45th International Conference on Environmental Systems
12-16 July 2015, Bellevue, Washington
ICES-2015-56

What Do We Give Up and Leave Behind?

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Nearly all habitability studies to date focus on defining what are the absolute minimum requirements to sustain human life, health (physical-only), and well-being. This inquiry asks the converse question in the negative: what will happen when a crew must give up so many of the familiar things, comforts, and personal associations that they take for granted? This essay begins with a review of minimalist humans to Mars mission concepts and their limitations. It applies the Crew Safety-Human Factors Interaction Model's criteria for *Critical Habitability*. The analysis presents five examples of what the Mars crewmembers must give up and leave behind. It illustrates them through classical and impressionist paintings and other images: restricted diet, constant confinement, disconnection from the natural world, no separation of work and social life, no family life, and repetitive tasks.

I. Introduction

The story of humans going on a voyage of transformation or no return is hardly new. Perhaps the most common reference is Noah's ark. This theme reappears in science fiction in the tales of a doomed Earth and the hardy pioneers who depart on their spaceships in time to escape. In modern planning for humans to become an interplanetary species, this theme recurs in several ways: What does the crew bring with them to maintain an Earth-like environment? How do they change and adapt to make a new life on the new planet (usually Mars)? And, what are they compelled to leave behind for which they must compensate?

FIGURE 1 shows an image from "the golden age of science fiction" that casts Noah's ark in the vernacular of the science fiction "pulps." The date is November 1, 1939, two months after Germany invaded Poland; the world is aflame with the start of the Second World War. As the crew load the animals two by two into the "Ark of Space" their guards keep the desperate masses at bay. Evidently, their decision about what to leave behind included whom to leave behind, including family, friends, garden, home, job, and sports. This paper focuses on the question of who and what the intrepid interplanetary voyagers leave behind.

What this type of story portends is that the ability of human crews to conduct a Mars/Phobos/Deimos mission of three years or more safely and in good health will depend to a great extent upon the habitability that the mission and spacecraft designs afford them. Nearly all habitability studies to date focus on defining what are

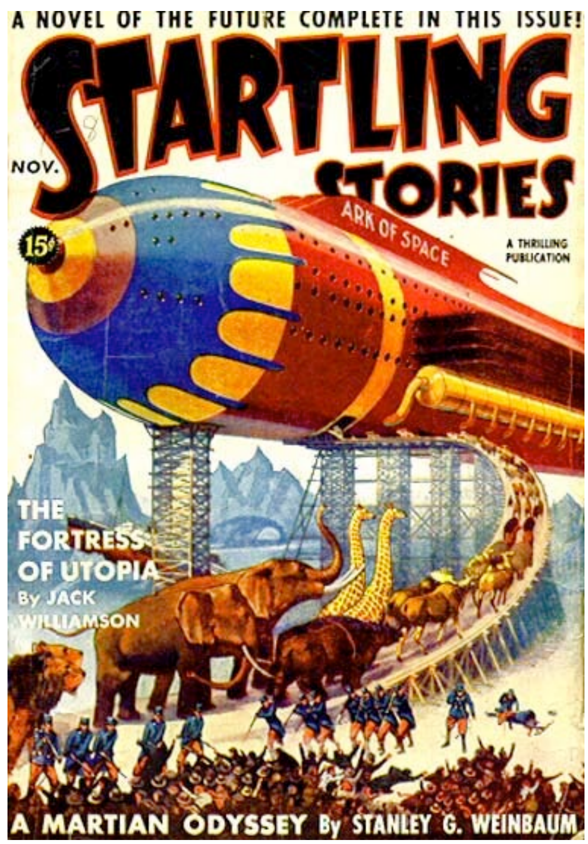

FIGURE 1. Nov. 1, 1939, *Startling Stories*, Cover Story: A Martian Odyssey by Stanley G. Weinbaum.

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the absolute minimum requirements to sustain human life, health (physical-only), and well-being. More recently, researchers and designers have been adding support for crew productivity and human reliability. These few enhancements tend to consist of better food, more recreation, and social contact with the folks back home, and better procedures to check crew fitness and ensure against crew errors.

To present its analysis, this paper takes an opposing, subtractive approach. Instead of seeking the minimum to support crew survival, it asks: what happens when the crew gives up everything else? For a long-duration mission lasting 500 to 1000 days or longer, where resupply of fresh food, amusements, and a stream of short-term visitors are not available, the situation diverges sharply from the Salyut, Skylab, Mir, Shuttle-Mir and ISS programs that afford the basis of nearly all studies to date. In the extant studies, psychological well-being appears largely unconnected to habitability except for anecdotes about how much space crews appreciate delivery of fresh food and limited notions demonstrated in Antarctica that proximity to plants is beneficial both for the connection to nature and fresh produce. At the same time, the tyranny of the mass budget militates against bringing anything "extra." What other factors play a role?

II. Long Missions, Tiny Habitats

Recently, the human spaceflight community has seen a surge of interest in sending human missions to Mars. Key among these players are the "NewSpace" initiatives from MarsOne and Inspiration Mars. MarsOne (2015) proposes a private colony on Mars in the 2020s. Inspiration Mars (Tito, 2013; MacCallum, undated) proposes a Mars flyby by two crewmembers within the next five or six years. NASA is talking about sending a crew to Mars by the 2030s through the still mostly undefined "Evolvable Mars Campaign" (Foust, 2015), but without specific plans beyond the current Mars Design Reference Architecture 5.0 (Drake, 2009). The MarsOne team proposes to send people one way to Mars relying "upon existing technologies available from proven suppliers" (MarsOne-The Technology). MarsOne proposes to use "a variant of the [SpaceX] Dragon Capsule" (MarsOne-The Technology) for entry, descent, and landing and as the permanent surface habitat.[3]

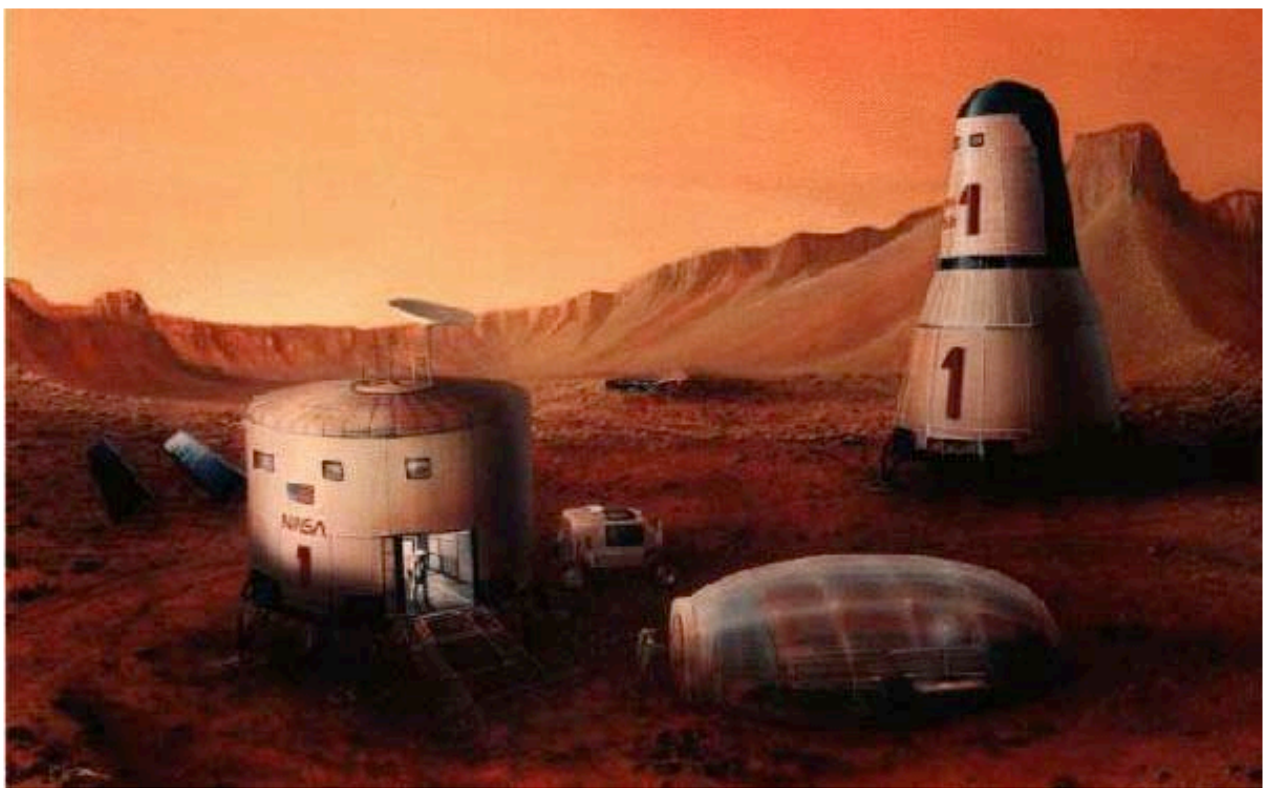

FIGURE 2. Robert Zubrin's Mars Direct minimalist concept showing the basic elements of the lander/ascent vehicle, the crew habitat, inflatable greenhouse, and rover.

[3] SpaceX has not confirmed this arrangement.

Robert Zubrin's Mars Direct was the mother of all minimalist missions (Zubrin, 1996). Its approach was to start with the smallest and most affordable concept that might be feasible. Key to this minimal payload delivered to the Mars surface would be the extensive use of in situ resource utilization (ISRU) that would include making fuel, oxygen, water, and other commodities from resources available on the Mars surface. The initial crew would live and work under extremely austere conditions, but their sacrifices would enable the buildup of a more complete Mars base or settlement. The Mars Direct base consists of a cluster of elements: the biconic lander/ascent vehicle, the two story habitat, the inflatable greenhouse, and a presumably pressurized rover. One example of the minimalism is that there is no pressurized connection between the habitat and the greenhouse. To cultivate or harvest food, the crew must don a spacesuit, go EVA, enter the greenhouse, and then take of some or all of the spacesuit so that they may use the dexterity of their fingers and arms. To return to the habitat, they must enclose the produce in a pressurized container, don space suits, and walk back to the farm house.

The crew accommodations in the Inspiration Mars vehicle and the early MarsOne landers would be even more confined and constrained than Mars Direct. These "NewSpace" initiatives would give up and leave behind even more infrastructure, capabilities, and support systems than Mars Direct (or at least initially for MarsOne). Their reasoning appears to be that if the sponsors could conduct the missions with even less of everything, they may have a chance of succeeding financially, or at least starting on their path to Mars.

A. The Inspiration Mars "Minimalist" Concept

Inspiration Mars proposes by comparison, an even more "minimalist" flyby of the Red Planet that will take an extraordinarily precise "501.2866668 days" (Tito; 2013; p. 5). The interplanetary vehicle appears in FIGURE 3. It includes a habitat section of a module shown in FIGURE 4 for the two crew members who will make this journey. The Inspiration Mars team makes these extraordinary assertions:

> *(Tito et al; p. 1) The isolated, confined environment psychology aspects of the mission are considered with regard to crew selection, training, capsule design, the role of mission control / support, and early ground testing.*

> *(Tito et al; p. 7) The ECLSS was assumed to meet only basic human needs to support metabolic requirements of two 70 kg men, with a nominal metabolic rate of 11.82 MJ/d. Crew comfort is limited to survival needs only. For example, sponge baths are acceptable, with no need for showers.*

Tito's language sounds eerily reminiscent of Karl Marx's (1867) observation, *"All the capitalist cares for, is to reduce the labourer's individual consumption as far as possible to what is strictly necessary, . . ."* Marx was first to describe food, rest, and recreation as necessary to allow the worker to "reproduce his labor," to renew and refresh oneself to go back on the job. How long can the crewmembers "reproduce their labor" and keep going on a 1000 plus-day mission without substantial creative, emotional, psychological, and social support? Will such renewal and refreshment be available?

