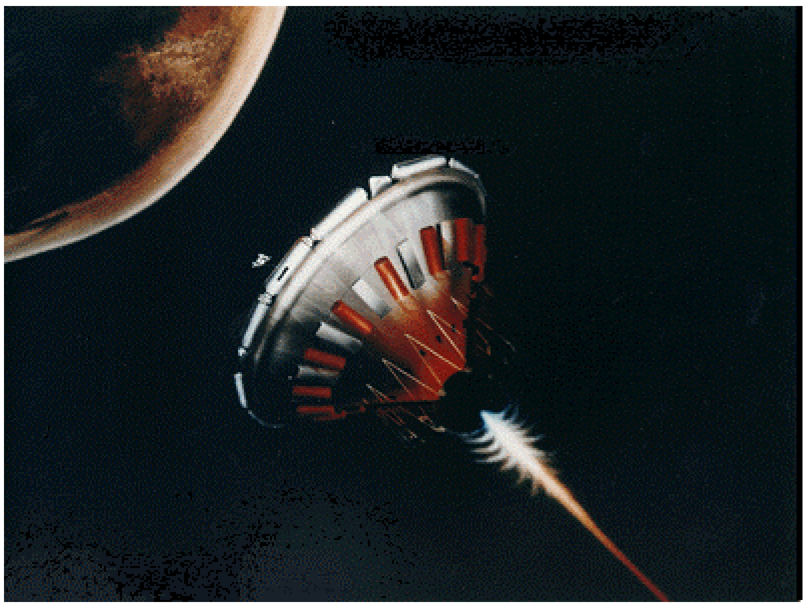
Magnetically Targeted Fusion for a Human Mission to Mars



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Even though humans have had strong interest in Mars for centuries before the achievement of human space travel, a human has yet to explore this mysterious planet. The lack of adequate propulsions is the main reason a human hasn't been to Mars. This report will discuss why a human should go to Mars and some of the possible ways one could get there. Then this report will focus on how fusion propulsions, specifically magnetically targeted fusion, could accomplish this mission.

Contents

Executive Summary 1

Introduction	3
Reasons for Further Mars Exploration	4
The Mars Meteorite	5
The Past and Future of Mars	6
Comparison of Propulsions	7
Types of Fusion Confinement	8
Magnetic Confinement	9
Inertial Confinement	10
Magnetically Targeted Fusion	11
The MTF Liner	12
Target Plasma for MTF	12
Cost of MTF vs Other Fusion Concepts	13
Conclusion	13
Appendix: A Table of Past Unmanned Missions to Mars	15
References	16

Executive Summary

It has been thirty years since a human first landed on the moon, but a human has yet to set foot on Mars. This is in spite of the fact that many people feel it is important to learn more about Mars. Some would like to know whether the fourth planet from the sun was once similar to our planet, and, if it was, why it isn't any longer so the same fate does not come to Earth. If this tragedy could not be avoided, others are curious to know if we could try to make Mars habitable for humans. To add to these concerns about the possible past and future lives of the Red Planet, a

meteorite from Mars has been found on Earth that contains microfossils, very much like bacteria native to our planet.

People's interest in the possibilities of life on Mars isn't the only reason to send a man there. In 1991, President Bush set forth an initiative to have a human land on the fourth planet by the year 2025. But to achieve this goal, one must consider the different propulsion systems that would best suit the mission.

With current propulsion systems, an average round trip to Mars would take about two years to complete. Currently, the longest human has spent in space is about a year, and the few that have stayed in space for comparable durations have suffered some physical and mental problems. Therefore, the propulsion best suited for a mission to Mars would be the one that would allow the lowest travel time.

The travel time is mainly affected by two parameters: the specific impulse and the jet power. The greater that either one of these are, the shorter the travel time will be. The propulsion system that could provide the highest values of specific impulse and jet power, and thus a much shorter round trip travel time of a hundred days, is inertial confinement fusion. The next lowest travel time a propulsion could allow is one hundred and sixty days, which could be provided by magnetic confinement fusion.

