Research Paper:

A Rock to Cling To

On the viability of independent, sustainable human colonies in space.

Adam Hovorka
ENGL 2020-017 :: Scott Hatch

4/20/2015

Table of Contents

Abstract

As of 2015, humanity is stuck on a single planet. Were a devastating cataclysm—an asteroid, a nearby gamma ray burst (GRB), World War 3, grey goo, or something worse—to happen, we'd be pretty much screwed. While most people still relegate the colonization of space to science fiction, it's really only a matter of time.

They'll need somewhere to go, though. For any long term success, we need to have completely self-sufficient human habitats in space capable of supporting thousands or hundreds of thousands of individuals.

I show that almost all aspects of human space colonization are feasible not only in the long term, but in the short term (e.g. 2020s) as well. I address two areas specifically: locations for colonization and the technology required.

The first obvious choice for settlement would be the planets, and perhaps the favorite destination planet of them all is our close neighbor Mars, but Venus turns out to be a viable choice too. The second common choice of destination is the moons of the solar system. Our Moon, as well as Phobos, Europa, and Ganymede, each provide unique challenges and benefits. Asteroids and free-floating space stations along strategic orbits are also considered.

But knowing where to go is useless if you die soon after you get there. Space is unlike anywhere else we've ever been, so to live there we need to figure out how to do all the things we take for granted on a scale, to quote Carl Sagan, of *"billions."* We need to come up with artificial atmospheres, food sources, gravity, radiation protection, and space-hardened systems of climate control.

But perhaps the largest barrier to large-scale space colonization is the cost. For humanity as a whole to move to the stars, the stars need to be accessible to the whole of humanity. We long to reach up and make our place, our *destiny,* out among the stars. And because of that, one day, we will.

Introduction

"Consider again that dot. That's here. That's home. That's us. On it everyone you love, everyone you know, everyone you ever heard of, every human being who ever was, lived out their lives. … Our posturings, our imagined self-importance, the delusion that we have some privileged position in the Universe, are challenged by this point of pale light. Our planet is a lonely speck in the great enveloping cosmic dark. In our obscurity, in all this vastness, there is no hint that help will come from elsewhere to save us from ourselves."

(Sagan, 1994)

As of 2015, humanity is stuck on a single planet. Were a devastating cataclysm—an asteroid, a nearby gamma ray burst (GRB), World War 3, grey goo, or something worse—to happen, we'd be pretty much screwed. Carl Sagan, one of the great science fiction authors and astrophysicists of the 20th century, believed, as I do, that the only way to combat this is to reach out into the universe and make ourselves a home among the stars.

Most people still relegate the colonization of space to science fiction due to the fact that we haven't been very far since the Apollo missions, despite the enormous progress we've made in other areas since that "one small step" in 1969. We may only be going as far as Low Earth Orbit, but we're very close to doing that on level with commercial air travel through SpaceX's reusable rockets and Virgin Galactic's Spaceship Two, and it's only a matter of time before people take it even further.

They'll need somewhere to go, though. And that's the hard part. The International Space Station (the "ISS") is the most expensive single construction project in human history (Lafleur, 2010), and it's only big enough for 6 people and some scientific experiments. For any long term success, we need to have completely self-sufficient human habitats in space capable of supporting thousands or hundreds of thousands of individuals.

I hope to show that almost all aspects of human space colonization are feasible not only in the long term, but in the short term (e.g. 2020s) as well. I will address two areas specifically, those being that of potential locations for colonization and that of unique things we'll need to be able to survive autonomously when we get there (i.e. the technology).

Locations

When we go to space, where will we go? Space isn't just an empty void. Stars, planets, moons, and the gravity of each give space its own geography in analogue with the Earth. There are enormous continents, vast oceans, desert oases, and innumerable small islands promising rich resources and a place to rest and refuel on the way to distant destinations.

Planets

The first obvious choice for settlement would be the planets. They're full of abundant natural resources that can be used to construct a base in situ, simplifying and lightening the loads of colonist rockets.

Mars

And perhaps the favorite destination planet of them all is our close neighbor Mars. It is, as of writing, proudly the only planet in our solar system with a majority population of robot explorers. We love to pepper it with landers and rovers, in the hope that we might find some clue as to whether life ever arose on the rusty and barren world that we now know was once covered in oceans and flowing rivers—and perhaps whether life still exists there today.

