Virgin Galactic craft crosses threshold of space

Though it did not reach orbit, the flight was the first launch of a spacecraft from U.S. soil with humans on board to reach the edge of space and it effectively opened a new era in human spaceflight.¹

Don’t get me wrong. I’d love to visit Mars!... But the reality of Mars makes the old American West look like a tropical paradise. There’s no oxygen, little to no water, frigid temperatures, fine-grained dust everywhere, no food, no easy way home. Mars will be the most barren, inhospitable, violent, unforgiving frontier that humans have ever encountered.² Planetary Scientist Jim Bell.

The irresistible urge of humans to expand their current competence in mastering the environment is nowhere more apparent than the attempt to conquer space and colonize other worlds. The promise of an expanded universe for earth’s life forms is irresistible. It is driven by positive and negative forces: among others, devastating climate change (and irreducible disagreements on the measures needed to reverse it), the threat of nuclear conflicts that will make huge segments of earth uninhabitable, and the possibility of harvesting precious resources on other celestial bodies. The questions that arise involve the selection and preparation of humans for life in other worlds but equally important, a consideration of the practical, moral, and ethical issues that arise in our exploiting novel environments. Our ethical deliberations should not only focus on the consequences of space travel for the astronaut, but just as responsibly on our impact on the geophysical features and life forms we encounter in the new worlds we explore and manipulate.

It is worth remarking that the push to explore other worlds (such as the proposal for human colonization of Mars in the next few decades) is regarded by some as yet hopelessly deficient in an adequate understanding of human physiology, and the vulnerability that makes individuals unequal to the harsh challenges of space. Anthropologist Rayna Slobodian mounts a cogent argument for remaining solidly earthbound, at least for the present; she correctly points out that the data on the impact of the unique environments astronauts will encounter although abundant and exponentially expanding, are still inadequate to adequately mitigate the dangers of space travel. She advocates ethical advertising in “selling space” to the public.

The way in which the space industry hides (at times without even knowing it) the full extent of the risks for Mars missions with humans involves...romanticism, utopian ideals, lack of cognitive awareness, and fear-based selling...The rush to settle is dangerous and careless.³

The notion that life on other planets would produce utopian communities miraculously free of all the evils that beset human interactions on earth is not only undocumented, but given human history, improbable. Equally important, the completely unfounded conviction that longer lives and even immortality would be realized in other environments as Slobodian puts it, “goes unexamined.” As exciting as the accounts of our recent excursion beyond earth’s space seems pursuing human colonization of space might end in unanticipated disaster.

Nevertheless, the momentum of the urge to visit and conquer space is irresistible. The science of which humans are best suited for the adventure was fueled more than any other factor by the deciphering of human genomic structure in 2000 to 2003—arguably the most important development in human history. Once we understood the genome’s composition, we rhapsodized, we could study its function, copy it, change it to modify the phenotype, and ultimately develop entirely new forms of life. New iterations of life forms no longer depend on random genetic mutations; current technology continues to develop that enables us to modify the very composition of the individual genome. Some of these modifications are inheritable. The new science is expanding exponentially, and in most cases, ethical questions and regulatory imperatives lag far behind what we are increasingly more able to achieve.

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In selecting humans for travel to and eventually exist for prolonged periods in the entirely new environments beyond earth’s atmosphere, we have already extensively exploited the techniques of personalized medicine to characterize the suitability of individuals for such an adventure. In an important review, Schmidt and Goodwin emphasize the uniqueness of individuals and advocate the use of Omic methodologies (genomics, transcriptomics, proteomics, and metabolomics) to more precisely assess individual persons for their competence and/or vulnerability for proposed voyages. They summarize the importance of personalized assessment of each individual traveler:

There are vast molecular networks that interact dynamically to influence astronaut susceptibility to any specific environment or condition to which he or she is exposed. Second, there are a series of mission stressors that impact heavily upon the individual susceptibility of each astronaut. Whether one thrives within the space environment may be heavily dependent upon individual susceptibility, space environmental exposures and whether the countermeasures deployed for an individual astronaut are sufficient to overcome these susceptibilities.

