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An Astrosociological Approach to Defining Indigenous Martian Architecture

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[Abstract] This paper takes social scientific structural, evolutionary, and ecological perspectives on the adaptive architectural expressions of colonizing Mars. It is best read as a companion piece to "The Globalization of Space – The Astrosociological Approach" by the secondary and tertiary authors. This treatment assumes that humans are able to begin a Humans-to-Mars effort before the challenges and costs of global warming on Earth shut the door to long-duration space exploration. In fact, it assumes that an evolution of technological and social innovations emerge by meeting the challenges to the human species heralded by the dawning of the next historical geological/environmental epoch of the Earth. The authors review the anticipated milestones of this evolutionary lineage that transforms capital and the technological means of production and that enables the expansion of the human ecology on a greater scale. *This evolution is essential and is the design driver of sustainable human settlements on Earth, the Moon, and Mars.*

Three distinct phases of human architecture on Mars are anticipated. The authors have embedded these over a timeline of exploration featuring a sequence of eight time intervals. The first Mars architectural phase involves responding to various physiological, sociological, and psychological factors expected to affect crew functionality over long durations away from Earth. Constructed from imported technologies, combining some easily processed *in situ* materials and delivered payload, the shelter is expected to adjust to the explorer's needs, well beyond the capabilities of a rigid habitat launched to a foreign body for a "flags and footprints" expedition. The second phase of Martian architecture meets the needs of the earliest scientific and mining missions to Mars. It is a transitory phase offering a viable shift from the temporary kluge between *in situ* and delivered payload materials to a more livable human settlement of the Red Planet. This will involve the cannibalization of earlier structures and the higher-level manufacture of other materials from *in situ* elements. The third phase is the primary use of manufactured materials from native elements in living and working spaces on Mars. Human history provides architectural parallels.

I. Introduction

THIS report is a companion piece to "The Globalization of Space – The Astrosociological Approach" by the secondary and tertiary authors. This treatment assumes that humans are able to begin a Humans-to-Mars effort before the challenges and costs of global warming on Earth shut the door to long-duration space exploration. In fact, rather than squelching human progress, the authors assume that there follows an evolution of technological and social innovations brought about by meeting the challenges to the human species heralded by the dawning of the next historical geological/environmental epoch of the Earth.

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A. Design Drivers, Scale of Vision, and Time

In the aggregate, the authors associated for several years with the American Institute of Aeronautics and Astronautics Design Engineering Technical Committee and its AeroSpace Architects Subcommittee and related projects. We saw all manner of designs for extreme environmental working and living spaces inside and out and sometimes contributed to them. The best of these took into account the comprehensive human factors at the human-technology, human-environment, and human-human interfaces.

In 2002, the primary author (Wapniak) introduced the twin notions of considering a wider range of design drivers[§] and the evolution of human living and work spaces on Mars.[**] Defining an indigenous Martian architecture depended on knowing the design drivers, he argued, including ones that were not usually considered by architects. We remember the reception this idea got among our colleagues who did not think that engineers and architects should wander into wider-ranging, multi-level units of analysis concerning a design article. However, when one is a planetary scientist also educated as a sociologist and social psychologist (Dudley-Flores) and when one is an aerospace engineer also educated as a political scientist and international relations scholar (Gangale), Wapniak's approach seemed quite natural. At the same time, it posed a challenge to aerospace architects whose "scales of vision" were different.

We had observed that at one polar end among aerospace architects and engineers, the people who would most likely be charged with designing for humans to and on Mars – many who had come out of mainstream architecture and engineering occupations – was a particular scale of vision from which they approach their tasks. Their "day jobs" may be designing multi-story buildings. At the most, the scope of time and space may come into the picture in terms of how such buildings weather years of usage and how the users may want to expand or modify these structures later on. So, they bring this scale of vision into designing spaceships or habitats off the Earth. Time and space for these thinkers tend to form a tight envelope around the built environment in the extreme setting. They are not overmuch concerned with other things happening along the human timeline that may impact their constructions as the projected date to ensconce them off the Earth approaches. To the reverse, the polar opposite among aerospace architects and engineers are those who design for the aesthetic pleasure of it, assuming that at some point in time the "smart" materials and the miraculous propulsion systems will be available to make possible their concepts. They are completely unrooted from the human timeline.

However, *time* in a multitude of forms is the overarching design driver behind the expansion of the human ecology into the solar system and onto a post-Holocene Epochal landscape Earthside brought prematurely on by global warming. The problem of human survival in extreme environments is a truly monumental task. There are depths to the course of human affairs, of extremities of environments as yet unexperienced, and of interplanetary space to be reckoned with. The greater the extremity of environment, often the lesser the utility of the usual resources at hand and the less luxurious the luxury of time in meeting the extremity. Expanding the human ecology to Mars is not undoable, as are none of the other things that we must do to ensure our survival against the ever-increasing challenges to the human species. But, those things require the proper scale to fully apprehend the design drivers of the task. Wapniak's 2002 conceptualizations about an indigenous human architecture for Mars called for the scale of vision to account for as many design drivers as possible that connect to the human timeline. A scale of vision that could count down the days till humans would stand on the Red Planet.

Table 1 compares three different types of space mission design concerns. From left to right, the first two models clearly bear a kinship. An in-depth comparison of Man-in-a-Can and Quality of Life design models can be found in "Design Implications of Latent Challenges to the Long-Duration Space Mission" (Dudley-Rowley, Okushi, Gangale, Flores, and Diaz 2003).[1] Briefly, Man-in-a-Can design characterizes the type of space mission we have seen to date – shuttle missions, Moon shots, and space station tours of duty. The Quality of Life design is informed by human experience aboard space stations. It is the type of "next generation" design that would serve well for the long-duration mission. But, for Humans-to-Mars, we are advocating another type of design model that considers not only these Quality of Life needs, but the macro-level considerations that are "first movers," that can be expected to evolve over time and that will be in play even before the spaceships and habitats are twinkles in their designers' eyes. These considerations create additional constraints and opportunities that drive design. Many of these

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[§] A design driver is essentially anything that drives the design of a space and influences the design solution one way or another. There are physical design drivers, operational needs, sun exposure, local climate, code requirements or ordinances, desire for future flexibility, modifications, and growth, owner preferences, staff input, limitations in space and terrain, etc. (Lee Simon, 23 March 2004, http://www.hotelinteractive.com/hi_articles.asp?func=print&article_id=3318).

[**] Most good architectural designs in extreme environments make some provision for the growth of a base into a something larger. However, Wapniak's approach called for truly evolutionary considerations.

considerations were discussed previously as a set of different types of long-duration space exploration sustainability challenges (Dudley-Rowley and Gangale 2006).[2]

If we conceptualize the Humans-to-Mars enterprise in different phases of 1) getting there, 2) being there, 3) staying there, and 4) returning from there, then this particular design model characterizes the needs involved in "preparing to go." Preparations to go to Mars will take place against several macro-level sustainability challenges on Earth (i.e., the public and political commitment, the long-term funding, etc.). Including these considerations on top of a design model that values Quality of Life in the extreme venue leads to a paradigm-shifting model – a model that reflects upon the flow of events in a changing world. Such a "long view" can be very informative for designing for long-duration space missions in the proximal and more distant future. We mean "ecology" in a comprehensive way, not simply meaning physical environments, but certainly inclusive of them. We can think in terms of the "ecology of capital," that today summons up a vista of petroleum exploitation and all of the transportation and power infrastructures of advanced industrial societies. But, the necessity of a transformation in that ecology of capital is close at hand. And, would we be asked to design a post-petroleum building complex, forethought would lead us to consider the likely sources that would power such a construct that would, in part, drive our design. We call these design considerations the Ecological-Evolutionary model. The immediate concerns of the Ecological-Evolutionary (EE) design are at the macro level.

