas exchange in the lungs continues as normal but results in the removal of all gases, including oxygen, from the bloodstream. After 9 to 12 seconds, the deoxygenated blood reaches the brain, and loss of consciousness results. Death would gradually follow after two minutes of exposure—though the absolute limits are uncertain.

Humans and other animals exposed to vacuum lose consciousness after a few seconds and die of hypoxia within minutes, but the symptoms are not nearly as graphic as the imagery in the public media suggests. Blood and other body fluids do boil when their pressure drops below 6.3 kPa, the vapor pressure of water at body temperature. This condition is called ebullism. The steam may bloat the body to twice its normal size and slow circulation, but tissues are elastic and porous enough to prevent rupture. Ebullism is slowed by the pressure containment of blood vessels, so some blood remains liquid. Swelling and ebullism can be reduced by containment in a flight suit. Space Shuttle astronauts wore a fitted elastic garment called a Crew Altitude Protection Suit (CAPS) which prevented ebullism at pressures as low as 2 kPa. Spacesuits are necessary to prevent ebullism above 19 km. Most spacesuits use 20 kPa of pure oxygen, just enough to sustain full consciousness. This pressure is high enough to prevent ebullism, but simple evaporation of blood, or of gases dissolved in the blood, can still cause decompression sickness (the bends) and gas embolisms if not managed.

A short-term exposure to vacuum of up to 30 seconds is unlikely to cause permanent physical damage. Animal experiments show that rapid and complete recovery is normal for exposures shorter than 90 seconds, while longer full-body exposures are fatal and resuscitation has never been successful. There is only a limited amount of data available from human accidents, but it is consistent with animal data. Limbs may be exposed for much longer if breathing is not impaired. Rapid decompression can be much more dangerous than

vacuum exposure itself. Even if the victim does not hold his breath, venting through the windpipe may be too slow to prevent the fatal rupture of the delicate alveoli of the lungs. Eardrums and sinuses may be ruptured by rapid decompression, soft tissues may bruise and seep blood, and the stress of shock accelerates oxygen consumption, leading to hypoxia. Injuries caused by rapid decompression are called barotrauma, and are well known from scuba diving accidents.

3.1.3 | EXTREME VARIATIONS IN TEMPERATURE AND RADIATION

In a vacuum, there is no medium for removing heat from the body by conduction or convection. Loss of heat is by radiation from the 310 K temperature of a person to the 3 K of outer space. This is a slow process, especially in a clothed person, so there is no danger of immediately freezing. Rapid evaporative cooling of skin moisture in a vacuum may create frost, particularly in the mouth, but this is not a significant hazard.

Exposure to the intense radiation of direct, unfiltered sunlight would lead to local heating, though that would likely be well distributed by the body's conductivity and blood circulation. Other solar radiation, particularly ultraviolet rays, however, may cause severe sunburn in a few seconds.

Without the protection of Earth's atmosphere and magnetosphere astronauts are exposed to high levels of radiation. A year in low-earth orbit results in a dose of radiation 10 times that of the annual dose on earth. High levels of radiation damage lymphocytes, cells heavily involved in maintaining the immune system; this damage contributes to the lowered immunity experienced by astronauts. Radiation has also recently been linked to a higher incidence of cataracts in astronauts. Outside of the protection of low-earth orbit, galactic cosmic rays present further challenges to human spaceflight, as the health threat from cosmic rays significantly increases the chances of cancer over a decade or more of exposure. Solar flare events (though rare) can give a fatal radiation dose in minutes. It is thought that protective shielding and protective drugs may ultimately lower the risks to an acceptable level.

Crew living on the International Space Station (ISS) are partially protected from the space environment by Earth's magnetic field, as the magnetosphere deflects solar wind around the earth and the ISS. Nevertheless, solar flares are powerful enough to warp and penetrate the magnetic defenses, and so are still a hazard to the crew. The crew of Expedition 10 took shelter as a precaution in 2005 in a more heavily shielded part of the station designed for this purpose. However, beyond the limited protection of Earth's magnetosphere, interplanetary manned missions are much more vulnerable.

3.1.4 | THE EFFECTS OF WEIGHTLESSNESS

Following the advent of space stations that can be inhabited for long periods of time, exposure to weightlessness has been demonstrated to have some deleterious effects on human health. Humans are well-adapted to the physical conditions at the surface of the earth, and so in response to weightlessness, various physiological systems begin to change, and in some cases, atrophy. Though these changes are usually temporary, some do have a long-term impact on human health.

Short-term exposure to microgravity causes space adaptation syndrome, a self-limiting nausea caused by derangement of the vestibular system. Long-term exposure causes multiple health problems, one of the most significant being loss of bone and muscle mass. Over time these deconditioning effects can impair astronauts' performance, increase their risk of injury, reduce their aerobic capacity, and slow down their cardiovascular system. As the human body consists mostly of fluids, gravity tends to force them into the lower half of the body, and our bodies have many systems to balance this situation. When released from the pull of gravity, these systems continue to work, causing a general redistribution of fluids into the upper half of the body. This is the cause of the round-faced 'puffiness' seen in astronauts. Redistributing fluids around the body itself causes balance disorders, distorted vision, and a loss of taste and smell.

A major effect of long-term weightlessness involves the loss of bone and muscle mass. Without the effects of gravity, skeletal muscle is no longer required to maintain posture and the muscle groups used in moving around in a weightless environment differ from those required in terrestrial locomotion. In a weightless environment, astronauts put almost no weight on the back muscles or leg muscles used for standing up. Those muscles then start to weaken and eventually get smaller. Consequently some muscles atrophy rapidly, and astronauts can lose up to 25% of their muscle mass on long flights. The types of muscle fibre prominent in muscles also change. Slow twitch endurance fibres used to maintain posture are replaced by fast twitch rapidly contracting fibres that are insufficient for any heavy labour. Advances in research on exercise, hormone supplements and medication may help maintain muscle and body mass. Bone metabolism also changes. Normally, bone is laid down in the direction of mechanical stress, however in a microgravity environment there is very little mechanical stress. This results in a loss of bone tissue approximately 1.5% per month especially from the lower vertebrae, hip and femur. Elevated blood calcium levels from the lost bone result in dangerous calcification of soft tissues and potential kidney stone formation. It is still unknown whether bone recovers completely. Unlike people with

osteoporosis, astronauts eventually regain their bone density. After a 3-4 month trip into space, it takes about 2–3 years to regain lost bone density. New techniques are being developed to help astronauts recover faster. Research on diet, exercise and medication may hold the potential to aid the process of growing new bone.

Currently, NASA is using advanced computational tools to understand the how to best counteract the bone and muscle atrophy experienced by astronauts in microgravity environments for prolonged periods of time. The Human Research Program's Human Health Countermeasures Element chartered the Digital Astronaut Project to investigate targeted questions about exercise countermeasure regimes. NASA is focusing on integrating a model of the advanced Resistive Exercise Device (ARED) currently on board the International Space Station with Open Sim musculoskeletal models of humans exercising with the device. The goal of this work is to use inverse dynamics to estimate joint torques and muscle forces resulting from using the ARED, and thus more accurately prescribe exercise regimens for the astronauts.

3.1.5 | ADVERSE EFFECTS OF WEIGHTLESSNESS

It is ironic that, having gone to great expense to escape Earth gravity, it may be necessary to incur the additional expense of simulating gravity in orbit. Before opting for artificial gravity, it is worth reviewing the consequences of long-term exposure to weightlessness.

1. **Fluid redistribution:** Bodily fluids shift from the lower extremities toward the head.
2. **Fluid loss:** The brain interprets the increase of fluid in the cephalic area as an increase in total fluid volume. In response, it activates excretory mechanisms. This compounds calcium loss and bone demineralization. Blood volume may decrease by 10 percent, which contributes to cardiovascular deconditioning. Space crew members must beware of dehydration.
3. **Electrolyte imbalances:** Changes in fluid distribution lead to imbalances in potassium and sodium and disturb the autonomic regulatory system.
4. **Cardiovascular changes:** An increase of fluid in the thoracic area leads initially to increases in left ventricular volume and cardiac output. As the body seeks a new equilibrium, fluid is excreted, the left ventricle shrinks and cardiac output decreases. Upon return to gravity, fluid is pulled back into the lower extremities and cardiac output falls to subnormal levels. It may take several weeks for fluid volume, peripheral resistance, cardiac size and cardiac output to return to normal.
5. **Red blood cell loss:** Blood samples taken before and after American and Soviet flights have indicated a loss of as much as 0.5 liters of red blood cells. Scientists are

investigating the possibility that weightlessness causes a change in splenic function that result in premature destruction of red blood cells. In animal studies there is some evidence of loss through microhemorrhages in muscle tissue as well.

6. **Muscle damage:** Muscles atrophy from lack of use. Contractile proteins are lost and tissue shrinks. Muscle loss may be accompanied by a change in muscle type: rats exposed to weightlessness show an increase in the amount of "fast-twitch" white fiber relative to the bulkier "slow-twitch" red fiber. In 1987, rats exposed to 12.5 days of weightlessness showed a loss of 40 percent of their muscle mass and "serious damage" in 4 to 7 percent of their muscle fibers. The affected fibers were swollen and had been invaded by white blood cells. Blood vessels had broken and red blood cells had entered the muscle. Half the muscles had damaged nerve endings. The damage may have resulted from factors other than simple disuse, in particular: stress, poor nutrition, and reduced circulation - all of which are compounded by weightlessness; and radiation exposure - which is independent of weightlessness. There is concern that damaged blood supply to muscle may adversely affect the blood supply to bone as well.
7. **Bone damage:** Bone tissue is deposited where needed and resorbed where not needed. This process is regulated by the piezoelectric behavior of bone tissue under stress. Because the mechanical demands on bones are greatly reduced in micro gravity, they essentially dissolve. While cortical bone may regenerate, loss of trabecular bone may be irreversible. Diet and exercise have been only partially effective in reducing the damage. Short periods of high-load strength training may be more effective than long endurance exercise on the treadmills and bicycles commonly used in orbit. Evidence suggests that the loss occurs primarily in the weight-bearing bones of the legs and spine. Non-weight-bearing bones, such as the skull and fingers, do not seem to be affected.
8. **Hypercalcemia:** Fluid loss and bone demineralization conspire to increase the concentration of calcium in the blood, with a consequent increase in the risk of developing urinary stones.
9. **Immune system changes:** There is an increase in neutrophil concentration, decreases in eosinophils, monocytes and B-cells, a rise in steroid hormones and damage to T-cells. In 1983 aboard Spacelab I, when human lymphocyte cultures were exposed in vitro to concanavalin A, the T-cells were activated at only 3 percent of the rate of similarly treated cultures on Earth. Loss of T-cell function may hamper the body's resistance to cancer - a danger exacerbated by the high-radiation environment of space.

10. **Interference with medical procedures:** Fluid redistribution affects the way drugs are taken up by the body, with important consequences for space pharmacology. Bacterial cell membranes become thicker and less permeable, reducing the effectiveness of antibiotics. Space surgery will also be greatly affected: organs will drift, blood will not pool, and transfusions will require mechanical assistance.
11. **Vertigo and spatial disorientation:** Without a stable gravitational reference, crew members experience arbitrary and unexpected changes in their sense of verticality. Rooms that are thoroughly familiar when viewed in one orientation may become unfamiliar when viewed from a different up-down reference. Skylab astronaut Ed Gibson reported a sharp transition in the familiarity of the wardroom when rotated approximately 45 degrees from the "normal" vertical attitude in which he had trained. There is evidence that, in adapting to weightlessness, the brain comes to rely more on visual cues and less on other senses of motion or position. In orbit, Skylab astronauts lost the sense of where objects were located relative to their bodies when they could not actually see the objects. After returning home, one of them fell down in his own house when the lights went out unexpectedly.
12. **Space adaptation syndrome:** About half of all astronauts and cosmonauts are afflicted. Symptoms include nausea, vomiting, anorexia, headache, malaise, drowsiness, lethargy, pallor and sweating. Susceptibility to Earth-bound motion sickness does not correlate with susceptibility to space sickness. The sickness usually subsides in 1 to 3 days.
13. **Loss of exercise capacity:** This may be due to decreased motivation as well as physiological changes. Cosmonaut Valeriy Ryumin wrote in his memoirs: "On the ground, [exercise] was a pleasure, but [in space] we had to force ourselves to do it. Besides being simple hard work, it was also boring and monotonous." Weightlessness also makes it clumsy: equipment such as treadmills, bicycles and rowing machines must be festooned with restraints. Perspiration doesn't drip but simply accumulates. Skylab astronauts described disgusting pools of sweat half an inch deep sloshing around on their breastbones. Clothing becomes saturated.
14. **Degraded sense of smell and taste:** The increase of fluids in the head causes stuffiness similar to a head cold. Foods take on an aura of sameness and there is a craving for spices and strong flavorings such as horseradish, mustard and taco sauce.
15. **Weight loss:** Fluid loss, lack of exercise and diminished appetite result in weight loss. Space travelers tend not to eat enough. Meals and exercise must be planned to prevent excessive loss.

16. **Flatulence:** Digestive gas cannot "rise" toward the mouth and is more likely to pass through the other end of the digestive tract - in the words of Skylab crewman-doctor Joe Kerwin: "very effectively with great volume and frequency".
17. **Facial distortion:** The face becomes puffy and expressions become difficult to read, especially when viewed sideways or upside down. Voice pitch and tone are affected and speech becomes more nasal.
18. **Changes in posture and stature:** The neutral body posture approaches the fetal position. The spine tends to lengthen. Each of the Skylab astronauts gained an inch or more of height, which adversely affected the fit of their space suits.
19. **Changes in coordination:** Earth-normal coordination unconsciously compensates for self-weight. In weightlessness, the muscular effort required to reach for and grab an object is reduced. Hence, there is a tendency to reach too "high".

Many of these changes do not pose problems as long as the crew remains in a weightless environment. Trouble ensues upon the return to life with gravity. The rapid deceleration during reentry is especially stressful as the apparent gravity grows from zero to more than one "g" in a matter of minutes. In 1984, after a 237-day mission, Soviet cosmonauts felt that if they had stayed in space much longer they might not have survived reentry. In 1987, in the later stages of his 326-day mission, Yuri Romanenko was highly fatigued, both physically and mentally. His work day was reduced to 4.5 hours while his sleep period was extended to 9 hours and daily exercise on a bicycle and treadmill consumed 2.5 hours. At the end of the mission, the Soviets implemented the unusual procedure of sending up a "safety pilot" to escort Romanenko back to Earth.

3.1.6 | OTHER PHYSICAL EFFECTS

After two months, calluses on the bottoms of feet molt and fall off from lack of use, leaving soft new skin. Tops of feet become, by contrast, raw and painfully sensitive. Tears cannot be shed while crying, as they stick together into a ball. Various other physical discomforts such as back and abdominal pain are commonly experienced with no clear cause. These may be part of the asthenization syndrome reported by cosmonauts living in space over an extended period of time, but regarded as anecdotal by astronauts. Fatigue, listlessness, and psychosomatic worries are also part of the syndrome. The data is inconclusive; however the syndrome does appear to exist as a manifestation of all the internal and external stress crews in space must face.

3.1.7 | PSYCHOLOGICAL EFFECTS OF SPACE FLIGHT

The psychological effects of living in space have not been clearly analyzed but analogies on Earth do exist, such as Arctic research stations and submarines. The enormous stress on the crew, coupled with the body adapting to other environmental changes, can result in anxiety, insomnia and depression. According to current data, however, astronauts and cosmonauts seem extremely resilient to psychological stresses.

There has been considerable evidence that psychosocial stressors are among the most important impediments to optimal crew morale and performance. Cosmonaut Valery Ryumin, twice Hero of the Soviet Union, quotes this passage from *The Handbook of Hymen* by O. Henry in his autobiographical book about the Salyut 6 mission: "If you want to instigate the art of manslaughter just shut two men up in a eighteen by twenty-foot cabin for a month. Human nature won't stand it."

The amount and quality of sleep experienced in space is poor due to highly variable light and dark cycles on flight decks and poor illumination during daytime hours in the space craft. Even the habit of looking out of the window before retiring can send the wrong messages to the brain, resulting in poor sleep patterns. These disturbances in circadian rhythm have profound effects on the neurobehavioral responses of crew and aggravate the psychological stresses they already experience. Sleep is disturbed on the ISS regularly due to mission demands, such as the scheduling of incoming or departing space vehicles. Sound levels in the station are unavoidably high because the atmosphere is unable to thermosyphon; fans are required at all times to allow processing of the atmosphere, which would stagnate in the freefall (zero-g) environment. Fifty percent of space shuttle astronauts take sleeping pills and still get two hours or less of sleep. NASA is researching two areas which may provide the keys to a better night's sleep, as improved sleep decreases fatigue and increases daytime productivity. A variety of methods for combating this phenomenon are constantly under discussion. A study of the longest spaceflight concluded that the first three weeks represent a critical period where attention is adversely affected because of the demand to adjust to the extreme change of environment. Culture, Ideology and Language are some of many factors which may affect long time space habitation with diverse group of people from different local. Astronauts may not be able to quickly return to Earth or receive medical supplies, equipment or personnel if a medical emergency occurs. The astronauts may have to rely for long periods on their limited existing resources and medical advice from the ground. On December 31, 2012, a NASA-supported study reported that manned spaceflight may harm the brain of astronauts and accelerate the onset of Alzheimer's disease.

3.1.8 | FUTURE PROSPECTS



Image comment: Space Elevator

Image source: www.innovateus.net/science/what-space-elevator

Space colonization efforts must take into account the effects of space on the human body. The sum of human experience has resulted in the accumulation of 58 solar years in space and a much better understanding of how the human body adapts. In the future, industrialization of space and exploration of inner and outer planets will require humans to endure longer and longer periods in space. The majority of current data comes from missions of short duration and so some of the long-term physiological effects of living in space are still unknown. A round trip to Mars with current technology is estimated to involve at least 18 months in transit alone. Knowing how the human body reacts to such time periods in space is a vital part of the preparation for such journeys. On-board medical facilities need to be adequate for coping with any type of trauma or emergency as well as contain a huge variety of diagnostic and medical instruments in order to keep a crew healthy over a long period of time, as these will be the only facilities available on board a spacecraft for coping not only with trauma, but also with the adaptive responses of the human body in space.

At the moment only rigorously tested humans have experienced the conditions of space. If off-world colonization someday begins, many types of people will be exposed to these dangers and the effects on the elderly and on the very young are completely unknown. Factors such as nutritional requirements and physical environments which have so far not

been examined will become important. Overall, there is little data on the manifold effects of living in space, and this makes attempts toward mitigating the risks during a lengthy space habitation difficult. Test beds such as the ISS are presently being utilized to research some of these risks.

The environment of space is still largely unknown, and there will likely be as-yet-unknown hazards. Meanwhile, future technologies such as artificial gravity and more complex bio-regenerative life support systems may someday be capable of mitigating some risks.

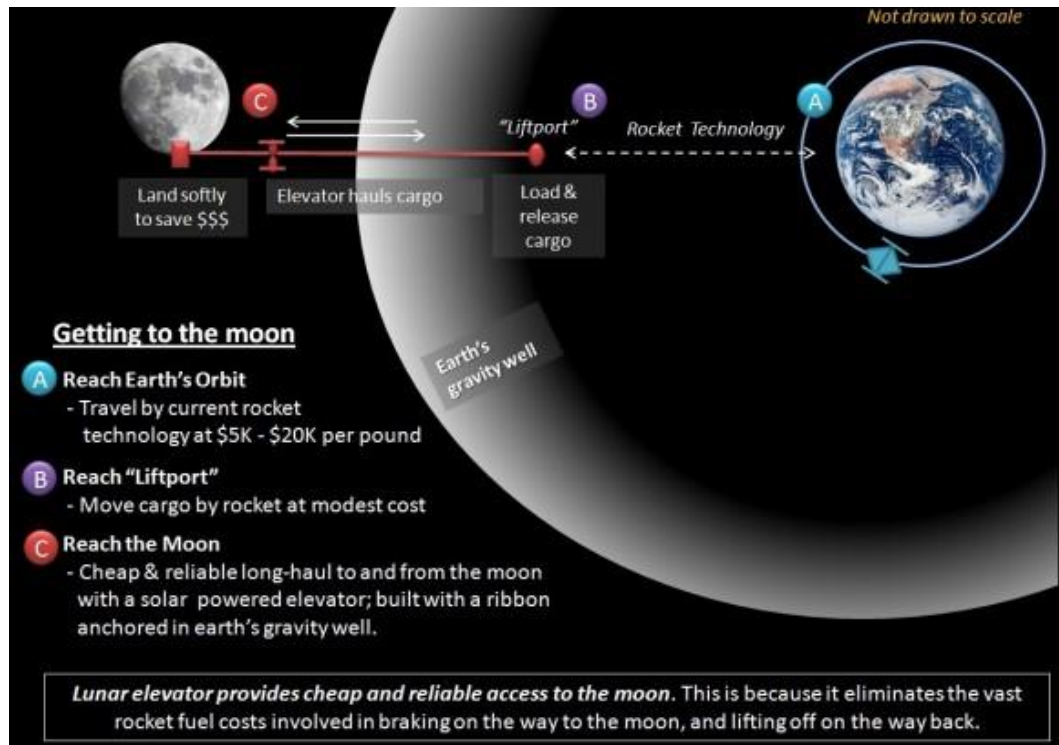
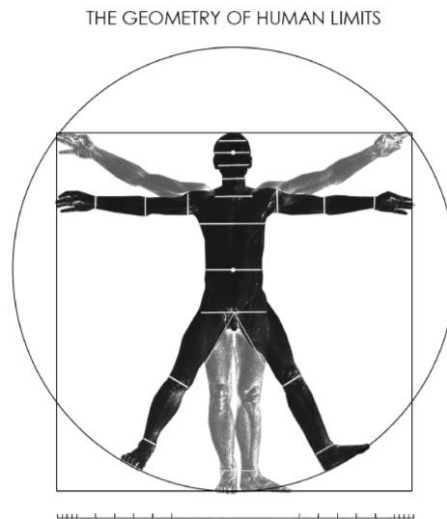


Image comment: Lunar Elevator

Image source: liftport.eventbrite.com

3.2 | ANTHROPOMETRY AND BIOMECHANICS



When in space, study of body dimensions and mobility is an important factor. For the sake of this research paper body dimensions and mobility descriptions are limited to the range of personnel considered most likely to be space module crewmembers and visiting personnel. It is assumed that these personnel will be in good health, fully adult in physical development. A wide range of ethnic and racial backgrounds may be represented, and crewmembers may be either male or female. Further notes about human ergonomics study can be found in the NASA-STD-3001 Space Flight Human-System Standard Volumes 1 (Crew Health) and 2 (Human Factors, Habitability and Environmental Health) and NASA/SP-2010-3407 the Human Integration Design Handbook (HIDH) are base lined and publically available.

(Link: <http://www.nasa.gov/centers/johnson/slsd/about/divisions/hefd/standards/index.html>)

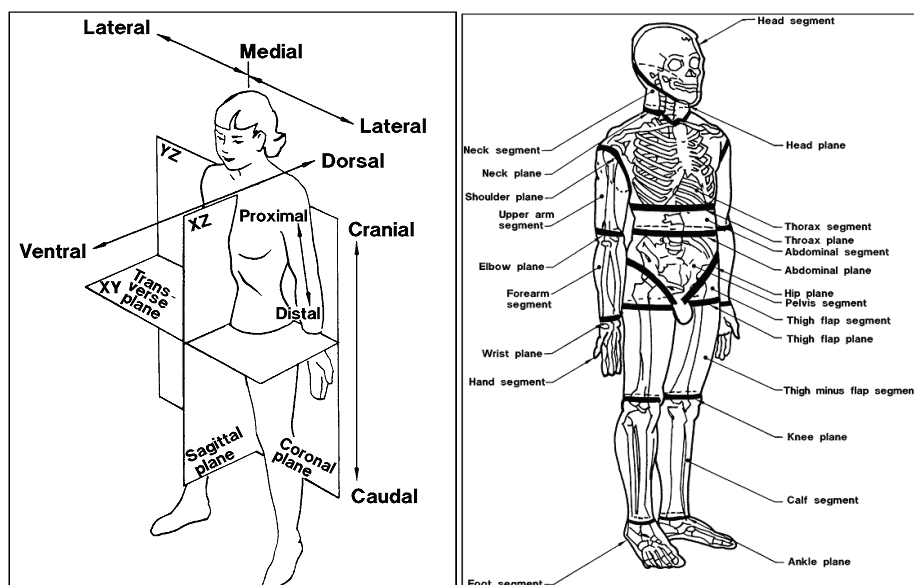


Image comment: Body Planes of Orientations and Planes of Segmentation

Image credit: pp. III-78; NASA-STD-3000 260 (Rev A), 273, p. 9-15; NASA-STD-3000 264

Plane Definitions

- HEAD PLANE: A simple plane that passes through the right and left gonion points and nuchal.
- NECK PLANE: A compound plane in which a horizontal plane originates at cervical and passes anteriorly to intersect with the second plane. The second plane originates at the lower of the two clavicle landmarks and passes superiorly at a 45 degree angle to intersect the horizontal plane.
- THORAX PLANE: A simple transverse plane that originates at the 10th rib midspine landmark and passes horizontally through the torso.
- ABDOMINAL PLANE: A simple transverse plane originating at the higher of the two iliac crest landmarks and continuing horizontally through the torso.
- HIP PLANE: A simple plane originating midsagittally on the perineal surface and passing superiorly and laterally midway between the anterior superior iliac spine and trochanterion landmarks, paralleling the right and left inguinal ligaments.
- THIGH FLAP PLANE: A simple plane originating at the gluteal furrow landmark and passing horizontally through the thigh.
- KNEE PLANE: A simple plane originating at the lateral femoral epicondyle and passing horizontally through the knee.
- ANKLE PLANE: A simple plane originating at the sphyrion landmark and passing horizontally through the ankle.
- SHOULDER PLANE: A simple plane originating at the acromion landmark and passing inferiorly and medially through the anterior and posterior scye point marks at the axillary level.
- ELBOW PLANE: A simple plane originating at the olecranon landmark and passing through the medial and lateral humeral epicondyle landmarks.
- WRIST PLANE: A simple plane originating at the ulnar and radial styloid landmarks and passing through the wrist perpendicular to the long axis of the forearm.

3.2.1 | GENERAL ANTHROPOMETRICS & BIOMECHANICS DESIGN CONSIDERATIONS

Design and sizing of space modules should ensure accommodation, compatibility, operability, and maintainability by the user population. Generally, design limits are based on a range of the user population from the 5th percentile values for critical body dimensions, as appropriate. The use of this range will theoretically provide coverage for 90% of the user population for that dimension.

Anthropometric data should be established from a survey of the actual user population. In the case of space programs, it is difficult to define the user population. With improved environmental controls, physical fitness will be a less important criterion. Skills and knowledge will be more of a factor in selection. International participation will also influence the character of the user population. In this document, the user population has not been defined.

Equipment, whether it be a workstation or clothing, must fit the user population. The user population will vary in size, and the equipment design must account for this range of sizes. There are three ways in which a design will fit the user:

- a. Single Size For All - A single size may accommodate all members of the population. A workstation which has a switch located within the reach limit of the smallest person, for instance, will allow everyone to reach the switch.
- b. Adjustment - The design can incorporate an adjustment capability. The most common example of this is the automobile seat.
- c. Several Sizes - Several sizes of equipment may be required to accommodate the full population size-range. This is usually necessary for equipment or personal gear that must closely conform to the body such as clothing and space suits.

All three situations require the designer to use anthropometric data.

3.2.2 | VARIABILITY IN HUMAN BODY SIZE DESIGN CONSIDERATIONS

3.2.2.1 | MICROGRAVITY EFFECTS DESIGN CONSIDERATIONS

The effects of weightlessness on human body size are summarized below and are discussed in greater detail. The primary anthropometry effects of microgravity are as follows:

Figure 3.2.2.1-1 ANTHROPOMETRIC CHANGES IN WEIGHTLESSNESS

Parameter	Anthropometric change		
	Short-term mission (1 to 14 days)	Long-term mission (more than 14 days)	
		Pre vs. during mission	Pre vs. post-mission
Height	<p>Slight increase during first week (~1.3 cm or 0.5 in).</p> <p>Height returns to normal *R+O</p> <p>Increases caused by spine lengthening</p>	<p>Increases during first 2 weeks then stabilizes at approximately 3% of pre-mission baseline.</p> <p>Increases caused by spine lengthening</p>	<p>Returns to normal on R+O</p>
Circumferences	Circumference changes in chest, waist, and limbs due primarily to fluids shifts.		
Mass	<p>Post flight weight losses average 3.4%; about 2/3 of the loss is due to water loss, the remainder due to loss of lean body mass and fat. Center of mass shifts headward approximately 3-4 cm (1-2in.) See paragraph 3.3.7.3.2.1 for details.</p>	<p>Inflight weight losses average 3-4% during first 5 days, thereafter, weight gradually declines for the remainder of the mission. Early inflight losses are probably due to loss of fluids; later losses are metabolic. Center of mass shifts headward approximately 3-4 cm (1-2in).</p>	<p>Rapid weight gain during first 5 days postflight, mainly due to replenishment of fluids. Slower weight gain from R+5 to R+2 or 3 weeks.</p>
Limb volume	<p>Inflight leg volume decreases exponentially during first mission day; thereafter, rate of decrease declines until reaching a plateau within 3-5 days. Postflight decrements in leg volume up to 3%; rapid increase immediately postflight, followed by slower return to pre-mission baseline.</p>	<p>Early inflight period same as short missions. Leg volume may continue to decrease slightly throughout mission. Arm volume decreases slightly.</p>	<p>Rapid increase in leg volume immediately postflight, followed by slower return to pre-mission baseline.</p>
Posture	<p>Immediate assumption of neutral body posture (see paragraph 3.3.4)</p>	<p>Immediate assumption of neutral body posture (see paragraph 3.3.4)</p>	<p>Rapid return to pre-mission posture.</p>

Note: *Recovery day plus post mission days

Reference: NASA RP 1024, Anthropometric Source Book: Volume 1: Anthropometry for Designers Anthropology Staff/Webb Associates, NASA, 7-78, Chapter 1; 208, pp. 132-133; NASA-STD-3000 265

3.2.2.2 | INTER-INDIVIDUAL VARIATION DESIGN CONSIDERATIONS

The two major factors of inter-individual variations are sex and race. The following general rules apply to the anthropometric variations due to sex and race:

- a. Sex Variations - Female measurements average about 92% of comparable male measurements (within race). Average female weight is about 75% of male weight.
- b. Racial Variations - Blacks and Whites are very similar in terms of height and weight measurements. The average torso measurement of Whites is longer than Blacks and limbs are shorter. Asians are generally shorter and lighter than Whites and Blacks. Most of this stature difference is in leg length. Asian facial dimensions may be larger in proportion to height.

Because of these variations, the extremes of the world population size range is represented in this document by the large (95th percentile) White or Black American male and the small (5th percentile) Asian Japanese female.

3.2.2.3 | SECULAR CHANGES DESIGN CONSIDERATIONS

For typical long-term space module design studies, it is appropriate to estimate the body dimensions of a future population of crew, passengers, and even the ground crew. Past experience has demonstrated that there is a historical change in average height, arm length, weight, and many other dimensions. This type of human variation, occurring from generation to generation over time, is usually referred to as secular change. Whether the effect results from better nutrition, improved health care, or some biological selection process has not been determined.

The validity of the design requirements for the actual operational years of the space module depends on the accuracy of the secular trend estimation, the basic assumptions concerning the baseline crew population, and the operational life of the system. For this standard, an operational year of 2000 and a crewmember age of 40 years has been selected.

3.3.1 | BODY SIZE

A partial study of the specific body distances, dimensions, contours, and techniques for use in developing design requirements are discussed in this section. There is no attempt to include all potentially useful anthropometric data in this document because much of these data are already available in convenient published form such as NASA RP 1024, Anthropometric Source Book: Volume 1: Anthropometry for Designers Anthropology Staff/Webb Associates, NASA, 7-78. Rather, one description set of the size range for the projected crewmember population is presented. The dimensions apply to nude or lightly clothed persons.

3.3.1.1 | BODY SIZE DESIGN CONSIDERATIONS

The following are considerations that should be made in applying the body size data:

- a. Effects of Clothing - In a controlled IVA environment there is little need for heavy, thick clothing. For most practical purposes, therefore, there is no need to consider the effect of IVA clothing on body size. When an individual must wear an EVA pressure garment or a space suit, body dimensions will be affected drastically. In this case, dimensional studies must be made for the user population wearing the garment. These data must then be substituted for unclothed or lightly clothed dimensions.
- b. Microgravity - the dimensions in Paragraph 3.3.1.3 apply to 1-G conditions only. Notations are made on appropriate dimensions that provide guidelines for estimating microgravity dimensions.

3.3.1.2 | BODY SIZE DATA DESIGN REQUIREMENTS

Dimensions of the year 2000, 40 year-old male and female are given in Figure 3.3.1.2-1. The data in this figure shall be used as appropriate to achieve effective integrations of the crew and space systems. The dimensions apply to 1-G conditions only. Dimension expected to change significantly due to microgravity are marked. Measurement data - the numbers adjacent to each of the dimension are reference codes.

Notes for application of dimensions to microgravity conditions:

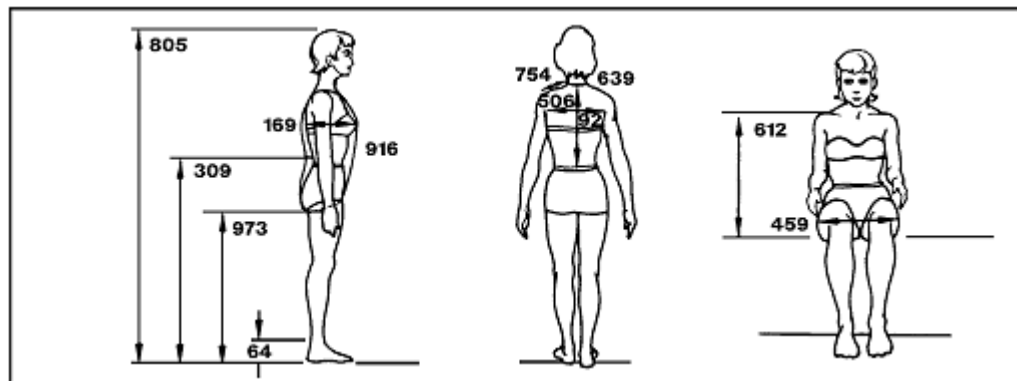
- 1) Stature increases approximately 3% over the first 3 to 4 days in. Almost all of this change appear in the spinal column, and thus affects (increases) other related dimensions, such as

sitting height (buttock-vertex), shoulder height- sitting, eye height, sitting, and all dimensions that include the spine.

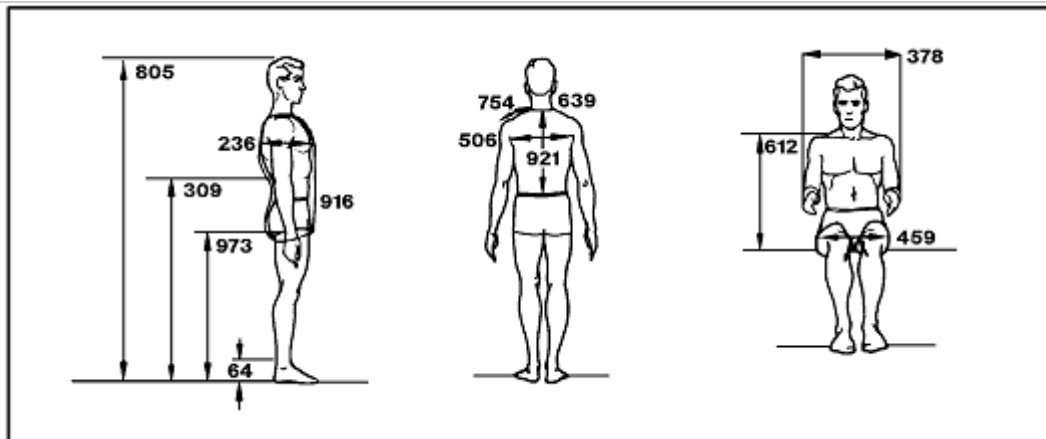
2) Sitting height would be better named as buttock-vertex in microgravity conditions, unless the crewmember were measured with a firm pressure on shoulders pressing him or her against a fixed, flat "sitting" support surface. All sitting dimensions (vertex, eye, shoulder, and elbow) increase in weightlessness by two changes:

Figure 3.3.1.2-1 ANTHROPOMETRIC DIMENSIONAL DATA FOR MALE AND FEMALE

Body Size in One Gravity Conditions



Microgravity notes	No.	Dimension	5th percentile	50th percentile	95th percentile
1	805	Stature	148.9 (58.6)	157.0 (61.8)	165.1 (65.0)
1	973	Wrist height	70.8 (27.9)	76.6 (30.2)	82.4 (32.4)
	64	Ankle height	5.2 (2.0)	6.1 (2.4)	7.0 (2.8)
1	309	Elbow height	92.8 (38.5)	98.4 (38.8)	104.1 (41.0)
	169	Bust depth	17.4 (6.8)	20.5 (8.1)	23.6 (9.3)
1	916	Vertical trunk circumference	136.9 (53.9)	146.0 (57.5)	155.2 (61.1)
2 1	612	Midshoulder height, sitting			
	459	Hip breadth, sitting	30.4 (12.0)	33.7 (13.3)	37.0 (14.6)
1	921	Waist back	35.2 (13.9)	38.1 (15.0)	41.0 (16.1)
	506	Interscye	32.4 (12.8)	35.7 (14.1)	39.0 (15.4)
	639	Neck circumference	34.5 (13.6)	37.1 (14.5)	39.7 (15.6)
	754	Shoulder length	11.3 (4.4)	13.1 (5.1)	14.8 (5.8)



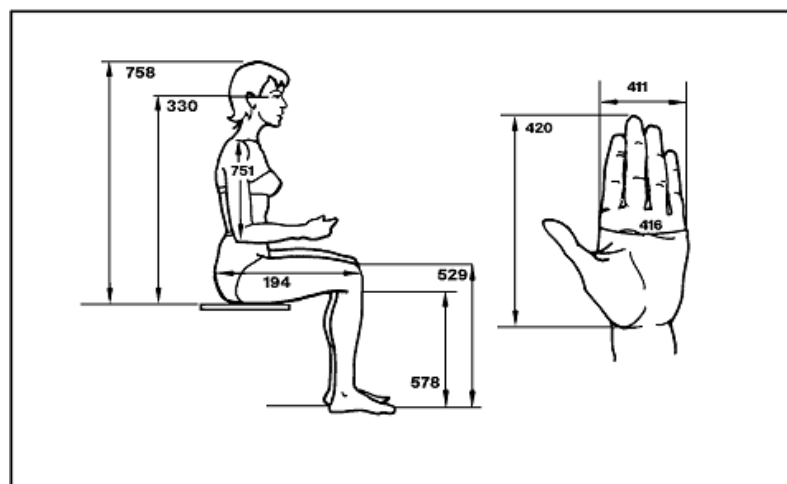
Microgravity notes	No.	Dimension	5th percentile	50th percentile	95th percentile
1	805	Stature	169.7 (66.8)	179.9 (70.8)	190.1 (74.8)
1	973	Wrist height			
	64	Ankle height	12.0 (4.7)	13.9 (5.5)	15.8 (6.2)
1	309	Elbow height			
	236	Bust depth	21.8 (8.6)	25.0 (9.8)	28.2 (11.1)
1	916	Vertical trunk circumference	158.7 (62.5)	170.7 (67.2)	182.6 (71.9)
2 1	612	Midshoulder height, sitting	60.8 (23.9)	65.4 (25.7)	70.0 (27.5)
	459	Hip breadth, sitting	34.6 (13.6)	38.4 (15.1)	42.3 (16.6)
1	921	Waist back	43.7 (17.2)	47.6 (18.8)	51.6 (20.3)
	506	Interscye	32.9 (13.0)	39.2 (15.4)	45.4 (17.9)
	639	Neck circumference	35.5 (14.0)	38.7 (15.2)	41.9 (16.5)
	754	Shoulder length	14.8 (5.8)	16.9 (6.7)	19.0 (7.5)
	378	Forearm-forearm breadth	48.8 (19.2)	55.1 (21.7)	61.5 (24.2)

Values in cm with inches in parentheses

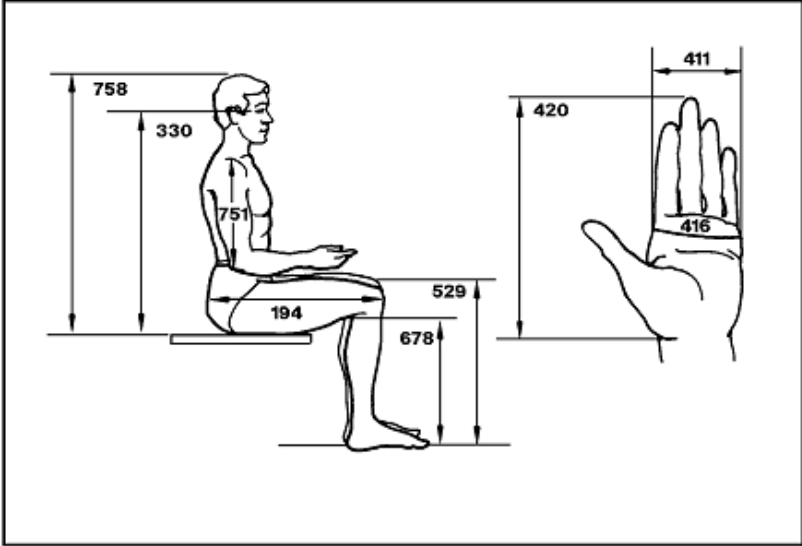
Image Reference: 274 p. 121-128; 308; 351; NASA-STD-3000 268

Figure 3.3.1.2-2 ANTHROPOMETRIC DIMENSIONAL DATA FOR MALE AND FEMALE

Body Size of the Male and Female in One Gravity Conditions



Microgravity notes	No.	Dimension	5th percentile	50th percentile	95th percentile
2 1	758	Sitting height	78.3 (30.8)	84.8 (33.4)	91.2 (35.9)
2 1	330	Eye height, sitting	68.1 (26.8)	73.8 (29.1)	79.5 (31.4)
4	529	Knee height, sitting	41.6 (16.4)	45.6 (17.9)	49.5 (19.5)
	678	Popliteal height	34.7 (13.6)	38.3 (15.1)	41.9 (16.5)
	751	Shoulder-elbow length	27.2 (10.7)	29.8 (11.7)	32.4 (12.8)
	194	Buttock-knee length	48.9 (19.2)	53.3 (21.0)	57.8 (22.7)
	420	Hand length	15.8 (6.2)	17.2 (6.8)	18.7 (7.3)
	411	Hand breadth	6.9 (2.7)	7.8 (3.1)	8.6 (3.4)
	416	Hand circumference	16.5 (6.5)	17.9 (7.0)	19.3 (7.6)

