SPACE

The Next Twenty-Five Years

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Space is only a hundred miles over our heads, about the distance between New York City and Philadelphia. Yet it has taken us millions of years to cross that distance. In the next century, I expect, it will be as routine to travel there as it is today to shuttle back and forth between two cities.

Space is, as Star Trek's Captain Kirk said, the final frontier. It is where the answers to many of our problems lie. It is where our industry ought to be focused, to free this planet to be the paradise it should be.

It is a place of unlimited resources, which we can harvest without harming the Earth's environment. It is a place where medicines and new materials can be manufactured. History shows the steady flow of humanity to habitable, commercially useful places and the incessant enlargement of cities, strongly suggesting that space is a place where many of us will live in the 21st century, some of us for a few

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There are two futures, the future of desire and the future of fate, and man's reason has never learnt to separate them.

—J.D. Bernal, scientist
People often think the U.S. is spending far more on space than it is. The budget of NASA is now about $10 billion per year, including the cost of replacing the Challenger. Compare this figure to a few other spending figures for 1986: $18 billion on international affairs, $269 billion on social security and medicare, or $286 billion on defense. About one cent in every tax dollar goes to the civilian space program.

The Near Future

For the near term, we have to make some important decisions about the future of the American space program. Since the Apollo program, NASA has had few long-term goals. Scientists, futurologists, representatives of ordinary citizens, and members of industry need to come together to form specific targets for the program.

We need to decide how much the country can afford to spend on space, bearing in mind that research has almost always more than paid for itself in its returns to society. Since the piloted space program seems popular enough to continue funding, we need to be sure that a healthy program of space probes is not lost in the budget debates over the Shuttle program and Space Station. We should try to keep the unpiloted program at a steady level, instead of letting it rise and fall so greatly that it drives skilled people away from the NASA centers.

We need to decide how much will be done at the taxpayers’ expense and how much by private citizens, through industry. There has been a tendency until recently for NASA to try to do almost everything.

We Americans suffer from too much data, too many facts, at times. We are bombarded by it on our television. One of the problems we’ve had the last few years, that NASA has had, is that we have seen almost too much space and have seen the wrong kind. We have been given the facts over and over again, and they are always diminished by what I call the aesthetic of size. Television diminishes everything it touches and makes it small. It takes a rocket that is 300 feet high and crushes it down to a 14-inch image.

—Ray Bradbury, author
and it's healthy to transfer economically sound parts of the program — such as communications satellites — to private industry, where competition will keep costs down. And we need to eliminate governmental obstacles to private space programs.

Many of the answers depend heavily on what we really want to do in the long run. The design of the Space Station will be determined by whether we want to use it for industry, or for scientific research, or for preparing for a lunar outpost, or for an asteroid mission, or for a human mission to Mars.

We need to involve our international colleagues more in these decisions, since such collaboration can greatly reduce the cost to the American taxpayer. The Japanese and the Western Europeans are determined to be involved in space research, and are willing to spend billions to help us build the Space Station.

Those two factions have also developed their own rocket-launch facilities in Japan and in South America. The Chinese and Russians, of course, have their own, too: Brazil is also starting to launch orbital rockets. This worldwide growth in space capability guarantees that competition will keep costs coming down, and soon no one disaster will be able to slow down space development as drastically as the Challenger did.

The Soviets have indicated their willingness to cooperate on certain projects, possibly including a joint human mission to Mars. We must take advantage of this opportunity to combine Western and Soviet strengths, reducing the cost of scientific exploration for all.

Individual citizens can help make these decisions by writing to their congressmen. So few letters are received on most subjects that a letter supporting a particular space project, or space exploration in general, will have much more impact on a congressman than you might expect.

The disaster of the Challenger explosion has given us an unusual opportunity to make decisions in a period of calm.

The U.S. needs to have a steady, long-term plan for space exploration and use, though it must be flexible enough to allow for scientific discoveries that change the direction of research, and for inventions that change the way we build our space vehicles. Instead of jumping this way and that, depending on our disasters or Russia’s successes or the political mood of the moment, we should have a program to explore the solar system systematically with robotic probes, revisiting the most interesting places that we found during the first generation of space exploration. To me, the most important robotic projects not yet funded are: a lunar polar orbiter to detect water on the Moon; a Mars rover to search for evidence of past or present life there and to pave the way for a human expedition; and a Titan probe to explore that extraordinary moon.

