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TOWARD A PERMANENT PRESENCE ON MARS*

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INTRODUCTION

Manned missions to Mars will probably be implemented soon [1]. However, are we going to send people there, explore, make some experiments, bring the astronauts back to Earth and finally wait several decades or even more before going to the red planet again in order to start a permanent settlement? Two aspects of the question have to be considered.

First, scientists, politics and economists are rather interested in the short-term. They usually want quick results and rapid return on investment. The most probable strategy is therefore a fast and short exploration, paying only attention to the scientific data and leaving to the successors the formidable investment of the first steps of the colonization.
Second, it is not clear whether the support of permanent bases would be strong, costly and would last several centuries or if it would be possible to settle the red planet and to establish self-sufficient bases in few years [2].

From a pragmatic and also financial point of view, if a permanent presence is sustainable and desirable, it is important to think long-term and to minimize the number of trips to Mars. However, in order to convince the deciders that a permanent settlement should be the main objective of a Martian program, the main steps and the total investment should be clearly stated.

The sustainability of the first Martian bases is therefore important and is addressed in this paper. It is assumed that several missions, probably crewed, will be sent to Mars prior to any endeavor for a permanent settlement in order to define the most appropriate location, to test different technologies and to assess the living conditions on the red planet. The problem of the sustainability of the base will be addressed in a second phase. There are basically two different strategies. The first one is to use high-technology devices to build the main infrastructures, grow rapidly and achieve partial autonomy, but relying on complex tools that could not be repaired or rebuilt on Mars. The second is to use more simple tools, which would not allow fast growing, but would make it possible to repair or to rebuild objects using local resources. Issues concerning energy, transportation means, construction and mining capabilities as well as the development of a basic industry are discussed.

FAST DEVELOPMENT SCENARIO

Needs and choices

In order to expand the base as fast as possible, complex tools can be sent to Mars [3]. Some needs are summarized in:

- In the energy domain, it is necessary to supply large amounts of power to different industries, for instance for the extraction and the process of ores. A nuclear power plant would probably be the best choice in terms of power to mass ratio [4].

- A greenhouse also requires a lot of power for growing plants. The sun can provide part of it, but since it is half as strong as it is on Earth, a complementary and artificial illumination will be deployed to make farming efficient. LEDs or other lighting devices can be used for that purpose.

- Ores have to be found and exploited to build other objects and expand the base. Long range pressurized rovers will make it possible to go far and explore the surface in an efficient way.

- New structures will be built for storage, habitation, industrial development, research, etc [5]. A bulldozer for clearing and a crane for carrying would probably be chosen to make it easy and fast.

- In order to extract water or to get access to underground mines, a drill is required. Then, if large quantities have to be carried, a truck is also needed.

- Metallurgy is probably a key industry to achieve self-sufficiency on Mars though plastics might replace metals in many cases [2]. Several furnaces will therefore be used for the production of iron, aluminum and other metals.

- Automation is a key issue for the maintenance of the base. There are too many complex objects to handle and too few human resources. Robots and computers can be used for different tasks, in particular for the maintenance and the expansion of the base. For instance, automation can help for drilling, farming, for chemical processes or for the surveillance and control of dangerous or complex tasks.

IMPLICATIONS

Efficient tools are usually high-tech. They cannot be rebuilt by a small community who does not have time and the required facilities to develop the industrial processes. If a specific tool is out of order, the risk is therefore important to lose the tool and the corresponding capability at the same time. For instance, if the pressurized rover breaks down, the transportation means are highly reduced. The problem might be even more critical if the tool is the nuclear power plant or a computer in charge of the control and revitalization of the atmosphere of the base.

All tools have to be built with long lifetime specifications. However, most tools would probably be designed for a maximum lifetime of several years but not decades. It is therefore questionable whether the base will still be habitable, safe and workable after one decade. If the development of the local industry is fast enough, it could be possible to change some defected parts and to build other tools that can partially replace the high-tech ones. Such a fast development is possible if the Martian community rapidly grows, build new facilities and if there is a commitment on Earth to help Martians in the first stages. In particular, vehicles and other critical high-tech tools have to duplicated before they break down. However, how many persons are required to develop and maintain a modern industry? What industrial processes? How much power? How much time? These important questions have to be addressed by engineers to assess the sustainability of a modern Martian base and to determine the feasibility of the fast development scenario.