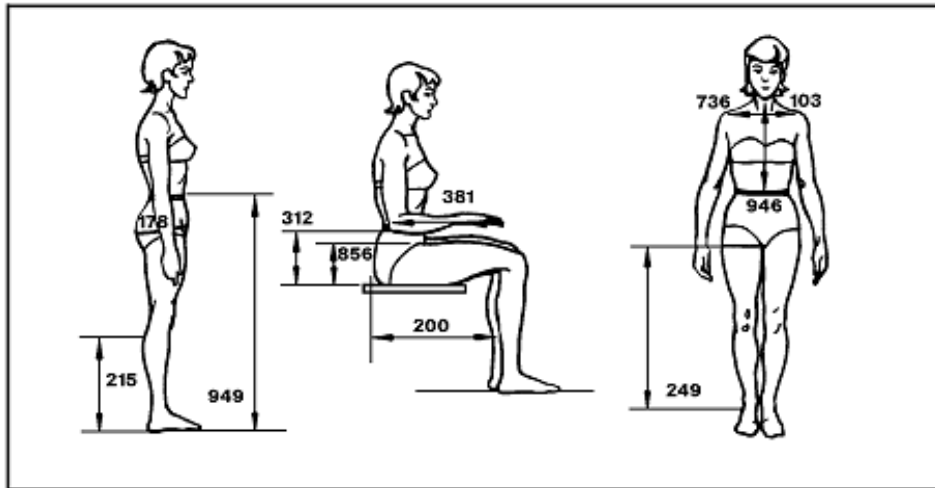


Microgravity notes	No.	Dimension	5th percentile	50th percentile	95th percentile
2 1	758	Sitting height	88.9 (35.0)	94.2 (37.1)	99.5 (39.2)
2 1	330	Eye height, sitting	76.8 (30.3)	81.9 (32.2)	86.9 (34.2)
4	529	Knee height, sitting	52.6 (20.7)	56.7 (22.3)	60.9 (24.0)
	678	Popliteal height	40.6 (16.0)	44.4 (17.5)	48.1 (19.0)
	751	Shoulder-elbow length	33.7 (13.3)	36.6 (14.4)	39.4 (15.5)
	194	Buttock-knee length	56.8 (22.4)	61.3 (24.1)	65.8 (25.9)
	420	Hand length	17.9 (7.0)	19.3 (7.6)	20.6 (8.1)
	411	Hand breadth	8.2 (3.2)	8.9 (3.5)	9.6 (3.8)
	416	Hand circumference	20.3 (8.0)	21.8 (8.6)	23.4 (9.2)

Image Reference: 274, pp. 121-128; 308; 351; NASA-STD-3000 268

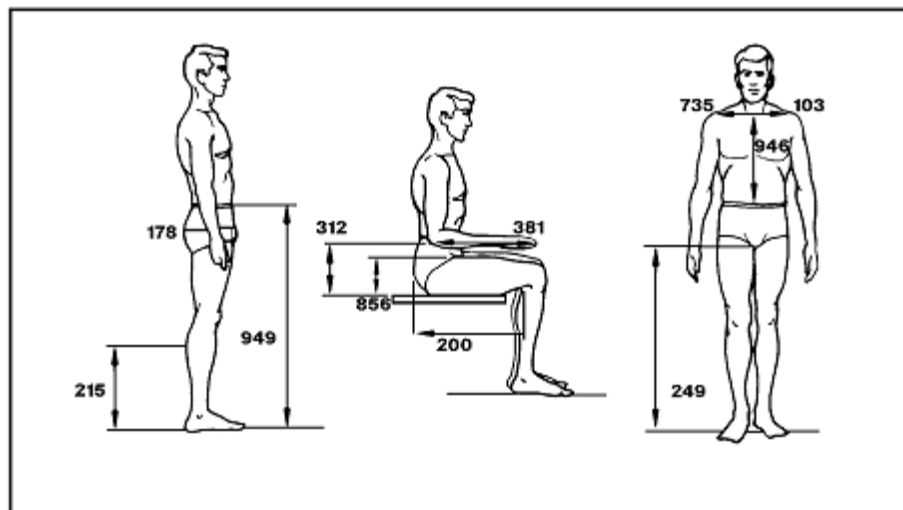
Figure 3.3.1.2-3 ANTHROPOMETRIC DIMENSIONAL DATA FOR MALE AND FEMALE

Body Size of the Male and Female in One Gravity Conditions



Microgravity notes	No.	Dimension	5th percentile	50th percentile	95th percentile
1	949	Waist height	90.1 (35.5)	96.7 (38.1)	103.4 (40.7)
	249	Crotch height	65.2 (25.7)	70.6 (27.8)	76.1 (30.0)
	215	Calf height	25.5 (10.0)	28.9 (11.4)	32.3 (12.7)
	103	Biacromial breadth	32.4 (12.8)	35.7 (14.1)	39.0 (15.4)
	946	Waist front			
1 2	735	Scye circumference	32.3 (12.7)	36.1 (14.2)	39.8 (15.7)
	178	Buttock circumference	79.9 (31.5)	87.1 (34.3)	94.3 (37.1)
	312	Elbow rest height	20.7 (8.2)	25.0 (9.9)	29.3 (11.5)
	856	Thigh clearance	11.2 (4.4)	12.9 (5.1)	14.5 (5.7)
	381	Forearm hand length	37.3 (14.7)	41.7 (16.4)	44.6 (17.6)
	200	Buttock-popliteal length	37.9 (14.9)	41.7 (16.4)	45.5 (17.9)

Values in cm with inches in parentheses

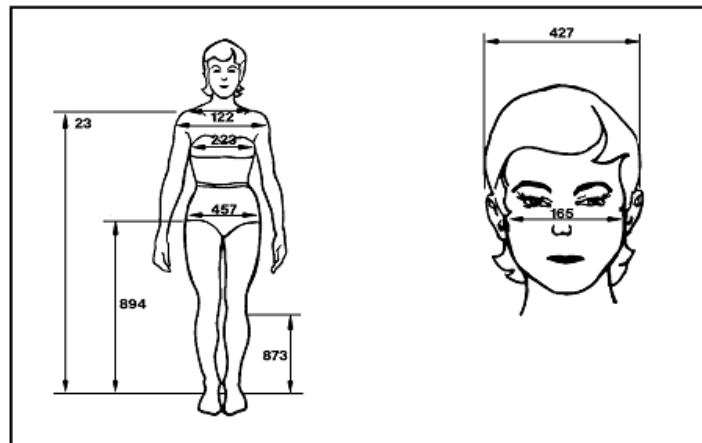


Microgravity notes	No.	Dimension	5th percentile	50th percentile	95th percentile
1	949	Waist height	100.4 (39.5))	108.3 (42.6)	116.2 (45.7)
	249	Crotch height	79.4 (31.3)	86.4 (34.0)	93.3 (36.7)
	215	Calf height	32.5 (12.8)	36.2 (14.3)	40.0 (15.7)
	103	Biacromial breadth	37.9 (14.9)	41.1 (16.2)	44.3 (17.5)
	946	Waist front	37.2 (14.6)	40.9 (16.1)	44.5 (17.5)
1 2	735	Scye circumference	44.4 (17.5)	49.0 (19.3)	53.6 (21.1)
	178	Buttock circumference	91.0 (35.8)	100.2 (39.4)	109.4 (43.1)
	312	Elbow rest height	21.1 (8.3)	25.4 (10.0)	29.7 (11.7)
	856	Thigh clearance	14.5 (5.7)	16.8 (6.6)	19.1 (7.5)
	381	Forearm hand length			
	200	Buttock popliteal length	46.9 (18.5)	51.2 (20.2)	55.5 (21.9)

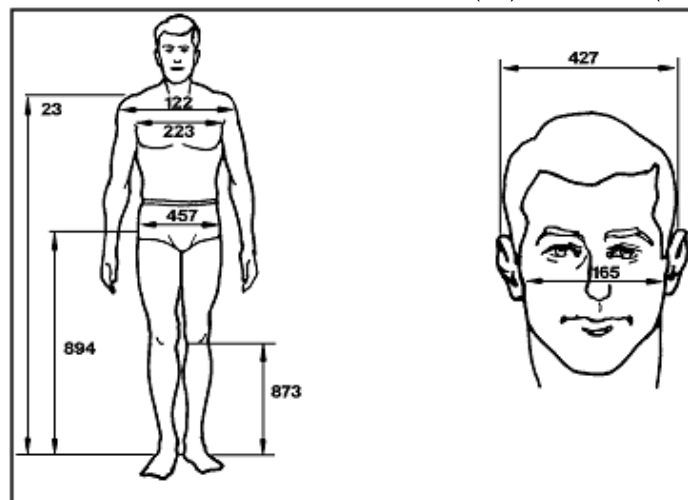
Image Reference: 274, pp. 121-128; 308; 351; NASA-STD-3000 268eT

Figure 3.3.1.2-4 ANTHROPOMETRIC DIMENSIONAL DATA FOR MALE AND FEMALE

Body Size of the 40-Year-Old Japanese Female for Year 2000 in One Gravity Conditions



Microgravity notes	No.	Dimension	5th percentile	50th percentile	95th percentile
3, 1	23	Acromial (shoulder) height	119.6 (47.1)	127.1 (50.0)	134.5 (53.0)
	894	Trochanteric height	71.0 (28.0)	76.7 (30.2)	82.4 (32.5)
	873	Tibiale height	35.9 (14.1)	39.3 (15.5)	42.7 (16.8)
	122	Bideloid (shoulder) breadth	35.6 (14.0)	38.9 (15.3)	42.1 (16.6)
	223	Chest breadth	24.5 (9.7)	26.8 (10.5)	29.0 (11.4)
	457	Hip breadth	30.5 (12.0)	32.9 (12.9)	35.3 (13.9)
	165	Bizgomatic (face) breadth	13.3 (5.2)	14.5 (5.7)	15.7 (6.2)
	427	Head breadth	14.4 (5.7)	15.6 (6.1)	16.8 (6.6)



Microgravity notes	No.	Dimension	5th percentile	50th percentile	95th percentile
3 1	23	Acromial (shoulder) height	138.0 (54.3)	147.6 (58.1)	157.3 (61.9)
	894	Trochanteric height	88.3 (34.8)	95.8 (37.8)	102.9 (40.5)
	873	Tibiale height			
	122	Bideloid (shoulder) breadth	44.6 (17.6)	48.9 (19.3)	53.2 (20.9)
	223	Chest breadth	29.7 (11.7)	33.2 (13.1)	36.7 (14.4)
	457	Hip breadth	32.7 (12.9)	35.8 (14.1)	39.0 (15.4)
	165	Bizgomatic (face) breadth	13.4 (5.3)	14.3 (5.6)	15.1 (6.0)
	427	Head breadth	14.8 (5.8)	15.7 (6.2)	16.5 (6.5)

Values in cm with inches in parentheses

Image Reference: 274, pp. 121-128; 308; 351; NASA-STD-3000 268hT

3.3.2 | JOINT MOTION

This section provides information for developing design requirements related to biomechanics, particularly skeletal joint angular motion capabilities and limitations. Joint motion data can be used to determine possible positions for the various parts of body.

3.3.2.1 | APPLICATION OF DATA DESIGN CONSIDERATIONS

Joint motion capability varies throughout the population. The values given are for the 5th and 95th percentile of the range. The data should be applied in the following manner:

- a. 5th Percentile - Use the 5th percentile limit when personnel must position their body to operate or maintain equipment.
- b. 95th Percentile - Use the 95th percentile limit when designing to accommodate a full range of unrestricted movement.

3.3.2.2 | MULTI-JOINT AND SINGLE JOINT DATA DESIGN CONSIDERATION

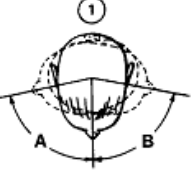
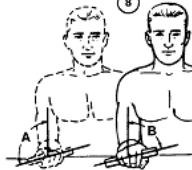
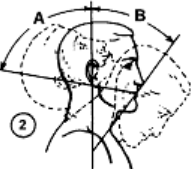
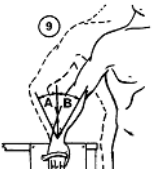
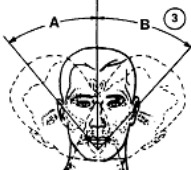
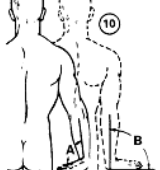
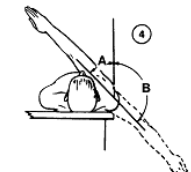
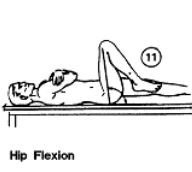
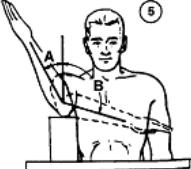
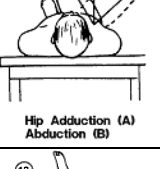
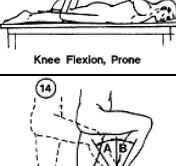
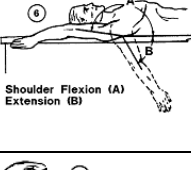
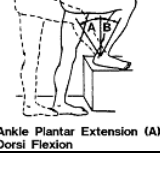
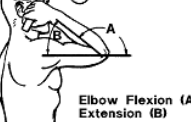
More often than not, human motion involves interaction of two or more joints and muscles. The movement range of a single joint is often drastically reduced by the movement of an adjacent joint. In other words, joint movement ranges are not always additive. For example, an engineering layout may show (using a scaled manikin) that a foot control is reachable with a hip flexion of 50 degrees and the knee extended (0 degrees flexion). Both of these ranges are within the individual joint ranges as shown in Figure 3.3.2.3.1-1.

The joint motion studies were performed in a 1-G environment. There are no data for the microgravity environment. Indications are that joint motion capability will not be drastically affected in microgravity. Given this, the data in this section can be applied to a microgravity environment.

3.3.2.2.1 | JOINT MOTION DATA FOR SINGLE JOINT DESIGN REQUIREMENTS

Figure 3.3.2.3.1-1 shows single joint movement ranges for both males and females. These data apply to both 1-G and microgravity environments. These data shall be used as appropriate to ensure the design accommodates the required body movements for the crewmembers.

FIGURE 3.3.2.2.1-1 JOINT MOVEMENT RANGES FOR MALES AND FEMALES

Figure	Joint movement (note b)	Range of motion (degrees)				Figure	Joint movement (note b)	Range of motion (degrees)			
		Males		Female				Males		Female	
		5%	95%	5%	95%			5%	95%	5%	95%
 Neck Rotation Right (A) Left (B)	Neck, rotation right (A)	73.3	99.6	74.9	108.8	 Forearm Supination (A) Pronation (B)	Forearm, pronation (B)	78.2	116.1	82.3	118.9
	Neck, rotation left (B)	74.3	99.1	72.2	109		Forearm, supination (A)	83.4	125.8	90.4	139.5
 Neck Extension [A] Flexion (B)	Neck, flexion (B)	34.5	71	46	84.4	 Wrist Ulnar Bend (A) Radial Bend (B)	Wrist, radial bend (B)	16.9	36.7	16.1	36.1
	Neck, extension (A)	65.4	103	4.9	103		Wrist, ulnar bend (A)	18.6	47.9	21.5	43
 Neck Lateral Bend Right (A) Left (B)	Neck, lateral bend right (A)	34.9	63.5	37	63.2	 Wrist Flexion (A) Extension (B)	Wrist, flexion (A)	61.5	94.8	68.3	98.1
	Neck, lateral bend left (B)	35.5	63.5	29.1	77.2		Wrist, extension (B)	40.1	78	42.3	74.7
 Horizontal Adduction (A) Horizontal Abduction (B)	Shoulder, abduction	173.2	188.7	172.6	192.9	 Hip Flexion	Hip, flexion	116.5	148	118.5	145
 Shoulder Rotation Lateral (A) Medial (B)	Shoulder, rotation lateral (A)	46.3	96.7	53.8	85.8	 Hip Adduction (A) Abduction (B)	Hip, abduction (B)	26.8	53.5	27.2	55.9
	Shoulder, rotation medial (B)	90.5	126.6	95.8	130.9	 Knee Flexion, Prone	Knee, flexion	118.4	145.6	125.2	145.2
 Shoulder Flexion (A) Extension (B)	Shoulder, flexion (A)	164.4	210.9	152	217	 Ankle Plantar Extension (A) Dorsi Flexion	Ankle, plantar extension (A)	36.1	79.6	44.2	91.1
	Shoulder, extension (B)	39.6	83.3	33.7	87.9		Ankle, dorsi flexion (B)	8.1	19.9	6.9	17.4
 Elbow Flexion (A) Extension (B)	Elbow, flexion (A)	140.5	159	144.9	165.9						

3.3.2.2.2 | JOINT MOTION DATA FOR TWO JOINT DESIGN REQUIREMENTS

Data to determine the range of movement for two joints are given in Figure 3.3.2.3.2-1. Figure 3.3.2.3.2-1 defines the changes in range of motion of a given joint when supplemented by the movement of an adjacent joint. These data apply to both 1-G and microgravity environments. These data shall be used as appropriate to ensure the design accommodates the required body movements of the crewmembers.

Figure 3.3.2.2.2-1 Change in Range of Movement With Movement in Adjacent Joint

Two-joint movement	Full range of A (degrees)	Change in range of movement of A (degrees)			
		Zero	Movement of B (fraction of full range)		
			1/3	1/2	2/3
Shoulder extension (A) with elbow flexion (B)	59.3 deg		+1.6 deg		+0.9 deg
			(102.7%)		(101.5%)
Shoulder flexion (A) with elbow flexion (B)	190.7 deg		-24.9 deg		-36.1 deg
			(86.9%)		(81.0%)
Elbow flexion (A) with shoulder extension (A)	152.2 deg			-3.78 deg	-1.22 deg
				(97.5%)	(99.2%)
Elbow flexion (A) with shoulder flexion (B)	152.2 deg		-0.6 deg		-0.8 deg
			(99.6%)		(99.5%)
Hip flexion (A) with shoulder flexion (B)	53.3 deg	-35.6 deg *	-24.0 deg		-6.2 deg
		(33.2%)	(55.0%)		(88.4%)
Ankle plantar flexion (A) with knee flexion (B)	48.0 deg		-3.4 deg		+0.2 deg
			(92.9%)		(100.4%)
Ankle dorsiflexion (A) with knee flexion (B)	26.1 deg		-7.3 deg		-2.7 deg
			(72.0%)		(89.7%)
Knee flexion (A) with ankle plantar flexion (B)	127.0 deg			-9.9 deg	-4.7 deg
				(92.2%)	(96.3%)
Knee flexion (A) with ankle dorsiflexion (B)	127.0 deg				-8.7 deg
					(93.0%)
Knee flexion (A) with hip flexion (B)	127.0 deg			-19.6 deg	-33.6 deg
				(84.6%)	(73.5%)

Notes: * The knee joint is locked and the unsupported leg extends out in front of the subject.

The following is an example of how the Figure is to be used. The first entry is as follows: the shoulder can be extended as far as 59.3 degrees (the mean of the subjects tested) with the elbow in a neutral position (locked in hyperextension). When shoulder extension was measured with the elbow flexed to 1/3 of its full joint range, the mean value of shoulder extension was found to increase by 1.6 degrees, or 102.7% of the base value. The results for other movements and adjacent joint positions are presented in a similar manner.

Reference: 16, pp. VI-12 to VI-15; NASA-STD-3000 289

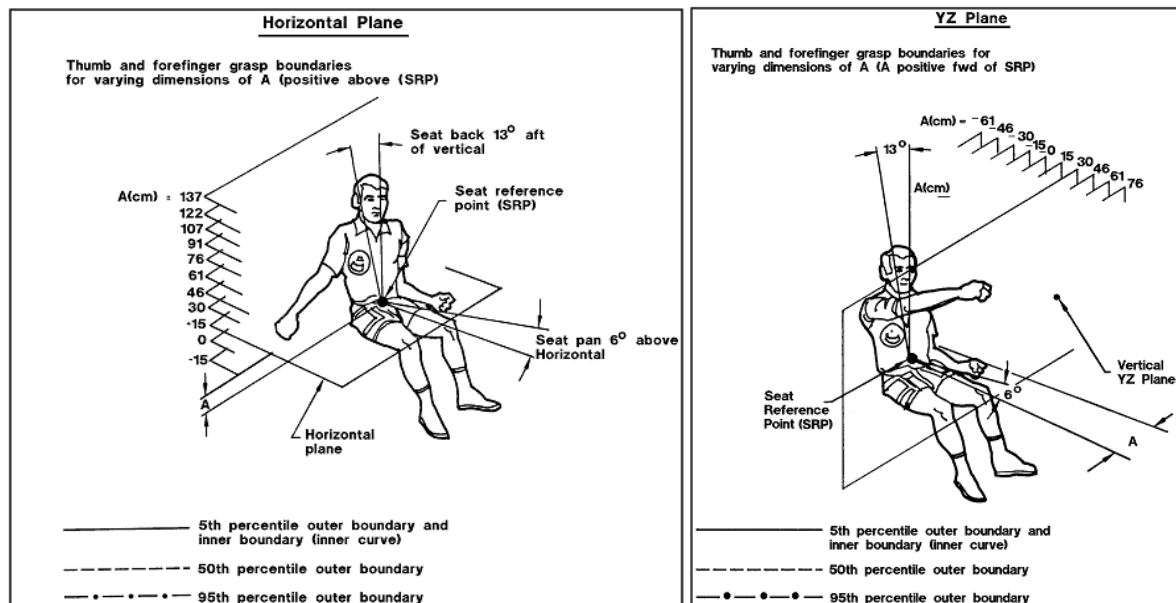
3.3.2.3 | REACH DATA DESIGN REQUIREMENTS

Equipment and controls required to perform a task shall be within the reach limit of the crewmember performing the task. The reach limit envelope cannot be considered a working reach envelope. Reach is effected by fatigue and force exerted and there is a marked variation in strength which can be exerted throughout this envelope. Tasks which require strength and dexterity should be located well within the perimeter of the reach limit envelope. This is especially true of repetitious tasks. For strength limitations, see Section 4.9. The following are functional reach limits for persons wearing non-restrictive clothing:

a. Torso Restrained Reach Boundaries - Equipment and controls operated by crewmembers restrained at the torso, shall be within the functional reach boundaries given in Figure 3.3.2.3.1-1. These boundaries shall be adjusted as appropriate to the task conditions:

1. Backrest Angle - The boundaries in Figure 3.3.3.3.1-1 apply when the operator's shoulders are against a flat backrest inclined 13 degrees from vertical. Adjustments shall be made for different backrest angles using the approximations in Figure 3.3.3.3.1-2.
2. Task Type - The functional reach boundaries apply to tasks requiring thumb and forefinger grasp only. Adjustment for other grasp requirements shall be made in accordance with Figure 3.3.3.3.1-5.

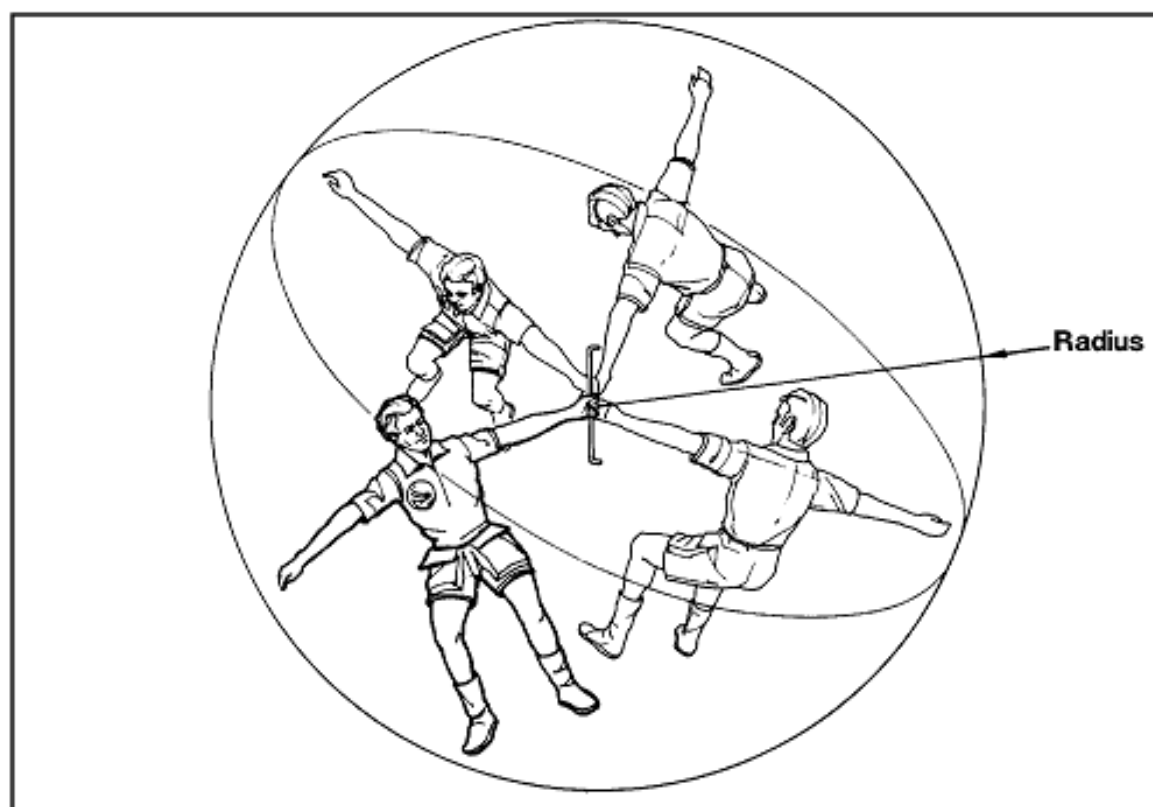
Figure 3.3.2.3 -1, 2 Grasp Reach Limits with Right hand for Male and Female



b. Microgravity Handhold Restraint - Equipment and controls operated in microgravity by crewmembers using a handhold restraint, shall be within the functional reach boundaries given in Figure 3.3.2.3.1-3. The functional reach boundaries apply to tasks requiring fingertip operation only. Adjustment for other grasp operations shall be made in accordance with Figure 3.3.2.3-5.

c. Microgravity Foot Restraint - Equipment and controls operated in microgravity by crewmembers using a foot restraint, shall be within the functional reach boundaries given in Figures 3.3.2.3-4 and 3.3.2.3-5. The functional reach boundaries apply to tasks requiring fingertip operation only. Adjustment for grasp operations shall be made in accordance with Figure 3.3.2.3-5.

Figure 3.3.2.3-3 Microgravity Handhold Restraint Reach Boundaries



Radius of fingertip reach boundary

95th percentile male 195 cm (77 inches)

5th percentile female 150 cm (63 inches)

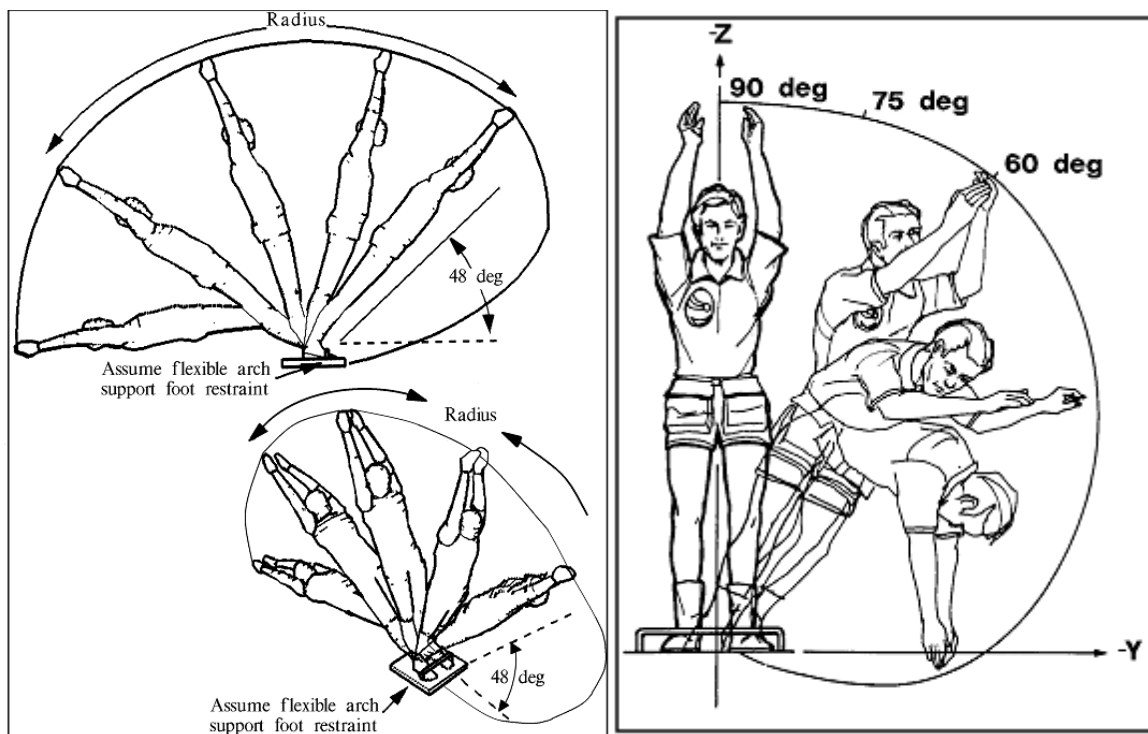
Notes:

- a. Subjects - These data were generated using a computer-based anthropometric model. The computer model was developed using a sample of 192 male astronaut candidates and 22

female astronaut candidates measured in 1979 and 1980 (Reference 365). The 5th percentile stature of the male population is 167.9 cm (66.1 inches) and the 95th percentile male stature is 189.0 cm (74.4 inches). The 5th percentile stature of the female population is 157.6 cm (62.0 inches) and the 95th percentile female is 175.7 cm (69.2 inches).

- b. Gravity conditions - Although the motions apply to a microgravity condition, the effects of spinal lengthening have not been considered.

Figure 3.3.2.3-4, 5 Microgravity Foot Restraint Reach Boundaries - Fore/Aft



Subject	Radius Of Reach Fingertip Boundary In X-Z Plane	
	Flexible arch support	Fixed 'flat' foot restraint foot restraint
95th percentile Male	222 cm (87 in)	212 cm (83 in)
5th percentile Female	188 cm (74 in)	172 cm (68 in)

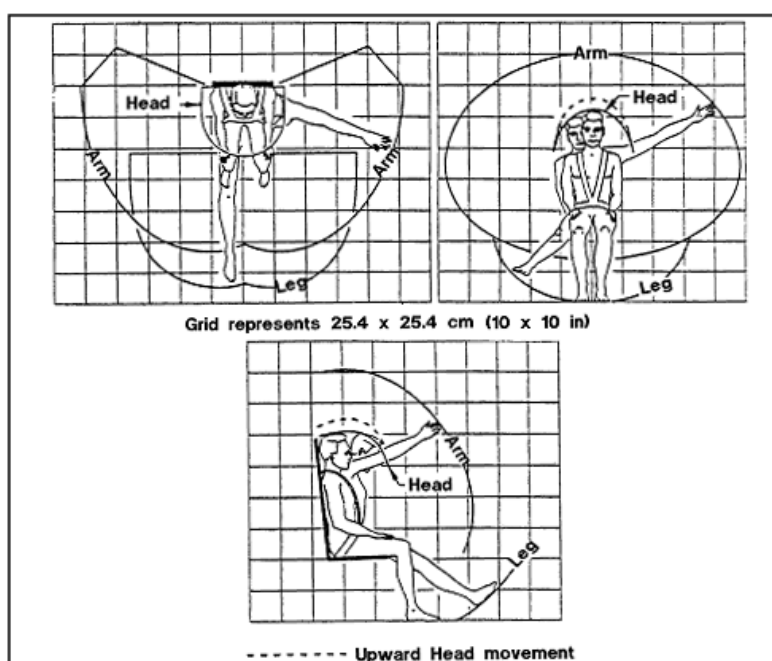
Dimensions of fingertip reach boundary in YZ plane

	Angle (degrees)	Y-axis dimension	Z-axis dimension
	90	0	222 cm
95th percentile male	75	80 cm (31 in)	193 cm (76 in)
	60	110 cm (43 in)	160 cm (63 in)
	90	0	188 cm (74 in)
5th percentile male	75	28 cm (11 in)	175 cm (69 in)
	60	80 cm (31 in)	140 cm (55 in)

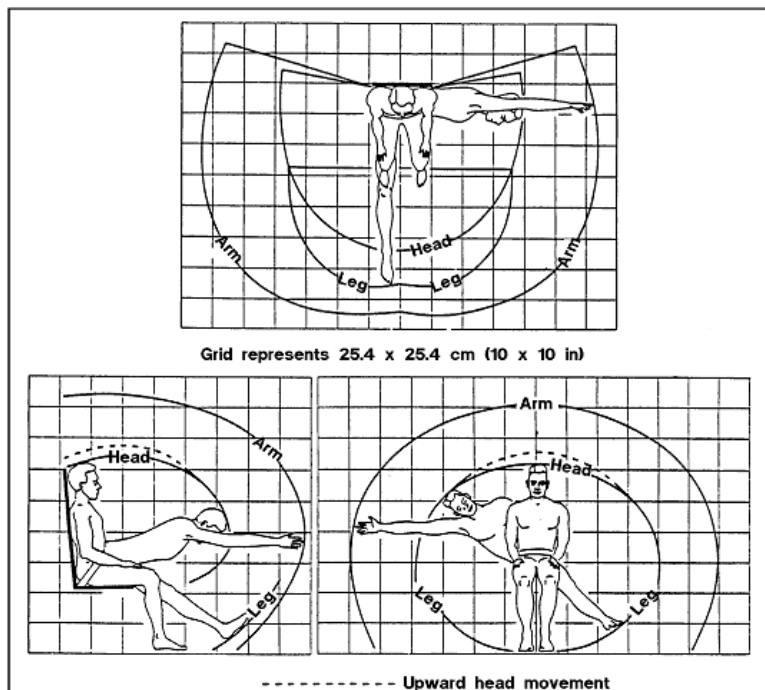
3.3.2.3.1 | STRIKE REACH ENVELOPE DATA DESIGN REQUIREMENTS

If abrupt high accelerations are expected, items within the strike envelope shall be designed to minimize injury to the crewmember. Body strike envelopes as defined in Figures 3.3.2.3.1-1 and 3.3.2.1.1-2 shall be used as appropriate

Figure 3.3.2.3.1-1 4-G Strike reach envelope of a Seated 95th Percentile Male



Notes: These figures show the envelope that the body extremities (arms, legs, head, and torso) could strike when the seated person is subjected to 4-G acceleration either fore and aft or to the side ($\pm G_x$ or $\pm G_y$). Refer to Paragraph 5.3.1, Introduction, for acceleration vector reference conventions).



Wearing Full Restraint
(Seat Belt and Dual
Shoulder Harness)

Lap Belt Only

Image Reference: 21, DN3Q4, p. 3; NASA-STD-3000 334-5

3.3.3 | NEUTRAL BODY POSTURE CONSIDERATIONS

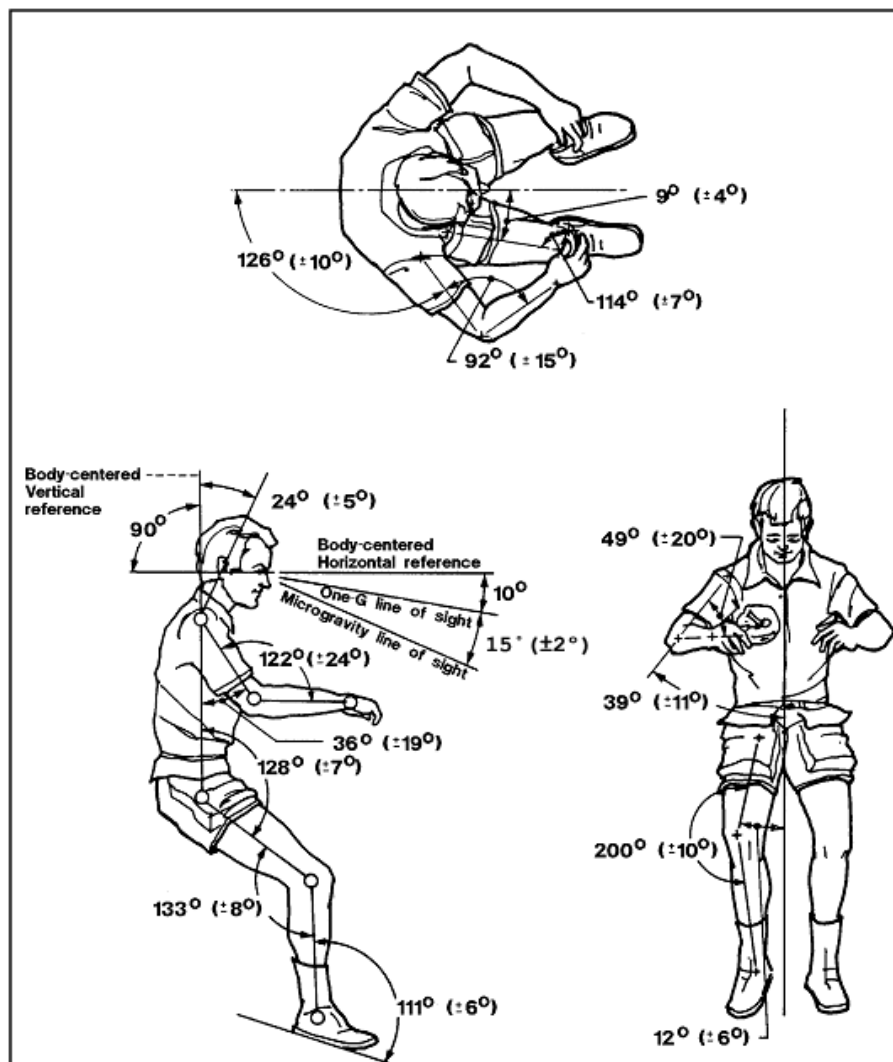
This section describes the posture that the body assumes in microgravity. Implications for habitat and crew station design are given.

The crewmembers should not be expected to maintain a 1-G posture in a microgravity environment. Having to maintain some 1-G postures in microgravity may produce stress when muscles are called on to supply forces that were normally supplied by gravity. Stooping and bending are examples of positions that cause fatigue in microgravity. In microgravity, the body assumes a neutral body posture. The natural heights and angles of the neutral body posture must be accommodated. Some of the areas to be considered are as follows:

- a. Foot Angle - Since the feet are tilted at approximately 111 degrees to a line through the torso, sloping rather than flat shoes or restraint surfaces should be considered.
- b. Feet and Leg Placement - foot restraints must be placed under the work surface. The neutral body posture is not vertical because hip/knee flexion displaces the torso backward, away from the footprint. The feet and legs are positioned somewhere between a location directly under the torso (as in standing) and a point well out in front of the torso (as in sitting).

- c. Height - The height of the crewmember in microgravity is between sitting and standing height. A microgravity work surface must be higher than one designed for 1-G or partial-gravity sitting tasks.
- d. Arm and Shoulder Elevation - Elevation of the shoulder girdle and arm flexion in the neutral body posture also make elevation of the work surface desirable.
- e. Head Tilt - In microgravity the head is angled forward and down, a position that depresses the line of sight and requires that displays be lowered.

Figure 3.3.3-1 Neutral Body Posture



Note: The segment angles shown are means. Values in parentheses are standard deviations about the mean. The data was developed in Skylab studies and is based on the measurement of 12 subjects.

Image Reference: 7, p. 24 to 26; 129, Fig. 11; NASA-STD-3000 285

3.3.4 | BODY SURFACE AREA

- a. Gravity Environment - Body surface area estimation equations apply to 1-G conditions only. They do not account for the fluid shifts and spinal lengthening in microgravity.
- b. Population - The equations given are most accurate for the White or Black male and female body form. The equations should not be used to estimate the body surface area of the Asian Japanese female.
- c. Application of Data - Body surface area data have several space module design applications. These include:
 - 1. Thermal control - Estimation of body heat production for thermal environmental control.
 - 2. Estimation of radiation dosage.

Estimated Body Surface Area of the Male Crewmember

5th Percentile	17,600 cm ² (2730 in ²)
50th Percentile	20,190 cm ² (3130 in ²)
95th Percentile	22,690 cm ² (3520 in ²)

3.3.5 BODY VOLUME DATA DESIGN CONSIDERATIONS

- a. Gravity Environment - The data are based on 1-G conditions and does not account for fluid shifts or spinal lengthening due to weightlessness.
- b. Population - The data provided in this paragraph apply only to the White or Black male body form.

Estimated Body Volume of the Male Crewmember	
5th Percentile	68,640 cm ³ (4190 in ³)
50th Percentile	85,310 cm ³ (5210 in ³)
95th Percentile	101,840 cm ³ (6210 in ³)

3.3.6 | BODY SEGMENT VOLUME DATA DESIGN REQUIREMENTS

Body Segments Volume of Male Crewmember

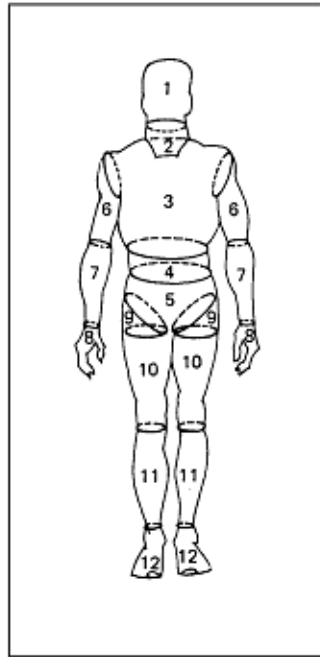
Segment	Volume, cm ³ (in ³)		
	5th percentile	50th percentile	95th percentile
1 Head	4260 (260)	440 (270)	4550 (280)
2 Neck	930 (60)	1100 (70)	1270 (80)
3 Thorax	20420 (1250)	26110 (1590)	31760 (1940)
4 Abdomen	2030 (120)	2500 (150)	2960 (180)
5 Pelvis	9420 (570)	12300 (750)	15150 (920)
6 Upper arm *	1600 (100)	2500 (130)	2500 (150)
7 Forearm *	1180 (70)	1450 (90)	1720 (100)
8 Hand	460 (30)	530 (30)	610 (40)
9 Hip flap *	2890 (180)	3640 (220)	4380 (270)
10 Thigh minus flap *	5480 (330)	6700 (410)	7920 (480)
11 Calf *	3320 (200)	4040 (250)	4760 (290)
12 Foot *	840 (50)	1010 (60)	1180 (70)
5 + 4 + 3 Torso	31870 (1940)	40910 (2450)	49870 (3040)
9 + 10 Thigh *	8360 (510)	10340 (630)	12300 (750)
7 + 8 Forearm plus hand *	1640 (100)	1980 (120)	2320 (140)

Notes:

*Average of right and left sides

a. These data apply to 1-G conditions only.

b. The male crewmember population is defined in paragraph 3.2.1, Anthropometric Database Design Considerations.



3.3.7 | BODY MASS PROPERTIES

- Body Mass - Both whole-body and body-segment mass data are provided.
 - Center of Mass - Center of mass locations are defined for both the whole body in defined positions and for body segments.
 - Body Moment of Inertia - Moment of inertia data are provided for the whole body in defined positions and for body segments.
- All data are based 1-G measurements.

The following are considerations for using the body mass properties data:

- Effects of Microgravity on the Body - Microgravity causes fluids to shift upward in the body and leave the legs. This results in an upward shift of the center of mass for the whole body and a loss of mass in the leg segments.

b. Population - The only body mass data provided for the Japanese female is whole body mass. Japanese female crewmember center of mass and moment of inertia data cannot be specified at this time due to insufficient data.

c. Body Weight Versus Body Mass - Although body mass remains constant, body weight will depend on gravity conditions. In 1-G body weight is calculated as indicated below:

1. Weight in lbs/32.2 = Mass in slugs

2. Weight in Newtons = mass in Kg X 9.8.

d. Application of Data - In microgravity, the body mass properties define body reaction to outside forces. These forces can be:

1. Reactive to forces exerted by the crewmember or a hand tool.

2. Active forces from devices such as the Manned Maneuvering Unit.

Both whole-body and body segment mass properties are given. The reaction of the body to a force depends on both the mass and the relative positions of the body segments. The whole-body center of mass and moment of inertia data are provided for 8 predefined positions. whole-body mass properties for other positions would have to be determined by mathematically combining the mass properties of the individual segments.

