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Design Implications of Latent Challenges to the Long-Duration Space Mission

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ABSTRACT

While expansion of space industry engineering standards over any human factors interface, except the human-technology interface, is a still a relatively new topic (Dudley-Rowley & Bishop, 2002), even rarer still is the consideration of the latent challenges of long-duration space missions. A *latent challenge* in this venue could be a social, behavioral, or a natural or human-engineered environmental phenomenon. Manifest challenges to long-duration spaceflight are numerous enough, with mission planners, managers, and engineers taking into account obvious things like spacecraft operations, communications difficulties, having enough onboard resources, and protection of crew from an airless, microgravity environment fraught with radiation and other hazards. Latent challenges are harder to grasp. A latent challenge is any item, aspect, component, or process that potentially poses difficulties in the performance of mission objectives, but is something about which not much is known. However, a mission to Mars is a long-duration space mission that is a significantly different experience than a tour-of-duty of the same duration aboard a space station in full view of Earth, with easier access to new or needed equipment, more supplies, or even returnability. Social and behavioral phenomena in such an extreme environment could generate their own set of latent challenges.

What steps could the crew take to ensure a high level of group functioning and minimize the impact to the accomplishment of mission objectives? How might design offset latent challenges on long-duration space missions? This report attempts to catalog the types of latent challenges that could pose difficulties to the long-duration space mission, and then gives a multidisciplinary perspective of how design could respond to these challenges.

Keywords: Man-System Integration Standards, human factors interfaces, latent challenges, long-duration space missions, multidisciplinary perspectives on design

HISTORY OF IDEAS

While expansion of space industry engineering standards over any human factors interface, except the human-technology interface, is still a relatively new topic (Dudley-Rowley & Bishop, 2002), even rarer still is the consideration of the latent challenges of long-duration space missions. A *latent challenge* in this venue could be a social, behavioral, or a natural or human-engineered environmental phenomenon. Manifest challenges to long-duration spaceflight are numerous enough, with mission planners, managers, and engineers taking into account obvious things like spacecraft operations, communications difficulties, having enough onboard resources, and protection of crew from an airless, microgravity environment fraught with radiation and other hazards. Latent challenges are harder to grasp. A latent challenge is any item, aspect, component, or process that potentially poses difficulties in the performance of mission objectives, but is something about which not much is known. An example of such a latent challenge for any crew compartment is an unexpected, unusual efflorescence of bacteria from the crewmembers' bodies that poses difficulties to their health or to the operation or maintenance of equipment.

However, a mission to Mars is a long-duration space mission that is a significantly different experience than a tour-of-duty of the same duration aboard a space station in full view of Earth, with easier access to new or needed equipment, more supplies, or even returnability. Social and behavioral phenomena in such an extreme environment could generate their own set of latent challenges. But, latent challenges will also emerge from among natural and human-made phenomena. For example, some medical researchers assert that the heart and other muscle tissue of crew will be so weakened in the long-duration microgravity venue that the team will not make it back to Earth and may not even be fit to effect a landing on Mars. A conjunction-class mission will require a 500-day stay on Mars. The long-term effect of 0.38 g on human physiology is not known. Is 0.38 g enough to maintain reasonable physical condition? Will astronauts need to do regular weight training using Martian sandbags? A possible design solution would be to put a spin on the spacecraft that journeys to Mars to simulate the effects of gravity. But, again, not much is known about short-radii coriolis effects on humans over the long duration. But, assume for the moment that the crew lands safely on Mars and begins planetary surface operations. Not much is known about how atmospheric electricity discharges on Mars. A regime that is markedly different than on Earth could pose hazards to those inside spacesuits, habitats, vehicles, and to other equipment. This may not be a problem except during dust storms, when there would be other reasons for staying inside.

The consideration of latent challenges must be of greater concern on long-duration missions, for the longer the mission, the greater the opportunity for latent challenges to emerge as manifest challenges. Three avenues of inquiry have informed the investigators' consideration as follow.