SLOW DEVELOPMENT SCENARIO

Needs and choices

If all tools can be rebuilt, the autonomy of the base is achieved and a permanent settlement is possible. The concept of a slow development is to increase the autonomy of the base by minimizing the number of high-tech tools that cannot be rebuilt using in-situ resources. The tools are chosen according to the reparability, the rebuild capability and the lifetime as it is suggested in . The question of their suitability to the sustainability of the Martian base is discussed in the section 3.2.

- In the energy domain, a nuclear power plant would not be appropriate, because it can not be easily repaired and maintained. Solar panels and windmills are better solutions. They can be easily built using in situ resources, even though the efficiency of both systems would be much less than the ones on Earth. Silicates are abundant on Mars and the production of silicon does not require high-tech technologies. Similarly, a windmill can be built from aluminum, iron, or even plastics elements. When the sunlight is absent (typically at night) and the wind is weak, other techniques have to be used to store or to supply energy. There are solutions if the requirements are not too strong.

- For the production of food by plants, the efficiency of the system mainly depends on the amount of light that is available. In order to avoid high-tech devices for lighting, it is possible to build reflecting mirrors, which would help in concentrating the sunlight on the greenhouse. The efficiency of the system is questionable but the saving in terms of energy is high and it is a key issue if simple technologies are used for energy supply.

- An important problem is the use of high-tech vehicles for transportation. All engines are complex and can not be easily repaired. It would be even more difficult to build a new one. Other parts of a vehicle are complex. Onboard automation can be reduced and mechanical structures can be simplified, but it is doubtful that any vehicle could be built on Mars without a modern industry. The simplest vehicle is the bicycle, eventually with three or four wheels. It is perhaps possible to build one using in situ resources and by means of simple industrial processes. However, such a vehicle can not help in transporting heavy loads and moving far and fast.

- For construction and mining, human strength and simple tools like picks, levers, ropes, can be used. However, the work would be very slow. Simple tools can easily be repaired or even rebuilt but at the expense of the efficiency of the task.

- In the metallurgy domain, it is possible to avoid high-tech furnaces if low quality metal is acceptable. In most cases, the quality of the metal is indeed not very important.

- Computers and other electronic devices probably are the most high-tech tools. Many of them improve our ability to measure, detect or process something, they can be replaced by simpler tools. Simple computations can be done by hand instead of using a computer. However, some electronic devices are part of the life support system, the spacesuit, the rover, etc. They play an important role and they can not be replaced by other tools.

IMPLICATIONS

In many cases, it is possible to avoid the use of high-tech devices. However, this strategy cannot be applied to all objects. The life support system, the spacesuit and the vehicle are typical examples [6]. If it is desired to achieve self-sufficiency, all high-tech tools should be resent to Mars during the expansion of the base to replace the defected ones. Since the number of high-tech tools is small, this strategy is not very costly in terms of payload and number of missions to the red planet. On the other hand, the development is very slow because of the simplicity of the tools. It would take time to build roads and facilities, to implement industries and finally to achieve self-sufficiency.

However, the most critical part of this scenario might be the survival on Mars. If the tools are not efficient and if time is a constraint, there are a number of tasks that might become unfeasible or impractical:

- Access to water if it is deep under the surface
- Food production by plants (what would happen if there is a long sand storm and insufficient sunlight?)
- Access, extraction or transportation of ores (too far or too complicated)
- Not enough energy for specific needs (processing of aluminum ores for instance)

The risk of the slow development scenario is to fail because of the poor quality of the tools and misconceptions in the rebuild capabilities. For instance, the Martian crew might not be able to reach an interesting zone for mining if the rover is not pressurized and designed for long range mobility, solar panels might not supply enough power for industrial processes and the quality of spare parts might be uncertain if the metallurgic process is not driven by high-tech sensors and devices.