Great interest has been expressed in a manned mission to the Red Planet as well, though one group in particular stands out. Mars One, a not-for-profit foundation based in the Netherlands, is in the process of selecting and training astronauts for a one-way trip. That's right, they're asking for people to live out the rest of their lives there, never again speaking to anyone still on Earth with a delay of less than six minutes. And what's more, they aren't affiliated with any governmental entity. They plan to gather the necessary funding primarily from reality TV deals and merchandise sale, with a large helping of donations on the side. Their timeline estimates that the first mission launch will be in 2020, followed by two more equipment launches in 2022 and 2024 and the first group of four astronauts in 2026. (Mars One) And while their lack of tangible planning and funding has seen light in recent media reports, I personally think they can do it, provided some unspecified changes in their approach. Getting humanity to the surface of mars in 11 years seems impossible now, but getting to the Moon in seven seemed just as impossible when John F. Kennedy gave his famous speech at Rice University in September of 1962.

Further into the future, Mars seems like it's an excellent candidate for Terraforming. Its polar ice caps are composed primarily of carbon dioxide. We could position a fleet of statites—a kind of solar sail made of aluminized PET angled to effectively "float" at one point in space above a gravity source—above the poles and use them to reflect sunlight down, increasing the planet's "insolation," releasing the gas and pressurizing the atmosphere slightly, setting off a chain reaction where the thicker atmosphere allows it to retain more heat, causing more of the ice caps to melt, pressurizing the atmosphere a little more, until the point where it's thick enough and warm enough that we could walk around on the surface with little more than a light jacket and a scuba tank. From there, we could introduce bacteria and plant life, converting the carbon dioxide into oxygen and releasing other gasses until it becomes just the way our lungs like it. (Zubrin, 1996)

Venus

That's not to discourage us from visiting the other planets though. Venus, commonly thought of as Earth's evil twin due to its acid rain and runaway greenhouse effect, is actually quite nice if you aren't on the surface. About 50 km up, the atmosphere is actually quite nice. Though wind speeds can surpass 200 mph, if a floating platform or dirigible weren't anchored to the ground all this would serve to do is shorten the apparent length of the day. One can imagine large floating facilities designed to capture gasses in a similar vein to the Cloud City from *Star Wars: The Empire Strikes Back*.

NASA has actually created a proposal for a mission they call HAVOC, which would involve a 30 day stay in orbit around (and in the atmosphere above) Venus, in preparation for a more permanent floating base. Why put in the effort? In terms of flight time, Venus is actually "closer" to the asteroid belt than Earth or Mars when taken along the minimum energy Hohmann trajectory, and conveniently, the atmosphere could, in theory, be converted into fuel for use in asteroid mining operations. (HAVOC)

Moons

The second common choice of destination is the moons of the solar system. They provide things similar to the planets they orbit—natural resources such as water—with the added benefit of lower gravity suggesting their use for construction yards for ships and stations destined for elsewhere in the cosmos.

The Moon

Starting at the top with our own Moon—the only other world we humans have visited in person—we have a nice spot that's not nearly as far away as everywhere else, complete with water ice and helium 3 deposits, not to mention silicates that can be used in electronic circuit and solar cell production. And at just over a light-second away, it's never too far to ask for help from home base.

It's also the perfect spot for a space elevator that we can build with today's material science and technology. It wouldn't extend out to a synchronous orbit, however; the moon is tidally locked to its orbit around the Earth. Instead, it would extend out to the Earth-Moon L1 point, a point where the gravity of the Earth and the Moon effectively cancel each other out. A station or other counterweight placed there could drop a long rope made from Kevlar or some other strong material and anchored to a base station along the equator. Robot "climbers" could then freely deliver materials to and from the surface. (LiftPort Group)

And the ESA has already been working on figuring out what they'd deliver besides helium 3, too. When mixed with magnesium oxide and a binding salt, lunar regolith turns into a material that can be used to 3D print with. Moon bases, structural elements for space stations, and even equipment for future exploration missions could be produced on the surface and shipped up cheaply thanks to the elevator. (Anderson, 2013)

Phobos (i.e. Mars Again)

A station at the Earth-Moon L1 point would be conveniently positioned as a low Δv jumping off point for interplanetary missions as well. In fact, from there, it's only one more kilometer per second to get to Phobos, the inner moon of Mars.