(1) TAXONOMY: An earlier formulation (Dudley-Rowley & Bishop, 2002) called for an extension of NASA's Man-Systems Integration Standards[1] and related documents along all the human factors interfaces. The formulation examined the possibility of devising a taxonomic schema that would be driven by several dichotomies. Though there would be quite a lot of overlap in how any component of a mission could be conceptualized, a taxonomic approach could be useful in guiding systematic thought about the human factors issues involved. Some of the dichotomies used in thinking about a taxonomy from the earlier work were:

- manifest challenges *vs.* latent challenges problems of basic survival *vs.* problems of quality of life
- life support *vs.* work support
- human factors issues of interiors of habitats and work spaces *vs.* human factors issues of exteriors of habitats and work spaces

Habitats were generally defined as spacecraft that were intended for the transport of humans; space stations, and planetary surface stations. Work spaces were generally defined as the command and control, maintenance, and laboratory portions of spacecraft, space stations, and planetary surface stations. However, as in any expeditionary enterprise, where expeditioners live is often where they also work. So, the taxonomizers expected a considerable amount of overlap in these venues. The opposition of these dichotomous topics was not merely an artificial construct for ease of conceptualization. Their opposition could be observed in the space mission record. For

[1] Until revisions are made to NASA's Man-Systems Integration Standards, a gender-inclusive re-titling of the standards cannot be made. Under discussion have been such titles as the Human-Space Interface Requirements.

example, life support *vs.* work support was an issue of tension aboard *Mir* in the days of collaboration with NASA. Cosmonauts were run ragged trying to keep the station habitable while astronauts felt the pressure to perform all their mission objectives handed to them by their agency (Burroughs 1998; Linenger 2000).

(2) HISTORY: Another route of inquiry for the current investigation into latent challenges of long-duration space missions was an earlier study funded by the National Science Foundation that let the primary author and associates examine various features of polar expeditions and space missions (Dudley-Rowley, Whitney, Bishop, Caldwell, Nolan, & Gangale, 2002).

(3) MODELS: Finally, especially fruitful have been the ongoing discussion among the investigators about the implications of different mission models that have run the gamut from basic survival to a high level of quality of life bounding on the "hotel in space" concept. We have estimated that off-planet tourism would set the upper-limit standards for the space human factors and top of the line human-rated engineering because of customer necessity and demand.

After thinking systematically about past missions in the expeditionary record and about the long-duration space missions of the future, the investigators were able to make some informed estimates about the nature of the latent challenges in store for the latter. What steps could the crew take to ensure a high level of group functioning and minimize the impact to the accomplishment of mission objectives? How might design offset latent challenges on long-duration space missions? This report attempts to catalog, by example, the types of latent challenges that could pose difficulties to the long-duration space mission, and then gives a multidisciplinary perspective of how design could respond to these challenges. Readers are invited to use this taxonomic schema to make their own estimates of latent challenges and design responses of long-duration space missions, as in a mission to Mars, and share them with the authors.

THE HUMAN FACTORS INTERFACES

A comprehensive human factors approach is central to the optimization of long-duration missions, irrespective of the missions' destinations and their objectives. All long-duration systems must be human-rated to a high degree. Human factors considerations cannot be strapped on at the last minute or given superficial treatment. They are integral to the long-duration mission and must be part of mission planning, platform and equipment design, and in the selection and training of crews.

Almost any item, aspect, component, and process involving humans and human usage can be categorized under each human factors interface. For instance, a laptop computer might best be characterized by the human-technology interface. It is a machine, a piece of equipment. However, it is a facet of space expedition interiors (inside spacecraft and space stations). Work spaces have to be designed for it and its human users. So, it can also be characterized by the human-environment interface. Because humans interact over laptop communication avenues and behave socially in the use of the item, the laptop and its work spaces play a role at the human-human interface, too.

The interfaces are separately useful in thinking about issues involving the environments humans must operate in, the equipment they use, and their properties in groups and as individuals. However, overlapping the interfaces is useful because it assures integration in mission components from multiple perspectives. The integrative benefit of examining the three interfaces together has long been recognized by those working in this field, within and outside of NASA. But, so far, the resources and the circumstances have not existed to encourage the comprehensive human factors approach.

