Interstellar Sweat Equity

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Dr. Marc M. Cohen, Arch.D
Marc M. Cohen Architect, PC
marc@astrotecture.com
http://www.astrotecture.com
100YSS Project Committee Chair
(ISDAC)

Declan J. O'Donnell
Law Office of Declan Joseph O'Donnell, P.C.
777 Fifth Ave.
Castle Rock, Colorado, 80104 USA
isdac.usis@gmail.com
President, United Societies in Space
President, ISDAC

Robert E. Becker
Systems Engineer
Northern Ireland, UK BT40 2LF
roberte.becker@prodigy.net
Regent, ISDAC

Adam Brody
Aerospace & Human Factors Engineer
Mountain View, CA 94025 USA
brody@alum.mit.edu

International Space Development Authority Corporation
http://www.internationalspacedevelopment.com/hello-world/

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Abstract

So, you have just launched aboard the Starship, headed to an exoplanet light years from Earth. You will spend the rest of your natural life on this journey in the expectation and hope that your grandchildren will arrive safely, land, and build a new settlement. You will need to govern the community on board the Starship. This system of governance will need to meet unique requirements for participation, representation, and decision-making.

On a spaceship that can essentially fly and operate itself, what will the crewmembers do for their generations in transit? Certainly, they will train and train again to practice the skills they will need upon arrival at a new world. However, this vicarious practice neither suffices to prepare the future pioneers for their destiny at a new star nor will it provide them with the satisfaction in their own work.

In order to hone the crewmembers' inventive and technical skills, to challenge them and prepare them for pioneering, the crew would build and expand the interstellar ship in transit. This transstellar "sweat equity" would give a stake in the enterprise to all the crew and provide meaningful and useful activity to the new generations of crewmembers. The crewmembers would build all the components of new segments of the vessel from raw materials – including atmosphere – stored on board. The construction of new pressure shell modules would be one option, but they would also reconstruct or fill–in existing pressurized volumes. The crew would build new life support system components and develop new agricultural modules in anticipation of their future needs. Upon arrival at the new star or planet, the crew would be able to apply these robustly developed skills and self–sufficient spirit to their new home.

Introduction

The strategy of interstellar sweat equity implies that the creators of the spacecraft must design it for this gradual expansion, providing tools, supplies, and materials. The crew will need the ability to create and test their own new tools and inventions to improve upon the training and practices that the Starship creators provide them.

A sweat equity model becomes necessary for this ultra-long space mission, and is also the optimal system solution, the broadest sense of systems engineering, for such an interstellar space mission.

In turn, the question of sweat equity raises a set of social, economic, and governance issues. Equity implies a share -- a unit of ownership – in the collective or corporate enterprise. That works fine for people who are able and willing to work as described. But what should be the policy for people who are unable or unmotivated (e.g., the disabled, the elderly, the clinically depressed, or mothers with young children, etc.)? Do they hold an equal share? Is their equity somehow adjusted or reduced? How can the sweat equity strategy succeed in creating a society that is not divided among "haves" and "have-nots?"

The answer is Space Governance. This system of Space Governance will consist of three levels of legal, contractual framework affecting the Starship society as a whole, as individual inhabitants, and the Starship itself. From the top down, these levels are:

- Creation of a "Starship Nation," body politic and polity.

- Sweat Equity – contracts, ownership share.
- Statute and regulation, laws, codes, permit processes.

Each level of Space Governance ties into Human Factors and Crew Productivity in multiple ways.

Assumptions about Interstellar Travel

Futurists, philosophers, scientists, and science fiction writers have created a complex of theory, assumptions, and outright speculation about interstellar travel. Each of these ideations leads to important human factors issues.

The duration of an interstellar mission or migration will define its character more forcefully than any other factor. The most common (and not necessarily compatible) assumptions, distilled from the literature about interstellar mission (Cohen, Brody 1991), include:

1. Using any currently forseeable technologies, exploration of another star system will require a one-way trip that will take most or all of a human lifetime.
2. Early interstellar voyages will be multigenerational emigrations in immense, self–sustaining vehicles based upon proposed space colonies.
3. Spaceflight safety, habitability requirements and social standards on an interstellar vehicle may be essentially the same as today, although perhaps more earth–like.
4. The interstellar travellers must bring a broad economic and vocational base with them to pioneer successfully on a new planet.
5. The Starship community will need a new and unique form of governance.

Mission Duration

Long mission duration compounds and magnifies all the critical aspects of isolation, confinement, social organization, training, and decision-making. Many authors present only selected values for the relativistic time dilation factor that enter into calculations of the differential ageing effects (so-called Twin Paradox) for a constant-speed cruise mission to a star bracketed by initial and final accelerated phases, to support a particular argument. It is essential to present the background to allow comparative analysis about interstellar mission duration. Any realistic interstellar mission will last decades or lifetimes (Cohen, Brody; 1991).

Iain Nicolson (1978, pp. 161, 174–176) proposes:

- Values of less than .01c to designate “space ark” scenario (a travelling O'Neillian “Island One” Space Colony in which approximately 10,000 people live for generations);
- Values between .01c and .05c for a “fast Starship” that makes a one way journey possible within a human's lifetime; and
- Values “near the speed of light” to indicate “relativistic spaceflight.”

He suggests .99c to illustrate a vehicle in which round trip journeys to star systems beyond Proxima Centauri theoretically become possible.

Louis Friedman (1988, p. 127) points out that to travel the four light years from earth to Proxima Century in 100 years, a spacecraft would need to achieve .04c with the average speed of 29 million miles/hour, including acceleration and deceleration time. And yet, Friedman advocates the use of solar sails for interstellar travel, but recognizes that the much slower solar sail voyage to Proxima Centauri could take about 6,600 years, a longer period than recorded human history.

Most any model for an interstellar mission with a reasonable chance for successfully establishing a settlement on an exoplanet will require robotic precursor missions to scout and relay data to Earth from intended targets. Yet barring the invention of Faster-than-Light (FTL) technology, such precursor missions will likely have durations not too much shorter than the human interstellar mission itself. This will prolong the overall interstellar mission, from inception to settlement, even further.

Thus, all three major phases of a successful interstellar mission – technology and mission development, precursor missions, and the human interstellar mission – will be extraordinarily prolonged. This implies that any mechanism, such as sweat equity, that may ameliorate the psychological and sociological impact of immense mission durations during interstellar transit should be applied wherever possible to the two earlier phases as well. It is therefore best to initiate the apparatus of a sweat equity model with its associated Space Governance framework, on Earth at the launch of the Project, not the interstellar mission itself.

Appropriate and Feasible Mission Durations

Given the range of possibilities described by Friedman, Nicolson, and many others, it is essential to evaluate the different classifications of mission duration. These classifications may be described as the millennial space ark, the multigenerational one–way, and the relativistic round trip. The period for each classification implies a profoundly different type of spacecraft and crew society to operate it.

A "Space Ark" might use solar sails or conventional propulsion to travel at relatively slow speeds, with trip time measured in millennia. As an assessment of human aspirations and motivation in the context of a "Space Ark," it would appear unlikely that many people would sign on for a journey beyond their lifetime. Call this effect the "Moses threshold." People may be willing to reach the mountaintop and see the promised land — or promised planet — even if they will be too old to live there, but a lifetime of totally deferred gratification would be an extremely hard sell outside of a few small monastic orders. This scenario might be the most that could be asked of humans, as they are now constituted. A crew that knows they will die many generations before reaching their goal would seem to need idealism so unrealistic or a desire to escape the earth so desperate that in neither case are they likely to make appropriate crew members. Nevertheless, many authors have delighted in the punch line of the space ark crew who were disappointed to find that someone departed after them to arrive sooner, using more advanced propulsion.

At the opposite extreme of the spectrum of interstellar travel possibilities, the relativistic round trip seems equally unrealistic as a millennial space ark. This unfeasibility is not just because of the formidable propulsion problem, that no propulsion system now imaginable could produce the sustained Δv necessary to achieve relativistic spaceflight. Robert Forward describes as "Stumbling Block 1" the idea that "A Starship must accelerate continuously at one earth gravity." He goes on to argue that beyond a certain speed, the relativistic mass of the spacecraft increases to pose a trade–off of reduced travel time at the cost of greatly increased fuel mass (Forward, 1986). However, if the difference between achieving, say, 0.05c and .50c means that the crew can arrive and return as heroes within their own lifetime, the additional expense may seem worthwhile to them.

This analysis leads to the proposition that interstellar travel will be primarily one way and multigenerational, but with few enough generations that the original travelers or at least their known descendents will reach their destination. This criterion puts the focus on achieving at least the .05c range before interstellar travel becomes realistically feasible from the human factors and motivational point of view.