Table 1. Needs for three different space mission designs

Concerns For Man-in-a-Can Design	**Concerns For Quality of Life Design**	**Concerns For Ecological-Evolutionary (EE) Design Macro-level Concerns**
-Enough consumables to sustain life for the mission duration -Enough air pressure to sustain life -Air scrubbing system to prevent toxic build-ups -Enough physical space to perform mission objectives -Overlap in habitat and work space -Screen-out of crewmembers with physical disease/disability and psychopathology at front-end of mission -Deference to ranks and certain occupations -Great personal sacrifice and internalization of problems -Crew required to perform task within tight time parameters	-Plentiful consumables -Air pressure close to Earth normal -Variety of food and extra rations to prevent boredom of palate and for celebrations -Odor and noise abatement systems -Recycling systems to reclaim resources -Less degree of overlap in habitat and work space; morph-ability of fixtures and spaces -Enough private, subgroup, and communal spaces -Microgravity/low gravity mitigation system -Relaxation of rigid time parameters for task performance -Heterogeneous crews -Non-authoritarian, more democratic leadership; deference both to the communal good and optimization of the individual -Core and emergent mission objectives met within a context of camaraderie and team spirit, with less reliance on great personal sacrifice and internalization of problems	-The national/international commitment to sustain multi-year long-duration exploration to the Moon, Mars, and beyond *within* the context of large-scale natural and social scientific and technological responses to global warming -Sustainability despite the transformation of the ecology of capital and development of new technological means of production -- owing to the need for new energy sources to power an increasing number of advanced industrial societies on Earth on the decline side of oil -Sustainability despite a decline in "knowledge troops" to work the problems of space exploration and settlement -The need to sustain long-duration exploration in the face of political obstacles generated by all of the above

Ecological-evolutionary concerns are not alien concepts. This design model is implied in President George W. Bush's statement on 14 January 2004 concerning an American Return-to-the-Moon plan.[††]

> Our third goal is to return to the moon by 2020, as the launching point for missions beyond. Beginning no later than 2008, we will send a series of robotic missions to the lunar surface to research and prepare for future human exploration. Using the Crew Exploration Vehicle, we will undertake extended human missions to the moon as early as 2015, with the goal of living and working there for increasingly extended periods....
>
> Returning to the moon is an important step for our space program. Establishing an extended human presence on the moon could vastly reduce the costs of further space exploration, making possible ever more ambitious missions. Lifting heavy spacecraft and fuel out of the Earth's gravity is expensive. Spacecraft assembled and provisioned on the moon could escape its far lower gravity using far less energy, and thus, far less cost. Also, the moon is home to abundant resources. Its soil contains raw materials that might be harvested and processed into rocket fuel or breathable air. We can use our time on the moon to develop and test new approaches and technologies and systems that will allow us to function in other, more challenging environments. The moon is a logical step toward further progress and achievement.

Those of us who were Baby Boomers schooled on the *Weekly Reader* tend to hear these future landmark dates with a tin ear. We know that likely not factored into this implied model were the enormous costs of the United States losing superpower status, the onset of costs related to global warming and related events, the decline of American postsecondary education that incubates new knowledge and technology, and the costs of powering an increasingly larger number of advanced industrial societies on other fuels than petroleum. It is easy to throw out some landmark ballpark dates when all things are equal in order to excite the public's imagination. It is much harder to stick to those dates and even count on public support, because all things are not equal. What is more, not sticking to those dates disappoints a public that, in the aggregate, is longer-lived and remembers being let down before. Space exploration co-occurs in a context of other fluid events, and its structures are tied directly and indirectly to the structures of those other events.

Before we move on, because we have promised an "astrosociological perspective," let us explain what astrosociology is. Dudley-Flores and Gangale specifically like to think of the proposed discipline of astrosociology as being "social factors" engineering benefiting from sociology, just as "human factors" engineering has benefited from psychology. Human factors engineering has typically installed in the engineer enough psychological knowledge to design a human-rated instrument panel in an aircraft, a computer keyboard for the user, or a soldier's body armor. Astrosociology holds the promise of installing enough technological consciousness in the sociologist and enough social and societal consciousness in the engineer so that they may work seamlessly on the thing that matters most to the human lineage – its survival safely on this planet and its ensured survival through its expansion of the human ecology off of the planet. Astrosociology is *not,* as some sociologists have argued from their tiny compartmentalizations, just another tiny fragment of sociology. Astrosociology is an instrument of integration -- attempting to integrate across sociology and other disciplines and bridge to the minds of natural scientists and engineers to assist them in ensuring the survival of the species (Dudley-Flores and Gangale 2007).[3] The overarching astrosociological perspective has been formally defined by Jim Pass (2004).[‡‡] Pass wrote:

> Astrosociology is defined as the **sociological study** of the two-way relationship between **astrosocial phenomena** and other aspects of society (i.e., **non-astrosocial phenomena** or other social phenomena) at the various levels of social reality and organization (i.e., the micro, middle, and macro levels of analysis). The concept of **astrosocial phenomena** … pertains to all social conditions, social forces, organized activities, objectives and goals, and social behaviors directly

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[††] Bush, George W. 2004. "A New Vision for the Space Exploration Program." Internet. Available from http://www.whitehouse.gov/news/releases/2004/01/20040114-3.html; accessed 6 January 2006.

[‡‡] Pass, Jim. 2004. "Space: Sociology's Forsaken Frontier." Internet. Available from http://www.astrosociology.com/Library/PDF/Submissons/Space_Sociology's%20Forsaken%20Frontier.pdf

> or indirectly related to (1) spaceflight and exploration or (2) any of the space sciences (e.g., astronomy, cosmology, astrobiology, astrophysics).

In short, any social and behavioral perspective, approach, or theory applied to any aerospace, especially *space,* issue can be deemed as taking an astrosociological perspective. The particular social scientific approaches taken in this paper to expand upon Wapniak's ideas are structural, ecological, and evolutionary. A number of these approaches are exemplified in the methods of the companion piece "The Globalization of Space – The Astrosociological Approach" (Dudley-Flores and Gangale 2007).[4] These approaches include the Ecological-Evolutionary (EE) approach of sociologists Patrick Nolan and Gerhard Lenski.

II. History of Ideas

In the companion piece, authors Dudley-Flores and Gangale addressed the development of the space shuttle and the international space station, how the twin technological articles meant to be developed together were downmoded and increasingly became unjoined. The capacious Space Station *Freedom* (the twin item in the shuttle-station package) never made it off the drawing board. While Cosmonaut-Physician Valery Polyakov was setting a record on orbit in a real Russian space station, American entrepreneurs with little space sciences background were playing space station in the desert of Arizona (something that was initially given serious consideration by NASA).[§§] Space station plans were downmoded to the International Space Station we have today whose final construction specifications still remain a bit of a mystery. This mystery is based on the uncertainty resulting from a lack of sustained commitment in American national space objectives, related issues among the other partners, and, now, the flightworthiness of the shuttle fleet. In another historical irony, the space shuttle system failed just as its primary civil mission was needed most. As a result of OV-102 *Columbia's* breakup in 2003, the partially-built International Space Station (ISS) limps along in orbit, tended by a skeleton crew who can do little more than maintain it, much less perform the science duties that justify its existence. Even should the ISS be finished, the crewing of this space station is not the exploration of space, it is merely the occupation of space, and moreover, a region of space that we have come to know quite well. It boldly goes where hundreds of people have been going for nearly half a century. As time and tide played out, the "Third Industrial Revolution" as detailed by G. Harry Stine (1975) would have to wait for another time in the lifetime of humanity.[6] In explaining how it happened that the United States did not go to Mars in the 1980s and other follow-on events, the authors will further demonstrate how political decisions are design drivers.