We should not neglect conventional astronomy, and should build Earth- and space-based observatories to systematically cover all sources of information about the universe that we are aware of: the electromagnetic spectrum, cosmic rays, neutrinos, and gravitational waves.

We need to have some practically oriented research to lay the foundations for a space industry that can gradually be taken over by private companies without further taxpayer expense, returning to the economy the benefits of space in much the way that research on microelectronics has created employment and profits for many.

We need to decide our next major astronaut missions. Shall we go back to the Moon, or to an asteroid, or to Mars? At this time, we can-
RATIONALE FOR EXPLORING AND SETTLING THE SOLAR SYSTEM

The Solar System is our extended home. Five centuries after Columbus opened access to “The New World” we can initiate the settlement of worlds beyond our planet of birth. The promise of virgin lands and the opportunity to live in freedom brought our ancestors to the shores of North America. Now space technology has freed humankind to move outward from Earth as a species destined to expand to other worlds.

The settlement of North America and other continents was a prelude to humanity’s greatest challenge: the space frontier. As we develop new lands of opportunity for ourselves and our descendants, we must carry with us the guarantees expressed in our Bill of Rights: to think, communicate, and live in freedom. We must stimulate individual initiative and free enterprise in space.

Historically, wealth has been created when the power of the human intellect combined abundant energy with rich material resources. Now America can create new wealth on the space frontier to benefit the entire human community by combining the energy of the Sun with materials left in space during the formation of the Solar System.

In undertaking this great venture we must plan logically and build wisely. Each new step must be justified on its own merits and make possible additional steps. American investments on the space frontier should be sustained at a small but steady fraction of our national budget.

In his essay Common Sense, published in January of 1776, Tom Paine said of American independence, “Tis not the affair of a City, County, a Province, or a Kingdom: but of a Continent. . . . Tis not the concern of a day, a year, or an age; posterity are virtually involved in the contest, and will be more or less affected even to the end of time, by the proceedings now.” Exploring the Universe is neither one nation’s issue, nor relevant only to our time. Accordingly, America must work with other nations in a manner consistent with our Constitution, national security, and international agreements.

As formerly on the western frontier, now similarly on the space frontier, Government should support exploration and science, advance critical technologies, and provide the transportation systems and administration required to open broad access to new lands. The investment will again generate in value many times its cost to the benefit of all.

When the first Apollo astronauts stepped onto the Moon, they emplaced a plaque upon which were inscribed the words, “We came in peace for all mankind.” As we move outward into the Solar System, we must remain true to our values as Americans: To go forward peacefully and to respect the integrity of planetary bodies and alien life forms, with equality of opportunity for all.

—Pioneering the Space Frontier,
The Report of the National Commission on Space. 1966

not afford to do all three, so we should choose one that excites the most interest among our potential collaborators, to reduce the costs and increase international cooperation.

We need to get rolling on the next generation of spacecraft, the aerospace plane, which could greatly reduce the cost of piloted missions, and set the stage for permanent habitation in orbit; perhaps this plane will even make space tourism possible.

I, personally, think we should develop a permanent human presence in space in three stages: first, by building a modest, flexible, permanent Space Station where it will be possible to perform materials research and to study the long-term effects of weightlessness on humans. We could use that as a way station for the second stage: A permanent lunar base similar to our Antarctic bases. There, we could begin to learn to harvest the resources of space and to solve the problems of living on another world permanently, while at the same time doing good scientific research. This would give us the experience of low gravity and closed ecologies that would serve as the foundation for the third step: a human expedition to Mars. The use of lunar resources could reduce the costs of building the Mars ships.
And building Jerome Wiesner's international Earth-watching station will go a long way toward ensuring that there's a civilization for our astronauts to return to.

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**New Space Drives**

There are several ideas to replace rockets that will probably become important in the next quarter-century.

The ion drive, as in the proposed TAU mission, could revolutionize interplanetary space travel by greatly reducing the cost of missions. In the inner solar system, as far out as Mars, solar panels can provide the energy to drive the spacecraft. The technology is already so well-developed that NASA had planned to use it to send a spacecraft to Halley's Comet, until budget-slashers chopped it down.

