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# A REALISTIC VISION OF THE MARS EXPEDITION: HOW MANY PEOPLE MUST GO?

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The explorers who first visited “the New World” from Europe did not sail over in tiny teams of three or four; they came in multiple ships with dozens of skilled people, to ensure that most of them could get back home alive. Long duration deep space human exploration missions to Mars and beyond must to share that approach: they will require many more than three or four crew members, if we care to make the missions successful, and get the crew back to Earth. This paper presents realistic human centred logic for configuration of deep space human exploration, using the lessons of architecture and history, biological and social sciences, systems and human factors engineering, rather than political expediency. The realities of the challenge have yet to be presented to the public who must support exploration with their enthusiasm and their money.

This paper will provide an overview of the physical and social realities of human exploration of our solar system by using a Mars trip as a Design Reference, and discuss:

- the number of people and competencies required for the three-year trip;
- requirements at the destination, and what that destination demands of both people and systems;
- interpersonal dynamics and their effect on space ship habitability;
- the size and structure of a space ship required to ensure the mission can actually work.

This reference mission may be conjecture, but the discussion is an application of research knowledge that we already have, toward this new challenge.

## I. EXPLORATION

Exploration is an activity of searching for resources or for knowledge in new areas. Among humans, exploration serves as a survival characteristic. Our bodies are naturally limited in physical prowess, but we are capable of devising technologies that help us adapt to our environments, or make our environments adapt to us, so long as we know enough about our surroundings. Additionally, we are social creatures, surviving and thriving much better in significant social groups and communities than as individuals or even small groups.[1] So exploration, for both knowledge and resources, is our heritage for as long as history has been recorded, and probably for longer than that. Exploration of space is the next chapter in our record, a chapter we are writing currently, and we seem to be “getting to the good stuff” in that chapter now…

In spite of the obvious differences, most characteristics of historical exploration certainly parallel space exploration and need to be considered when planning and executing human space exploration missions – especially deep space and long duration missions beyond low Earth orbit.

Exploration has typically been dangerous, because it has required the explorers to visit physical environments different from the ones they are used to, where many of their learned responses to situations do not apply. Dangers have come from the natural environment (quicksand, fruit that smells bad and makes people sick, deserts that stretch seemingly forever without water) and from the human element (natives who consider explorers gods, natives who like to eat explorers). Space exploration increases the level of danger because the space environment itself is hostile to life as we know it. In spite of venomous snakes and durian fruit, the Earth environment is relatively benign, with an atmosphere we can breathe, a magnetic field that protects us from external radiation, etc. Space has none of that, so we have to build analogs of our Earth environment to keep our explorers alive long enough to reach their destinations.

However, earlier exploration was faced with similar needs. No matter who initiated the expeditions, exploration utilized the latest technologies to create and maintain artificial environments that supported the explorers in their travel, and gave them access to their distant and frequently unknown destinations. Crews were required to maintain those artificial environments (their ships) as well as to conduct exploration, so voyages included adaptable technologies and individuals with requisite skills that could be applied in multiple ways. Most trips to the International Space Station include spare parts, installation or repair of new or updated system components, maintenance or replacement of system elements, etc. Technologies inherent in exploration vehicles of today (such as the ISS) change much more rapidly than in the days of wooden sailing ships, but the basic requirements inherent in maintenance have not really changed much.

Important elements of any exploration are crew expectations and a level of ambiguity at the destination. Sometimes even the destination itself may not be clearly specified, and journey objectives must be adjusted on the way. Early explorers of Africa, Antarctica, both Americas and other continents did not have enough information about their destination points before they actually got there and were forced to adapt to new conditions in order to survive. Today, robotic space technology sends us a lot of knowledge about potential human space destinations before we go there. Mars, for example, has been investigated over 50 years, but the unexpected events will still be commonplace, especially in early missions.