The manned Mars mission plan that Wernher von Braun presented in 1969 was a 21-month round trip, with an 80-day stay on Mars; the first manned landing on Mars was scheduled for August 1982. The scenario assumed the completion of the development of the NERVA nuclear thermal propulsion system, which had been ongoing since the early 1960s, as well and the development of a manned space shuttle, an Earth orbital space station, and an uprated Saturn V launch system. The only new vehicle critical to von Braun's plan was the Mars landing craft (Fig. 1). Thus, his Mars mission plan built upon a *developing space infrastructure* which provided routine access to Earth orbit and the Moon, whereas more limited concepts provided for "flags and footprints" missions to Mars, which, as the fate of the Apollo program would soon demonstrate, could be terminated after a few flights.

The greatest barrier to Von Braun's vision proved to be not technological, but cultural; it assumed the transformation of the United States into a spacefaring society, a culture with its heart in the New Frontier and a deep commitment to the exploration of and expansion into the solar system. It was not to be. By 1969, the novelty of the Space Age had already worn off, and public reaction to von Braun's Mars project was generally negative. What now held captive the American imagination were POWs in Hanoi and "shoot to kill" orders against rioters in the burning inner cities. Lyndon Johnson failed to deliver the Great Society, so John Kennedy's New Frontier was abandoned, and Richard Nixon was left to lead the Silent Majority toward a circumspect future of smaller dreams.

[§§] Dr. Roy Walford of the University of California-Los Angeles, who was the physician aboard Biosphere II's first long-duration containment, told author Dudley-Flores (1997) that when NASA representatives showed interest in resourcing the project, NASA's questions about the project were obfuscated. Typical questions that would be asked of a contractor like Boeing, for example, would be met with the response, "That's proprietary information." Frustrated, a serious NASA tie evaporated.

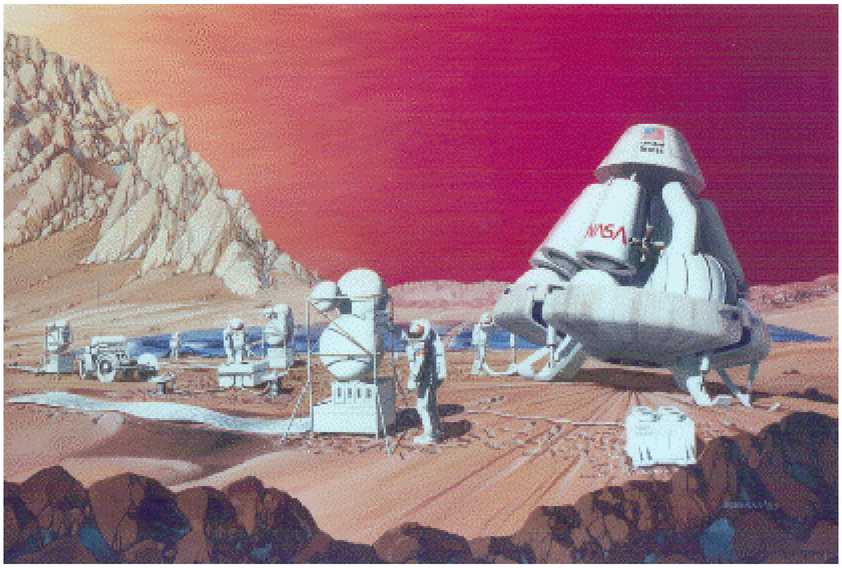

Figure 1. 1969 NASA Concept for a Mission on Mars

Source. NASA

This is not to say that the United States has engaged in no Mars exploration whatsoever, but simply no human space exploration. A programmatic survivor of the heady days of the New Frontier, albeit scaled down from its original form, was the ambitious 1975 Viking mission, consisting of two orbiters, which would image Mars in unprecedented detail, and two landers containing miniature chemical laboratories that would examine the Martian regolith for evidence of life. The ambiguous data returned from these expensive probes put an end to the exploration of Mars for two decades; no life on Mars, no reason to go there. Still, the thousands of channels carved into the surface of the planet was clear evidence that it had at some point in time a liquid water environment, and at the same time, life was being discovered on Earth in very inhospitable environments. There was growing realization in the scientific community that wherever there was liquid water, there was probably life. Thus, life on Mars, either present or past, might be difficult to find, but it might be there. As the US returned to Mars with the 1996 *Sojourner* rover and the 2004 *Spirit* and *Opportunity* rovers, as well as a suite of orbiters examining the planet from above, the evidence mounted for a warm, wet Martian past.

Despite this human non-exploration and robotic missions, the dream of sending humans to Mars remains alive. In the late 1970s, with the failure of the Viking landers to find conclusive evidence of life, Mars became a "four-letter word" around NASA. Funding for Mars research was scarce. During this era of institutional neglect, a network of young researchers known as the Mars Underground coalesced in the breach, organizing the 1981-1996 triennial *Case for Mars* colloquia.

The 1988 perihelic opposition of Mars occasioned an upturn in public interest as the Red Planet shone unusually brightly in the summer sky. A year later, on the 20th anniversary of the first manned landing on the Moon, President George Bush called for a return of manned missions to the Moon and for manned missions to Mars and directed NASA to report to him in 90 days. It did, and the price tag was half a trillion dollars. Political support for the vision, which had been weak at best, evaporated with the sticker shock. The unfolding savings and loan debacle, which ultimately cost the federal government about the same amount of money, didn't help. In the cold light of new budgetary reality, even Al Gore, who had been on the Mars bandwagon during his brief campaign for the Democratic presidential nomination in 1988, said to his fellow senators in 1991, "Before discussing a mission to Mars, the Administration needs a mission to reality." NASA got real a year later with its Mars Design Reference Mission, which incorporated in situ resources utilization concepts to reduce the cost by a factor of ten to about $46-$55 billion. However, the political damage had been done, and the new Clinton Administration had no interest in expending precious political capital on re-fighting a lost battle for Mars.

The Cold War post-lunar landing Man-in-a-Can Mars Mission model, by the very nature of the time, distance, and complexity of getting from here to there, was not a “flags and footprints” mission model. Yet, even today, the administrative and engineering mindset views the problem like a “flags and footprints” expedition to the Moon, only on a stretched-out basis involving many more days. In the companion piece to this report, authors Dudley-Flores and Gangale pointed out the dangers of “stretching out” space missions. A paradigm shift in cognition about Humans-to-Mars must first occur and here is why. One picture is worth a thousand words, but in this report, we provide two. Figures 2 and 3 are enough to show that a manned mission to Mars far outlies the experience in manned spaceflight that has been accumulated in the course of the past half-century. First of all, a round-trip to Mars is twice as long as any mission flown to date. But, more important than mission duration is the return time to Earth in case the mission goes sour. A space shuttle or a Soyuz is only hours away from recovery. Even a compromised mission to the Moon can get back home in two or three days, as *Apollo 13* demonstrated. However, in the worst-case scenario, a Mars expedition might be as much as two years from Earth. Nor will help be a phone call away. The illusion of control from Earth will drop away as the home world shrinks in the rear-view window, as the communication delay increases, as the voices from Earth become more virtual than real. “Mission Control” will become “mission support,” performing something more akin to a helpdesk function. More than any small group of human beings has ever been, the expeditioners will be *on their own.*