Human Accommodations

One of the most vexing questions about interstellar travel is what would motivate somebody to go on a journey that he would likely never complete, or if he did complete it, might not have sufficient life left to him to benefit from the journey. Other than avid readers of science fiction or refugees from dire economic or political circumstances, it is difficult to imagine many people electing the lifetime of routine, monotony, boredom, and constant peril associated with interstellar travel. Interstellar travel advocates love to cite the colonization of America and Australia as precedents. Despite the hardship of these voyages and the pioneering life that met the immigrants when they landed, the journey from Europe to North America was six to eight weeks, and to Australia, it was eight months to a year (and most of them were non-voluntary, convict immigrants). Moreover, the earliest expeditions during the Age of Exploration were primarily exploratory in nature, rather than for immediate purposes of colonization. Those explorers expected to return home. Once again, barring development of FTL drives; there is almost no chance that the inhabitants of a starship shall ever return to Earth.

Maslow's Model of Human Needs and Motivation

The psychologist Abraham Maslow (1970, p. 35) developed a model of human motivation as “an attempt to formulate a positive theory of [human] motivation.” Although this model is not a scientific hypothesis about human behavior, it is a useful concept of human motivation and needs. It represents an attempt to create a synthesis of the diverse physiological, social, emotional, perceptual, and cognitive bases of human motivation. The habitable environment is an influence on human motivation behavior, through gratification or deprivation, or a host of other perceptions or conditions (Maslow, 1970, p. 46). FIGURE 1 illustrates Maslow's model as a hierarchical pyramid, characterized by the most fundamental needs from the bottom up. Each level is necessary to support the levels above it. Failure of any level can lead to the “cascading” system effects that are characteristic of human error–caused disasters in aviation and nuclear power plants.

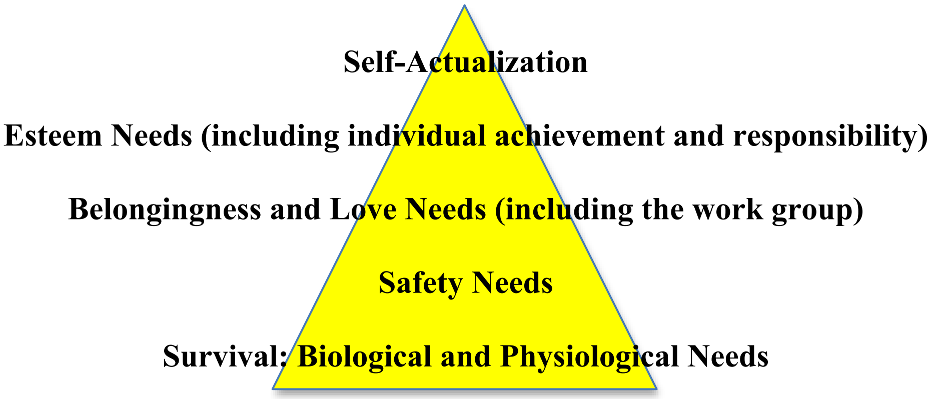

FIGURE 1. Abraham Maslow’s original hierarchy of human needs and motivation.

Maslow's theory poses far-reaching implications for space habitat architecture. It matched up with issues in the International Space Station (ISS) program and in the contemplated Lunar and Mars bases. While fundamental agreement exists upon on biological needs such as air, water, food, and thermal comfort, as one moves up the pyramid, the issues become increasingly treated as "options." Connors, Harrison, and Akins (1985) described the baseline human requirements for long duration missions, and sought to illuminate the consequences of not meeting these needs.

Space Systems Engineering holds that every component of a space program has features of cost and benefit that are subject to manipulation and "trade–offs." For a successful interstellar journey (and most other, more near–term long duration missions), these fundamental methods and principles of Systems Engineering must be maintained and fully utilized. However, the scope and weight given to different factors that enter into the trade studies and system design analyses for massive human space exploration projects, whether to Mars or to the stars, must be changed and broadened to incorporate sociological and anthropological sources of requirements, alongside more traditional human factors and classical physical engineering sources (Becker; 1998). In short, the concept of systems engineering must expand to recognize that some elements are essential to crew performance beyond just keeping them alive and working long shifts.

For instance, Clearwater and Harrison (1990) argue that for Mars Missions, the engineering temptation to "trade–off" cost for comfort would be a "major mistake" from the human factors point of view. If this precept affects a Mars mission, it will create exponentially greater effect for an interstellar journey.

Human Motivation and Needs

Countermeasures to weightlessness and radiation are good examples of how this greater impact will occur. Sporadically, the Soviet/Russian and American space programs contemplate missions to Mars (of 1 to 3 years) using drug and exercise countermeasures to counteract bone demineralization and muscle atrophy. According to Dennis Newkirk (1990, p. 303), they consider some degree of deterioration (and recovery after return to earth) as acceptable. However, for a journey that lasts a lifetime, providing artificial gravity shifts from a safety trade–off option to an absolute physiological requirement. Similarly for radiation protection, Johnson and Holbrow (1979, pp. 21, 43) note that the traditionally allowable exposure is measured by the month, 90 days or the year, or a "career," but not for a lifetime. Raasch, Peercy, and Rockoff (1985, p. 99) state

> "The time is coming when the astronaut population will need to be considered as part of the general population and not a small and separate group with separate standards or radiation exposure levels."

Other components of the space habitat would shift on Maslow pyramid. Crew teamwork and autonomy will become more than a de facto residual of the supervisory role played by Mission Control in Houston or Star City, and become instead an essential component of life on board, even defining their own levels of need.

The definition of human productivity will shift, from the focus on near–term economic return to a view toward investment over the lifetime of the mission. According to Karasek and Theorell (1990) this "new value" approach to productivity would place an added emphasis on education, learning, skill–enhancement, quality, stimulation, feedback processes, and adding value to the people and the organization. The "new value" measure of productivity would approach work life as sustaining and enhancing the overall quality of life rather than purely on the economic bottom line — the primary source of chronic stress. Cohen (1990, p. 8) observes that it suggests an "unpriced value" system of personal and professional development to encourage the creativity and serendipity required upon arrival at a new star or planet. This model is consistent with a sweat equity model for the hermetic society of a starship, with no external economic relations, at least for many years following settlement of the destination planet.

Beyond the economic aspect of productivity, at the top of the pyramid, "self-actualization" is the reason why space agencies and societies send humans into space: for the creativity, discovery, experience (however vicarious), self-discovery, serendipity, and transcendence of the human condition. Cohen and Houk (2010, p. 3) define Crew Productivity in a new way:

Crew Productivity means ***how well the spacecraft system supports the crew:***

- *To be effective in carrying out the mission accurately and successfully,*
- *To be efficient in performing tasks in a timely manner with reasonable use of available resources, and*
- *To optimize the human suitability of the operational environment*

The resulting seven level hierarchy shown in FIGURE 2 corresponds to the needs that the crew encounters on a space mission. In attempting to delineate the metrics that can measure Crew Performance (CP), it became necessary to resolve a contradiction with the closely related topic of crew safety.

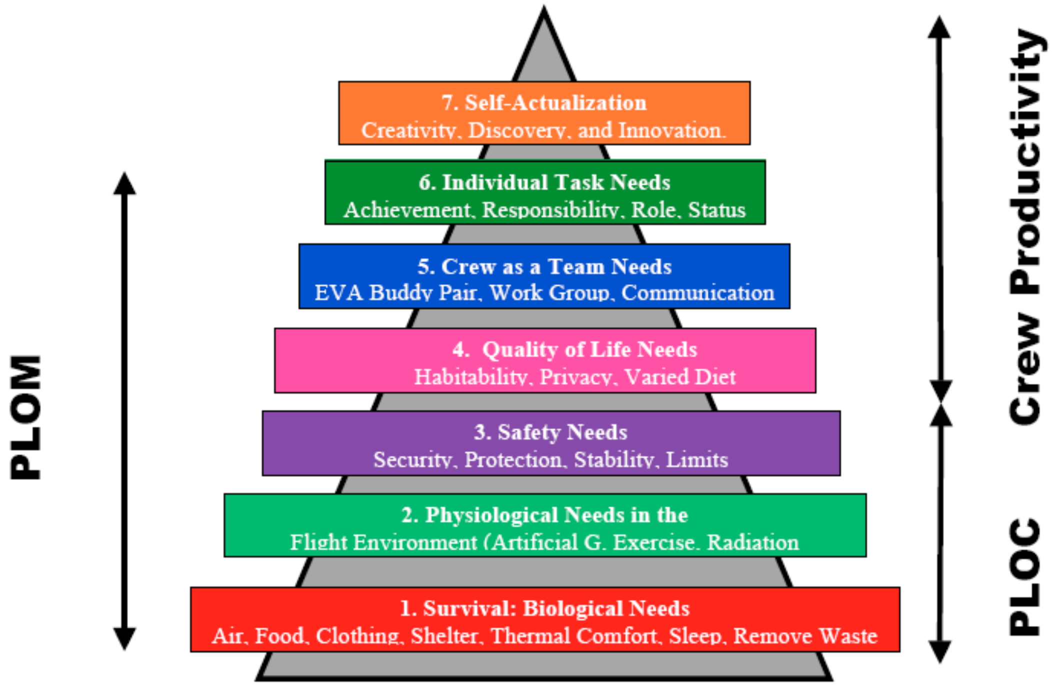

FIGURE 2. Adaptation of the Mallow Hierarchy to the Human Exploration Crew Productivity Study (Cohen, Houk; 2010).

