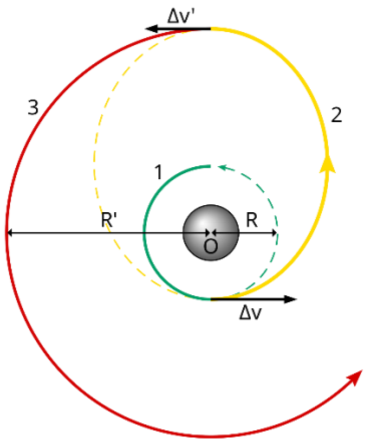
Given the extreme conditions on Mars and the challenge of travelling there, how realistic is Mars colonization?

To evaluate how realistic an idea is, we must first examine the obstacles which the idea involves, and then explore if we will be able to overcome these obstacles. In the case of Mars colonization, the process can be split into three sequential processes – travel, survival, and energy generation – each of which have their own specific challenges. To determine the probability of Mars colonization, this essay will examine how realistic it is that humans will be able to overcome the obstacles within each step of the process by considering current infrastructure, technology, and developments, as well as potential developments in the near future.

Before analysing the challenges involved in the establishment of a Mars colony, it is important to clearly define what can be classified as a "colony." The size and other features of the hypothetical "colony" directly affect the feasibility of the idea due to their effect on the resources, technology, and infrastructure required. Space colonization has been defined as the "hypothetical permanent habitation and exploitation of natural resources from outside spaceflight or operating space outputs" (Shreya Mane, 2022). Thus, to qualify as "Mars colonization," our hypothetical mission must result in permanent settlement on Mars, which utilizes natural resources present. A mathematical model which compared "required working time," or the time required to fulfil all needs for survival and "working time capacity" of individuals found that the minimum number of individuals for settling on Mars was 110 (Jean-Marc Salotti, 2020). This estimation will be used later when discussing food requirements.

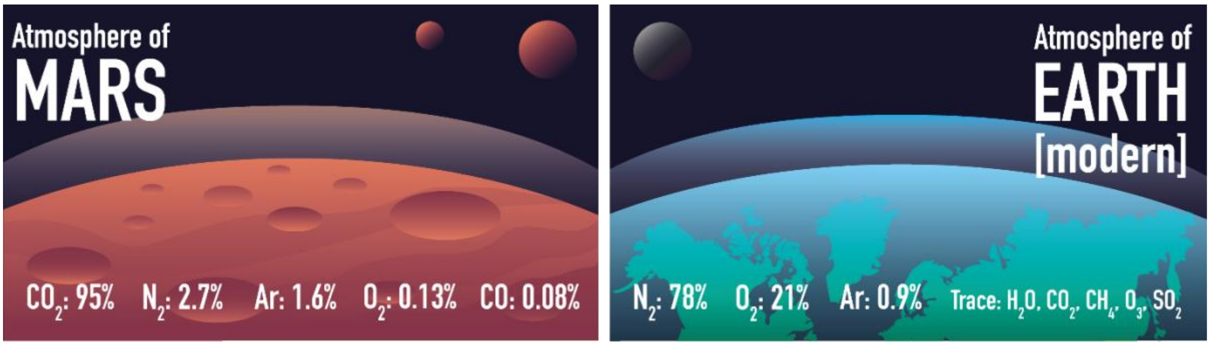
The first challenge associated with Mars colonization is the travel period. Due to its elliptical orbit, the distance between Mars and Earth varies, but even when the planets are closest together, Mars is still 150 times further away from Earth than the Moon. The Hohmann transfer orbital manoeuvre, generally the most fuel-efficient method for orbital transfer (John Prussing 1992), utilizes two engine burn impulses to transfer a spacecraft between two coplanar orbits. The opposite sides of the initial and desired orbit are connected by an ellipse. The first impulse (fuel burn) boosts the spacecraft into the elliptical orbit, and once the far side of the ellipse is reached, a second impulse moves the spacecraft into the desired orbit. Because Mars is constantly in motion, and has a slightly elliptical orbit, launch windows arise approximately every 26 months, when the planets are lined up perfectly for the manoeuvre. Under optimal conditions, using a Hohmann-like transfer allows arrival to Mars in around nine months (Dobrijevic and Tillman, 2025).



The most fundamental Hohmann Transfer. Δv is the first impulse, which is followed by Δv' the second impulse or fuel burn

However, developments in rocket technology will significantly reduce travel time – SpaceX's *Starship* rocket can in theory reach Mars in just ninety days (Kingdon, 2025) due to its orbit refuelling and aerocapture capabilities. Aerocapture involves the use of aerodynamic drag force from a planetary atmosphere to decelerate and insert itself into planetary orbit. *Starship* is still in a developmental and testing phase, however, and further test runs will be required to determine the plausibility of these manoeuvres. Thus, travel to Mars is challenging but nevertheless possible. With the advent of faster travel time, more frequent missions will become a real possibility, thus making the eventual goal of permanent Mars colonization more realistic.

