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Microscopic Astronauts: Engineering Bacteria to Aid Human Space Travel

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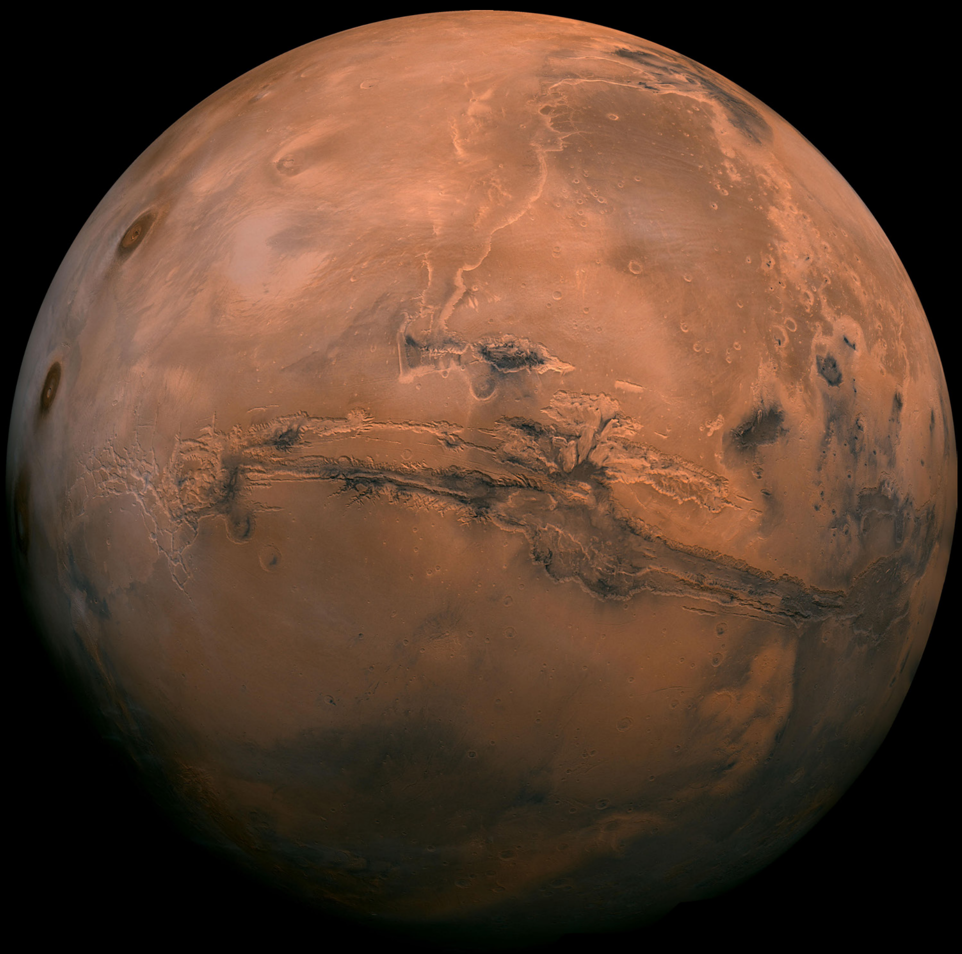

BY ANDERSON LEE

On February 18th, 2021, NASA's rover, "Perseverance," and its mini-helicopter, "Ingenuity," landed in the Jezero Crater on the surface of Mars. Percy and Ginny, as they are colloquially called, are the most advanced robots ever sent to Mars. Soon, however, we will be sending something less durable, more variable, and *much* more valuable: humans.

Supporting human life inherently makes this mission more difficult: people need food, water, and oxygen. The waste produced—carbon dioxide and physical excrements—must then be recycled or discarded into the environment.

The long-term viability of humans in space also raises concerns. Exposure to radiation and zero-gravity environments will alter DNA and break down tissue, posing a myriad of health problems during a multi-year mission. Bringing medicine along is problematic because many drugs will expire before the end of the mission.

In order to address these biological concerns, NASA has started to employ biological technologies. When mixing the realms of space travel and biology, *The Martian* and Matt Damon's potatoes tend to be on the forefront of people's minds. Plants, however, require room to grow, soil, and water, and most of the biomass produced is either nutrient sparse or inedible.

Instead, scientists are now focusing on edible bacteria. Many species of bacteria (and other microorganisms) produce biomass full of proteins and vitamins.[1] These bacteria don't take up much space and are relatively simple to genetically engineer. Scientists are engineering bacteria in new ways to address the unique challenges of space travel.

Scientists are employing a technique called metabolic engineering in order to optimize bacteria to meet the demands of space travel. At a broad level, metabolism in plants and bacteria is similar to that in humans: they break down food and modify it to make energy. You can think of metabolism as a collection of many overlapping pathways, each composed of sequential steps in which an enzyme—a protein machine—converts one molecule into another. Each of these steps produces byproducts in addition to energy, and it is these byproducts that are potentially useful.

Different enzymes can bind to the same molecule and produce different products. Researchers can genetically engineer bacteria so that so that specific enzymes are present or absent, changing the final product of metabolism. This is when scientists can start using their creativity: from producing essential vitamins to making plants taste better, the possibilities of metabolic engineering are only limited by our knowledge of nature and our ability to manipulate it.