> *(Tito et al; p. 13) At a current value of roughly 7 m^3, the representative spacecraft free volume is deemed adequate. However, given the requirement for food and water storage and additional equipment and access, the free volume could shrink considerably. Prior studies we have performed indicated that, for this mission duration, crew volumes of less than 3-5 m^3 per person would border on untenable. Available crew volume is a significant consideration for this mission. The increased need for isolation during privacy functions (defecating, body cleansing), and activities related to crew exercise (using simple stretchable resistance devices) suggest more space than some historical two-crew vehicle such as Gemini which had approximately 1.25 m^3 /person.*

This argument is highly questionable; that because Gemini is "historical," it somehow represents a relevant benchmark. Gemini afforded the smallest volume per crewmember of any spacecraft that has flown, smaller than the preceding Mercury capsule. What is most significant about the weaknesses of this approach is the super-precision of the mechanistic and deterministic aspects of the project compared to the blithely vague and overconfident aspects of the human element. This "Can-do" attitude is great for sending a small metal can on an optimal trajectory around the Earth or the Moon and return, but it completely disregards any realistic assessment of the human factor for the Mars/Phobos/Deimos mission.

FIGURE 4 shows a drawing of the Inspiration Mars crew habitat, with a circular plan view and a longitudinal section through the cylindrical module. The principal features of this concept include the radiation/sleep shelter and its supporting components in the main cabin, the exercise equipment, the experiment rack, and the 3D printer to make replacement parts en route. The designer attempted to soften the hard structural-mechanical envelope with indirect lighting. What are unclear from the drawing is where the crew would eat, where is the hygiene compartment (toilet), and how well the two are separated.

FIGURE 5 shows a more detailed sketch of the radiation/sleep shelter in the habitat. This bedroom accommodates two crew members in sleeping bags for the 500+ days of the flyby. It includes a display monitor and some controls on the wall adjacent, but beyond that it is quite plain. Here also, the designer tries to provide some softness, interest, and variety with the lighting, as virtually the only concession to comfort.

FIGURE 6 presents the "Celentano Curve" distribution of spacecraft volume maxima from Vostok in 1961 to the ISS in 2006 (Cohen, 2009, p. 20). Cohen (2009) demonstrates conclusively that there is a direct and causal relationship between mission duration and required pressurized volume. The ISS has received a few more modules since that date, but the "permanent presence" crew size has also doubled, so the curves would tend to continue as shown. Gemini 6 appears at the bottom, center, of the logarithmic plot. Its volume is at least two orders of magnitude less – 1/100 or less -- than the ISS and Mir volumes/crew member for 6 month missions. Remember that a central goal of exploration spacecraft is for the crew to do productive work, which requires the appropriate quality and quantity of volume.

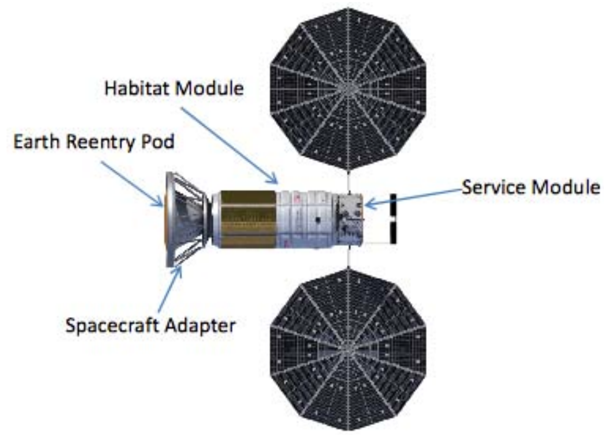

FIGURE 3. Inspiration Mars interplanetary vehicle showing the major parts. Credit: Inspiration Mars.

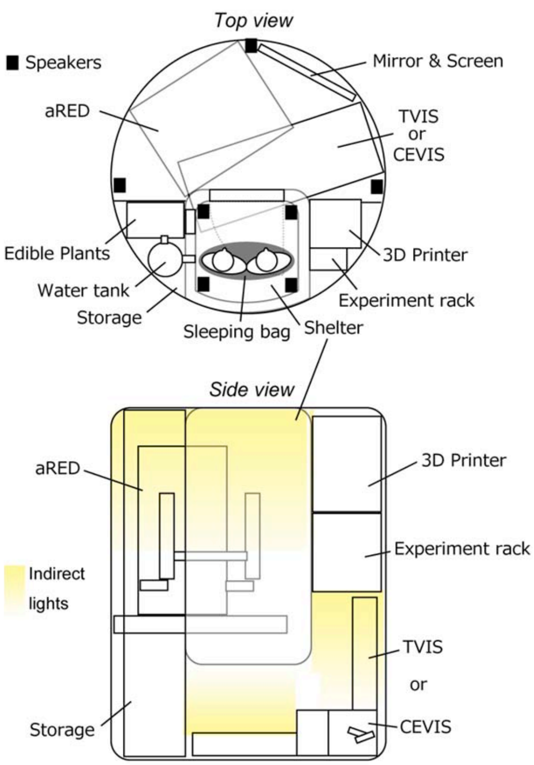

FIGURE 4. Design of the Crew Habitat from the Inspiration Mars "Kanau" student competition entry by Keio University and Purdue University.

https://sites.google.com/site/occupyplanet4/documents

There are so many questions to ask about this approach, that it seems more useful first to exclude the strictly programmatic questions to *not ask* at this time, for example, what about life support reliability or can they stow enough food and water for 1000 crew-days? However, because it bears on the core competence of habitability – sufficient pressurized volume – it is essential to point out that for a volume of 3.5m^3per crewmember[4], these historic missions have been orders of magnitude shorter in duration than Inspiration Mars.

The Apollo Command Module (CM) contained about 3.3 m^3 pressurized volume per crewmember. The longest continuous Apollo flight by three crewmembers flying in only the CM was Apollo 8, which lasted 6 days and 3 hours, around the Moon and back. No spacecraft have flown with a crew for 500 days. The closest precedent was the Mir EO 15/16/17 LD4 mission, when Valery Polyakov stayed on board for 437.75 days. With three crew members always present, the volume averaged about 90 m^3 per crewmember.

A decade earlier, in the heroic era of Soviet spaceflight, Atkov, Kizim, and Solovyov flew in Salyut 7 for 237 days with a per crewmember volume of 30 m^3. The one Gemini mission that Tito et al cite, Gemini 6, flew for14

[4] Tito et al do not distinguish between total pressurized volume and "free volume" as in unobstructed by equipment or stowage, but in the context, it seems they mean pressurized volume.

days and was a miserable, unsanitary, and smelly experience for the crew who lived in 1.25 m^3 per person. Gemini 6 is the exception that proves the rule of the Celentano Curve. Inexplicably, Tito et al rely upon it to the exclusion of all other knowledge.

B. The MarsOne One-way Mission to Mars

MarsOne embodies an initial minimalist approach because for the first several 26-month launch windows, the crew will live in "capsules." MarsOne constitutes a private/commercial initiative to send humans one-way to Mars where they would establish a permanent settlement, all playing out as a reality television series. The cargo- and crew-lander modules are supposedly based on the SpaceX *Dragon* capsule, enlarged from the first generation 11 m^3 to 25 m^3.[5] The lander modules connect through tunnels like beads on a string. The two modules dedicated as airlocks appear in the center two of the six shown, as indicated by the ladder to the hatch (FIGURE 7). It is not clear if the lander modules provide an airlock function beyond just sealing the connecting tunnels and opening the exterior hatch, sacrificing the atmosphere in the lander when the crew goes EVA.

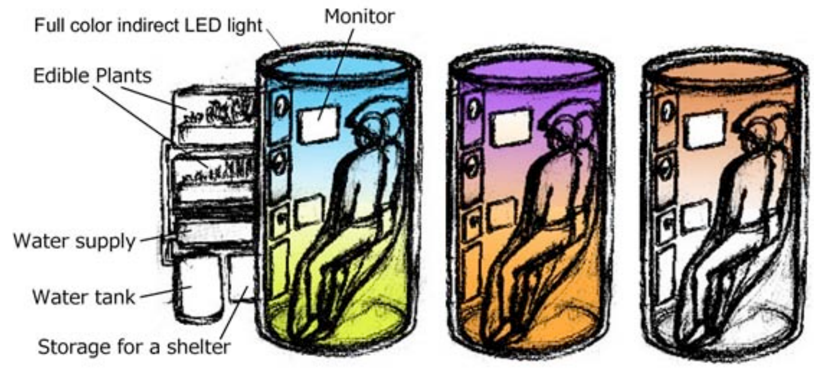

FIGURE 5. Inspiration Mars radiation/sleep shelter for two crewmembers in the habitat. Credit: Kanau Project.

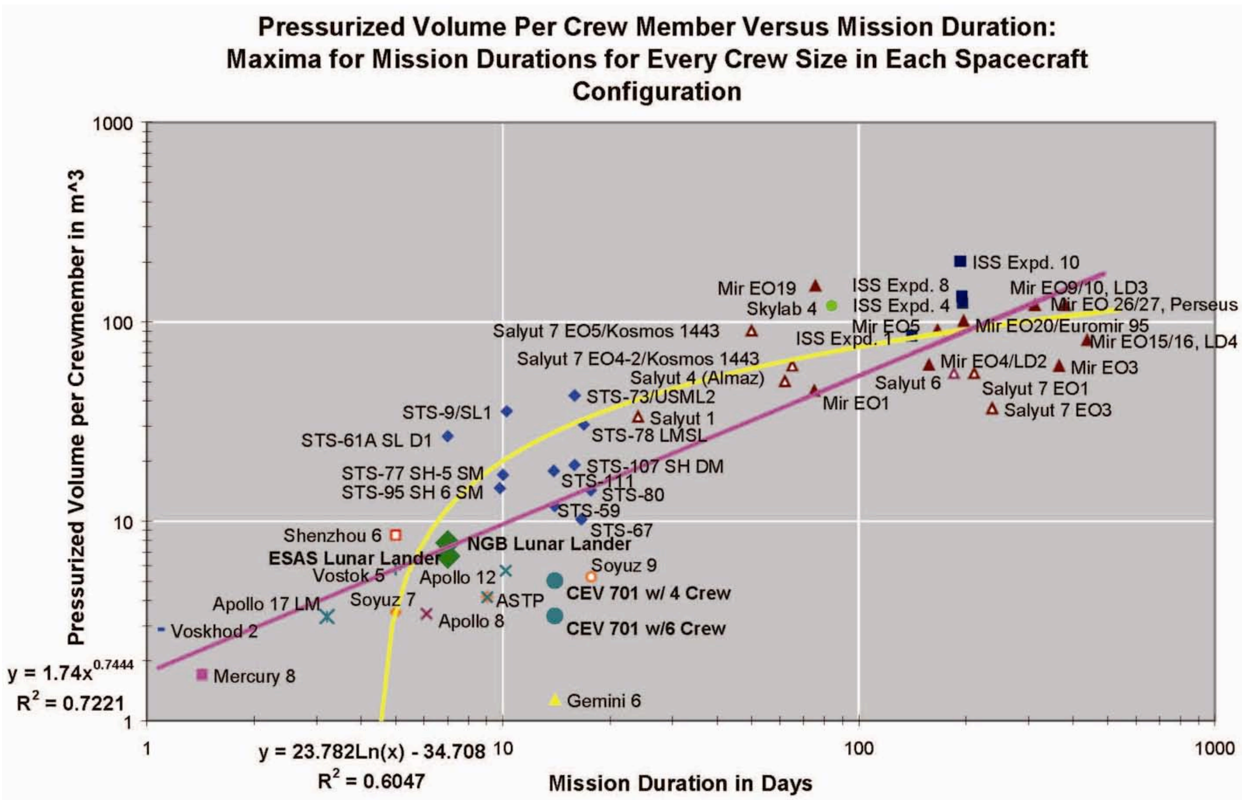

FIGURE 6. Plot of the "Celentano Curve" showing pressurized volume per crewmember of specific missions in the designated spacecraft. ESAS Lunar Lander, NGB Lunar Lander, and CEV 701 are speculative data points from the cancelled Constellation program. Adapted from (Cohen, 2009, p. 20).