3.3.7.1 | BODY MASS DATA DESIGN REQUIREMENTS

Whole body mass of year 2000 crewmember population (age 40)

Male			Female		
5 th percentile	50 th percentile	95 th percentile	5 th percentile	50 th percentile	95 th percentile
65.8 kg (145.1 lb)	82.2 kg (181.3 lb)	98.5 kg (217.2 lb)	41.0 kg (90.4 lb)	51.5 kg (113.5 lb)	61.7 kg (136.0 lb)

Reference: 16, 308, pp. III-92, III-85; NASA-STD-3000 281

Body Segment Mass Data Design Requirements

Mass of Body Segments for Male Crewmember

Segment	Mass, gm (oz, weight)		
	5th percentile	50th percentile	95th percentile
1 Head	4260 (150)	440 (160)	4550 (160)
2 Neck	930 (30)	1100 (40)	1270 (40)
3 Thorax	20420 (720)	26110 (920)	31760 (1120)
4 Abdomen	2030 (70)	2500 (90)	2960 (100)
5 Pelvis	9420 (330)	12300 (430)	15150 (530)
6 Upper arm *	1600 (60)	2500 (70)	2500 (90)
7 Forearm *	1180 (40)	1450 (50)	1720 (60)
8 Hand	460 (20)	530 (20)	610 (20)
9 Hip flap *	2890 (100)	3640 (130)	4380 (150)
10 Thigh minus flap *	5480 (190)	6700 (240)	7920 (280)
11 Calf *	3320 (120)	4040 (140)	4760 (170)
12 Foot *	840 (30)	1010 (40)	1180 (40)
5 + 4 + 3 Torso	31870 (1120)	40910 (1440)	49870 (1760)
9 + 10 Thigh *	8360 (290)	10340 (360)	12300 (430)
7 + 8 Forearm plus hand *	1640 (60)	1980 (70)	2320 (80)

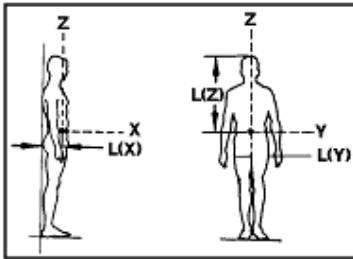
Notes:

- These data apply to 1-G conditions.
- The American male crewmember population is defined in paragraph 3.2.1, Anthropometric Database Design Considerations Average of Right and Left Sides

Image Reference: 276, pp. 32-79 With Updates; NASA-STD-3000 280

3.3.7.2 | CENTER OF MASS DATA DESIGN REQUIREMENTS

The whole body center of mass location data for the American male crewmember in 1-G are in the figure below along with equations for locating the whole body center of mass in males of different sizes.

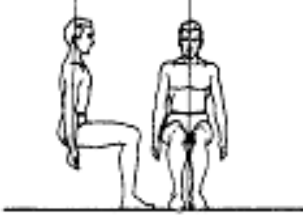
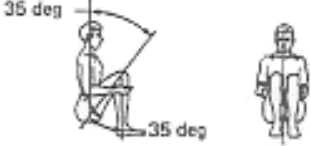
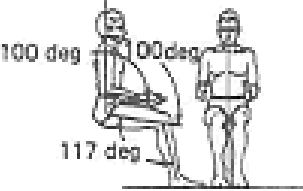
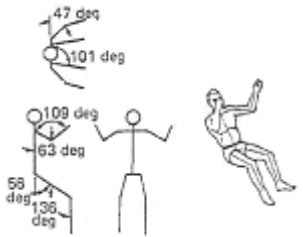


Whole Body Center of Mass and Moment of Inertia of the Male Crewmember

L(Y) - 1/2 distance between anterior superior iliac spine landmarks (1/2 bispinous breadth).

Moment of Inertia, $g = \text{cm}^2 \times 10^6$ (lb-in-sec²)

Posture	Dimension	5th percentile	50th percentile	95th percentile	
1. Standing 	L(X)	8.6 (3.4)	9.1 (3.6)	9.6 (3.8)	CENTER OF MASS
	L(Y)	11.7 (4.6)	12.5 (4.9)	13.3 (5.2)	
	L(Z)	75.7 (29.8)	80.2 (31.6)	84.7 (33.3)	
	X	106.5 (94.2)	144.5 (101.3)	182.3 (161.2)	MOMENT OF INERTIA
	Y	94.9 (83.9)	129.2 (114.3)	163.4 (144.5)	
	Z	10.3 (12.7)	14.4 (12.7)	18.5 (16.4)	
2. Standing with arms over head 	L(X)	8.7 (3.4)	9.0 (3.6)	9.4 (3.7)	CENTER OF MASS
	L(Y)	11.7 (4.6)	12.5 (4.9)	13.3 (5.2)	
	L(Z)	69.9 (27.5)	73.9 (29.1)	77.9 (30.7)	
	X	141.0 (124.7)	191.9 (169.7)	242.6 (214.6)	MOMENT OF INERTIA
	Y	124.6 (110.2)	172.9 (152.9)	221.0 (195.5)	
	Z	10.6 (9.4)	14.1 (12.5)	17.5 (15.5)	
3. Spread Eagle 	L(X)	8.2 (3.2)	8.6 (3.4)	9.0 (3.6)	CENTER OF MASS
	L(Y)	11.7 (4.6)	12.5 (4.9)	13.3 (5.2)	
	L(Z)	69.4 (27.3)	73.5 (28.9)	77.5 (30.5)	
	X	137.2 (121.3)	190.4 (168.4)	243.4 (215.3)	MOMENT OF INERTIA
	Y	104.2 (92.2)	144.8 (128.1)	185.2 (163.8)	
	Z	32.0 (28.3)	46.6 (41.2)	61.3 (54.2)	
4. Sitting 	L(X)	19.4 (7.7)	20.6 (8.1)	21.8 (8.6)	CENTER OF MASS
	L(Y)	11.7 (4.6)	12.5 (4.9)	13.3 (5.2)	
	L(Z)	65.2 (25.7)	68.6 (27.0)	71.9 (28.3)	
	X	57.3 (50.7)	76.9 (68.0)	96.5 (85.3)	MOMENT OF INERTIA
	Y	62.0 (54.8)	83.2 (73.6)	104.3 (92.2)	
	Z	30.7 (27.2)	42.4 (37.3)	54.0 (47.8)	

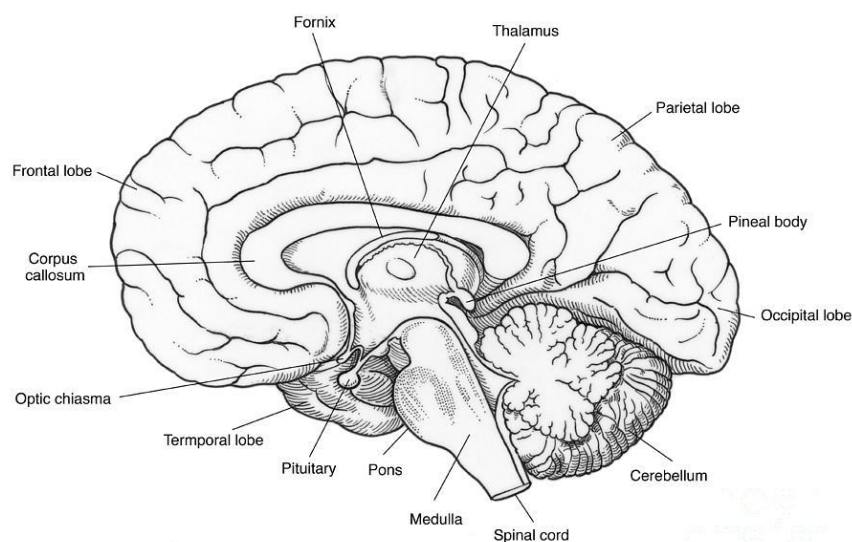
Posture	Dimension	5th percentile	50th percentile	95th percentile	
5. Sitting, Forearms Down 	L(X)	18.9 (7.4)	20.0 (7.9)	21.1 (8.3)	CENTER OF MASS
	L(Y)	11.7 (4.6)	12.5 (4.9)	13.3 (5.2)	
	L(Z)	66.0 (26.0)	69.3 (27.3)	72.5 (28.6)	
	X	59.2 (52.4)	77.6 (68.6)	96.0 (84.9)	MOMENT OF INERTIA
	Y	63.9 (56.5)	86.3 (76.3)	108.6 (96.0)	
	Z	30.9 (27.3)	42.8 (37.9)	54.6 (48.3)	
6. Sitting, Thighs Elevated 	L(X)	17.6 (6.9)	18.8 (7.4)	20.1 (7.9)	CENTER OF MASS
	L(Y)	11.7 (4.8)	12.5 (4.9)	13.3 (5.2)	
	L(Z)	57.3 (22.5)	59.4 (23.4)	61.5 (24.2)	
	X	37.6 (33.3)	48.7 (43.1)	59.8 (52.9)	MOMENT OF INERTIA
	Y	37.2 (32.9)	48.6 (41.2)	55.8 (49.3)	
	Z	23.9 (21.1)	33.7 (29.8)	43.5 (38.5)	
7. Mercury Configuration 	L(X)	19.4 (7.6)	20.5 (8.1)	21.5 (8.5)	CENTER OF MASS
	L(Y)	11.7 (4.6)	12.5 (4.9)	13.3 (5.2)	
	L(Z)	66.8 (26.3)	69.9 (27.5)	73.0 (28.7)	
	X	62.5 (55.3)	82.2 (72.7)	101.8 (90.0)	MOMENT OF INERTIA
	Y	69.6 (61.6)	95.5 (84.5)	121.3 (107.3)	
	Z	31.9 (28.2)	43.0 (38.0)	54.0 (47.8)	
8. Relaxed (weightless) 	L(X)	18.0 (7.1)	18.8 (7.4)	19.6 (7.7)	CENTER OF MASS
	L(Y)	11.7 (4.6)	12.5 (4.9)	13.3 (5.2)	
	L(Z)	68.0 (26.8)	70.9 (27.9)	73.7 (29.0)	
	X	88.0 (77.8)	114.5 (101.3)	140.9 (124.6)	MOMENT OF INERTIA
	Y	84.1 (74.4)	109.6 (96.9)	134.8 (119.2)	
	Z	39.8 (35.2)	50.5 (44.7)	61.2 (54.1)	

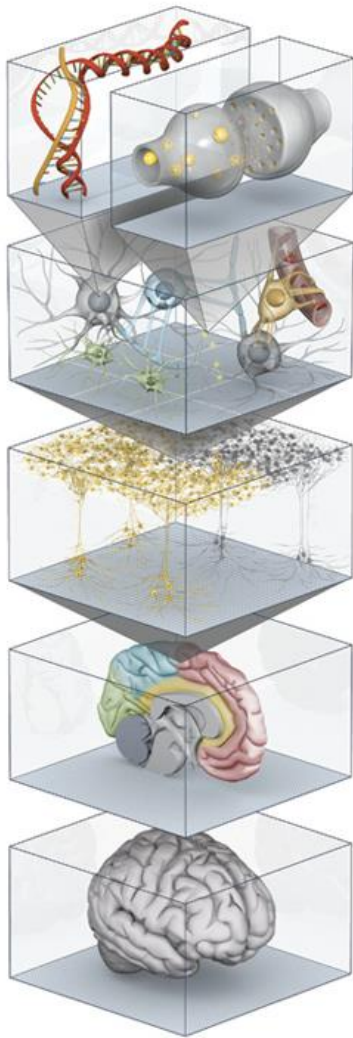
3.4 | HUMANS IN METAPHYSICAL DIMENSION



The human brain – an unpredictable device – something we are slowly trying to understand ourselves. The unlimited potential one carries within this one organ is unparalleled. But not everyone is gifted the same. Our differences makes each and everyone unique.

Evolution of Humans from the Metaphysical point of view, according to Architect Benjamin Betts, resides deep within the human Brain, the Consciousness. His work on the “Geometrical Psychology”, tries to represent the human consciousness from the animal basis, the pure sense-consciousness, to the spiritual or divine consciousness; both which extremes are *not man* – the one underlying the other transcending the limits of human evolution.





When one starts to understand the geography and climate of one's mind, one wonders am i but a machine, a natures device? My identity, my roots compact within a DNA strand, my actions do they have any significance in this material reality?

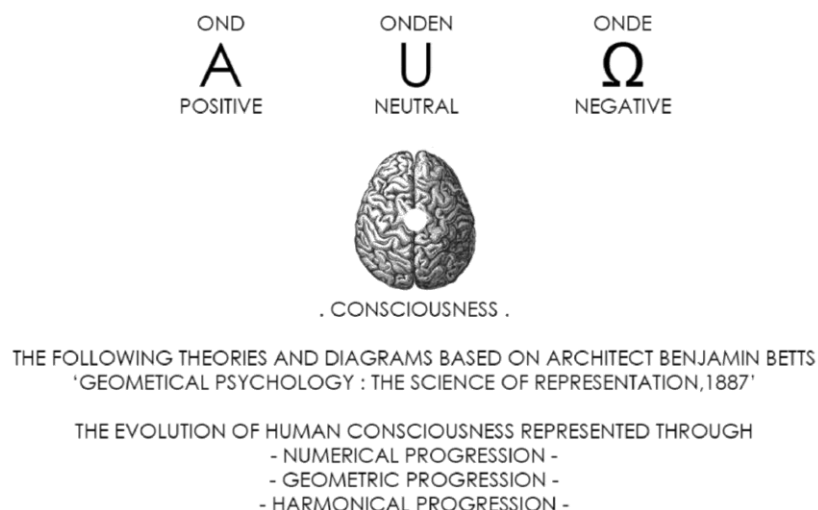
We are a work of art. Through constant learning and mixture of skills and sorting information we express our intellegence. We are born with certain mental potentials, and with time we develop and grow with respect to our surrounding environments. Architect Benjamin Betts tries to look at the workings of the mind, the consciousness in a geometric approach. His attempts to trace the course of the evolution of life must begin at some point of the eternal circle. Mr. Betts has begun with the evolution of man, but the principles of evolution which he discovers through his studies apply equally to the evolutions of higher or lower forms of consciousness, and even to those planes of existence which we usually term inanimate. Only by studying ourselves, he believes, can we ever arrive at a true knowledge of the external.

The starting-point of the human evolution is the animal sense-consciousness, which, though a positive plane of life for the lower animals, affords but a negative basis of consciousness for man. The symbolic representation of animal sense-consciousness is in two dimensions, and in form resembles a leaf whose apex is about equal to a right angle. The first human standing-ground is that of rational sense-consciousness. Self-gratification is the predominant motive on this ground. It is represented by a series of diagrams in two dimensions resembling leaf forms. They are in pairs, of which those which he calls positive or male forms usually have an apex less than a right angle, and those which he calls female or negative an apex greater than a right angle. The second standing-ground is negative, the reaction from the first, which is positive. It is the ground of the lower morality. Will is developed as distinguished from the mere impulsive volition of the first ground. Self-control is the predominant motive. The dimensions of the form are contracted to a point which is now not a mere point of possibility as at first, but a focus of realized sensuous activity, repressed. Commonly, however, this ground consists rather in the circumscription than suppression of sensuous activity (the total suppression of sensuous activity would be death), which is now no longer allowed exercise for its own sake, but as a means to an end. Thus

the representation of forms actually possible in life, instead of being a point will be a circle, or rather a circumference, for it is not necessarily a true circle. The third standing-ground Mr. Betts calls the ground of spiritual activity, but it is rather psychical than truly spiritual, the spiritual evolution being that of the fifth ground. Work is the motive of this ground. The sensuous activities are now allowed free exercise again, but as servants not as masters. The representative diagrams are in three dimensions, for the consciousness now has depth as well as surface extension. In form they resemble the corollas of flowers, the male series trumpet-shaped, and the female series bell-shaped.

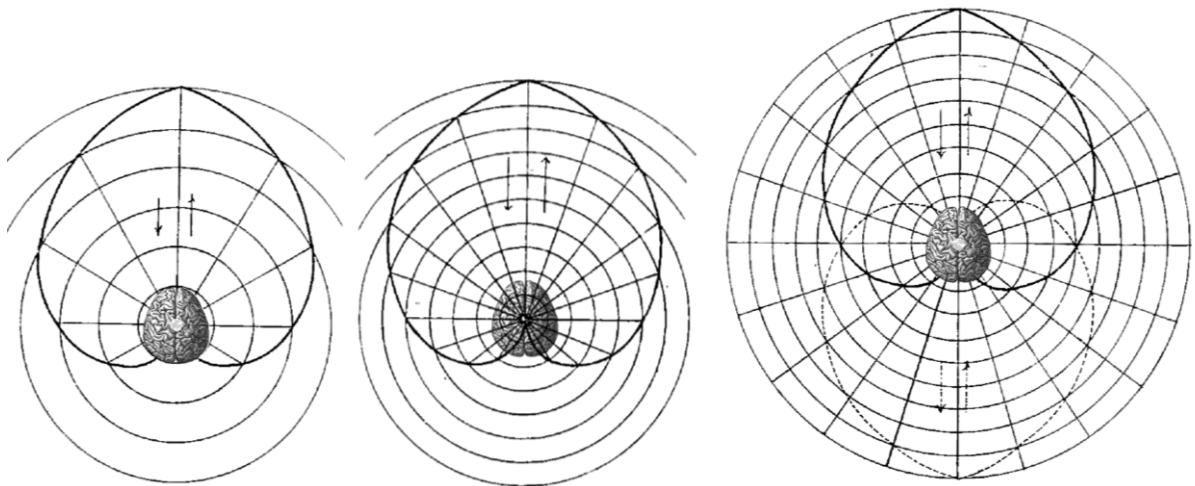
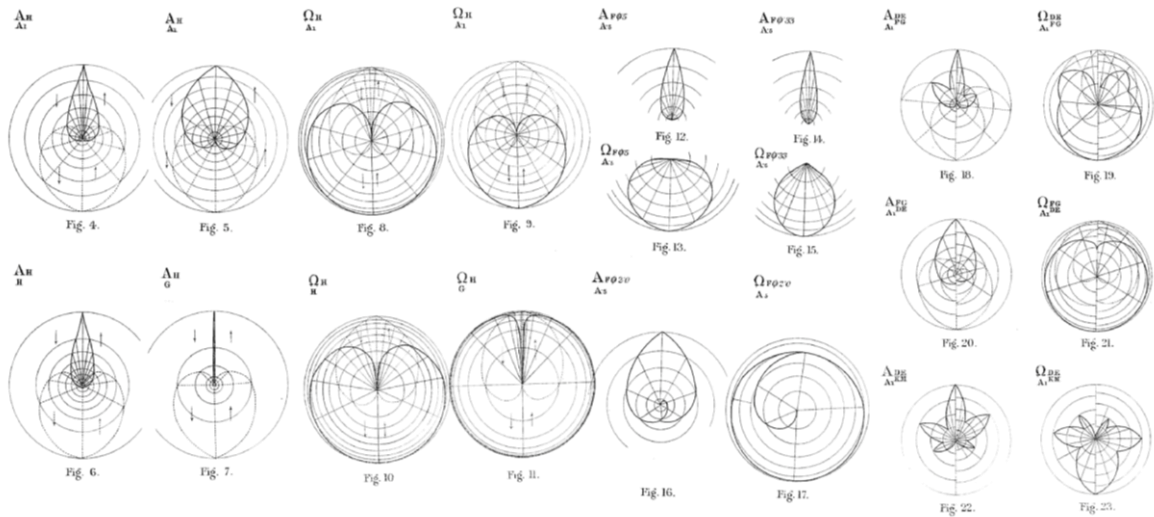
The fourth is again a negative standing-ground of life, the reaction from the third ground, as the second from the first. It is the sacrifice of the personal Will, from which sacrifice it is reborn as a spiritual Will, in union with the divine or universal Will. Mr. Betts professes himself unable to give any representation of life on this ground, since even the most advanced of ordinary humanity have scarcely entered upon it; also being a negative and reactionary ground it would be almost un-representable by diagram. The motive of this ground is a yearning for union with the infinite. The fifth standing-ground is spiritual, the ground of intuitive knowledge. As the spiritual now becomes a positive plane of life it would be capable of representation if we were able to draw diagrams in four dimensions, but our present consciousness is limited to only three. Normal human beings have not yet attained to this plane of life, though the aspirations of a few tend thitherward; consequently no definite conception can be formed of such a condition, except by inference from the analogies and correspondences of lower planes of life, or through the revelation of higher beings who have already developed this grade of consciousness in themselves. It is the plane of the occult—what we with our limited ideas of nature call the Supernatural.

Using two dimensional diagrams he tried to represent them in a graphics,



OND: Λ : POSITIVE
ONDE: Ω : NEGATIVE

HEAVENLY ORBITS
METAPHYSICAL LIMITS



ARITHMETICAL PROGRESSION—COMMON DIFFERENCE 1.													EQUAL TERMS.													SCALES FOR THE ANGULAR MEASUREMENT OF THE DIAGRAMS.												
A	B	C	D	E	F	G	H	I	K	L	M	N	A	B	C	D	E	F	G	H	I	K	L	M	A	B	C	D	E	F	G	H	I	K	L	M		
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1000	476	903	317	167	134	118	103	90	78	68	60	54	1000	500	333	250	200	166	143	125	111	100	90	81	1000	500	333	250	200	166	143	125	111	100	90	81		
1000	476	903	317	167	134	118	103	90	78	68	60	54	1000	500	333	250	200	166	143	125	111	100	90	81	1000	500	333	250	200	166	143	125	111	100	90	81		
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CHAPTER | 4

ARCHITECTURAL CONSIDERATIONS IN OUTERSPACE

This section discusses the placement, arrangement, and grouping of compartments and crew stations in space modules. The section also includes design parameters for items which integrate the crew stations:

4.1 | MICROGRAVITY DESIGN – CONSIDERATIONS

Many space modules will have a microgravity environment. The following are general considerations that must be made when designing the overall layout of the space module for microgravity:

- a. Access - Microgravity allows greater access to places that would otherwise not be possible in 1-G.
- b. Restraints - Many of the activities in microgravity require that the individual be restrained or tethered. Layout of crew stations must consider the extra time for the crewmember to secure him or herself. Activities which require restraints should be grouped as much as possible within the same reach envelope.
- c. Pre-Mission Training - Training and simulation done on Earth will be conducted in 1-G. The design should be such that the transition from Earth to space environment does not completely negate the effects of this training.

4.2 | MULTIPURPOSE USE OF VOLUME DESIGN CONSIDERATIONS

It is often more efficient to design the workspace so that it can be used for a number of different activities. It may be possible to use a volume which is dedicated to a specific activity and which would otherwise be wasted space when that activity is not being performed. Multipurpose utilization of volume can increase the efficiency of the space module. The activities should be compatible with the surrounding area and with each other. Possible limitations for multipurpose utilization of a volume include:

- a. Hygiene and Contamination - One activity may contaminate another, such as body waste management and food preparation.
- b. Time - It may take too much time to efficiently convert the volume from one function to another.
- c. Privacy Infringement - An activity may infringe on the privacy of a crewmember. This is the main objection to having two persons on different work shifts sharing the same quarters.

4.3 | PHYSICAL DIMENSIONS OF CREWMEMBERS DESIGN CONSIDERATIONS

The space module must support mixed crews with different skills living and working together in space for months at a time. The design goal of a space module should be to provide a facility that, within some understandably necessary size constraints, provides a comfortable and functionally efficient environment. In order to achieve this goal, consideration must be given to the physical dimensions of the human. The design must accommodate from the smallest in size to the largest of the selected design crewmember population. Anthropometrics and Biomechanics, Envelope Geometry for Crew Functions, provide data for sizing the space module to accommodate all crewmembers.

4.4 | MODULE LAYOUT AND ARRANGEMENT DESIGN CONSIDERATIONS

Equipment arrangement, grouping, and layout of the space module should enhance crew interaction and facilitate efficient operation. The module layout and arrangement should be based on detailed analyses using recognized human factors engineering techniques. This analysis process should include the following steps:

- a. Functional Definition - Definition of the system functions that must occur in the mission.
- b. Functional Allocation - Assignment of these functions to equipment, crewmembers, and crew stations.
- c. Definition of Tasks and Operations - Determination of the characteristics of the crew tasks and operations required to perform the functions, including:
 1. Frequency.
 2. Duration.
 3. Sequence.
 4. Volume required.
 5. Special environmental requirements.
 6. Privacy and personal space requirements.
- d. Space Module Layout - Using the information determined above, the layout of the space module should:
 1. Minimize the transit time between related crew stations.
 2. Accommodate the expected levels of activity at each station.
 3. Isolate stations when necessary for crew health, safety, performance, and privacy.
 4. Provide a safe, efficient, and comfortable work and living environment.

4.5 | DEDICATED - MULTI PURPOSE SPACE UTILIZATION DESIGN REQUIREMENTS

The interior accommodations shall be designed so that multipurpose utilization of the space meets the requirements:

- a. Compatibility of activities within crew stations - Activities that occur within the same station shall not interfere with each other. It is best if the different activities occur at different times.
- b. Compatibility with surrounding activities and facilities - Each of the activities performed at a station shall be compatible with surrounding activities and facilities.

4.6 | CREW STATION LOCATION

Stations that perform related functions should be adjacent to each other, if possible. Activities performed at a station should be compatible with surrounding activities and facilities (i.e. non-interference in terms of physical, visual, or acoustical considerations). Crew stations should be separated or isolated if it improves the overall performance and/or safety of the crewmembers. Crew stations within the space module shall be arranged and grouped to meet the goals of accessibility, activity level and optimization of transits.

4.6.1 | CREW STATION ADJACENCIES

Design of any system or facility should be based on the logical sequence and smooth flow of activities that are to occur in the facility. Generally, the most efficient layout is to place crew stations adjacent to each other when they are used sequentially or in close coordination. There are some limitations to this general rule, however. Adjacent positions should not degrade any of the activities in the stations, nor should the positioning degrade any of the activities in the surrounding stations. General adjacency considerations, beyond simple activity flow, are listed and discussed below.

- a. Physical Interference - Some crew stations require a high volume of entering and exiting traffic (both personnel and equipment). Placement of these stations adjacent to each other could result in traffic congestion and loss of efficiency.
- b. Noise - Activities such as communications, sleeping and rest, and mental concentration are adversely affected by noise. Activity centers generating significant noise levels should not be placed adjacent to those activity centers adversely affected by noise.

c. Lighting - Ambient illumination from one activity center may either interfere with or benefit the activities in an adjacent center. Activities that require illumination will benefit from the Activities adversely effected by light could be:

1. Certain experiments or lab activities such as photographic development.
2. Sleeping.
3. Use of some optical equipment (such as windows) and self illuminated displays.

d. Privacy - There are cultural and individual requirements that should be considered. Certain personal activities such as sleeping, personal hygiene, waste management, and personnel interactions require some degree of privacy. These private areas should not be placed in passageways or highly congested activity centers.

e. Security - Many of the experiments and production processes will be confidential to a specific industry or organization. These activity centers may require visual, audio, or electrical isolation from the rest of the space module.

f. Vibration - Certain personal activities, such as relaxation and sleep, will be disturbed by vibrations and jolts. In addition, many production, experimental, and control functions will require a stable and vibration-free platform. Crew stations of these types should be isolated from sources of vibration.

g. Contamination - Crew station activities can generate contaminants. These activities may include manufacture, maintenance, personal hygiene, or laboratories. Other crew station activities may be extremely sensitive to contamination. These activities include food storage and consumption, laboratory research, some production processes, and health care. Contaminant sources and areas highly sensitive to contamination should be physically separated in the overall space module layout.

4.6.2 | CREW STATION ADJACENCIES DESIGN REQUIREMENTS

Crew stations shall be placed adjacent to each other (or combined) when any of the following conditions exist:

a. Sequential Dependency - The activities occurring in one station are sequentially dependent on the activities occurring in another station (i.e., one activity provides the reason or need to perform the other activity).

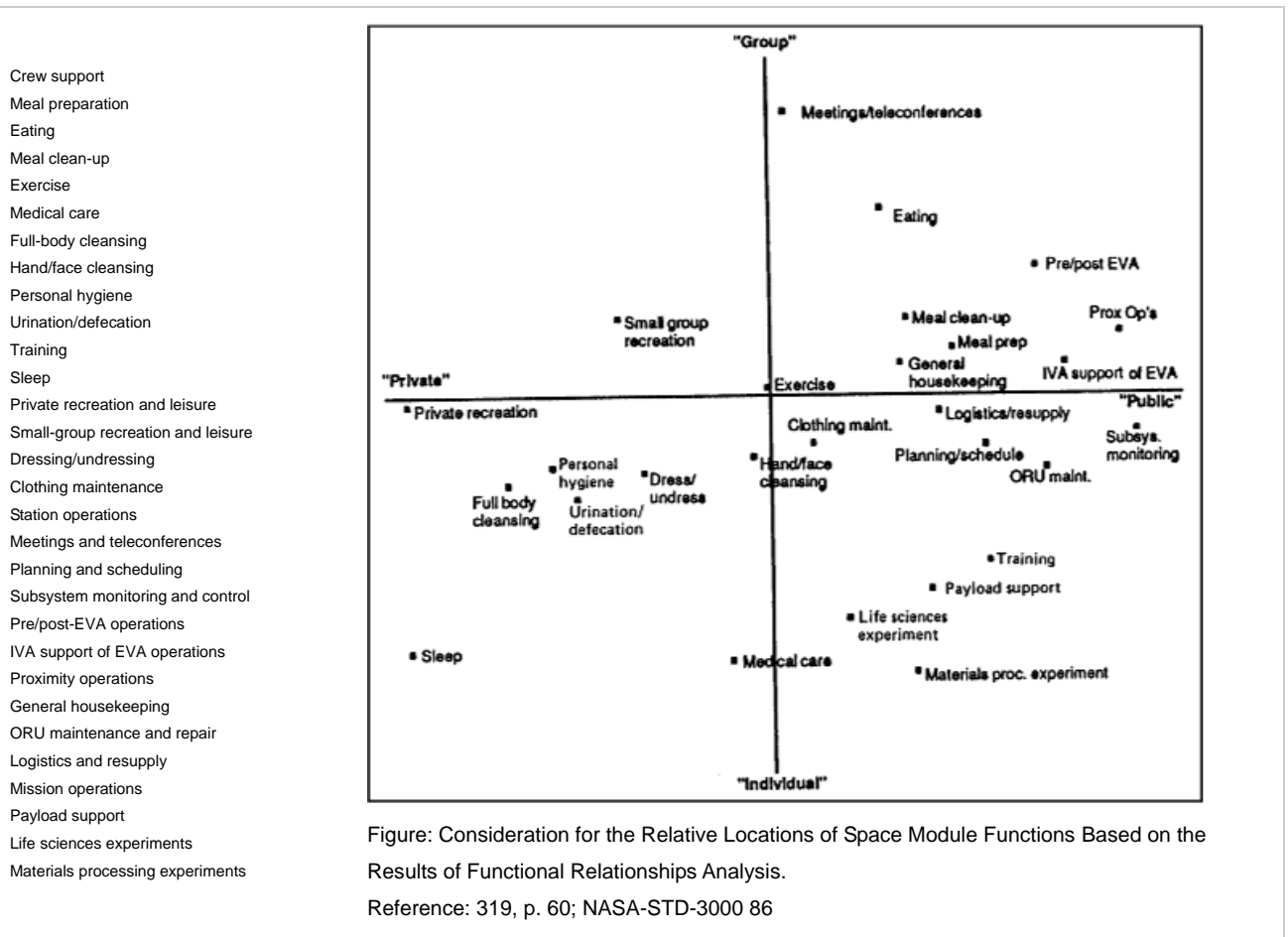
b. High Transition Frequency - Crewmembers change frequently from the activities occurring in one station to the activities occurring in another station.

c. Shared Support Equipment - The equipment used to support the activities in each station is similar or identical.

4.6.3 | SPECIFIC ADJACENCY DESIGN CONSIDERATIONS

Analyses have been performed on typical space module crew functions to determine adjacency considerations for specific crew stations and functions. The functions considered in the analysis are listed in Figure 4.6.3-1. The following criteria were used to evaluate adjacency of the functions. Each of these criteria were given equal weighting:

FIGURE 4.6.3-1 TYPICAL FUNCTIONS OF A SPACE MODULE CREW



- Transition Frequency - The frequency with which crewmembers switch from performing one function to another.
- Sequential Dependency - The extent to which one function provides the reason, or need, to perform another function.
- Support Equipment Commonality - The percentage of support equipment shared by the functions.
- Noise Output and Sensitivity - The potential for noise generated by crew activities and support equipment associated with one function to interfere with the performance of another function.
- Privacy Requirements - The similarity of the privacy requirements (both audio and visual).

4.6.4 | NON-ADJACENT CREW STATIONS - DESIGN REQUIREMENTS

Crew stations shall not be located adjacent to each other when any of the following conditions exist:

- a. Physical Interference - Crew traffic flow, equipment movement, and activities of one station physically restrict the activities in another station.
- b. Environmental Interference - The activities in one station affect the surrounding environment so that the activities in an adjacent station are degraded. These environmental effects include lighting, noise, vibration, heat.
- c. Degradation of Crew Health and Safety - The activities or contents of one station could, within a reasonable possibility, degrade the health and safety of the crew in an adjacent station.
- d. Infringement on Privacy - A station infringes on the privacy of the crew members in an adjacent station to an extent unacceptable to the crew members.
- e. Infringement on Security - A station infringes on the security and confidentiality of the activities of an adjacent station to an extent unacceptable to the mission of the two functions.

4.7 | COMPARTMENT AND CREW STATION ORIENTATION

This paragraph discusses the orientation of crew stations (workstations, crew activity centers, etc.) within the space module. The information in this section applies to a microgravity environment where there is no gravity to define a single orientation.

4.7.1 | ORIENTATION DESIGN CONSIDERATIONS

In a 1-G or partial gravity environment, orientation is not a particular problem. Down is the direction in which gravity acts and the human is normally required to work with feet down and head up. In a microgravity environment, the human working position is arbitrary. There is no gravity cue that defines up or down. In microgravity, orientation is defined primarily through visual cues which are under the control of the system designer. The orientation within a particular crew station is referred to as a local vertical. There are several orientation factors to be considered when designing a microgravity environment.

- a. Work Surfaces - Microgravity expands the number of possible work surfaces (walls, ceilings, as well as floors) within a given volume. This could result in a number of different local verticals within a module.

b. Training and Testing - Some of the working arrangements that are possible in microgravity will not easily be duplicated on Earth. Pre-mission training and testing will suffer with these arrangements. Additional training might have to be conducted during the actual mission. This could drastically reduce the effectiveness of a short duration mission.

c. Disorientation - Humans, raised in a 1-G environment, are accustomed to forming a mental image of their environment with a consistent orientation. People locate themselves and objects according to this mental image. If the person is viewing the environment in an unusual orientation, this mental image is not supported. This can promote disorientation, space sickness, temporary loss of direction, and overall decreased performance.

d. Visual Orientation Cues - Visual cues are needed to help the crewmember quickly adjust his or her orientation for a more familiar view of the world. These visual cues should define some sort of horizontal or vertical reference plane (such as the edges of a CRT or window). Of the two, it appears that the horizontal cue is more effective. Further research is presently being conducted by NASA to determine additional guidelines for the design of visual orientation cues.

e. Equipment Operation - Due to prior training and physical characteristics of the human, some pieces of equipment are more efficiently operated in one specific orientation. Labeling must also be properly oriented to be readable. Direction of motion stereotypes exist for most controls. For instance, in the US, power is turned on when a switch is positioned up or toward the head. If equipment items, labels, and controls have different orientations within the same crew station, human errors are likely to occur.

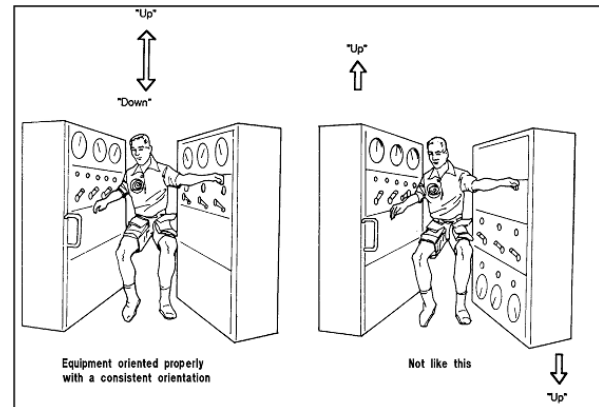
4.7.2 | ORIENTATION DESIGN REQUIREMENTS

The following are design requirements for establishing an orientation within a space module:

- a. Consistent Orientation - Each crew station shall have a local vertical (a consistent arrangement of vertical cues within a given visual field) so that the vertical orientation within a specific work station or activity center shall remain consistent.

b. Visual Orientation Cue - A visual cue shall be provided to allow the crewmember to quickly adjust to the orientation of the activity center or workstation.

c. Separation - When adjacent workstations or activity centers have vertical orientations differing by 90 degrees or more, then clearly definable demarcations shall separate the two areas.



4.8 | LOCATION CODING

This section discusses the standards for defining locations throughout a space module and or vehicle. The location coding system shall apply to all crew interface areas including:

- a. Control and display panels.
- b. Stowage areas, lockers, sub-compartments, and containers.
- c. Access panels.
- d. Systems, components, and equipment.

4.8.1 | USERS OF A LOCATION CODING SYSTEM DESIGN CONSIDERATIONS

Many different people will use the space module location coding system (both crewmember and non-crewmember personnel) and the system will be used in a wide variety of situations (both emergency and routine). It is therefore important that the system be simple to use, easy to remember, easy to communicate, and consistent throughout the system. The following is a list of the personnel who might use a space module location coding system and ways in which it might be used:

- a. Space Module Crew - Locations codes are necessary to minimize crew search time and maintain consistent equipment placement during nonuse periods. This is especially important for single equipment items requiring rapid use by more than one crewmember.
- b. Ground Support Personnel - A location coding system will be used to communicate information and instructions between ground and module crews.
- c. Crews of Other Modules - Location codes will be necessary for docking or any coordinated activity between modules.

d. Maintenance and Emergency Personnel - Repairs and rescue operations require an accurate and easily communicated location coding system.

e. Logistics and Resupply Personnel - Location codes are required for inventory assessment and resupply plan development and communication.

4.9 | ENVELOPE GEOMETRY FOR CREW FUNCTIONS

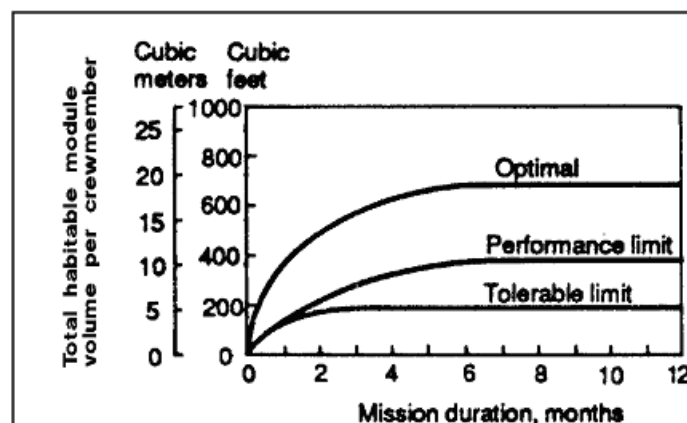
This section provides information for sizing the space module for human work and habitation. Physical body envelopes for various crew functions are given. The information in this section can be used to develop a preliminary overall layout of the space module. There are four basic factors that affect the required habitable volume and envelope geometry in a space module. These factors are listed below:

a. Mission duration. b. Visual factors. c. Physical body envelope. d. Social factors.

4.9.1 | MISSION DURATION DESIGN CONSIDERATIONS

The duration of the mission has an overall effect on the required envelope geometry. Increasing mission duration requires a greater physical envelope to accommodate mission tasks and personal needs. Crew accommodation needs are additive, so the total required habitable volume per crewmember increases with mission duration. Guidelines for determining the amount of habitable volume per crewmember for varying mission durations are shown in Figure 4.9.1-1.

Figure 4.9.1-1 guideline for determination of total habitable volume per person in the space module



4.9.2 | VISUAL DESIGN CONSIDERATIONS

As the mission duration increases, there is a greater tendency for the crew to feel confined and cramped. This can affect psychological health and crewmember performance. The judged physical space is not necessarily relative to the physical size of the room. The feeling of spaciousness can be achieved visually through the arrangement, color, and design of the walls and partitions of the space module. Some of the facts that are known about visual spaciousness are listed below:

- a. **DISTANCE FROM VIEWER** - Errors of overestimation of space increase as the distance from the viewer increases. This indicates desirability of long view axes.
- b. **ROOM SHAPE** - Irregular shaped rooms are perceived to have more volume than compact or regular shaped rooms of equal volume.
- c. **VIEWING ALONG A SURFACE** - Distances judged along surfaces are overestimated with respect to those judged through empty space. If an observer looks along a wall to another boundary wall, the boundary wall would be judged as further away than if it is seen from the same physical distance across the empty space of the room.
- d. **LIGHTING AND COLOR** - The effects of brightness, color saturation, and illumination levels on perception of volume are listed in Figure 3.4.12.2-1.
- e. **CLUTTER** - Clutter, or items that visually detract from long view axes, decrease the perceived room volume.
- f. **WINDOWS** - Windows allow the crewmember to focus on objects (such as Earth) outside the space module. This can significantly increase the sense of spaciousness and psychological well-being of the crewmember.

FIGURE 4.9.2-1 EFFECTS OF BRIGHTNESS, COLOR, COLOR SATURATION, AND ILLUMINATION LEVEL ON PERCEPTION OF VOLUME

Volume perception (roominess)	Brightness*	Color saturation	Illumination level
Enlarge	Areas will be enlarged by lightness. (Use to alleviate feelings of oppression or "closed-in").	Pale or desaturated colors "recede" and open up a room	High
Close-in	Areas will be closed-in by darkness	Dark or saturated hues "protrude", and close-in a room	Low
Note: * Brightness is a function of surface reflectance and illuminance			

Reference: 134, Figure 4-35 With Updates NASA-STD-3000 91

4.9.3 | BODY ENVELOPE DESIGN CONSIDERATIONS

The interior volume of the space module must accommodate not only the static human body but also the body when it performs the activities required of the mission. The body motion envelope is a conceptual surface which just encloses the extreme body motion of an activity. Crewmembers vary in size and the body motion envelope varies accordingly. The space module should not intrude on the body motion envelope of the larger crewmembers and yet not be so large that it is inconvenient or inefficient for the smaller crewmembers. In microgravity, additional considerations must be made for an expanded range of possible movements and for the neutral body posture. Approximate dimensions required to accommodate the body motion envelope of the 95th percentile male crewmember performing various IVA activities in microgravity are given in Figure 4.9.3-1. These volumes can be arranged and grouped to give an approximate estimate of the interior volume required for different crew stations.

