Introduction to

The Steel Seeds Plan

to Start Human Settlement of Mars

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Introduction

There have been many more or less serious plans to colonize Mars, or just put humans on it.

The first noteworthy one was from Wernher von Braun (1948, 1953). It used a fleet of ten interplanetary spaceships to take seventy people to Mars and put them on its surface. The fleet would have been constructed in orbit around the Earth and 1000 three-stage rockets would have lifted everything up to the orbiting construction sites. Von Braun pushed for funding of a similar plan after the Apollo missions ended but was famously snubbed around Washington.

US President G.H.W. Bush ordered a plan to be written in 1989. This plan was called variously the Human Exploration Initiative, the Space Exploration Initiative (SEI) and the 90-Day Report (NASA 1989). Although this plan stated one of its goals was to get humans on Mars, it was not really a plan to go to Mars at all, but, rather, it laid out a smörgåsbord of goals and program outlines for potentially interested parties in Washington. This initiative's extremely high price tag ensured its quick demise in the US Congress and this demise consequentially set-off a long-term shift in how the National Aeronautics and Space Administration (NASA) has operated.

Spurred on by problems with the SEI, Robert Zubrin and David Baker developed an alternate plan called Mars Direct (Baker and Zubrin 1990; Zubrin 1996). Mars Direct was the first plan to feature pre-positioning of useful manufacturing assets on the surface of Mars prior to the arrival of humans on long-stay[1] missions on the Red planet. These assets would manufacture rocket propellant and oxygen using local Mars resources, which is an example of in-situ resource utilization (ISRU). Mars Direct was the first Mars plan to give detailed proposals of ISRU implementations for Mars. Mars Direct also required that a habitat unit ("hab") with a high mass (~40,000 kg) be landed on Mars in one piece. This land-a-giant-object-in-one-piece feature of Mars Direct meant it could not be implemented in the 1990s, the 2000s or now in the 2010s.

Buzz Aldrin (2008) has called for Mars settlement in which settlers should go to Mars with no intention of returning to Earth but with some capabilities to return, rather like the seventeenth century colonial settlers of the American colonies that eventually became the United States. Buzz Aldrin also had one of the most creative ideas for transport between Earth and Mars, variously called the Mars Cycler, Aldrin Cycler and Cyclic Trajectory Concept, in which a spacecraft continously cycles back and forth between Earth and Mars and in which payloads are sent up and dropped off from the cycling spacecraft (Aldrin 1985). Whether or not this cycler idea will be implemented is currently unclear.

One recent Mars plan, from a NASA working group, would land the first humans on Mars not as settlers but as brief visitors (Naderi, Price and Baker 2015). This plan needs space vehicles, such as the Space Launch System (SLS), which are under development by long, established aerospace contractors.

When discussing plans to go to Mars and colonize Mars in July of 2016, there is a giant in the Mars community, Elon Musk, who is enormously influential at driving what might happen or will happen regarding the colonization of Mars. His rocket company, Spacex, has rapidly growing capabilities for sending cargo to Mars and landing cargo on Mars. Elon Musk is committed to colonizing Mars either in partnership with government agencies or, if necessary, through private efforts led by himself and Spacex (Musk 2012). In addition, the capabilities of Spacex, Tesla Motors (Mr Musk's car company) and OpenAI (an organization researching artificial intelligence (AI) that Mr Musk funds), for carrying out colonization operations on the surface of Mars are unknown but might already be substantial and they are likely to grow to become very substantial. What is meant by that is that (i) Spacex, Tesla and Open AI have a wealth of hardware and programming skills and resources that can be applied to automated manufacturing and running semi-autonomous robots in digitally described environments, (ii)

[1] Over an Earth year.

these technical capabilities will be key for establishing a first Mars base or seed settlement. Mr Musk has announced that he will be presenting plans for the colonization of Mars at the International Aeronautical Congress in September 2016 (Musk 2016). His plans can have some flexibility through the array of capabilities that his companies and their partners have, or will soon have; however, he has indicated the importance of new, very large, reusable rocket boosted transporters that will, early on, transport a lot of equipment on to the surface of Mars and, as time progresses swap to transporting more people and less equipment (Musk 2012; Musk 2016).

On Mars, basic human life requirements, like breathing, will be enabled and sustained by technology, such as pressure vessels that contain interior living spaces and pressurized suits for walking around outside. Very often this technology will be vital, that is, on Mars humans will die without appropriate sustaining technology. This will also be true for the animals, plants, fungi, bacteria and other organisms that get transported from Earth to Mars. Again, on Mars, life will be enabled and sustained by technology.