The next key factor is if we can survive on the surface of the red planet. The ensuing paragraphs will detail some of the factors that make survival on Mars very difficult, and how we will be able to overcome these obstacles. The most obvious is the atmospheric makeup: Mars' atmosphere is over a hundred times thinner than Earth's, and its composition does not support aerobic life. The chart below compares the makeup of the two planets' atmospheres:



The near-lack of oxygen as well as the extremely low air pressure (0.6% of Earth's value) means that humans on Mars require a spacesuit to survive outside of a pressurized environment. However, not all oxygen will have to be brought to Mars by astronauts. NASA's MOXIE technology (Mars Oxygen In-Situ Resource Utilization Experiment) successfully extracted oxygen by performing solid oxide electrolysis on the Carbon-Dioxide rich Martian atmosphere during the *Perseverance* Rover's mission in 2021. NASA has since expressed that the next steps would be to create a full-scale system with a scaled-up version of the technology, and the liquification and storage of the oxygen extracted (*NASA's Perseverance Mars Rover Extracts First Oxygen from Red Planet - NASA*, no date). If these endeavours are successful, it is realistic that we will be able to respire on Mars. The next challenge connected with survival is the extremely low pressure – the atmospheric pressure on Mars is below the Armstrong limit, the point at which bodily fluids will boil at body temperature (Misachi, 2017). Current spacesuits account for both oxygen and pressure requirements, as well as the shielding required against the extreme surface temperatures. However, there are also the challenges of solar radiation and toxic dust. Mars' lack of magnetic field as well as its thin atmosphere means radiation levels are much higher than on Earth (Frazier, 2023) and current spacesuits do not offer adequate production against this level of radiation. Hydrogenated Boron Nitride Nanotubes – hydrogenated BNNTs – offer a potential solution. Hydrogen is interspersed in the spaces between nanotubes of Carbon, Boron, and Nitrogen, creating an ideal shielding material. Hydrogen's similar size enables it to block both protons and neutrons, while Boron is also a powerful absorber of secondary neutrons (Frazier, 2023). BNNTs have already been successfully woven into yarn (Frazier, 2023), meaning there is great scope for their use in spacesuits in the future.

"Mars dust" also presents another challenge: the reddish iron-oxide rich heterogenous particulate coating the planet's surface is extremely fine in nature and has the tendency to settle onto spacesuits due to Van Der Waal's forces (Geoffrey A. Landis, 1998). As a result of its small grain size, Martian dust is more likely to be absorbed into the bloodstream and cause lung irritation (Wang *et al.*, 2025). The presence of perchlorates, silica and trace amounts of toxic metals makes the dust dangerous and exposure can be life-threatening (Wang *et al.*, 2025). Dielectrophoretic forces have been tested with 95% performance in terms of clearing dust which is in direct contact with the Electrostatic Removal Device (Benjamin M. Griggs, *et al*. 2024). In this system, dielectric particles present in the Martian dust are subjected to a non-uniform electrostatic field, leading to a force being exerted on them. However, this system has not yet achieved dust removal on the constituent materials of present spacesuits