FIGURE 4.9.3-1 APPROXIMATE DIMENSION REQUIRED TO ACCOMMODATE THE BODY MOTION ENVELOPE OF THE 95TH PERCENTILE MALE

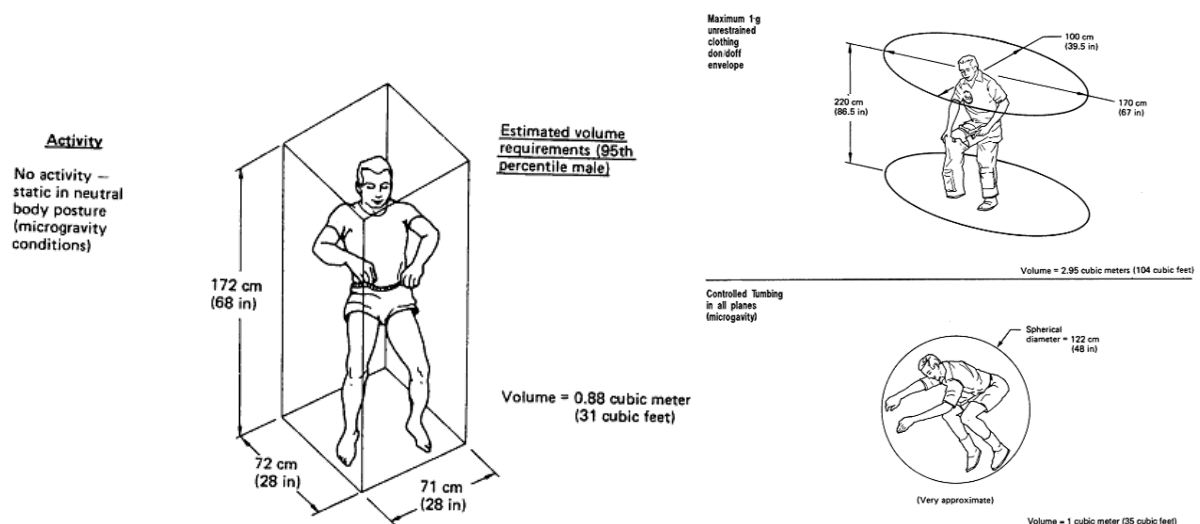


Image Reference: 215, pp. 38, 39; 310; 320 With Updates; NASA-STD-3000 92

4.9.4 | SOCIAL DESIGN CONSIDERATIONS

Some of the social factors that should be considered in the layout of the interior volume of the space module are discussed below:

a. Privacy - Visual privacy is a major concern for some activities such as body waste management and personal hygiene. Volumes devoted to these functions must be visually isolated. In addition, it has been found that a general sense of privacy increases when visual

exposure of the individual is decreased and the individual has controllable visual access to the outside world. In other words, the individual feels private if he or she has the ability of observing without being observed. This should be considered when designing individual crew quarters.

b. Leadership Role - The size and location of a crewmember's private quarters can impart a sense of status to other crewmembers. If desirable for organizational purposes, this fact can be used in configuring the space module.

c. Proxemics - Proxemics encompasses the study of space as a communications medium. Some factors to consider are:

1. When conversational or recreational space is necessary, the space should be configured so that the crewmembers can be at distances of 0.5 to 1.2 meters (1.5 to 4.0 feet) and at angles of approximately 90 to 180 degrees from each other. In general, 90 degrees is preferred for casual conversation while 180 degrees is for competitive games or negotiations.
2. Equal relative heights among social conversant should be maintained through spatial configuration and the placement of restraints.
3. In a socially communicating group it should be possible for all to position themselves in relatively similar body orientation and limb location. Maintaining a similar vertical orientation is also desirable.

4.10 | ENVELOPE GEOMETRY DESIGN REQUIREMENTS

The following are requirements for crew station body envelope geometry:

- a. Adequate Volume - Adequate crew station volume shall be provided for the crewmembers to perform tasks and activities (including exit and entry) without restriction. The volume shall also accommodate tools and equipment used in the task.
- b. Accessibility - The geometric arrangement of crew stations shall provide necessary and adequate ingress and egress envelopes for all functions within the station.
- c. Full Size Range Accommodation - All workstations shall be sized to meet the functional reach limits of the smaller of the defined crewmember size range and yet shall not constrict or confine the body envelope of the larger of the defined crewmember size range.

4.10.1 | TOTAL MODULE HABITABLE VOLUME DESIGN REQUIREMENTS

The following requirements apply to the total habitable volume in the module:

Mission Function Accommodation - Sufficient total habitable volume shall be provided to accommodate the full range of required mission functions.

No Degradation to Mission - Sufficient habitable volume shall be provided and configured to decrease the possibility of degradation of crew performance due to detrimental psychological effects from feelings of confinement. Design shall permit total habitable volume growth to accommodate the full range of required mission functions as number of crewmembers and station operations increase.

4.10.2 | SKYLAB FOOD MANAGEMENT COMPARTMENT

The Skylab Food Management Compartment for a crew of three was combined with a wardroom. The area measured 2.29 m (7.5 ft) long by 2.44 m (8 ft) wide by 1.98 m (6.5 ft) high. Total combined habitable volume was 11.1 m³ (391 ft³). This compartment was used by three crewmembers for a mission of 84 days.

4.10.3 | SKYLAB SLEEP COMPARTMENT

The Skylab sleep compartment for one crew member was 0.92 m (3 ft) long by 1.07 m (3.5 ft) wide by 1.98 m (6.5 ft) high. The total habitable volume was approximately 1.92 m³ (68 ft³).

4.10.4 | SKYLAB WASTE MANAGEMENT AND PERSONAL HYGIENE COMPARTMENTS

The Skylab combined both the waste management and hygiene functions in a single compartment. The dimensions were 1.98 m (6.5 ft) long by 0.92 m (3.0 ft) wide by 1.98 m (6.5 ft) high. The total combined free volume was 3.57 m³ (126 ft³). The total habitable volume utilized by the hygiene function was approximately 2.42 m³ (85 ft³). The total habitable volume utilized by the waste management function was approximately 2.42 m³ (85 ft³). This compartment was satisfactory for three crewmembers for 85 days, but interference between crewmen doing both functions simultaneously led to their suggesting separate compartments.

Figure 4.10.4-1 Skylab Food Management Compartment

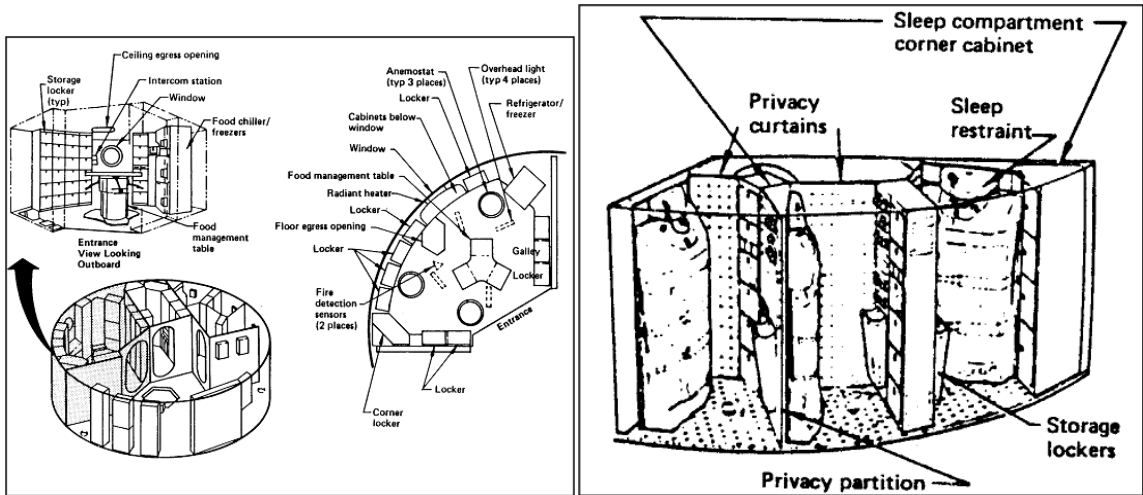


Image Reference: 130, figure 7, p. 11; NASA-STD-3000 93, 155, p. 3-4; NASA-STD-3000 94

Figure 4.10.4-2 Skylab Sleep Compartments

4.11 | TRAFFIC FLOW

The following analytical process can help to optimize traffic flow and crew functioning:

- a. Analyze Functions and Tasks - Determine the type and level of activity that occur at each of the crew stations and the required movement of crew and equipment between the stations.
- b. Locate Crew Stations - Locate crew stations to minimize the traffic flow.
- c. Design Translation Paths - Once the crew stations are located, design the translation paths for efficient traffic flow. First, design the paths to accommodate the traffic flow requirements of the worst case conditions. Then, complete the design to meet other traffic flow requirements. The following are steps for translation path design:

Figure 4.11-1 Guide for Determining Type of Translation Path

Priorities of Functions	Usage	Type of translation path
Primary - - IVA and EVA	Frequently traveled path by both IVA and EVA suited crewmembers. Will accommodate translation of an EVA crewmember with package. Can be used as an emergency path	Primary passageway
Primary -- IVA only	Frequently traveled path but only by IVA suited crewmembers. Will accommodate translation of an IVA crewmember with package. Can be used as an emergency IVA path	Standard passageway.

Secondary - - IVA only	Very low frequency transit from one point to another, IVA Pass-through only	
Emergency	Infrequently traveled but necessary for emergency repairs, rescue, or escape. Will accommodate EVA suited crewmember. Packages must be translated in front or behind crewmember.	Minimal passageway

Image Reference: 250 With Updates NASA-STD-3000 178

4.11.1 | CONGESTION AVOIDANCE DESIGN REQUIREMENTS

Traffic congestion shall be avoided. The following methods shall be taken to avoid congestion:

- a. Reduce the Need for Traffic - Crew stations shall be located and designed to minimize the need for transit within the space module.
- b. Alternate Paths - Provide alternate paths around congested areas.
- c. Proper Scheduling - Schedule activities to avoid congestion.
- d. Reduce Congestion Due to Large Volume Transfer - Traffic flow patterns shall minimize the distance large volumes are transported and reduce as much as possible congestion caused by large volumes transported through tight areas.
- e. Reduce Cross Traffic - Avoid crossing heavily traveled paths.
- f. Translation Path Size - Translation paths and hatch and door openings shall be of proper size and configuration to accommodate predicted traffic flow.

4.11.2 | EMERGENCY AND ESCAPE ROUTE DESIGN REQUIREMENTS

The design for traffic flow shall take into account the possibility of a space module or subsystem failure or damage that could require evacuation. Specifically, the following requirements apply:

- a. Escape Routes and Isolation Areas - Crewmembers shall be provided with escape routes for egress and/or isolation in the event of the need for an emergency egress from their immediate location.
- b. Dual Escape Routes - Where practical, dual escape routes shall be provided from all activity areas to serve in the event that the use of one route is impossible.

- c. Protection of Entry/Exit Path - Provisions shall be made to the maximum extent possible to ensure that compartment entry/exit paths can be maintained in the event of an accident (fire, explosion, abrupt accelerations, etc.).
- d. Escape From Crew Stations - Crew station openings and egress paths shall be large enough to permit rapid egress.
- e. Emergency Rescue and Return Route - An emergency rescue and return route shall be available for all planned IVA activity areas. The route shall be capable of accommodating an EVA-suited individual.
- f. Dead End Corridors - Dead End Corridors shall be avoided whenever possible.
- g. Emergency Regulation and Routes - Emergency traffic regulations and appropriately marked emergency routes shall be established for safe and efficient movement of personnel and equipment.

4.12 | TRANSLATION PATHS

The following factors must be considered when designing translation paths in a space module:

- a. Type of Translation Path - The required size and shape of the translation path depend on its function. Design considerations for each type of translation path are given below:
 - 1. Pass Through - A pass-through (or tunnel) need only be large enough to permit passage by a crewmember with his or her long axis in the direction of travel. A pass-through is illustrated in Figure 4.12.1-1. By definition, the pass-through need only accommodate an IVA clothed crewmember.
 - 2. Minimal Passageway - A minimal passageway is similar to a pass-through but must accommodate an EVA suited crewmember.
 - 3. Standard Passageway - A standard passageway should accommodate a crewmember in an upright working position or neutral body posture. A standard passageway is illustrated in
 - 4. Primary Passageway - A primary passageway is the same as a standard passageway but must accommodate an EVA suited crewmember.
- b. Aisle Clearances - Aisles are defined as translation paths that pass crew stations. In this case the translation path must be located outside the maximum working envelope of the crew station.

c. Translation of Packages and Equipment - The translation path should be sized to accommodate the largest crewmember and any packages or equipment that must be transported. Both the package size, the manner that the package is to be carried, and acceptable clearances must be considered.

d. Number of Persons Using Translation Path - The translation path must be sized according to the traffic considerations. Persons often travel in pairs. A busy path may have to be wide enough for four crewmembers: two pairs passing each other.

e. Orientation of the Body - Turning or rotation required to position the body to translate from one path to another path, module, or door requires an increase in the minimum path size. The minimum dimensions of the path will be defined by the body orientation and method of negotiating the path.

Figure 4.12.1 Types of Translation Paths

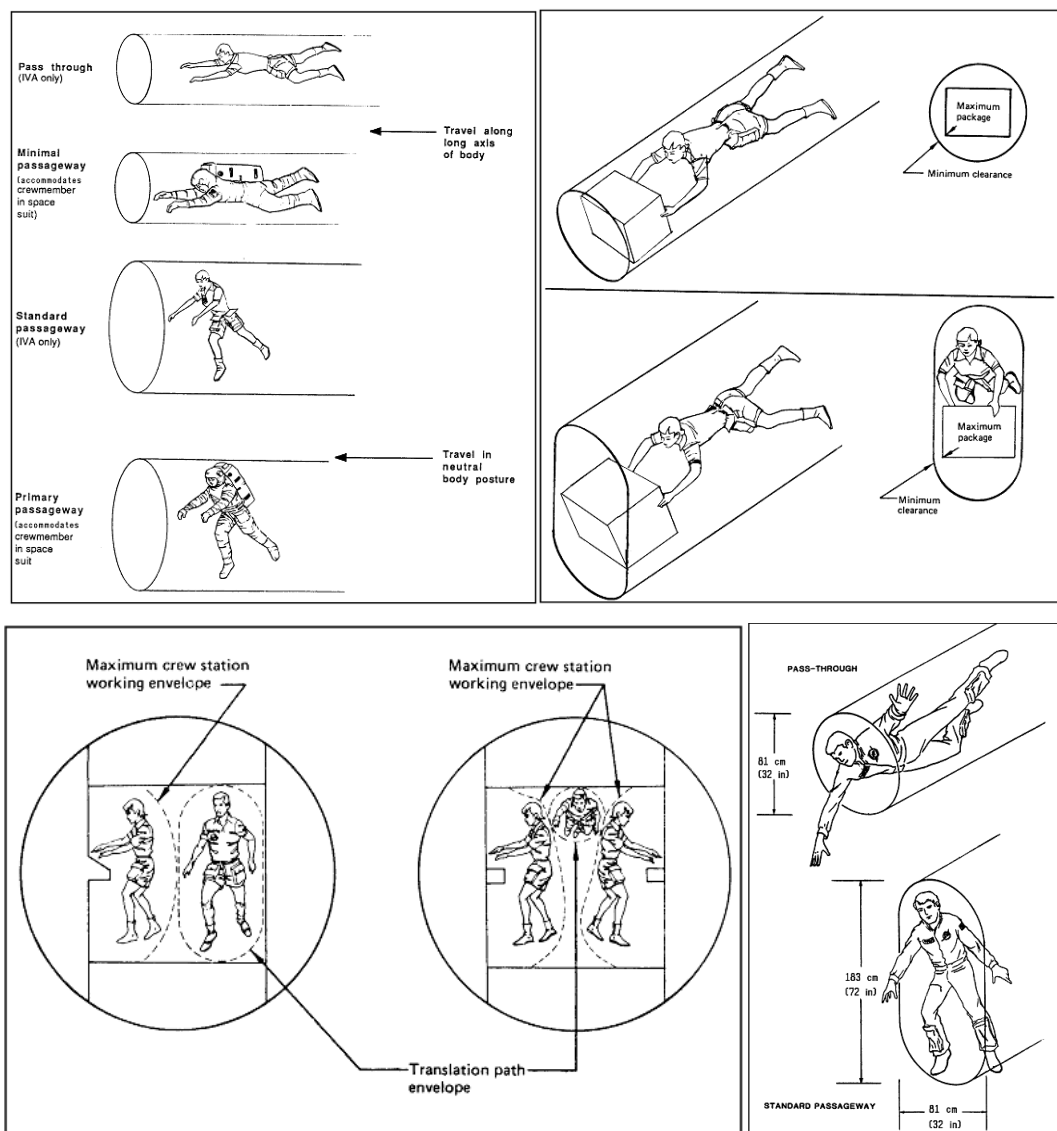


Image Reference: 250; NASA-STD-3000 209 – 11, 12

4.13 | MOBILITY AIDS AND RESTRAINTS ARCHITECTURAL INTEGRATION

The following considerations should be observed when locating IVA mobility aids:

- a. Method of Use - Previous experience has shown that mobility aids such as hand rails are not used for hand over hand translation. Mobility aids are used primarily for control of body orientation, speed, and stability. After humans gain confidence in free-flight translation, contact with planned fixed mobility aids is primarily at free-flight terminal points or while changing direction. Padding or kick surfaces should be considered at these points.
- b. Package Transport and Mobility Aid Use - Consider the packages that the crewmembers might be carrying. One or two hands may be required to negotiate and guide the package.
- c. EVA Use in Emergency - IVA mobility aids may have to be used by space suited crewmembers under emergency conditions. The location should, therefore, account for bulky garments that reduce joint movement and clearance.
- d. Substitute Mobility Aids - Walls, ceilings, or any handy equipment item may be used as a mobility aid. Surfaces and equipment along translation paths should, therefore, be designed to accommodate this function.

4.13.1 | CONSIDERATIONS FOR LOCATION OF IVA PERSONNEL RESTRAINTS

The following considerations should be observed when locating IVA personnel restraints:

- a. Operator Stability - Locate restraints where it is critical that a workstation operator remain stable for task performance (i.e., view through an eyepiece, operation of a keyboard, repair a circuit, etc.).
- b. Counteracting Forces - Locate restraints where task performance causes the body to move in reaction to the forces being exerted. For instance, a crewmember using a wrench should be restrained from rotating in an opposite direction to the applied torque.
- c. Two Hand Task Performance - Some simple tasks can be easily performed with one hand while using the other hand for stability. More complex tasks, however, require coordination of both hands and somebody or foot restraint system may be required.
- d. Restriction of Drift Into Undesirable Area - Not all restraints are necessary for keeping a crewmember at a station. Sometimes a restraint is necessary to keep the crewmember

from drifting into another area. A relaxing or sleeping crewmember, for instance, should be restrained from drifting into a traffic, work, or hazardous area.

- e. Location According to Crewmember Size - The restraint should properly position a crewmember at a station. The proper position is dependent on the crewmember size. The restraint should be located so that the smallest and the largest of the defined crewmember population range can perform the task. Restraint adjustment or multiple positions may be necessary.
- f. Noninterference - The restraint should not interfere with other tasks. It may be necessary to use a portable restraint and remove it when a station is used for another purpose.
- g. Typical Areas Requiring Restraints - Based on the above information, restraints should be considered for the following locations within the space module:
 - 1. Body waste management facility.
 - 2. Exercise area.
 - 3. Sleeping area.
 - 4. Clothes changing locations.
 - 5. Trash handling locations.
 - 6. Airlock.
 - 7. Space suit don/doff area.
 - 8. Housekeeping and cleanup centers.
 - 9. Maintenance areas.
 - 10. Galley and eating areas.
 - 11. Workstations.
 - 12. Space medical facility.

4.13.2 | MOBILITY AIDS AND RESTRAINTS DESIGN REQUIREMENTS

The following are requirements for integration of fixed IVA mobility aids into the space module architecture:

- a. Translation Path Locations - Mobility aids shall be located along translation paths as necessary for crewmembers to initiate translation movement, terminate translation movement, or change direction or speed.
- b. Orientation Requirements - The orientation and location of mobility aids shall be such that approximate body positions normally assumed to perform a task can be attained upon reaching the crew station.
- c. Noninterference - Mobility aids shall be located so as not to restrict or interfere with traffic flow or operations at crew stations.
- d. Contingency Space Suited Operations - IVA mobility aids shall be sized and located as necessary for contingency space suited operations (i.e., EVA rescue or recovery).

4.14 | HATCHES AND DOORS

The following are considerations for the location and design of hatches and doors:

a. Use of the Hatch or Door - The following is a list of the types of hatches and doors and some of their specific design considerations:

1. Pressure Hatch - Although the pressure hatch must be able to withstand high-pressure loads, it must not be too massive or difficult to operate. Due to the criticality of the pressure hatch, operating procedures and hardware must minimize the chance of unsafe operations. Normally, the pressure hatch opening size and controls must be designed to be used by a space suited crewmember. Reliability is enhanced if hatches open toward the higher pressure volume, thus making them essentially self-sealing.

2. Internal Doors - Internal doors may be necessary for visual privacy, reduction of light, reduction of noise, fire barriers, and restraint of loose equipment. The configuration will vary accordingly.

3. Emergency Hatches - Emergency hatches are used primarily for escape or rescue. A dedicated emergency hatch should not interfere with normal activities. In an emergency, however, hatch operation should be simple and quick. Where pressure loss is a possibility, emergency hatch openings must be sized for space suits.

b. Opening Size and Shape - The following considerations should be observed when selecting the hatch and door opening size and shape:

1. Body Orientation - Frequently used hatches and doors should not require body reorientation to pass through. In microgravity conditions, this means that the opening should allow passage of a crewmember in the neutral body posture.

2. User Size - The size of the hatch and door opening should accommodate the largest crewmember plus any equipment to be transported.

3. Space Suited Crewmembers - Generally, internal doors need only be used by IVA crewmembers; in some cases, however, it may be necessary to provide opening room for passage for a space suited crewmember.

c. User Strength - The operating forces of the door opening system must be within the strength range of the weakest of the defined crewmember population.

d. Traffic Considerations - Internal doors and hatches are points of potential traffic congestion. The following considerations should be made to ease the traffic flow:

1. Do not place doors or hatches near a corner where a translation path junctures with another path and/or where a single path turns the corner. The doorway should be at least 1.5 m (5 ft) from the corner.
2. Door and hatch covers should not open into congested translation paths. Rather, they should open into the compartment.
3. Door and hatch openings should be sized for the traffic flow. To be efficient, a high use doorway may require an opening to accommodate more than one crewmember at the same time.

Figure 4.14-1 Place Door Openings Away From Traffic Congestion

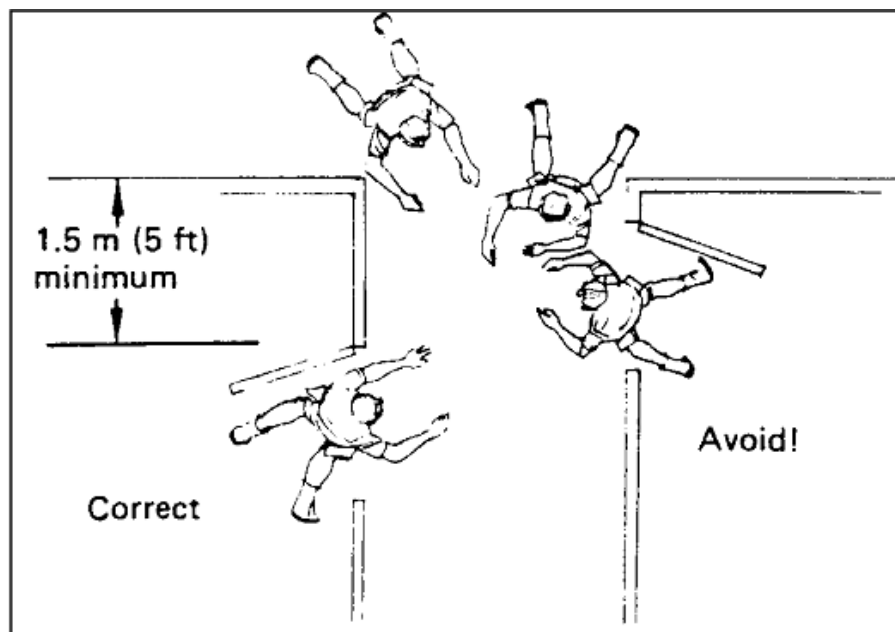


Image Reference: 111, p. 303; NASA-STD-3000 214

4.15 | HATCH AND DOOR DESIGN REQUIREMENTS

Hatches and doors shall meet the following location requirements:

- a. Internal Door Placement - Enclosed crew stations shall have entrances/exits to permit unrestricted flow for all anticipated traffic. They shall be located so personnel who are entering or leaving will not interfere with surrounding operations or traffic flow.

b. Away From Hazards - In compartments with a single ingress/egress, the opening shall not be located near flammable, explosive, or otherwise hazardous substance such that the energy content, if released, will result in damage that prevents access through the entrance.

c. Emergency Passage - Capability should be provided to allow emergency exit and rescue entry into a compartment. This may require two or more entrances into a compartment and/or a pressure hatch.

4.15.1 | PRESSURE HATCH INDICATOR/VISUAL DISPLAY DESIGN REQUIREMENTS

Pressure hatch covers shall have the following visual displays and indicators:

- a. Visual Inspection of Hatch Security - A means shall be provided on both sides of the pressure hatch for visual safety check to ensure that it has been secured properly.
- b. Remote Status Display - Pressure differentials and hatch operational status displays shall be provided as necessary for safety at appropriate space module command and control center(s).
- c. Pressure Difference Indicators - Pressure hatches shall have pressure difference indicators visible on both sides of the hatch.
- d. Windows - All airlock hatches shall have windows for visual observation of all decompression operations with a minimum of blind spots inside the airlock.
- e. Operating Instructions - All pressure hatches shall display operating procedures on both sides of the hatch.

4.15.2 | OPENING AND CLOSING MECHANISMS DESIGN REQUIREMENTS

The hatch and door opening and closing mechanisms shall meet the following design requirements:

- a. Emergency Operation - Latching mechanisms shall provide for emergency operation in case of a latching system failure.
- b. EVA Operation - All opening/closing mechanisms shall be operable by a pressure-suited crewmember.
- c. Operation From Both Sides - Hatches shall be capable of being operated, locked, and unlocked from either side.
- d. Interlock - Pressure hatches shall be prevented from unlatching prior to pressure equalization.

- e. Single Crewmember Operation - Hatches shall be capable of being operated by one crewmember.
- f. Parts Tethering - All safety pins or other detachable parts required for the opening/closing shall be tethered and able to be stowed.
- g. Emergency Closing - Hatches and doors shall allow crewmembers to close covers with or against pressure differentials, for the worst case pressure differential anticipated.
- h. Rapid Closing - Hatches used to isolate interior areas of the space module shall be designed to allow rapid closing.

4.16 | WINDOWS INTEGRATION

The following are considerations that should be observed when locating windows within the space module:

- a. Functional Considerations - Figure 4.16.1-1 shows possible uses of the space module window and the effect of the use on the location of the window within the space module
- b. Traffic - The windows should be located so that use of windows will not interfere with required traffic flow.
- c. Light and Glare - The following are lighting and glare considerations for window location:
 - 1. Glare on window - Bright interior illumination could reflect from the window surface and degrade visibility.
 - 2. Dark adaptation for celestial viewing - Bright interior illumination may degrade dark adaptation required for celestial viewing.
 - 3. Light sensitive activities - Exterior light through windows could degrade light sensitive activities such as sleeping, use of CRT displays, or tasks requiring dark adaptation.
 - 4. Natural light and calcium loss - Calcium loss from bones in microgravity is a problem of major concern. Since vitamin D obtained from certain wavelengths of natural sunlight facilitates absorption of calcium by the gastrointestinal tract, it is postulated that provided by controlled crew exposure to appropriately designed and located windows.
 - 5. Destruction of bacteria with natural light - A window could be located so that the light could be used against the growth of pathogenic bacteria.
 - 6. Use of natural light for illumination - A properly designed and located window can use natural sunlight as a supplementary source of internal space module illumination.

Figure 4.16-1 Functional Considerations for Location of Window Within a Module

WINDOW FUNCTIONS	LOCATION CONSIDERATIONS
PROXIMITY OPERATIONS	
Coordination of docking and berthing of other modules	Near module workstations with communications, control displays, video backup, etc
Monitor and support of EVA personnel	Location to provide a clear, stereoscopic view of EVA operations
Tele-operation of EVA equipment	
EARTH/CELESTIAL OBSERVATIONS	
Discovery and documentation of unpredicted features and events.	Near scientific workstations
Scientific research and experimentation.	Away from high traffic volume
Support of crew morale	
Offset claustrophobic effects of tightly confined, long-term isolation.	Near recreational, socialization areas.
Provide recreational and awe-inspiring experiences.	Near areas of boring, monotonous tasks (exercise, for instance).
Enable photography	Near private quarters
Provide educational benefits	Location to provide view of Earth (if possible) or other interesting celestial sight
Provide a psychological link to the home planet.	
Afford natural illumination and day/night cycles.	

Image Reference: 322, pp. 2,3; NASA-STD-3000 180

4.16.1 | WINDOW CONFIGURATION DESIGN CONSIDERATIONS

The following are considerations for the design of the window and the surrounding area:

- a. Anthropometrics and Neutral Body Posture - The window must be placed on the line of sight of the user. The size range of the users must be considered. In microgravity conditions the neutral body posture must be accommodated.
- b. Total Visual Field - The total visual field out the window must be compatible with the task of the viewer. Calculate the total visual field using the following dimensions:
 1. Window width.
 2. Bezel thickness.
 3. Distance of the viewer from the window.
 4. Lateral offset.

These dimensions are illustrated in Figure 4.16.1-1 along with the factors that affect them.

- c. Window Shape - In proximity operations, cues to establish viewer or target orientation are important. A square or rectangular window with flat frame edges can provide the viewer with orientation cues. Round windows do not provide these cues.
- d. Restraints - Body restraints compatible with the viewing task must be provided for microgravity conditions. The restraints should allow the full size range of users to position themselves for viewing.
- e. Protection of the Window Surface - In a microgravity environment, crewmembers are able to use all exposed surfaces for stabilization and mobility. Care should be taken in designing and locating the window to ensure that it is not damaged by the crew during translation.
- f. Space Module Windows - Windows located in the habitation module should be used primarily for crew recreation and observation during off-duty periods.

Figure 4.16.1-1 Calculation of Visual Angle From Window

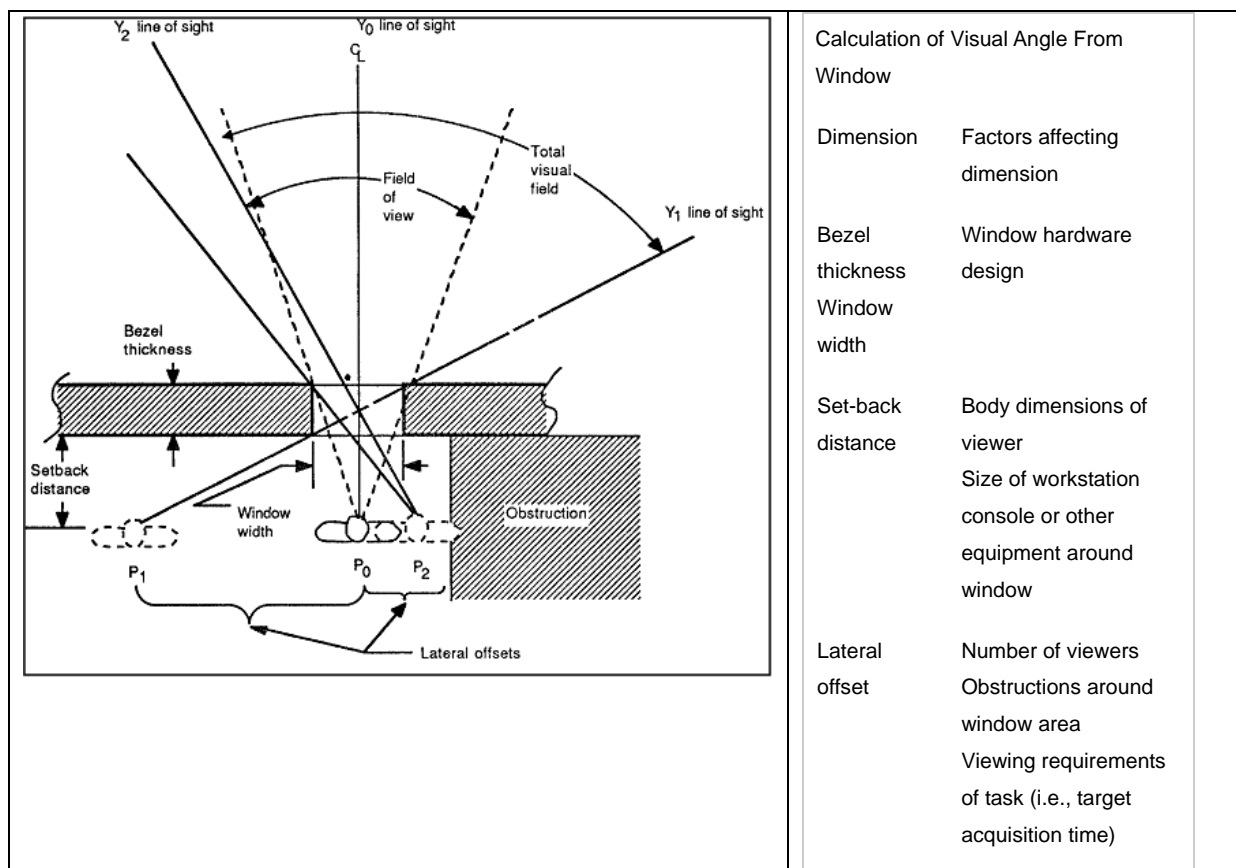


Image Reference: 323, p. 7; NASA-STD-3000 181

4.17 | PSYCHOLOGICAL EFFECTS DESIGN CONSIDERATIONS

There are several psychological effects of color and light that should be considered in space module habitat design.

a. **Compartment Spaciousness** - Color can effect perceived spaciousness. The primary qualities of color that effect spaciousness are brightness (lightness) and saturation. There are small receding and advancing effects due to hues, but these effects are secondary to brightness and saturation. The following color scheme will help to maximize spaciousness:

1. Keep boundary surfaces at high brightness and low saturation.
2. Color interior partitions at medium brightness and medium saturation.
3. Accent elements at either medium or low brightness and high saturation.
4. Color protruding elements the same as the boundary surfaces.

b. **Perceived Temperature** - Some investigators claim that perceived temperature can be influenced by color and texture. Hue is by far the most important dimension of the color for this effect. Perceived temperature can also be strongly enhanced by texture. The reported effects of color and texture on perceived temperature are listed below:

1. Warmth - Warm colors (red, yellow, pink, brown, etc.) and highly textured surfaces.
2. Coolness - Cool colors (green, violet, blue, etc.) and polished surfaces.

c. **Psychological Response to Light** - The psychological response to light is a combined function of its amount, direction ability, and power spectrum, and their suitability for different types of activities. Good lighting design incorporates more than a simple concern for illumination of a visual task.

d. **Stress Reduction** - Certain interior decor features such as pictures or panel coverings with natural/naturalistic themes may aid in stress reduction for occupants.

4.18 | MATERIALS DESIGN CONSIDERATIONS

Durability, nonflammability, and safety are all considerations for the selection of materials for interior decor. The materials should not impart chemical, mechanical (abrasive surfaces, sharp corners, edges, etc.), or any other hazard to the crew.

4.18.1 | SAFETY

The use of hazardous materials shall be minimized; those used shall meet the applicable requirements specified in NHIB 8060.1B, Flammability, Odor and Offgassing Requirements and Test Procedures for Materials Used in Environments That Support Combustion (J8400003). Materials and components subject to insidious degradation in the space module ionizing environment shall not be used where that degradation can cause or contribute to any crew hazards. In the event of fire, the interior walls and secondary structures within space module shall be self-extinguishing.

4.19 | LIGHTING

Space module lighting systems should be designed to optimize viewing conditions for all mission activities. This will vary from very gross visual requirement (such as seeing to move about) to very critical visual tasks that require discrimination of color codes, seeing fine detail an instruments, or detection of dim objects or planetary detail at night. The key factors to consider are:

4.19.1 | LIGHT SOURCE DESIGN CONSIDERATIONS

White light sources should be used for most nominal work and living space areas because this makes people and things look natural and allows use of special surface color codes to be recognized. Designers should strive to utilize interior lighting that approximates the full spectral range of sunlight.

Red lighting should be considered where it is necessary for a crewmember to remain dark adapted. An example would be when the crewmember has to look out of a window (at night), but also read instruments inside the space module. Light level or intensity should be sufficient to allow the crewmembers to perform their visual tasks efficiently, but not so high as to create glare sources. Generally, the more detailed or long duration the task, the higher the illumination should be. Each lighting system should be dimmable to allow crewmembers to optimize their viewing conditions.

Light sources should be placed according to what they are intended to illuminate, i.e., surfaces, objects, people, instruments, documents or signs. They should not shine in crewmember's eyes, or cause serious reflections that could degrade visual task performance. Supplemental lighting should be provided for personnel performing specialized visual tasks in areas where fixed illumination is less than the minimum required.

As a general rule, illumination in work and living spaces should eliminate glare and shadows that interfere with prescribed tasks. The following are three important factors of light distribution and some of the exceptions to this general rule:

- a. Ambient Light - Ambient light for general, gross illumination should be distributed so as to enhance the appearance (e.g., spaciousness) and functional performance of an interior volume.
- b. Supplemental Light - Supplemental light may be required for local illumination of a special task.
- c. Self Illuminated Displays - Self-lit or luminous displays such as a CRT may require a reduction of illumination.

The operator should be provided with a control over each type of light where practical.

4.19.2 | CHARACTERISTICS OF TASK MATERIALS DESIGN CONSIDERATIONS

Different material and surfaces react differently to various lighting techniques. Slick, glossy materials, instrument covers, windows and painted surfaces tend to create reflection and glare problems. Reduction of such problems requires consideration of the type and positioning of light sources, control of illumination level, and possible use of anti-reflection coatings. Whenever possible avoid glossy, highly-polished surfaces. Figure 4.19.2-1 gives typical reflectance values for various surfaces. Task/lighting conditions should be planned and executed to preclude or minimize the need for a crewmember to suddenly shift from a very bright to very dark environment, or vice-versa.

Figure 4.19.2-1 Typical Work Surface Reflectance Values

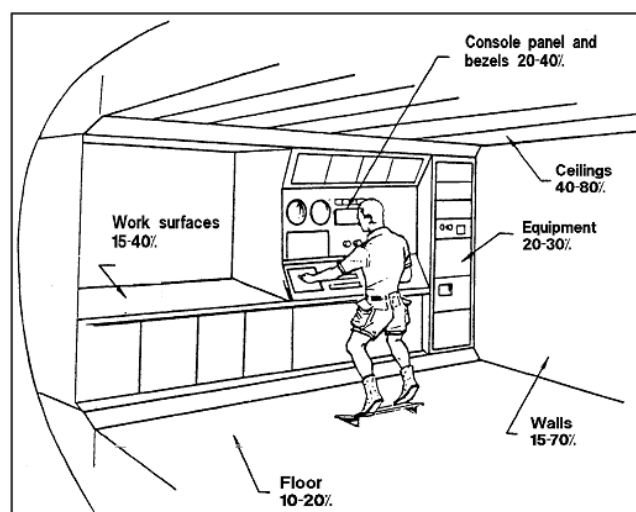


Image Reference: 15, p. 3-23; NASA-STD-3000 223

4.20 | WINDOWS

Window transmissivity is a critical design parameter because some visual tasks require perception of very small, faint sources of light. Visual perception decreases with decreased window transmissivity. The window transmissivity must be constant across its entire surface to prevent distortion of viewed objects. The glass must be free of inclusions (e.g., air bubbles, foreign particles). These glass imperfections can 1) cause the viewer to focus improperly on objects and 2) cause glare which can also degrade visual perception.

The line of sight (LOS) of the viewer looking through a window system of multiple glass surfaces, may be altered by a variety of factors; nonparallel multiple glass surfaces create a prism effect causing line of sight deviation wherein the visual judgment of target motion normal to the LOS may be in error. Each surface of a window panel must be flat and parallel so that it does not contain an astigmatic error in which the observer perceives out-of-focus images. Since the eye cannot focus at two distances at the same time, it will likely seek an intermediate focus. This results in blurring or distortion which causes visual fatigue. Reflections produced by internal or external light sources can interfere with visual identification and other judgments of luminous targets and cause eye fatigue. Anti-reflection coatings, polarizing filters, or glare screens can help reduce these reflections.

In general, even though the optical qualities of windows should be dictated by the various uses to which they will be put, it is reasonable to design into them as high optical quality as is affordable in anticipation of future experimental and other mission requirements.

4.20.1 | VISUAL PROTECTION DESIGN CONSIDERATIONS

Internal and external shutters or shades have been employed on previous manned space vehicles to protect the crewmember from the high intensity sunlight, to reduce glare, and to reduce ambient lighting where low light levels were needed for operational tasks or for sleep periods. The external shutters also act as protection from micrometeorites and other potential external sources of damage or contamination, thus preserving the life and quality of the window.

Filters and coatings are used to protect the observer's eyes and exposed skin surfaces from harmful infrared or ultraviolet radiation. Filters may be required to protect the eyes from laser light. Applicable laser light safety criteria should be adhered to so that inadvertent admittance of laser light through the windows is prohibited.

4.20.2 | PHYSICAL PROTECTION DESIGN CONSIDERATIONS

There are many sources of natural and manmade external window surface contaminants. Natural sources of contamination include micrometeoroids, cosmic particles, and electrons. Manmade sources of contamination include propellants, ECLSS outgassing, sealant outgassing, fluid leaks, waste dumping, atmosphere leakage, and EVA glove and boot prints.

Between-pane contamination may result from outgassing of gaskets or from moisture that is not removed during the window assembly process. Provision for early detection and removal of moisture from spaces between multiple window panes should be provided, particularly for long-duration missions.

Window surface contamination sources inside the space module include breath condensation, finger prints, body oils, urine, skin, and bacteria. These window surface contaminants scatter sunlight into the observer's eyes and produce glare that reduces the crewmembers ability to detect faint visual targets. The space module design should prevent or minimize these sources of contamination whenever technically and economically feasible. Anti-fogging coatings, heated glass, sacrificial (i.e. removable) surfaces, and protective covers are some of the ways that contamination can be prevented.

Window flaws and cracks can grow imperceptibly until they reach a catastrophic magnitude. A means should be provided for performing continuous window integrity inspections.

4.20.3 | WINDOW MAINTENANCE DESIGN CONSIDERATIONS

Due to the external and internal contaminants and accidental mechanical damage, contingency window maintenance must be provided.

Window surface cleaning materials and processes must be designed to preserve the optical qualities of the window by not scratching or staining the surfaces. Polishing/buffing operations are not recommended since they are likely to do more damage than good.

Removable, transparent window covers (i.e., sacrificial surfaces) should be considered as a means to expedite the window maintenance. These disposable covers would be designed to absorb most of the mechanical damage or staining that cannot otherwise be avoided.

The possibility of replacing one or more window panes on-orbit should be considered for permanently orbiting space modules. Techniques for accomplishing this replacement operation should not entail depressurization of the module.

4.20.4 | WINDOW DESIGN REQUIREMENTS

This section provides the design requirements for the optical characteristics, visual protection for the window user, physical protection of the window panes and window maintenance.

The following optical characteristics requirements shall apply to window and viewport design in order that no visible distortions or optical defects shall be detectable by a person possessing 20/20 acuity within the normal viewing envelope under operational lighting conditions.

4.20.5 | WINDOW SIZE

- a. Hatch windows shall be minimum of 20.3 cm (8 in.) diameter.
- b. General area windows shall be a minimum of 50.8 cm (20 in.) in height and width or diameter.

4.20.6 | SURFACE REFLECTIONS

- a. Windows shall be designed such that specular reflectance from each air-glass interface shall not exceed 1.5 percent for light incident on the surface.
- b. When anti-reflection coating are applied to windows, they shall not cause resolution degradation exceeding .007 mr (1.5 arc seconds).

4.20.7 | OPTICAL CHARACTERISTICS

At completion of manufacture, the window panes, with all accepted coatings shall meet the following optical requirements within the clear viewing area.