5 SpaceX has not confirmed these assertions by MarsOne.

MarsOne follows the strategy of prepositioning cargo and habitat landers articulated in the first NASA Mars Design Reference Mission (Hoffman, Kaplan; 1997). Following the automated/robotic setup of the MarsOne base, four crew members would arrive at the next launch window 26 months later, and then four more at every 26-months interval.

FIGURE 7 shows the MarsOne base situated on the relatively featureless, dusty Mars terrain. No vegetation or colors besides the powdery rouge relieves the monotony. Crewmembers can venture out of the pressurized and environmentally controlled base only in a pressurized and environmentally controlled spacesuit or rover. While in these pressurized volumes, habitation accommodations are basic at best. The MarsOne plan to date considers food, dining, sleep, and hygiene – but not much else in terms of tangible support for the crew, for whom there is no return to Earth option.

FIGURE 8 shows a longitudinal cutaway section of the 500 m^3 inflatable module that serves as the "greenhouse" to grow plants for food. MarsOne states that they dedicate 50 m^3 of "shelves" to growing plants for food. However, the MIT review team led by Sydney Do found that to grow all the food for a crew of four would require at least 200 m^3. Unfortunately, a life-threatening problem arises when trying to raise all the food for humans in a closed atmosphere. The plants produce a surplus of oxygen, which can create oxygen toxicity for the crew and a fire hazard (Do et al, 2014).

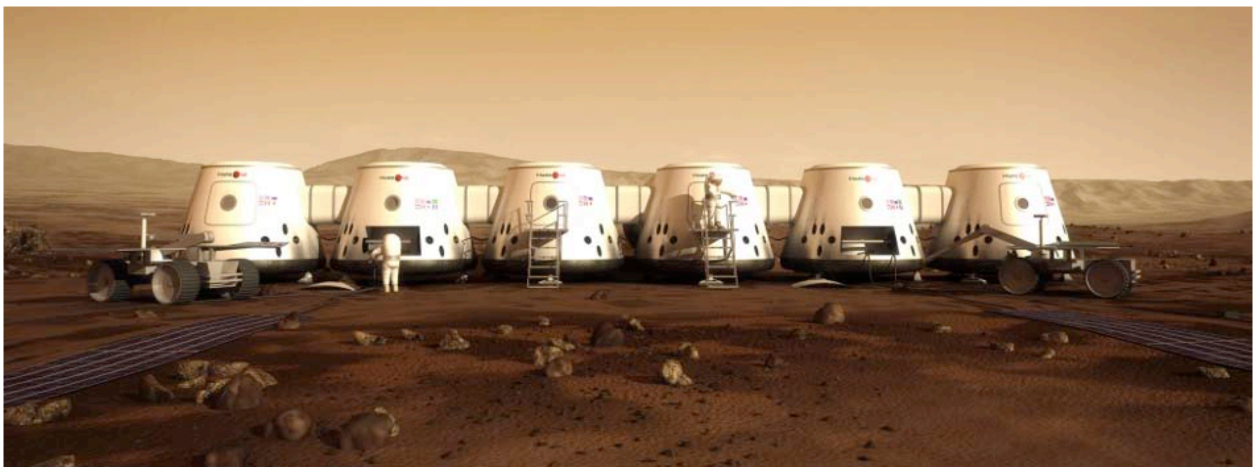

FIGURE 7. The MarsOne "2023 Roadmap" image shows the extremely bleak and desolate Martian landscape with the 25 m^3 cargo- and crew-landers linked together by extension tunnels. The spacesuited crewmembers give a sense of scale to these capsules. Credit: MarsOne.

FIGURE 8. Longitudinal, cutaway view of the MarsOne 500 m3 habitation and plant growth inflatable module. Credit: Bryan Versteed, MarsOne.

Harry Jones in the Bioengineering Branch at NASA Ames Research Center (2006) explains that in terms of raising vegetables and fruit for food as part of a bioregenerative life support system, the optimum balance is about 50% grown on site, and 50% resupply of dry food. The reasons are that plants producing 50% of the food to feed one person generate 100% of the oxygen he or she will need. Growing more food means producing excessive O_2 that poses problems in two ways: First, it creates a toxicity and fire hazard to live in a too-rich oxygen atmosphere. Second, dumping the excess O_2 means breaking the closure of the life support system to run more open loop. One possible but hardly ideal solution would be to oxidize the excess biomass from the plants, thereby consuming the excess O_2. Then the CO_2 produced could provide respiration for the plants. This method requires more equipment, power, and poses a different potential fire risk.

FIGURE 8 also shows what appear to be galley, dining, and lounge areas for the crew. It is not clear where the crew would sleep, in the inflatable module or back in the lander modules. According to the MarsOne website, shower and toilets are in the landers, which does not suggest recycling through the agricultural system. In the inflatables there are stowage areas for supplies and some work areas. What do not appear are the exercise equipment and perhaps sports facilities. A spacesuit appears on the left end near the back wall, suggesting perhaps that area serves for EVA maintenance and repair. Or, would the crew have need sometimes to enter the inflatable module in their pressure suits? That scenario might become necessary case of elevated oxygen toxicity or excess CO_2. The website states that the inflatable module includes an airlock, which would allow suited ingress and egress.

Although the MarsOne concept provides much greater volume than does Inspiration Mars, it still must make a persuasive case that the quality and quantity is sufficient to support a permanent human colony from which there is no return to Earth, permanently cut off from the natural world. The highly controlled and contained agricultural plant growth chambers hardly qualify as the "natural world," although their presence would be better than no plants.

III. Critical Habitability

In 1985, Rockwell International (now Boeing-North American) completed the Space Station Crew Safety Alternatives Study for NASA. This five-volume study identified a wide range of potential safety threats and hazards that the crew might encounter on the future International Space Station. Volume III (Rockoff et al, 1985) focused on the *Safety Impact of Human Factors*, featuring the Crew Safety-Human Factors Interaction Model shown in DIAGRAM A, which Cohen and Junge (1984) developed for the early Space Station program.

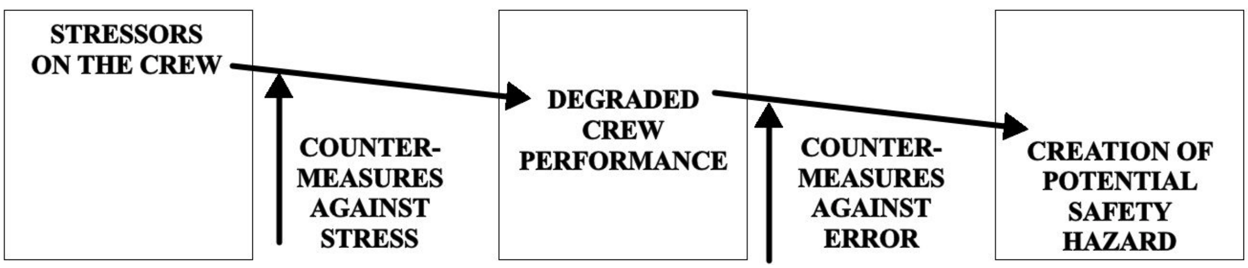

DIAGRAM A. The Crew Safety-Human Factors Interaction Model.

In this model, a stressor (such as one of the threats) can lead to degraded performance, which can contribute to human error, unless appropriate and effective countermeasures are available to the crew. The several topics within the Crew Safety-Human Factors Interaction Model included:

- Protocols, such as stressors exacerbated by varying degrees of autonomy from ground,
- Critical Habitability, such as living in a closed atmosphere with severe volume limitations, noise, and sanitation,
- Task-Related Issues, such as responsibility for task assignment, role definition, monotony, and boredom,
- Crew Incapacitation, in terms of illness, injury, or and emotional or mental health problem, and
- Personal Choice, such as restrictions on cooking or eating habits, restrictions on personal property, and limits to personal hygiene.

Among these topics, Critical Habitability emerges as most fundamental for the question of crew survival on extremely long duration missions (as compared to ISS crew rotations of six months), whether flyby, round trip, or one way. Critical Habitability arises as a leading concern, particularly in terms of what is lacking from the living and working environment.

Subsequently, Dudley-Rowley, Cohen, and Flores (2004)[6] compared these findings to the results from the Soviet Mir Space Station. It was from their assessment of how well the model applied to Mir that the following quotations come. Many of these potential stressors appear to occur in the realm of small group dynamics and social psychology, with implication for design of the habitable environment, including life support systems. However,

[6] The genesis of this paper was that author Cohen provided the Crew Safety-Human Factors Interaction Model and a little new material. Professor Dudley-Rowley wrote the paper. Pablo Flores, the Argentine Cosmonaut Candidate presented it at the Russian Academy of Science.

while there are vital psychological dimensions to the crew experience and performance in long-duration spaceflight, this essay takes more of a philosophical perspective. Dudley-Rowley makes this overall assessment of the Crew Safety-Human Factors Interaction Model:

> *So, how predictive was the Cohen and Junge model? Too little quantification of the model exists as yet to say that it was 80% predictive, for example. However, on a scale of poor, fair, good, and excellent, one could say that it was a good predictor. What has come out of this study are ways that the model can be modified from the Mir experience for use in counter measuring against stressors aboard the International Space Station and on long-duration space missions. Most of the modifications of the model are in expansion of the countermeasures against stress and those against errors, and also in terms of the safety hazards.*

TABLE 1. CRITICAL HABITABILITY I[7]

STRESSORS ON THE CREW	COUNTER-MEASURES AGAINST STRESS	DEGRADED CREW PERFORMANCE	COUNTER-MEASURES AGAINST ERROR	CREATION OF POTENTIAL SAFETY HAZARD
Volume Limitations: Insufficient Pressurized Volume, Inadequate Free Volume.	Architecture, Design, Privacy, Windows, Stowage, Sufficient Work Envelopes.	Feelings of Claustrophobia, Lack of Privacy, Irritability.	Increased Privacy or personal space, More Volume, Evacuation.	Irritability, Conflict, Paranoia.
Noise.	Vibration Isolation, Control.	Sleep Disturbances, Sleep Deprivation, Circadian Desynchronization, Poor Communication.	Earmuffs, Headsets, Drugs, Communication Devices.	Failure to Respond, Failure to Communicate, Failure to Coordinate.
Inadequate Housekeeping (or Lack thereof)	Routines and Training, Assignment of Responsibilities, Teamwork.	Environment Quality Deterioration, Unhealthy or Unsanitary Environment.	Assignment of Responsibilities, Teamwork.	Breakdown in Life Support.
Lack of Hygiene, Lack of Cleanliness.	Improve Personal Practices, Repair Hygiene Facilities, Training.	Discomfort to Others, Illness, Disease.	Group Standards, Teamwork.	Individual or group Illness, Inability to Perform Tasks, Death.