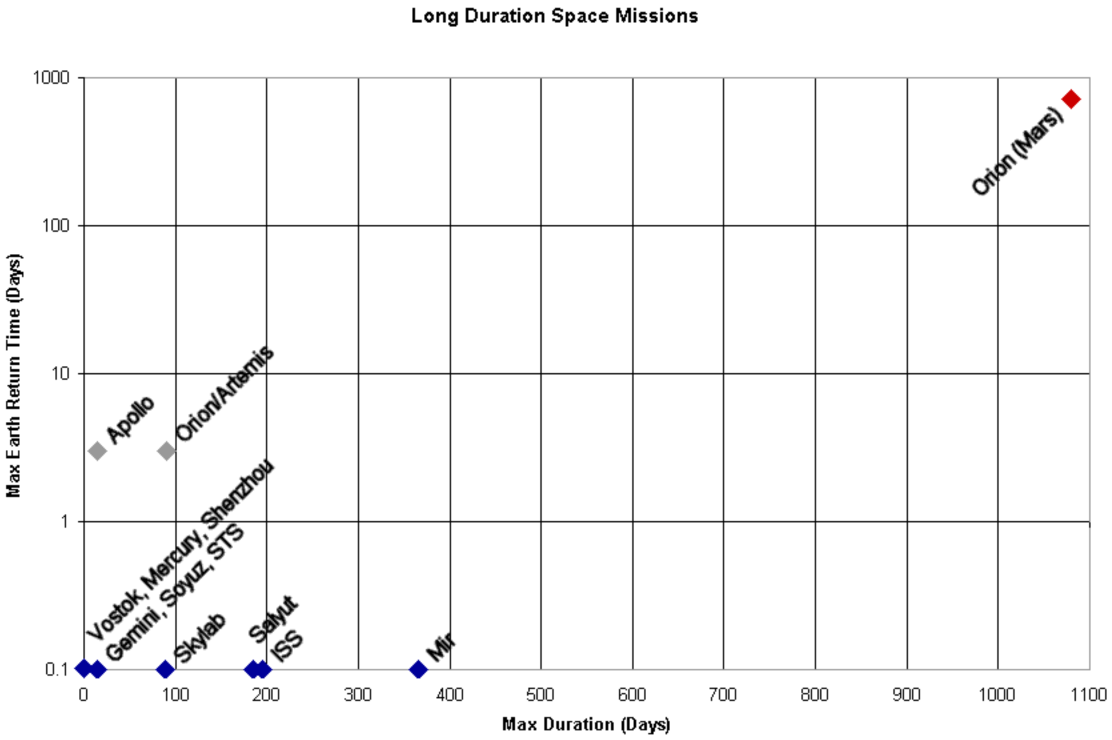

Figure 2. Comparative Space Missions by Duration

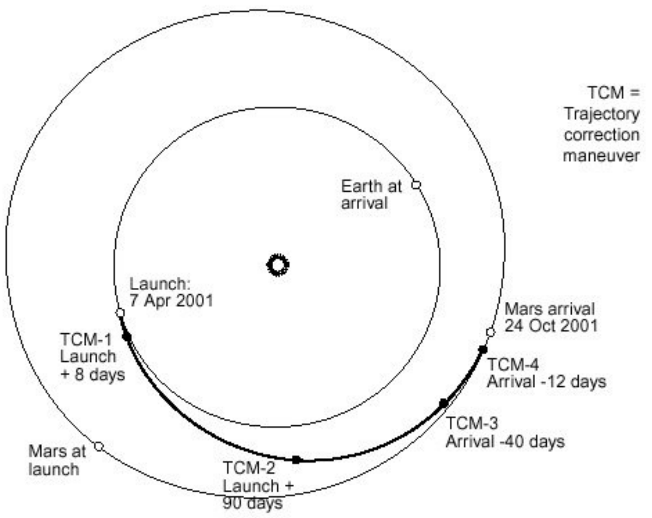

Figure 3. Trans-Mars Trajectory

Distance: 310,000,000 km Travel Time: ~5000 hours (7 months)

Source. NASA

The paradigm shift in Mars planning and design cognition that would have occurred in the 1980s and 1990s had the Apollo program continued has not yet happened. NASA mission planners and designers were still demonstrating short-duration cognition during the NASA-Mir missions of the 1995-1998 (Burrough 1998,[7] Dudley-Rowley 2006[8]). However, long-duration planning and design cognition means more than "duration." Armed with a growing stratified random sample of Arctic and Antarctic expeditions and space missions, the authors Dudley-Flores and Gangale and colleagues have analyzed over various expeditions, from the Apollo missions to the Moon that ranged from a few days to early polar expeditions that spanned several years. Seven factors have emerged which seemed to coincide with the subjectivization of time and the differentiation of situational reality for the crews in the field from their baselines. "Baseline" means the expedition's base headquarters, mission control, or just "folks back home." These seven factors are (Dudley-Rowley and Gangale 2006):[9]

1. Increasing distance away from rescue in case of emergency (lessening chances of "returnability");
2. Increasing proximity to unknown or little-understood phenomena (which could include increasing distance from Earth);
3. Increasing reliance on a limited contained environment (where a breach of environmental seals means death or where a fire inside could rapidly replace atmosphere with toxins);
4. Increasing difficulties in communication with Ground or Base;
5. Increasing reliance on a group of companions who come to comprise a microsociety as time, confinement, and distance leave the larger society behind, and where innovative norms may emerge in response to the new sociophysical environment;
6. Increasing autonomy from Ground's or Base's technological aid or advice; and
7. Diminishing resources needed for life and the enjoyment of life.

The presence and prevalence of these factors in each of the sample missions/expeditions are discussed more in depth in Dudley-Rowley, Whitney, Bishop, Caldwell, and Nolan 2001[10]; Dudley-Rowley, Whitney, Bishop, Nolan, and Gangale 2002[11]; Dudley-Rowley, Nolan, Bishop, Farry, and Gangale 2000.[12] The derivation of these factors was an effort to resolve the debate concerning the question of just "how long" was long-duration spaceflight. The more an expedition has of these factors, the longer its duration, so to speak. As might be expected, therefore, *the longer-duration the mission, the more difficult it is to sustain.* Or, in other words, the more it requires sustainability. The concept of sustainability is a constellation of things, including political will and the support of many organizations and individuals. That is because we are dealing with more than just providing enough consumables and just building equipment to stand up to the long journey.

Stewart B. Whitney, who was able to head an award-winning university program[***] for many years concerning space settlement wrote (Whitney 1984, pp. 12-13):[13]

[***] In a salient example of the decline of American Academe in the post-Apollo years, the Space Settlement Studies and other forward-looking "social investment" programs in the Department of Sociology and Anthropology at Niagara University were steadily eroded away by administrators cannibalizing their resources for a "'lock'em up and throw away the key' vs. dreams" Criminal Justice program (Whitney 2006).[14]

> The relatively new idea of space settlements has attracted the interest of few social scientists; publications are rare and appear in disparate sources. Much of the material that is published on “space colonies,” “space humanization,” “human communities in space, etc., is written by technologists and reveals little significant knowledge about the complexities of human society....
>
> We need an international cadre of space planners. Rather than replicating and concretizing political economic forms of the past through haphazard and string-budget planning efforts... space warrants international planning and organization. I am calling for... a redevelopment and [re]arrangement of Humankind’s priorities: a 21st century political economy

In the companion piece to this report, the authors Dudley-Flores and Gangale outlined how a multi-planet political economy might emerge among sustainable off-the-Earth human settlements. We even mentioned the pressing need to focus knowledge workers on the solutions to “big science” problems of global warming, alternative energy development, and long-duration space exploration. We argued for a transnational effort to implement these solutions that would include government agencies, corporations, for-profit contractors, non-profit organizations, and individuals. Consistent with our own ideas, Whitney’s call for a redevelopment and rearrangement of humanity’s priorities implies that new political economic realities will begin to emerge here on Earth hand-in-hand with the transnationalization of “big science” demands, like sustaining human expansion into the solar system. These realities encompass the macro-level concerns that will drive the ecological-evolutionary design of establishing a human presence on Mars.