A representative example of the hazards of living in space is illustrated by the finding that about 20% to 25% of people stationed in the International Space Station for over 4 months developed persistent ocular problems. Their vulnerability was attributed to the state of their 1-carbon metabolism, which involves the transfer of methyl groups from donors such as folate, B12, and choline, all provided from dietary sources. Genetic polymorphisms in key methyltransferase genes can lead to significant vulnerability; 1-carbon metabolism is intimately involved in chromosome stability via direct effects on DNA. The implications of this become critically important: during a 360-day transit journey to Mars, every cell in an astronaut’s body is exposed to radiation at levels that correspond to a 3% risk of cancer.8

The NASA Twins Study yielded a comprehensive collection of omics information on the impact of life in space on human function. Scientists compared data from one of monozygotic twins who spent a year in the International Space Station with those of his brother, who remained on earth.9,10 Significant differences between the twins in lipid metabolism, telomere and telomerase behavior, cognitive function, microbiomic composition, bone metabolism, and inflammation were documented. Genomic studies revealed more than 200,000 RNA molecules that were differently expressed between the twins. Of interest was that telomere length returned to normal within 2 days of the space-twin’s return to earth. While 93% of his genes returned to normal after landing, 7% did not and may underlie long-term changes in genes related to his immune system, DNA repair, bone formation networks, hypoxia, and hypercapnia.

One of the most important issues in screening space travelers for their ability to endure flight and long-term stays in novel environments is that the phenotype might be quite specific for each voyager. Given the complexity of what the pursuit of personalized medicine has already demonstrated, truly informed consent for the individual prospective traveler is obviously impossible: our assessment of precisely what features of an individual’s molecular biology are essential to assess and what reactive measures might be taken to minimize vulnerability is obviously still very much a work in progress.

In view of the increasing sophistication and variety of techniques for genomic manipulation, one might speculate that genomic tailoring might be an acceptable tool for making existing life forms, including humans, more suited to the unique demands of novel environments. A thorough understanding of the consequences of such a manipulation, an assessment of whether it will be accurate, that is, work as planned, is not only essential, but in the case of humans, a nonnegotiable element of informed consent. Whether or not genetic/epigenetic tailoring of humans for optimal function in novel environments is moral is essentially unexplored,11 but it will certainly become technically possible in the future. Ultimately, through the techniques of manufacturing de novo genomes, entirely original species of life might be created for survival in the unique environments we will encounter in space exploration. The ethical and moral considerations involved concern not only how we achieve these goals, but the impact of our designs on the environments of celestial bodies we will eventually visit, inhabit, and populate.

In constructing a system of ethical guidelines for the screening and preparation of humans for travel to and life in space, Cooper presents an in-depth discussion of several points:12

- Whose ethical system do we use, and how do we adapt to changes in those systems over time?
- How do our own moral and ethical systems compare with and intermesh with other collaborating organizations/cultures/individuals?
- What is the design of the organizations that survey and sustain ethical conduct?
- Should all individuals in a society be treated equally or should ethical standards be differently applied to diverse populations?

An excerpt from the executive summary of the accident report when Columbia exploded on February 1, 2003, illustrates the importance of global interaction and agreement between different cultures and organization involved in a project.13

The organizational causes of this accident are rooted in the Space Shuttle Program’s history and culture... Cultural traits and organizational practices detrimental to safety were allowed to develop, including: reliance on past success as a substitute for sound engineering practices, organizational barriers that prevented effective communication of critical safety information and stifled professional differences of opinion, lack of integrated management across program elements; and the evolution of an informal chain of command and decision-making processes that operated outside
the organization’s roles (Columbia Accident Investigation Board 2003).9

Summary
The use of a detailed map of the functional human genome in analyzing individual phenotypic competence for space travel and ultimately for the colonization of space is the essential first step in ensuring safety and ultimate survival in new worlds. Although progress in perfecting the accuracy and completeness of personalized medicine has been enormously impressive, we are clearly not yet ready for the colonization of novel environments like those of the moon or Mars. Robotic surrogates might provide a partial solution to exploiting/exploring such celestial bodies. We should begin to consider in earnest the interesting issues of genetic modification of existing life forms and/or the creation of entirely new living species through the assembly of synthetic genomes for life beyond our own planet. Inevitably, we will develop those competencies. Clearly, the momentum behind conquering space with the ultimate aim of exploiting other worlds is on our agenda and irrevocably moving forward. Whether the motivation for that movement is soundly anchored in realistic concepts of what space colonization will yield and whether the steps we take to achieve it are morally and ethically sound should be topics for serious debate. Finally, we should prepare for meticulous surveillance of how our intrusion into other celestial systems will impact not only the geophysical characteristics of those systems but of the life forms that exist there. Regarding the latter, the value we place on those life forms is an important consideration; traditionally, we have used ourselves as the peak of evolutionary development and judged the importance of other living entities by how closely they resembled us. We have pro-

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