TABLE 1, Critical Habitability I shows the range of habitability concerns. The first concern is the limited volume, whether described as pressurized, "habitable," or "free." The architectural design of the spacecraft or space habitat is the first countermeasure against this stressor. Degraded performance may include claustrophobia, lack of privacy, or irritability. Countermeasures against error are limited to increased privacy or personal space, increased volume, or evacuation of the crewmember. Noise is a constant irritant in spacecraft today, as Tico Foley called it "All Noise, All the Time (Foley, 1998, p. 6). Noise affects the quality of sleep and communications.

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[7] Expanded for this publication

Inadequate housekeeping could lead to failures of sanitation, degradation of personal hygiene, and ultimately to a breakdown in the environmental control and life support system (ECLSS). Countermeasures equate to the crew performing regular maintenance tasks, despite the tedium. Conversely, a breakdown in the ECLSS systems such as waste or water processing can lead to a decline in sanitation and failures of hand washing, shower, or toilet, possibly leading to sickness or worse.

TABLE 2, Critical Habitability II starts with another potential vulnerability of the ECLSS, the quality of the breathable atmosphere. Things that can go wrong in the atmosphere include extreme temperatures, excessive humidity or lack of it, contaminants, or odors. The gravest potential threat would come from a failure to remove enough carbon dioxide or to produce enough oxygen. The consequences of the ECLSS going bad include illness, injury, or death. The main countermeasure must exist within the ECLSS itself: a high level of reliability throughout its functions.

TABLE 2. CRITICAL HABITABILITY II

STRESSORS ON THE CREW	COUNTER-MEASURES AGAINST STRESS	DEGRADED CREW PERFORMANCE	COUNTER-MEASURES AGAINST ERROR	CREATION OF POTENTIAL SAFETY HAZARD
Thermal/ Humidity, Closed Atmosphere – odors, bad air.	Environmental Controls	Discomfort; Irritability, Illness	Air Movement; Gas Composition and Control; Temperature and Humidity Control; Mitigation Against Inadequate Environmental Controls	Increased Anxiety, Toxicity Concerns, Threat of Heat Prostration, Cold Injury, Illness, Suffocation.
Confinement, Isolation, Separation from society, Separation from nature.	Reliable Comm with Family and Friends, Social Events, Recreation, Counseling, Architecture, Stowage.	Loneliness, Morale Deterioration, Impaired Judgment, Skewed Perception Under Stress, Claustrophobia.	Group Activities, Hobbies; Personal Interests, Judgment Checks, Color Coding, Lighting; Multiple Access to Modules, Mobility Aids.	Breakdown in Group Process, Faulty Teamwork, Mistakes in Judgment, Perception, or Action, Paranoia, Depression.
Artificial Lighting.	Lighting Design, "Natural Light."	Fatigue, Irritability, Blurred Vision	Indirect, soft lighting, Special Task Lighting.	Mistaken Perception,

Tito et al (2013) mention confinement in a very small volume but fail to recognize its consequences. Confinement, isolation, and separation from normative human society and nature can also act as a stressor. The availability of countermeasures available today is mostly limited to improved communications, social events, looking out the window (or cupola), and teamwork. This stressor may cause loneliness, poor morale, impaired judgment, or errors that lead to a safety hazard. Artificial lighting will be all-pervasive in a spacecraft or surface habitat – direct exposure to sunlight would be problematic and rare. Effects of stress may include eye-fatigue, blurry vision, or the depression or irritability that accompanies seasonal affect disorder (which gives the poetic acronym, SAD). The principal countermeasure to problems of artificial lighting will lie in the design of the lighting itself for varied uses, changing times of day and night, shifts in mood, and as an energy source for photosynthesis.

III. What Do We Sacrifice for Long Duration Spaceflight?

The previous examples of extremely austere missions that demand huge personal sacrifices illustrate the predominant engineering thinking about human needs for extremely long duration spaceflight and permanent habitation. The paper examines these issues in terms of specific sacrifices that crewmembers must make as a condition of sojourning on the mission lasting years or a lifetime:

FIGURE 9 Jean Mortel (1652-1719), *Still Life*, San Francisco Legion of Honor Museum. Marc Cohen Photo http://www.artnet.com/artists/jan-mortel/früchtestillleben-mit-pfirsichen-trauben-3_YVPOfS3fgC0UR57l14qw2.

A. **Restricted Diet:** How will it affect crewmembers' health and moral to never eat fresh fruit or vegetables more complex than lettuce for many years?

B. **Constant Confinement:** What will it mean to never go "outside" without a spacesuit, to never feel the wind or breathe "fresh air," to never swim in liquid water?"

C. **Disconnection from the Natural World:** What would it be like to lose contact entirely with the environment of the natural world in which humans evolved: no seasons, no swimming, no long walks in the woods?

D. **No Separation of Work and Social Life:** What will it mean to socialize only with the people with whom we work, never go on a picnic outside?

E. **No Family Life:** How will it affect crewmembers emotionally to live without children or pets?

F. **Repetitive and Often Meaningless Tasks:** What will it mean to follow the same routines over and over again, every day, without variety or diversion?

Astronauts have always made great self-sacrifices to qualify and fly on space missions. French Mir astronaut Jean-Pierre Haignere said he trained for eight years and gave up certain activities, such as skiing in order not to risk his participation. (Haigneré, 2009). Elizabeth Landau (2014) published a set of interviews with MarsOne candidates on CNN that reveals the tough choices the would-be Marsonauts would face:

> *Mars One candidate Dan Carey, married 28 years, two college-age children states: "It's hard for Carey to think about leaving his wife and kids behind forever and never meeting future grandchildren. Still, he likes the idea of making history and seeing things that no one has seen directly before."*
>
> *"Well, we're going to die here, too. So might as well live your whole life to the fullest."*
>
> *"The first hardest thing to give up would obviously be my husband," Zucker said. "The second hardest thing would be meat. But for this opportunity, I would kiss them both goodbye."*

A. Restricted Diet

NASA, Russia, Japan, and the European Space Agency fund research into space food. The common focus of this research is upon preservation and maintaining freshness for dehydrated food that the crew can reconstitute with water when they want it. The reason for this emphasis is that food is tremendously important to crew morale and sustained ability to do their work. Insufficient and bad food, historically, has led to mutinies in exploration expeditions, immigrant ships, and military units. Alan B. Chambers, Chief of the Man-Vehicle Systems Research Division at NASA Ames Research Center posed the question:

"How do we weigh the morale value of a kilogram of filet mignon against a kilogram of propellant?"[8]

FIGURE 9 shows a still life by Dutch painter Jean Mortel (1652-1719), featuring a big variety of fruit. Presumably, the artist wanted to create the illusion that he painted this image in the late summer, when all the fruit, the maize, and the peppers would have been ripe. However, it is unlikely that all were actually available and ripe at one time, so probably he painted some items from memory to suggest such an overflowing bounty. This bounty of fruits and vegetables would have been treasured before refrigeration. How much more should the crewmembers treasure it with refrigeration but no tree crops or other fruit?

FIGURE 10. *Nature Morte Aux Oranges Et Citrons* (Still Life with Oranges and Lemons)- Jean Capeinick (1838-1890). http://www.wikigallery.org/wiki/painting_89971/Jean-Capeinick/Nature-Morte-Aux-Oranges-Et-Citrons-(Still-Life-With-Oranges-And-Lemons).

FIGURE 10 shows a more close-up still life by the Belgian painter Jean Capeininck (1838-1890), featuring only oranges and lemons, but with the citrus fruit peeled in its distinctive fashion. The sections of the orange project upward, separated, as if asking to be plucked from the cluster. Fresh oranges will not be available for long for Martian crews, if ever. Will long duration crewmembers dream of such simple pleasures and nutrition? Will the limited availability of fresh produce become a source of frustration, irritation, or conflict?

Dudley-Rowley et al give this illuminating account of potential morale issues and mission conflicts around food and eating:

> *The typical food incident that occurs on space missions is eating something that one is not supposed to eat. Lebedev and Berezevoy on Salyut 7 ate onions that were meant for an agricultural experiment. One can perhaps look the other way when one considers that the men may have been craving "freshies" (fresh vegetables), and that the dulled palate that space flyers experience dictated they eat something spicy. Probably more than one astronaut or cosmonaut has consumed foodstuffs meant for television commercials. Jerry Linenger, expecting pretzels to be sent up to him, almost ate the pretzel bag prop that was needed for the Rold Gold commercial.*

This quotation provides an example of another issue that may arise. Historically crews find ways to "go around" or even "to skip" tasks assigned to them. (Lebedev ate the onions, but didn't tell ground immediately, instead he told them they were blooming, which eventually blew the lie / Skylab astronauts refused to work etc.) For the Martian crew it will even be easier to withdraw from the laws and orders from Earth.

FIGURE 11 shows a painting of a monk by Eduard Grützner. The monk is smiling, looking forward to his first sip of the beer. Beer was brewed in many monasteries across Europe since the Middle Ages, some becoming very famous for that. Monks grew and traded their own food and drinks. At that time, water was not clean to drink and brewing beer sanitized the water. It was part of an everyday diet.

Alcohol was never officially allowed onboard space stations. However, there is evidence that astronauts and cosmonauts on Salyut and Mir space station did drink alcohol (Häuplik-Meusburger 2011, p. 219). Often wine and beer was smuggled into the station and enjoyed by the astronauts. Assuming that the right "biomass" grown in the greenhouse will be available in sufficient quantity, will crewmembers follow the monks' routine and brew their own

[8] At the Space Station Technology Workshop in Williamsburg Virginia (March 27—April 1, 1983), Marc Cohen attended the Human Factors session when Chambers spoke.

"moonshine" alcoholic beverages? Will alcohol become a problem, as it has on Antarctic stations or will it be used only to relieve stress and be helpful instead? And what effects will that have on crew morale and work efficiency?

The larger question that arises for designing a long-duration or permanent space habitat is: How much fresh food can the crew grow and how much must they receive via resupply? To what extent does the O_2/CO_2 balance limit the expansion of is this agricultural to full self sufficiency?

The takeaway from this example is that every process in the habitat ecosystem involves manifold complexities that need careful experimentation to find an optimum solution. This condition of irresolution leads to the central question for fresh food: How will it affect crewmembers' health and moral to never eat fresh fruit or vegetables more complex than lettuce for many years?