Studies are now underway at JPL on the feasibility of using ultralight and very small spacecraft to explore the planets, using chemical, ion, or other drives. With microminiaturization and artificial intelligence progressing as rapidly as they have, we will probably see low-cost, miniature spacecraft flying around the solar system in the next decade; in the decade after that, we could see hundreds of tiny, cheap probes visiting every interesting place in the solar system.

Eventually, the technology should be adapted to piloted vehicles so that human missions could get to Mars in months rather than years.

Another elegant idea NASA has worked on in the past (but which has never flown) is the solar sail, another way of taking advantage of the abundant source of solar energy in space. It puts to use the principle that sunlight exerts pressure on any object. On Earth, that pressure is too feeble to be felt. It can be measured only by the most delicate experiments in the laboratory. But in space, if you put up a giant umbrella made of a very light material such as mylar or kevlar, sunlight exerts a gentle but noticeable pressure.

As with the ion drive, the pressure is very small but steady, so it can accelerate a spacecraft over months with no rocket fuel at all. A private organization, the World Space Foundation in Pasadena, California, has been experimenting for years with solar-sail designs and hopes to launch the first experimental solar sail in space in a couple of years. This could prove to be the cheapest way yet of traveling through the solar system.

The similarities to sailing by boat are remarkable. Just as it is possible to travel upwind in a sailboat by tacking, it is possible to travel toward the Sun as well as away from it by orienting the sail properly.

At first, this technology will be used only for robotic probes, but within 25 years, astronauts may find themselves sailing very much as those aboard galleons once did—solar sailors sailing on sunbeams in the solar wind.

Other potentially revolutionary technologies could be used during the difficult and expensive lift-off stage. Some researchers have proposed beaming power from microwaves or lasers to spacecraft taking off from Earth. If this technology is feasible, it could greatly reduce the cost of getting payloads from Earth into orbit. Also worthy of research are electromagnetic catapults or even chemical-powered cannons that could shoot small payloads to orbit directly from Earth's surface. This could be a cheap way to resupply orbiting astronauts.

And one technology now being explored by NASA and aerospace companies is *tethers*. These are lines miles in length that can drop probes into the atmosphere, exchange energy between two spacecraft, or transmit power from a large vessel to a small probe. By making them conductive, we may be able to generate power directly from Earth's magnetic field.

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**The Long Run: Space Colonization**

In the long run, the solar system will be our playground and our living room.

Some years ago, Princeton physicist Gerard O'Neill posed a problem to his students: Just for fun, could they solve some of the problems involved in building a space colony orbiting the Earth? He intended it only as a teaching trick to make the class more interesting, but to his amazement, students came up with potentially practical solutions to all the problems he could pose in the design of a space colony. He suddenly realized that such colonies were not something out of future centuries of history but could be built right now.

Furthermore, he discovered they'd be able to solve one of the world’s most pressing problems—the shortage of energy. By putting a giant solar collector in orbit, sunlight could be converted into electricity and
beamed down to Earth. Without using polluting fossil fuels, the world could have all the energy it needed.

O’Neill was so profoundly influenced by this discovery that he has since devoted much of his career to making space colonization a reality. He founded the Space Studies Institute in Princeton, New Jersey, to sponsor research projects directed toward space colonization and space power generation, and to educate the public about these possibilities.

His imagination and enthusiasm have stimulated scientists and engineers around the world to begin attacking these problems seriously. One of the earliest designs the students came up with was of two giant cylinders that would be tied together and put into orbit. The cylinders would spin around their long axes to generate artificial gravity so the colonists could live inside them. They would have long windows to admit sunlight, and houses and crops could be situated within.

One of the delightful consequences of this design would be that if you climbed up to the center of the cylinders—the long axes around which they would spin—there would be no gravity. You could fly with wings, like Icarus in Greek mythology.

Another design that has been extensively studied looks like the space station in many an old science-fiction film. It would be wheel-shaped, a design often called the Stanford torus (doughnut) named for the research group that dreamed it up while assembled at Stanford University to study space colony designs. The wheel would rotate, making artificial gravity for the inhabitants within. The outside of the wheel would be covered with debris, perhaps from the surface of the moon, like sugar on a doughnut, shielding the inhabitants from solar flares.