- a. Deviation at any point on the window panes shall not exceed 1.45 mr (5 arc minutes).
Tempered window panes shall not exceed 2.9 mr (10 arc minutes).
- b. Distortion of all types of window materials shall not exceed a plane slope of 1:24.
- c. Haze of the uncoated window pane for all thicknesses shall not be greater than 2%.
- d. Warp and Bow-All glass window panes shall not exhibit warp or bow greater than 0.030 inch per linear foot of the glass.
- e. Surface Parallelism-The surface parallelism between multipanes of window systems shall not exceed 0.58 mr (2 arc minutes) from inner surface to outer surface of the complete assembly.

4.20.8 | OPTICAL DENSITY

Each pane shall be manufactured so that when multi-panes for window group the following shall be met.

- a. Infrared-The optical density shall be greater than one for wavelengths between 850 and 1000 nanometers (less than 10%). For wavelengths greater than 1000 nanometers, the transmittance shall be less than 8%.
- b. Ultraviolet-The optical density shall be greater than three for wavelengths between 320 and 280 nanometers. The optical density shall be greater than four for wavelengths between 220 and 280 nanometers.
- c. Visible-In the region between 420 and 800 nanometers, the transmittance through a window composite shall not be less than 70%. The transmissivity shall not vary more than 25% for incident angles between the window surface and LOSs ranging from 30 to 60 degrees.

4.20.9 | SURFACE QUALITY

The surface of each window pane shall be such that digs shall not exceed 0.122 cm (0.050 inches) diameter and scratches shall not exceed 0.0015 cm (0.0006 in.) deep. Chips shall not exceed 0.078 cm (0.032 inch.) in surface penetration and 0.04 cm (0.016 inch.) in thickness.

4.20.10 | BUBBLES, SEEDS

The maximum number of open seeds per surface shall not exceed three and shall not exceed 0.1225 cm (0.050 inch) in diameter or exceed a total number of 5 per cubic inch.

- a. Striae - Striae shall not exceed a diameter of 0.2 cm (0.080 inch) and are limited to no more than 2 square inch.
- b. Inclusions-Inclusions shall not exceed 0.37 cm (0.15 inch) in diameter and more than 1 per cubic inch.

4.20.11 | VISUAL PROTECTION DESIGN REQUIREMENTS

The window design shall meet the following requirements:

a. Sun Shields/Shades

1. Sun Shields - All viewing windows shall be provided with crew-operated, opaque sun shields which are capable of restricting all sunlight from entering the habitable compartments.
2. External Sun Shades - If external shades are provided there shall be a means to reposition by the window user.

b. Heat Rejection - The sun shade, whether internal or external, shall be capable of rejecting radiant energy away from the window assembly.

Window design shall be coordinated with other shielding protection design to achieve less than or equal to allowable radiation dosages given in these paragraphs.

4.20.12 | PHYSICAL PROTECTION DESIGN REQUIREMENTS

Window design shall meet the following surface contamination and breakage requirements which are imposed to ensure that the windows can be used for the intended observation functions and that the module pressure integrity is maintained:

- a. External Surface Contamination Protection - Window design shall take into account all sources of external contamination and shall provide a means for cleaning or replacing when degradation exceeds optical transmissivity requirements.
- b. Between-Pane Contamination Protection - Window design shall take into account all sources of contamination that can occur between the transparency panes and shall provide a means of preventing optical degradation due to these contaminants.
- c. Internal Surface Contamination Protection - Window design shall take into account all sources of internal surface contamination and provide a means for preventing or minimizing optical degradation due to these contaminants.
 1. Anti-fogging - All innermost panes shall be designed for anti-fog protection.
 2. Inner Pane Coatings - The innermost pane shall have no coatings except for anti-reflective coatings.
- d. Impact Load Protection - The window assembly shall be capable of withstanding a blunt object impact load of 550 N (125 lb) from any angle of incidence.

- e. Protection Covers - Removable or extractable protection covers shall be provided where the window assembly does not meet crew and equipment impact load criteria or the launch and reentry pressure profiles.
- f. Retractable External Protective Covers - If external protective covers are opaque, then IVA controls shall be provided with a backup EVA capability to override the IVA system.

4.20.13 | WINDOW MAINTENANCE DESIGN REQUIREMENTS

The following window maintenance requirements are imposed to minimize the crew workload and prevent degradation of the optical qualities of the windows:

- a. Window Servicing - Equipment and supplies shall be provided for efficient contingency window cleaning.
- b. Protective Covers - Where surface scratching, pitting, or staining cannot be prevented by other means, removable window protective surfaces shall be provided.
- c. Window Replacement - Window assemblies shall be designed to eliminate the need for depressurizing modules in order to replace window panes or the entire window assembly.

4.20.14 | SCIENTIFIC WINDOW DESIGN REQUIREMENTS

This section defines the requirements for a scientific window for special photographic and scientific investigation.

- a. Aperture Diameter-The window shall be a single pane or multipane system with a minimum aperture diameter of 55.9 cm (22 inches).
- b. View - The window shall be located to provide unobstructed viewing.

4.20.15 | MATERIALS REQUIREMENTS

- a. Window Pane Material - the window panes (glass) shall be fabricated from optical quality fused silica or equivalent.
- b. Inclusions - The silica (glass) shall meet Inclusion Number (Class) 0 as defined in MIL-STD-174B; i.e., seeds and bubbles, to the extent that the total bubble and seed cross section per 100 cubic cm (6.1 in^3) volume as viewed normal to the surface shall be less than 0.03 mm^2 (0.00005 in^2).
- c. Homogeneity - The index of refraction as measured normal to its surface of the glazing shall not show a variation greater than 3×10^{-6} over the entire sensing unit viewing area.

- d. Birefringence - Birefringence shall be kept to less than 6 nm/cm over the entire sensing unit viewing area.
- e. Veiling Glare - The complete single window glazing shall not contribute more than 2% veiling glare to the sensing systems.

4.20.16 | OPTICAL REQUIREMENTS

- a. Wavefront Error - The RMS wavefront variation through each multipane window system shall not exceed 1/10 of a light wavelength of 632.8 nm (helium neon) over any 16.5 cm (6.5 in) diameter aperture within the clear viewing area, obtained after all necessary optical coatings have been applied. This specification shall apply when viewing through the window from normal through 30 degrees off normal to the viewing surface in any axis.
- b. Surface Finish - The surface finish shall be polished to meet or exceed the requirements of a scratch-dig standard of 60-40 as described in MIL_0-13830A. The surface roughness shall be no greater than 10 angstroms remote manipulating system before coating. The roughness shall be measured across two perpendicular diameters.
- c. Wedge - Deviation of the transmitted beam shall not exceed 3.5 arc-seconds in any direction through a single pane.
- d. Parallelism Between Panes - Adjacent panes of a multipane window shall be parallel between 0.1 degree to 3 degrees. The innermost and outermost panes of a window system shall not be more than 3 degrees from parallel; this requirement shall not be met by matching tilted panes.
- e. Grinding and Polishing Sequence - Each optical surface will be polished using a control grind schedule wherein the material is removed to a depth equal to 3 times the diameter of the previous grit size through the polish operation. See Figure 11.11.3.2.1.2-1 for example sequence.
- f. Edges and Chamfers - All edges and chamfers shall be polished to relieve stresses caused by grinding. As these are not optical surfaces, a minimum of orange peel is permissible and may be felt-polished. However no chips shall be allowed.
- g. Residual Stress - The manufacturing process shall be such that when polished, the window pane shall contain no residual stresses or flaws introduced during processing.

4.20.17 | REFLECTANCE

The reflectance of the window shall be less than 2 percent from a wavelength of 450 nanometers to 900 nanometers. If an electro-conductive coating is used, the reflectance shall be less than 2% for wavelengths of 400 nanometers to 700 nanometers and less than 4% for wavelengths of 700 nanometers to 900 nanometers. These requirements shall apply for incidence angles from 0 degrees to and including 15 degrees from normal.

4.20.18 | VISUAL PROTECTION DESIGN REQUIREMENTS

The window design shall meet the following requirements:

a. Sun Shields/Shades:

1. Sun shields-All viewing windows shall be provided with crew-operated, opaque sun shields capable of restricting all sunlight from entering habitable compartments.
2. External sun shades repositioning-If external shades are designed to cast a shadow over a window, they shall be provided with a means to be remotely repositioned by the window user.

b. Radiation Protection:

1. Infrared-The maximum transmissivity of infrared shall be no more than 10% (density = 1) in the range of 800 to 1200 nm.
2. Ultraviolet-The maximum transmissivity of ultraviolet shall be no more than 0.001% (density = $10E-5$) in the range of 200 to 300 nm.
3. Heat rejection sun shade, whether internal or external, shall be capable of rejecting radiant energy away from the window assembly.
4. Window design shall be coordinated with other shielding protection design to achieve less than, or equal to, the allowable radiation dosages given in these paragraphs.

c. Optical Filters-Optical filters shall be provided to meet visual protection requirements if operational functions require light transmissibility in excess of the requirements given in item b, above.

4.20.19 | PHYSICAL PROTECTION DESIGN REQUIREMENTS

Window design shall meet the following surface contamination and breakage requirements which are imposed to ensure that the windows can be used for the intended observation functions and that the module pressure integrity is maintained:

- a. Physical Protection Design Requirements - Window design shall meet the following surface contamination and breakage requirements which are imposed to ensure that the windows can be used for the intended function.
- b. Surface Contamination Protection - Window design shall take into account all sources of external between pane, and internal contamination and shall provide a means for cleansing or replacing when degradation exceeds optical transmittance requirements. Scientific windows shall have an external cover that shall be closed except when these windows are in use, and shall have an internal transparent removable cover to protect the internal surface from scratches, smudges and protect the crewmembers' eyes from UV and IR transmittance. The removable cover shall be designed such that its removal is evident to all crewmembers within the module.
- c. Protective Cover - Removable or retractable protective covers shall be provided where the window assembly does not meet crew and equipment impact load criteria.
- d. Retractable External Protective Covers - If external protective covers are opaque, then IVA controls shall be provided with a backup EVA capability to override the IVA system.
- e. Impact Load Protection-The window assembly shall be capable of withstanding a blunt object impact load of 550 N (125 lb.) from any angle of incidence.

4.21 | BODY WASTE MANAGEMENT FACILITIES

This section discusses the human factors design considerations and requirements for the collection and disposal of wastes generated by the human body. The body waste management facilities handle feces, urine, vomitus, diarrhea, menses, and other wastes. Transfer, storage, and processing of waste products are not covered in this section; only facilities that directly interface with the crew are covered.

The following considerations should be made in the design of the waste management system:

- a. Reliability and Maintainability - System servicing and repair tasks are neither pleasant nor mission productive. Therefore, the system should be as reliable as possible and require a minimum of repair time. Scheduled maintenance and servicing times, including unloading and refurbishment, should be kept to a minimum.
- b. Ease of Use - The system should be simple and quick to use. The system should readily be available for emergencies such as vomiting or diarrhea. As a design goal, the facilities

should be used like and require approximately the same amount of time for use as equivalent Earth facilities.

- c. Acceptance - The body waste management systems must be both psychologically and physiologically acceptable to the crewmembers. An unacceptable system can result in deliberate restriction or modification of the diet by the crew and possible nutritional deficiencies.
- d. Microgravity Considerations - Gravity plays an important role in the removal of feces from the body during defecation in a 1-G environment. A substitute must be provided in a microgravity environment. Air flow has been used successfully in the past for the entrainment of both feces and urine in microgravity.
- e. Post Defecation Cleansing - In microgravity, many more tissues are needed for cleansing the anal areas after defecation, because gravitational forces are not present to aid in separation of the feces from the body. Also, since settling does not occur, the uncompacted wipes occupy 1 1/2 to 3 times the volume that would be used in a 1-G environment.
- f. Volume and Mass of Body Waste Products - The volume and mass of human body wastes along with additional information is given below:
 - 1. The normal feces bolus of a healthy adult varies in size from 100 to 200 mm (4 to 8 in) long by 15 to 40 mm (0.5 to 1.5 in) in diameter and weighs 100 to 200 grams (3.5 to 7 oz).
 - 2. Urination time and rate of flow ranges are shown in Figure 3.4.21-1. Urine volumes tend to be larger in microgravity.
 - 3. The maximum volume of expelled vomitus can be 1 liter (61 in³) of solids and fluids. This is with a fully distended stomach. The average volume of vomitus is more likely to be 200 to 500 ml (12 to 31 in³).
- g. Anatomical Considerations - Dimensions of the body that should be considered for design of waste management facilities. The body protuberances of the pelvis, ischial tuberosities, support the seated body in 1-G conditions. In reduced gravity conditions, seat contours and restraints can help the crewmember to locate the ischial tuberosities and thereby properly position the anus and urethra in relation to the collection devices. If air flow is used for collection and entrainment of feces and urine, it may be necessary to minimize the opening size for sealing. It has been found in both 1-G and microgravity conditions that it is possible to defecate through a 10 cm (4 in) diameter opening, although significant problems have been noted with this small an opening.

h. Body Posture - The following are considerations for determining the body posture during body waste management functions:

1. Urination - There is no evidence to suggest that posture has any effect on facilitating the act of urination.
2. Defecation - The act of defecation involves the use of the stomach muscles. The body should be positioned so that these muscles are supported and not strained.

Figure 4.21-1 Volume and Mass of Human Body Wastes

WASTE PRODUCTS	MASS (gm/person/day)	VOLUME (ml/person/day)
Hair growth	0.03 (0.3 to 0.5 mm per day)	
Desquamated epithelium	3	2
Hair - depilation loss	0.03	0.03
Hair - facial - shaving loss	0.3	0.28
Nails	0.01	0.01
Solids in sweat	3	3
Sebaceous excretion - residue	4	4.2
Solids in saliva	0.01	0.01
Mucus	0.4	0.4
Mensus (see note 1)	113.4	113.4
Flatus as gas	-	2000
Solids in feces	20	19
Water in feces	100	100
Solid in urine	70	66
Water in urine (note 2)	1630	1630

Notes:

1. Approximately once every 26 to 34 days and lasts 4 to 6 days, approximately 80% released during first 3 days.
2. Based on Skylab data

Reference: 19, Section DNK3, pp. 2, 229; 278, Sec. C-2-3, p. C-26, NASA-STD-3000 215

Figure 4.21-2 Overall Layout of the STS Waste Management Station

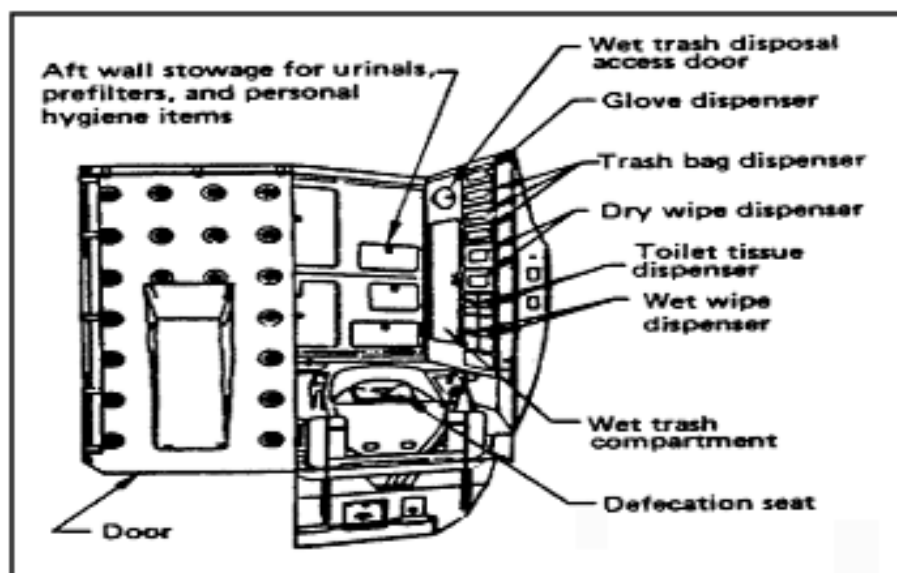


Image Reference: 312, Page 882; NASA-STD-3000-218

4.22 | RESTRAINTS

4.22.1 | PERSONNEL RESTRAINTS DESIGN CONSIDERATIONS

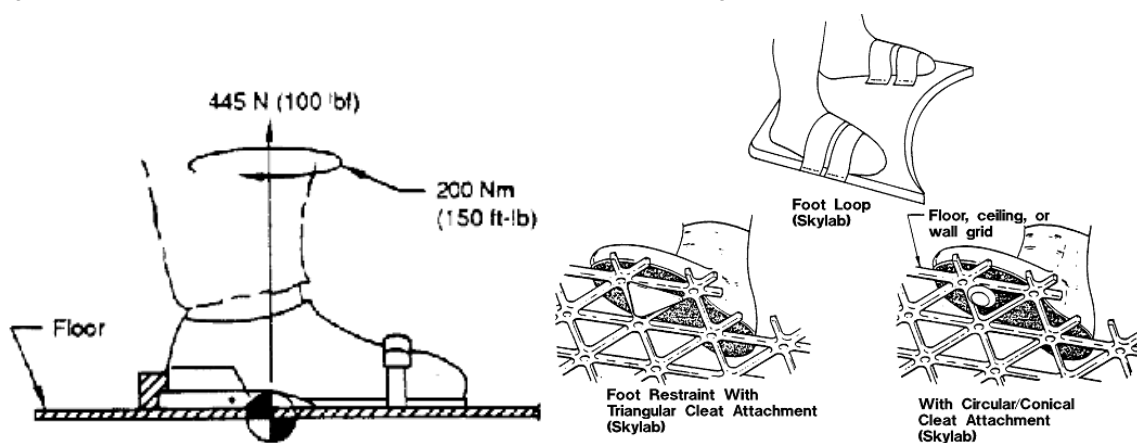
Personnel restraints are required at liftoff, during major thrusting maneuvers, microgravity/partial-gravity operations, and during return-to-earth operations. This section includes seat belts, shoulder harnesses, fixed and portable foot restraints, and body restraints. Donning/ doffing, loads, materials, color, temperature limits, and dimensional requirements are included for each type of personnel restraint.

Openings, holes, ductwork, and protrusions in and around equipment have been used by crewmembers as informal microgravity body restraints. Equipment designers must take this into account when designing equipment. These informal restraints are acceptable for short-duration tasks. They should not be the only method of restraint for long-duration operations where IVA foot restraints or fixed body restraints should be considered.

Foot restraints (and/or body restraints) may be required for tasks requiring precision. Unique foot restraint designs should be minimized and standardized design should be maximized. Any portion of the restraint worn on the foot shall be as low in mass as possible. In order to aid foot restraint ingress and egress, handholds that are located between the waist and shoulder should be available at all workstations. Commonalty requirements for foot restraint attachment, finish, durability, and color should be incorporated into the design. Foot restraints can be built into the equipment or into the crewmember's shoes.

4.22.2 | RESTRAINT DESIGN REQUIREMENTS

Figure 3.4.22.1 -1, 2, 3 Example Foot Restraints, Example Lower Leg Restraint



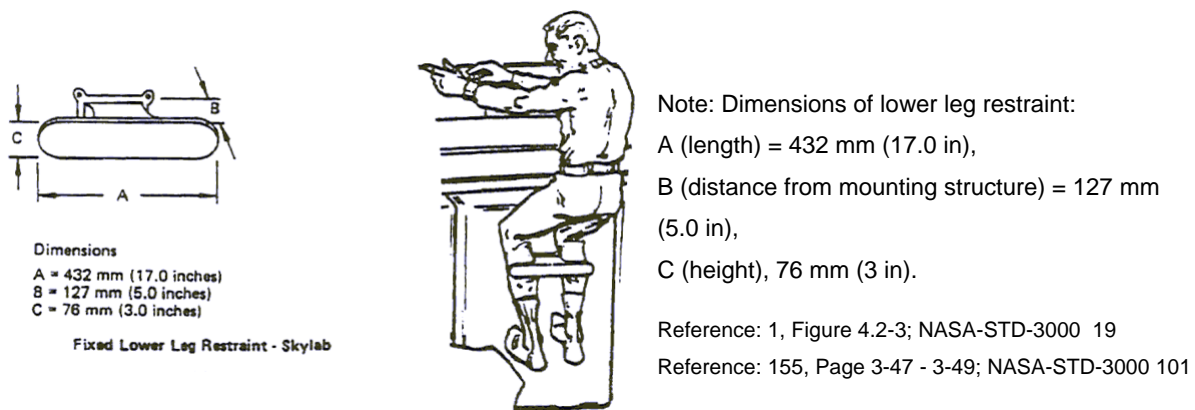
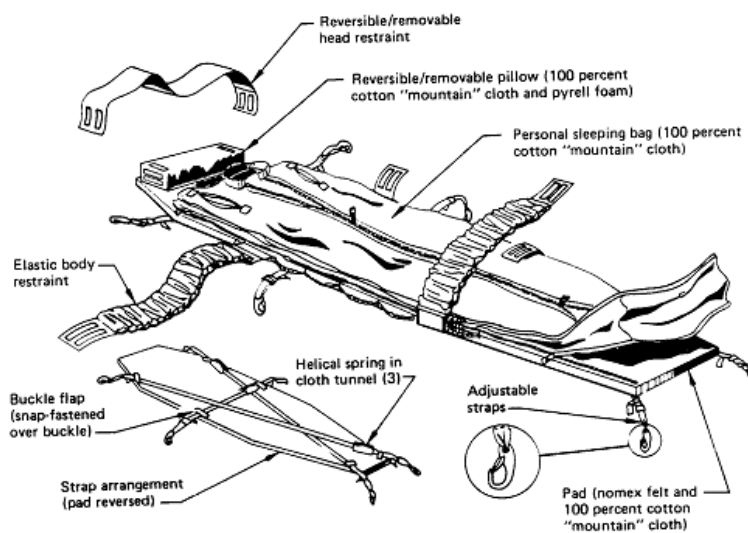


Figure 4.22.2 -2 Standard Sleep Restraint



Reference: 150, p. 3.18-26; NASA-STD-3000 20

4.23 | MICROGRAVITY COUNTERMEASURE FACILITY

This section discusses the facilities used in a microgravity environment to combat the harmful effects of microgravity on the human body. The requirement for a microgravity countermeasure facility assumes that the mission duration will be 10 days or longer. A summary of the effects of microgravity on the human body, possible countermeasures, and considerations for the design of facilities to support these countermeasures is shown in Figure 4.23 -1.

Figure 4.23 -1 Micro-Gravity Countermeasures Facility Design Considerations

Zero gravity effect	Possible countermeasures	Facility and equipment	Notes
Cardiovascular deconditioning	Low resistance, high frequent exercise of large muscle groups (aerobic exercise)	Exercise device (aerobic ergometer) Heart rate and metabolic monitoring system	Need volume for storage and use Heart rate and metabolic monitoring systems could be part of Space Medical Facility (see Para. 10.9). Heart rate monitoring should be routine; metabolic monitoring could be periodic (weekly).
		Adequate ventilation, cooling Timer Diversion from boredom Post exercise body wash Athletic games Game equipment Adequate ventilation, cooling Post game body wash	
Fluid loss	Fluid loading prior to 1-G entry	Storage area for fluids and fluid administration supplies	Could be part of Galley
	Pharmaceuticals	Storage area	Would be part of Space Medical Facility
Bone mineral loss	Skeletal loading through low frequency, high resistance exercise (anaerobic exercise)	Inventory system Exercise equipment	Need volume for storage and use Considerable impact on vibration, dynamics, volume, and cost
	Pharmaceuticals	Storage area Inventory system	Would be part of Space Medical Facility
Disorientation; space adaptation syndrome; neuromuscular patterning not adapted to micro gravity; loss of one gravity neuro-muscular patterning.	Psycho-motor exercise	Padded surfaces	Could be part of Recreational Facility
	Pharmaceuticals	Mobility aids and restraints for practicing body movements and placement Visual orientation cues Storage area	Could be done in Health Facility
Loss of muscle mass, strength and endurance	Exercise of specific muscle groups; 1. Low frequency, high resistance anaerobic exercise. 2. High frequency, low resistance aerobic exercise (primary exercise)	Inventory system Exercise devices (both isotonic and isokinetic devices)	Need volume for storage and use

Reference: 208, pages 265-280 NASA-STD-3000183, Rev. A

a. **MISSION DURATION** - This section assumes a mission duration of at least 10 days. For missions less than 10 days, an exercise facility is desirable for crew morale and well-being. The anticipated physiological decrements of a short mission can be countered by compensatory conditioning programs prior to the mission.

b. **MULTI FACILITY FUNCTION** - The effects of microgravity can be counteracted in a number of different facilities in the space module, if such are equipped with appropriate countermeasures exercise equipment. The primary function of the microgravity

countermeasure facility would be to serve as an area for exercise specific to countermeasure capability and for storage of this equipment.

c. SCHEDULING CAPABILITY - The microgravity countermeasure facility should have means to control the type and quantity of countermeasures administered to each crewmember. This would include a means to track the effects of the countermeasure and provisions for revising the countermeasure protocol and/or schedule.

d. BOREDOM AND CREW PRODUCTIVITY - Microgravity countermeasures such as exercise may be boring because of a lack of mental stimulation. Recreational facilities, social interaction, workstation facilities, mobile facilities etc can act as mental refreshment.

e. FACILITY LOCATION - The following considerations should be made when locating a fixed facility within the space module:

1. Vibration and noise - Some exercise equipment is noisy and causes vibration. This equipment should be isolated from sensitive areas such as crew quarters or sensitive workstations.
2. Personal hygiene area - Post exercise whole or part body washing facilities should be close to the countermeasure facility.
3. Galley or potable water dispenser - Liquids should be available for crewmembers during strenuous exercise.

f. MICROGRAVITY CONSIDERATIONS - The design of the countermeasure facilities should account for the effects of microgravity. Some of these considerations are listed below:

1. DRYING OF PERSPIRATION - Perspiration will not drip from the body but will pool on the body and then float into the atmosphere. Methods of eliminating perspiration before it has a chance to contaminate the module, such as absorptive clothing or a high flow level or dry air, should be investigated.
2. CONVECTION COOLING - In 1-G, warm air around the body will rise providing cooling. In microgravity this will not occur. Ventilation for cooling must be provided through forced air.
3. DEBRIS CONTAINMENT - Debris, such as hair and lint, will not fall to the floor where it can be swept up. There must be a means, such as a vacuum system, to collect such material.

4.23.1 | EXAMPLE MICROGRAVITY COUNTERMEASURES DESIGN SOLUTION

The following are example design solutions to the microgravity exercise requirements.

a. **STRENGTH EXERCISES** - Several devices that utilize an electromagnetic brake or hydraulic mechanism to impose resistance equivalent to those of a 1-G environment have been developed. With a cable/pulley system and proper positioning, all major muscle groups of the body could be exercised. The exercises include leg extensions, military press, bench press, sit-ups and back extensions, plus leg curls, and arm curls; these exercises constitute a workout for the major muscle groups of the body and should maintain the strength of the arm extensors and leg flexors (which the programs during Skylab 4 failed to do) as well as the arm flexors and leg extensors which were adequately maintained during Skylab 4. The abdominals and back extensors are included because of their importance as antigravity muscle groups for maintaining an erect posture in a 1-G environment. These are not adequately stressed by the natural body position assumed during microgravity exposure.

b. **AEROBIC EXERCISE EQUIPMENT** - A bicycle ergometer similar to that used in the Skylab series will provide aerobic exercise. It could be modified to include a video display terminal and computer programs (both commercially available) to simulate bicycle touring in Earth environments (e.g., through Yellowstone Park, coast-to-coast, hilly terrain, etc.). Data storage, allowing each crewmember to keep performance and status records, should be included. These modifications, while not essential to the physiological performance, will greatly enhance the motivation to exercise and adherence to prescribed regimens.

c. **SKELETAL LOADING EXERCISES** - A treadmill similar to that used on Skylab 4 and the Shuttle could be provided as an adjunct to the other exercise equipment. Its principal attribute is as an impact device to potentially counter mineral loss in the long bones of the leg. Some crewmembers may prefer it over the bicycle ergometer for aerobic exercise.

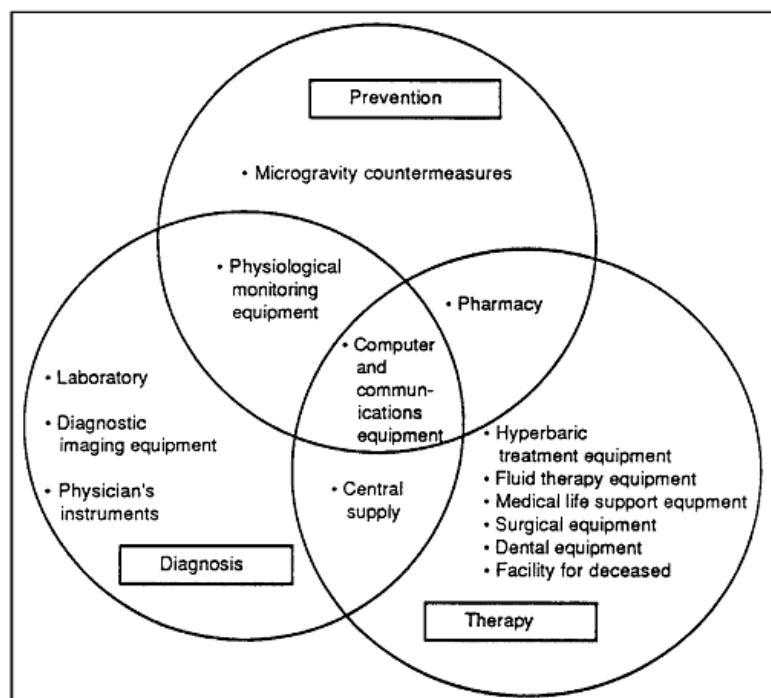
4.24 | SPACE MEDICAL FACILITY

This section deals with the design of a Space Medical Facility (SMF). An SMF is any area that is set aside primarily for medical treatment of crew members. The requirement for an SMF assumes that the mission duration will be long term (in excess of 2 weeks) and that medical treatment outside the module is not immediately available. The information in this section applies to any gravitational environment, although some areas emphasize microgravity conditions and will so state. This section addresses both the environmental and physical requirements of the SMF. Prior to the design of the Space Medical Facility (SMF) the following information must be determined:

- a. Duration of the Mission.
- b. Crew Statistics - The health status, age, and number of crewmembers.
- c. Mission Activities - The nature of the activities required during the missions.
- d. Medical Support - The availability of medical support outside the module.

This information, together with historical data on the nature and frequency of illness and injuries, will determine the size of the SMF and the specific types of equipment required. Once these decisions are made, the detail design process can begin. The SMF must provide the equipment and supplies to perform the following functions:

Figure 4.24-1 Function and Equipment Related to the Space Facility



Reference: 229, p. 11; NASA-STD-3000 184

4.25 | TRASH MANAGEMENT FACILITY

The following are considerations for the design of the space module trash management facilities.

- a. Quantity and Nature of Trash - The amount and nature of the trash will depend on the nature of the mission and the design of the space module. All wrappings, etc., should be minimized and disposables chosen for maximum efficiency and minimum residual. Some of the variables are listed below:

1. Number of crewmembers.
2. Disposable versus reusable items (clothing, utensils, etc.).
3. Mission duration.
4. Type of work performed (experimentation, processing, manufacturing, etc.).

b. Separation - The system may require separation of biologically active and inert trash in order to facilitate stowage and disposal. The crew may have to participate in this function.

c. Location of Trash Receptacles - The selection of trash receptacle types and locations must consider crew productivity. Several small throughout the module may initially save crew time but will cost time if the crew must gather the trash from the receptacles and transport it to a central receptacle.

d. Productivity - Trash management is not a productive crew function. Every effort should be made to automate trash management, reduce volume by compaction, and reduce manual manipulation.

e. Human Interface - The following considerations should be made when designing the trash collection devices and receptacles:

1. All equipment should be operable by the full range of crewmember size and strength.
2. Appropriate restraints should be available in microgravity conditions.
3. All trash handling supplies (wipes, bags, wrapping tape, labels, etc.) should be located so that they are easily accessible.
4. Noise generation equipment (e.g., compactors) should be insulated or isolated from noise sensitive areas.

4.25.1 | TRASH MANAGEMENT FACILITY DESIGN REQUIREMENTS

The following are the design requirements for trash management from the source to the disposal area:

a. Trash Sorting - Where it is necessary to sort trash before depositing in a receptacle, the following requirements shall be met:

1. Receptacle labeling - Each of the receptacles shall be appropriately labeled defining acceptable and non-acceptable trash.

2. Transfer package labeling - If trash must be transferred from one receptacle to another, there shall be a method of identifying the trash so that it is placed in the proper receptacle.
3. Human error - The system shall be capable of recovery in the event that trash is inappropriately placed in a receptacle.

b. Trash Receptacles:

1. Identification of receptacles - All trash receptacles shall be clearly identifiable.
2. Receptacle location - The location of trash receptacles shall meet the following requirements:
 - a) The location shall effectively reduce trash in the crew stations.
 - b) The location shall minimize crew trash handling time.
 - c) The location shall not interfere with crew movement.

c. Odor and Contamination Control - The following requirements apply to control of odor and contamination:

1. Trash handling equipment shall be designed to preclude module contamination during introduction of trash.
2. Trash storage areas shall preclude contamination of the living environment by harmful microorganisms or odor.
3. The trash management equipment area shall be capable of being cleaned and sanitized.
4. There shall be a safe means for disposal of any harmful chemical or radioactive wastes.

d. Operation - All trash collection, handling, and disposal equipment shall be capable of being operated by the full size and strength range of the defined crewmember population.

e. Receptacle Capacity - Crewmembers shall be capable of easily determining the level of trash (in relationship to capacity) in each of the trash receptacles.

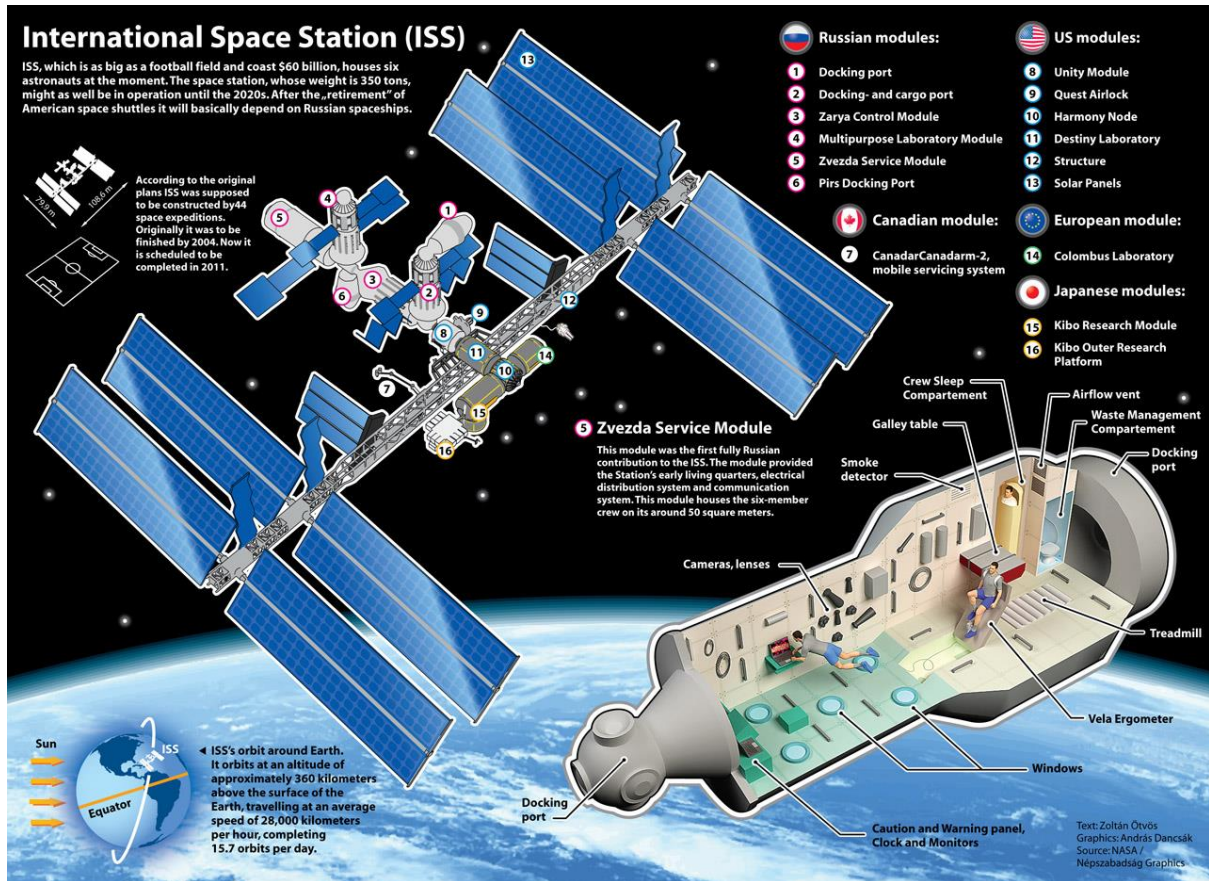


Image comment: International Space Station

Image credits: <https://internationalspacestation.zeef.com/>

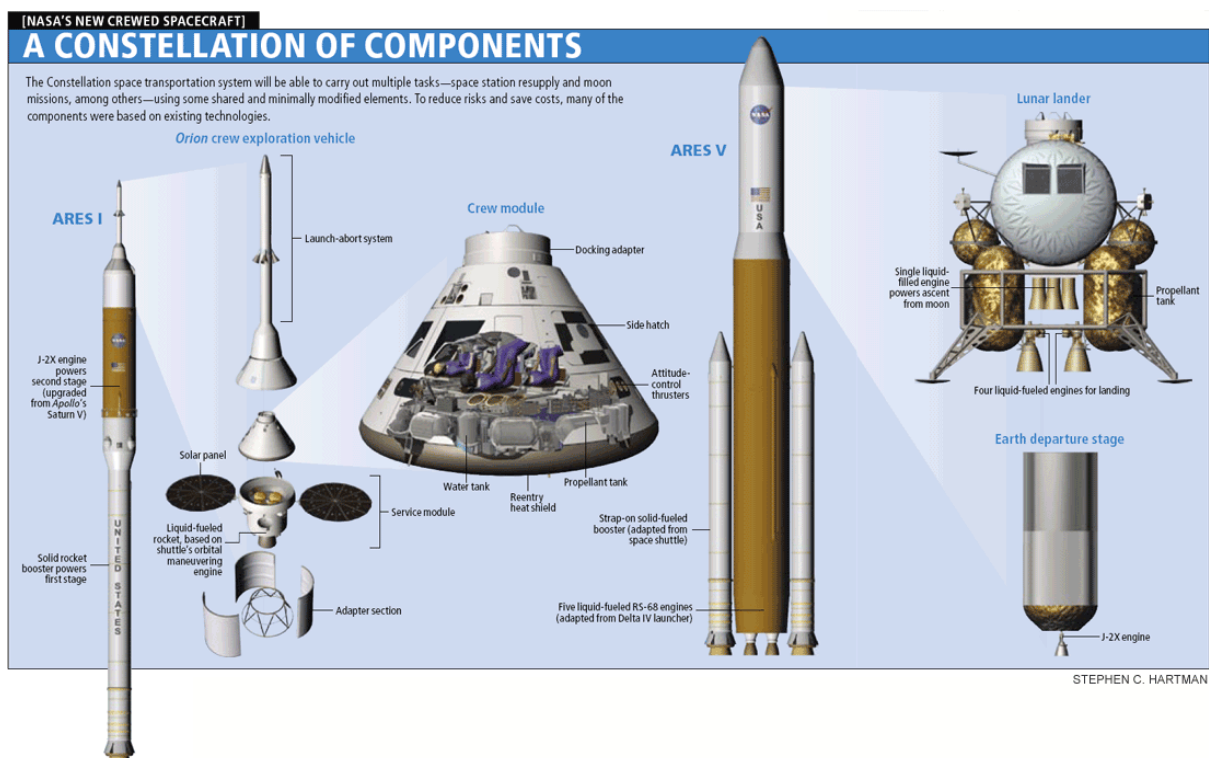


Image comment: A Constellation of Components

Image source: <http://www.nature.com/scientificamerican/journal/v297/n4/images/scientificamerican1007-62-l3.jpg>

CHAPTER | 5

IDEAS AND HYPOTHESIS

5.1 | CURRENT THOUGHTS ABOUT THE MOON

“Three things cannot be long hidden: the Sun, the Moon, and the Truth.”

- BUDDHA

The Moon has always been silent. It stares down at us from a distant. From children fairy tales to rocket science, the moon has been a propeller of progress. Since the dawn of human civilization on Earth, we have developed cultures, provoked by multiple metaphors shaped via our distant companion. Our idea of the origin of existences, evolution of policies and politics - unity amongst nations, leaders, and spiritual firmness may have evolved from the revelation from the moon. The concept of time itself origins when man first started calculating the moon cycles.

The space age, the Apollo program established a dream among people of all nations, "folks around the world have been thinking about returning to the Moon, and what they would like to do there," says Jeff Volosin, strategy development lead for NASA's Exploration Systems Mission Directorate. Now, NASA *is* going back; the agency plans to send astronauts to the Moon no later than 2020. "So we consulted more than 1,000 people from businesses, academia and 13 international space agencies to come up with a master list of 181 potential lunar objectives."

For instance, the moon could be a good location for radio astronomy. A radio telescope on the far side of the Moon would be shielded from Earth's copious radio noise, and would be able to observe low radio frequencies blocked by Earth's atmosphere. Observations at these frequencies have never been made before and opening up a window into this low frequency universe will likely lead many exciting new discoveries.

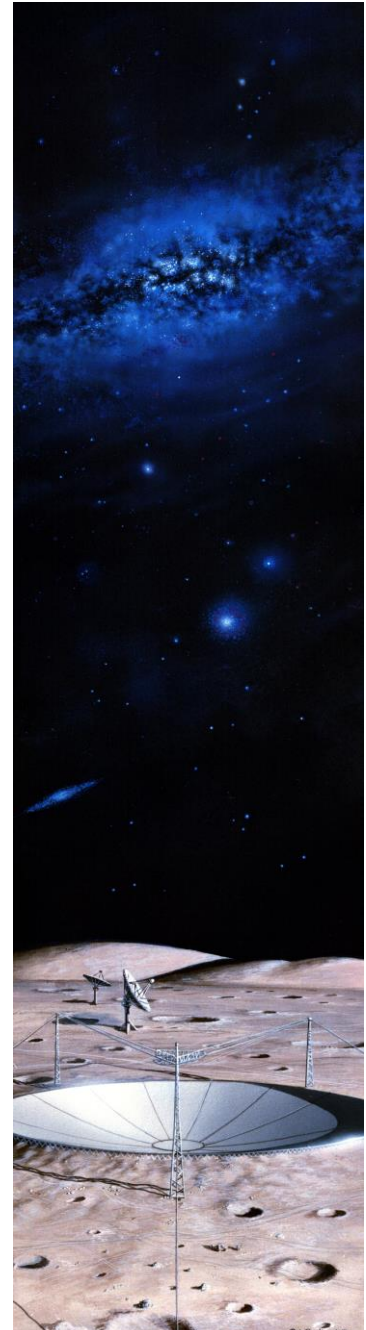


Image comment: Lunar Telescope

Image source:

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The Moon would also be an excellent place to study the high-energy particles of the solar wind, as well as cosmic rays from deep space. Earth's magnetic field and atmosphere deflect many of these particles, so even satellites in low-Earth orbit can't observe them all. The moon has virtually no atmosphere, and it spends most of its 28-day orbit outside of Earth's magnetosphere. Detectors placed on the moon could get a complete profile of solar particles, which reveal processes going on inside the sun, as well as galactic cosmic radiation from distant black holes and supernovas.