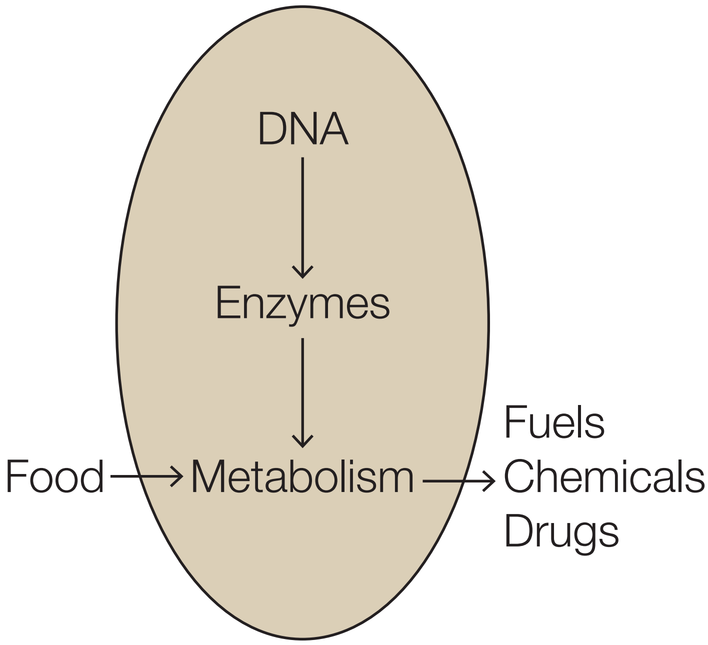

Figure 1: Overview of the metabolic process. *DNA encodes for enzymes, which turn food into specific molecules by the metabolic process.*

The Center for Utilization of Biological Engineering in Space (CUBES) showcased their creative ideas in a review focusing on the biological production of useful compounds. Acetaminophen, the active ingredient in Tylenol, is one such example. Producing common medicines like acetaminophen on demand is critical for long duration missions because their shelf life is shorter than the length of the trip.[2]

The production of therapeutics by organisms, known as molecular pharming, could also include cytokines, molecules that the immune system uses to communicate. Astronauts could eat the bacteria containing these molecules to counter the short-term effects of radiation sickness and the long-term effects of exposure to radiation, such as cancer.[3]

Bacterial production in space extends beyond pharmaceuticals—photosynthesizing bacteria could uptake the carbon dioxide produced by humans and recycle it into breathable oxygen. They could also be metabolically engineered to grow off of the compounds present in the Martian soil or human waste, creating a closed-loop life support system.[1]

> "From producing essential vitamins to making plants taste better, the possibilities of metabolic engineering are only limited by our knowledge of nature and our ability to manipulate it."

The disparity between theoretical plausibility and dependable technology, however, spans many years into the future. So far, the vast majority of metabolic engineering has been focused on creating biofuels to address the need for alternative energy.[4] A select few model organisms have been extensively characterized in the interest of biofuel production, but scientists can apply this already acquired knowledge to the context of human space travel. This application makes photosynthetic and edible organisms valuable so that they can be grown easily and their products don't have to be extracted.

In 2012, molecular pharming became a reality when a company received FDA authorization to sell a therapeutic protein that was made in plants.[5] This marks the first biologically-produced medicine with FDA approval, demonstrating molecular pharming's plausibility here on Earth and out in space.

Figure 2: Fred Haise, Apollo 13 astronaut, suiting up for his mission. *The urinary and kidney infections he struggled with during the trip could be prevented by growable antibiotics in the future. In the public domain.*

"One day, we all might be growing Tylenol next to our tomato plants."

The challenges facing molecular pharming and metabolic engineering in general are undoubtedly more daunting in space travel than on Earth. When an organism is genetically edited to make a product, its number one priority is survival, not producing whatever compound scientists are interested in. In space, these organisms will likely be under stress due to the different environmental conditions, like the lack of gravity. Consequently, they might produce less of their desired product, wasting precious energy in the process.

Additionally, the power of replication is coupled to the problem of mutation. If a mutation causes a critical enzyme to stop working, that cell will no longer be able to produce the desired product. On top of that, this cell will not experience the metabolic burden of producing its biologic, so it could out-compete the other, non-mutated cells and take over the culture. Other challenges include simply keeping the bacteria alive during the arduous trip—something that is currently being investigated on the International Space Station.[6]

If all of these problems are addressed, what would this system look like on a Mars trip? Ideally, cells would be genetically engineered, frozen, and stored in small, labeled tubes. When needed, a tube could be removed, thawed, and grown up into a large culture that produces significant quantities of its biologic. Though it will be a while until this technology is completely developed, preliminary missions could harbor these engineered cells as a worst-case scenario, à la Matt-Damon-stranded-on-Mars.

This technology will likely not be exclusive to spaceships and research labs. Scientific research meant for space travel has already infiltrated normal life, including innovations like Tempur-Pedic mattresses, cell phone cameras, and LASIK, along with many others.[7] One day, we all might be growing Tylenol next to our tomato plants.

The future of human space travel lies within the powers of biology; the natural problems that organisms pose have natural solutions. The terraformers of Mars will be a blend of astronauts—human-sized and microscopic—working together to start exploring the universe.

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