With these interfaces in mind, several dichotomies are useful in thinking taxonomically about challenges to long-duration space missions, such as a mission to Mars.

- Manifest Challenges *vs.* Latent Challenges
- Interiors *vs.* Exteriors
- Basic Survival *vs.* Quality of Life
- Habitats *vs.* Work Spaces

A couple of these dichotomies are worth remarking on more at length.

MANIFEST CHALLENGES *VS.* LATENT CHALLENGES

The expeditionary record is a tale told of one latent challenge after another. Latent challenges can come in the form of social and behavioral (including organizational), natural, or human-engineered phenomena or some combination of them. The combinatorial nature of many latent challenges is particularly difficult to prepare for and to deal with (Rockoff, Raasch, and Peercy,1985). Any expedition in extreme environments requiring highly technological, risky systems involve coupling of components and processes, and they involve complexity. Perrow has written that, where complexity and coupling exist, quality control and training will not be enough (1984, p. 257).

Why do we need to be so concerned about latent challenges when so many manifest challenges need to be attended to for any long-duration space mission? Well, recent history is a harsh schoolmaster. A good-sized water or ice-laden chunk of foam striking the space shuttle *Columbia* on the leading edge of a wing upon take-off at high velocity is a manifest challenge, although many NASA employees believed at the time that it was a latent challenge -- so “latent” as to not be worth much time and resources to follow through on. However, the actual latent challenge in this case was the organizational “group-think” that had evolved from a run of shuttle flights that had suffered few incidents, and that had lulled the employees into a sense of false confidence (people who together possessed an amazing battery of engineering degrees) making them believe everything was “A-OK.”

BASIC SURVIVAL *VS.* QUALITY OF LIFE

In thinking about latent challenges to the long-duration space mission, the authors derived two kinds of models that are evident from a study of the broad spectrum of the expeditionary record (i.e., space missions, polar expeditions, sea voyages, etc.). We compiled a list of features unique to each that could apply to a mission to Mars.

The “Man in a Can” Model

The “Man in a Can” Model focuses on meeting expected manifest challenges within the rigid parameters of the mission that are defined by tight timeframes and limited resources. The accomplishment of a set of core mission objectives is dependent upon the survival and minimal comfort of the crew. What the crew can tolerate within the mission parameters is the hallmark of this mission model. It is mostly concerned with the human-technology interface and is typical of “flags and footprints” type of expeditions. Such a model applied to a Mars mission would be characterized by:

- Enough air, water, food and other consumables to sustain life for the projected mission duration.
- Air pressure may not be at Earth normal.
- Air scrubbing system (preventing CO_2 and nitrous oxide build-up).
- Basic human waste and garbage management.
- No or few odor abatement systems.
- Few or no recycling systems.
- Enough physical space to perform mission objectives.
- High degree of overlap in habitat and work space.
- Potential crewmembers with physical disease/disability and psychopathology selected out at the front-end of the expedition.
- No or minimal noise abatement system.
- No microgravity mitigation save for foodholds and other appurtenances and exercise gear.
- Performance of mission objectives within rigid time parameters.
- Crew more likely to be homogenous across many indicators than heterogeneous.
- Authoritarian leadership; deference to ranks and certain occupations.
- Core mission objectives are met at great personal sacrifice despite the happenstance of deaths, near-destruction, conflict, and physical and mental ailments. In the case of the latter three, they may only become apparent or emerge *after* the expedition is over.

The Quality of Life Model

The Quality of Life Model takes into account the comfort of the crew. The comfort is not at the level of a four-star hotel or luxury cruise liner, but its redundant systems and plentitude of space and resources make it preferable to the stripped-down “Man in a Can” Model. While it, too, focuses on meeting manifest challenges, it takes a wider purview of what those challenges might be along all the human factors interfaces. The Quality of Life

Model is typical of expeditions that have scientific purposes high on their list of priorities or that take place in more mature expeditionary venues, like latter-day Antarctica. It is characterized by:

- Plentiful air, water, food, and other consumables in the event the mission is extended.
- Air pressure close to Earth normal.
- Variety in food to prevent boredom of palate and enough to ensure extra rations for celebrations.
- Care taken to prevent unfavorable odors and tastes from permeating food, water, and air supplies.
- Several recycling systems to reclaim resources.
- Noise abatement systems.
- Less degree of overlap in habitat and work space or else "morph-ability" of fixtures and spaces to easily convert habitat to work space and vice versa.
- Care taken in crew selection to ensure a high degree of heterogeneity of ages, gender, cultural diversity, and skill sets.
- Enough space to ensure personal space, privacy, communal activities, and subgrouping activities.
- Microgravity mitigation in flight to destination provided by centrifugal force.
- Performance of mission objectives within time parameters more closely resembling a 40-hour workweek.
- Decisions are made more along democratic lines with deference to the good of the community and optimization of the individual experience than to rank and certain occupations.
- Core, as well as emergent, mission objectives are met in a context of camaraderie and team spirit with a minimum of conflict among individuals.

Heterogeneity is an important factor in expeditions that are successful in terms of having fewer incidents of conflict, dysfunction, and deviance -- not just in terms of accomplishing mission objectives. The NASA-*Mir* experience, at first blush, appears to argue against the benefits of heterogeneous crew selection. The crews consisted of two Russian cosmonauts and one American astronaut. The astronaut often found himself or herself in a situation of being "the fifth wheel." An examination of the record shows that crew heterogeneity had little to do with that, but that differing mission objective regimes and national agendas were the chief culprits for any tensions among crewmates**.** Andy Thomas, the last NASA-*Mir* astronaut has indicated that heterogeneity among crew is beneficial. In his experience after months on *Mir,* he was still excited to learn about Russian language and culture (Weed 2001, p. 40). Heterogeneity of any kind seems to allow crewmates to maintain a high level of interest in each other and also promotes "thinking outside of the box" when situations arise that might be outside the experiences of a more homogenous crew complement (Dudley-Rowley *et al.,* 2002). Heterogeneity adds another dimension to the quality of life on an expedition. And, attention to the quality of life goes further in ensuring basic survival. A quality of life model provides fallback positions, extra resources, and a wider range of expertise in case new situations arise and mission objectives are extended or core mission objectives reformulated or scrapped altogether.

Many latent challenges can be estimated from careful consideration of the expeditionary record from naval, polar, and previous space missions. The investigators have estimated several across all three of the human factors interfaces for both the basic survival and quality of life models.

THE "MAN IN A CAN" MODEL AT THE HUMAN-TECHNOLOGY INTERFACE

Latent Challenges to Basic Life Support and Core Mission Objectives – Interiors of Habitats and Work Spaces

Habitats

Human-Engineered: The food preparation system malfunctions owing to a key component thought by system designers to be foolproof, that cannot be repaired on site and no spare part or system redundancy is available.

Work Spaces

Social/Behavioral: Two crewmates get on each other's nerves having to work at odd angles and in close proximity to one another. The ergonomic arrangement has not bothered any of the other crew, but the constant bickering of the two people is causing a rift to develop within the crew.

Latent Challenges to Basic Life Support and Core Mission Objectives– Exteriors of Habitats and Work Spaces

Habitats

Human-Engineered: An access panel to infrastructure critical to life support is located on the outside of the spacecraft and not quickly or easily opened during EVA. In addition, it is an older design that does not take into account the increased work envelope needed by crewmembers using a newer-model EVA suit.

Work Spaces

Human-Engineered + Natural: There are not enough handholds on the spacecraft near an important communication array that is best adjusted by hand during EVA under certain conditions.

THE "MAN IN A CAN" MODEL AT THE HUMAN-ENVIRONMENT INTERFACE

Latent Challenges to Basic Life Support and Core Mission Objectives – Interiors of Habitats and Work Spaces

Habitats

Natural: Bacteria from the crew's bodies somehow find a medium in the soft components of an isolation sample-processing unit, making its structural integrity suspect.

Natural: A trivial hygiene issue comes to have larger ramifications. Sudden earwax build-up in one of the older crewmembers that causes eardrum pressure has gone undetected because of the low atmospheric pressure of a space station that requires crewmates to shout to be heard. (Adapted from the *Skylab* experience.)