Another food-related issue that may arise concerns the times, places, and modes of eating and drinking. Presumably, not all crewmembers will be on duty all the time they are awake. Therefore, some part of the crew may take a break while the other crewmembers are exerting themselves at work. Dudley-Rowley offers an observation on this question:

> *Another issue on more of a serious note is the resentments that could accrue owing to those who take coffee, tea, or meal breaks while others are working furiously when life support is at stake. Other resentments could occur if crew cannot eat at the same times together or if someone who wants to dine alone cannot. . . . As the volume and variety of people living and working together in space increase, we may expect different personal and cultural cuisines and regulations to pose problems.*

FIGURE 11. *Bier Test* (1905) by Eduard Grützner. http://brookstonbeerbulletin.com/beer-in-art-75-eduard-grutzners-monastery-brewers/ (retrieved March 10, 2015).

Similar issues may arise due to different circadian rhythms in the absence of natural Zeitgebers and other cues, such as daylight, night, or seasons. People can become desynchronized or *"in extreme cases, an individual can free-cycle completely around the clock,"* (Stuster, 1986, p. 47). In this correlation, plants can provide an instrument for marking time. As living elements in an otherwise sterile and never changing environment, they provide stimuli within a life cycle (Häuplik-Meusburger and Paterson, 2014).

Furthermore plants nourish more than just the physical body. Experiences in space and Antarctic stations confirm the importance of growing and tending plants as counterpart to heavy workload or day-to-day work. Astronauts and polar station inhabitants confirm the calming effect (Häuplik-Meusburger, 2014) that is even measurable in brain activity.   *"They are our love",* said Vladislav Volkov (Zimmermann 2009, p. 20), *"These are our pets"*, said Viktor Patsayev (p. 42). As such the two Salyut 1 cosmonauts talked about their plants in the Oasis greenhouse.

B. Constant Confinement

With respect to the stressors of constant isolation and confinement within limited volumes and floor areas, Dudley-Rowley, (2004) found:

> *In regard to those issues identified under Critical Habitability I stressors, more countermeasures against stress need to be added in response to volume limitations. These additions are 1) mitigating the problem of stowage of items brought aboard by guest astronauts and cosmonauts and 2) the design of sufficient work envelopes to get at potential areas of repair. In the area of housekeeping, assignment of responsibilities and teamwork should be countermeasures against stress, as well as against errors.. . . Safety hazards that pertain to confinement, isolation, and separation include mental depression.*

Dudley-Rowley et al addressed also the stressors that derive from living always in a mechanically controlled environment and breathing an "artificial" atmosphere.

> *In regard to those issues identified under Critical Habitability II stressors, in the problems of the closed atmosphere, countermeasures need to be devised against errors when environmental controls are*

inadequate. The safety hazards extend beyond increased anxiety. When environmental controls are inadequate, there are toxicity concerns, the threat of heat prostration or cold injury, and that of suffocation.

Other researchers take different approaches to understanding minimal volume confinement. Sharon Matsamura (1983) prepared a review of court rulings about how small an area (or volume) in a prison in the United States constitutes cruel and unusual punishment under the 8th Amendment of the Constitution. She found that in several states, judges ruled that floor areas of less than 50 to 60 square feet (4.6 m^2 to 5.5m^2) per prisoner in a cell for 10 or more hours a day constituted cruel and unusual punishment. Assuming a standard ceiling height of about 8 ft. (2.4 m), those volumes amount to 400 ft^3 to 480 ft^3 (11.1 m^3 to 13.3 m^3). In comparison to Inspiration Mars, these prison cells would be luxurious, not including the fact that the inmates might be moving about outside the cell for up to approximately 14 hours per day in common areas, dining areas, and exercise areas. Of course, the social matrices of a space mission and a prison are different. Astronauts and cosmonauts are the ultimate volunteers, highly motivated to endure the hardships of the mission, including confinement in a small space. Prisoners are rarely motivated to endure the hardship of confinement. However, the effects of this long-term confinement in a small area or volume will wear on the space crew in some of the same ways it does on the prison population.

On Earth, when a room becomes "stuffy," the normal reaction is to "step outside for a breath of fresh air." Not so, in a prison. So, what if there is no "outside?" What if there is no "fresh air" available – only the recycled air that the crew is now breathing and have been breathing for years? This scenario requires outstanding capabilities in the air revitalization, decontamination, and purification by the ECLSS.

C. Disconnection from the Natural World

Few, if any researchers study the effect of disconnection long-term from the natural world in which humans and our ecosystem evolved, and in which all humans grow up. The contrived environment of a spacecraft or space habitat would be contraindicated by all standards for what makes a healthy environment for children: fresh air, sunlight, fresh fruits and vegetables, safe and uncluttered areas to play, and the sense of safety and security that comes from feeling a sense of belonging and being loved in a family. Although all these requirements tie together for children growing up in good health and happy, this section focuses more broadly upon the natural world and what is lost when the crew would be separated from it.

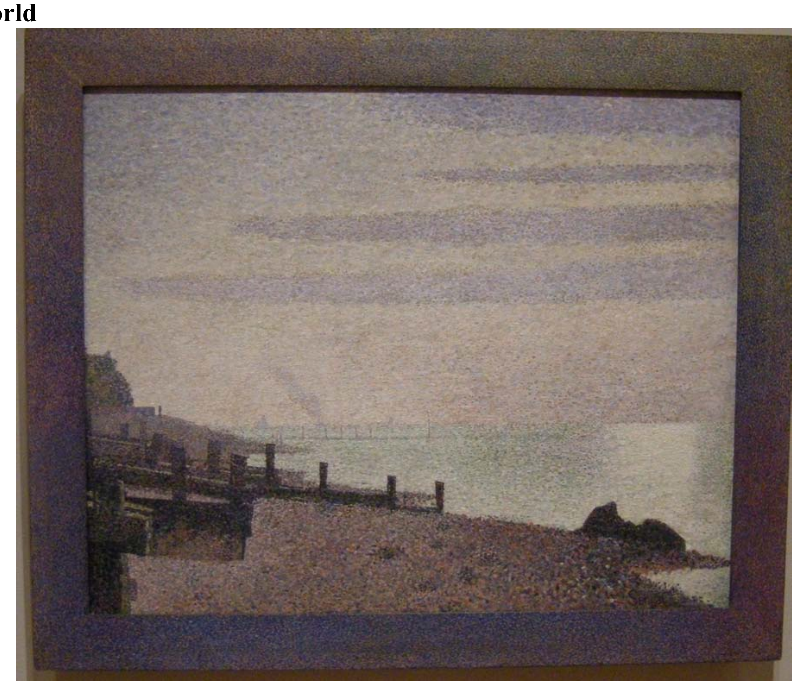

FIGURE 12. Georges-Pierre Seurat (1859-1891), *Evening, Honfleur*, Marc Cohen Photo. San Francisco Legion of Honor Museum.

FIGURE 12 shows Georges-Pierre Seurat's seascape Evening, Honfleur, showing a smooth sea with a simple reflection of light with a subtle horizon line separating the sea from the sky He lived in a nearby harbor and enjoyed the quiet calm and peaceful atmosphere. Once Seurat wrote in a letter: "*Let's go and get drunk on the light once more, that's a consolation"* (Herbert, 1991, p. 244).

The colors are subdued, but the full range of hues is present, suggesting a richness to be exposed in bright sunlight. There are no figures of people in this image, but it is eminently of our world. It could be as featureless as the dusty pink of Mars shown in FIGURE 6, but it is not. The presence of liquid water, however understated, makes all the difference. Add to the primordial presence of water some living organisms.

FIGURE 13 shows one of the most famous of French Impressionist Claude Monet's *Water Lilies.* Water lilies from the Flower Garden at Giverny became Monet's favorite model. He painted more than sixty paintings of water lilies in diverse variations. It is a triptych extending about 18 m, creating a sweeping view of the lily pads and the clouds reflected around them. With the addition of the living, wild plants, the ecosystem of the pond fills the width of the range of vision. FIGURE 13 shows the reflection of clouds on the water-lily-pond. The format is very big and allows the spectator to 'dive in'. The viewer feels as if being drawn into the ecosystem of the pond life, almost expecting a frog to grivet from the lily pads or a fish to jump.

FIGURE 13. Claude Monet, *Water Lilies*, NYMoMA, Marc Cohen Photo of the center panel.

FIGURE 14. B*oys Fishing in Gloucester [Massachusetts] Harbor*, Winslow Homer. http://www.classicartpaintings.com/Painters-W/Winslow+Homer+_1836-1910_/Homer_Winslow_Boys_Fishing_Gloucester_Harbor.jpg.html (Retrieved March 15, 2015).

The great majority of people on Earth live close to water: to rivers, lakes, ocean ports, or to the beach. Nearly all the great cities are closely associated with ocean ports or river ports that lead to the ocean. People live on the water, they play on the water, and they work on the water. Water pervades our lives, from the wettest to the driest climates. Adam Smith (1776, Vol I, Chap 4) wrote, “Nothing is more useful than water.” Water pervades and shapes so much of human experience. FIGURE 14 shows Winslow Homer’s (1836-1919) watercolor of two boys fishing on a bay off the ocean, with some schooners (probably going fishing too). He lived along the shore of Maine and carefully painted his observations of man and nature. Fish and fishing require water. It is one of the oldest modes of gathering food, and one of the most widespread modes of relaxation.

FIGURE 15 shows the painting ‘The Swimming Pool’ by French painter Henri Matisse (1869-1954). The New York Museum of Modern Art tells the story of its creation (NYMoMA, 2014):

> *One morning in the summer of 1952, Matisse told his studio assistant and secretary Lydia Delectorskaya that “He wanted to see divers,” so they set out to a favorite pool in Cannes. Suffering under the “blazing sun,” they returned home, where Matisse declared, “I will make myself my own pool.” He asked Delectorskaya to ring the walls of his dining room at the Hôtel Régina in Nice with a band of white paper, positioned just above the level of his head, breaking only at the windows and door at opposite ends of the room. . . .Matisse then cut his own divers, swimmers, and sea creatures out of paper painted in an ultramarine blue. . . . Matisse saw in paper’s pliability a perfect representation of the fluidity of water, making The Swimming Pool a perfect melding of subject and means.*

What kinds of paintings or pieces of art will the crew on Mars create to compensate for their confinement? Will they also make their own “pool,” due to the inability to enjoy the real thing?

FIGURE 16 shows one of the many ‘Sun Flowers’ paintings by Egon Schiele (1890-1918). He shared this fondness with his fellow artists Van Gogh (1853-1890) and Gustav Klimt (1862-1918). Schiele's sunflowers are shown in their natural state with leaves and stalk, but the background has been left out. He also shows the flowers after they have bloomed with hanging leaves and imperfect flowerpot. In all his paintings life and death are close together. He coined the statement: “Everything is living dead” (Seldom, 2012, p. 43). For the first crews on Mars, the risk of death will always be close, but where will the sunflowers be?