These particles are trapped by lunar regolith, the layer of crushed rock and dust covering the moon's surface. This means that lunar regolith contains a historical record of solar output: core samples could tell us about changes in solar output over billions of years. "We believe that the moon's preservation of this solar record is unique and can provide us with insights on how past fluctuations in the solar output have affected, for example, the history of life on Earth," says Volosin. In particular, it could shed light on the extent to which solar variability and galactic cosmic radiation influence climate change.

The Moon itself is a scientific gold mine, a nearby example of planetary formation largely unaltered by the passage of time. Some scientists call it "a fossil world." The moon is a small, non-dynamic planetary body and its interior state is largely preserved since the early days of solar system history. Studying its interior would tell scientists a lot about how a planet's internal layers separate and solidify during planetary formation. But the moon would be far more than just a platform for scientific instruments gazing into space.

Even something as simple as establishing the dates when various craters on the moon were formed can provide us with a unique picture of how the flux of meteoroids in the vicinity of Earth has changed over time. This impact history is lost on Earth by the constant renewal of the crust but on the moon it is intact, rich with clues to periods in the past when an increase in bombardment may have affected the climatic history of Earth and even the evolution of life.

Science accounts for only about a third of the 181 objectives, however. More than half of the list deals with the many challenges of learning to live on an alien world: everything from keeping astronauts safe from radiation and micro-meteors to setting up power and communications systems to growing food in the airless, arid lunar environment.

"We want to learn how to live off the land and not depend so much on supplies from Earth," says Tony Lavoie, leader of NASA's Lunar Architecture Team (Phase 1) at the Marshall Space Flight Center.

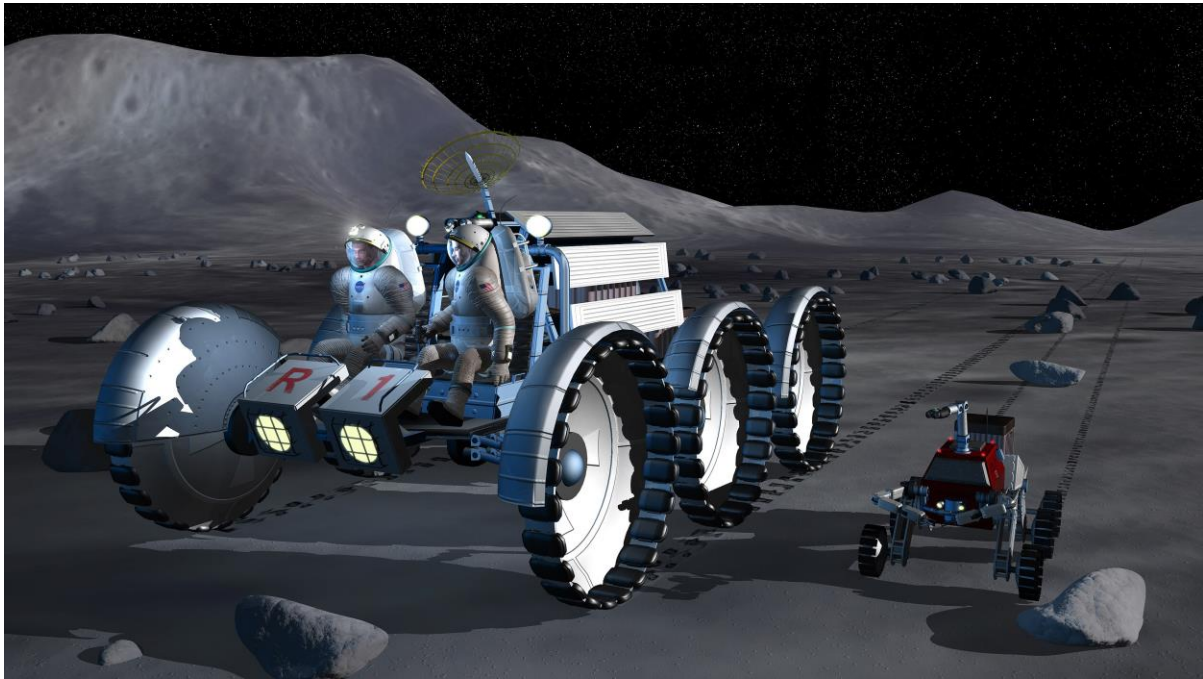


Image comment: Two astronauts go prospecting with a robotic sidekick.

Image source: www.nasa.gov/exploration/multimedia/jfa18842.html

Astronauts would face the same problems on a manned mission to Mars, so much of the experience gained on the moon would carry over when NASA eventually sends people to the Red Planet.

The Moon could also provide some Creative Commercial opportunities: **Lunar Power from Solar Cells**, **Protected Data archives**, **Mining of Lunar Metals**, and **Research under conditions of Low Gravity and High Vacuum**. In fact, mining the Moon may eventually yield rocket propellant that could be sold to commercial satellite operators to access and service their satellite assets in Earth orbit. Beyond charging **Space Tourists** for a chance to visit the moon, lunar entrepreneurs might host **Special Television Events** from the moon to boost publicity, or place a remote-controlled rover on the moon. People back on Earth could pay to take turns controlling the rover from their Internet-connected computers, letting them take a virtual drive across the moon's crater-pocked surface. In short, let your imagination be the guide.

Not all of the ideas on the list will necessarily happen. From the master list of 181, NASA currently is selecting a smaller number of high priority goals for its initial return to the moon. Other goals could be considered by other space agencies or private entrepreneurs who have an interest in exploring the moon. NASA continues to receive input from scientists at space agencies and universities around the world; the list itself is still evolving and expanding.

Complete list of objectives can be found in the link below.

http://www.nasa.gov/pdf/163560main_LunarExplorationObjectives.pdf

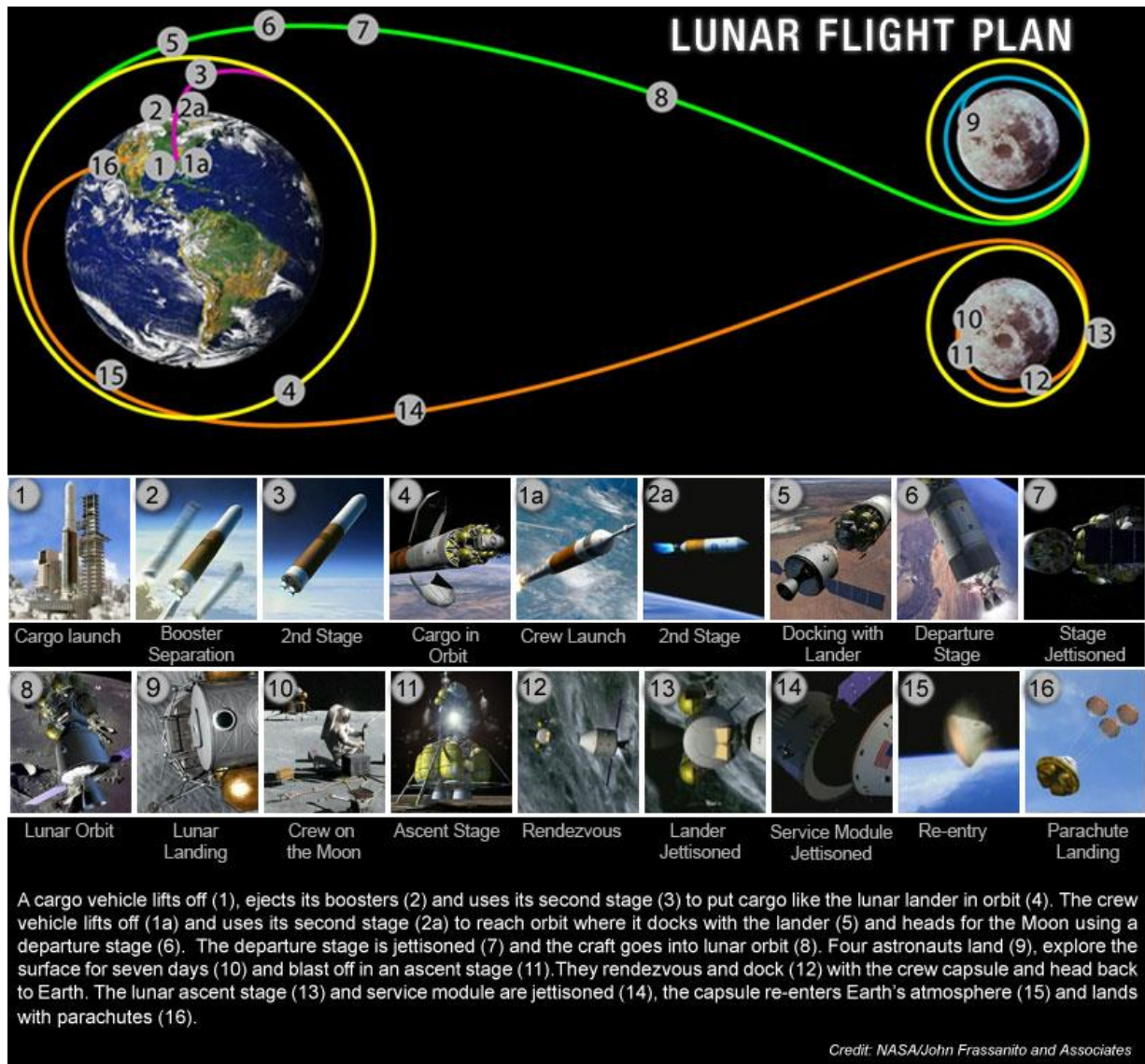


Image comment: Lunar Flight Plan

Image source: [http://1.bp.blogspot.com/-](http://1.bp.blogspot.com/-Gdm3NS5VJAE/T6GMeKX5kLI/AAAAAAAAADpw/1q2mHwgKImU/s640/125171main_flight_plan_graphic.jpg)

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5.2 | THE MOON

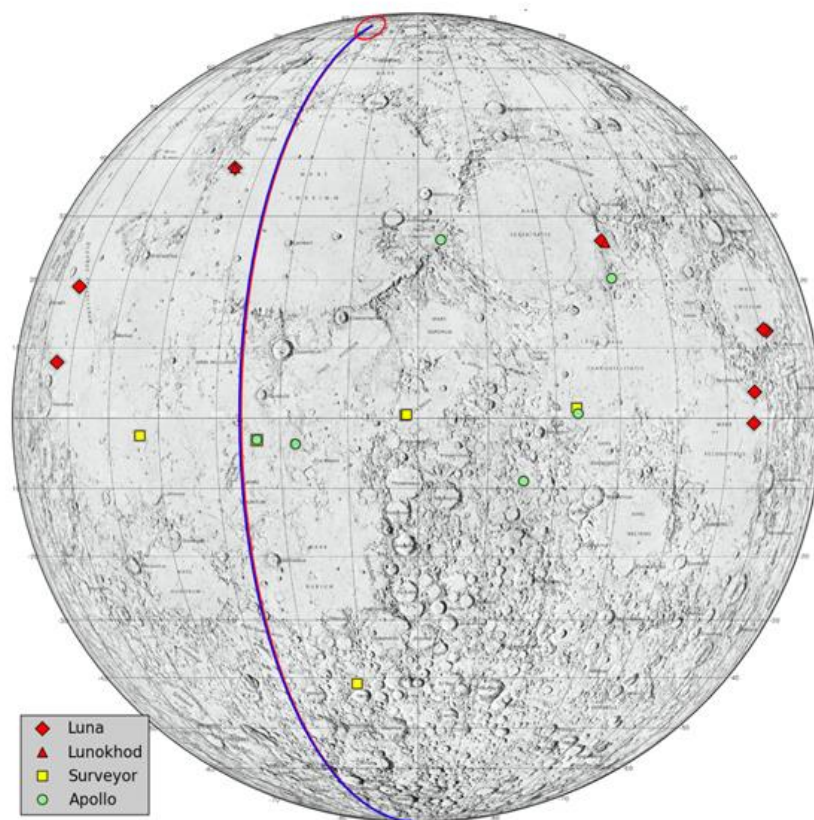


Image comment: Grail moon

Image source: http://www.wired.com/images_blogs/wiredscience/2012/12/713769main_pia16494-43_800-600.jpg

The Moon (Latin: Luna) is Earth's only natural satellite and the fifth largest natural satellite in the Solar System. The average centre-to-centre distance from the Earth to the Moon is 384,403 km, about thirty times the diameter of the Earth. The Moon's diameter is 3,474 km, a little more than a quarter that of the Earth. This means that the Moon's volume is about 2 percent that of Earth and the pull of gravity at its surface about 17 percent that of the Earth. The Moon makes a complete orbit around the Earth every 27.3 days (the orbital period), and the periodic variations in the geometry of the Earth–Moon–Sun system are responsible for the lunar phases that repeat every 29.5 days (the synodic period).

The Moon is the only celestial body to which humans have travelled and upon which humans have landed. The first artificial object to escape Earth's gravity and pass near the Moon was the Soviet Union's Luna 1, the first artificial object to impact the lunar surface was Luna 2, and the first photographs of the normally occluded far side of the Moon were made by Luna 3, all in 1959. The first spacecraft to perform a successful lunar soft landing was Luna 9, and the first unmanned vehicle to orbit the Moon was Luna 10, both in 1966. The United States

Apollo program achieved the only manned missions to date, resulting in six landings between 1969 and 1972. Human exploration of the Moon ceased with the conclusion of the Apollo program, although several countries have announced plans to send people or robotic spacecraft to the Moon.

5.2.1| LUNAR SURFACE

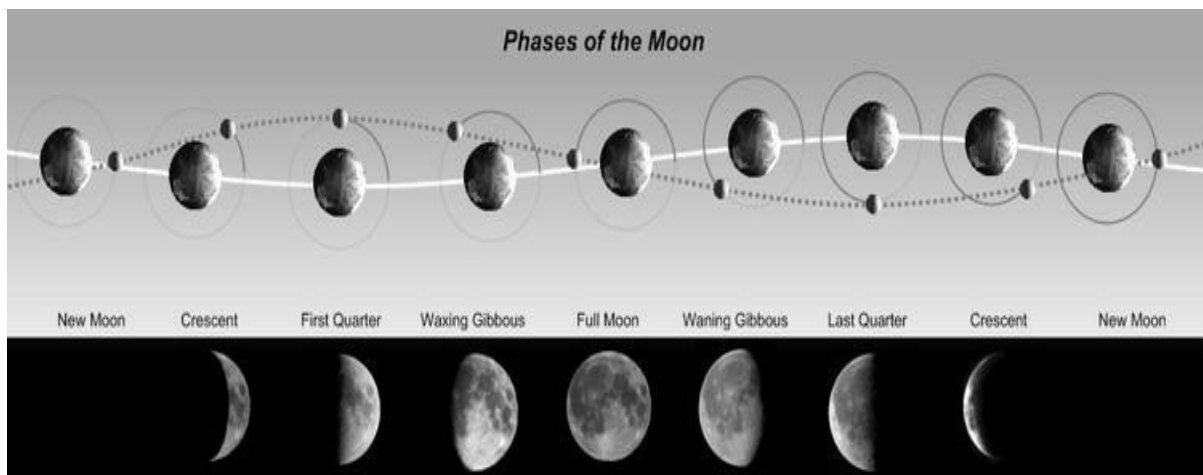


Image comment: Phases of the Moon

Image source: ringofbrodgar.com/wiki/Fishing:Phases_of_the_Moon

The Moon is in synchronous rotation, meaning that it keeps nearly the same face turned towards the Earth at all times. Early in the Moon's history, its rotation slowed and became locked in this configuration as a result of frictional effects associated with tidal deformations caused by the Earth. Before the Moon spun much faster, its tidal bulge preceded the Earth-Moon line because it could not "snap back" its bulges quickly enough to keep its bulges in line with Earth. The rotation swept the bulge beyond the Earth-Moon line. This out-of-line bulge caused a torque, slowing the Moon spin, like a wrench tightening a nut. When the Moon's spin slowed enough to match its orbital rate, then the bulge always faced Earth, the bulge was in line with Earth, and the torque disappeared. That is why the Moon rotates at the same rate as it orbits and we always see the same side of the Moon.

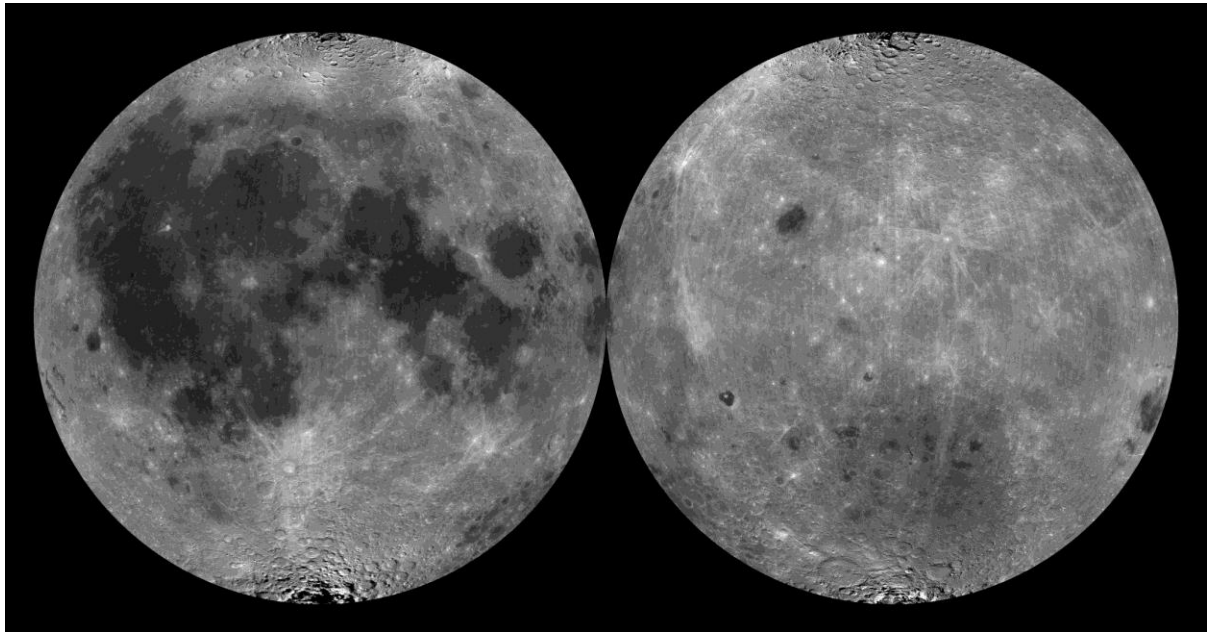


Image comment: Two Sides of the Moon (left: Earthside, right: Farside)

Image source: http://www.spudislunarresources.com/Images_Maps.htm

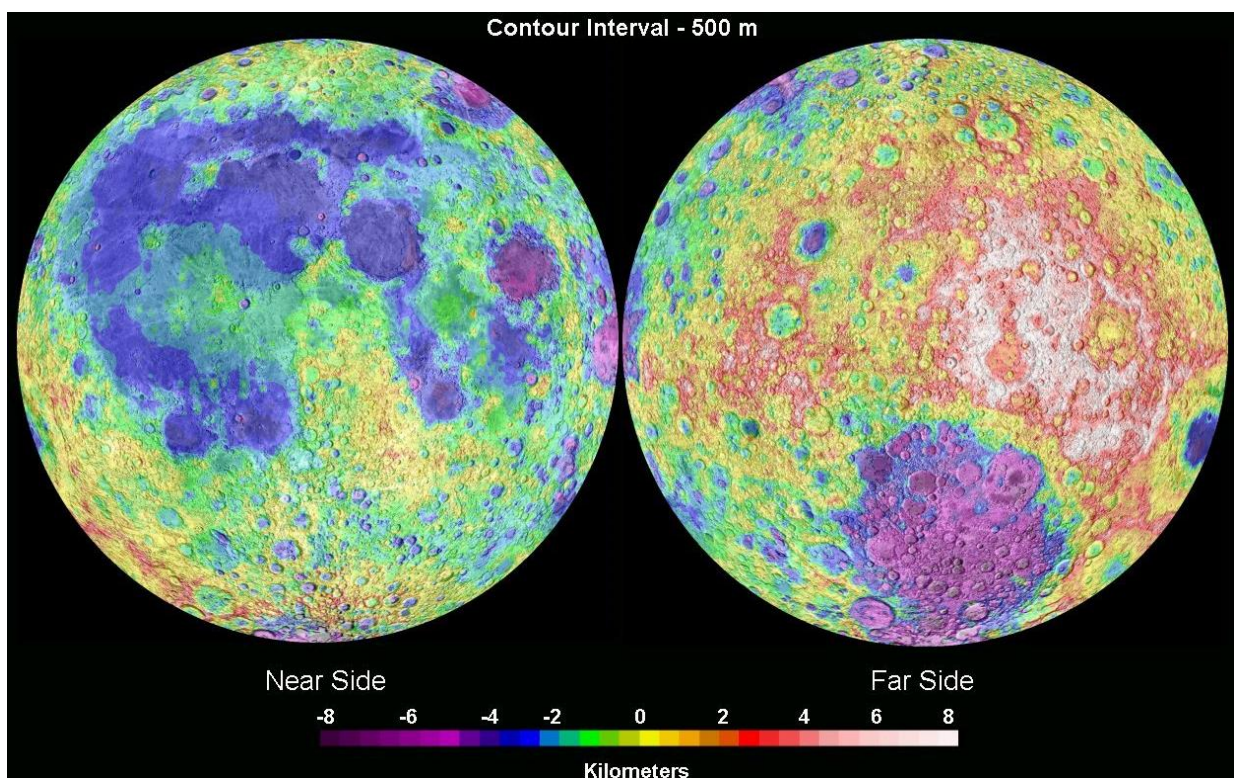


Image comment: Map of topography of Moon

Image source: http://www.spudislunarresources.com/Images_Maps.htm

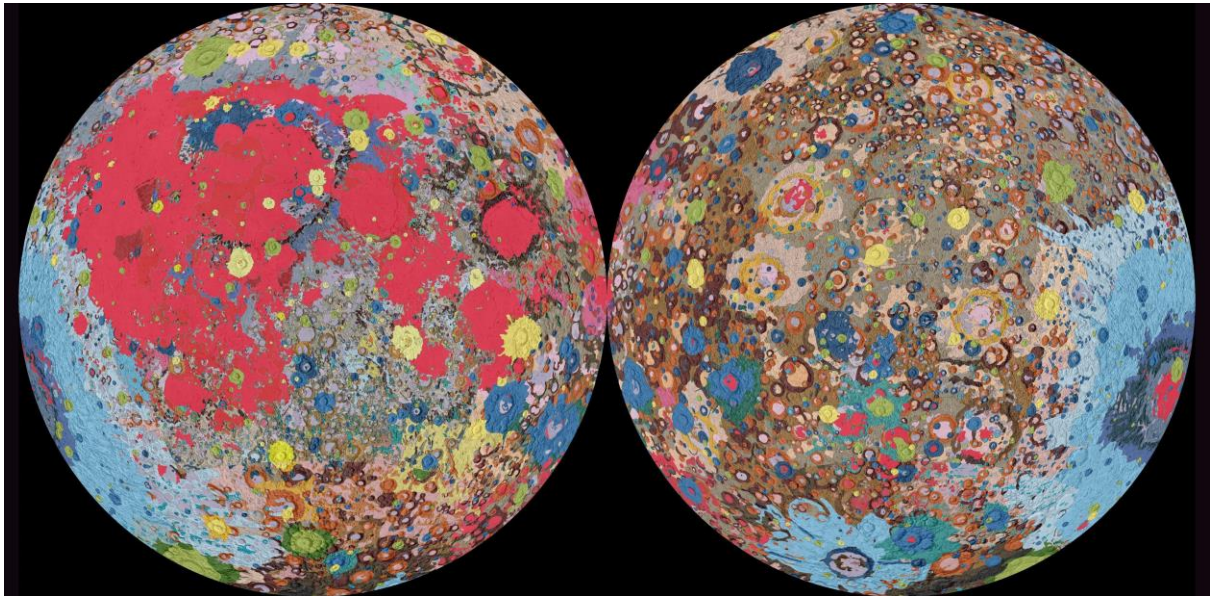


Image comment: Map of geology of Moon

Image source: http://www.spudislunarresources.com/Images_Maps.htm

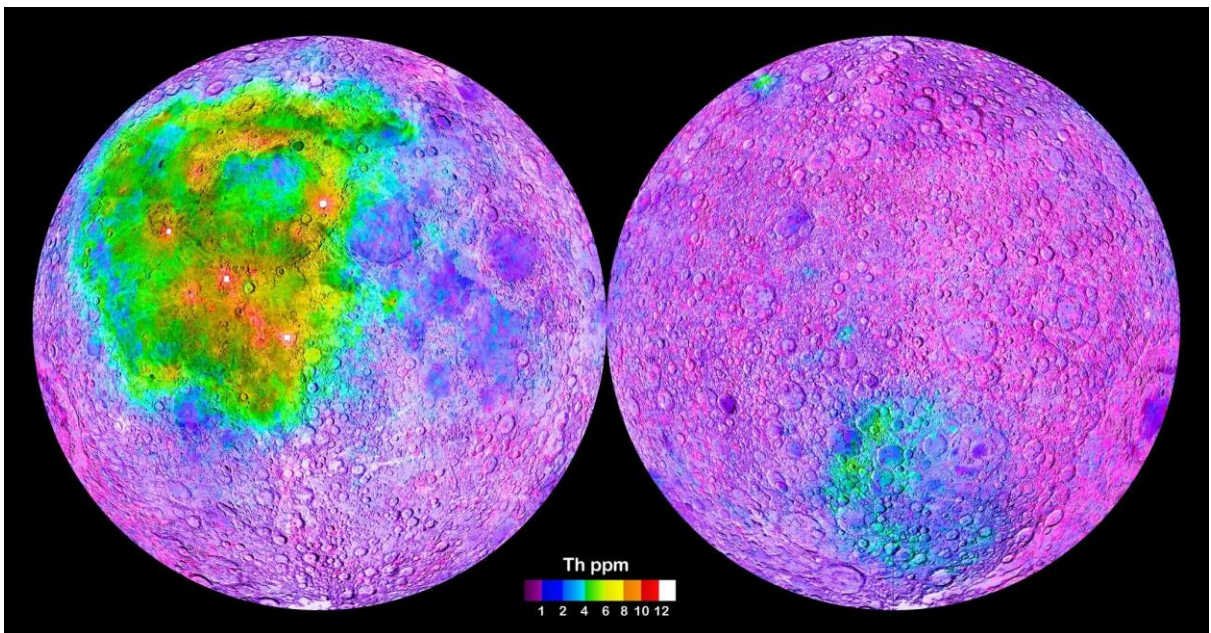


Image comment: Map of thorium content of Moon

Image source: http://www.spudislunarresources.com/Images_Maps.htm

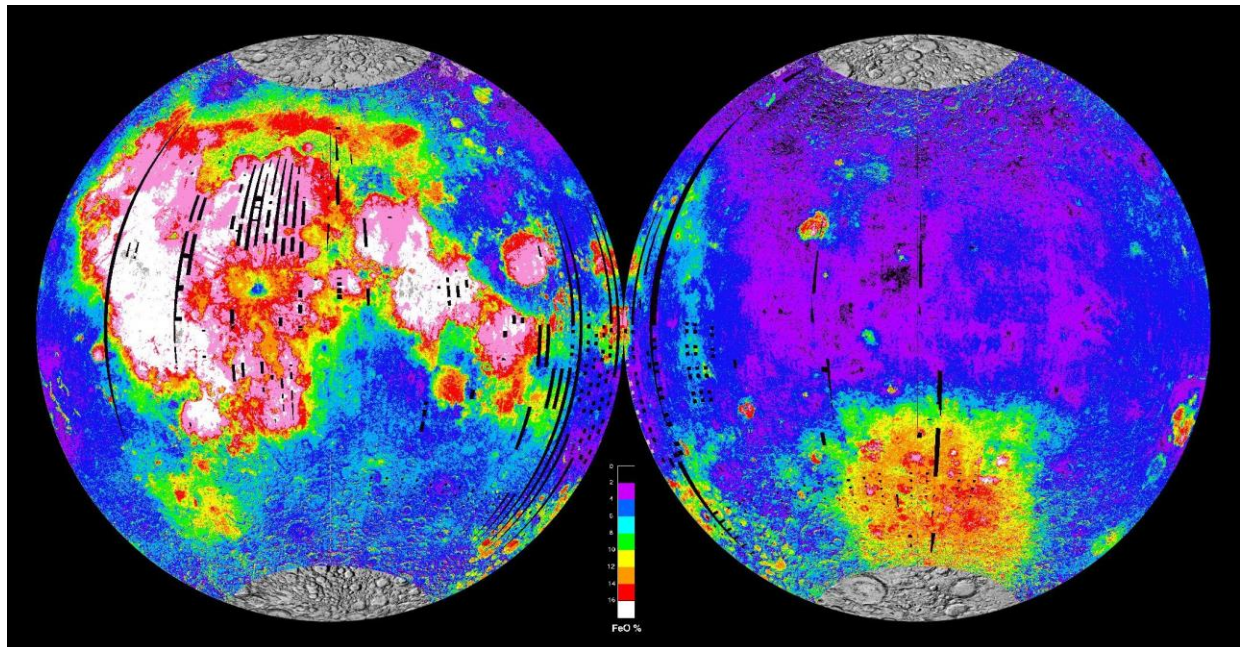


Image comment: Map of iron deposits on the Moon

Image credits: http://www.spudislunarresources.com/Images_Maps.htm

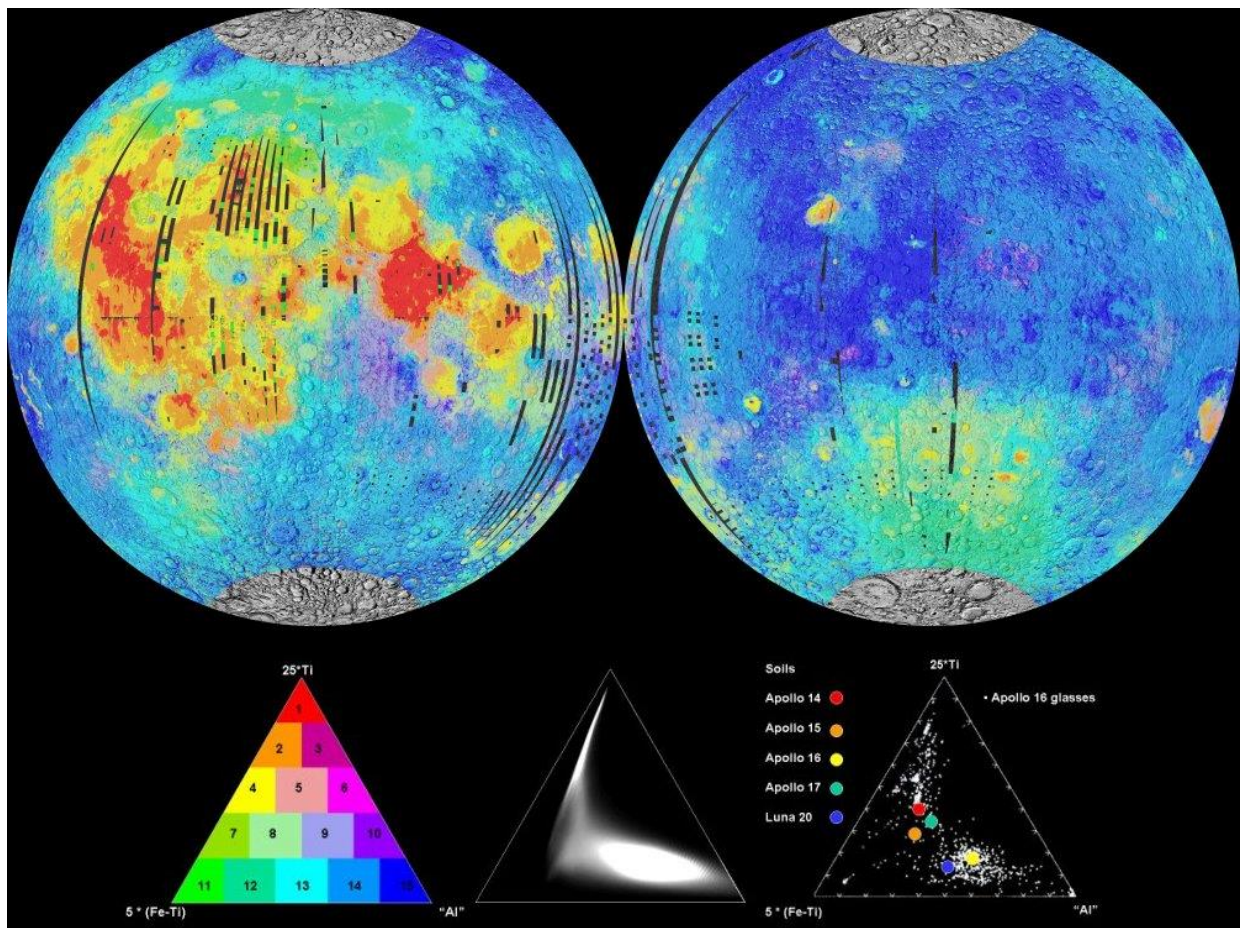


Image comment: Petrologic (rock type) map of Moon

(http://www.spudislunarresources.com/Images_Maps/Global%20petrologic%20map.pdf for explanatory paper)

Image source: http://www.spudislunarresources.com/Images_Maps.htm

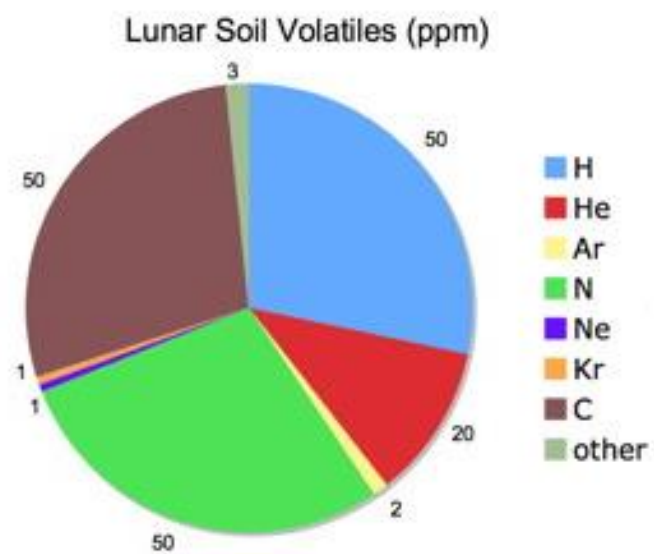
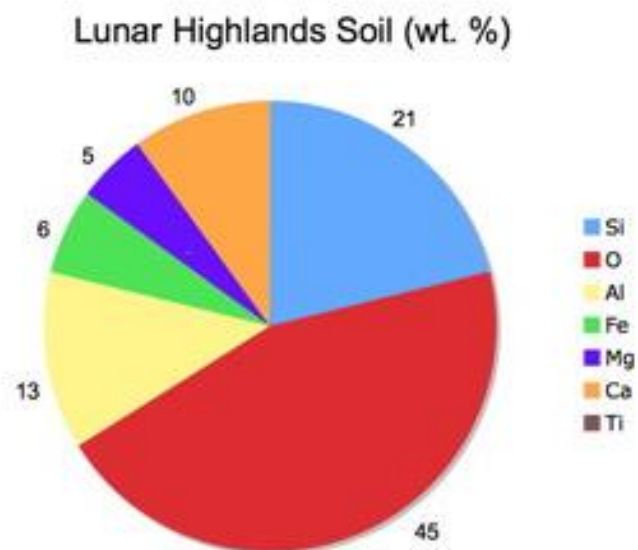
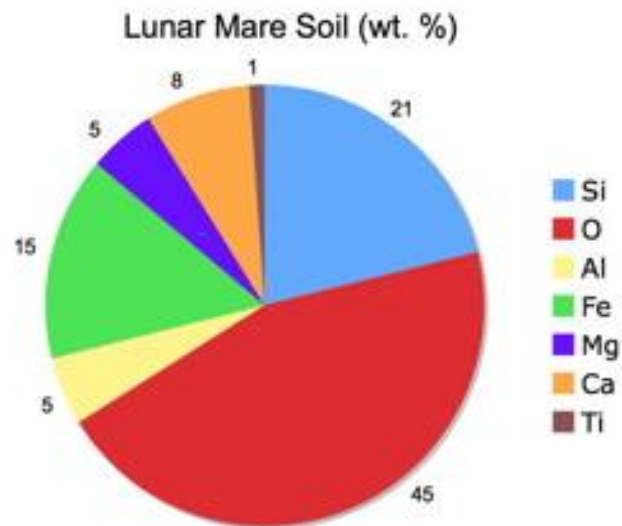


Image comment: Chemical Composition of Mare and Highland Soils

Image source: http://www.spudislunarresources.com/Images_Maps.htm

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LUNAR FARSIDE CHART

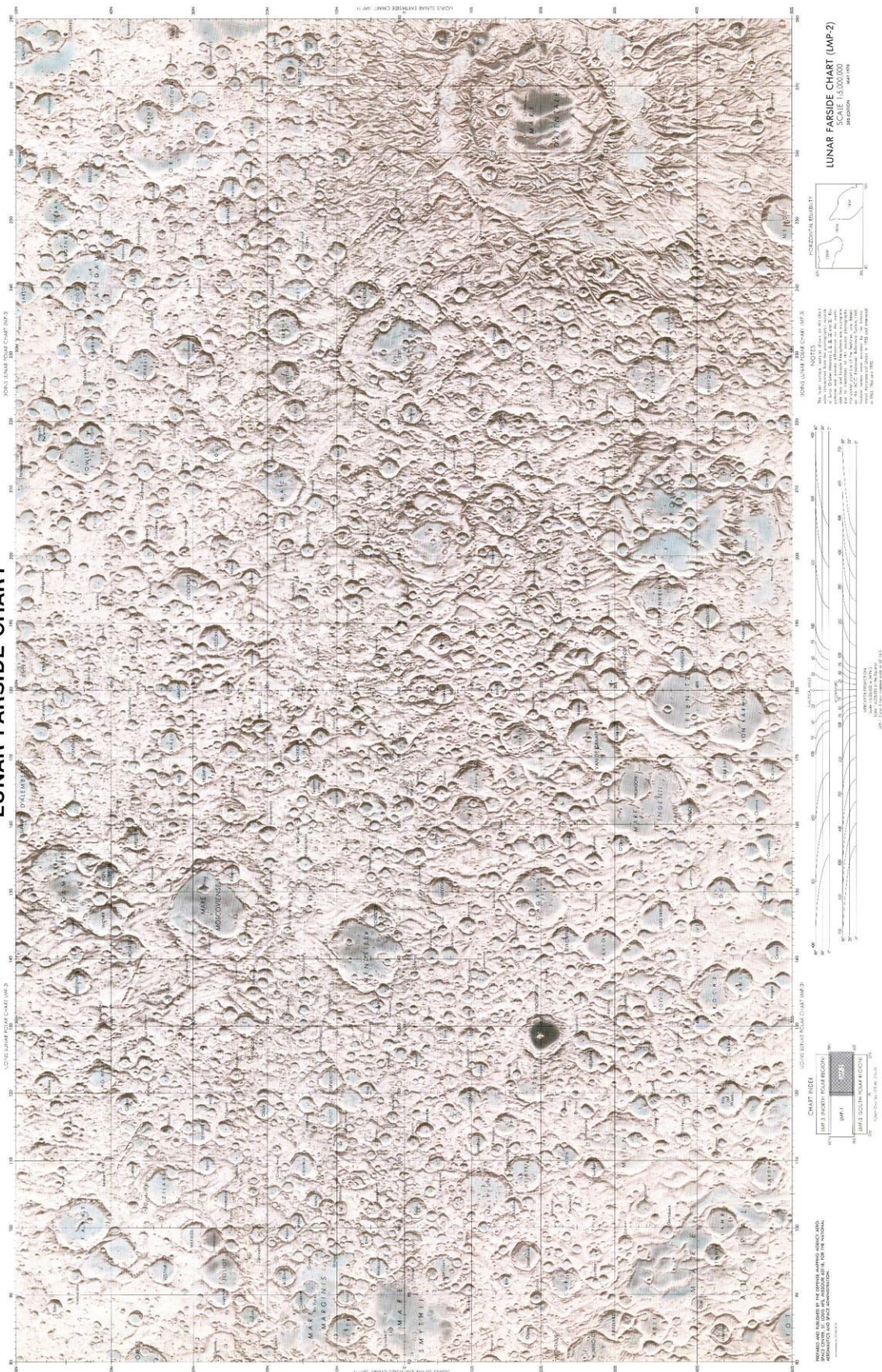


Image comment: Lunar Farside Chart

Image source: http://www.spudislunarresources.com/Images_Maps.htm

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LUNAR POLAR CHART



Image comment: Lunar Polar Chart

Image source: http://www.spudislunarresources.com/Images_Maps.htm

5.2.2 | LUNAR ARCHITECTURE

Writers, Painters, Architects, Scientists and Space agencies from all over the globe are currently working ground breaking research on the lunar expansion. The Moon holds the potential for human intervention. Various proposals are being devised to make moon hospitable for human civilization to prosper.

The Earth and the Moon are complete opposites, one taking 24 hour rotation on its axis, and the other revolving around earth, unchanged, gazing from afar. One divided into multiple nations, brew with complex forms of life, diversity and culture, and the other empty with shades of grey. The two sides of Moon - the near earth side, and the farside, holds much possibilities. But when designing on the Moon, we must take into account that the decisions we make about selection of site, which will not adversely affect the cultural and natural forces of Earth. Building something on the near-earth side may result in cultural and religious clashes, tidal interferences, animal and marine life disturbances. When building a settlement on the moon the farside seems to be the more plausible solution.

Researchers are working on the Cislunar Tether Transport System, which is to use a rotating tether in Earth orbit to pick payloads up from LEO orbits and toss them to the Moon, where a rotating tether in lunar orbit, called a “Lunavator™”, could catch them and deliver them to the lunar surface. As the Lunavator™ delivers payloads to the Moon’s surface, it can also pick up return payloads, such as water or aluminum processed from lunar resources, and send them down to LEO. By balancing the flow of mass to and from the Moon, the orbital momentum and energy of the system can be conserved, eliminating the need to expend large quantities of repellant to move the payloads back and forth.