Phobos is already at the perfect position to serve as the counterweight for a Mars elevator, despite having an orbital period of only 8 hours (over 3x shorter than the Martian day). Because Mars is wracked every so often by dust storms that can cover the whole planet, the most effective construction strategy for an elevator would be to not have it anchored anywhere, instead dangling just above the clouds and thicker atmosphere, sort of like our Venusian cities above. Normal airplanes could fly up and attach their payload to the cable, then fall off and return to the airport they came from while the payload climbs up to orbit.

It's also an excellent candidate for being "paraterraformed" into what's called a "shield world." Its surface gravity isn't nearly strong enough to hold onto an atmosphere, so instead the idea is that you could build a shell around it and pressurize the interior. From there, it could essentially be terraformed as normal, with introduction of bacteria and plant life, and eventually animals.

Europa

Another favorite is the Jovian ice moon Europa, with its subsurface ocean heated by tidal forces and high hydrocarbon content heavily implying the potential for life. Which is unfortunate; radiation from Jupiter serves to make surface colonization more difficult and dangerous on Europa than on the larger and slightly more distant moon Ganymede.

Ganymede

While many people know about Europa's ocean, thanks to it being fairly apparent on its surface, few seem to know that a few of its siblings have subsurface oceans as well. Ganymede's is actually superior, in this case, because it also encloses a molten iron core, complete with a functioning magnetic field and auroras, which could serve to cheaply protect colonists from the harmful solar and Jovian radiation. (Kramer, 2015)

Asteroids

Third on our list, we have asteroids. In our solar system, most asteroids are conveniently found in a belt between Mars and Jupiter. This is because gravitational perturbations from Jupiter have prevented them from ever forming into a planet. As they are, they contain abundant, relatively easily accessible natural resources like iron, silicon, platinum, and most importantly, water.

Even barring direct use as a colonization platform, they can be used for raw materials and counterbalances for space elevators, among many other things. A company called Planetary Resources is in the process of developing the infrastructure required for industrial scale asteroid mining—and chief among their targets are those with high quantities of water. The current average going price to put a liter of water into LEO stands around $20,000. If they can develop a system that can retrieve watery asteroids for cheaper than that, they can easily profit. The water can be sold off, or it can also be used as a reusable fuel for automated tugs that can then go out and pull down even more asteroids. (Planetary Resources | The Asteroid Mining Company)

Ceres

Largest among the asteroids is Ceres 1. Recently reclassified as a dwarf planet along with Pluto, and having a radius slightly less than 30% of our own Moon, Ceres has been explored primarily in science fiction as a strategic “home base” for even larger asteroid mining operations. Cererian colonies are generally depicted as being subsurface tunnels—often more than 10km below the surface to avoid radiation, though many consider this overkill. The environment within would resemble that in current microgravity stations; Ceres’ mass is only enough to provide 0.029 g. (Ceres: Overview)

Core Paraterraforming

But perhaps a more interesting concept comes from considering smaller targets. Both Sagan, in his book “Pale Blue Dot,” and G. K. O’Neill, in his 1974 Physics Today article “The Colonization of Space,” propose using mirrors to focus a large amount of solar energy into a hole drilled through the core of a relatively small (e.g. 2km) slowly rotating asteroid to superheat water which would melt the surrounding material, slowly causing it to expand out to a hollow balloon shape, almost like glass blowing. The inside could then be sealed and pressurized, then set spinning even faster to provide the inhabitants with artificial gravity (as further discussed below).

Lagrange Points

But just leaving these new asteroid stations (as well as other, more artificial stations like the Kalpana One) out in the middle of interplanetary space is rather careless. Perturbations could easily send the stations on collision courses with each other or with a planet, to devastating effect. Instead, after the construction in LEO is complete, they should be carried out and placed at one of several points of gravitational equilibrium—the “Lagrange points,” named after Italian-French mathematician Joseph-Louis Lagrange. (WMAP, 2015)

An object placed at one of the five Lagrange points will stay in exactly the same position relative to the two larger bodies that create the points. These points exist for every pair of objects that orbit each other. In fact, after the asteroid belt, the highest concentrations of asteroids are around the “Trojan points”—the Jupiter-Sun L4 and L5 points.