Work Spaces

Human-Engineered + Social/Behavioral + Natural: A crewmember is urged by Mission Control to dock a re-supply vessel despite a problem with the targeting system and slices open the pressurized laboratory module of a space station to the vacuum outside. (Adapted from the *Mir* experience.)

Latent Challenges to Basic Life Support and Core Mission Objectives– Exteriors of Habitats and Work Spaces

Habitats

Natural + Social/Behavioral: During intermittent dust storm conditions on Mars, crewmembers just a short distance from the habitat lose their way because the engineer has removed the guidelines that were previously laid out to use in a pet project of his. (Adapted from the Antarctic experience.)

Work Spaces

Social/Behavioral + Natural: En route to their destination, crewmembers responsible for the laboratory mice lose a male-female pair that proceed to procreate despite microgravity conditions. Before long, signs of rodent infestation are manifest throughout the spacecraft, *i.e.*, insulation is gnawed from wiring; fabrics are holed, etc.

THE "MAN IN A CAN" MODEL AT THE HUMAN-HUMAN INTERFACE

Latent Challenges to Basic Life Support and Core Mission Objectives – Interiors of Habitats and Work Spaces

Habitats

Social/Behavioral + Human-Engineered: A crewmember consistently hogs the only communication systems to the Ground, depriving others from having enough time to speak to their family and friends. (Adapted from the *Salyut 7* and the Frozen Sea Expedition.)

Social/Behavioral + Human-Engineered + Natural: As a practical joke, a crewmember smuggles aboard a ham sandwich. During the mission, he produces it and offers it to his crewmate. However, the bread rapidly dries out in the pure oxygen atmosphere and soon the spacecraft is filled with floating crumbs. (Adapted from *Gemini 3.*)

Work Spaces

Social/Behavioral: A crewmember attempts to enforce a rule about conversation in a work area that improves his concentration but creates a strain on others.

Latent Challenges to Basic Life Support and Core Mission Objectives– Exteriors of Habitats and Work Spaces

Habitats

Social/Behavioral + Human-Engineered: A crewmember is so excited about being outside the spaceship on an EVA that he talks on and on about the splendid beauty of space. His crewmates switch their radios off, including his EVA companion who is working with his back to the talkative astronaut. They fail to notice that his tether has gotten snagged on some protuberance until he is beside himself with panic and happens to pass in front of a camera mounted on the hull.

Work Spaces

Social/Behavioral: A crewmember given the role of being commander of a particular field party enacts his role as a martinet to the great suffering of those under his command. When he takes a nap, the others ruin his samples that he has collected over several hours of work. They fantasize about pushing him into a deep impact crater.

While latent challenges might be coped with better if the long-duration mission is planned as a Quality of Life Model, latent challenges can still be expected to crop up.

THE QUALITY OF LIFE MODEL AT THE HUMAN-TECHNOLOGY INTERFACE

Latent Challenges to Quality of Life and Extended Mission Objectives – Interiors of Habitats and Work Spaces

Habitats

Human-Engineered + Natural: Microgravity is mitigated by centrifugal force but short-radii coriolis effects make the crew nauseous and disoriented, a condition that only two or three crewmembers are able to overcome.

Work Spaces

Human-Engineered + Natural: Crewmembers on a field party on Mars suffer severe shocks inside their suits because the unique way that atmospheric electricity discharges on Mars was not factored into the design of their suits.

Latent Challenges to Quality of Life and Extended Mission Objectives – Exteriors of Habitats and Work Spaces

Habitats

Social/Behavioral: The commander schedules the daily round inside the habitat in such a way that one or two individuals hardly ever get the opportunity to engage the external environment. They become depressed, careless, and have doubts about the mission.

Work Spaces

Human-Engineered: There are plenty of handholds on the outside of the spacecraft where work has to be performed EVA. However, an unusual circumstance requires a tether to be rigged and threaded through the handholds in a particular way, but the arrangement in the placement of the handholds makes this hard to do.