But there is a type of fusion that combines the desirable qualities of magnetic and inertial confinement fusion: magnetically targeted fusion. This type of fusion uses a liner to compress plasma, while a magnetic field minimizes thermal losses. Magnetically targeted fusion could provide a faster and much cheaper approach to fusion energy, and it appears that the benefits of this type of fusion could allow humans to achieve a manned mission to Mars by the year 2025, and then beyond.

Introduction

Although few people might realize it, humans have studied Mars as far back as 400 BC. The Babylonians first studied this planet that they called Nergal, after the king of conflicts, for religious reasons. Then Egyptians discovered that several objects in the sky, including Mars, moved in similar manners, or in orbits. These people were the first to give the planet the nickname of the Red One. But the Romans were the ones who gave the fourth planet from the sun the name Mars, after their god of war ["History," 1997-1999].

In the seventeenth century, after Galileo invented the microscope, people could start researching Mars in more detail. A Dutch astronomer named Christiaan Huygens was the first human to map Mars. His observation of the southern polar ice cap triggered him to write *Cosmotheros*, a paper that discussed requirements of life and also the speculation of intelligent extraterrestrials. This paper caused other people to ponder the existence of life on Mars because of the presence of ice on the planet, since water is considered to be the main building block of life [Goldsmith, 1997].

After a few more centuries of telescopic research of Mars, the evidence of life on this planet is still inconclusive. If there is life, it must be either lying beneath the surface or too small to see with current technologies because scans of the surface yielded no results. That is why humans started sending spaceships to Mars, to get a closer view of the planet and to get soil samples in order to continue the investigation of life on the Red Planet (for information on these unmanned missions, see the Appendix). Unfortunately, these missions did not supply people with the evidence they were looking for. Therefore, the next logical step in the search for life on Mars is human exploration of the planet.

The purpose of this paper is to establish the need for a manned mission to the Red Planet, explore different propulsion systems for this mission, and then focus on how fusion propulsions could be used to accomplish this journey. First, this report will discuss the need of a manned mission to Mars by exploring signs of life on Mars and then the possible past and future of the Red Planet. This report will then illustrate the benefits that fusion propulsions have over other types of propulsions. Next, the two main concepts of fusion propulsion, magnetic confinement fusion and inertial confinement fusion will be explained. Finally, magnetically targeted fusion will be described, and the reasons why this type of fusion could allow a human to walk on Mars by the year 2025.

Reasons for Further Mars Exploration

For centuries, people have researched Mars to try to uncover whether or not life existed, or currently exists, on the planet. Telescopes were mostly used for this exploration of the fourth planet from the sun, but current telescopes cannot detect microscopic life or life hidden below the surface of the planet. But the evolution of the rocket put exploration of Mars into new perspective. Many unmanned missions have been sent to either fly by the planet or land on the planet in order to continue research. Of the few missions that have succeeded, the possibilities of life on the Red Planet are still inconclusive.

The Mars Meteorite

Although searching Mars for signs of life have been unsuccessful, evidence on Earth has suggested that living creatures once inhabited Mars. In 1984, a meteorite was found in Antarctica that is believed to have originated from Mars. Scientists believe this meteorite came from the Red Planet due to the gases found trapped within the rock. The gases found in the meteorite match those found in Mars' atmosphere by Viking landers in 1976 ["Mars, Water," 1997-1999].

After the conclusion was made that this meteorite was from the fourth planet from the sun, it was put into a collection of other samples of rock from the planet for further investigation. It was not until 1996 that a person did an extensive analysis of this meteorite, which yielded a shocking discovery. There appeared to be microfossils within this rock, as seen in Figure 1. These microfossils are very similar to bacteria that are found on Earth and are believed to be 4.5 billion years old ["Mars Facts," 1997-1999].

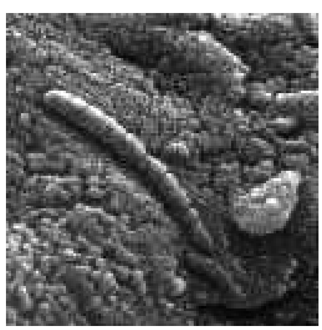

Figure 1. A cross section of the meteorite from Mars. The elongated shape in the center of the picture could be a microfossil [Goldsmith, 1997].

If the structure is a microfossil, it is possible that organisms still exist on Mars. These organisms could be living under the surface, where water could exist to supply life for them. The only way to find out for sure is to conduct subsurface research on the planet.