Optimal choices for station positions are the Earth-Moon L1, L4, and L5 points (L4 and L5 because they are as easy to reach as the Moon in case of emergency, and L1 because it’s where the counterweight for a Lunar space elevator would be), the Earth-Sun L4 and L5 points (ideal for power stations as per Project Solaris), and the Jupiter-Sun L4 and L5 points (because of the afore-mentioned Trojan asteroids).

Cyclers

Beyond the Lagrange points, there are also orbits called “cyclers” discovered in part by Buzz Aldrin which constantly transfer between two planets with little to no course correction required (McConaghy, 2002). These orbits could be useful for frequent interplanetary travel; instead of hauling food, water, and shielding every single trip, you could simply get yourself and your actual cargo into a cycler’s orbit, dock to it, and use it for shelter for the ~2 month trip. Stations positioned along cycler orbits are, in this way, analogous to cruise ships too large to pull in to a land dock. Economically ideal cycler positions would be between Earth and Mars, and Earth and Jupiter, but they can be found between any two planets desired.

Technology

But knowing where to go is useless if you die soon after you get there. Space is cold, dark, and incredibly inhospitable to human life. To survive out there, we need to make it a lot more like Earth—we need to be able to breathe, eat, not get cooked, and not get cancer, and being able to actually walk around on a floor would help with all sorts of problems that we're only now experiencing and experimenting with. Space is unlike anywhere else we've ever been, so to live there we need to figure out how to do all the things we take for granted on a scale, to quote Sagan again, of *"billions."*

Atmosphere

Let's start with breathing. On Earth, it's possibly the biggest thing we take for granted, and it's where the traditional analogy between the colonization of Space and the colonization of the American frontier breaks down; in the 17th century, a single man could strike out with naught but the clothes on his back and reasonably expect to survive. Attempting to apply that to Space in the 21st is laughable.

The average human requires 0.8 kg of oxygen per day and produces 1.04 kg of carbon dioxide (Chung, 2015). The oxygen must be replenished, but that's comparatively simple. One person-day of liquid O_2 has a volume of just 0.7 mL. The CO_2, on the other hand, can't just be released from a tank. Without expendable filters or complex oxygen reclaimers, CO_2 levels in a pressurized container can quickly reach toxicity, characterized by flushed skin, muscle twitches, headaches, lethargy, and ultimately death. (Clinical Anesthesiology)

Of course, on larger scales the problem of air can be solved much more simply by implementing direct ecosystem replication. Many space station designs include large areas of plant life and open tanks of water filled with fish and algae which can easily be used for recreation as well. Even weather, to some extent, could be replicated given enough head room. The more that is copied, the more hands-off the control is. Barring other equipment failure, an artificial ecosystem of sufficient size can in theory expect to run indefinitely.

Food

Having large, open replicated ecosystems would also solve the problem of food production. People could simply hunt, fish, and farm, returning again to the frontier metaphor we discounted earlier. However, that would require truly massive scales that we can't yet reasonably expect to create with today's technology, so let's take a step down.

Currently, astronauts planning for a long stay on the ISS prepare their food menus well in advance, and then have them shipped up either with them or on supply missions during their time on-station. And it's not like they're still sipping bean paste from tubes; modern astronaut food is still dehydrated by and large, but chefs from around the world have been able to do some amazing things. Astronauts have had the ability to enjoy steak, sushi, coffee, kimchi, ramen, (Perchonok, 2012) and very nearly reindeer jerky, but it was thought to be too "weird" for the American astronauts less than two weeks before Christmas, so Swedish astronaut Christer Fuglesang had to make due with moose jerky instead. (Ohlsson, 2007)