Natural: Fittings on the outer hatch of a Mars planetary surface vehicle do not function properly after being coated with just a light sheen of dust. This is perplexing to the astronauts as Martian dust was thought to be well characterized after several decades of data from unmanned vehicles. But, this dust is different than any that they have encountered to date. This makes it difficult for the crew to get in and out of the vehicle or to effect airtight seals within the craft.

THE QUALITY OF LIFE MODEL AT THE HUMAN-ENVIRONMENT INTERFACE

Latent Challenges to Quality of Life and Extended Mission Objectives – Interiors of Habitats and Work Spaces

Habitats

Social/Behavioral: After a series of mishaps that have left them limping back to base camp on the last of their consumables, the commander's field party returns to find the habitat nearly uninhabitable from a lack of maintenance of key systems on the part of those crewmembers left behind. (Adapted from the Frozen Sea Expedition.)

Work Spaces

Human-Engineered + Social/Behavioral: The crew has fallen behind in mission objectives owing to responding to a number of small system failures that, if cumulatively unattended to, could jeopardize the lives of the astronauts. However, Mission Control feels the pressure for results from corporate and academic agencies that have experiments on the expedition. Controllers urge the crew to step up progress on the experiments and it attempts to follow through. Conflict among several crewmembers erupts when some components of two separate experiments are confused as a result of overcrowding in the laboratory. (Adapted from the *Salyut 7, Skylab,* and *Mir* experiences.)

Latent Challenges to Quality of Life and Extended Mission Objectives – Exteriors of Habitats and Work Spaces

Habitats

Social/Behavioral + Natural: The commander of a crew on Mars takes his weekly stroll on the surface, along with a few of the others (a form of rest and relaxation) becomes enthralled by the alien wilderness of the locale, gets separated from the others, causing much consternation. (Adapted from the Lady Franklin Bay experience.)

Work Spaces

Natural + Social/Behavioral: Several strains of bacteria on the Martian surface are found by a field party, and owing to the mishandling of a sample, the entire field party is exposed to a life form that it has no knowledge about.

THE QUALITY OF LIFE MODEL AT THE HUMAN-HUMAN INTERFACE

Latent Challenges to Quality of Life and Extended Mission Objectives – Interiors of Habitats and Work Spaces

Habitats

Social/Behavioral + Human-Engineered: Through a combination of different interests, work schedules, and a few trivial disagreements, the crew, for all intents and purposes, divide up the spacecraft in different "turfs" replete with territorial behaviors and feelings. The spaciousness of the ship and the "morph-ability" of its areas and fixtures mask this development until a real blow-up occurs between the commander and the medical officer. (Adapted from the Lady Franklin Bay and Biosphere II experiences.)

Work Spaces

Social/Behavioral + Human-Engineered: Owing to a combination of inconvenience and a bit of passive-aggression toward his fellows, a crewmember begins to allow his hygiene to slip. He is key to the enactment of several mission objectives, but he is avoided by crewmates who are needed to assist him because they cannot stand his foul body odor. When the commander approaches him about this, he responds with the explanation that the human body is self-cleaning according to his cultural beliefs. (Adapted from the Frozen Sea Expedition.)

Latent Challenges to Quality of Life and Extended Mission Objectives – Exteriors of Habitats and Work Spaces

Habitats

Human-Engineered + Natural: Some equipment and supplies vital to the completion of the habitat, that had been delivered by an unmanned flight prior to the crew's touchdown on the surface is found strewn about from a rupture in the hull of the supply module. They had been warned that the landing might have damaged the supply vessel because of a "glitch in the software" that could have prematurely switched the rockets off about fifty meters above the surface. But, the damage is worse than they expected and dust permeates everything that might be salvageable. (Adapted from the 2000 Devon Island field season and *Mars Polar Lander* experiences.)

Social/Behavioral +Human-Engineered + Natural: Leonard in Mission Control was the only one who seemed to understand the commander's problem with the malfunctioning gravimetric instrument. Yet Leonard never seemed to be on shift back on Earth at a decent Mars hour. The commander found himself having to get up in the middle of the night or some other inopportune time, Mars time, to talk to the engineer. It would take a month to fix the instrument at this rate. For, on top of the problem of synchronization of Mission Control shifts and the Mars crew's diurnal cycle, there was the problem of the agonizing communications delay.