Exploration is expensive in terms of resources used by its sponsors – whatever those resources are – and requires a commensurate return on the investment. The Chinese spent enormous money and assigned uncounted human resources (military and otherwise) to establish the Silk Routes that allowed trade among China, Eastern Europe and the Persian world. Lewis and Clark's two-year expedition failed to discover a Northwest Passage, but what they learned about Native American tribes and the huge American landscape was incredibly valuable to future growth of our nation. Typically governments pay for exploration, but the financial development comes when private enterprise finds ways to exploit new discoveries profitably – first setting up the trading posts to collect the beaver skins and send them back to the city, then building the transcontinental railroad to encourage further settlement and exploitation... Similarly, the exploration of space is extraordinarily expensive, but both the United States and the Soviet Union were willing to pay that bill for the return of international prestige, as well as the development of valuable technologies that brought commercial return. Current exploration is funded for the same reasons, and commercial companies are beginning to develop the technologies and infrastructure that will allow them to exploit space travel profitably – suborbital flights and tourism are the tip of the spear. In addition, space exploration beyond Low Earth Orbit will require more international cooperation that ever before, in funding and new technology development.[2]

Historical overview and comparison of some aspects of terrestrial exploration are shown in the table below:

| **Aspects** | **Earth Exploration (historical)** | **Space Exploration (up to now)** | **Space Exploration (future)** |
|---|---|---|---|
| Level of expectancy | Not really known/some limited knowledge | Initially very limited, now high level of knowledge | Some information is available but high level of unknown |
| Mission timeframe | Several months up to years | Days, up to more than a year on orbit | Several years |
| Potential danger, hazards & challenges | Deceases, natural risks, lack of familiar resources & tools | 100% dependency on supplies from Earth | Maximize ISRU & independence from supplies from Earth |
| Diversity:<br>• Gender | • Mixed social classes<br>• Mixed/mission based<br>• Very rarely mixed | • No diversity<br>• Some diversity<br>• Very limited | • Mission based (e.g. client-service)<br>• Mixed<br>• Mixed |

Table 1: Exploration Historical Overview and Comparison

## II. WHO MUST MAKE THE TRIP?

Consider some basic parameters of our Design Reference Mission (DRM), a human exploration flight to Mars (Figure 1). Given the celestial mechanics of our solar system, the desirable (least energy) route to Mars from Earth is available about every two years. The trip outbound takes about 9 months, the mandatory stay at Mars is about 15 months, and the trip inbound is another 6 months – the whole trip is nearly three years. There is a faster way, with a stopover at Mars of less than one month; the amount of energy and the engines needed for this version of the trip are astonishing, but we will consider it in this paper anyway.

There are requisite skills for any science-focused mission of this kind, and we can extrapolate from both Low Earth Orbit (LEO) and lunar missions to identify the scientific competencies needed for this DRM.

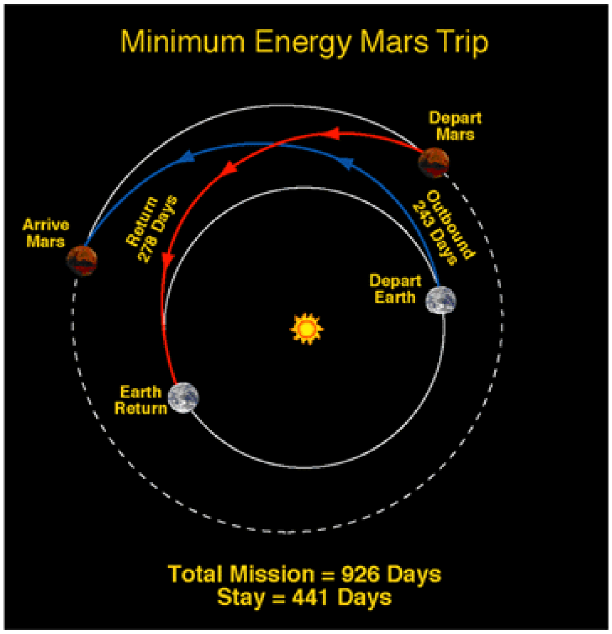

Fig. 1: Minimum Energy Mars Trip.

The mission's trajectory is calculated and recalculated by computers on Earth, and the spacecraft is "aimed" by navigation experts here too. Still, the spacecraft is a vehicle in flight and there are flight-related adjustments that must be made from time to time – especially during orbit insertion around Mars, and while in orbit there. This requires people with a unique version of the skills we associate with pilots – and of course it requires more than one person with those skills, since redundancy is a significant key to managing the risk in the mission. If there will be a landing on the surface of Mars rather than 15 months looking down from orbit, the landing vehicle will require a similar but distinct set of competencies.