We can take it back even further though. Recently, a Silicon Valley startup has been experimenting with a powdered drink designed to be a complete food replacement. They call it Soylent, in homage to the novel *Make Room! Make Room!* and the Charlton Heston movie adaptation *Soylent Green*. This Soylent isn't made of people though. It's made of what inventor Rob Rhinehart has determined to be the precise daily nutrition needs of an average adult; nothing is left out (which, in itself, makes it superior to the diets of most Americans). It's manufactured almost entirely from the raw chemical products, and takes the form of a tan colored drink—best served chilled—that is said to, unflavored, have a taste similar to that of oatmeal water. After an initial adaptation period (during the first week or so people consuming only the drink have reported copious flatulence) the two liters a day can serve as a low cost, low effort "staple meal" indefinitely; as of 2015, Rhinehart himself has been on an 80% Soylent diet for over a year, and many others have joined him, several with extensive personally funded medical journaling. (Soylent - Free Your Body)

Perhaps it's too soon to jump the food ship and switch over to Wall-E style everything smoothies though. A company called the Mirai Group (Japanese for "future") has been producing the technology required for complete indoor, climate-controlled, three dimensional farms. In 2014 in collaboration with GE, they built a complete farm system inside an old Sony semiconductor factory that is producing 10,000 heads of lettuce a day year-round. The technology is currently optimized for small, purely green plants—tuning the wavelengths is somewhat complex, it seems—but given some effort it could easily be extended to the full range of domesticated plants. (Lettuce See the Future, 2014) (Mirai)

Gravity

It's obvious that we humans are adapted for gravity. Our feet are differentiated from our hands, and our hearts and blood vessels are optimized to provide the right amount of flow to our head despite it being higher than about everything else. Put us in a microgravity environment and not only do we get head rush, we lose all sense of balance (there's nothing pulling on our inner ears) and our bones and muscles start to rapidly deteriorate. (Garrett, 2000, p. 459)

While this can be (and is, currently) combatted with daily exercise, jogging while strapped to a treadmill and pulling on resistive weights for two and a half hours a day just to maintain your health isn't something that can be forced onto the whole of spacefaring humanity when there's a much simpler solution: fake gravity. (Exercising in Space, 2014)

True gravity is available anywhere you've got a large mass or constant acceleration (e.g. on a planet or in a ship with a high-powered Hall thruster), but where it's unavailable it can easily be simulated with rotation. Centrifugal force, countering the centripetal force provided by the spacecraft's hull, can provide an adequate simulation of gravity in the outward direction. When the spacecraft is constructed adequately, adverse effects from the Coriolis force and internal motion can be minimized. Research collected by Theodore Hall suggests that, given a minimum 12 meter radius and 7 meters per second tangential velocity to provide approximately 0.4 g, the negative health effects would disappear (2000). However, maximizing both and obtaining a full g would obviously be preferred.

This technique can be applied to greatest effect on long-term stations as exemplified by Space Station V from *2001: A Space Odyssey* and the Kalpana One space station proposal (Arora, 2006), and the comfort it provides would help give an economic backing to stations constructed along the Cycler orbits mentioned above.

One other famous example of a rotating space station design is the O'Neill Cylinder. It's seen reimaginings all throughout science fiction, but the general idea is that they are long, graceful tubes with huge cities hanging on to their slowly spinning hulls. This romantic vision of a rotating station is, unfortunately, not sound; more recent work done by groups such as the Kalpana One team suggest that any lateral motion on the inside of the cylinders would eventually cause them to fall into an uncontrollable tumble. To combat this, they can, at most, only be about as long as their diameter—Kalpana One, for example, is 325 meters long with a radius of 250 meters. (Arora, 2006)

Radiation

Another thing the Kalpana One station design successfully addresses is the need for protection from harmful radiation. Stations placed in Low Earth Orbit have the benefit of Earth's magnetic field and the Van Allen belts, but any higher up and the occupants will quickly ~~gain superpowers~~ get cancerous, life-threatening tumors. And with no atmosphere to get in the way, the only way to protect ourselves against the ever-present radiation in space (besides regular organ transplants) is shielding.

To be on the safe side, the design for Kalpana One calls for up to ten tons of lunar regolith or asteroid mining refuse per square meter of shielded surface area. (Arora, 2006) This is obviously purposefully excessive, but not by too much. Comparable figures can be expected for covered planetary bases, but when you take into account the fact that most rock is slightly radioactive on its own, it becomes apparent that past a certain point you aren't gaining anything anymore.