Work Spaces

Natural: The Martian wind is not normally strong enough to knock down a person working outdoors. However, the field party finds that the series of valleys they had been exploring chute and funnel the wind in such a way to make it a formidable force. It is slow going and consumables are running low. (Adapted from the *Terra Nova* Expedition.)

DISCUSSION: DESIGN IMPLICATIONS

Sometime, in spite of the best efforts, expeditions that start out resembling the Quality of Life Model devolve into the "Man in a Can" Model, and that is owing to latent challenges. The Lady Franklin Bay Expedition is a perfect example. It started out with the crew in capacious quarters in the Canadian High Arctic with a variety of menu and comforts of home. Despite being a 19th century military-headed scientific expedition, its officers were relatively democratic in dealings with the rest of the crew, some of them scientists who had taken Army enlistments to join the expedition. However, as history has borne out, the changeable and unpredictable nature from year-to-year of semi-permanent pack ice in the Arctic, a natural latent challenge, put a chain of events into motion that caused the destruction of most of the crew. The U.S. Navy officers charged with meeting the expedition were not able to meet the crew at the primary pick-up point. The pre-arranged contingency plan called for the expedition members and the Navy to make their separate ways to a secondary pick-up point, which the explorers in the field accomplished shortly after the Navy departed the second pick-up point. A second latent challenge had emerged when the Navy officers made the faulty "group think" assumption that the expeditioners had met grief because they were not on hand when the Navy arrived Since the Navy officers did not wait long enough to meet the explorers at the second pick-up point, the still largely healthy expeditioners were abandoned in the field, in an area of low resources, reduced to a more precarious situation hunkered down in a makeshift shelter of tenting and an inverted boat. They were far worse off than if they had spent another long winter at their original base camp. Twenty-five men were reduced to just a handful over the next several months largely because of exposure and starvation conditions. In the meantime, the U.S. Congress and the American military effectively washed their hands of the matter. The few survivors were only saved through a bounty posted among shipping interests in the area by the expedition commander's wife.

What are the design implications posed by latent challenges to long-duration space missions? From these examples, several environmental and organizational design implications emerge:

- Institute some form of "group think" abatement in organizations involved in the long-duration space mission.

- Design redundancy into systems and have as many critical replacement parts available as weight constraints allow.
- Train crew in how the microgravity environment "reworks" the ergonomics of living and working volume.
- Attend to all work envelope requirements in the mission environment.
- Design all mission systems with a clear knowledge of the effects on materials of bacteria strains that are common to contained humans living in close proximity over the long term.
- Reconcile medical skills and resources to conditions that might be less than optimal (and include responses to issues unique to both masculine and feminine hygiene).
- Give the crew the authority to override orders and demands from Mission Control that could create unsafe conditions.
- Parcel out authority roles more along the lines of task domains than of military rank.
- Understand how the circumstances of the field differ from those of the base camp and how that creates different perspectives and relationships between the disparate groups.
- Understand that things like communications, food, and ability to engage all the mission environments come to be viewed as resources among the crew and must be available to all in more or less equal amounts.
- Investigate use of social/behavioral, natural, and human-engineered boundaries to create spaces for individual, communal, and sub-group activities.
- Make available visual or other detection systems to know what is going on in the external areas near spaceships, main habitats, and outlying enclosures.
- Investigate short radii coriolis effects on humans in microgravity.
- Investigate available data about the Martian atmosphere and weather in the locale of planned planetary surface operations, looking for unique circumstances that might offer latent challenges to the crew.
- Investigate the use of "buddy system" procedures and resources in all field activities.
- Synchronize Mission Control shifts with the crew's diurnal cycle.
- Investigate communications protocols that anticipate inquiries and responses to mitigate the problem of time delay in communications between Earth and Mars.
- In mission system design, design as many improvisation measures as possible and ensure that crewmembers are trained in those measures.

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