The idea of living in space seems far-fetched to the average person, but in the 19th century, 19 million people immigrated to the U.S., suffering long, expensive, difficult journeys across thousands of miles of ocean to get here. They sought freedom, prosperity, and the chance to get away from the wars, prejudices, and decay of their own societies. The 21st century will, I expect, see similar numbers of people moving into space for the same old reasons.

There will be colonies of factories, colonies of Mormons and Seventh Day Adventists, vegetarians, Chinese, Socialists, Libertarians, and every other group looking for a new start. Earth is already overpopulated by many measures, and the population continues to increase, even if at a slower rate than before. Billions of people will be added in the next decades, and the yearning for a fresh start will sing in the hearts of many.

At first, it will be too expensive for most, but the costs will fall every year as new technologies and new ideas come along. Just as the costs of air travel have fallen so much that, where only the rich could afford to travel by plane before World War II, now it’s hard to find an American who hasn’t flown at least once.

Several of the moons and planets can be transformed into livable places with the technology that should become available in future centuries. The first place to be converted—“terraformed”—into a comfortable world may well be our own familiar moon.

At first glance, it looks as if the Moon is one world that could never have a home-like atmosphere. The Moon is too small to hold onto an atmosphere—that’s why it’s a vacuum today. But it was suggested many years ago that the Moon could be given an artificial atmosphere. The
TWELVE COMING TECHNOLOGICAL MILESTONES IN SPACE

Initial operation of a permanent Space Station;
Initial operation of dramatically lower cost transport vehicles to and from low Earth orbit for cargo and passengers;
Addition of modular transfer vehicles capable of moving cargoes and people from low Earth orbit to any destination in the inner Solar System;
A spaceport in low Earth orbit;
Operation of an initial lunar outpost and pilot production of rocket propellant;
Initial operation of a nuclear electric vehicle for high-energy missions to the outer planets;
First shipment of shielding mass from the Moon;
Deployment of a spaceport in lunar orbit to support expanding human operations on the Moon;
Initial operation of an Earth-Mars transportation system for robotic precursor missions to Mars;
The first flight of a cycling spaceship to open continuing passenger transport between Earth orbit and Mars orbit;
Human exploration and prospecting from astronaut outposts on Phobos, Deimos, and Mars; and
Start-up of the first Martian resource development base to provide oxygen, water, food, construction materials, and rocket propellants.

—Pioneering the Space Frontier, The Report of the National Commission on Space, 1986

idea would be to put a power source on the Moon, or to beam sunlight to extract the oxygen from the minerals there and release it to begin the formation of an atmosphere.

It's true that the atmosphere will leak away eventually, but it might not do so for millions of years. The ingenious idea is that if we continue to supply the atmosphere, pumping it faster than it leaks away, then it doesn't matter if it eventually leaks into space. Over a period of many years, even centuries, a breathable atmosphere of oxygen could be built up on the Moon.

Undoubtedly, someone will file a gargantuan environmental impact statement exploring the effects the air will have, since that will then allow winds and weather to exist. However, taking into account the slow rotation of the Moon and the absence of large lakes or oceans of water, the weathering would be slow. So, before the reader runs out to form an environmental conservation group to protect the Moon, rest assured that the dangers to the lunar environment are small, and the benefits to humanity are many.

An atmosphere would moderate the temperature extremes on the Moon, producing an average temperature similar to Earth's. There would be a greater range of temperatures because day and night are each two weeks long. The Moon will heat up more during the lunar day than the Earth, and will cool down more at night. With an atmosphere, we could put water into small craters and form little lakes. (This possibility assumes that water is found on the Moon, or alternatively, imported from a comet or asteroid.)

Imagine swimming in the lunar lake. The gravity is one-sixth of Earth's, and you can breathe the new lunar atmosphere. You can jump six times higher than on the Earth. You can dive into the lake and watch the splash rise up, far overhead. Even if you are a terrible swimmer, you would be in no danger of drowning, because your body would be so light that it would hardly sink into the water. With simple floating shoes, you might even be able to walk on water.

In the weak lunar gravity, human-powered flight should be duck soup, almost as easy as in O'Neill's space colony, enabling any healthy person to fly with muscle-powered wings on the Moon.