The Past and Future of Mars

If life did exist on Mars, many people are curious to know what might have happened to it. Since it is believed that Mars and Earth were once very similar, people want to know what changed the atmosphere of the Red Planet so that it could no longer sustain life on the surface. Once the cause of the change in the Martian atmosphere is known, it is hoped that this information will help humans to avoid the same fate from occurring to Earth [Goldsmith, 1997].

Other people are interested to know if Mars could be made to support life in the future. The population of Earth is growing rapidly, and, since Mars is the next habitable planet in the solar system, it is hoped that Earth could avoid overpopulation by finding residence on the Red Planet. But more importantly, if something should happen to Earth that would make it uninhabitable, Mars might become the new home for Earth residents [Goldsmith, 1997].

Whether people are concerned about the events that changed the Mars' atmosphere or the events that may change current conditions on Earth, a manned mission to Mars would be desirable to learn more about the possibilities of life on

Mars. That is probably why, in 1991, President Bush set forth an initiative to have a human land on the fourth planet by the year 2025 [Kammash, 1995]. But to in order to achieve this goal, one must consider the different propulsion systems that would best suit the mission.

Comparison of Propulsions

With current propulsion systems, an average one-way trip to Mars would take about a year to complete [Kammash, 1995]. This is the longest amount of time a human has spent in space, and the few that have stayed in space for comparable durations have suffered physical and mental problems [Goldsmith, 1997]. A mission to Mars would leave people in space for about two and a half years with current propulsions, such as chemical, electrical, or fission propulsions, with two years of this time being spent traveling. So it appears that the propulsion best suited for such a mission would be the one that would allow the lowest travel time.

The travel time is mainly affected by two parameters: the specific impulse and the jet power [Brown, 1996]. The greater that either one of these are, the shorter the travel time will be. Figure 2 shows the specific impulse and jet power that certain types of propulsions can achieve. The propulsion system that could provide the highest values of specific impulse and jet power, and therefore a much shorter round trip travel time of a hundred days, is inertial confinement fusion (ICF). The next lowest travel time a propulsion could allow is one hundred and sixty days, which could be provided by magnetic confinement fusion (MCF) [Kammash, 1995].