III. Results – Extension of Ideas

In the traditions of the structural, ecological, and evolutionary perspectives of social change, the authors have constructed a framework as follows (Table 2). We seek to examine sustainable Mars settlement, and therefore, our conceptualizations about habitat design for Mars, against a human timeline. In “Globalization of Space” (2007),[15] Dudley-Flores and Gangale have already explored the various political, social, economic, and technological events that have or will likely unfold that pertain to the public and political will to go to Mars, the likely transformation of capital and technological means of production according to alternate energy sources, emergent reasons to explore and develop the solar system, and the techno-economic impacts to Earth.. As yet unexamined by all the authors in any depth is the sequence of sustainability events leading to Mars settlement that will specifically drive human architecture on Mars. In this report, we have applied ecological-evolutionary (EE) design driver concerns in the construction of our timeline. Our timeline hosts no speculative landmark dates. We are more interested in the time intervals reliant upon unfolding and overlapping events and the opportunities and constraints posed by them. Landmark dates in the steps to Mars may accelerate proximally because of seminal innovations or slip distantly away owing to political obstacles or latent dysfunctions.

In 1969, NASA proposed a manned Mars mission for 1981, and in 1989, President George H. W. Bush proposed one before 2019. From our vantage point of 2007, it appears that an expedition to Mars might occur in the middle of the century, with sustained, profitable development of Mars occurring in the late 21st century or early 22nd century. In short, if 1961 was 1492, then 2007 is only 1538; and there is a long way to go before the Pilgrims land at Rupes Plymouthensis.[†††]

Table 2. Political, Social, Economic, and Technological Events to Sustainable Mars Settlement Through Time.

Unit of Analysis	**Opportunities**	**Constraints**
Macrosociological Level of Analysis	**Concerning**	**Concerning**
T_1 American/international public/political will to go to Mars	Return to the Moon/global warming and other challenges/contributions from a world system of societies increasingly more industrially advanced	Return to the Moon/global warming and other challenges/resistance from a world system of societies increasingly more industrially advanced

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[†††] “Plymouth Rock” in Latin, the language of lunar and Martian geography.

Table 2 (Continued). Political, Social, Economic, and Technological Events to Sustainable Mars Settlement Through Time.

Unit of Analysis	**Opportunities**	**Constraints**
Macrosociological Level of Analysis	**Concerning**	**Concerning**
T_2 Transformation of capital based on the energy needs of an increasing number of advanced industrial societies on Earth. What those new energy sources are will transform the ecology of capital and the technological means of production	Ecologies of capital and technologies of production that present chances for new capital to emerge; human permanency on the Moon creates benefits, becomes a staging platform for Mars exploration	Political or other social reasons may render unavailable the human resources and/or the technologies needed to step to Mars; overwhelming environmental problems on Earth absorb attentions; Low Earth Orbit (LEO) and lunar exploration impedes exploration of Mars
T_3 Reasons emerge to go to Mars	The human resources and the technologies to go to Mars are easily within reach; Mars-specific technologies create commercializable products	Earth's environmental issues and/or LEO/lunar development impedes exploration of Mars
Unit of Analysis	**Opportunities**	**Constraints**
Microsociological Level of Analysis	**Concerning**	**Concerning**
T_4 First-generation missions see infrastructure and resources, to include human resource, ensconced on Mars to prepare for second-generation missions	Scientific, mineral sampling for transformed capital and human investment are promising; value accrues to organizations/individuals who go to Mars; establishment of a Martian first-sector economy	Latent challenges to humans emerge, specific to the stages of going to, living on, and returning from Mars
T_5 Second-generation missions begin to transition to permanent settlements	Establishment of a second sector economy	Limitations of the Martian second sector economy
T_6 First- and second-generation Mars missions have assessed the latent challenges and mastered the "arts" of 1) getting there, 2) being there, 3) staying there, and 4) returning from there	First- and second-generation Mars missions learn much in accomplishing these stages using the material culture they arrived with and that which they can easily kluge together from what was and is imported in and raw, easily processed indigenous resources; maturation of first- and second-sector economies	"Kluge'd" material culture has its limitations
Mesosociological Level of Analysis		
T_7 Third-generation missions ensure largely self-sustainable settlements that are on the way to being permanent settlements	Establishment of second-, third-, and quaternary-sector economies	Limitations of these indigenous economies; newcomers pose a challenge to the members and descendents of the pioneering missions
T_8 Mars presents an unique ecology of capital and technological means of production that produces a signature surplus, that makes its contribution to a multi-planet economy of the Earth, Moon, and Mars and that lends to the decline of the Westphalian nation-state system	Mars production is welcomed by those Earthside.	Status quo interests Earthside pose obstacles to Mars production

B. T_1 -- Harnessing the Political and Public Will.

At the present time, there are no pressing tangible reasons to send humans to Mars. Currently, the only reasons to make an effort are scientific and/or just to see if it can be done. Those may not be good enough to sustain the investment in long-duration human exploration. Lighting a fire under space exploration in general is required to enflame public and political passions for Mars. This first requires returning to the Moon and doing something there other than cavort around for television audiences. The same can be said for space station development.

People are concerned about things that degrade their well-being. Cashing in on this basic concern is how consumerist societies are created. Corporations advertise increasingly gorgeous products and services that they convince the public that they need for their well-being. Now, outer space production *really has* contributed to the well-being of the global public. Satellite technology has enabled the level of globalization that the public usually enjoys, though, like any technology, it can be used for ill (i.e., think of rapid financial transactions among terrorists). In the main, however, satellite technology has been beneficial. Satellite imagery has let us detect the coming weather. It has verified information that has kept nations' feet to the fire concerning treaties, including the ones that defused the nuclear madness of the Cold War. It has given us an eye-in-the-sky on global climate change. It has drawn the peoples of the Earth together in ways that never existed before. And, the uses continue to mount. With existing satellite resources, we can upgrade tsunami warning systems, as Dudley-Flores and Gangale discussed in their companion report.

And, as those authors also discussed in the twin piece to this report, the most important concerns to the well-being of the public, whether the public perceives them to greater or lesser degree, are epochal climate change, the need for alternative energy sources to run an increasing number of advanced industrial societies coming online, and the mitigation of natural disasters in increasingly populated areas. The social and natural scientific challenges of these phenomena are great. Knowledge from almost any discipline will be useful in ameliorating the challenges. The space endeavor, particularly human spaceflight, has demonstrated time and again the creation of new knowledge. In the United States, we saw the creation of new knowledge coming not just from the enactment of space goals, but also from the technocratic demands placed on K-12 and postsecondary institutions.[‡‡‡] So, from the historical record, we know there is a general connection in the abstract to outer space production and solving for "big science" problems. However, better for us in this pre-Orion Era would be concrete ways to show the necessity for sustained, long-duration human space exploration that the global public and their leaders could more easily comprehend. If these concrete ways answered to the assaults on their well-being, then the global public would demand that their politicos contribute vigorously to sustained, long-duration space exploration.

The authors view the "big science" challenges to the Earth as occasions of opportunity for space-capable nations, industry players, and knowledge workers in general. One instance of opportunity is in the realm of alternative energy production. There are near-term and longer-term technologies of alternative energy production that are available from off-the-Earth venues. Solar-to-microwave-to-electrical power generation shows proximal promise, and its spaceborne infrastructures, if implemented, could function in other ways as well – ways that answer the "big science" demands of the 21st century:

- Hurricane, typhoon, and tornado mitigation
- Agricultural uses (helpful to warding off threats to food security and adequacy as rising sea levels cover and salinate croplands, for example)
- Solving the problems of an increasingly large corps of human workers on orbit living in contained environments (a necessary preamble to sustainable settlements at longer distances from the Earth)

There are constraints to any opportunities to innovation presented by climate change, the decline side of oil, and natural disasters in increasingly more populated areas of the Earth. Non-gradual climatic events and the business-as-usual "turn a blind eye" approach to alternate energy development and natural disaster mitigation could converge in a multiplication of detriments to humanity that would degrade advanced industrial abilities – beyond a point from which they could not return. In such a "have not" scenario, rather than increasing cooperation, nation-states in the world system of societies might unplug from the system. "Raiding" rather than "trading" would become the standard. Privateering might again become a noble profession.

[‡‡‡] Which involved increased focused federal attention, oversight, and resources to educational venues. During the Apollo Era, postsecondary education was treated more like a valued industry of the state, unlike the laissez-faire regard it has had for the past 30+ years.