For example, if the crew is fearful for their safety, their productivity will become impaired, perhaps dramatically. In order to resolve the contradiction, it became essential to identify the demarcation between these two emphases.

PLOC, PLOM, and Crew Productivity Figures of Merit

A purpose of this application of Maslow's Hierarchy is to identify and calibrate the Figures of Merit (FOM) that interact with it. Traditionally system engineers work with four FOMs: Cost or Affordability, Mass or Delivered Payload, Mission Success or Probability of Loss of Mission (PLOM) and Safety or Probability of Loss of Crew (PLOC). The Northop Grumman lunar lander study (Cohen, Houk; 2010) added Crew Productivity as the fifth FOM (CP).

It became important to distinguish the new CP FOM in its levels of human need and motivation from the well-established PLOC and PLOM. To the right of the pyramid, the double-headed arrows show that PLOC spans from Biological Needs through Safety. Crew Productivity picks up where PLOC leaves off, so it spans from Habitability through Self-Actualization. To the left of the pyramid, PLOM overlaps both PLOC and CP, spanning from Biological Needs to Individual Task Needs, but does not extend to Self-Actualization.

Traveling Space Colonies?

Jones and Finney (1985, p. 93) describe how the most common assumption about interstellar spacecraft is that they would be essentially travelling space colonies,— constructed in space from millions of tons of materials, mined from the moon or asteroids -- self–sufficient and multigenerational, with a population fixed at about 10,000 people. The underlying assumptions that drive the immense size are the needs for:

- A diverse economy to provide essential goods and services Johnson and Holbrow (1977, pp. 25–27) cite the economist Colin Clarke that economic organization such as cities require a population "of 100,000 to 200,000 to provide 'an adequate range of commercial services . . .'" The question is: adequate for what?.
- Diverse and robust vocational skills among the crew to support that economy and the sustainment of the Starship, (Johnson, Holbrow, 1977, pp. 49-51; Nicholson, 1978, pp.)
- Cultural diversity to create a stimulating and dynamic society as "heterogenistic, mutualistic and symbiotic" (Nicholson, 1978, pp. 30-31).
- Genetic diversity to guard against the emergence of undesirable recessive traits (e.g. hemophilia, Tay–Sachs, sickle cell anemia, etc) (Terra, 1990, p. 27; Birdsell, 1985, p. 118.)

The great practical difficulty in the O'Neillian space settlement schemes is the immense size and cost of these space settlements. In the first Space Settlements study, (Johnson and Holbrow, 1977, pp. 25–27) projected a construction cost of $190 billion in 1975 dollars, spread over 22 years (average of $8.6 billion/year), at a time when the NASA budget was less than $3.3 billion/year. These estimates typically relied upon extremely rosy predictions of mass to orbit costs, such as Gerard O'Neill's (1982, p. 262) for sending each space colonist into low earth orbit for $4,500 (in 1982 dollars). This number is based on the 2nd Space Settlements Study

(Billingham, Gilbreath, O'Leary, O'Neill, 1979, p. 64-Table 1). With some baggage, bringing the average weight per passenger to 300 kg, their cost per kg to orbit is a mere $15.00 [compared to about $10,000 per kg, at the culmination of the Space Shuttle program in 2011]. This cost is daunting given current or foreseeable technologies. Even at much lower orbit launch to orbit costs (say $1000/kg), the annual space colony construction, deployment, and logistics cost is much more than the total NASA budget, adjusted for inflation.

Interstellar Spacecraft Size

To bring the interstellar spacecraft cost into the realm of possibility it will necessary to reduce the initial size and cost by at least two orders of magnitude, which means reducing the initial crew size from 10,000 to 100. William Hodges (1985) argues that an interstellar migration crew of 10 would be sufficient for "the cheapest possible spaceship," so the proposed reduction to 100 may not be so extreme. This reduction in crew size means several fundamental changes in the common assumptions about a traveling space colony or "space ark." This smaller crew of 100 people would have a different set of tasks, particularly as each crewmember would need to learn multiple professions. However, they will have a lot of time to learn these skills during their journey. To allow for full generational realization (4 generations concurrently alive) the crew would plan for population growth from 100 to about 500.

Human Factors Technology Issues

The emergence of human factors takes on two thrusts: the philosophy / theory of human factors issues and the technology necessary to address those issues. The philosophical issues are largely imbedded in the approaches to the technology, and only become manifest in specific potential technical solutions. The key human factors issues in question are habitability, human–machine interfaces, crew selection, crew training, population control or growth, and "transstellar sweat equity."

Habitability – the "Human–Environment Interface"

Habitability will be crucial for interstellar travel; it is an essential component of operational safety, pushing the technology necessary for Mars exploration much further. Habitability issues (Cohen, Junge, 1984) will shift from support of human productivity to a critical factor in long-term safety. Life support, food supply and hygiene systems will need to be totally closed and self–regenerating. Both private spaces and group activity places will become much more important for crew social interaction and cohesion than presently found on ISS, since the "crew" will largely be what is today thought as civilians. Public spaces for ceremonies, meetings, and even courts of law would take on an importance comparable to terrestrial society. The internal architecture of the spacecraft will need be able to respond to changes and developments in the crew society. This flexibility would include the ability to metamorphosize the floors, ceilings, partitions, and configurations of rooms and zones on the spacecraft.

Human Biomedical Engineering

Fantasists, Futurists, and Science Fiction writers propound about how biomedical science and engineering will change the human organism, although not always for the better. With respect to space exploration including interstellar travel, the most popular speculations include suspended animation, genetic modification, and "the Singularity." It is vital to discuss these potentialities because of the potential huge impact upon crew productivity and even the definition of who is the crew.

Genetic Modification

Genetic science and engineering has made remarkable advances in only a few decades that enables the medical profession to trace the origin of a wide range of disorders, but not nearly so much the origin of special capabilities. Birdsell (1985, pp. 25-27) advocates meticulous crew genetic selection to diversify the gene pool as widely as possible to avoid undesirable recessive traits emerging. At the same time, Birdsell (1985, pp. 117-118) advocates simplifying certain gene selections, such as advocating that all crewmembers be Blood Type O, Rh positive, to make blood banks and transfusions much less complex than on earth. These genetic approaches to crew selection raise profound issues of medical ethics, as well as a potential form of genetic fascism. The assumption that "Homo Spacian" would be some kind of genetic superman compared to Homo sapiens deserves to be treated with great suspicion. The notion is particularly suspect that medicine or science can help human beings leave some undesirable part of their character or being behind while bringing with them only the attributes they consider most desirable. This hubris can lead to tragedy.

The Singularity

The Singularity Institute (2011) (http://singinst.org/overview/whatisthesingularity/) defines its namesake:

> The Singularity is the technological creation of smarter-than-human intelligence . . . A future that contains smarter-than-human minds is genuinely different in a way that goes beyond the usual visions of a future filled with improved gadgets.
>
> And: (http://singinst.org/overview/whyworktowardthesingularity)
>
> A conservative version of the Singularity would start with the rise of smarter-than-human intelligence in the form of humans with brains that have been enhanced by purely biological means. This scenario is more "conservative" than a Singularity which [sic] takes place as a result of brain-computer interfaces or Artificial Intelligence, ...
>
> But the conservative scenario would not last long. Some of the areas most likely to receive early attention would be technologies involved in more advanced forms of superintelligence: ***broadband brain-computer interfaces*** or full-fledged Artificial Intelligence. The positive feedback dynamic of the Singularity . . . would also apply to ***enhanced humans*** creating the next generation of Singularity technologies [emphasis added].

A common target date for the Singularity to occur is 2050. One of the common concepts of the Singularity is that humans will merge with smarter machines to create a superior evolved species. These interfaces would not necessarily be as gaudy as Borg implants or even Bluetooth earpieces. Keep in mind that the United Nations (2005) projects that world population will expand to 9.1 billion people by 2050. Assuming that this enhancement will not be available – at least initially – to the great majority of the human species, what does selective entitlement to "superhumanity" entail? Would these Homo Singularis beings arise as the logical candidates for interstellar travel? Alternatively, would they be the people trying to escape from Homo Singularis?