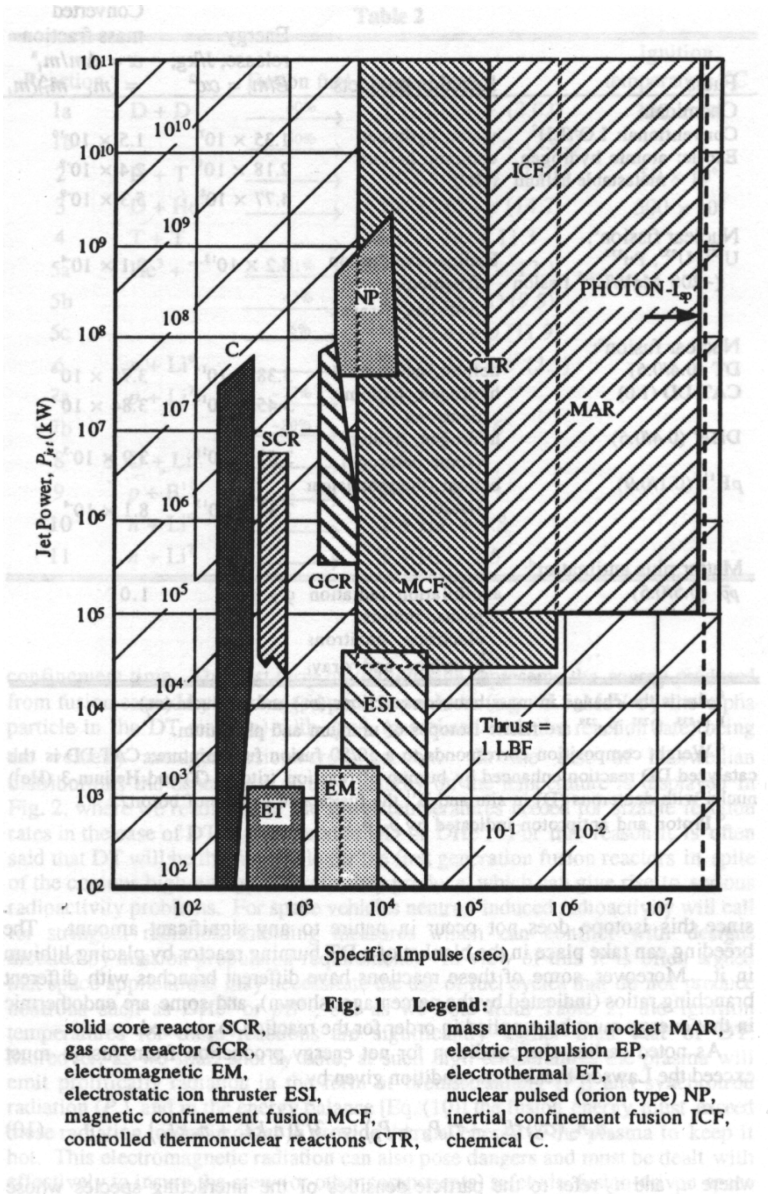

Figure 2. A graph showing the specific impulse and jet power that are achievable by certain types of propulsion systems [From Kammash, 1995].

Types of Fusion Confinement

Although fusion propulsions would be ideal candidates for a short manned mission to Mars, one must consider how to confine the massive energy and heat of a fusion reaction. There are three ways to confine fusion: gravitational, magnetic, and inertial [Krane, 1988]. Gravitational confinement is how stars confine their massive fusion reactions. The star interacts with other bodies in the solar system and allows the fusion process to be confined without the use of a material container. This type of confinement would be ideal, but even if humans could simulate such a method of confinement, gravitational confinement would not be able to lend itself to propulsion applications with much ease. Therefore, this report will discuss magnetic and inertial confinements, not gravitational confinement, and compare the relative costs of each.

Magnetic Confinement Fusion

The fusion process leaves behind plasma, which consists of many electrons and ions. Magnetic confinement makes use of the classical theory that states charged particles will gyrate about magnetic field lines (see Figure 3). The magnetic field lines will therefore contain the plasma formed from fusion, as Kammash states, "much like a bead on a string" [1995]. These electrons and ions will gyrate about magnetic field lines until an energy-producing collision occurs.

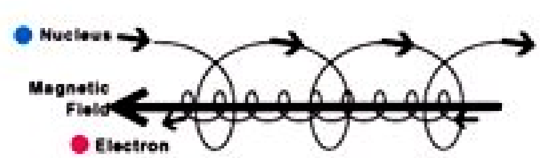

Figure 3. An illustration of how charged particles gyrate about magnetic field lines [Adapted from Kammash, 1995].

Not only will this approach safely contain the hazardous materials that are analogous to nuclear reactions, it also insulates the fuel from the container walls [Kammash, 1995]. If the plasma were to come in contact with the container walls, the reaction will become much less efficient. The plasma is at very high temperatures; so if it was to touch the walls of the container, it would be cooled down, and, accordingly, lose energy. But if the appropriate radius is used in the design of the container, the plasma will never get near the walls.

Lawson took this fact into account when defining a parameter for fusion reactions, which basically states that plasma must be dense enough and confined away from material walls long enough in order to get positive net energy. This parameter is expressed as n_, where n is the plasma density, and _ is the confinement time. For DT reactions at 10keV, n_ = 10^{14} s/cm^3. This requires that MCF has a plasma density of about 10^{14} cm^{-3} in order to compete with other propulsion systems [Kammash, 1995].

This approach to fusion is much more developed than inertial confinement fusion, with a lot of research done with tokamaks. Although tokamaks have advanced our comprehension in plasma physics, it also proved how expensive this approach to fusion can be. The International Tokamak Experimental Reactor has cost estimates of about $10 billion, where a large amount of this is related to the cost of the magnet technology [Siemon, 1997].

Inertial Confinement Fusion

Inertial confinement tries to simulate gravitational confinement with the use of lasers. Much like gravitational confinement, one form of inertial confinement fusion, called implosion, would not need a container. This approach makes use of the fact that reactions take place in nanoseconds during inertial confinement fusion because of a high plasma density of about 10^{25} cm^{-3}. This time period is so small that the reactions could be considered as micro-explosions, and therefore don't necessarily need any type of container [Kammash, 1995]. For safety reasons, some sort of container is used to protect people from the possible escape of radiation or energy from this reaction.