Plants grow well in Moon dust, and it should not be long before we establish farms and parks there. The Moon will probably become the favorite recreation park of Earthlings, who will think no more of going to the Moon for a vacation than North Americans think of going to Europe.

Mars and Venus offer excellent prospects for terraforming into habitable worlds. Both already have atmospheres. Since they're carbon dioxide, they could be seeded with plants genetically engineered to fit local conditions, and the air could be converted into oxygen, in much the way it happened on Earth billions of years ago.
Initially, this would be done inside domes or tunnels, but over the centuries, we might decide to convert the entire planet's atmosphere into something breathable.

Mars already has water, in the form of ice, but Venus is a desert, so we'd have to import ice, perhaps from comets. One way or another, civilization will probably spread to those worlds.

**What Now?**

Momentum is building for an international human expedition to Mars. There is more support for such a joint mission in the U.S. and U.S.S.R. than ever before, and its major benefit to humanity might well be a reduction of tensions and a relief from the threat of world war.

The Russians know full well that a nation that masters the use of space will have the same global power that the great seafaring nations of old had. The Japanese, the Western Europeans, and the Chinese also know that a command of space travel is essential to future growth, and they are determined not to be left out.

The great seafaring nations—Britain, Spain, Portugal, France, Italy, Holland—owed much of their commercial power and cultural growth to the exploration and exploitation of resources around the world, permitted by their ability to travel vast distances in their vessels.

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What are the three things we can do in the future? The first... is genetic engineering. What I predict... is that before long [we will say], "Why did those people build spacecraft instead of growing them?" It would be much easier in the long run to use biological organization to build a spacecraft: To program the DNA and let the creature grow by itself rather than building it laboriously, one little piece at a time. So one might think of the spacecraft of the year 2000 or 2100 at least, that young people are going to be flying, as something alive....

The second big step in technology which we are going to see is artificial intelligence. That's to say, the programming of computers in such a way as to be compatible with the organization of a brain. That you could have a creature like the hummingbird with a brain that weighs a few grams, which can in fact do all kinds of wonderful things. But we don't have access to the brain of a hummingbird because we're not smart enough to program computers in such a way to be compatible... Well, I think it is pretty clear that in twenty to thirty years we shall. So we will be able to build a machine, which is sort of a hybrid symbiosis of a plant, animal and electronic computer, the three components all working together, and information flowing back and forth between them.

The third new technology which we don't yet have... is just better propulsion systems. Particularly, solar electrical systems.

If you put those three systems together, I would say you could imagine... a spacecraft which is as capable as Voyager, which weighs a kilogram instead of a couple of tons. That of course will make an enormous difference. We shall have then the possibility of getting to Uranus much quicker with a solar electrical system. ...

What I think we should do is to think small and to think quick. That's the way space science should be going. We should be making our plans for the next 25 years on the assumption that we are not going to fly things like Voyager. Voyager was fine, but in a sense, that is the end of the technology of the 1970s. We're going to need radically different technology for the twenty-first century....

The kind of spacecraft I envision is something that will get to Uranus in two years, and is slowed down by atmospheric braking, which for a light spacecraft is not too difficult. Then coast around, and with the residual sunlight, you would still have enough power to navigate from satellite to satellite. In the end, you will be carrying onboard something like a bombardier beetle. That's this famous creature which already developed, for its own nefarious purposes, a propulsion system which enables it to squirt scalding hot gas at its enemies, so a little of that would enable you to hop around from satellite to satellite, or to go and graze on the rings of Uranus. Your imagination can take it from there.

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*Freeman Dyson, physicist, Institute for Advanced Study*
Of course, much of their wealth was gained at the expense of the natives of other lands. Fortunately, there are no natives in the solar system whose lands may be stolen, so we have here a superb opportunity to bring wealth to our planet without hurting others. We can be sure that if the U.S. does not vigorously participate in this greatest of all adventures, plenty of others will.

Once we have obtained a foothold on other worlds, there will be no stopping human civilization. Even the destruction of a planet will not annihilate our species. We will continue to move on to other planets and moons, to asteroids and comets, and gradually we will bridge the gulf between the stars.

The end result will be prosperity and the answers to some of the greatest mysteries in the universe.

References


