America in Space:
The New Industrial Revolution

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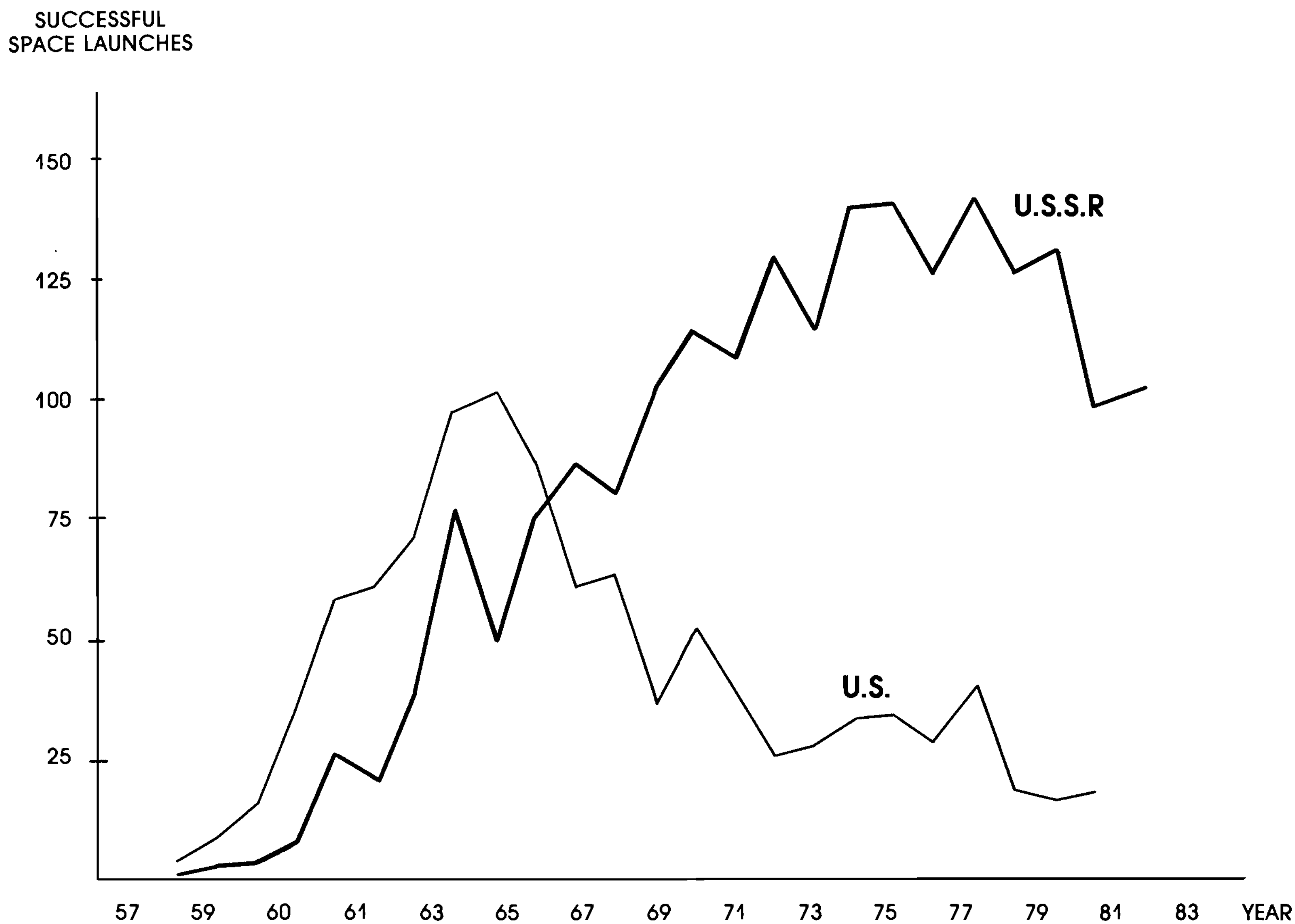
THE SPACE RACE



SOURCE: National Center for Policy Analysis

U.S. COMMITMENT TO SPACE

SOURCE: National Center for Policy Analysis

AMERICA IN SPACE: THE NEW INDUSTRIAL REVOLUTION[1]

A handful of scientists and visionaries are proclaiming that the next economic frontier, the one that will carry us into the 21st century, lies in outer space. They foresee a greatly increased role for satellites in communications and in surveying the Earth's resources. They foresee factories in outer space producing new products which cannot be manufactured on Earth. And they see a day beyond that when men, women, and children will live and work on other planets, on the moon, and in space itself.