However, if the important challenges of the 21st century are gradual and catastrophic feedback interactions can be minimized among them, then it is more likely that transnational cooperation will be the rule, rather than the exception. That is good, because doing “big science” is costly and must be sustained to make a difference. And, these types of partnership are essential. In terms of long-duration space exploration, stepping to settlement off-world, must be sustained. The Return-to-the-Moon is an opportunity in many ways, as pointed out in the companion piece. Among them, is the opportunity to forge a transnational team of partners that learns how to cooperate efficiently on “big science” enterprises. The sooner this paradigm is ironed out, the better. The idea that we can “stretch out” “big science” endeavors to fit fluctuating budgets, as has been seen with space projects, will not only get a few more space crews killed or a few more space probes lost, but could spell the doom for millions. Ask Bangladesh if it is willing to “stretch out” the responses to the global warming flooding of that nation.

C. T2 -- Transformation of Capital, of the Ecology of Capital, and the Technological Means of Production.

When the ecology of capital changes, the opportunity exists for the transformation of capital and the technological means of production. It will begin with the need for energy to run an increasingly larger number of advanced industrial societies. A dramatic example of this ecological change will occur as world oil supplies become ever more sparse over the next 30 years. There will be a tendency to increase investment in hydroelectric projects. The energy they produce is relatively clean. However, they are costly to construct, they displace towns and other infrastructure, they are vulnerable to natural disasters, and they are built to stay, so relatively immovable. Nuclear plants have their own unique set of drawbacks that we will not belabor here.

A nimbler solution may be investment in the spaceborne solar-to-microwaves-to-electricity system. If this investment is made, the ecology of capital is the high ground of Low Earth Orbit, and the technological means of production are space stations, satellites, sheets of solar cells, and reflective sheets. Mastering this infrastructure teaches humans how to live off-the-Earth and positions us for the expansion of the human ecology to other venues. The poundage-to-orbit problem is likely to be lessened as governmental and corporate consortia vie to control this new ecology of capital. If China and India are the early investors in this new technological means of production, and therefore, on the ground floor, Chinese and Indian firms will likely benefit from business relationships ranging from transport and cargo services to supplying the stations. Except for human shuttle and cargo services up to power stations, most human spacefaring activities will take place among the stations and the Moon once the infrastructure is there. Why bother with the deep gravity well of Earth unless absolutely necessary? By necessity, the power stations become the first space roadhouses, the precursors of space hotels.

The Third Industrial Revolution as envisioned by G. Harry Stine will likely still play out -- between the Earth and the Moon. Investing in human permanence on the Moon guarantees that future lunar bases are able to have a ready-made first-sector raw material extraction and second-sector manufacturing economy right out of the gate. This sophisticated economy would underpin lunar expeditioners’ subsistence and sustainability and richly reward the stakeholders who freighted their explorations. Among the promise of space manufacturing are materials and pharmaceutical industries dependent upon crystal growth. Crystal growth can flourish in both the reduced gravity of the Moon and in the microgravity areas of Earth orbital stations. Because the process of crystallization is often slower in reduced gravity, materials may be produced with different, larger, and defect-free crystal structures. Because highly ambitious and trained individuals come to live and work there -- innovations will be incubated that drive third- and quarternary-sector industries dependent upon intellectual production and provision of services. But, the one resource upon which the hopes of lunar exploration advocates are pinned is helium-3. A couple of “ifs” attach to those hopes. *If* fusion reactors can produce more energy than is required to operate them, and *if* helium-3 is plentiful and not hard to extract on the Moon, then not only does the Moon provide an energy source for its own human infrastructure, but for Earth’s world system of increasingly advanced societies. Efficient fusion reactors also open up another important innovation: better propulsion for humanity’s spaceships. So, human permanency on the Moon could be a potential quantum leap for humankind as a staging area to Mars, certain asteroids of value and opportunity, and certain of the moons of the outer planets.

But, those cynical Baby Boomers among us realize all too keenly that what holds great promise can still be shelved for subsequent generations to undertake and even re-invent. Political or other social reasons may render an unavailability of human resources and the technologies don’t get developed. Unforeseen environmental factors on Earth may absorb our attentions and downmode our scientific and technological abilities. Or, the “men, moments, and machines” don’t come together in the right ways. Or, in another permutation of events, lunar and LEO development and settlement somehow poses a drag in and of itself on further human progress – a golden apple that might be squabbled over or that occupies a focus to the exclusion of other exploration destinations.

D. T_3 – Emergent Rationale For Humans-to-Mars, Latent Dysfunctions, and Political Obstacles

But, if social forces and other cosmic tumblers line up according to the best-case scenarios, there will emerge good solid reasons to go to Mars after humans hone their skills between the Earth and the Moon. Technically speaking, humans could have gone to Mars by now, had the sustainability factors been arrayed in favor of that exploration. However, with mature infrastructure on orbit and on the Moon, the sustainability factors would likely be available for expansion to Mars. The human resources and the technologies would be more than adequate to enact missions to establish a good deal of infrastructure there, usable to expand the human ecology. Historically, to be able to accomplish a thing is good enough reason to do it, especially when the measures of risk are considerably lowered. And, there are plenty of scientific and exploration reasons to go to Mars. The burning questions are: Did Mars generate simple life forms? And, does it still hold reservoirs of those life forms scattered across the planet?

We can expect some latent benefits to spin off just in preparation to going to Mars. Developing technologies specific to Martian exploration may create lucrative commercial applications. Among those technologies will certainly be spin-offs concerning data compression. The increasing lag time in communications between a group of humans on the way to Mars and those on Earth will require innovations in this area of information technology.

Still, there may emerge political or other social reasons why the human resources are not available for Mars exploration and/or why the Mars-specific technologies have not been developed. Environmental conditions may worsen on Earth that require "big science" apparatus to focus sustainability resources there. A boom in lunar development could just as easily draw resources away from Mars exploration rather than lend it impetus.

E. T_4 – First-Generation Mars Missions, Martian First-Sector Economy, Constraints

Off-the-Earth, subsistence (economy) and architecture are linked in ways they are not on the Earth. On Earth, architecture is shelter, it is expression of a nation's pride, it is fortification against dangers posed by hostile human groups and ferocious animals, etc. Off-world, in the extremest of environments, its primary function is to *be* the world. Until far-future terraforming makes off-world moons and planets Earth-like or until humans can be genetically changed to live in more extreme environments, architecture off the Earth are micro- and meso-ecosystems, Earth-like oases, that humans will depend on to expand into the Cosmos.

Earth's whole suite of economic sectors arrives on Mars with its human crews. As has been pointed out elsewhere, the technological means of production in the form of equipment and materiel do not all have to arrive with the human crews. Unmanned shipments may be sent ahead and in follow-on supply vessels. However, the sophistication of first- and second-sector Martian economies depends on a necessary link with Earth. That link is a weak link, owing to distance and costs of missions. Human groups on Mars will attempt to get indigenous first- and second-sector economies up and running at the soonest for use in their own architectural structures. Figure 5 shows the likeliest habitat for a first-generation-level mission (first round of missions). Figures 6 – 8 depict the likeliest Earth-imported architectural forms to be attempted with Martian native materials. Then, after all of that, it may occur that Mars exploration gets stalled because of a weight of latent challenges to humans on Mars. These latent challenges may outweigh follow-on exploration. Such latent challenges and their design implications have been detailed in Dudley-Rowley, Okushi, Gangale, Flores, and Diaz (2003).[15]