Although inertial confinement fusion is less developed than magnetic confinement, it happens to be a cheaper approach to fusion. The National Ignition Facility, which will demonstrate ICF ignition, is estimated to cost over $1 billion. A majority of this cost reflects the high cost of lasers powerful enough to ignite the plasma.

Magnetically Targeted Fusion

Another form of inertial confinement fusion is Magnetically Targeted Fusion (MTF), which is an approach to fusion that combines the desirable qualities of MCF and ICF. It is basically magnetically insulated inertial confinement fusion. MTF uses the kinetic energy of an imploding liner to compress and ignite a plasma, while a magnetic field prevents thermal losses. MTF is also the mid-point between MCF and ICF in density, and, therefore, according to the Lawson parameter, in time scales [Lindemuth, 1995].

The basic MTF process is as follows: preheated fuel embedded with a magnetic field would be surrounded by a liner, and then a current imposed on the liner would cause the liner to implode on the fuel because of the magnetic forces, therefore causing the fusion reaction [Wurden, 1998]. Therefore, the majority of research in this technology is revolved around designing the liner and target plasma.

The MTF Liner

The magnetically targeted fusion approach is one that has not been pursued much until the last decade or so. The main reason focus has shifted to developing this technology is because of the Department of Energy's advancements in imploding liners [Siemon, 1997]. This imploding liner is basically an aluminum can that would be slammed over the plasma. Although the DOE research has nothing to do with fusion, their facilities provide an advantage in the progress of imploding liners for magnetically targeted fusion, because most of their research can be applied to MTF.

Target Plasma for MTF

A plasma has also been developed by Los Alamos National Laboratories that would be quite suitable for implosion by liners developed by the DOE. The technology for this plasma is borrowed from MCF compact toroid research, and is called field-reversed-configuration. It is believed that this target plasma would apply well with MTF, but most research was done on plasmas with lower densities than are needed for MTF, so work would have to be done with compact toroids at higher densities.

Another type of plasma for use in MTF is being worked on by LANL and Russia called MAGO [Lindemuth, 1995]. This type of target plasma less complicated than compact toriods, and would be fairly compatible with linear implosion. Also, the plasma density of MAGO is more appropriate for MTF than compact toroids.

Cost of MTF vs Other Fusion Concepts

As stated earlier, MTF is intermediate between MCF and ICF in densities and time scales, but it is also between these other two in plasma energy. Even though magnetically targeted fusion is considered to be the combination of ICF and MCF, there is one major difference between the three: cost. The MTF facility that is currently under construction is called ATLAS, and is going to cost about $50 million. This cost is compared to $10 billion for MFC and $1 billion for ICF. The main reason for the dramatic decrease in cost is that most of the money doesn't go towards an expensive magnet or laser.

Conclusion

There are many reasons why humans would like to explore Mars. The main reason would be to finally find conclusive evidence whether or not life did or does exist on the planet. Other reasons are centered on past and future changes in the Martian atmosphere. If it was like Earth's, why isn't it now? Also, could it be made to be similar to Earth's atmosphere in the future? These are questions that can only be answered through continued research of Mars.

Although numerous unmanned missions have been sent to try answering some of the questions about Mars, few have succeeded in their goals. The ones that have succeeded could not provide much more evidence than that that could have been retrieved from Earth with powerful telescopes. That is why a manned mission is being suggested, so that there is more of a chance that some of people's questions will get answered.

A manned mission with current propulsions would take too long, but fusion propulsions could cut this trip time by about a seventh. Further advancements need to be made in these types of propulsion systems in order to make a manned trip to Mars more feasible. If magnetically targeted fusion could be developed, frequent trips to Mars and other planets could be taken to answer the question: "Are we alone in the universe?"