Will these visions become a reality? If the history of technology teaches us anything, it teaches us that things never work out quite as planned. Yet something new and revolutionary is surely lurking around the next technological corner, and we need to prepare now to take advantage of new opportunities and unexpected developments as they present themselves.

COMPETING FOR DOMINANCE IN SPACE

Although no one can predict with any degree of accuracy how the economic development of space will unfold, there is one thing we may be sure of. If the U.S. does not take the lead in pursuing the economic opportunities which flow from the commercial development of space, other countries stand ready to fill that void.[2]

- Already, the European Space Agency is providing serious competition for NASA in the satellite launching business.
- By 1990, Canada, France, Japan and perhaps the Soviet Union plan to deploy systems that will compete with our land and ocean remote sensing satellite systems.
- The French are considering the establishment of a space shuttle and a space station of their own.
- West Germany, Japan and the Soviet Union are all actively involved in researching space-based production of numerous materials.

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1. This study is largely an outgrowth of materials and ideas presented at an NCPA conference on the economic development of space. (Dallas, Texas. June 7-8, 1984)

2. Office of Technology Assessment, International Cooperation and Competition in Civilian Space Activities. (Washington, D.C., 1984)

Clearly, if the U.S. does not develop the next frontier, other nations stand ready to do so. We are in a highly competitive race and the stakes could be enormous. The worst thing we could do is pull out of the competition without considering the consequences. Nonetheless, the United States appears to be doing this by default.

Despite political rhetoric, America clearly has lost its commitment to space.

- Since 1964, there has been a steady, almost unbroken decline in the percentage of the federal budget devoted to space--from almost five percent to less than one percent today.[3]

- In 1964, federal spending on space-related research and development was 21 percent of the country's R & D expenditures. Today, it is only seven percent.[4]

While our commitment in space has waned, the Soviet Union has devoted an increasingly larger share of its resources to the military and commercial development of space. As a consequence, we are in danger of losing the space race due to a failure to compete.[5]

- Since 1958, the Soviet Union has launched twice as many satellites as the U.S., and the trend is growing worse.

- In 1958, the U.S. had five times as many successful satellite launches as the Soviet Union. Today that situation is reversed. The Soviet Union is now successfully launching five times as many satellites as the U.S.

Most experts put the Soviet Union ahead of the U.S. in the development of "star wars" technology. They appear to have the lead in particle beam and laser technology. They have fully operational killer satellites, while we do not. Their permanently manned space station will be operational five years ahead of ours.[6]

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3. Office of Management and Budget, Aeronautics and Space Report of the President, selected years; and Council of Economic Advisors, Economic Report of the President, selected years.

4. National Science Foundation, National Patterns of Science and Technology Resources, selected years.

5. Statistics compiled by the Science Policy Research Division of the Congressional Research Service of the Library of Congress.

6. For a report on the Soviet plans for military domination of space, see Thomas Krebbs, The Soviet Space Threat, (Dallas, Texas: NCPA), 1984.

Whether or not it is desirable to take the arms race into space, a strong case can be made for competing commercially with the Soviet Union as well as with other countries. The theme of this report is that, by all indications, investing in space is good business.

REVOLUTIONIZING COMMUNICATIONS

The first commercial opportunity in space was in communications satellites. Today, telecommunications is truly the "big business" of outer space.[7]

- The communications satellite industry currently does more than $2 billion in business each year.

- More than two-thirds of all overseas communications traffic is relayed by satellites.

- More than 80 communication satellites are now in orbit. By the turn of the century, 300 new ones will be launched.

Originally proposed by British science fiction writer Arthur C. Clarke (author of 2001: A Space Odyssey), communications satellites have revolutionized long distance telephone, television, and data transmissions. Sending messages across a large land area like the United States used to require a vast network of copper wires, or hundreds of microwave relay towers. Sending a signal across the oceans required even more expensive underseas cables. Communications satellites eliminated this need for cumbersome and costly ground-based systems. They provide a more flexible and reliable communications system at a substantially lower cost.