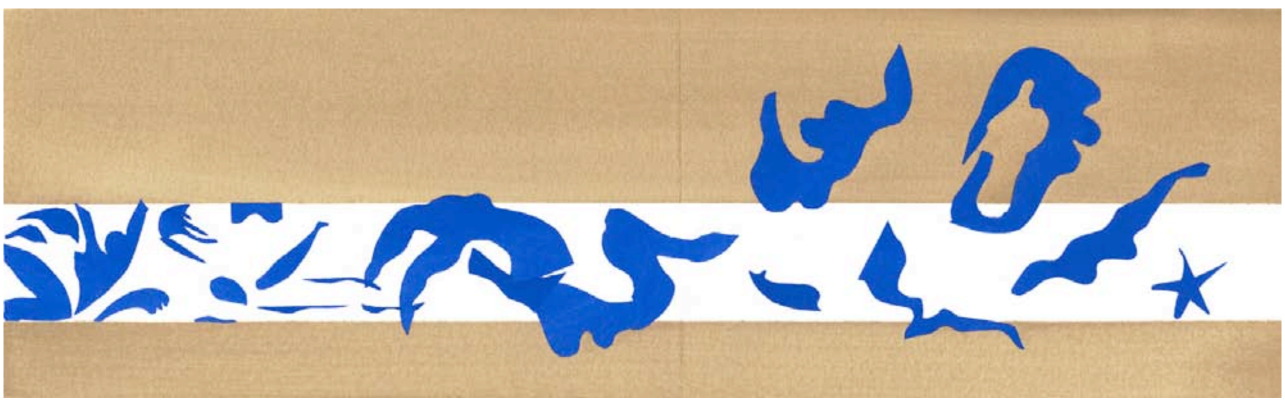

FIGURE 15. T*he Swimming Pool,* Henri Matisse, paper collage. New York Museum of Modern Art. http://www.moma.org/interactives/exhibitions/2014/matisse/the-swimming-pool.html (retrieved October 20, 2014).

FIGURE 17 shows Paul Cezanne’s painting of a forest. It articulates the individuality of the trees that grow from the rocks and seem to stand at arm’s length from one another. Cezanne’s forest appears inviting, to entice the viewer to wander between the rocks and look up at the trees. This forest primeval embodies the raw presence of the natural world containing not only the trees but also the wildlife to which they give shelter and help form the ecosystem that they share. Humans are part of the ecosystem as well, even if humans may be destroying the environment that makes tour life and survival possible.

Contact with nature varies with the degree of urban settlement in which people live. In rural areas, people live closer to the wonders of nature and to its forces and their effects. For city dwellers, there is less immediate contact. For them, walking in a rainstorm is often their most intimate contact with forces of nature. FIGURE 18 shows Childe Hassam’s painting of a rainy and windy day in New York City. The people walk with a little difficulty, holding their umbrellas against the pull of the wind. The pavement is slick and shiny, freshly washed. The fall of rain renews the promise of life.

FIGURE 16. Egon Schiele, *Sun Flowers*, 1911. http://www.egon-schiele.com/images/paintings/sunflowers.jpg (Retrieved March 10, 2015)

FIGURE 17. Paul Cezanne, *In the Forest,* San Francisco Legion of Honor Museum. Marc Cohen Photo.

FIGURE 18. Childe Hassan (1859-1935), *Rainy Day on Fifth Avenue.* Princeton University Art Museum. http://upload.wikimedia.org/wikipedia/commons/c/c3/Rainy_Day_on_Fifth_Avenue_1893_Childe_Hassam.jpg. (Retrieved May 20, 2015).

FIGURE 19 shows Dirk Hal's painting "The Merry Company" from the "Dutch Golden Age" (painted 1627-1629). It portrays a rambunctious group of friends and perhaps family reveling in a home or in the equivalent of a bar or public house. This type of painting of social enjoyment was apparently such a favorite in the 17th century that art historians consider "the merry company" to represent a genre of its own.

FIGURE 19. Dirk Hals, *The Merry Company.* San Francisco Legion of Honor Museum, Marc Cohen photo.

FIGURE 20. Pierre-Auguste Renoir (1841-1919), *Le Dejeuner des Canotiers (The Luncheon of the Boating Party)*. The Phillips Collection, Washington DC. http://commons.wikimedia.org/wiki/File: Pierre-Auguste_Renoir_-_Luncheon_of_the_Boating_Party_-_Google_Art_Project.jpg (Retrieved October 25, 2014).

FIGURE 20 shows one of Pierre-Auguste Renoir's masterpieces, The Luncheon of the Boating Party. In this painting, a group of family or friends take an outing on boat where the deck is arranged for their party with table, chairs, and canopy. They are probably cruising slowly on a river or a canal, close to the trees that line the banks. Unlike Hal's Merry Company, there is a range of ages. The girl in the straw hat is a young teenager, gazing dreamily in the direction of the painter. There is lively conversation and flirtation. This "crew" embarked together on this outing specifically to enjoy themselves, which they appear to be doing.

What will it mean to socialize only with the people with whom we work, to see them every day, wherever we go?

How will a Mars crew "blow off steam," celebrate, relax in a *merry company*?

What will if feel like to never go on a picnic outside and enjoy the pleasures of a fresh breeze on the naked skin while chanting with friends?

D. No Family Life

Dudley-Rowley et al considered only the situation on Mir where the crewmembers are separated from their families, but where frequent communications are possible, without any time latency. They found:

> *In terms of family problems, counseling needs to be also a countermeasure against stress, as well as against errors. This issue of family problems can be expected to become more salient as tours-of-duty in space become longer in duration. Family problems are a normal part of life and are mitigated better when an open avenue is available for people to express themselves.*

The separation for long-duration crewmembers on a Mars round trip will be more extreme, typically three years away from home, assuming the mission goes according to plan. For a one-way mission, the crewmembers will experience an extreme and permanent separation from their families, akin in this respect to immigrants to North America from Europe in the 19th century or earlier. They did not expect to see their loved ones ever again.

So, is the solution or "countermeasure" to no family life to start a new family on the new world? Is it reasonable to assume that the small selection of crewmembers, one can find among themselves compatible and mutually agreeable mates? FIGURE 20 shows an aspect of family life with its ambiguities and ambivalences. How will such behaviors and feelings play out in space?

FIGURE 21 shows Mary Cassatt's (1844-1926) painting that illuminates the special bond between a mother and her child. She often painted this theme with local women, instead of professional models. According to Zerbe (1987), Mary Cassatt never had children, but a very close relationship with her mother. She also lost several siblings, which may have informed the intimate quality of her paintings.

FIGURE 21. Mary Cassatt, *Motherhood,* http://sketchbook.cheapjoes.com/wp-content/uploads/2012/05/Mother-Rose-Nursing-Her-Child1.jpg (Retrieved March 23, 2015).

Will the crewmembers have already borne and raised children before their departure from Earth? Will the crewmembers be younger, never having raised children? Or will they leave families and children behind to probe the vast unknown?

FIGURES 22 to 26 and 29 show scenes of domesticity with children and pets. These images evoke a sense of familiarity and even normality that spans across the generations. They address the multi-generational context in which most people live; there is always hope for the new generation. The new generation -- even if they don't know it carry those hopes. What carries hope for people in an environment where they cannot give birth or raise children?

Animals, either as pets or working beasts also form part of the living environment. It is well accepted that the bacteria in the digestive track evolved with the hosts they inhabit. Surely higher order "social parasites" like dogs and cats have co-evolved with humans. Dogs, *Canis lupus familiaris became* social parasites by fulfilling emotional needs for their humans (Causey, Goetz, 2009). In the absence of children or pets to serve as recipients for the natural urge to bond, to mother, to love, how will the first people on Mars fulfill or compensate for these needs?

Does leaving *humanity's childhood* behind on Earth mean *leaving children* behind?

How suitable would a planetary habitat be for being pregnant, giving birth, and raising children?

How would the community or family educated the children about their world of origin, and the natural world on Earth that they cannot experience first-hand?

Would it even be possible to bear healthy babies in the confined and artificial Mars habitat environment? Conditioned to Mars gravity (.38 G), would these Martian-born children ever be able to 'return' or visit Earth? What effect will the crew's awareness of these limits have on their outlook, morale, and sustained performance?

FIGURE 22. *Portrait de Claude*, Pierre-Auguste Renoir's grandson. http://www.wikiart.org/en/pierre-auguste-renoir/portrait-of-claude-renoir-painting-1907 (Retrieved March 10, 2015).

FIGURE 22. Alfred Hitchcock and his Dog. http://www.boredpanda.com/famous-historic-people-pets-cats-dogs/?image_id=famous-historic-people-with-their-pets-cats-dogs-26.jpg. (Retrieved March 20, 2015).

FIGURE 24. *Sarah in a Large Flowered Hat, Looking Right, Holding her Dog*, Mary Cassatt. https://www.pinterest.com/pin/375839531375008412/ "pinned" from the Art Renewal Center. (Retrieved March 10, 2015).

FIGURE 25. *Mother and Child in the Field*, watercolor and gouache, Claudia Tremblay, contemporary, Montréal, QB, Canada. https://s-media-cache-ak0.pinimg.com/736x/c2/a4/df/c2a4dfec31c51a7589c20c89f6b9bd87.jpg (Retrieved May 20, 2015).

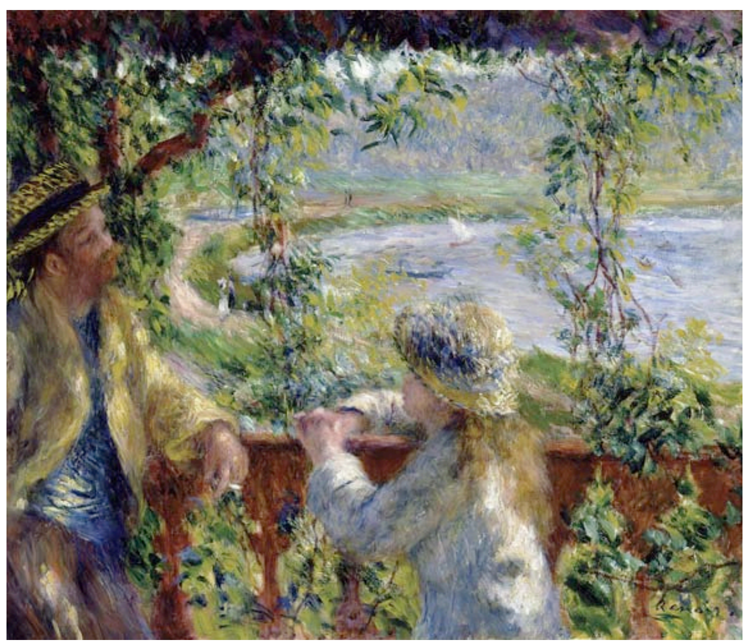

FIGURE 26. *By the Water*, Pierre-Auguste Renoir. Chicago Art Institute. http://commons.wikimedia.org/wiki/File: Pierre-Auguste_Renoir_-_By_the_Water.jpg (Retrieved April 20, 2015).

FIGURE 29, Summertime by Mary Cassatt, shows a mother and child watching a male mallard and a white duck and perhaps, feeding them. What are the implications of going to a world where there is no wildlife, no birds? Will the crewmembers feel a sense of *cosmic aloneness* as the only multicellular animal species on Mars, much less the only one with intelligence?