Although discussions of the settlement of life on Mars often focus on rocket launchers and space ships, the settlement of life on Mars is becoming a big subject with many facets. Two of these facets might be called 'the seeding and germination of human settlement on Mars.' What is meant by this phrase is the landing on Mars of collections of equipment capable of mining, making and building useful things on Mars, along with the early operation of this equipment, to grow the capabilities of the equipment and its output to enable and sustain first human life on Mars, and, also, after the first people land on Mars, the immediate continuations to keep sustaining human life, and grow the life enabling and sustaining technological infrastructure, and increase the number of people living on Mars.

A question arises, what technology should be landed on Mars for the seeding and germination of human settlement of Mars?

This draft plan proposes a specific answer: Redundant collections of equipment, and robots, capable of (i) generating electricity, (ii) mining iron ore, (iii) processing the ore to make fine steel powder, generate oxygen and liberate bound water, (iv) fabricating finished steel products, including spare parts, building structural elements and panels, as well as building fittings and fixtures and more, (v) carrying out repair and maintenance by the robots of themselves and of other pieces of equipment, (vi) making, on Mars, mostly steel, small, solar parabolic dish power units for additional thermal and electrical power generation (also large dishes with human assistance), (vii) making, with assistance from people on Mars, robotic steel trucks, with mostly steel engines, and starting truck fuel/rocket propellant production to establish muscular ground transportation and abundant water collection, (viii) making, with some human assistance, additional pieces of equipment for gas compression, ceramics and glass manufacture, soil improvement, fertilizer production and more. Re-phrasing the answer from describing the equipment and robots in terms of their capabilities to describing them as specific pieces of equipment, a single collection of equipment and robots would include the following (a) power units, or unit, which are most probably solar photo voltaic (PV) panels, (b) units for reducing iron and other transition metal oxides to metal and oxygen (and also liberating some bound water), (c) units for final refinement and powderization of the reduced iron and minor transition metals (collectively Martian steel powder) (d) a small, modular, gang-able Martian 3D metal powder printer, (e) a set of spare parts which are hard to make on Mars from steel, (f) a (somewhat smart) roving robot with at least two mechanical arms and multiple arm-end attachments. The plan needs multiple sets of these individual collections of equipment and robots to supply redundancy, to supply multiple robots which can then take and make collective actions and operations (including complicated repair and maintenance actions), to gang together several small, modular, Martian 3D metal powder printers into one printer with a large build bed.

Some practical points about such seed collections of equipment and robots include: (a) they can be made, (b) they can be operated by the robots with only occasional guidance from humans, (c) they can be made compact and light (using very little mass), (d) because of their compactness and small mass, a single collection of equipment and robots can be easily transported onto the surface of Mars in a relatively small landing craft (if necessary). This last point allows some implementations of this plan to avoid the land-a-giant-object-in-one-piece feature of several previous and current plans. This is potentially very important for removing obstacles and delays that have occurred, and may well yet occur, in the development and funding of any very large systems required to implement land-a-giant-object-in-one-piece on Mars.

These redundant collections would work on Mars for at least two Earth/Mars synodic periods,[2] *i.e.* a 2 x 780 days, prior to the arrival of the first humans but this preparatory period could be extended to as many synodic periods as needed to properly prepare for the safe arrival of the first humans. Further, each synodic period after the landing of the first settlement collections of equipment and robots can include the landing of extra supplies, spare parts and equipment as will be necessary for settlement success.

Another important point arises out of the plan's scheduling possibilities: The longer a seed collection of equipment and robots is up and running on Mars the more valuable it becomes. This is because the total mass of all the useful, finished steel objects produced by a collection increases linearly with the amount of time the collection is up and running (the same is true for the total mass of oxygen generated by the same collection). In fact, the value increases more than linearly with the amount of up-time, since some of the steel objects made by a collection will be put to uses, like making solar parabolic dishes, that themselves increase overall capacity and capability: This kind of growth is properly exponential. So, growth of the value of infrastructure stemming from a single collection of equipment and robots will be exponential growth in the operating up-time of the collection. One way to think of this is that a relatively, small and inexpensive (in Earth dollars) group of collections of equipment and robots will eventually produce very high value results on Mars, so long as these collections are kept operating for long enough.

It is a key idea of the Steel Seeds Plan to structure all the plan's components such that the average working life of a collection of equipment and robots is long and very useful and valuable. To this end the plan builds in (a) redundancy, (b) steel spare part manufacture on Mars, (c) occasional spare part deliveries from Earth and (c) teams of robots with the mechanical and computing abilities to perform repair and maintenance tasks.