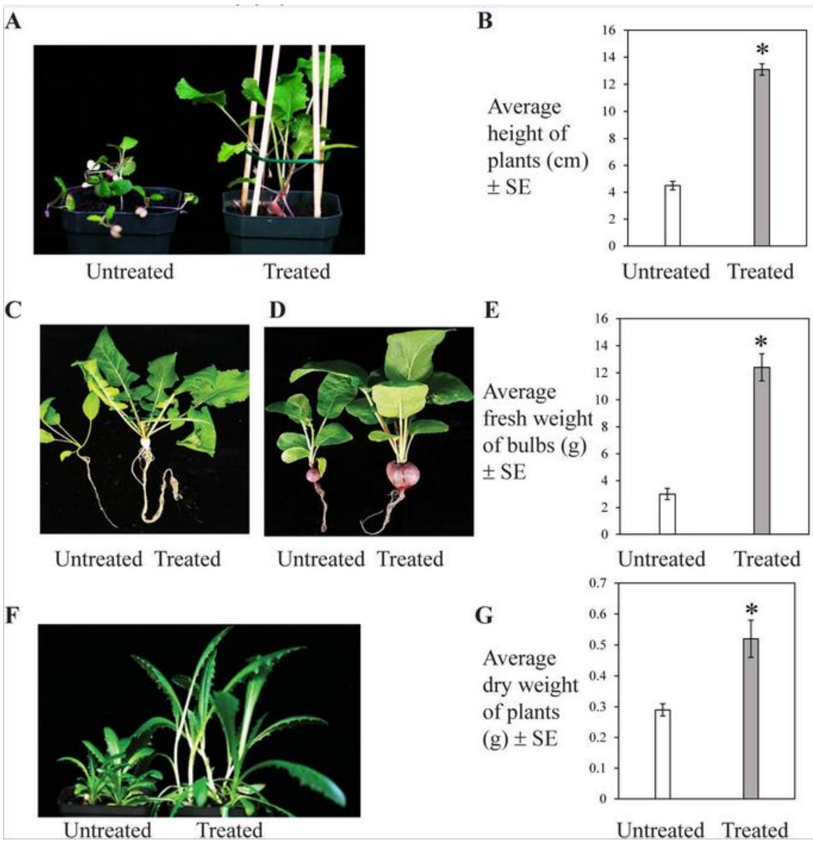
(Benjamin M. Griggs, *et al*. 2024) meaning there is more development and testing required before the technology is functional to the degree required.

Thus, the requirements for a Mars suit are as follows: supplying astronauts with oxygen while also protecting them from the dangers of extremely low atmospheric pressure, solar radiation, and corrosive dust. While there is currently no spacesuit or prototype that can perform all these functions, several prototypes are in development. Therefore, our ability to colonize Mars directly depends on the successful development of a spacesuit that can ensure the safety of astronauts while on the surface. Given the ongoing development and testing of MOXIE, hydrogenated BNNTs and electrodes to remove Martian dust, survival on Mars is certainly plausible.

Beyond merely surviving the elements, obtaining food and water are also necessary for the establishment of a colony on Mars. Food can be transported directly from Earth, grown on Mars, or a mix of both. If we use our estimate of 110 people from earlier, it becomes clear that all food needs cannot be satisfied by simply transporting food from Earth, as doing so will add excess weight to the payload. According to NASA data, dry food per person per day weighs 0.7 kg, and packaging adds 0.5 kg. Thus, the net mass of food and packaging required per person per day is 1.2 kg. Since there are 110 people, if they stay on Mars for two years, the net mass of food required is 1.2 times 110 times 730 = approximately 96 metric tons of food. The Starship rocket has a maximum crew capacity of 100 individuals, and an estimated maximum payload capacity ranging from 100 to 150 metric tons. Thus, there are three possibilities:

- The crew is sent in instalments, reducing the food payload necessary
- Food is pre-sent as part of a separate mission
- Some proportion of the food is sent, and the rest is grown on Mars

Because of the large duration between launch windows, the first two options will require a launch cadence that we have not attained yet. Hence, we consider the third option, which revolves around us being able to cultivate edible crops on Mars. Martian Regolith (the unconsolidated particulate that covers the planet’s bedrock) lacks organic material and is toxic to humans, making it unsuitable for crop growth. Lack of nitrogen, oxygen and necessary sunlight are other challenges opposing the growth of crops on Mars. Promising research has shown that Martian Regolith is not impossible to farm on. Intercropping, or growing different crops close together, has been used to grow Peas, Carrots and Tomatoes in a Mars Regolith simulant (Wamelink, 2024) produced by researchers at NASA, which is a “near perfect physical and chemical match” to the real Regolith. While the Peas and Carrots suffered detrimental effects, with improvements, the intercropping method can be optimal for food growth in Mars colonies. (Gonçalves *et al.*, 2024). A second study demonstrated how Alfalfa plants grow even in nutrient limited Regolith simulant soil (Kasiviswanathan *et al.*, 2022). The Alfalfa was also demonstrably used as a biofertilizer, sustaining the growth of Turnip, Radish, and Lettuce in the Regolith simulant soil (Kasiviswanathan *et al.*, 2022). The graph below shows the growth comparison between Turnip, Radish and Lettuce treated with the Alfalfa biofertilizer versus without. For all three species, the plants which were treated with the biofertilizer had greater dry mass, greater fresh weight of bulbs and higher average height (Kasiviswanathan *et al.*, 2022).