But that's only necessary for where there is concern about permanent protection. For short-term jaunts, such as a trip to Luna or Mars, you can easily get away with just a 30 cm thick shell of water—which, conveniently, can double as fuel when electrolyzed, as well as have use culinarily and hygienically.

For even more efficiency, we need to realize that there are actually two kinds of radiation we need to be concerned about: ionizing (high-energy) electromagnetic radiation, and particle radiation (e.g. alpha and beta particles). They both require different amounts of different kinds of shielding. Ionizing radiation is best with high density materials because it is stopped by electrons, and high density materials have more electrons in the same amount of space. Conversely, particle radiation is better with low density shielding because it has more protons. (Chung, 2015)

With this in mind, we can create layered shielding with a fraction of the weight of uniform rock or water shielding. It's important to make sure the outer layer is the particle shielding, however; the Bremsstrahlung effect can convert some of the particle energy into x-rays, which will either bounce back out if the shield is layered properly, or bounce around on the inside, cooking the occupants. (Chung, 2015)

A useful property of radiation is that it's directional. If you have a point source of radiation that you need protection from, say a nuclear engine, you can usually get away with what's called "shadow shielding," which is where you place the radiation source on one side of your ship and only build enough heavy shielding to protect the forward part of the ship—enough to put it in the shield's "radiation shadow." (Chung, 2015)

Heat rejection

While it may seem at first that, with space being as "cold" as it is, the problem you'd have with temperature would be heat *retention,* it's actually heat *rejection* that causes the most difficulty. Space is a vacuum, so there isn't a lot of matter around to take away heat by convection. The only way, then, to transfer a lot of heat is by radiation, and thanks to the sun you're gaining it everywhere that's lit up.

(Note that this section doesn't really apply to colonies on planets and moons; they can effectively serve as giant rock heat-sinks.)

If heat is being absorbed everywhere that's lit, the simplest way to regulate heat intake is to have the spacecraft either painted white or coated with reflective baffling (in the infrared spectrum, of course). That's why, save the large solar arrays, the ISS is coated with silvery layered "space blankets," which have found use in emergency situations for the same reason—they have impressive insulating power. (Staying Cool on the ISS, 2001)

In some cases, though, this isn't enough. The ISS still has an impressive array of radiators as part of the External Active Thermal Control System (EATCS). The radiator arrays, nearly half the size of the main solar arrays, are attached to the main truss, just like the solar arrays, but they are only on the back; during operation, they must be kept in the ISS's shadow. What's the point of a radiator if it absorbs heat rather than dissipates it? (Staying Cool on the ISS, 2001)

Conclusion

But perhaps the largest barrier to large-scale space colonization is the cost. The average consumer just can't afford to blow a few thousand dollars per pound to get themselves to space, let alone to hoist the materials needed construct a home. For any of the above to matter, the cost to launch to LEO needs to go down significantly. For humanity as a whole to move to the stars, the stars need to be accessible to the whole of humanity.

SpaceX and Virgin Galactic have been making excellent progress on this front. As I stated in the introduction, their fully reusable Falcon 9 rockets and spaceplanes will open up cheap access to space to, at first, institutions and the moderately wealthy, and later, once they enter mass production and use, to all of us, the explorers and the pioneers.

And once that's done there's the dream. Through educational programs like STEM, and popular media like the Cristopher Nolan movie *Interstellar* or the upcoming movie *The Martian* starring Matt Damon, we can come to wonder at the beauty of the cosmos. We long to reach up and make our place, our *destiny,* out among the stars. And because of that, one day, we will.

"Even after 400 generations in villages and cities, we haven't forgotten. The open road still softly calls, like a nearly forgotten song of childhood. … Maybe it's a little early. Maybe the time is not quite yet. But those other worlds—promising untold opportunities—beckon. Silently, they orbit the Sun,

Waiting."

(Sagan, 1994)

References

2001: A Space Odyssey [Motion picture]. (1968). MGM.

Anderson, T. (2013, February 1). How to build a lunar base with 3D printing. Retrieved April 20, 2015.

Arora, N., Bajoria, A., & Globus, A. (2006). Kalpana One: Analysis and design of space colony. *AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, 47*.