(more information at <http://www.tethers.com/papers/cislunaraiaapaper.pdf>)

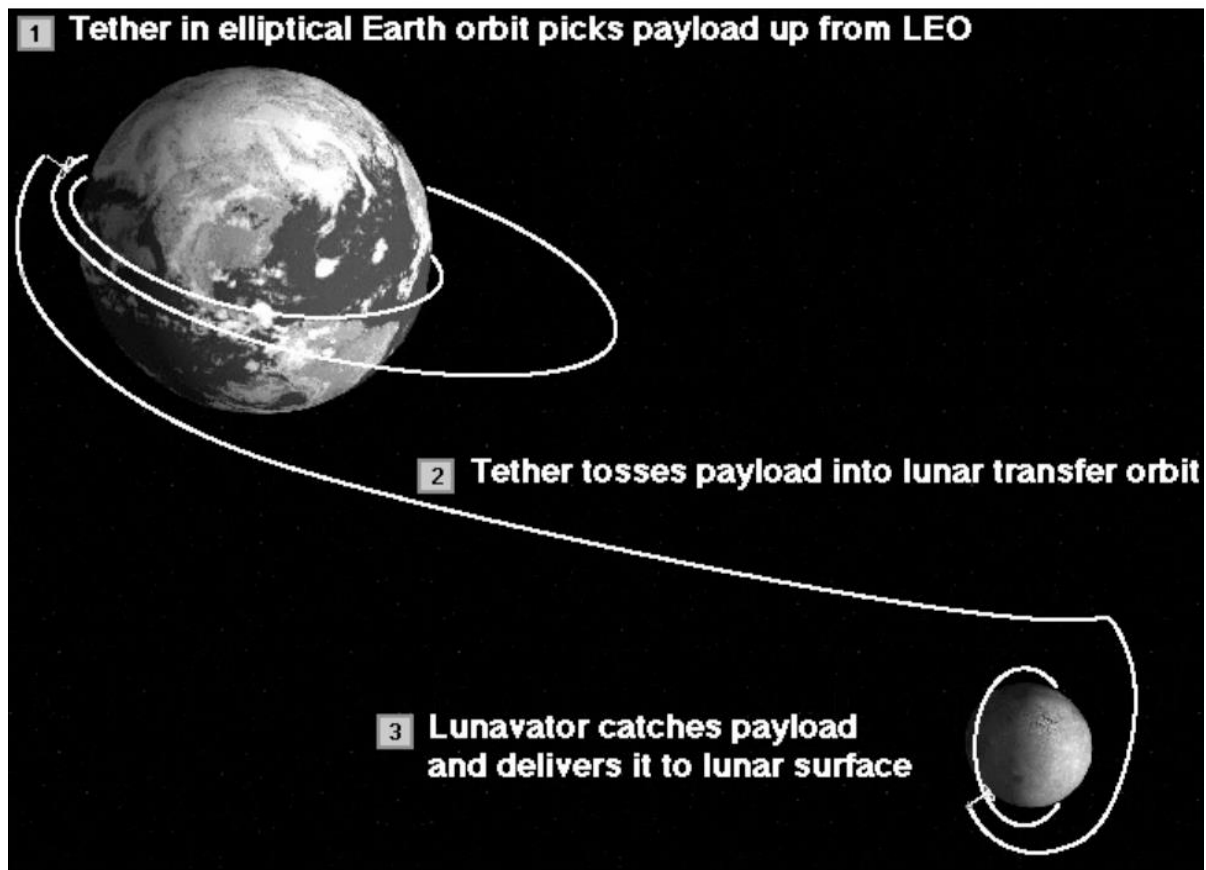


Image comment: Tether Transport System

Image source: www.tethers.com/papers/cislunaraiaapaper.pdf



Image comment: Contour Crafting on Lunar Surface

Image credits: <http://www.33rdsquare.com/2012/08/behokh-khoshnevis-wants-to-3d-print.html>

Another team of London "Space Architects" has developed a proposal for a lunar base that would be 3D printed by spider robots using microwaves, solar energy and lunar dust. Tomas Rousek, Katarina Eriksson and Dr. Ondrej Doule are collaborating with NASA's Jet Propulsion Laboratory on plans for a modular architectural structure at the lunar South Pole. Each module would be printed using a NASA robotic system, which would produce a ceramic-like material by microwave-sintering lunar soil, also known as regolith. There would be no need for glue, as the particles would naturally bond themselves together when heated to the right temperature by the robots.

5.3 | FUTURE EARTH ASSUMPTIONS 2013 +

Where do we see ourselves in about one hundred years? With rising population, increasing use of fossil fuel and depletion of natural resources, we are counting our own dooms day. For over a century, writers and architects have imagined Earth booming with cities of the future as giant structures that contain entire metropolises. To some, these buildings present the best means for cities to exist in harmony with nature, while others foresee grotesque monstrosities destructive to the human spirit. In the mid-20th century, engineer and futurist R. Buckminster Fuller imagined city-enclosing plastic domes and enormous housing projects resembling nuclear cooling towers. These ideas are impractical but they explore the limits of conventional architectural thinking.

Science fiction writers and artists often imagine future architecture that oppresses the human spirit. Mega structures such as the pyramid-like Tyrell Buildings of "Blade Runner" dominate a decrepit skyline. The decaying old city is simply covered with layers of newer, larger buildings in a process of "retrofitting." Architect Paolo Soleri envisioned a more humane approach. The word "Arcology" is a combination of "architecture" and "ecology." The goal is to build mega-structures that would house a population of a million or more people, but in a self-contained environment with its own economy and agriculture.

"In the three-dimensional city, man defines a human ecology. In it he is a country dweller and metropolitan man in one. By it the inner and the outer are at 'skin' distance. He has made the city in his own image. Arcology: the city in the image of man." (Paolo Soleri) In 1996, a group of 75 Japanese corporations commissioned Soleri to design the one-kilometer-tall Hyper Building, a vertical city for 100,000 people. Existing in harmony with nature, the Hyper Building was designed to recycle waste, produce food in greenhouses, and use the sun's light and heat for power and climate control. The structure was designed for passive heating and cooling without the need for machinery. An economic recession put

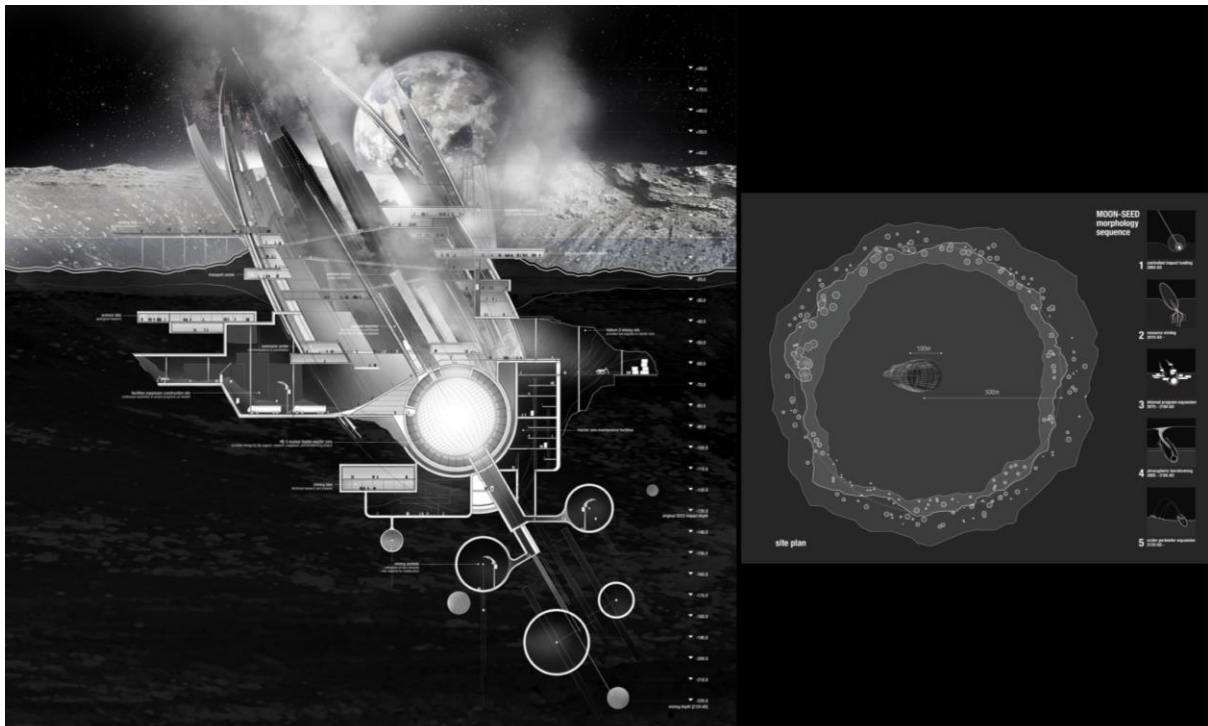


Image Comment: Lunar SEED Project

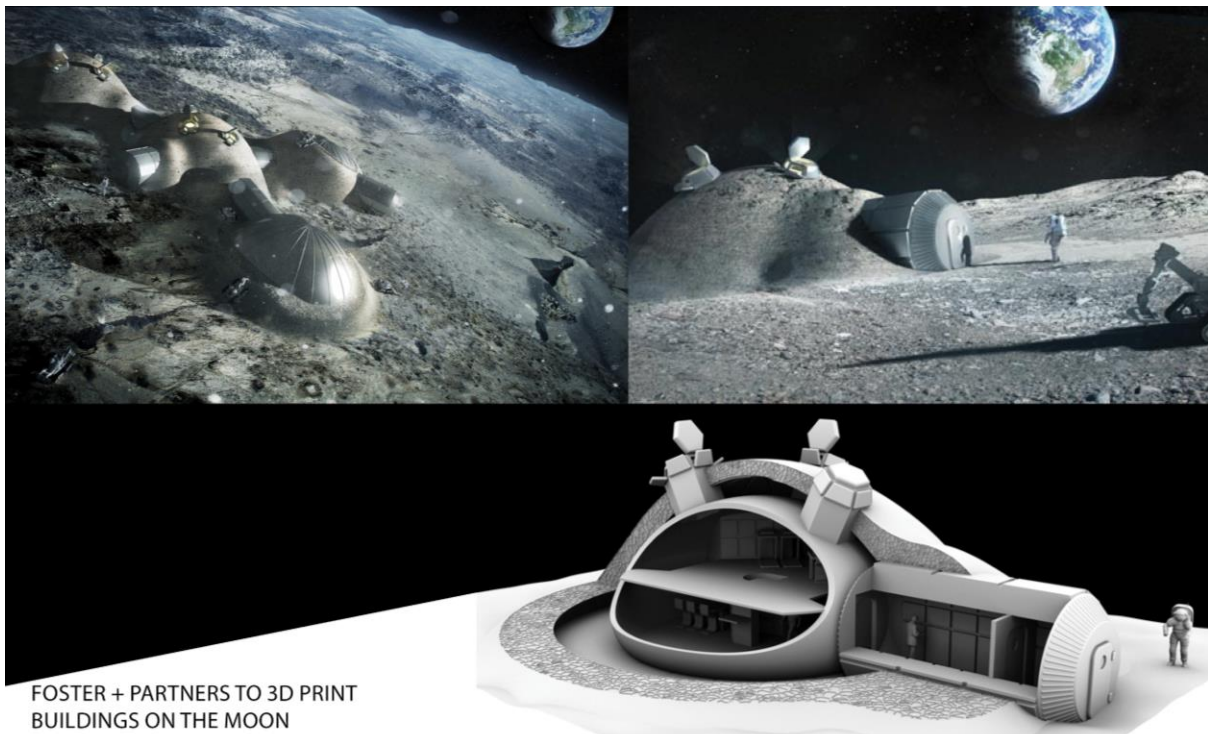


Image Comment: Foster + Partners – Building on the moon

CHAPTER 6 | HUMANS IN 1/6th THE GRAVITY OF EARTH

6.1 | ARCHITECTURE IN ARTIFICIAL GRAVITY

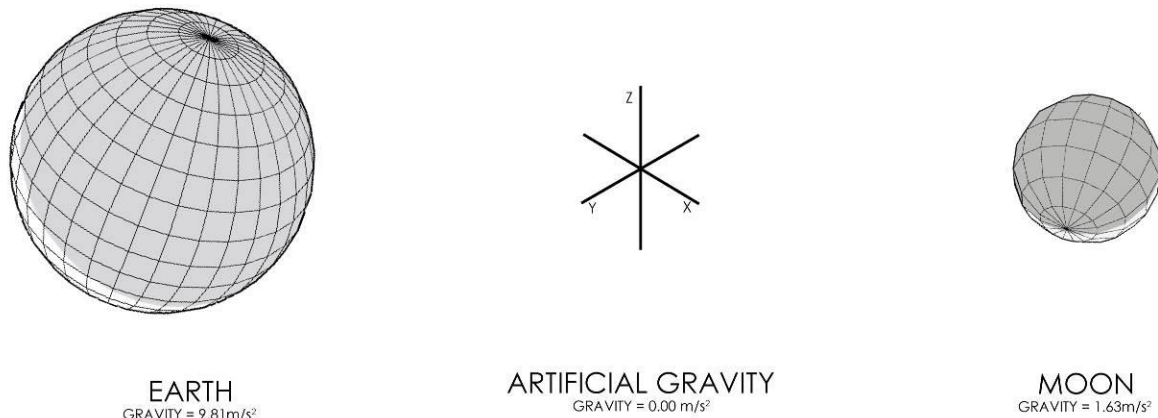


Image Comment: Gravity Analysis Diagram

To think rationally human being behaves quite differently in artificial gravity. Be it in outer space, the moon or other planetary systems, limitations and implications of artificial gravity in the design of orbital habitats. Long-term exposure to weightlessness leads to a chain-reaction of undesirable physiological adaptations. There are both theoretical and experimental evidence that artificial gravity can substitute for natural gravity to maintain health in orbit. Aerospace medical scientists have conducted many studies during the past forty years to determine the comfort boundaries for artificial gravity. They express comfort in terms of centripetal acceleration, head-to-foot gravity gradient, angular velocity, tangential velocity, cross-coupled head rotations and the Coriolis effects of relative motion in rotating environments. A review of the literature reveals the uncertainty in these boundaries and suggests that "comfort" in artificial gravity depends as well on other aspects of environmental design, beyond the basic rotational parameters. Artificial gravity is distinct from both Earth-normal gravity and weightlessness. The goal of architectural design for artificial gravity is not to mimic Earth but rather to help the inhabitants adapt to the realities of their rotating environment.

6.2 | COMPONENTS OF ARTIFICIAL GRAVITY

Acceleration by any force other than gravity provides a body with weight. Gravity acting alone leaves a body in weightless free-fall. Earth weight results not from the downward pull of gravity but from the equal and opposite upward push of the ground.

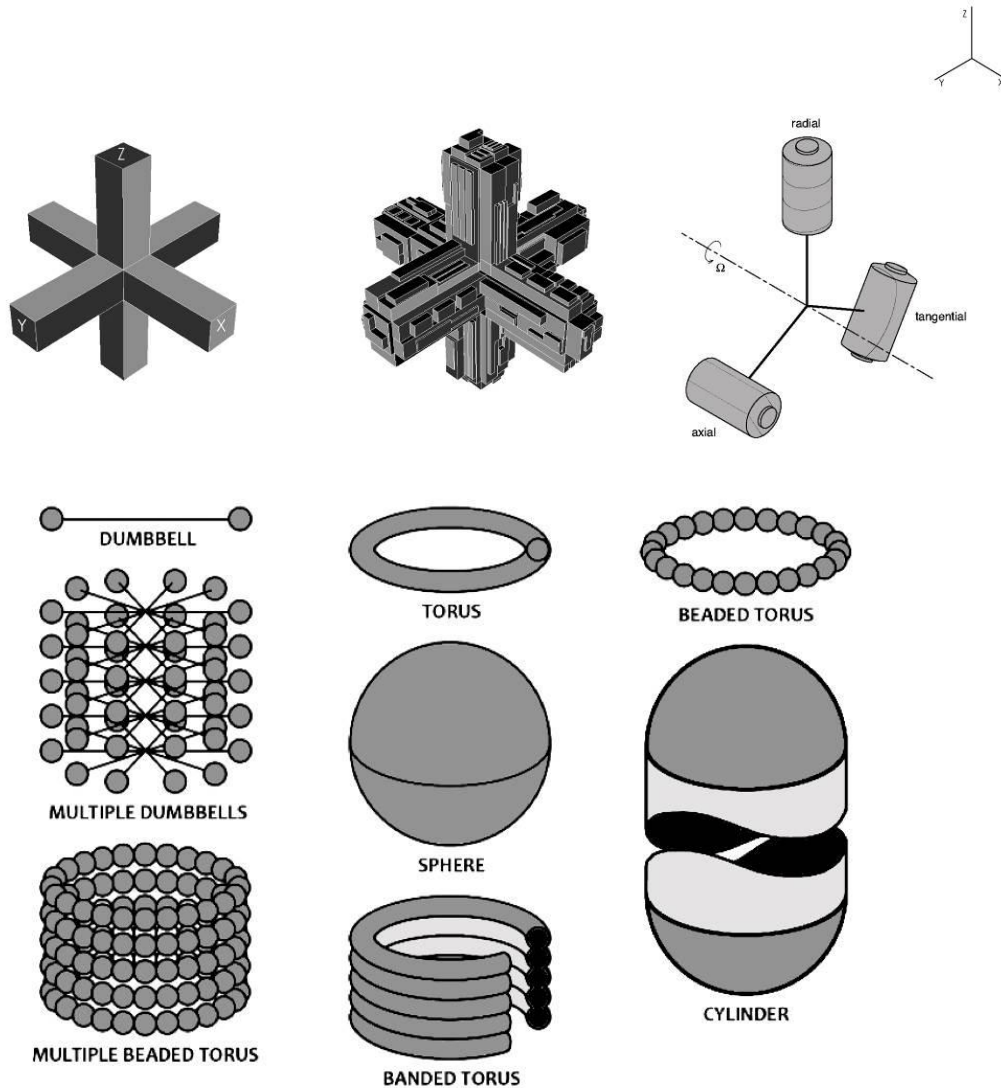


Image Comment: Artificial Gravity Structure

Assuming that the environment is un-propelled and that its rotation is constant, artificial gravity depends on the following quantities.

Ω is the angular velocity of the environment in inertial space, in radians per second.

r is the radial position of an object in the environment, measured from the center of rotation, in meters.

v is the velocity of the object relative to the environment, in meters per second.

a is the acceleration of the object relative to the environment, in meters per second-squared.

The total apparent artificial gravity derives from the total inertial acceleration. This is the vector sum of three components:

1. **Global Centripetal Acceleration:** This is the "design gravity". It is the only component that is independent of the relative motion of objects within the environment. It depends only on the angular velocity of the environment and the radial position of the object. The acceleration is radial, directed inward toward the axis.

$$\mathbf{A}_{\text{cent}} = \boldsymbol{\Omega} \times (\boldsymbol{\Omega} \times \mathbf{r}) \quad (1)$$

2. **Coriolis acceleration:** This is proportional to the vector product of the environment's angular velocity and the object's relative velocity. It is perpendicular to both. When the relative velocity is parallel to the axis of rotation, the Coriolis acceleration is zero.

$$\mathbf{A}_{\text{Cor}} = 2 \boldsymbol{\Omega} \times \mathbf{v} \quad (2)$$

3. **Relative acceleration:** This is generally independent of the environment and may assume any value.

$$\mathbf{a} = \dot{\mathbf{v}} = \ddot{\mathbf{r}} \quad (3)$$

The total apparent artificial gravity is the vector sum of these three components. The apparent "up" direction is aligned with the acceleration:

$$\mathbf{A} = \mathbf{A}_{\text{cent}} + \mathbf{A}_{\text{Cor}} + \mathbf{a} \quad (4)$$

In the special case of relative motion around the circumference of the environment, in the plane of rotation at constant speed and radius, the three components are parallel. Another expression is convenient for the magnitude of the total gravity. Define two additional quantities:

V_t is the magnitude of the environment's tangential velocity (rim speed) in inertial space.

v_t is the magnitude of the object's tangential velocity relative to the environment.

In this case, the magnitude of the total apparent artificial gravity derives from the following:

$$V_t = \Omega r \quad (5)$$

$$v_t = v \quad (6)$$

$$\Omega = V_t / r \quad (7)$$

$$A_{\text{cent}} = V_t^2 / r \quad (8)$$

$$A_{\text{Cor}} = 2 V_t v_t / r \quad (9)$$

$$a = v_t^2 / r \quad (10)$$

$$A = A_{\text{cent}} + A_{\text{Cor}} + a \quad (11)$$

$$= (V_t \pm v_t)^2 / r \quad (12)$$

choosing "+" for prograde and "-" for retrograde motion. The acceleration is radial, directed toward the center of rotation.

Only the global centripetal acceleration represents "design gravity". The other components are gravitational distortions that arise from motion within the environment. They affect the magnitude and direction of the total acceleration, causing changes in the apparent weight of objects and the apparent slope of surfaces. Taking Earth as the norm, one's experience of gravity should be independent of one's motion. Hence, the goal is to design the environment such that the global centripetal acceleration yields some preferred level of artificial gravity while simultaneously minimizing the other components. The equations suggest that the angular velocity should be kept low and that the radius should be large.

In a rotating system, one must also consider the non-intuitive effects of angular momentum. To turn an object about some local axis, in an environment that is rotating about some other global axis, requires a moment about a third axis perpendicular to the other two. The moment is proportional to the vector product of the environment's angular velocity and the object's angular momentum. The non-aligned rotations about the global and local axes are said to be "cross-coupled".

For example, consider a person standing in a rotating orbital habitat, facing prograde. The habitat may resemble a giant bicycle wheel. Artificial gravity aligns his apparent vertical axis along a radius or "spoke" that rotates with the habitat. The habitat's rotation axis is overhead, horizontal in his frame of reference, directed left-to-right. As long as he remains motionless relative to the habitat, he rotates with it effortlessly. When he turns to his left, he adds vertical components to his angular velocity and momentum. His angular momentum is no longer aligned with the habitat's angular velocity. To sustain this leftward turn about his vertical axis (while that axis rotates with the habitat) requires a left-leaning moment about his front-to-back axis. Moreover, this leftward turn about his vertical axis induces effects on his vestibular organs *as if* he was rotating about his front-to-back axis.

Experiments with human subjects in centrifuges and rotating rooms have confirmed this. When subjects turn their heads about any axis that is not aligned with the rotation of the environment, they experience vestibular illusions of rotation about a perpendicular axis. The illusions are approximately proportional in magnitude and direction to the vector product of the angular velocities of the environment and the head. The resulting mismatch between the vestibular and visual senses of motion are believed to be a major cause of motion sickness. To minimize these illusions while permitting the normal range of human motion, the angular velocity of the environment should be kept low.

Unfortunately, when the radius is limited, reducing the angular velocity may increase other aspects of gravitational distortion. One measure of this distortion is the ratio of the

magnitudes of the Coriolis and global centripetal accelerations. To emulate a natural gravitational environment, this ratio should be minimized without constraining the relative motion of people or objects within the environment. Define the following symbols:

v_p is the magnitude of an object's relative velocity in the plane of rotation (including radial and tangential velocity but not axial velocity).

V_t is the magnitude of the environment's tangential velocity (rim speed) in inertial space.

A_{Cor} is the magnitude of the Coriolis acceleration:

$$A_{Cor} = |2\boldsymbol{\Omega} \times \mathbf{v}| = 2\Omega v_p \quad (13)$$

A_{cent} is the magnitude of the global centripetal acceleration:

$$A_{cent} = |\boldsymbol{\Omega} \times (\boldsymbol{\Omega} \times \mathbf{r})| = \Omega^2 r \quad (14)$$

If decreasing angular velocity is compensated by increasing radius, so that centripetal acceleration remains constant, then decreasing angular velocity Ω decreases this ratio:

$$A_{Cor} / A_{cent} = 2\Omega v_p / A_{cent} \quad (15)$$

However, once the maximum feasible radius is reached, further reduction of angular velocity Ω decreases both the Coriolis *and* centripetal accelerations and *increases* the *ratio* of Coriolis to centripetal:

$$A_{Cor} / A_{cent} = 2\Omega v_p / \Omega^2 r = 2v_p / \Omega r = 2v_p / V_t \quad (16)$$

Thus for any given radius, while reducing Ω ameliorates problems associated with rotational cross-coupling (such as dizziness, ataxia, and nausea), it exacerbates gravitational distortion.

6.2.1 | COMFORT CRITERIA IN ARTIFICIAL GRAVITY

The physical theory behind artificial gravity is as old as Isaac Newton's *Principles*. Nevertheless, there was no significant research into the human factors of artificial gravity until Sputnik inaugurated the "space race". As experience with weightless space flight accumulated, artificial gravity assumed a lower priority. The NASA Langley simulator was dismantled in the early 1970s. Since the beginning of the Salyut and Skylab missions, access to a micro-gravity environment has been one of the main motivations for space flight. Ironically, while extended stays in weightlessness have revealed its dangers, they have also shown that it is survivable. Artificial gravity is now discussed primarily in the context of interplanetary missions, in which long periods of weightless coasting through empty space are an annoyance, not an objective.

Hence, much of the research into the human factors of rotating habitats is twenty or thirty years old. Over the past four decades, several authors have published guidelines for comfort in artificial gravity, including graphs of the hypothetical "comfort zone" bounded by values of acceleration, head-to-foot acceleration gradient, rotation rate and tangential velocity. Individually, these graphs depict the comfort boundaries as precise mathematical functions. Only when studied collectively do they reveal the uncertainties.

1. **Apparent Gravity:** This is stated in multiples of Earth gravity: $1\text{ g} = 9.81\text{ m/s}^2$

Most authors apply these limits solely to the global centripetal acceleration (the nominal "design gravity"): $A = \Omega^2 r = V_t^2 / r$

Stone applies them to the total acceleration, including the Coriolis and relative components, when walking prograde or retrograde at 1 meter per second:

$$A = \Omega^2 r \pm 2\Omega + 1 / r = (V_t \pm 1)^2 / r$$

- a. *Minimum Apparent Gravity:* This parameter usually aims to provide adequate floor traction for mobility. In the case of Hill and Schnitzer, it appears to be an arbitrary lower bound on a logarithmic scale. The minimum required to preserve health remains unknown.
 - b. *Maximum Apparent Gravity:* For reasons of both comfort and cost, this generally should not exceed 1 g. Gilruth gives no explanation for his specification of 0.9 g. Similar to Stone, he may be allowing for some inevitable increase from the extra accelerations while walking prograde.
2. **Maximum Apparent Gravity Gradient per Meter:** This is a decrease in apparent gravity over a radial distance of 1 meter, divided by some reference value.

- a. *relative gradient:* When the gradient is given as a percentage, the reference value is the apparent gravity at the floor:

$$\Delta A / A_{\text{ref}} = (A_{\text{floor}} - A_{\text{floor-1}}) / A_{\text{floor}}$$

When this is applied only to centripetal acceleration, it directly determines the floor radius. For example, a 25% gradient per meter in centripetal acceleration implies a floor radius of 4 meters.

- b. *absolute gradient:* When the gradient is given as a definite "g" value, the reference is Earth gravity:

$$\Delta A / A_{\text{ref}} = (A_{\text{floor}} - A_{\text{floor-1}}) / 9.81$$

Most authors specify a percentage gradient over a "head-to-foot" distance of 2 meters or 6 feet. Cramer specifies an absolute gradient, so the percentage depends on the selected value for the apparent gravity at the floor.

3. **Maximum Angular Velocity of Habitat:** This is stated in rotations per minute:

$$1 \text{ rpm} = (2\pi / 60) \text{ radians per second} = (\pi / 30) \text{ s}^{-1}$$

The limit aims to avoid motion sickness caused by the cross-coupling of normal head rotations with the habitat rotation. The value depends largely on the susceptibility of the inhabitants and the time permitted for their adaptation. Lower values accommodate a broader sample of the general population. Gilruth specifies 6 rotations per minute for "comfort" but only 2 for "optimum comfort". In this context, "comfort" does not imply luxury but merely mitigation of symptoms.

4. **Minimum Tangential Velocity of Habitat:** This should be large compared to the relative velocity of objects within the habitat. The goal is to keep the Coriolis acceleration small in proportion to the global centripetal acceleration. (For relative motion in the plane of rotation, the ratio of Coriolis to global centripetal acceleration is twice the ratio of relative velocity to habitat tangential velocity. See equation 16 above.) Hill and Schnitzer specify a tangential velocity of at least 6 meters per second (20 feet per second) so that walking prograde or retrograde will not change one's apparent weight by more than 15%. Even so, a person would have to walk very slowly - less than 0.5 meters per second - to stay within the 15% limit. Stone proposes that an object's apparent weight should not change by more than 25% when carried at 1.2 meters per second. This implies a minimum habitat tangential velocity of about 10 meters per second.

TABLE 6.2.1.1: Comfort Boundaries in Artificial Gravity.

Author	Year of Publication	Min. Apparent Gravity	Max. Apparent Gravity	Max. Apparent Gravity Gradient per Meter	Max. Angular Velocity of Habitat	Min. Tangential Velocity of Habitat
		A 9.81	$/ A$ 9.81	$/ \Delta A / A_{ref}$	$\Omega / (2\pi / 60)$	$V_t = \Omega r$
Clark & Hardy [23]	1960	-	-	-	0.1 rpm	-
Hill & Schnitzer [25]	1962	0.035 g	1 g	-	4 rpm	6 m/s
Gilruth [26] "optimum"	1969	0.3 g	0.9 g	8 %	6 rpm 2 rpm	-
Gordon & Gervais [27]	1969	0.2 g	1 g	8 %	6 rpm	7 m/s
Stone [28]	1973	0.1 g	1 g	25 %	6 rpm	10 m/s
Cramer [29]	1985	0.1 g	1 g	0.03 g	3 rpm	7 m/s

6.2.2 | ENVISIONING ARTIFICIAL GRAVITY

The comfort criteria described above are succinct summaries of abstract mathematical relationships, but they do nothing to convey the look and feel of artificial gravity. Consequently, there has been a tendency in many design concepts to treat any point within the hypothetical comfort zone as "essentially terrestrial", although that has not been the criterion for defining the zone. The defining criterion has been "mitigation of symptoms" and authors differ as to the boundary values that satisfy it. This suggests that the comfort boundaries are fuzzier than the individual studies imply. Comfort may be influenced by task requirements and environmental design considerations beyond the basic rotational parameters.

Perhaps a more intuitive way to compare artificial-gravity environments with each other as well as with Earth is to observe the behavior of a free-falling object when dropped from a certain height or launched from the floor with a certain velocity. Fig. 1 shows, for Earth-normal gravity, the effect of hopping vertically off the floor with an initial velocity of 2 meters per second and of dropping a ball from an initial height of 2 meters. The "hop" and the "drop" each trace vertical trajectories. The "hop" reaches a maximum height of 0.204 meters, indicated by a short horizontal line. The "drop" is marked by dots at 0.1-second intervals. Fig. 6.2.3.2 shows a typical comfort chart for artificial gravity, after that of Hill and Schnitzer, surrounded by five similar "hop and drop" diagrams - one for each boundary point of the comfort zone. When compared with the Earth-normal standard of fig. 6.2.3.1, these diagrams reveal certain features of the comfort boundaries:

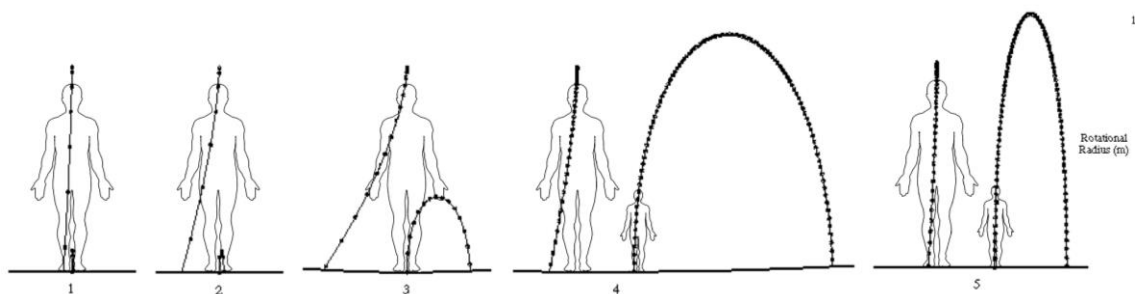


Image Comment: Standards for comfort boundaries in Artificial Gravity.

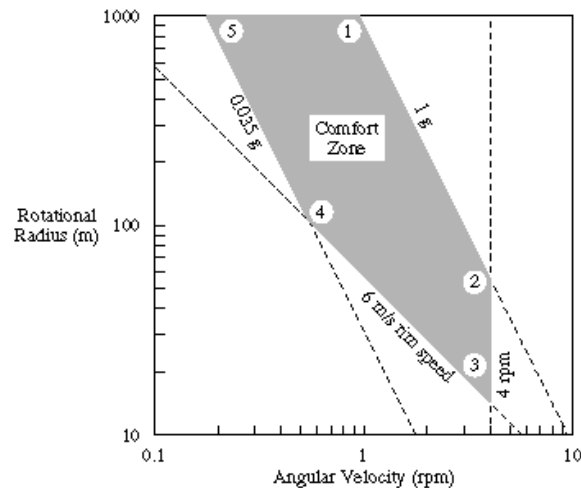


Image Comment: Artificial Gravity and the Comfort Zone.

1. **Large radius** (points 5 and 1): Artificial gravity becomes increasingly "normal" as the radius of rotation approaches infinity. The trajectory of a dropped object depends only on the radius of rotation and the initial height of the object. Thus, the drops at points 5 and 1 follow congruent paths, although the drop at 5 is much slower due to the low gravity. (The dots are spaced at 0.1-second intervals.) The trajectory of a thrown object is influenced by the ratio of its initial relative velocity to the habitat's tangential velocity. Thus the hop at point 5, besides being much higher (due to the low gravity), is also more distorted than at point 1 due to the lower tangential velocity. Point 1 is the most "Earth-normal" point on the chart. Point 5 approaches "normal" for a planetesimal or asteroid.
2. **Earth Gravity** (points 1 and 2): Earth-magnitude does not imply Earth-normal. Although both points represent 1-g environments, both the hop and the drop are more distorted at point 2, due to the smaller radius and lower tangential velocity.
3. **High Angular Velocity** (points 2 and 3): The upper limit of angular velocity is determined by the onset of motion sickness due to cross-coupled rotations. At this boundary, reducing the radius reduces the centripetal acceleration and tangential velocity as well. As judged by the "twisting" of the apparent gravity, point 3 is the least normal point in the comfort zone.
4. **Low Tangential Velocity** (points 3 and 4): For a given relative motion, the ratio of Coriolis to centripetal acceleration increases as tangential velocity decreases. Between points 3 and 4 it is constant. Hence, the hops at these points have similar shapes, though the hop at point 4 is larger due to the lower acceleration. The drop at point 4 is straighter due to the larger radius.

5. **Low Gravity** (points 4 and 5): Although the centripetal acceleration at these points is equal, the gravity is less distorted at point 5 due to the larger radius and higher tangential velocity.

Evidently, the comfort zone encompasses a wide range of environments, many of them substantially non-terrestrial. Conformance to the comfort zone does not guarantee an Earth-normal gravity environment, nor does it sanction "essentially terrestrial" design.

6.3 | ARCHITECTURE FOR ARTIFICIAL GRAVITY

In the twenty years since the Skylab workshop, micro-gravitational habitat design has progressed from an almost anti-terrestrial disregard for Earth-normalcy to a realization that some Earth norms can serve a useful coordinating function. One now sees designs for orbital habitats that provide distinct "Earthy" floor, wall, and ceiling references and consistent cues for vertical orientation, without denying either the possibility of ceiling-mounted utilities or the necessity of foot restraints.

Exactly the opposite sort of progression is needed in artificial-gravity design. Most concepts published to date have implied complete Earth-normalcy with regard to perceived gravity, stability, and orientation. A more appropriate approach calls for preserving those Earthly elements that serve a positive function while incorporating modifications that accommodate the peculiarities of rotating environments.

An important organizing theme in architectural design theory is the notion of principal directions, which imbue space with an inherent structure. The identification of these directions is powerfully influenced by gravity.

In terrestrial architecture, six directions on three axes are innately perceptible: up-down (height), left-right (breadth), and front-back (depth). The up-down axis is normally tied to the force of gravity. The other axes are free to rotate around it. The up-down axis is called "vertical", while all possible left-right and front-back axes are called "horizontal". The anisotropic character of this space is judged by the effort required to move in any given direction: up and down are distinct irreversible poles. Left, right, front and back are interchangeable simply by turning around. Thus, gravitationally, there are three principal directions - up, down, and horizontal - and three basic architectural elements - ceiling (or roof), floor, and wall. The walls, which bound the horizontal dimensions, are not inherently distinct.

The design of an orbital habitat for artificial gravity depends on much more than physics. A few simple formulae relate the habitat's size and rotation to the apparent gravity. Unfortunately, the formulae are powerless to predict the satisfaction of the inhabitants. Many empirical studies have attempted to identify the comfort boundaries for artificial gravity, to constrain the values of the variables. Nevertheless, they have arrived at substantially different conclusions. The disagreement may be due in part to different assumptions regarding the mission, selection, motivation and adaptability of the target population. To support a large clientele, it may be safe to stay within the common ground of all of the empirical studies, choosing the most restrictive bounding value for each variable.

Ultimately, an inhabitant's ability to adapt to artificial gravity will depend on how well the habitat itself is adapted. As a matter of principle, it is probably not possible to design for artificial gravity without having lived in it. Nevertheless, in designing the first such habitats, one must make the effort.

Based on current knowledge, we can imagine an zero-gravity enclosure with maximum mobility parameters. Depending on the number of habitant, the cell modules can have single or multiple internal partitions. The following diagrams will help understandstand architectural synthesis in lower gravity.

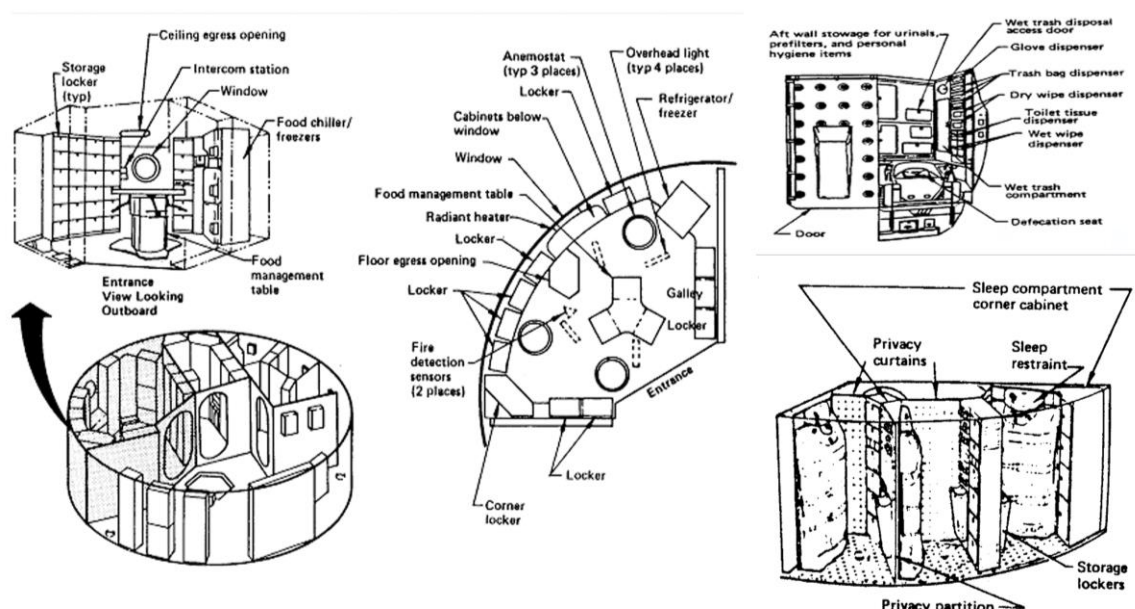


Image Comment: Design of a zero Gravity Enclosure.

ZERO GRAVITY ENCLOSURE

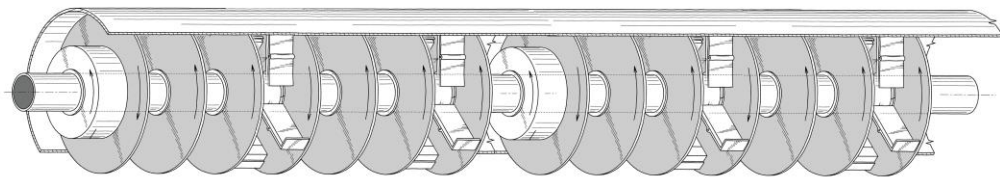
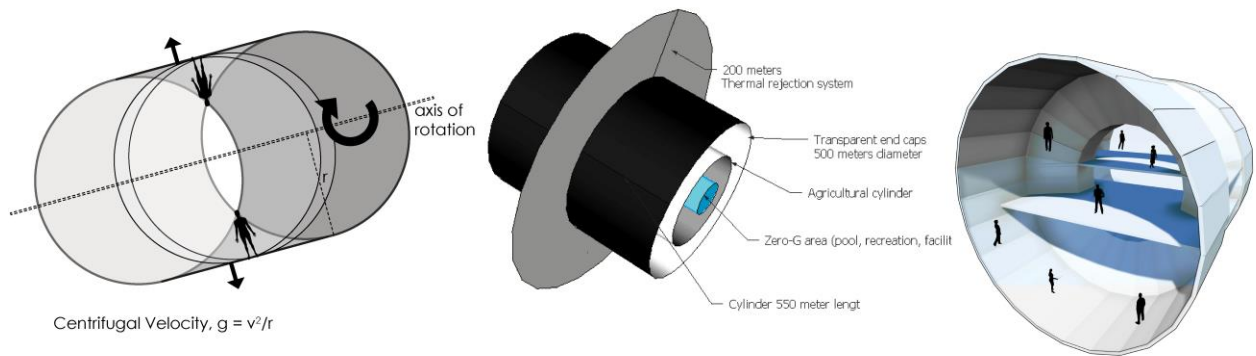


Image Comment: Design of Multiple Cells

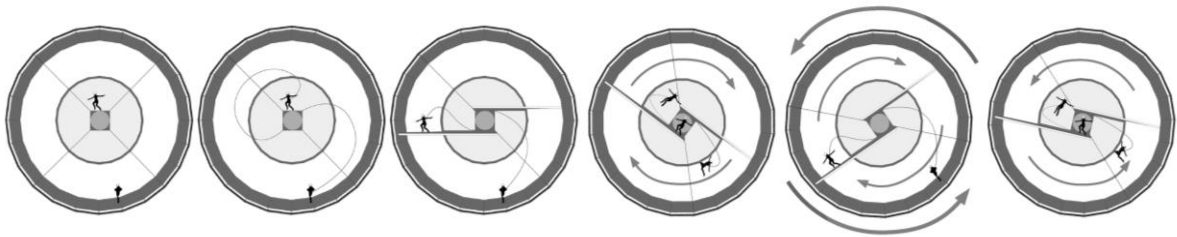


Image Comment: Plan view

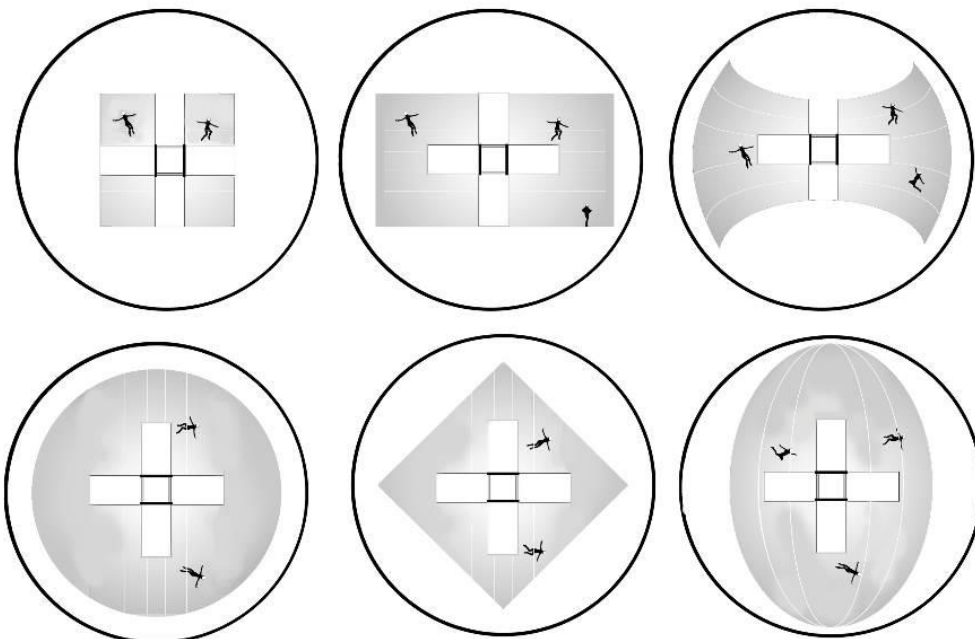


Image Comment: Interior Spaces



Figure 4: Centripetal, Coriolis, and total acceleration while walking prograde at 1 m/s, radius 12.2 m, tangential velocity 6.0 m/s (Table 1 row 2).