Water is the next essential component to survival that must be satisfied if Mars colonization is to be plausible. Mars' lack of liquid surface water means we must turn to other sources for the obtainment of water on Mars. The first is liquid water that has been detected under the surface, and the second is the polar ice caps. In terms of liquid water under the surface, mid-crust igneous rock fractures are hypothesized to be filled with liquid water (Wright, Morzfeld and Manga, 2024). Liquid water is also theorized to exist in the form of brines – high-concentration solutions of salt – mixed with Regolith. Brine can stabilize liquid water due to its ability to remain a liquid under colder and drier conditions (Hensley, 2024). Brine can be electrolysed to produce hydrogen gas, which is used on missions as rocket fuel. However, while Brine is a potential source for liquid water on the surface, it is not suitable for all uses, being specifically unusable for drinking and agricultural processes. Desalination of Brine is a promising area that could yield water suitable for agriculture and drinking, thus meeting the water needs of a Mars colony. Research has shown that the *Synechococcus sp*. PCC 7002 marine cyanobacterium can desalinate Brine, and this desalination is enhanced if the Brine is filtered through basalt-type volcanic rocks (Kasiviswanathan *et al.*, 2022). This desalination will enable the use of Brine for irrigation.

For potable water, we may have to turn to the polar ice caps. The northern pole of Mars is primarily water ice, believed to be around 3 kilometres thick. However, this ice is locked into permafrost (Jakosky, B. M *et al. 1992*) which is frozen soil/sediment, making the water significantly more difficult to extract. Drilling systems for extracting water from ice caps are in development, notably Honeybee Robotics' "RedWater" concept (David, 2024). RedWater involves the use of coiled composite tubing (CT) for drilling and RodWell technology for water extraction. After reaching an ice layer, the drill continues for three meters and then heaters are activated. A peristaltic pump moves the water up to the surface. (Zacny *et al.*, 2019). While feasible, this extraction process is both time consuming (Zacny *et al.*, 2019) and requires significant energy.

An alternate way of extracting water from ice is using Calcium Perchlorate, which has been demonstrated to "melt" water ice (Fischer *et al.*, 2014). However, the toxicity of the substance means this water will require treatment like reverse osmosis (*Perchlorate in drinking water Frequent questions | US EPA*, 2024) before use. Another system utilizes microwaves to heat Martian soil to temperatures between 200^0C and 500^0C, allowing extraction of water in vapor form (Colorado School of Mines *et al.*, 2001). Thus, water on Mars can be extracted in a variety of ways, but each of them requires some form of processing or treatment to make it fully usable.

Energy generation is the final aspect of Mars colonization. Energy, specifically electricity, is required to run and operate the entire colony, including but not limited to: life support systems, communication systems, vehicular equipment, and scientific equipment. It is unlikely that fossil fuels exist on Mars due to the lack of organic matter on the planet throughout its existence, as well as the lack of tectonic movement required to create the conditions conducive for formation of fossil fuels. ('On the Prospect of Fossil Fuel on Planet Mars,' 2023). Therefore, we will have to turn to Solar or Nuclear power (Bartelds, Alies 2025) as an energy source for a Mars colony. In terms of Solar Energy, it has already been used for some of the Mars rovers. However, the problems faced by the Mars rovers using Solar Energy underscore the problems which would be faced by a Mars colony entirely reliant on Solar Energy. The planet's distance from the sun reduces light intensity compared to on Earth and dust deposition reduces solar array performance (Landis *et al.*, 2004). As with all solar-powered systems, energy can only be generated during daylight, leading to varying output. Solar energy has been used previously on Mars with known shortcomings, and nuclear power is a potential solution to some of them. NASA has selected nuclear fission power as the primary surface energy generation source for Mars missions. Radioisotope power systems have already been successfully used on the *Curiosity* and *Perseverance* rovers. For higher energy needs, fission power will have to be used. Nuclear power maintains a consistent output regardless of day-night cycles and the systems fit well in spacecraft (NASA, 2024). One challenge facing nuclear power is the removal of waste heat. Valuable water cannot be wasted on removing heat, and the thin atmosphere makes convection ineffective. Radiators may provide a potential solution.

All in all, there are several developments that must happen before we can even begin to consider colonizing Mars. New materials to protect us from extreme conditions still need to be developed and extensively tested so that astronauts are not at risk every time they step out on the surface. Rockets capable of making the titanic journey must be engineered, tested, and improved. Agricultural methods must be demonstrated successfully enough to support a community of astronauts, and we must be able to generate energy such that we can truly colonize Mars for the betterment of humanity. Mars colonization is without a doubt the most ambitious and challenging project humanity has ever undertaken, but if there is one thing we have proven time and time again, it is that no problem is insurmountable. We have broken barriers. We have invented flying machines, supercomputers, genetic engineering, and other concepts that would seem like magic if our predecessors were to experience them. So if these achievements are any indication, we may colonize Mars just yet.

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