Buldrini, N. (2015, February 20). Introducing Project Solaris – Towards the Conception of a Distributed Solar Energy Harvester | Icarus Interstellar. Retrieved April 20, 2015.

Ceres: Overview | NASA Solar System Exploration. (n.d.). Retrieved April 20, 2015.

Chung, W. (2015, April 14). Atomic Rocketships of the Space Patrol. Retrieved April 20, 2015, from http://www.projectrho.com/public_html/rocket/

Clinical Anesthesiology, 4e. (n.d.). Retrieved April 20, 2015, from http://accessanesthesiology.mhmedical.com/content.aspx?bookid=353§ionid=40148760

Exercising in Space. (2014, August 4). Retrieved April 20, 2015, from http://www.asc-csa.gc.ca/eng/astronauts/living-exercising.asp

Farr, S. (2013). Ice Dome Construction for Large Scale Habitats on Atmosphereless Bodies. *SAO/NASA Astrophysics Data System*. Retrieved from http://arxiv.org/abs/1303.5356

Fritz, J., Bitsch, B., Kührt, E., Morbidelli, A., Tornow, C., Wünnemann, K., . . . Werner, S. (2014). Earth-like Habitats in Planetary Systems. *SAO/NASA Astrophysics Data System*. Retrieved from http://arxiv.org/abs/1404.4460

Garrett, W. (2000). *Exercise and sport science*. Philadelphia: Lippincott Williams & Wilkins.

Hall, T. (2012, October 21). Artificial Gravity. Retrieved April 20, 2015, from http://artificial-gravity.com/

HAVOC. (n.d.). Retrieved April 20, 2015, from http://sacd.larc.nasa.gov/branches/space-mission-analysis-branch-smab/smab-projects/havoc/

International Space Station: Environmental Control and Life Support System. (2008). Retrieved April 20, 2015, from http://www.nasa.gov/sites/default/files/104840main_eclss.pdf

Kennedy, J. (1962, September 12). JFK Rice Moon Speech.

Kramer, M. (2015, March 12). Jupiter's Moon Ganymede Has a Salty Ocean with More Water than Earth. Retrieved April 20, 2015.

Lafleur, C. (2010, March 8). Costs of US piloted programs. Retrieved April 20, 2015.

Lettuce See the Future: Japanese Farmer Builds High-Tech Indoor Veggie Factory. (2014, July 9). Retrieved April 20, 2015.

Lifeboat Foundation. (n.d.). Retrieved April 20, 2015, from http://lifeboat.com/ex/ark_i

LiftPort Group. (n.d.). Retrieved April 20, 2015, from http://lunarelevator.com/

Mars One. (n.d.). Retrieved April 20, 2015, from http://www.mars-one.com/

McConaghy, T., Longuski, J., & Byrnes, D. (2002). Analysis of a Broad Class of Earth-Mars Cycler Trajectories. Retrieved April 20, 2015.

Mirai, Inc. (n.d.). Retrieved April 20, 2015, from http://miraigroup.jp/en/

Ohlsson, E. (2007, November 16). Christer Fuglesang redo för rymden efter 14 års träning. Retrieved April 20, 2015.

O'Neill, G. K. (1974, September). The Colonization of Space. Retrieved April 20, 2015, from http://www.nss.org/settlement/physicstoday.htm

Perchonok, M., Douglas, G., & Cooper, M. (2012, June 26). Risk of Performance Decrement and Crew Illness Due to an Inadequate Food System. Retrieved April 20, 2015.

Planetary Resources | The Asteroid Mining Company. (n.d.). Retrieved April 20, 2015, from http://www.planetaryresources.com/

Sagan, C. (1994). Pale blue dot: A vision of the human future in space. New York: Random House.

Soylent - Free Your Body. (n.d.). Retrieved April 20, 2015, from http://soylent.me/

Space Habitat. (n.d.). Retrieved April 20, 2015, from http://www.spacefuture.com/habi tat/habitat.shtml

Staying Cool on the ISS. (2001, March 21).

WMAP Observatory: The Lagrange Points. (2015, February 23). Retrieved April 20, 2015.

Zubrin, R., & Wagner, R. (1996). The case for Mars: The plan to settle the red planet and why we must. New York: Free Press.