E. Repetitive and Often Meaningless Tasks

Dudley-Rowley et al examine several aspects of task-related issues, including the organization of work that can lead to stressors. They write about tasks but touch only peripherally on monotony and boredom, or whether the work is "meaningful" beyond ensuring the common survival of the crew:

> *In regard to those items identified under task-related issues, more countermeasures for stress and for errors need to ward against "rat-packing," keeping materiel and equipment aboard from past guest astronauts and cosmonauts that are not essential. In terms of task assignment, there needs to be a dominance of the task-assignment model over the military rank model overall. Countermeasures against stress for task assignment should include task alternatives inasmuch as possible. However, when [urgent] tasks emerge, as in situations where life support might be at stake, all crew need to play some part. As a countermeasure against error, task rotation might not be possible. In terms of physical limitations of crew, countermeasures against stress should take into account ecological considerations in design and environment. . . . In terms of scheduling and coordination conflicts, allowing for more in-flight coordination among the crewmembers would be more beneficial. Provision for onboard training in advance of more complex tasks would also make coordination less stressful and error-free.*

FIGURE 27 shows a classic comic portrayal of overwork, repetitive tasks, and monotony – Charlie Chaplin in the film *Modern Times.* The contradiction that Chaplin presents, are the humans serving the machines or are the machines serving the humans? If it is a symbiotic relationship between the crew and the machines, is the symbiosis equal? This contradiction will confront the crews on long-duration space missions with a wide range of possible autonomy implementations. In the American Astronauts' experience, having meaningful and stimulating work has often emerged as an important value just as scheduling overload is sometimes a contentious issue. The Shuttle astronaut Byron Lichtenberg (1988, pp. 2-3) wrote:

FIGURE 27. Charlie Chaplin, *Modern Times* (1936 film). http://thecharnelhouse.org/2011/09/09/industrialism-and-the-genesis-of-modern-architecture/ (retrieved November 1, 2014).

> *The crew should have the benefit of working on intellectually valid tasks, not simply controlling a parameter like DC offset or gains. The philosophy should be to use the person in the higher-level control of experiments rather than closing the loop to control a specific parameter. . . . Research concepts that need to be explored include the degree to which automated systems control experiments.*

Skylab 4 was the first (known) mission on which the pressure of intensive scheduling over a very long period of operations provoked an adverse reaction in the crew. It was a showed the need for a different way to approach mission operations design, management and scheduling than running everything on demand from Mission Control. For a Mars mission to succeed, the crew will need a higher level of autonomy than the Skylab crew, but the issues of scheduling and handling the workload are always there. Rockoff et al (1985, pp. 9, 44) explained:

> *Midway through the 84-day mission, the third crew refused to conduct assigned tasks. This one-day "strike" was imposed to protest the overloading of time by mission controllers. The crew spent the day in individual pursuits, mostly looking out the window. . . . The third Skylab crew demonstrated the problems associated*

with overscheduling. With boredom a constant threat of potential stress, it is often seen as wise to make days extremely busy, leaving little time for reflection or inactivity.

For the crew on the long duration mission, what will it mean to follow the same routines over and over again, every day, without variety or diversion? This issue confronts people in every walk of work life. How does one deal with repetition and tedium to remain happy, productive, and achieve one's objectives?

Never the less, "routine" does not need to be boring, colorless, or monotonous. Bawalla Yusuf Osama painted the scene in FIGURE 28 showing people going about their business doing a variety of daily tasks. It looks like a market day; women are carrying piles of produce on top of their heads. The people are socially and culturally engaged in what they are doing. Here, *routine* does not carry a negative connotation. Instead, it suggests activities that are familiar and comfortable, that are comforting.

What happens if the crew or certain crewmembers become alienated from their labor and don't care anymore about their mission?

What happens if after, say, half the mission, a crewmember wants to "change career?"

What are the consequences if the crew comes to regard their role serving the automation as oppressive?

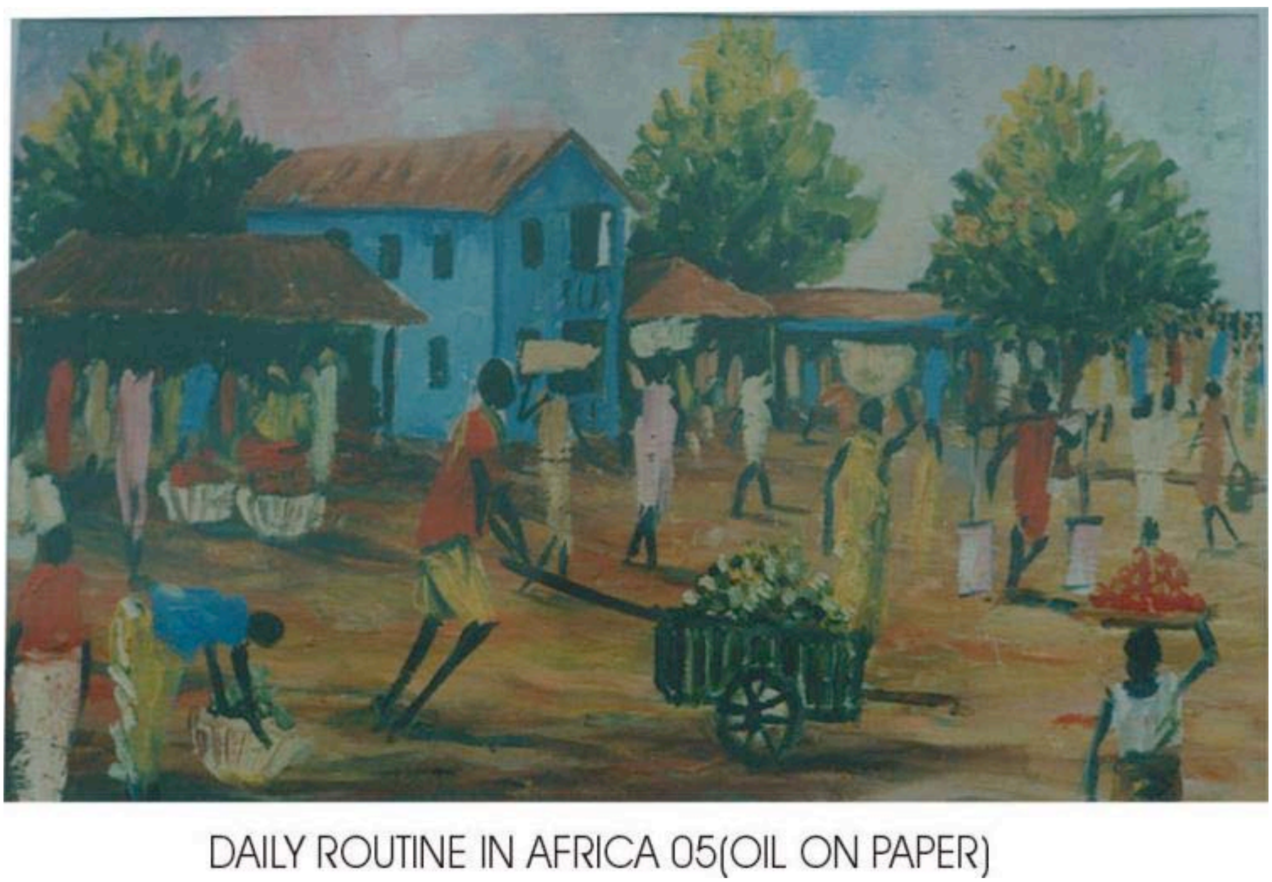

FIGURE 28. Bawalla Yusuf Osama, *Daily Routine in Africa*, courtesy of Artmajeur.com. http://www.artmajeur.com/en/artist/yusuf/collection/brainfillfd/1049489/artwork/daily-routine-in-africa/697057 (Retrieved May 1, 2015).

IV. Discussion

The purpose of this paper is ***not*** to argue that what Mars crews must give up and leave behind will be so difficult a sacrifice that it would make it impossible for a human Mars mission to succeed. On the contrary, the authors offer every hope for success. However, this success *will not be possible* if the mission designers and engineers pursue their single-minded denial of human needs in minimal or subminimal concepts like Mars Direct, Inspiration Mars, and MarsOne. Each of these three concepts demonstrates a key dimension of the challenges unmet. Mars Direct demonstrates the shortcomings of a mass budget so tight that it is not possible to connect pressurized elements so the only way to transfer from one to another is by EVA or pressurized rover. Mars Direct installs the EVA airlock in the most misguided way, locating a pressure vessel within the pressure vessel of the habitat. Inspiration Mars demonstrates the complete failure to recognize or understand the crew's need for sufficient volume to live and function without developing severe psychological stress. It also shows a near total lack of architectural programming for adjacencies or separations of functions, and no vision of what the experience of the internal volume would be. MarsOne demonstrates a lack of awareness of the consequences of the one-way trip in terms of being cut off from the natural environment and the existential angst of never being able to return to Earth, to friends and family. Although MarsOne implies growth options with the 500 m^3 inflatables, they will still be small for a lifetime to come.

It is not a viable approach to calculate the spacecraft trajectories to absurdly over- precise numbers while allowing only the most vague, unsubstantiated estimates of habitability requirements for the crew. The attitude that seems to prevail now among these ardent Mars exploration advocates is that anything they do not already know or that does not interest them cannot be important. This essay addresses some those neglected topics that will prove necessary for mission success and crew health and prosperity.

The paintings used in this paper illustrate activities to which people are so accustomed on Earth: breathing fresh air, walking in nature, swimming in liquid water, or having social encounters outside work, but which would not be possible on Mars. So, what can mission planners and designers do to compensate for these losses to supplement the minimal mission designs? How can they design the spacecraft or habitat to enable and enhance the quality of the crew's living experience? What should be the architectural design brief (requirements) to ensure the most supportive crew accommodations? What are the best ways to design to meet those requirements?

For example, could art help to overcome such restrictions? Beyond the obvious and essential habitability accommodations that Mars mission designers must learn to accommodate and incorporate from the beginning of their work, can art serve as a "connection to Earth?" Ono and Schlacht (2010) advocate for the inclusion or installation of a variety of art forms in spacecraft and planetary habitats, including soundscapes, "sound wave sculpture," Zen gardens, color highlights, light sculptures, and fractal imagery. They also argue in favor of providing the crew with materials to create their own artwork to personalize the environment and for its therapeutic value.

During extended missions, astronauts often reported their longing for the tastes and smells of home. When Jerry Linenger, MIR astronaut, received fresh fruit, he stated "it was not only, that the fresh fruit tasted delicious, but it was seen as a gift, as "the aroma of the good Earth" (Linenger 2000, p. 97). Linenger's experience evokes the episode in Marcel Proust's seven volume <u>À la recherche du temps perdu (Remembrance of Things Past, Swann's Way, Combray I)</u> when the taste of a madeleine cookie soaked in lime flower tea brought on overwhelming recollections of his childhood. What will the crew experience when a resupply cargo lander arrives with rare treats that evoke such bygone tastes, smells, sensations, and experiences that are out of reach, perhaps forever? When we notice a particular scent, immediately memories come up and our brain connects with this specific smell. Could this effect occur with art too?

Prof. Maria J. Durao at the Technical University of Lisbon writes (2008, Fabrikart 8):

Art makes one see, hear, think and feel reality on a more profound level since it creates forms not as an imitation but a revelation. Painting is an alchemical process, a ritual act as a psychic container for transformation.

Durao (2008, *Artitextos, p. 5)* argues further that:

A certain color impression not only evokes a momentarily visual sensation, it also involves our entire experience, memory and thought process and appeals not only to the sense of sight but, by synesthetic association, also to other sense such as temperature, hearing, touch, taste and smell.

What will the crewmembers truly need for a round trip to land them on Mars then return them safely to the Earth, for a fly-by, or for a one-way trip to stay on Mars for the rest of their lives? This inquiry leads to parsing the question for future research a different way:

- What must we leave behind?
- What can we leave behind?
- What can we take with us?
- What must we take with us?