Interstellar Sweat Equity

Cohen and Brody (1991, pp. 11-14) introduced the concept of interstellar sweat equity to address the question, what do the crew do for their entire lives onboard the Starship. On a spaceship that can essentially fly and operate itself, what will the crewmembers do for their generations in transit? Certainly, they will train and train again to practice the skills they will need upon arrival at a new world. However, this vicarious practice neither suffices to prepare the future pioneers for their destiny at a new star nor will it provide them with the satisfaction in their own work that comprises the apex of the Maslow Pyramid. The construction of the Starship economy and equity-sharing system depends upon a series of considerations: precursors, supplies and materials, autonomy, expansion, trajectory design, and arrival at the new world. The equipment and materials needed to build, expand, and modify the Starship in flight will be part of its planning and design, but what the crew needs upon arrival at the new world will depend upon the local situation on the planet.

Precursors

The interstellar mission design relies upon a set of robotic precursor missions to provide accurate and detailed knowledge of the destination solar/planetary system and the future home world. These surveys will provide data and analysis of the environmental conditions and resources available there. They will inform the mission designers of what specialized equipment and supplies to load on the Starship for use at the destination. It will also enable an analysis of what specialized skills the crew will need to make the best use of the conditions and resources. Failure to conduct this reconnaissance could create a situation where, after a century of preparation and another of travel, the crew arrives at the destination world only to find it is unsuitable or even uninhabitable. Going on to the "next-best" destination could involve another century or more of travel.

Supplies and Materials

Once the mission designers and prospective crew obtain a good idea from the precursors of what materials, supplies, and equipment they will need on the new world, they will need to select, acquire, and pack them onto the Starship. Selection of a sweat equity model will be a major decision point in determining how much and of what nature, material must be loaded onto the starship at the start of the mission.

Will the entire starship be pre-designed and pre-fabricated on or near Earth, and therefore necessary supplies may be limited to consumables for the journey and equipment required for settlement of the destination planet?

Or will the inhabitants of the starship largely determine their own habitat design as the mission proceeds? In that case, there must be an abundance of raw materials for fabrication and construction, and the manufacturing and construction equipment to utilize them. Naturally, the intent is that this experience and expertise will be carried over to settlement on the destination planet.

Autonomy, Automation, and Self-Reliance

In order to hone the crewmembers' inventive and technical skills, to challenge them and to prepare them for pioneering, the crew would build and expand the interstellar ship in transit. This transstellar "sweat equity" would provide meaningful and useful activity to the new generations of crewmembers. The crewmembers would build all the components of new segments of the vessel from raw materials – including atmosphere – stored on board. The construction of new pressure shell modules would be one option, but they would also reconstruct or fill–in existing pressurized volumes. The crew would build new life support system components and develop new agricultural modules in anticipation of their future needs. Upon arrival at the new star or planet, the crew would be able to apply these robustly developed skills and self–sufficient spirit to their new home.

Flight Trajectory Design Considerations

The design of the Starship trajectory has three parts:

1. Departure from the Solar System
2. Interstellar travel at relativistic speeds
3. Arrival at the new solar/planetary system.

1. Departure from Earth through the solar system involves the potentially ticklish task of navigating a more than 2 km-sized spacecraft through the asteroid belt, the Kuiper Belt, and the Oort Cloud. Advanced surveillance satellites will help to chart the safest optimal path through the cosmic obstacle course. The Starship must fly under controlled, fine maneuvering-capable propulsion under the "speed limit" described above. At this velocity, departure from the solar system could take several years.

2. Everything in the Milky Way Galaxy is moving. Plotting the course from the outer edge of the Oort Cloud to the new solar/planetary system is a problem not yet addressed. The challenge is to fire the engines to send the Starship at relativistic velocities through space-time to intercept the destination system where it will arrive in 80 to 100 years, while accounting for the effects of any propulsive malfunction or failure.

3. Arrival at the new solar/planetary system will be the converse of the departure process. The Starship must decelerate to maneuvering speed before entering the Oort Cloud equivalent of the new system. The several years in this flight mode required to arrive at the new world will give the crew the opportunity to make their own detailed observations of their new neighborhood. After the Starship enters orbit around the new planet, they will make new, highly detailed and targeted observations to identify landing, settlement, farming, mineral extraction, and industrial sites.

Arrival at the New World

Once arrived at the destination planet, the residents of the starship finally have a means to "cash in" their sweat equity beyond the confines of their ship. Initial settlement will probably be constrained in surface area due to the number of settlers, the need for mutual support and any constraints on resources either offloaded from the starship or lacking on the planet. Thus, divvying up the surface of the planet into new dukedoms will probably not be the way sweat equity is cashed in initially. Indeed, consistent with a less economic approach to determining value and sweat equity itself, goods and land may not be divided at this point to any great extent. After all, inasmuch as the experience gained through the investment of sweat equity in expansion of their starship facilitated their survival on a new world, that their sweat equity may already have been "cashed in."

Eventually, as population expands if the initial settlement is successful, a transition to a more terrestrial economic and legal fabric may be engendered. In such a transformation, the sweat equity can now be translated into more traditional rewards if so desired; these may take forms more recognizable to terrestrials as "sweat equity" in its classical sense.

Fundamental "Theorem" of Large-Scale Human Space Missions

Thus far the focus has been on the role of sweat equity on the interstellar voyage itself. Successful implementation of sweat equity demands that the methodology and attitudes characteristic of it be introduced well before launch. As it so happens, what is intended to enhance the psychological and sociological strength of the travelers, can also serve well in overcoming one of the biggest obstacles to any major human exploration mission.

While sublime considerations in favor of space exploration are the primary motivating factors for space agencies and space enthusiasts, they are usually far from sufficient to motivate the general populace to support and fund massive human missions, which is one reason why creative methods such as the 100 Year Starship project need to be invoked, and something similar may ultimately be needed even for solar system exploration.

Likewise, the financial community will not invest in this for the same reason it will not invest in less grandiose space projects, unless some other entity, like the much despised (by space advocates) government steps in first. Indeed, it was the few, short halcyon years in the late 1980s when it appeared that the government would fund such a program with a serious Space Exploration Initiative that the commercial business community did jump in and started exploring and advocating for the possible role in such an adventure. But the investment would not come from them.

The stark reality is that were it at all feasible to fund the O'Neill Mode (or even its smaller 100 person variant proposed herein), we would already be landing, or at least seriously working towards landing, humans on Mars. Instead, human space exploration is in effective stasis and nobody of middle age or above should expect to see humans visiting Mars or even the asteroids in their lifetime.

There is no evidence that there is now a prolonged, sustained commitment to human space exploration akin to that of medieval cathedral construction that sometimes took centuries to complete, and which is perhaps the closest historical analog to the developmental phases of an interstellar mission.

Why has this happened? The causes may be legion, but a key aspect is that despite the vast enthusiasm for, long list of reasons for, and the belief in the self-evident value of, this exploration by the space advocacy community, the general populace does not share the opinion that human space exploration is directly pertinent to their lives, and their elected representatives certainly do not. Therefore, such hugely expensive endeavors will not be funded adequately.

This obstacle can be encapsulated by what may be called the Fundamental "Theorem" of Large-Scale Human Space Missions (Becker, 1998):

Large-scale, long-term human space exploration and/or settlement programs shall be fundable and maintainable if and only if it can first be demonstrated that such a program has a short-term socioeconomic justification for the general populace of a nation or world as a whole.

By large-scale and long-term programs are meant missions of the scope and expense of human Mars exploration and the DARPA Starship Project.

By short-term is meant tangible benefits accrue within no more than a few years of the initiation of the program. This means such benefits must start accruing during the *development* phase of the program, not once the mission is underway or after the mission has been completed. Gratification, from that immense investment must be quicker than that.

By general populace is meant the bulk of the citizenry of a nation or the world who are not space advocates and who do not work or are not directly affected by the usual aerospace industry firms and institutions. What form could such benefits take? It may be different for each nation or even state and community. This policy would need to be determined by a concerted study. It also depends on the current problems that the nation faces. Clearly though, secular unemployment or underemployment, particularly for former blue-collar workers, is an issue. So are the economic dislocations forced by technological advances and the drive to cost reduction at any price, typified by outsourcing to other countries (from a US perspective). Work on the developmental and construction phases of an O'Neill Mission could expand the manufacturing base again in this country. It could expand the markets and sectors for which commercial companies were not previously exposed due to the necessity to equip the Mission with all the appurtenances of a full living community. This effort entails the participation of not just the aerospace or the military, but of wider society. If a boost can be given to lower socioeconomic classes by their participation in this mission both in its development and the mission itself; and if the weighting given to pure cost reduction on this project is lessened when compared to the weighting given to socioeconomic benefits; then perhaps there is a chance.

Note that the "Theorem" does *not* state that such a short-term socioeconomic justification actually exists; it only states its necessity. In fact, this justification may not exist because if it did, it might violate economic principles as much as FTL Communications may violate physics principles.