Six Apollo missions sent explorers onto the surface of the moon a total of 11 times, and collected 382 kilograms of samples to return to Earth for study. While it might be possible to return Martian samples to Earth in the same way, a more effective use of the science time will be to conduct studies in situ, with follow-up exploration and further study as indicated. Time spent on the moon was limited, time spent at Mars during our DRM is necessarily over a year, and information is less costly in energy to send back to Earth than rocks and soil. The competencies required for the science are varied and can be argued, but most mission planners would include: Geology, Geophysics, Chemistry, Soil Science, Physics of various specialties, Astronomy, Astrophysics, Meteorology, Hydrology, Systems Science, and (we hope!) some Biology specialties.

Additionally, a variety of engineering and technical disciplines will be required for the trip, to support the scientific research and to observe and manage the operation of the spacecraft and its components. These will include Aerospace Engineering, Electrical Engineering, Computer Science and Software Engineering, Thermal Engineering, Materials Science, Telecommunications, Optics, Radar Science and related sensor disciplines, Instrumentation, Navigation, and Control Systems Engineering. Given that the explorers will spend considerable time on the surface of the planet, the Civil and Structural Engineering disciplines will be needed to ensure their protection, and likely the disciplines of the Robotics field too. These scientific and technical fields are typically focused and deep, and individuals are expert in one or even two of them, usually not more.

Managing spacecraft operations is not enough, though; given a three-year mission, in the hostile environment of space and the hostile surface of another planet, components of the space system will certainly need repair or replacement during the mission. Engineering skills are not necessarily sufficient for routine or off-nominal maintenance of the spacecraft's systems that control life support; an electrician is also needed…and occasionally a plumber and a general handyman, when water recycling systems need maintenance or air flow is less than adequate.

The crewmembers themselves also need maintenance, requiring regular diagnostics (and sometimes intervention) from a physician. The medical specialties are as focused as those of the other sciences, although for most health care services a General Practitioner can meet the needs…but the female crewmembers will need ObGyn specialists, injuries on the surface may require orthopedic or surgical skills, and of course dental care will be required on such long duration missions. It's possible that some doctors will be able to cover more than one specialty, but managing risk on the mission will require two people who can practice each specialty, ensuring redundancy if one of the doctors is a casualty.

## III. THE HUMAN DYNAMIC

There is another human aspect of this DRM that points toward the need for a larger community rather than a minimum number of explorers. During a mission of this duration, conflict will inevitably arise regarding issues of daily life, as well as issues of scientific or exploratory direction. Referring conflicts to mission controllers on Earth and asking for a decision can always resolve them; but this process removes the immediacy of control authority from the mission members who have the best situation awareness, and therefore the best chance to make a correct naturalistic decision. Resolving conflicts in the context of a community tends to defuse the personal sensitivities related to resolution, and allows relatively impersonal perspectives to guide the strategic decision. The larger community also gives resolutions their guidance from a variety of perspectives, decreasing the chance that important issues will be overlooked. (These are among the reasons we have juries of twelve, rather than two or three, deciding our civil litigations).[3,4]

Humans are social creatures, having evolved to work and protect ourselves in groups.[5] Learning is enhanced by social interactions, and increased by multiple observational perspectives. There are various opinions regarding optimum size for effective teams, always based on what the team is designed to accomplish, but numbers between five and twelve are presented often in leadership studies. Given the established need for so many operational competencies in this mission, it is likely that the most realistic number for a successful mission is the largest number possible without reaching a state in which diminishing returns makes further additions ineffective.

Finally, we must consider the reality of humans as intensely sexual beings, with our sexuality stimulated by hazard and by close, concentrated working relationship.[6,7] If the explorers are not already "couples" or some other sets of sexual units when the mission begins, they will be when the mission returns. The number and genders and sexual orientations of mission members will have to be considered during mission planning, as well as the potential for re-arrangement of sexual units during the mission. This is another way that a larger community will help defuse the potential (and the reality) of conflict among team members, giving the opportunity for shifts in alignment of sexual units if necessary or desired by team members. The evidence also suggests that mix-gender groups can handle crowding in confined environments much better than same-sex groups and their sex ratio should be reasonably balanced.[8] Human sexuality will also drive some aspects of the functional and physical architectures of the space ship and habitats, as we will explain.