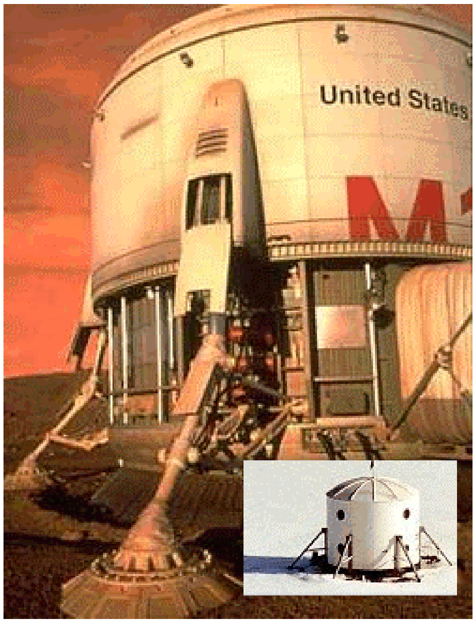
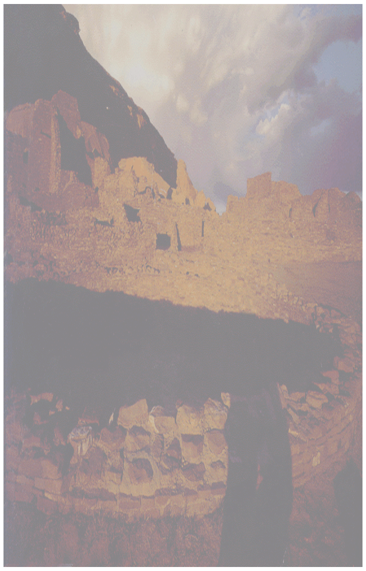


Figure 5. Conceptualization of an Early Mars Mission Habitat Brought Directly From Earth. Authors Dudley-Flores and Gangale were members of the original design team of the Mars Arctic Research Station (inset) resourced by NASA that was testbedded in the Eastern Canadian High Arctic. This Mars conceptualization is of a similar design.

Source.http://www.marshome.org/images2/thumbnails.php?album=lasthits&cat=0&page=1

Figures 6, 7, and 8. Below middle, Georgi Petrov tested one of the premises of his Master's of Architecture thesis project: that hand-laid masonry domes are usable for Mars habitats. This was his first day's effort, 26 January 2004, Mars Desert Research Station (MDRS), Utah. To left, Inuit peoples use a similar concept in snow-knifing blocks out of the hard-packed snow cover of the Arctic to build winter shelters. To right, Chacoan Anasazi kiva.

Sources. Architect Georgi Petrov; http://chamberlin.sbschools.net/users/rbarone/thingsto.htm; Adam Wapniak



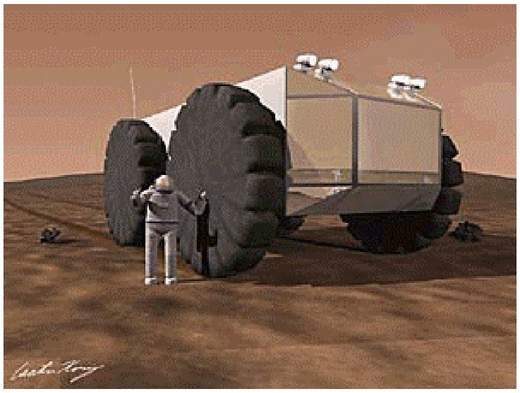


Figure 9. To left, conceptualization of Mars exploration transport and field facilities.

Source. http://www.marshome.org/images2/thumbnails.php?album=lasthits&cat=0&page=1

Figure 10. To right, Geophysical Year Era tractor train leaving Little America, Antarctica for a 400-mile traverse to Marie Byrd Station. Among the sleds being pulled was a combined kitchen, sleeping quarters, and sickbay.

Source. "The tractors were constantly on the move, 24 hours a day, and only stopped when they reached fuel caches where they refilled their tanks with diesel fuel. The caches were propositioned and filled with fuel by the R4D and Otter aircraft." (Commentary and photo, courtesy of Jim Waldron and http://www.vaq34.com/vxe6/otter.htm.)

F. T_5 – Second-Generation Mars Missions, Martian Second-Sector Economy, Limitations

Barring impediments to their progress, a second generation of Mars missions occurs. Humans on Mars will have begun indigenous manufacturing of many necessities and goods with materials extracted from Mars, using manufacturing equipment and materials sent from Earth or, more likely, mature lunar operations. The Habot concept (Fig. 11 below), designed originally for Mars surface operations, but later reconfigured for lunar missions, is a facile constellation of equipage that could be useful to set up manufacturing operations. Its modularity allows habot modules to operate independently or in conjunction with one another.

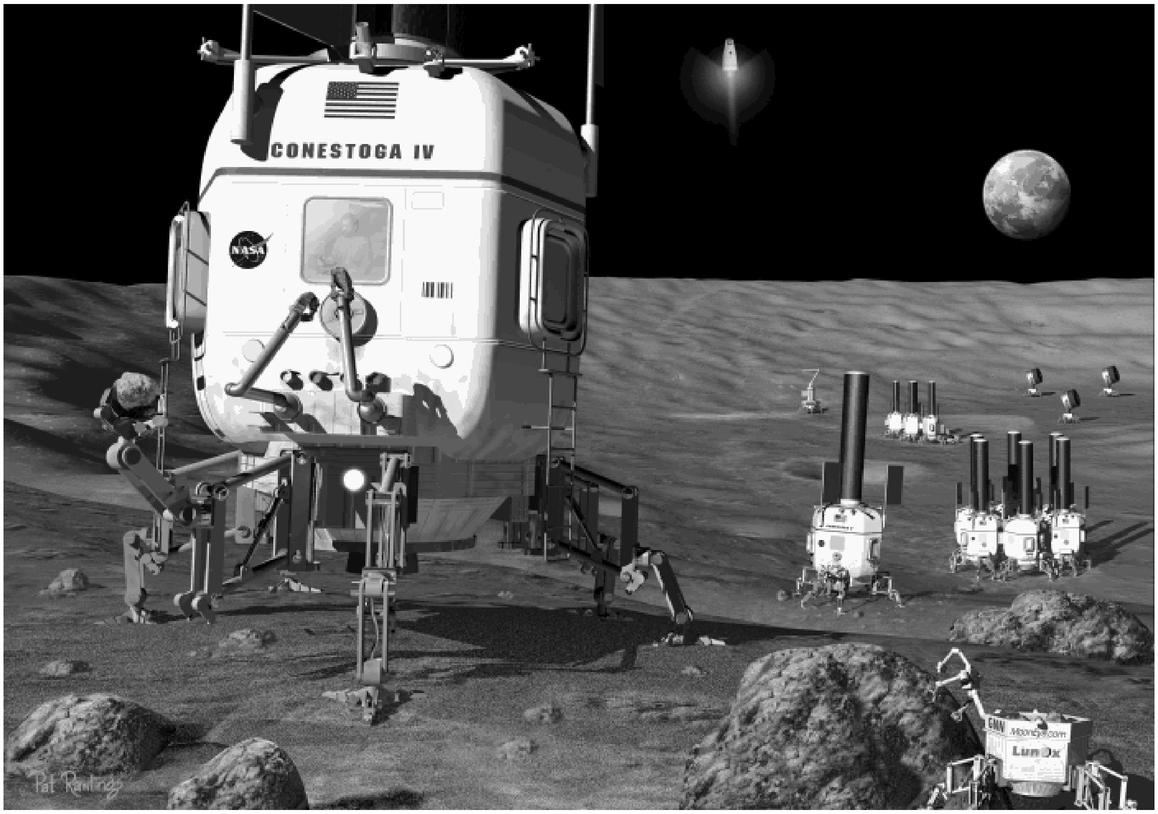


Figure 11 . Artist's rendering of the Habot Mobile Lunar Base concept. Pat Rawlings, artist. Courtesy of Neville Marzwell, NASA-JPL and John Mankins, NASA HQ. From "Habot Lunar Crew Size, Skill Mix, and Time Model" (Dudley-Rowley, Gangale, Lemke, and Cohen 2005).[16]

Limitations to the success of the Martian second-sector indigenous economy may emerge from an amalgam of social and political factors back on the Earth and the Moon and various latent challenges, especially along the limits posed by the kluging of available materials brought from the Earth and the Moon, in situ resources, and indigenous manufactured materials and equipment. This time interval is a transition phase for human groups on Mars whose architectures are beginning to offer the possibility of permanent settlement (Fig.12).