Yet sweat equity may provide a way around these strictures. Almost by definition, a population devoted to the development of the interstellar mission and then becoming its inhabitants in the most active of ways will find the sublime explanations sufficient and may be willing to fund it as a "cost" of effective citizenship in a newborn entity. And at the same time, those people who will be most affected by this mission because they bear it onwards, may also be best placed to also find creative means of demonstrating that for the rest of the population of the nations of Earth, there *will* exist the conditions necessary for premises of this theorem to be true.

Interstellar Starship Governance

For Interstellar Starship travel to become feasible, certain human factor issues need to be chiseled into legal requirements for the benefit of travelers and for the long-term survival of the human race. These issues and their putative solutions will include the existence of a relevant space governance framework and procedure and its capability to nurture nation building onboard the starship. This framework includes the maintenance of a fair and comprehensive common law code that addresses the ethical questions posed by sweat equity. It applies specific, detailed measures, analogous to local or industry terrestrial laws and regulations, such as a space building code with Starship design requirements, a statute on radiation protection, another on alien contact and communication, one on speed limits, and another on universal continuing education. United Nations Treaties and its Global Governance must be respected as precedent wherever relevant.

Space Governance

Currently there are six governance models for space travelers:

1. Soviet/Russian Semi-Military,
2. NASA Civil Service,
3. NASA Commercial Space Contract
4. ESA Quasi-International
5. Non-Profit NGO
6. Chinese Military

1. The Soviet Semi-Military Model

During the glory days of the Soviet Union, from Yuri Gagarin in 1961 to the launch of the Mir Space Station in 1986, the Soviet space program was closely coordinated with its military. Yuri Gagarin's Vostok 1 spacecraft was a modification of a military spy satellite that was pressurized originally to provide a suitable environment for a film camera. With the advent of the Salyut program, the Soviet program began to show the beginning of a civilian/military divergence. The NPO Mashinostroyenia (NPOM) originally designed for the Almaz (Diamond) Orbital Piloted Station for the Soviet military **(Spaceflight Magazine Reference).** Later, the Politburo ordered the transfer of Almaz production to the Central Design Bureau of Experimental Machine Building (TsKBEM), the precursor to NPO Energia and later RKK Energia. A leading theory for this transfer was that it was intended to conceal the Soviet military space station program under the same name as the civilian/scientific program Salyut. Salyuts 1, 4, 6, and 7 were genuine civilian Salyuts. However, Salyuts 2, 3, and 5 were military missions crewed by "cosmonaut soldiers." Salyut 5 carried a cannon that it fired remotely after departing the station. During the Almaz missions, the governance was purely military.

During the civilian Salyut missions, the civilian mission control played a leading role, but the authority of the state and its system of governance were plainly behind its decision-making and operations. Despite operating in the "shadow of the Kremlin," the Soviet program made pioneering advances in personalized and individualized crew support, including family visits and conversations with famous and popular people in Russian society.

2. The NASA Civil Service Model

All key operational personnel are civil servants, or contractor personnel who work so closely with civil servants (e.g. in the "back room at Mission Control in Houston) that they might as well be civil servants; the fact that the "contractor" companies change but the same contract personnel stay in the same jobs indicates that their positions are "inherently governmental." The astronauts train for their missions, learn their roles, and contract with NASA as to their behavior, the rules, and how to react to emergencies. The current Russian Glavcosmos civilian space agency has moved closer to the NASA civil service model, in part because of the need to collaborate closely with NASA first on Mir in the 1990s, the first decade after the collapse of the Soviet Union and in the current millennium for the International Space Station Program.

3. The NASA Commercial Space Contract model

The commercial and entrepreneurial space development model is really just starting in the first two decades of the third millennium of the Common Era (AD). As of this writing, it has flown two suborbital crew flights, two orbital inflatable test habitat flights, and one orbital test cargo vehicle flight. Therefore, there is much to learn and much to try before it is possible to characterize the Commercial Space Contract with in the framework of NASA's Commercial Crew Development (CCDev) program. Also, it is probable that these commercial providers will generate their own business and organizational models once they can operate beyond the initial "seed money" scope of CCDEV.

4. The European Space Agency Quasi-International Model

ESA has emerged as the one space agency that follows an internationalist path. Multi-national by charter among the members of the European Union, it is subject to multiple levels of parliamentary and governmental decision-making. Presumably, each member country would sign on to a proportional and stable level of contribution both financial and technical. However, over the three decades that ESA has been active in human spaceflight, there has been considerable variability from year to year among the commitments and contributions of the member states. This variability can cause frustrating delay, instability, and uncertainty in some of the ESA programs. Nevertheless, ESA may provide the leading example for an international model of space governance, including both its success and failure modes. One seemingly paradoxical success has been that despite the extra layers of pan-European bureaucracy, ESA has been able to sponsor paid workshops and collaborative studies for non-governmental specialists from member countries without the mountain of paperwork that NASA would require for paid participation through the Federal Acquisition Regulations.

5. The Chinese Military Space Model

In contrast to the current Russian and preceding Soviet programs, the Chinese space program is purely military. So far, there have been no efforts to even make it look like a civilian program. With any military program, obviously the system of governance will be completely hierarchical to reflect the military chain of command. This unification with the military has already become an obstacle to China's participation in international programs; it raises the question about whether the People's Republic actually wants to engage in international participation.

6. Non Profit, NGO Space Governance Model

A Non Profit, NGO Space Governance Regime has been initiated and maintained by United Societies In Space, Inc., a Colorado non-profit corporation with IRS 501(c)(3) public charity qualification. It introduced this mission at the Denver Convention of 2001 at the University of Denver Law School hosted by Professor Ved Nanda, Chairperson of the International Affairs Department. Since then a Regency of 50+/- Ph.D. level Regents has served to flesh out this model. It organized itself (O'Donnell; 2000, 2001, 2007) into a governance structure of a Legislature, an Executive Department, and a Court System, which was formally incorporated on June 11, 2011 at the Denver Press Club Conference as the International Space

Development Authority Corporation, accepting a type A merger from USIS of its Regency Program.

USIS/ISDAC's first important achievement was to pass and publish a Constitution for itself and all space governance participants. With respect to an interstellar expedition, its leading contribution may be to create a new society – a Starship Nation.

United Nations and International Space Laws

The background to all the models for Space Governance involves the United Nations agreements, treaties, and international space law. While the forms of government described above (with the exception of ESA) evolved largely – if not entirely – in a national context, each must come to terms with International Space Law. For example, if the nations negotiate a treaty banning anti-satellite tests in orbit as a means to forestall the growth of space debris that is hazardous to space navigation, no signatory would feel free to blow one of its own satellites to smithereens.

Under the United Nations and International Space Laws a spokesperson for the U.N. recently declared it to represent "Global Governance of Space Activities." This 46-page declaration covered motives for space activities by States, crowding of orbits, exploding population of Space Debris, frequency spectrum problems, and the economic sustainability by governments. Brachet (2009) notes that it concludes, "A better global governance is needed."

Specifically, this declaration is focused on the UN Committee On Peaceful Uses of Outer Space, (UN COPUOS). Its salient principal activities are providing a UN legal framework and encouraging developing countries to access space applications. In 2007, the UN General Assembly adopted resolution 62/217 endorsing the UN COPUOS guidelines on space debris mitigation. Space traffic management is being studied, GNSS is being coordinated, and space-based data and services in support of natural disasters are being assisted. At page 44, the author recommends other areas of Global Governance that should come before the UN COPUOS, such as:

- "Environmental protection on the surface of the Moon and other planets";
- "The possible concept of 'common heritage' sites to be protected"; (i.e., not used),
- "Developing an appropriate legal regime for resource extraction on the Moon and other celestial bodies, taking lessons from the Law of the Sea Treaty,"
- "Examine the legal implications of Commercial personal space flights and develop appropriate recommendations" and,
- "UN COPUOS has a role to play" (in this Global Governance).

For these reasons the authors foresee the equitable estate of space governance as likely to mature in good company with NASA contract law, the UN Treaty regimes, and International Law generally. For example, by treaty, the USA is liable for all damages rather than the astronauts, and this preempts domestic laws, presumably to the contrary.[1] This example shows how domestic and international law can grow entwined for Space Governance.

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[1] Convention on International Liability for Damage Caused by Space Objects, 1972. Article II, "A launching State shall be absolutely liable State shall be absolutely liable to pay compensation for damages caused by its space objects on the surface of the Earth or to aircraft in flight."

Space Governance and the Starship Mission

Examination of the role of Space Governance for an interstellar mission, and in particular, for sweat equity, can perhaps be best undertaken by starting with the more familiar and more detailed lower end of the governance hierarchy. From there, the analysis moves upwards to the lacework of contractual law that is needed for sweat equity, and finally up to the culminating stage of broadest mission governance, which should entail nationhood or the equivalent.