Figure 5: Apparent gravity for the inhabitant in Figure 4, while walking prograde at 1 m/s, radius 12.2 m, tangential velocity 6.0 m/s (Table 1 row 2).

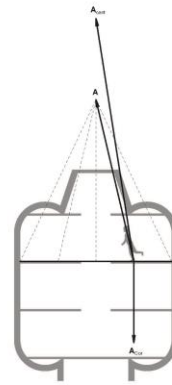


Figure 6: Centripetal, Coriolis, and total acceleration while walking retrograde at 1 m/s, radius 12.2 m, tangential velocity 6.0 m/s (Table 1 row 2).



Figure 7: Apparent gravity for the inhabitant in Figure 6, while walking retrograde at 1 m/s, radius 12.2 m, tangential velocity 6.0 m/s (Table 1 row 2).

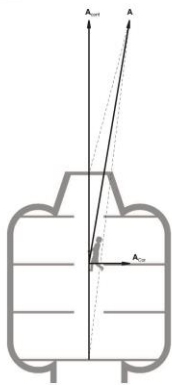


Figure 8: Centripetal, Coriolis, and total acceleration while descending at 0.5 m/s, radius 12.2 m, tangential velocity 6.0 m/s (Table 1 row 2).

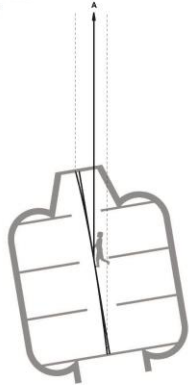


Figure 9: Apparent gravity for the inhabitant in Figure 8, while descending at 0.5 m/s, radius 12.2 m, tangential velocity 6.0 m/s (Table 1 row 2).

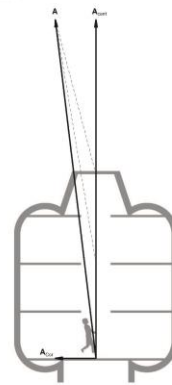


Figure 10: Centripetal, Coriolis, and total acceleration while ascending at 0.5 m/s, radius 17.0 m (12.2 + 4.8), tangential velocity 8.3 m/s.

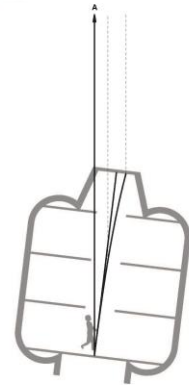


Figure 11: Apparent gravity for the inhabitant in Figure 10, while ascending at 0.5 m/s, radius 17.0 m (12.2 + 4.8), tangential velocity 8.3 m/s.

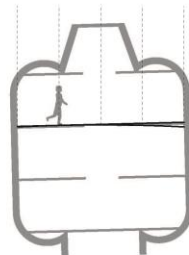


Figure 12: Apparent gravity while walking prograde at 1 m/s, radius 67.1 m, tangential velocity 14.0 m/s (Table 1 row 3). Compare Figure 5.

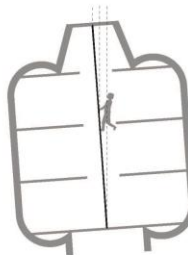


Figure 14: Apparent gravity while descending at 0.5 m/s, radius 67.1 m, tangential velocity 14.0 m/s (Table 1 row 3). Compare Figure 9.



Figure 16: Floor curvature for a top-floor radius of 12.2 meters (Table 1 row 2).

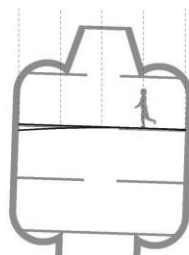


Figure 13: Apparent gravity while walking retrograde at 1 m/s, radius 67.1 m, tangential velocity 14.0 m/s (Table 1 row 3). Compare Figure 7.



Figure 15: Apparent gravity while ascending at 0.5 m/s, radius 71.9 m (67.1 + 4.8), tangential velocity 15.1 m/s. Compare Figure 11.



Figure 17: Floor curvature for a top-floor radius of 67.1 meters (Table 1 row 3).

6.3.1| HABITAT DESIGN IN ARTIFICIAL GRAVITY

The basic functional requirement for human survival in artificial environment is varied by the number of inhabitants, the time allocation for stay in space station, and the space requirements for fulfillments of all basic necessities. Understanding group behaviour and individual activities may help us allocate space in artificial environment. Note that engineering details, and use of mechanical hardwares has not been included in the studies.



Various Group level activities, such as Agriculture and Food Harvesting, Waste Recycling, Power generation and Distribution, Medical Services, Ventilation and Air Purification, Water Synthesis and Purification can be mechanized and requires only administrative support for control and maintenance. Other public activities can be generalized in the following diagram.

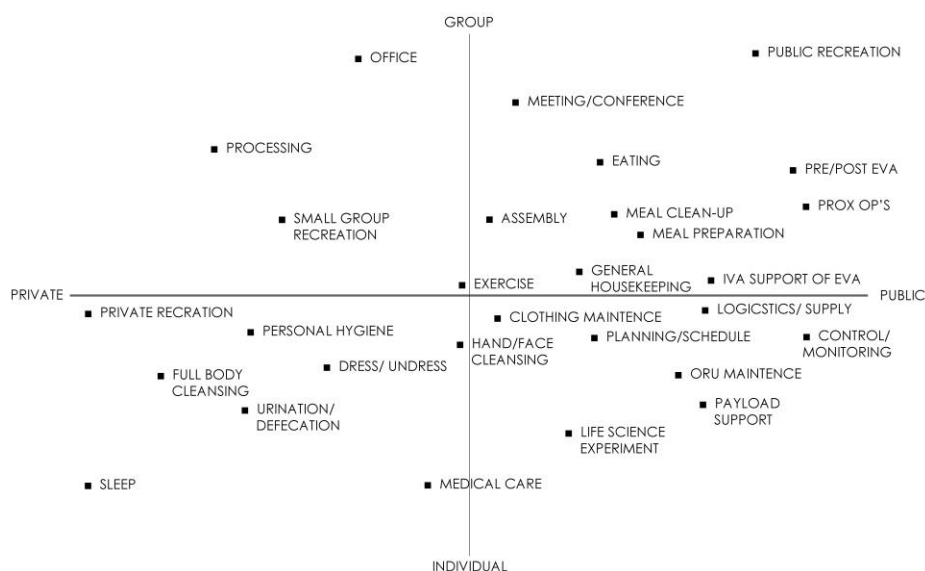


Diagram: Private vs. Public / Group vs. Individual Function Allocation.

The diagram below has the basic volumetric analysis of public functions.

PERSONAL HABITAT 4,900m ² x 3m = 14,700 m ³							
STORAGE AREA 1,500m ² x 3m = 4,500 m ³	RECREATION 500m ² x 3m = 1,500 m ³	ENVIRONMENT CONTROL 400m ² x 3m = 1,200 m ³	MECHANICAL STATION 50m ² x 3m = 1,50 m ³	TRANSPORTATION 200m ² x 3m = 1,200 m ³	SERVICE INDUSTRY 400m ² x 3m = 1,200 m ³	HOSPITAL/CLINIC 150m ² x 3m = 450 m ³	
STORAGE AREA 1,500m ² x 3m = 4,500 m ³	FOOD PROCESSING 500m ² x 4m = 2,000 m ³	ANIMAL AREAS 1,000m ² x 4m = 4,000 m ³	WASTE RECYCLING 800m ² x 4m = 3,200 m ³	AGRICULTURE DRYING 500m ² x 4m = 2,000 m ³	OFFICES, SHOPS, BUSINESS 340m ² x 4m = 1,360 m ³	ASSEMBLY HALL 150m ² x 5m = 750 m ³	
STORAGE AREA 1,500m ² x 3m = 4,500 m ³		RAW MATERIAL 2,500m ² x 10m = 25,000 m ³	PRODUCT MANUFACTURE 1,500m ² x 10m = 15,000 m ³	PUBLIC OPEN SPACE 1,000m ² x 20m = 20,000 m ³			REPAIR AND MAINTENANCE 1,000m ² x 10m = 10,000 m ³
PLANT GROWING AREA 2,500m ² x 4m = 10,000 m ³						MISCELLANEOUS 300m ² x 3m = 900 m ³	
POWER GENERATION 250m ² x 4m = 1,000 m ³						COMMAND & CONTROL 500m ² x 3m = 1,500 m ³	

Diagram: Volumetric Analysis of Space Allocation.

6.3.2 | SINGLE PERSON HABITAT DESIGN

The basic requirement for a single individual to survive in artificial gravity, consists of the following activities, considering the necessities for survival, such as, air, water, light, heat, gas, food, waste management etc. are provided for.

1. Leisure, Sleeping, Relaxation
2. Living, Social, Recreational
3. Cleaning and Defecation
4. Maintenance and Control
5. Dining and Utility and Services
6. Duty Fulfillment and Group Activities.

When designing an enclosure, we can control the space allocated by these following functions, such that external activities can be invited alongside the basic necessities. Imagine the six basic functions are allocated within a cube of $7'-0'' \times 7'-0'' \times 7'-0''$, including a framework for support and structure. The design solution hence can be incorporated within this parameter, leaving the external space for extracurricular activities.

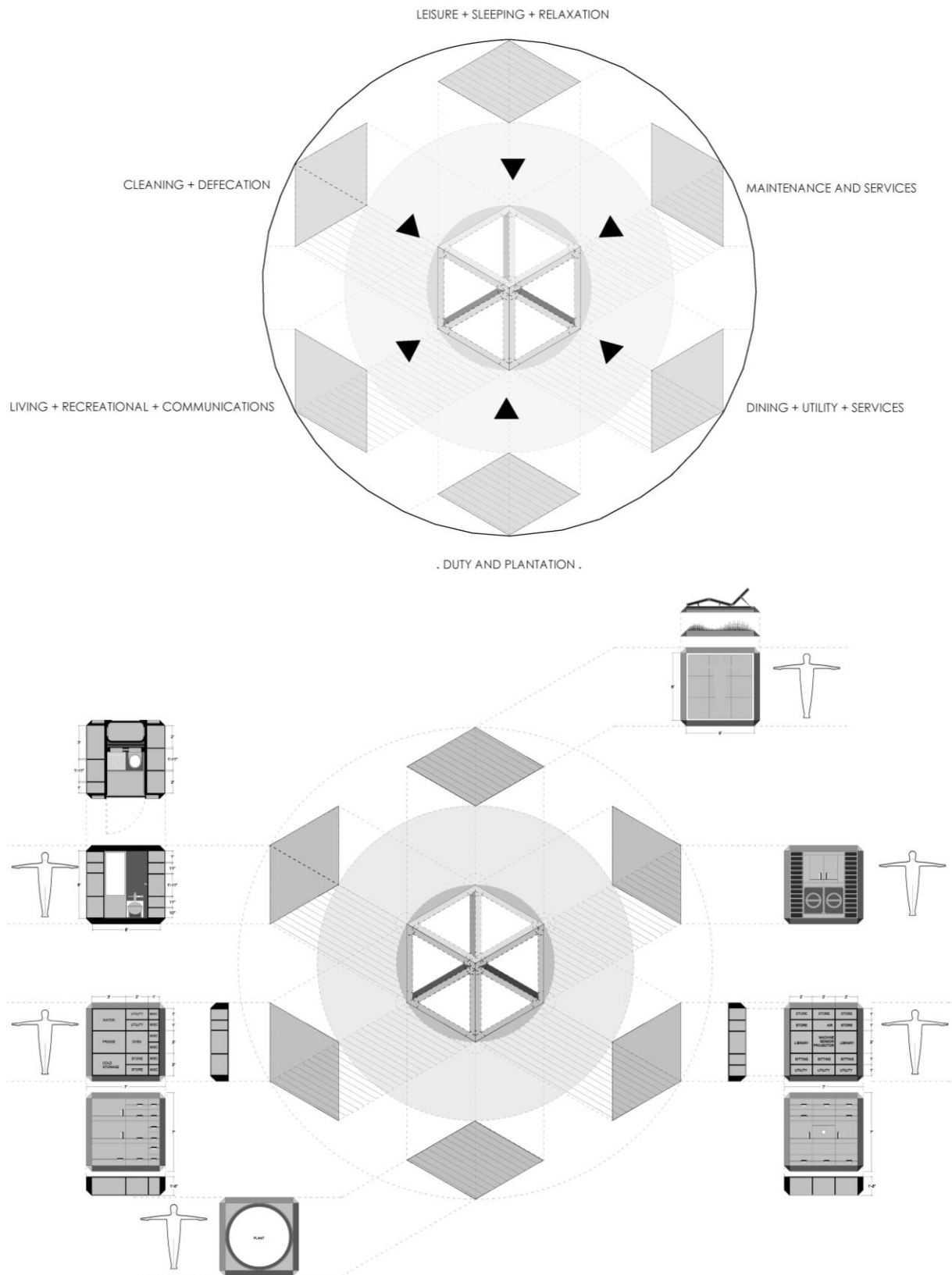
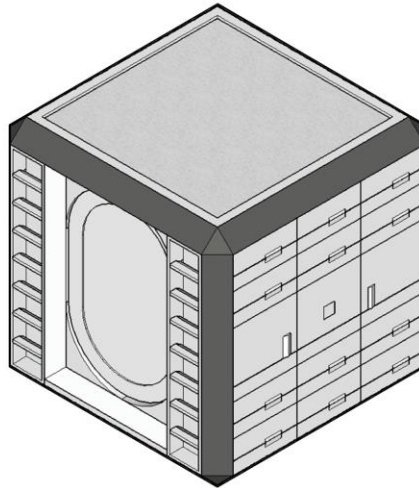


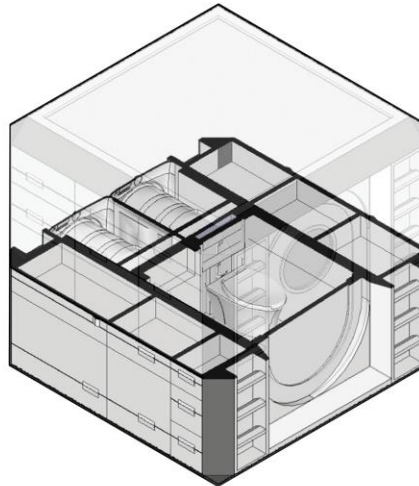
Diagram: Individual cell module in Second Dimension

RESTING >
MEDITATION >

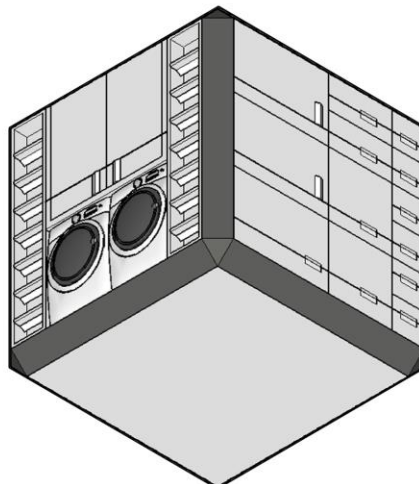
CLEANING >
DEFICATION >



< COMMUNICATION
< RECREATION
< STORAGE
< LIBRARY
< ENTERTAINMENT
< LIVING



AIR >
GAS >
WASHING >
DRYING >



< WATER
< FOOD
< DINING
< UTILITY
< OVEN
< FRIDGE

Figure: Individual Cell Module in Third Dimension

6.4 | FORM ANALYSIS AND SYNTHESIS

Provided the basic module is fixed, the form, partition, and shape of the dwelling unit can be contained within any shape or form

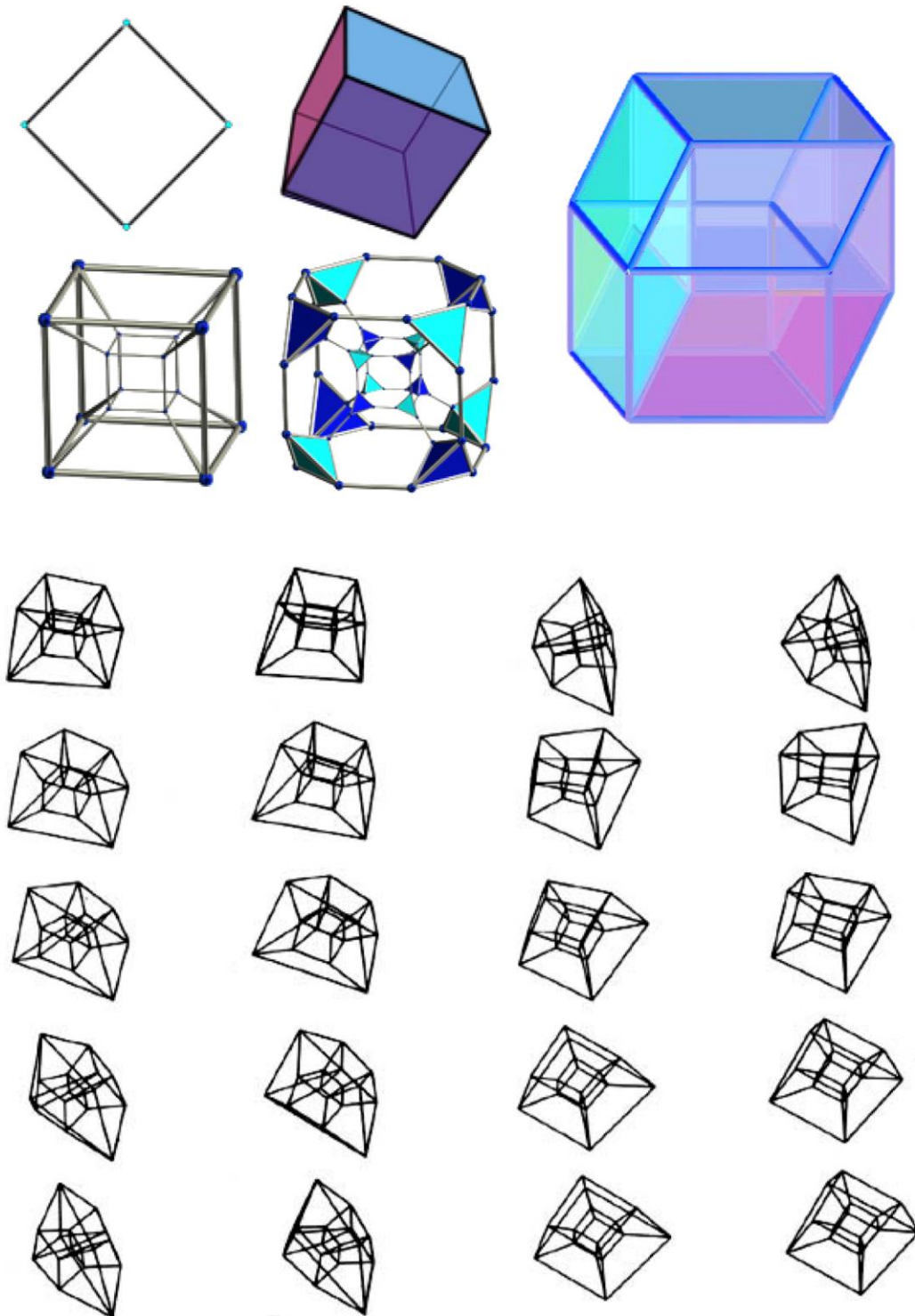


Image Comment: Internal Structure Development, in fourth dimension of space-time.

The following is a conceptual form analysis, which can have multiple probabilities, depending on Architect and Designers' creativity on transformation of form, space and function.

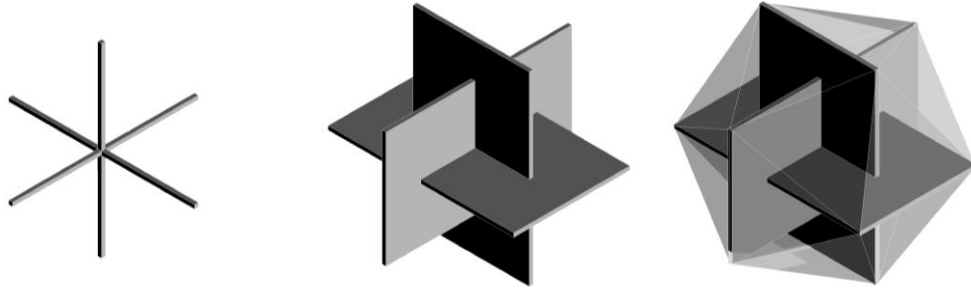


Image Comment: Axis Partitions

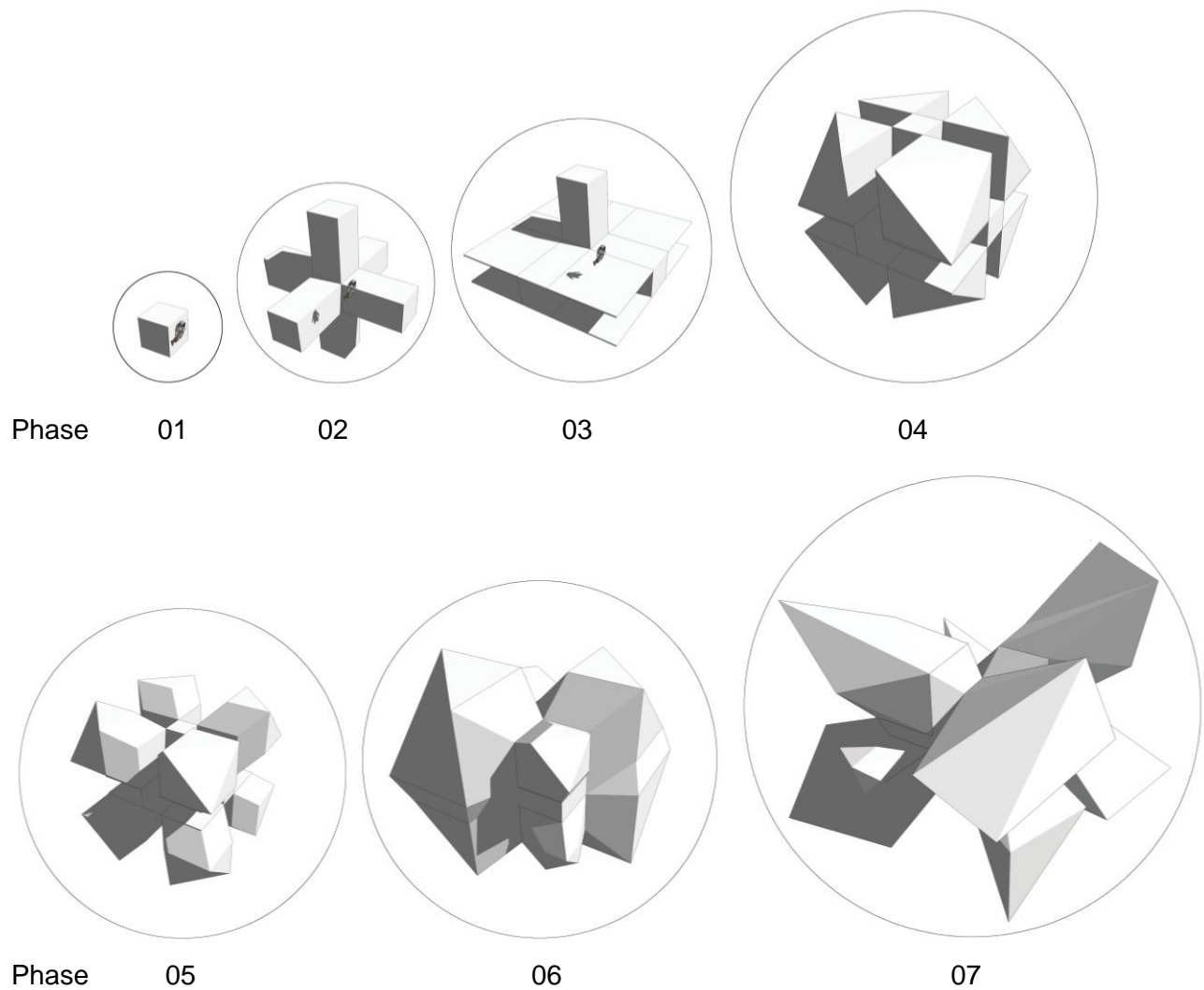
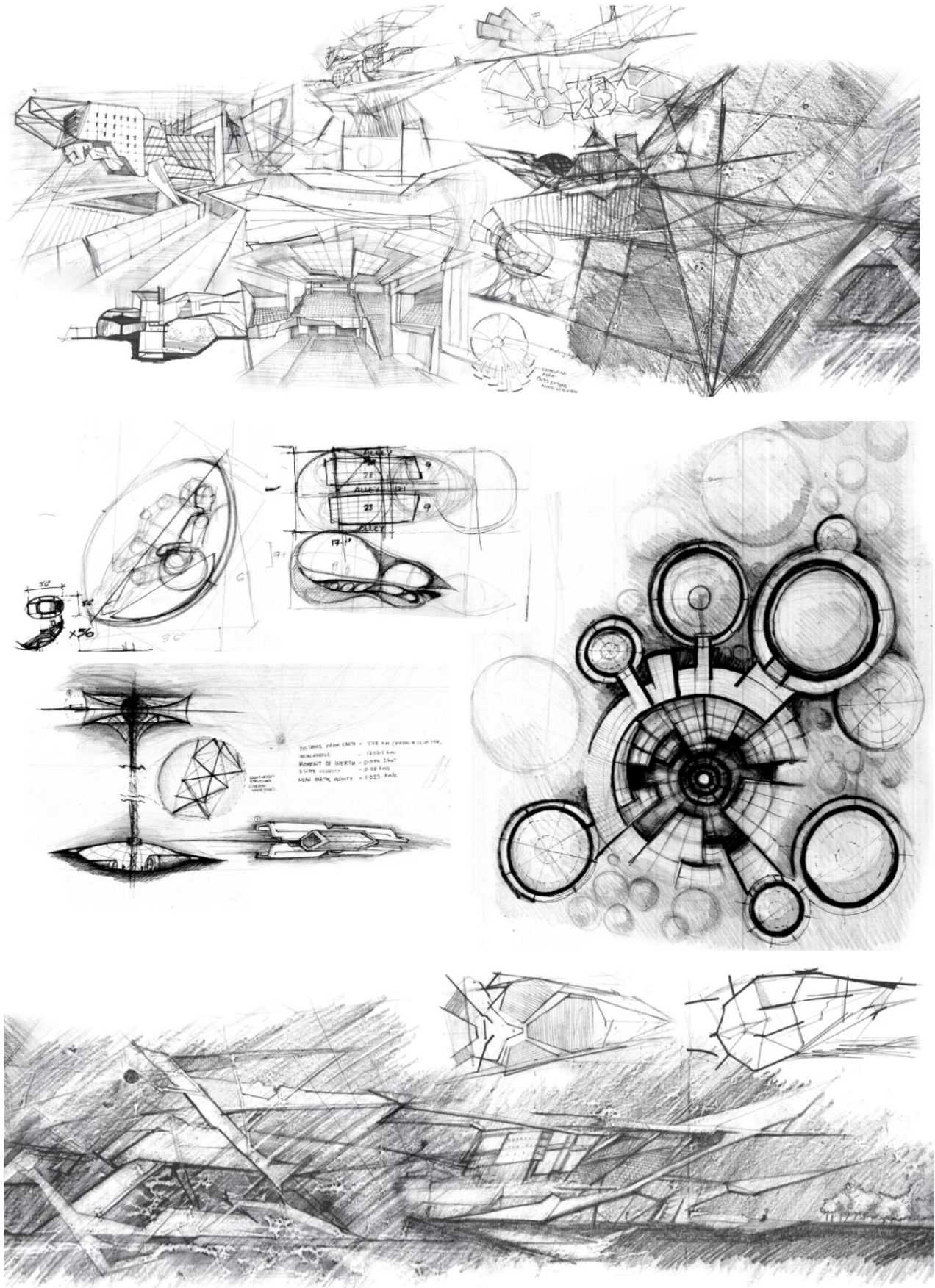


Image Comment: Shell Transformation



Images Comment: Conceptual Sketches for Community Facility

7.2 | CONCEPTUAL COLLAGE

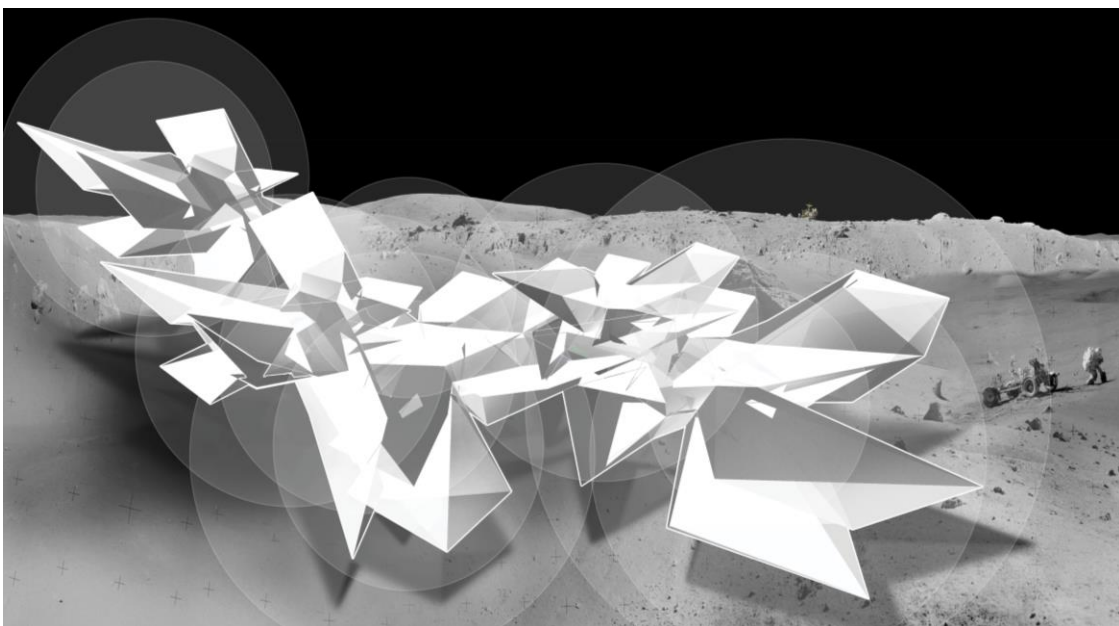
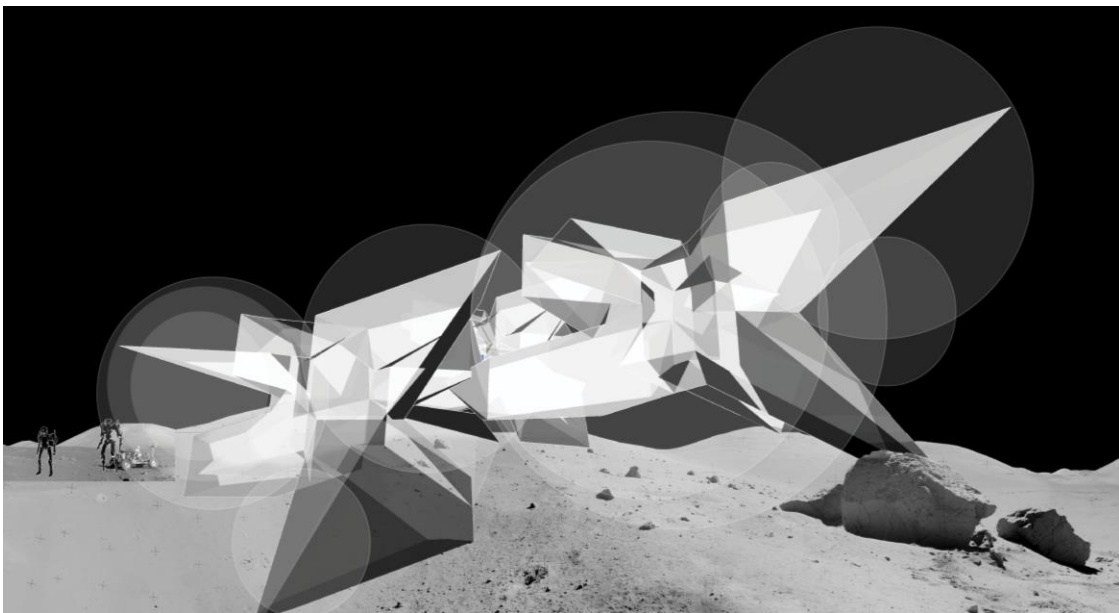
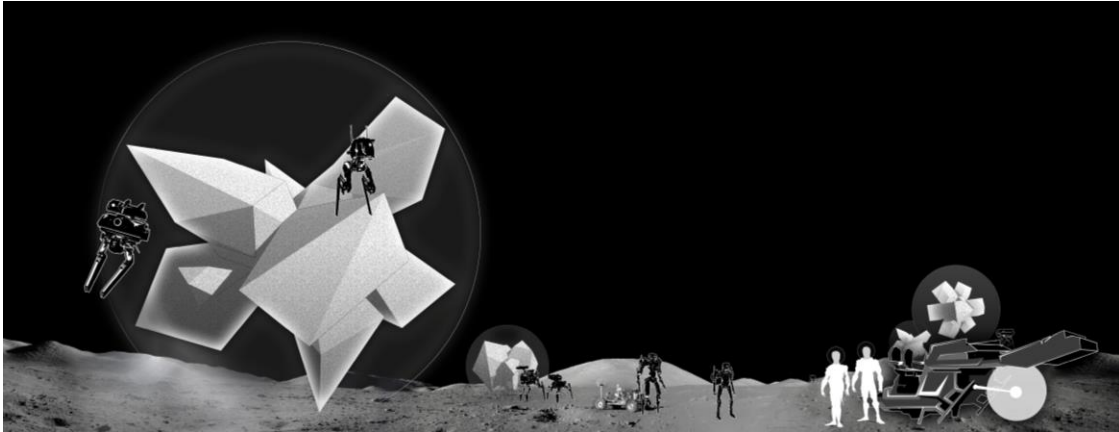


Image Comment: Conceptual Photomontages.

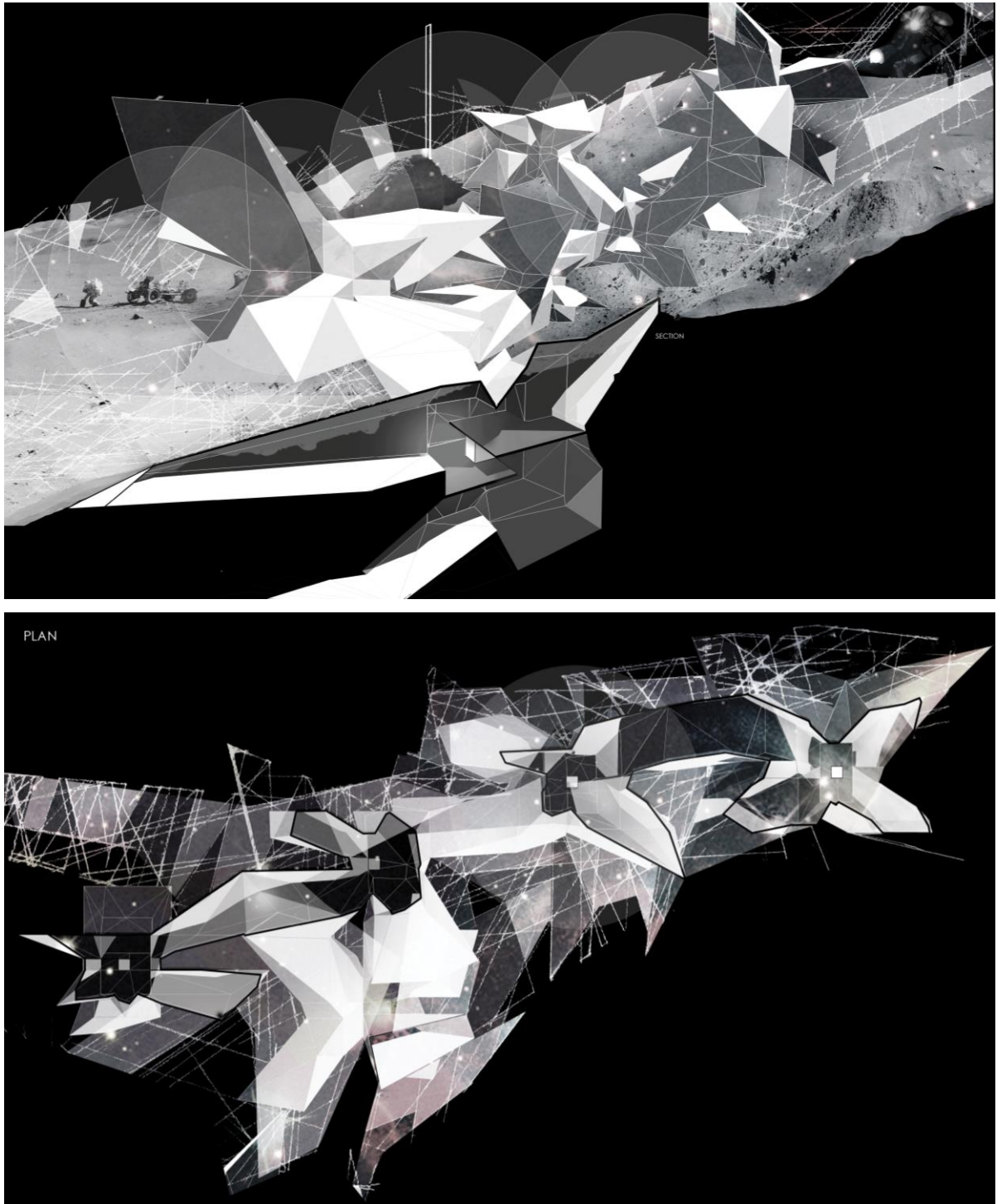
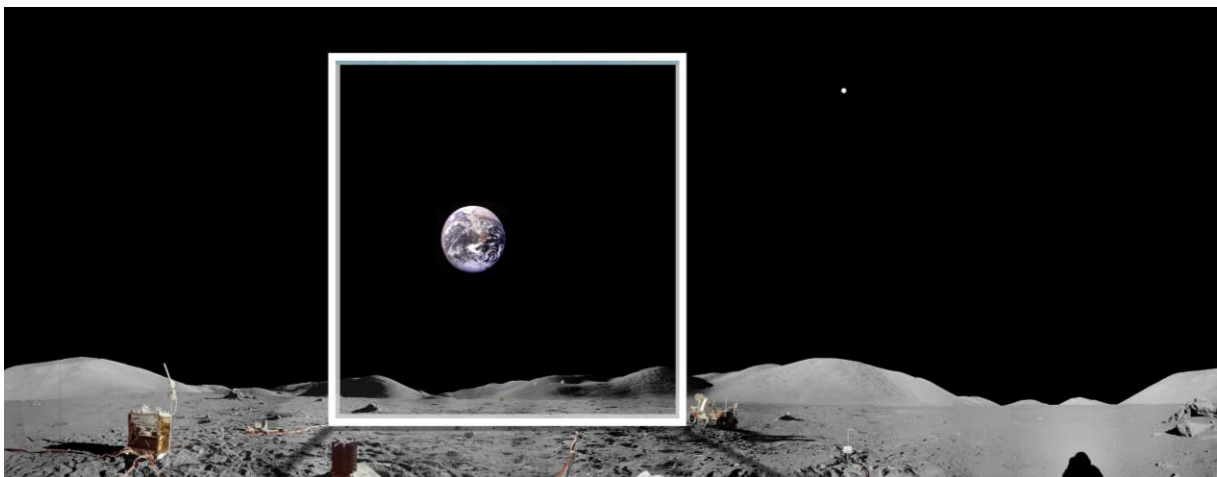
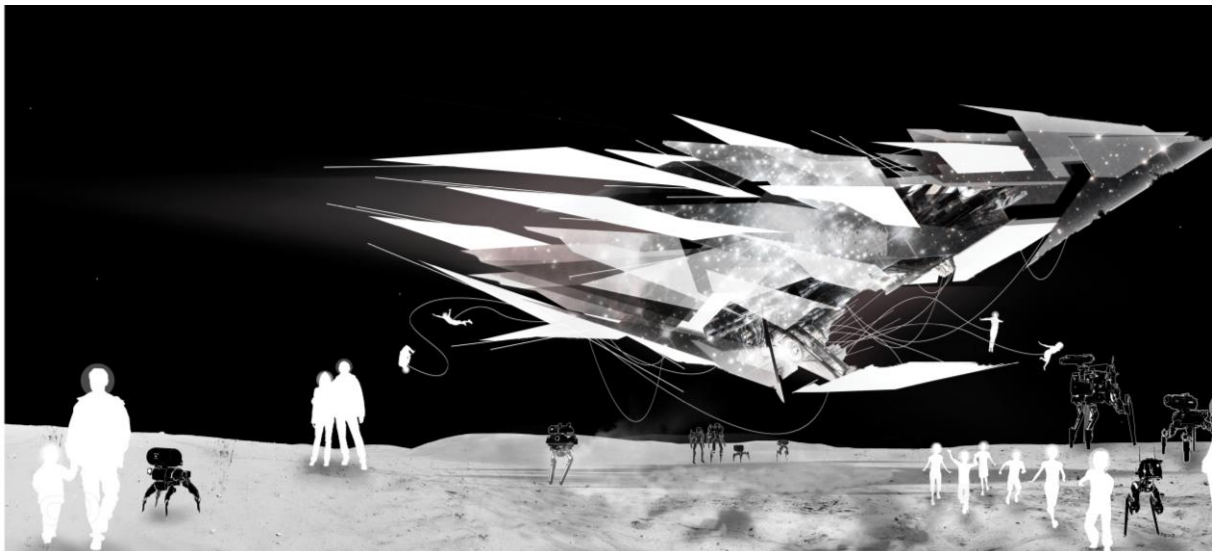


Image Comment: Plan and Section

7.3 | VISIONS



...CONTINUED...

CHAPTER 8 | REFLECTION AND CONCLUSION

8.1 | REFLECTION OF THESIS

We are at the dawn of an era, with information system at our fingertips, and future advances in technology knocking on our door, we have started to create pockets of extra dimensional possibilities. That which once listed as magic is now a reality. Our truth is subject to change, with discoveries of the known and the unknown, who knows what the future holds for us. Maybe someday travelling to other worlds will be a taxi ride away, and we will meet stranger like ourselves in distant galaxies.

8.2 | PERSONAL ANALYSIS AND DISCOVERIES

Throughout the thesis period, I have tried to stay positive and clear in my intentions and will. My curiosity and passion for Human Nature, Space Exploration, Fantasy Novels and Architectural Intervention has led me to believe - 'Yes We Can' - realize our true potential and start living our dreams. But one cannot dream alone. It takes collaboration from multiple disciplines, team work and guidance. I would like to thank my senior instructors, and my parents to have the patience and spirit to let me grow and acknowledge me for who I am. My pondering into space exploration has led me to believe, yes I am not alone in this quest, there are others like me, wonderers on a mission to answer the question, are we alone in this universe.

8.3 | FUTURE DEVELOPMENT

This research thesis is partially complete, and requires further scholarly revisions in other disciplines. I would like to continue the research on my own on my spare time and pursue abroad for development in the research, and I would encourage others like me to never stop believing. Please take aid from the research, and use the references provided for further understanding on the exploration into the unknown. I would encourage the Department of Architecture of BRAC University to investigate further on the possibilities of spatial dimensions on artificial gravity. Please use the research and guide future students to unlock their hidden potentials, design alternatives and learn to respect the Moon in the sky. May it always shine in the darkness and help us make our dreams come true.

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