The combination of iron ore mining, ore to steel powder processing and finished steel part manufacture can collectively be a core technological capability, quite possibly *the* core technological capability, for the seeding and germination of human settlement on Mars. This technological capability enables the start and growth of extra power generation, water collecting and manufacturing capabilities, which, will start an upward spiral in life-sustaining capabilities. The net output from, steel-making, oxygen generation, steel fabrication and muscular water collection and can provide the large majority of the mass of all the useful technological objects, liquids and gases that will be needed to enable and sustain human life on Mars in a first habitat and workshop.

The literature on steel-making on Mars is, at the moment, quite limited. Molten metal oxide electrolysis research has been carried out, with NASA funding, for the purpose of generating oxygen on the Moon (Curreri *et al.* 2006; Vai *et al.* 2010). Such electrolysis splits metal oxides to produce both

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[2] The main launch windows for flights from Earth to Mars are separated by an Earth/Mars synodic period, which is very close to 780 Earth days in length.

oxygen and metal, the American Iron and Steel Institute funded a feasibility study to see whether molten metal oxide electrolysis could be practically implemented to produce iron (AISI 2005). Shaun Moss (2006) reviewed steel-making methods and techniques on Earth and recommended direct reduction techniques for Mars steel-making. Some prominent people have also made brief talking points on iron and steel-making on Mars.[3]

The rest of this plan draft is organized into sections as follows. **Capable, Slightly Smart Robots:** A description of the capabilities and specifications of the robots needed for mining ore and the operation of other pieces of equipment. **Massive Masses, Repair and Maintenance:** This section covers considerations of the mass of things, and how and why mass considerations should factor into the design of a plan for seeding and germinating the human settlement of Mars. **Mars Dust and Mars Sand (Regolith):** In this section the composition of Mars dust and sand is looked at with the benefit of detailed sand and dust composition data gathered by NASA robotic rovers *Spirit*, *Opportunity* and *Curiosity*. In addition, an initial discussion is given of how this sand and dust might be very useful as a potential ore for steel-making, ceramic and glass manufacture and also for agricultural soil. **Martian Regolith: Iron Ore and Enrichment:** This section reviews how iron ore mining and iron ore enrichment (beneficiation) is done on Earth. This review serves to shows how very good it is to start iron ore mining and enrichment on Mars with an ore in sand or dust form. This is important for making small-scale steel-making on Mars mechanically feasible, as the small robotic rovers have only a little mechanical muscle. The section also points to specific sand dunes on Mars which are likely to be especially good for iron ore mining. **Steel-powder Making from Enriched Martian Regolith Ore:** This section discusses the processes and equipment needed for the small-scale conversion of enriched, sand/dust iron ore into fine steel powder that is suitable to be used in three dimensional (3D) metal powder printing machines. **3D Metal Printing Machines on Mars:** This section discusses 3D metal printing machines on Earth and on Mars and the significant differences between such machines on Earth and Mars. The first 3D metal printing machine on Mars will have especially low mass and low power consumption per unit printing bed area in comparison to those on Earth. Also, the first Martian machine will have a printing bed that is especially long. **Growing Power Generation Capacity:** This section discusses developed power generation technology, *i.e.* solar parabolic dishes, that can provide either thermal power or electrical power on Mars that can be made almost entirely out of steel parts, that can be fabricated on Mars by the first 3D metal powder printer using steel powder made from Martian iron ore. So that, early human settlement of Mars can have all the thermal and electrical power it needs to grow, if it starts steel-making and fabrication early. **Collecting Water, Muscular Ground Transportation:** This section discusses water sources on Mars, including the lack of certainty about abundant water sources in the most desirable, equatorial regions for living. The section also points out that large capacity trucks can be built locally on Mars from steel and also their engines and the solar powered systems needed to produce suitable fuel and oxidizers to run the truck engines. The introduction of a muscular transportation capability can then be used for all sorts of things including overcoming likely water supply problems by providing the capability to use distant water sources. **Making Other Equipment, Doing More Things:** This section gives a brief outline of other equipment that can be made on Mars using Martian

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[3] Robert Zubrin was quoted saying "Iron oxide and silicon oxide are also common in Martian soil, so human pioneers would be able to make iron, steel and glass" (Wall 2013); while answering a conference question Elon Musk (2016) stated that if large numbers of people and goods were transported to Mars that this would create tremendous opportunities "for everything from creating the first iron ore refinery to the first pizza joint to something that does not exist on Earth."

steel and what this other equipment can do to make more useful things on Mars from local Martian ore resources. **Summary**: The summary gives a compact, outline of the Steel Seeds Plan for seeding and germinating the human settlement of Mars. An appendix to the section on Martian 3D metal printers, **Oxidation of Fine Steel Powder in the Martian Atmosphere**, is included.

The rest of the draft plan can be requested by emailing Rif Miles Olsen at rmo@twoplanetsteel.com .

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