Vehicle Architecture and Operational Statutory and Regulatory Measures

There are several aspects of an interstellar mission that would require, or at least would benefit from, statutory or regulatory measures that have terrestrial analogs in building codes, fire codes, and local speed limits.

1 Artificial Gravity: The "Universal Antidote"

Gravity is the one constant. Since the evolution of life began over 500,000,000 years ago, everything else has been changing: atmosphere (composition, density, pressure), geology (plate tectonics, seismology, etc), climate, radiation, and tidal forces. Only Gravity has remained constant for "life as we know it." Given this history, why would designers of a long duration interplanetary spacecraft or a Starship expect the crew to get along without gravity?

Prof. Laurence Young at MIT characterizes artificial-G as "The Universal Antidote" for a host of ocular, cardiovascular, cognitive, metabolic, neurological, orthostatic, and physiological problems encountered in space. The National Academy of Science (Space Studies Board; 2000; p. 50) states:

> ***Need for Artificial Gravity***
> Amid concerns for the effects of low or variable gravity, it is important to keep in mind that technical means exist for supplying artificial gravity, and these should be explored by NASA, the purpose being not to make things more familiar, but to counter the real technical penalties suffered when body force is not available. The technical means include, but are not limited to, rotation to provide centrifugal body force. Rotation might be imposed on the scale of the spacecraft itself or on the smaller scales of components. . . . [Original emphasis].

There is an extensive and profound scientific (Vernikos, Schneider; 2009) and engineering (Hall, 1988-2009) literature on artificial gravity. This literature (Cramer; 1983) provides the baseline for an artificial-G habitat system with a diameter of 2km in a design that balances and limits centripetal acceleration, angular velocity, and coriolis effects. The fact that NASA downgraded the priority and ceased funding serious research into artificial gravity decades ago does not diminish its importance today (Space Studies Board, 2000, p. 170). On the contrary, as the Life Sciences learn more about the debilitating effects of prolonged exposure to the space environment, the battery of countermeasures becomes more important all the time. Recognition by codification into statute or regulation of the major changes in the interpretation of artificial gravity for a long duration interstellar mission will be necessary, particularly for a sweat equity model whereby the inhabitants will be expected to expand their own habitation and work zones.

2 Micrometeoroid, Dust, and Space Debris Countermeasures

Christiansen (2009) summarizes the history and status of micrometeoroid and orbital debris (MMOD) protective systems:

> Providing effective and efficient MMOD protection is essential for ensuring safe and successful operations of spacecraft and satellites. A variety of shields protect crew modules, external pressurized vessels, and critical equipment from MMOD on the ISS. Certain Space Shuttle Orbiter vehicle systems are hardened from MMOD impact, and operational rules are established to reduce the risk from MMOD (i.e., flight attitudes are selected and late inspection of sensitive thermal protection surfaces are conducted to reduce MMOD impacts) . . . . The development of low-weight, effective MMOD protection has enabled these spacecraft missions to be performed successfully. This handbook describes these shielding techniques. For future exploration activities to the moon and Mars, implementing high-performance MMOD shielding will be necessary to meet protection requirements with minimum mass penalty.

Christiansen concludes by asserting the importance of detecting micrometeoroid damage promptly, identifying the location, and applying leak-sealing repairs. What is probably more important is to avoid the impact with larger objects using advanced space radar, Lidar, digital scanning telescopes, and other systems of detection. If detected far enough ahead, it should be possible for the Starship to maneuver to avoid impact.

Protection against micrometeoroids consists of two main properties: the strength of the shielding material breaking or resisting the impact and the standoff depth of the protection. When a particle traveling at several kilometers per second hits the outer layer of sacrificial material known as a bumper or Whipple shield, it breaks up into smaller secondary pieces that continue traveling but spread out behind the “exit wound.” The strength of the protective material helps to determine the size reduction and number of these secondary particles. The depth of the protective shield until the particles hit the next material determines how widely they spread out, reducing the areal density of the kinetic energy release and damage in any one location, in accordance with the inverse square law. The conventional MLI absorbed the energy of the dispersed secondary particles by spreading out the secondary particles to disperse the impact over a much wider area (Christiansen, 2004, p. 17).

Protection against micrometeoroids in deep space will involve both aspects of these countermeasures. Outside the Kuiper Belt and Oort Cloud, it is possible that a conventional MLI approach may suffice, but there are new technologies involving other lightweight materials available such as aramid, aerogel, and carbon foams. The longer a habitat resides in deep space, the greater the risk of being hit by a larger particle that could penetrate the pressure vessel and cause damage and danger to life and mission. The larger the particle, the less practical it is to increase shield strength in a flight vehicle (applying regolith as shielding on the lunar surface is suitable only for a module that does not need to fly again). The more practical solution is combine avoidance maneuvers, to increase the “bumper” stand-off distance, and to strengthen the shields. A possible intermediate solution is to generate an electromagnetic force field that can repulse some particle sizes, especially if they include ferrous content such as the nano-phase iron as in lunar dust. Again, either on Earth and/or the Starship, these limits of required collision countermeasure parameters will need to be codified, particularly for areas of the starship subject to evolution or expansion under sweat equity.

3 Radiation Protection Required

The Committee on the Evaluation of Radiation Shielding of the National Research Council (on which author Marc Cohen served) summarized the hazards of radiation in their 2008 study, Managing Space Radiation Risk in the New Era of Space Exploration:

> Space is a harsh environment. Nevertheless, engineering technology is capable of protecting astronauts against vacuum, extreme thermal conditions, and micrometeoroid environments. Protection from radiation, however, is much less straightforward. . . .
>
> While the general climate of galactic cosmic radiation (GCR) varies predictably on an 11-year cycle, solar particle events (SPEs) are unpredictable, both in timing and character. Whereas the radiation hazard posed by episodic SPEs can be managed by providing sufficient shielding, GCRs pose a radiation hazard that is distinctly different: (1) GCRs are always present, and (2) their energy spectra extend to very high energies with sufficient intensity that the hazard cannot be eliminated by shielding. Moreover, both SPEs and GCR contain not only protons but also heavier nuclei (also known as HZE particles, for "high Z [atomic number] and energy"). Not enough is currently known about the biological effects of HZE particles. . . . (NRC, 2008, p. 7).

In the first sentence of the above paragraph, the Committee refers to the phenomenon that the intensity of GCRs varies *inversely* with the intensity of the sunspot cycle. At *solar maximum*, when sunspots are the most active the heavier flux of solar particles – the solar wind – counteracts and reduces the GCR flux. Conversely, at *solar minimum*, when sunspots are the least active, the weaker solar wind allows a heavier GCR flux. The Committee on the Evaluation of Radiation Risk continues:

> The health risks to be considered are of two kinds: risks to mission success and risks to health following a successful mission. The success of a mission is jeopardized whenever a crewmember is unable to perform his or her functions properly, if at all. In such cases, one or more of the mission objectives may be compromised; in extreme cases, the mission may be lost. In terms of radiation, the mission could be compromised by these short-term consequences or "acute effects," which may include headaches, dizziness, nausea, fatigue, and illness ranging from mild to fatal (NRC, 2008, p. 7).

Since 1972, the radiation research community has amassed a greater knowledge of space radiation and its risks for humans and electronics. In that time, the standards for allowable radiation exposure have developed much greater sophistication and conservatism than the minimal standards available in the 1960s. TABLE 1 illustrates this dramatic reduction in allowable exposure. The Committee continues:

> Risks incurred during a mission may also extend beyond its successful completion. . . . Radiation risks are of even greater concern, these risks—in particular the increased risk of fatal cancer—last for the entire life of the crewmember. Astronauts may also face other dangers, including cataracts, skin damage, central nervous system damage, and impaired immune systems. Although these effects are not immediate enough to be classified as acute, they have the potential to impact very long missions or an astronaut's future missions. . . .
>
> Radiation protection must become a matter of constant vigilance . . . (p 7-8).

In response to this severe threat environment, the Human Systems Integration Requirements, CxP-70024 states unequivocally in section 3.2.7.1.1, Radiation Design Requirements, Rationale that radiation exposure should be kept As Low As Reasonably Achievable (ALARA):

> Rationale: The radiation design requirement is imposed to prevent clinically significant deterministic health effects, including performance degradation, sickness, or death in flight and to ensure crew career exposure limits are not exceeded with 95% confidence. The ALARA principle is a legal requirement intended to ensure astronaut safety. An important function of ALARA is to ensure astronauts do not approach radiation limits and that such limits are not considered "tolerance values."

An interstellar analog to ALARA will be necessary no matter what societal model is used for the mission.