This scenario is therefore risky and would take time. Is the risk acceptable? How much time is needed to grow the base and implement a modern industry, which would produce complex tools such as electronic devices? How many missions to Mars? Is it realistic?

TRADE-OFF

In the fast development scenario, it is suggested that many high-tech tools would be used, which would break down at some point. Therefore, numerous missions to Mars would have to be designed during several decades with high payloads to replace the defected objects.
In the slow development scenario, the number of high-tech tools is minimized. The payloads of the next missions are therefore lighter but the development of the base is much slower and the survival is more difficult.

A trade-off can be envisaged.

- In the first phase, high-tech tools can be sent to Mars to speed up the expansion of the base and implement the first industries. A nuclear power plant is typically used to supply energy, and cranes, bulldozers, trucks, drills, etc. help in the construction process or transportation of heavy loads. At the same time, a slower development using more simple tools is prepared. If water is hardly accessible, a high-tech drill is used. If a mining site is far, a road is created to facilitate the access and several refuges are built on the way. Solar panels and windmills are massively built using in situ resources to prepare the stop of the nuclear power plant. New habitats, factories, facilities, roads and greenhouses are built at this stage, even if they are going to be used much later.

- In the second phase, one or two decades later, cranes, bulldozers, trucks and most complex tools are out of order or not reliable. Most of them are not replaced because it would cost too much to send such heavy objects once again to the red planet. However, the most critical elements of the base are built and simple tools can now be built and used instead of the high-tech ones. A slower development of the base can begin. New crews are regularly sent to Mars in order to help in the maintenance and the implementation of new industries. The nuclear power plant is stopped when its lifetime is ended and other energy sources are used. In greenhouses, artificial lighting is replaced by reflecting mirrors to enhance the lighting conditions.

CONCLUSION

It is difficult to establish a clear strategy for the first stages of the settlement of a Martian base. A trade-off between a fast and a slow development has been proposed. The idea is to send to Mars many high-tech tools and machines in order to be able to build quickly all the necessary infrastructure for the construction of roads, habitats, facilities, water wells, greenhouses, mines, etc. In a second phase, one or two decades later, high-tech tools and machines are replaced by more simple ones to prepare a slower development. All problems are not solved and the proposed trade-off is probably still naive. However, if it is desired to go to Mars and to build there a permanent and self-sufficient base, it is important to address the problem of the sustainability and to determine the best strategy to achieve this goal. The objective is to avoid that humans just explore Mars and never settle there. It is also to define a clear, coherent and long term perspective in the space policy.

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Table : Choice of tools and reparability implications for the fast development scenario.

Domain	Needs	Choice	Reparability / Rebuild capability	Lifetime (years)
Energy	100 kW	Nuclear power plant	low	5-10
Food	Efficient farming	Greenhouse + LEDs to improve lighting conditions	low	5-10
Transport	Long range transportation Heavy loads	Heavy pressurized rover	low	5-10
Construction	Strong lifting and clearing capabilities	Crane	low	5-10
		Bulldozer	low	3-10
Mining	Drilling and transport capabilities	Drill	low	3-10
		Truck	low	5-10
Metallurgy	High temperature and pressure	Furnace	high	10-20
		Sensors	low	3-10
Automation	Automatic information processing	Automatons, computers	low	3-10

Table : Choice of tools and reparability implications for the slow development scenario.

Domain	**Needs**	**Choice**	**Reparability / Rebuild capability**	**Lifetime (years)**
Energy	10 kW	Solar panels	high	10-20
Food	Farming	Greenhouse + reflective panels	high	10-20
Transport	Slow transportation light loads	Simple rover Bicycle	low high	5-10 10-20
Construction	Lifting and clearing capabilities	Human strength, pick, lever, rope	high	10-20
Mining	Drilling and transport capabilities	Pick	high	10-20
		Wheelbarrow	high	10-20
Metallurgy	High temperature and pressure Low quality metal	Furnace	high	10-20
Automation	Automatic information processing	Human intelligence	low	30-50