Appendix

Table of Past Unmanned Missions to Mars

Mission Name	Mission Designer	Year of Mission	Mission Purpose	Mission Status
Marsnik 1	USSR	1960	Mars Flyby	Launch Failure
Marsnik 2	USSR	1960	Mars Flyby	Launch Failure
Sputnik 29	USSR	1962	Mars Flyby	Failure
Mars 1	USSR	1962	Mars Flyby	Lost Contact
Sputnik 31	USSR	1962	Mars Flyby	Failure
Mariner 3	USA	1964	Mars Flyby	Failure
Mariner 4	USA	1964	Mars Flyby	Success
Zond 2	USSR	1964	Mars Flyby	Lost Contact
Zond 3	USSR	1965	Earth Lunar Flyby/Mars Test Vehicle	Success
Mariner 6	USA	1969	Mars Flyby	Success
Mariner 7	USA	1969	Mars Flyby	Success
Mars 1969A	USSR	1969	Mars Lander	Launch Failure
Mars 1969B	USSR	1969	Mars Lander	Launch Failure
Mariner 8	USA	1971	Mars Flyby	Launch Failure
Cosmos 419	USSR	1971	Mars Orbiter/Lander	Failure
Mars 2	USSR	1971	Mars Orbiter/Lander	Success/Failure
Mars 3	USSR	1971	Mars Orbiter/Lander	Success/Lost Contact
Mariner 9	USA	1971	Mars Orbiter	Success
Mars 4	USSR	1973	Mars Orbiter	Achieved Mars Flyby
Mars 5	USSR	1973	Mars Orbiter	Success
Mars 6	USSR	1973	Mars Lander	Success
Mars 7	USSR	1973	Mars Lander	Achieved Mars Flyby
Viking 1	USA	1975	Mars Orbiter/Lander	Success
Viking 2	USA	1975	Mars Orbiter/Lander	Success
Phobos 1	USSR	1988	Mars Orbiter/Mars Lunar Lander	Lost Contact/Lost Contact
Phobos 2	USSR	1988	Mars Orbiter/Mars Lunar Lander	Success/Lost Contact
Mars Observer	USA	1992	Mars Orbiter	Lost Contact
Mars Global Surveyor	USA	1996	Mars Orbiter	Success
Mars 96	Russia	1996	Mars Orbiter/Lander	Failure
Mars Pathfinder	USA	1996	Mars Lander/Rover	Success
Nozomi	Japan	1998	Mars Orbiter	Pending
Mars Climate Orbiter	USA	1998	Mars Orbiter	Lost Contact
Mars Polar Lander	USA	1999	Mars Lander	Lost Contact
Deep Space 2	USA	1999	Mars Surface Penetrator	Lost Contact

[Adapted from “History,” 1997-1999]

References

Brown, C. D., *Spacecraft Propulsion* (Washington, DC: AIAA, 1996).

El-Genk, M. S., *AIP Conference Proceedings 324 of the 12th Symposium on Space Nuclear Power and Propulsion: Part One* (New York: AIP, 1995).

Furlong, R. R., and E. J. Wahlquist, "U.S. Space Missions Using Radioisotope Power Systems," *Nuclear News* (April 1999), pp. 26-34.

Goldsmith, D., *The Hunt for Life on Mars* (New York: Dutton, 1997).

"History of Mars Exploration," *http://www.sgi-mars.com/mep/history/index.html* (JPL, CIT, NASA, & UCLA, 1997-1999).

Kammash, T., *Fusion Energy in Space Propulsion* (Washington, DC: AIAA, 1995).

Krane, K. S., *Introductory Nuclear Physics* (New York: John Wiley & Sons, 1988).

Lindemuth, I. R., et al, *Target Plasma Formation for Magnetic Compression/Magnetized Target Fusion (MAGO/MTF)* (New Mexico: LANL, 1995).

"Mars Facts," *http://www.sgi-mars.com/mep/mars/index.html* (JPL, CIT, NASA, & UCLA, 1997-1999).

"Mars, Water and Life," *http://polarlander.jpl.nasa.gov/why.html* (JPL, CIT, NASA, & UCLA, 1997-1999).

Siemon, R. E., et al, *Why Magnetized Fusion Offers A Low-Cost Development Path for Fusion Energy* (New Mexico: LANL, 1997).

Wurden, G. A., et al, *Magnetized Target Fusion: A burning FRC in an imploded metal can* (New Mexico: LANL, 1998).