## IV. THE ARCHITECTURES

Superior architecture happens if architects design physical structures based on operational and functional needs of the people who will inhabit and use them. The realities of this mission should drive the architectural design of the vehicles and habitats, and we will point out a few of the major drivers for that design. Architecture of the spaceship and surface structures should provide at least the following: protection from surrounding hazardous environment, internal safety (fire hazards, any type of contamination etc.), health safety (physical and psychological), and optimization of crew operating environment to maximize their work performance.

It should be clear by now that the ship must be capable of serving a crew of at least twelve, up to a potential of fifteen or eighteen. It will have to include both public spaces for both social and work-related gatherings of the crew community; as well as private spaces for individual work without distraction, for personal solitude, and for private activity among smaller groups of crewmembers. There are terrestrial models for structures with similar operational and functional requirements: boarding houses, yachts, submarines, retreat centers, monasteries, polar stations etc.[8,9] These structures are all larger than any space ship ever built; and even when we consider sending the smallest possible crew members, and squeezing them into the smallest functional volume, we still end up with a ship at least as big as a suburban house – for their living and working area.

Human protections in all areas of the ship must be considered above all else. The vacuum of space must be held out, and any breaches of this protective integrity must be easily and quickly repaired. Constant radiation from the sun, and occasional surges in radiation due to solar activity, create the need for on-going mitigation. This requirement places constraints on the nature of materials, and their arrangement, in the ship's physical architecture.

The operational area of the ship is increased by the need for storage of a three-year food supply, the need for huge quantities of water, and the necessity of air and water recycling systems. The large amount of water could serve the double purpose of crew use and radiation shielding, depending on where it is contained in the ship. There will also be a need for fuel storage, a requirement if the mission is to return from Mars after its 15-month stay. Airlocks, connections between modules and EVA (External Vehicular Activities) supplies will require significant amount of volume and area in the ship and in the surface facilities. Finally, the ship will need room for spare parts and for other repair materials to be stored.

Extrapolating the losses in bone density and muscle mass in the International Space Station after only six months of microgravity, our mission may simulate gravitational acceleration or provide some other countermeasures or the crew might never be able to return to the Earth itself. Functionally artificial gravity has been depicted as spinning at least a portion of the ship or habitat, so fictitious centrifugal force creates resistance that allows bone and muscle maintenance. This type of simulation creates multiple design challenges and will require special engineering and architectural attention to every detail.

The Earth is a benign environment that corrects itself when elements that support its life move outside their usual parameters. This mission's space ship will have to do that by human design and maintenance, using automated systems to monitor and control both life support and engineering systems; if the crew are to spend their time doing exploration, they will not be able to perform constant housekeeping functions. These automated systems, including any robotic assistance they require, will add to the necessary volume and mass of the ship; and the functionality of these systems will need to be designed in from the beginning, not added on later![10]

There is no known propulsion system that could lift a ship of this size out of the Earth's gravity well. The ship will have to be built in space; much like the ISS was built in space, probably by assembling various units together over time. This points to a need for perfecting not just the ship's design, but the design of the actual construction processes used to execute its architecture.[11,12] Allowing the kind of delays experienced in building the ISS will increase the potential for incompatibility of elements in the ship; and without the nearness of Earth to supply it with new or improved parts, the results of such incompatibility could be fatal to the crew.

## V. CONCLUSIONS

There is much more to planning and executing a mission of human space exploration than typically seen by the public, and this may lead to unrealistic expectations regarding when and how such a mission can take place. We believe that making the real needs common knowledge, and explaining how current and projected future technologies will contribute, can help build appreciation and understanding of the long-term commitment required to explore our solar system. Using the metaphors provided by history and by our architectural heritage, these explanations become easier and more relevant – and may even help point toward solutions to some of the exploration challenges. There is no room for wrong decisions in Mars mission planning; any slight mistake or overlooking of any small issue may result in a mission failure or a tragedy. Addressing human factors properly in mission planning will be a key to space exploration success.

## ABOUT THE AUTHORS

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