Solar Particle Events (SPEs)

SPEs are generally tied to the sunspot cycle (peaking each eleven years), when the sun puts out huge flares that release particle events consisting mainly of protons and some helium nuclei. However, individual SPEs -- and the solar flares that produce them -- are unpredictable and can occur at any time. These flare particles radiate from the sun in a wave front, but when they arrive at the moon or LEO, they behave locally like an omni directional swarm. The SPEs can be very intense, with the peak flux reaching five Sievert/day (500 Rem equivalent), which is sufficient to give an LD-50 lethal dose to the average human. For the lunar crew on the early short duration sortie and outpost assembly missions of 30 days or less, the SPE poses the greater risk compared to GCRs. The ESAS Report (NASA, 2005, pp. 109-112) proposed a dose of 4x the 1972 SPE as the maximum credible event for Constellation missions. The occurrence of such large flares is unpredictable; the NASA approach is to prepare for what they anticipate as the worst.

The effects of SPEs and required mitigation actions and regulations will depend in part on where in the solar system the Starship is constructed. However, no matter where the Starship initiates its voyage, when it arrives at its destination, SPEs will again become a major issue, especially if the target star is more active than the Sun. The interstellar medium is also not bereft of particle flux from stellar populations below the energy level of cosmic rays.

Galactic Cosmic Rays (GCRs)

The GCR flux is relatively constant, and constitutes a potential long-term threat to the health of insufficiently shielded astronauts. For this reason, GCRs pose a more certain risk of radiobiological damage to the crew in a long duration of 180-days or more than the unpredictable threat of an SPE. Hoffman, Pinsky, Osborne, and Bailey report that one of the ubiquitous effects of GCRs is the experience some astronauts had with light flashes from charged particles when their eyes are closed. Hoffman, Pinsky, Osborne, and Bailey (1977, p. 127) and Edward Gibson (Gibson, 1977, p. 25) recount these phenomena. They create a basis for concern that these transmitted particles could cause damage to the optic nerve or other parts of the brain and central nervous system. Again, acceptable levels of GCR exposure may need to be legally codified during the development phase and the interstellar mission itself to prevent as much as possible any deleterious effects on the inhabitants.

Radiation Exposure Limits

Since the Apollo era, the allowable radiation exposure limits have been decreasing steadily, with no stopping point in sight. These decreases in allowable exposures mean greater requirements to shield and otherwise protect the crew from ionizing radiation. TABLE 2 shows the historic changes in allowable exposure limits to the benchmark Blood Forming Organs (BFO) from the Apollo era to the present decade (Townsend, Fry; 2002). The BFO are the bone marrow principally in the femurs and pelvis, and secondarily in the ribs and other bones. Severe exposure to the BFO can cause radiation-poisoning leading to death. Exposure to the BFO and nearly all other organs can cause increased risk of cancer. (Note that the SI unit of one Sievert = 100 Rem of absorbed dose.) From 1989, the National Council on Radiation Protection (NCRP) rates career exposure limits by age and sex. The newest NASA standard, the Human System Integration Requirements (NASA CxP 70024) adopts the NCRP increment for 35 years of age as its metric, so that is the one used here. The "3% excess risk of cancer" is a commonly cited metric for increased cancer risk in space crews. In the 2000 NCRP limits, "Gray Equivalent (Gy-Eq) is used instead of Sievert as the unit to express dose limits for deterministic effects . . ." (Townsend, Fry; 2002, p. 962).

These radiation exposure and dose units are somewhat of a moving target, having been changed at least three times since the Apollo era. NCRP Report No. 153 (2006, p. 100) establishes Gy-Eq as the current unit of measure, and NASA is now applying it to all its radiation studies and precautions.

TABLE 1 shows that the 30-day allowable exposure limits have been reduced only 40 percent (from 0.25 to 0.15 Sv for a 35 year old) since the 1970 NAS/NRC study for Apollo. Meanwhile, the ***career limit*** has shrunk more substantially, by approximately 80 percent (from 4.0 Sv for any astronaut to 1.0 for a 35-year-old male or 0.60 for a 35-year-old female). In addition, the same numerical value for Gy-Eq units for incident radiation *exposure* generally means a lower radiobiological dose than the *absorbed* dose in Sv.

The preferred method of radiation shielding is to employ low-Z (low atomic number) materials. Hydrogen is the optimal shielding material, but it is difficult to provide it at high density. Boron, carbon, and oxygen are also suitable low-Z materials. Polyethylene is often considered the most practical material because it is solid, rigid, non-toxic, and workable at ambient temperature and pressure. The ideal construction is where all the materials work together in a multifunctional wall in which all contribute to radiation protection, micrometeoroid shielding, thermal control, atmosphere containment, and perhaps even power generation. The dream of a future technology is an electromagnetic field that would capture or repulse these charged particles, provided it did not drain too much power or affect the humans and electronics within it. Like all the other safety-related human factors parameters, codification of radiation exposure levels in something akin to a Health Code for the Starship will be necessary.

4 A Starship Speed Limit?

Velocity is at a premium to complete the interstellar voyage during the lifetime of the original crew. However, there are potential obstacles and hazards associated with departure and arrival in the threat of MMOD. The cluttered environs of the solar system extend to the exterior of the Kuiper Belt with its minor planets at 55AU. Beyond the Kuiper Belt, the Oort Cloud extends to about 50,000 or 100,000 AU – roughly one light year and nearly a quarter of the distance to Proxima Centauri. Until the Starship clears the Oort Cloud, it may not be advisable to ignite its relativistic velocity engines because it will need to be able to maneuver to avoid abundant objects as large as several kilometers.

This Solar System hazard zone suggests a speed limit until the Starship reaches the "autobahn" of true interstellar space. In approaching the new solar/planetary system, the Starship will need to decelerate not just to come to a stop but also to navigate the corresponding cometary, minor planet, and asteroid belts safely.

It is perhaps ironic that in traveling the furthest from our terrestrial confines, at the fastest conceivable speeds, we come back to that most quotidian of laws: the speed limit. Yet for mission safety, some form of speed limits, will become necessary, particularly if solar system infrastructure and transport is built up by the time the starship mission embarks.

5 Procedures For Alien Contact Must Be Required By Law

At first blush, discussions of alien contact may appear extremely speculative, particularly when it comes to codification into law. Yet, at one time, the prospect of a starship was nothing more than the figment of creative imaginations.

Mr. Steven S. Doyle, Esq., long-time American Representative to the International Astronautical Federation's International Institute of Space Law, dedicated a large portion of his official energies to advocating for a UN adopted special procedure regarding any and all alien contact. The dangers of miscommunication, lack of understanding, and irrelevant replies could have damaging consequences. His plan was to channel all alien communication to the office of the UN Secretary General for further distribution to six standing committee Chairpersons in the UN affiliate IAF for evaluation and decision on how to reply, or not to reply. This valuable proposal has not yet been adopted formally at the UN.

Some higher degree of urgency for such a plan is recognizable when nations, corporations, and individuals commence long-term interstellar voyages, perhaps in different directions. For example, all vessels so contacted should stress the peaceful purposes of such vessels equally. Beyond that, there are many safety and societal concerns to be considered.

Table 1. The Reduction in Allowable Human Radiation Exposure Since the Apollo Program

Standard or Guideline	30 Day Limit	Annual Limit	Career Limit
NASA SP-71, 2nd Symposium on Protection Against Radiations in Space, 1965	200 Rad (2 Gray) from one acute exposure from an SPE	55 Rad (0.55 Gray)	-
Apollo Maximum Operational Dose (English et al, 1973, p.3)	0.50 Sv (50 Rem) from an SPE	-	-
NAS/NRC, 1970	0.25 Sv (25 Rem)	0.75 Sv (75 Rem)	4.0 Sv (400 Rem)
NCRP, Rpt. 98, 1989, 35 years of age.	0.25 Sv (25 Rem)	0.50 Sv (50 Rem)	1.75 Sv female, 2.5 Sv male
NCRP, Symposium Proceedings No. 3, 1997, 35 years of age: 3% excess risk of cancer.	-	-	0.9 Sv female, 1.4 Sv male
NCRP Rpt. 132, 2000, 35 years of age.	0.25 Gy-Eq.	**0.50 Gy-Eq.**	**0.6 Gy-Eq. female,** **1.0 Gy-Eq. male**
NASA HSIR CxP 70024C, 3.2.7.1, 2009, p. 75. Effective (Integrated Body) Dose	**0.15 Sv from an SPE**	-	-

For the even-handed protection of all such voyagers a pre-set plan for handling alien contacts and communications is paramount. Once the experts in this field on how to organize this activity, ISDAC may be expected to enact a reasonable procedure for all to follow, how to communicate, and who to contact for advice on what to say. Of course, for an interstellar mission, concerns over alien contact work both ways. On the one hand, the starship mission will likely require the legal equivalent of the famed Star Trek Prime Directive to avoid contaminating autochthonous life forms.