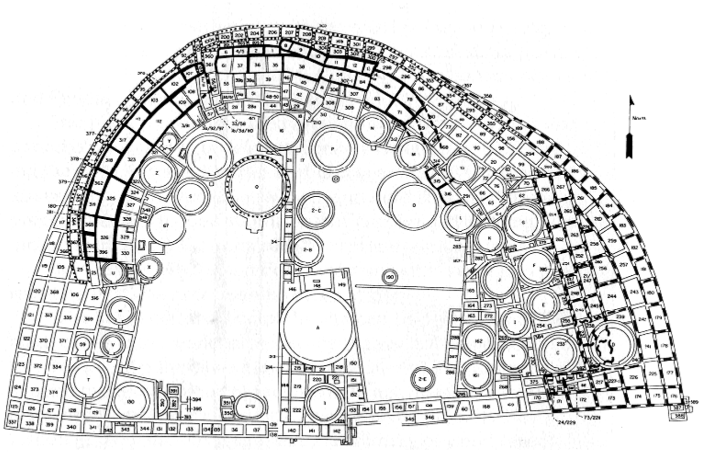


Figure 12. Author Wapniak's topdown sketch of his Pueblo Bonito concept of a human group on Mars transitioning from simple kluges of imported and indigenous materials and equipment.

G. T_6 – Mastery of Getting There, Being There, Staying There, and Returning From There

If Martian first- and second-sector economies have matured, then they have mastered the "arts" of 1) getting there, 2) being there, 3) staying there, and 4) returning from there. In this time interval, humans on Mars are from among the first- and second-generation of missions. Perhaps the first glimmers of a unique Martian culture from among these groups begin to appear. As they get to know their planet and themselves better in their unique social and physical environments, they expose themselves to further latent challenges. Mars exploration is positioned for third-generation-level missions dependent upon a fairly mature infrastructure on the planet.

H. T_7 – Third-Generation Missions, Third- and Quaternary-Sector Economies

Third-generation missions to Mars find largely a self-sustainable settlement (or more than one) there. Third- and fourth-sector economies (services and intellectual production, respectively) have arrived on Mars with the first-generation and second-generation rounds of missions. Back on Earth, on the orbital stations, and on the Moon, people and organizations have always wanted information on various phenomena on Mars. Some cottage industries will have emerged around this activity already by this time interval. The influxes of people from third-generation missions arrive to find pioneering Martians ready to provide them with a host of services to help them make a go of it "in the country." In this, they are not unlike settlers who have come later on to Earth's frontiers, after those frontiers have had some infrastructure established.

Figure 13. Architect-Engineer Bruce Mackenzie's conceptualization of an underground vaulted habitat on Mars.

Source.
http://www.marshome.org/images2/thumbnails.php?album=lasthits&cat=0&page=1

Between in situ experimentation and an influx of others with new ideas, a number of different architectural styles become evident in the ecosystems that humans build for themselves on Mars. The third-generation arrivals will likely find the settlements on Mars an amalgam of kibbutzim and high technology frontier towns with shops, restaurants, and hotels. From there on out, the latent challenges that emerge for humans on Mars will increasingly be traceable to their activities for permanency on their world. External challenges are not out of the picture. New diseases from the Earth and the Moon might still slip in, for example.

I. T_8 – Mature Contributor to the Rise of the Multi-Planet Economy

Figure 14. Town on Mars.

Source.
http://www.marshome.org/images2/thumbnails.php?album=lasthits&cat=0&page=1

The success of the third-generation missions ensure that Mars settlements continue. Unique ecologies of capital and technological means of production generate a signature surplus that makes its contribution to the maturing of a multi-planet economy of Earth, orbital and other space stations, the Moon, and Mars. As outlined in "Globalization of Space," authors Dudley-Flores and Gangale discuss the rise of this multi-planet economy that lends to the decline of the Westphalian nation-state system on Earth. Mars production is welcomed throughout the multi-planet economy. Constraints to Martians may come in the form of obstacles to Mars production as those who benefit the most from the status quo back on Earth resist the maturation of the multi-planet economy.

IV. Conclusion

Going to the Moon posed an opportunity to develop as a more *humane* humanity, but that opportunity failed to flower (Gangale 2005):[17]

> The most important thing that we discovered on the Moon was part of ourselves. In the few hours that a few of us spent on the Moon between 1969 and 1972, we became better Earthlings. As the poet Archibald MacLeish wrote, we were "riders on the Earth together." We realized that we were our brother's keeper, and we remembered that God had appointed us stewards of the Earth. And yet, a third of a century later, we must reflect on how pitifully less we have done with that revelation than we should have. It is high time that we journeyed outward to that distant perspective, to see again how close we really are to each other, and to relearn those lessons that have faded with the passing of a generation. There are new lessons to be learned on Mars. There are new poems waiting for us on Mars.

But, first, must come the long-forgotten lessons to be learnt from epochal climate change and natural disasters in ever more populated parts of the Earth, lessons our primal human ancestors mastered or died trying to learn. With the decline side of oil and a global warming to which we humans contributed, we must learn new primary lessons. Civilizations have risen, fallen, and in time others have risen in their place, but this time the stakes are greater. If, for some reason, our technological civilization should collapse, either because of nuclear war, pandemic, climate change, cosmic impact, or resource depletion, we can never pass this way again. No previous culture has been the massive consumer of non-renewable resources that ours is. Each decade that passes, we must dig deeper and drill farther to extract the materials that fuel the Great Machine. The advance of technology continually extends our reach for these resources, but these advanced methods would be far beyond the grasp of a post-apocalyptic agrarian culture trying to make another go of it. What we think of as non-renewable resources actually are renewable of course—on a geologic time scale. Left to itself, the Earth would again form subterranean pools of petroleum. Another Industrial Revolution might be possible on this planet, but only for a species as far removed from us in the future as the trilobites are in our past. Our civilization has the one and only chance the human race will ever have to reach beyond this planet and establish itself elsewhere in the universe. If we miss this opportunity, our species will be bound to the Earth until we become extinct.

If, on the other hand, we survive the various threats to the progress of technological civilization, we will see a branching of the human timeline. Humans will go to live and work indefinitely on orbiting space platforms, in lunar settlements, on Mars, and then out to the planet-sized moons of the gas giants. The process of inhabiting and thriving in ever more extreme environments is the natural extension of the coldward course of progress, the process by which humans left their tropical home-of-origin and ventured into the temperate and polar zones. The experience the solar system explorers, pioneers, and settlers will gain will pave the way to the stars—and beyond. As visionary scientist Carl Sagan (1995)[18] pointed out, this gets the human eggs out of the single basket in terms of any sort of catastrophic mass extinction event. It also gets our eggs out of the basket in terms of the natural processes of passive extinction, where we lose so much genetic vigor that we can no longer cope with our constantly changing single planetary environment. Because of the distances involved alone, not to mention the effects of wholly new planetary environments, in journeying outward we set in motion new speciation and differentiation of the *Homo sapiens sapiens* line. For our species to survive, we must diffuse into the Cosmos. We must engage the grand environment, and who can say for how long our window of opportunity will remain open (Dudley-Rowley 1999)?[19] On Earth, the best we can look forward to is a future of husbanding limited resources, some renewable, others inexorably dwindling. Although reaching beyond Earth in a sustained effort does not lessen our responsibility to manage Earth responsibly, it opens possibilities as yet unfathomable. The promise of space, although easy to oversell and challenging to fulfill, is impossible to abandon.

Acknowlegements

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