TABLE 3 lays out this parsing in two dimensions, with what we leave behind on the x-axis and what we take with us on the y-axis. TABLE 4 lays out this parsing differently, with the permissive of what we *can* do on the x-axis and what we *must* do on the y-axis.

TABLE 3. Matrix of Leave Behind versus Take with us		
	What Can We Leave Behind?	What Must We Leave Behind?
What Can We Take with Us?		
What Must We Take with Us?		

TABLE 4. Matrix of Can versus Must Leave Behind or Take With Us		
	What Can We Leave Behind?	What Can We Take with Us?
What Must We Leave Behind?		
What Must We Take with Us?		

IV. Conclusion

Ironically, the very same "Can-Do!" spirit that characterized so many of the successes throughout the Space Age, also blinds the current crop of Mars advocates to the profound challenges of habitability that lie ahead. Despite all the knowledge we have gained about long-duration spaceflight from Salyut, Skylab, Mir, and ISS, these-would-be Mars pioneers willingly jettison it all in favor of deterministic and reductionist mission designs. Long duration missions to Mars and beyond cannot succeed if the human support and human system integration strategy is based on denial and avoidance of the crew issues that are as real as burning all the propellant.

On the contrary, this essay demonstrates that mission designers must be honest and open-minded about the risks and challenges that the crew will face over their long voyage and return or their permanent stay on the surface. What mission designers must do with the close involvement of well-qualified space architects is to take into account the human needs of the crew, finding ways either to satisfy them or to compensate for the loss of what they give up and leave behind to fly on these missions. These solutions include bioregenerative life support systems that are sustainable to produce a breathable and healthy atmosphere, to grow food, and to bring essential features of the Earth's ecosystem with the crew to their new home world. These quality of life provisions will prove essential to sustain the crew for years. Human missions to Mars and beyond can succeed only if they take fully into account how best to accommodate and support the crew's needs across the broad spectrum of human experience.

Acknowledgments

We wish to thank Marilyn Dudley-Rowley, Pablo Flores, Maria Junge, Robert Piercy, Robert Raasch, Lisa Rockoff, and Trieve Tanner for their earlier contributions to the method of analysis conveyed in the Crew Safety-Human Factors Interaction Model.

References

Causey, Kayla; Goetz, Aaron T. (2009, April 24). The Most Manipulative of Species, Psychology Today. https://www.psychologytoday.com/blog/natural-history-the-modern-mind/200904/the-most-manipulative-species retrieved May 4, 2015.

Cohen, Marc M. (2009 April). Testing the Celentano Curve: An Empirical Survey of Predictions for Human Spacecraft Pressurized Volume (SAE 2008-01-2027). *38th International Conference on Environmental Systems (ICES),* San Francisco, California, USA, 30 June - 2 July 2008. In, *SAE International Journal of Aerospace (vol. 1, no. 1, p. 107-142)*. Warrendale, Pennsylvania, USA: Society of Automotive Engineers.

Cohen, Marc M.; Junge, Maria K. (1984 October). Space Station Crew Safety: Human Factors Model. In, *Proceedings of the Human Factors and Ergonomics Society 28th Annual Meeting (vol. 28, no. 10, p. 908-912),* San Antonio, Texas USA, 21-26 October 1984. Santa Monica, California, USA: Human Factors and Ergonomics Society.

Do, Sydney; Ho, Koki; Schreiner, Samuel Steven; Owens, Andrew Charles; de Weck, Olivier L. (2014, Sept). An Independent Assessment of the Technical Feasibility of the Mars One Mission Plan, IAC-14,A5,2,7,x24778. 65th International Astronautical Congress, Toronto ON Canada, 29 Sept-3 Oct 2014. Paris France: International Astronautical Federation. http://hdl.handle.net/1721.1/90819 (http://hdl.handle.net/1721.1/90819)

Drake, B. G. (Ed.) (2009). Human Exploration of Mars: Design Reference Architecture 5.0. NASA SP-2009-566. Houston, TX, USA: Johnson Space Center, National Aeronautics and Space Administration.

Dudley-Rowley, Marilyn; Cohen, Marc M.; Flores, Pablo (2004, March). 1985 Nasa-Rockwell Space Station Crew Safety Study: Results From Mir, Presented at the Russian Academy of Science for the *Institute for Biomedical Problems 40th Anniversary Conference,* November 2003. Published in the (Russian). Moscow, Russia: *Journal of Aerospace and Environmental Medicine.*

Durão, Maria João (2008). Sketching the Ariadne's Thread for Alchemical Linkages to Painting, *Fabrikart: arte, tecnología, industria, sociedad* (8). La Rioja, Spain: Universidad de la Rioja.

Durão, Maria João (2008 December). Body in Weightlessness: Cartography of a Sentient Place. In, *Artitextos* (no. 7, p. 47-61). Lisbon, Portugal: Faculdade de Arquitectura, Universidade Técnica de Lisboa.

Foley, Tico (1998). Everyday Noise — All Day, (SAE 981787), *28th International Conference on Environmental Systems,* Denver, CO, July 12-15, 1999, Warrendale, PA: Society of Automotive Engineers.

Foust, Jeff (2015, April 10). NASA Hopes Mars Plans Flexible Enough to Survive Administrations, Space News. http://spacenews.com/nasa-hopes-mars-plans-flexible-enough-to-survive-administrations/, (retrieved April 15, 2015).

Haignére, Jean-Pierre (2009). Transcript not published. [Interv.] Sandra Häuplik-Meusburger, Paris, France.

Häuplik-Meusburger, Sandra (2011). Architecture for Astronauts: An Activity-based Approach. Wien, Springer Wien – New York

Häuplik-Meusburger Sandra, Paterson Carrie, Schubert Daniel, Zabel Paul. (2014). Greenhouses and their humanizing synergies, *Acta Astronautica 96* (2014) 138-150

Herbert, Robert L.; Cachin, Françoise; Distel, Anne; Stein, Susan Alyson; Tinterow, Gary (1991). Georges Seurat, 1859-1891, New York, NY: Metropolitan Museum of Art.

Hoffman, S. J.; Kaplan, D. I. (Eds) (1997). Human Exploration of Mars: The Reference Mission of the NASA Mars Exploration Study Team (NASA SP-6107). Washington DC: National Aeronautics and Space Administration.

Linenger, Jerry M. (2000). Off the Planet – Surviving five perilous months aboard the Space Station MIR, New York: McGraw-Hill.

Jones, Harry (2006, July). Comparison of Bioregenerative and Physical/Chemical Life Support Systems, *36th International Conference on Environmental Systems*, Norfolk Virginia, July 17-20, 2006. Warrendale PA, USA: Society of Automotive Engineers.

Jørgensen, Jesper (2005 July). Sensory Deprivation – a Challenge for Space Architecture? (SAE 2005-01-2912). 35th International Conference on Environmental Systems (ICES), Rome, Italy, 11-14 July 2005. Warrendale, PA, USA: Society of Automotive Engineers.

Landau, Elizabeth (2014, May 17). Mars hopefuls ponder life without families, favorite foods, http://edition.cnn.com/2014/05/16/tech/innovation/mars-one-candidates/ (retrieved 19 May 2015) Atlanta GA USA: Cable News Network (CNN).

Lichtenberg, Byron K. (1988). Concepts for Crew Experiment Interaction—Future Space Flights: Workstation Design and Requirements, (SAE 881025), *18th Intersociety Conference on Environmental Systems*, San Francisco, CA, July 11-13, 1988, Warrendale PA: Society of Automotive Engineers.

MacCallum, Taber (undated). Inspiration Mars – A Mission for America, A Mission for the World: Architecture Study Report Summary. Tucson AZ: Inspiration Mars Foundation.

MarsOne (2014). The Technology (retrieved January 30, 2015). http://www.mars-one.com/mission/the-technology.

MarsOne (2015). Human Settlement for Mars (last retrieved May 22, 2015). http://www.mars-one.com.

Marx, Karl (1867). Das Kapital: Kritik der politischen Ökonomie (Capital: Critique of Political Economy), Vol 1, Chap. 23, Hamburg, Germany: Verlag von Otto Meissner. http://www.marxists.org/archive/marx/works/1867-c1/ch23.htm retrieved May 12, 2015.

Matsumura, Sharon (1983 October 20). Prison Space Standards for Space Station Design Study. San Francisco, California, USA: NASA-Ames/ University Consortium for Astrolaw Research. http://spacearchitect.org/pubs/Astrolaw-Matsumura-19831020.pdf (retrieved May 1, 2015).

New York Museum of Modern Art (2014) (retrieved May 6, 2015). New York NY: MoMA. http://www.moma.org/interactives/exhibitions/2014/matisse/the-swimming-pool.html.

Ono, Ayako; Schlacht, Irene Lia (2010). "Space art: aesthetics design as psychological support", *Personal and Ubiquitous Computing* Volume 15, Issue 5, pp.513-517.

Proust, Marcel (1913; 1922 in English). À la recherché du temps perdu, (C. K. Moncrieff, Trans.) Paris: Gasset. Project Gutenberg, March 21, 2009 [EBook #7178], http://www.gutenberg.org/files/7178/7178-h/7178-h.htm, retrieved March 10, 2015.

Rockoff, Lisa. A.; Raasch, Robert F.; Peercy, Robert L., Jr. (1985, June). *Space Station Crew Safety Alternatives Study—Final Report*: Volume III—Safety Impact of Human Factors, NASA CR-3856, Washington DC: NASA Scientific and Technical Information Branch.

Selsdon, Esther; Zwingerberger, Jeanette (2012). Egon Schiele, New York NY: Parkstone International Press.

Smith, Adam (1776, 1904 5th Ed). An Inquiry into the Nature and Causes of the Wealth of Nations, I.4.13, Library of Economics and Liberty (Retrieved May 24, 2015). http://www.econlib.org/library/Smith/smWN1.html#B.I,%20Ch.4,%20Of%20the%20Origin%20and%20Use%20of%20Money.

Stuster, Jack. (1986). Space Station Habitability, Recommendations Based on a Systematic Comparative Analysis of Analogue Conditions. NASA-CR-3943, Washington DC: National Aeronautics

Tito, Dennis A. et al (2013, March). Feasibility Analysis for a Manned Mars Free-Return Mission in 2018, *IEEE Aerospace Conference,* Big Sky Montana, USA. March 2-March 9, 2013. New York, New York, USA: Institute of Electrical and Electronics Engineers.

Zerbe, K. J. (1987, Spring). Mother and child: A psychobiographical portrait of Mary Cassatt, *Psychoanal Rev.* 74(1): 45-61. http://www.ncbi.nlm.nih.gov/pubmed/3112829, (retrieved May 6, 2015).

FIGURE 29. Summertime, Mary Cassatt (1894), Daniel J. Terra Collection. http://wsimag.com/images/article_image.image/c6/efc6/4_Cassatt_verano_copy_06de4b_ms.jpg. (Retrieved March 23, 2015).

Zimmerman, Robert. (2003), Leaving Earth: Space Stations, Rival Superpowers, and the Quest for Interplanetary Travel, Joseph Henry Press, Washington, D.C.,

Zubrin, Robert (1996, May/June). The Promise of Mars. *Ad Astra*, Washington DC: National Space Society. http://www.nss.org/settlement/mars/zubrin-promise.html, (retrieved April 4, 2015).