Conversely, the starship may require protective procedures, encompassed in the form of laws akin what has been proposed to the UN, against contact *from* a superior alien life form. And unlike almost any other aspect of the starship mission, where distance ensures the hermetic, autonomous nature of the expedition, with virtually no effective command or control from Earth, potential contact with a more advanced alien species may pose threats to the home world itself. If an interstellar spacefaring species exists, it should have the capability of tracking the starship back to its point of origin, with dire implications for Earth if this species is unfriendly. Thus, well-constructed first contact procedures will be of the essence.

6 The Education Institution

Nothing may be more ubiquitous on Earth from a governance perspective than the requirement and right to childhood education. Though often handled and governed at a local level, this right is effectively enforced at the highest level of national laws. Thus, education bridges the lowest rung of the governance hierarchy and that of the next levels, where individual rights and obligations and their implementation and management through society as a whole, are enshrined.

Institutions onboard interstellar vessels must tie in with all voyagers and sponsor appropriate and required education programs for each of them. The unique and most important feature here is the continuing education required for all adults onboard the vessel. This important adjunct to the traditional educational structure is justified because so much new information will be developed as the voyage matures, particularly in a sweat equity mode where much of the responsibility for the evolution of their habitation will fall on these voyagers. For a multi-generational mission, the current distinction for terrestrial transport systems between crew and passengers will be largely extinguished. The passengers, or better, the inhabitants and their descendants, will be the crew, to the degree that the starship is not completely automated, and this tendency may be heightened by a sweat equity model.

In addition, uninformed travelers will heighten the risk of mistakes that may affect all. In the event of a crisis, like penetration of the hull, a well-trained and educated crew is needed to respond, without fear and panic. In continuing universal education, for adults will be invited to teach sessions in which they have an interest and express their thoughts to their peers. ISDAC first endorsed this concept of continuing adult education in the outer space arena in 1998.[2]

The interstellar crew would need new training and learning technologies that would allow for the diversification in the skill base of each individual. These new technologies could be cognitively and perceptually focused training techniques, incorporating extrapolations of present expert systems and virtual reality. Some training tasks might be delegated entirely to computers

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[2] Raygoza, Jesus, “Space Continuing Public Education”, Space Governance Journal, 1998, p. 80.

or robots, but much of the training responsibility would necessarily devolve upon the crewmembers (inhabitants) themselves.

The crew will need to maintain two general classes of skills. Class One are the skills that the crew can practice and utilize while in transit, such as medicine, computer science, biology, chemistry, hydroponic/aeroponic agriculture and certain kinds of engineering, manufacturing or crafts such as mechanics or welding. Classes Two are those skills that the crew cannot practice effectively until they reach the target planet. These skills include farming, mining, drilling for petroleum, logging, civil engineering (dams, roads) hydrology, etc. — skills having to do with the exploitation and processing of natural resources. How would one teach farming to someone who has never stood on a planet or seen dirt? Expert systems and virtual reality could only take one so far at a conceptual level. At some point, people must experiment with their own attempts at new solutions. The sweat equity concept provides a means for the voyagers to expand their habitation zones in a fashion conducive to getting this experience prior to landing on their destination. But since the spacecraft will likely be largely self–sufficient, the crew should have time to experiment on their way to their destination.

Interstellar Sweat Equity and Space Governance

Even if sweat equity is not embodied in the project plan from the very beginning, the point at which an overall design philosophy is established and the logistics of the operation is analyzed introduces the first questions that couple *sweat equity* with the Space Governance necessary to make it feasible:

- Who owns the supplies, the equipment, indeed – the Starship itself?
- If an Earth-bound corporation, NGO, government or other entity owns the Starship, what does that ownership mean after it passes heliopause on a one-way trip?
- In what manner is property owned on the Starship?
- Does a collective, communal, or corporate entity own the whole configuration?
- Are the crewmembers initial equal shareholders in that entity?
- Can they buy and sell their shares?
- Does the "corporation" (for lack of a better term) start out owning all the shares that the crewmembers and their families can earn through their labor over the multigenerational mission?

The design of the Starship requires that it be capable of growth and expansion to keep pace with the growth of the population. Expansion raises the next set of questions and underscores the importance of Space Governance:

- Who owns the expanded areas that did not exist for ownership before departure from Earth?
- Do they belong to the people who work on building them, to the people who live in them, to the people who provided the materials and equipment, or are they held jointly in a cooperative or condominium?
- If the crew members develop their own new and improved techniques for customized additions, who owns the intellectual property for this know-how?

- Since the construction industry is no stranger to labor disputes, how will the crew handle such disagreements?
- Can they form a union?
- Would this union own a share of the "means of production" or its products?

Once arrived and settled at their new world, settlers should expect to receive at least part of their share of the "profits" in the form of resources and capabilities unloaded from the Starship: equipment, finished materials, food growth capabilities, including seeds and tools, or resources of their new planetary environment. The latter might take the form of the potential distribution of equity via the land that people could claim under a form of homesteading. All the questions and issues listed above now get transferred to the surface of the new planet.

All these economic activities and property apportionment will depend upon a successful implementation of Space Governance at the level of contract and real estate law that the new electorate accepts as fair, just, equitable, and what is most important: their own. Most likely this should and will follow the centuries-old precedents of Common Law, but the new residents must have legal scaffolding available to them to choose their own way and their own methods, given their likely permanent separation from their birth world

Interstellar National Governance

The combination of United Nations treaties, domestic space law and policy, and a growing space governance movement based on equitable precedent, may be expected to provide the groundwork and framework for a relevant and unique government for the benefit of those traveling in space generally, and for particular comfort to those who care to engage in interstellar voyages. No other mode of coordination can be relied upon. No other agency can enforce rules and statutes, provide a legislature for space related issues, and maintain a court system to settle disputes peacefully. Without Space Governance by a respected equitable Authority, the interstellar mission may become doomed to anarchy or tyranny.

That Authority is most naturally that of a nation. Lower-level governmental entities such as cities, states, or provinces possess much of the governance and legal apparatus that will be required for this mission. However, the fusion of the three branches of government (at least in the American model) --characterized by separation of powers and a powerful Constitution with its guarantees for human rights -- is best bestowed on nations. This Constitution provides the scaffolding, upon which the more detailed Common Law of a community may effectively function, plus an ability to establish equitable and legal relationships with external entities and powers,

In the sense of being standalone, of being autonomous and self-deciding due to no effective communications with Earth - and certainly if alien life should ever contact the intrepid adventurers - all the manifestations of a nation are present. Small size is not necessarily a bar to this status either. There are tiny, sovereign nations on Earth that by population are approximately the same sizes as an O'Neill expedition. If the much smaller mission proposed herein is chosen instead, then desired population growth should eventually lead to similar sized community.

Sound Space Governance, establishing an equitable legal framework for the mission, and even (or especially) in the preliminary stages before launch, will be necessary no matter what model is chosen. But the demands of and questions raised by sweat equity, as outlined above, make it all the more imperative. Without the highest-level conceptual and operational legal constructs in place, functioning and well understood by those they serve, sweat equity turns from a major advantage to a potential disaster.

ISDAC inherits from its predecessor a legal and governance structure, complete with Constitution, designed to provide just such functions and service for solar system exploration, exploitation, and settlement. The venues of the solar system and exoplanets and the nature of the missions to them are very different. For one thing, the legal issues revolving around the equitable exploitation of solar system resources by and for humanity as a whole should largely not arise for an interstellar mission because that mission will be decoupled from Earth. However, the governance mechanisms are in place and should be adaptable and evolvable for the needs of an interstellar mission.

Conclusion

For interstellar travel to be realistically feasible from a human factors perspective, a Starship would need to attain a speed of at least .05c, to arrive at Proxima Centauri in 80 to 100 years of multigenerational travel. To be financially viable, the initial crew size would not exceed 100 souls. However, the interstellar spacecraft would be designed to accommodate expansion or "filling–in" during interstellar transit, which would allow for natural population growth to 400 or 500.

Probably the most important human factors consideration will by the design of the organization that organizes the interstellar mission. Among the critical human factors technologies for this interstellar mission will be habitability, crew selection and crew training. Crew training will involve a range of perceptual and cognitive aids to learning, including the heirs to expert systems and virtual reality.

The long-term success of the interstellar migration will depend on human motivation and the provision for human creativity, discovery, inventiveness, and serendipity. The key to sustaining this motivation and the economic self-interest that would underlie it is interstellar sweat equity. Sweat equity share means to develop and support a system of interstellar equity sharing in which the multigenerational crew builds a stake in the economic and technological success of the mission, not just during the 80 years or so of the journey, but upon arrival and settlement on the new planet.

Inextricable from the sweat equity mode is the governance and legal framework, closely associated with nascent nationhood, that will permit the development and operation sweat equity mission model to proceed in an orderly, equitable, and ultimately, successful fashion for the many generations it takes to construct the starship, voyage to a new star, and settle an exoplanets.

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