The first communications satellite, Echo, was simply a large, aluminum coated balloon placed in low Earth orbit. When it passed overhead, a powerful ground-based transmitter bounced a signal off it which could be picked up on the other side of the Atlantic Ocean. It was purely a passive system, merely reflecting a radio beam that became very weak by the time it reached the ground again. The first satellite to employ an active relay system, Telstar I, was placed in low Earth orbit a few years later. It was designed to receive a signal, amplify it, and broadcast it again at higher power back to Earth. While an improvement over Echo, it suffered the same shortcoming: It could be used only when it passed overhead. Most of the time it was out of range.

7. The demand for all international telecommunication services is increasing about 10 percent per year. Satellite communications are expected to continue to dominate this market.

Today, communications satellites are placed in orbits approximately 22,000 miles above Earth.[8] These satellites rotate with the Earth and thus stay in a fixed position over one spot on the ground. Since they are less expensive to operate than ground-based systems, major communications companies including AT&T, Western Union, and RCA are placing more and more of them in orbit. The drastic decline in the price of leasing a long distance communication channel has led to innovations that were undreamed of 20 years ago:

- Live broadcasts of news events can now occur from anywhere in the world.

- Time, Newsweek, USA Today and the Wall Steet Journal all are electronically "mailed" from New York via communications satellites.

As communications satellites become more sophisticated, new developments are just around the corner.

Direct Broadcast Satellites. Instead of requiring an expensive, complex ground station to receive their signals, direct broadcast satellites are powerful enough to transmit television pictures directly to the homes of individual viewers. Only a small, rooftop antenna is needed to pick up their signal. The advantage of direct broadcast satellites is that they permit viewers to choose from a wide variety of programs being broadcast into their homes. Because local television broadcasting is restricted to only a few stations, and because cable television requires an expensive system of wiring, direct broadcast satellites may someday carry almost all television signals.

- A single direct broadcast satellite can blanket an entire continent with its signal, bringing hundreds of programs simultaneously into viewers' homes.

- Japan already has launched a direct broadcast satellite, and the government-owned television networks of western Europe are on the verge of launching one.

The political consequences of direct broadcast satellite television may be more far-reaching than the economic consequences. Outer space has no geopolitical boundaries. American satellites fly over the Soviet Union, and Soviet satellites fly over the U.S. The Kremlin goes to great efforts to jam Voice of America broadcasts, which currently are transmitted by short wave radio. How might they react to an American direct broadcast satellite beaming "Dallas," or the "CBS Evening News" into every Soviet household?

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8. Such satellites are said to be in geosynchronous orbit.

Satellites and Cordless Phones. Just as communications satellites are being made to transmit more powerful signals, they can be designed to receive less powerful ones sent up from Earth. Today we have cellular telephone systems operating in a few major cities that can pick up signals from mobile phones installed in automobiles. These operate with local, ground-based equipment and are limited to the city streets. But suppose we had communications satellites sophisticated enough to detect signals from mobile or cordless telephones. We then would have world-wide direct telephone communications between any two points on the Earth. Developments in this direction are already underway:

- By this time next year, three satellite-based, "beeper" paging systems will be operating nationwide in the U.S.

- Someday we will be able to talk to anyone on Earth with cordless communicators like the one used by Star Trek's Captain Kirk.

With a little imagination, we can envision exciting possibilities. An executive kayaking down a glacial stream in Iceland could pick up his cordless phone and place a direct dial call to his stockbroker skiing in Patagonia. The call would go through instantly. Or he could call his business associates lounging on their yachts in the Mediterranean, circling over Singapore in their private aircraft, or bargaining with vendors in the bazaars of Rabat.

The political consequences could be portentous. In recent years Soviet authorities have limited dissent in the U.S.S.R. by shutting down telephone contact between dissenters and their western contacts. With satellites capable of picking up mobile phone signals, the Iron Curtain could be pierced in yet another way.

LOOKING AT EARTH FROM SPACE

Weather Forecasting. Another type of space satellite of great economic value is the weather satellite. Before satellites, weather forecasters had to rely on individual sightings taken from thousands of locations to determine the overall extent of fronts, rainstorms, or hurricanes. A weather satellite can snap a single picture and provide the same information in an instant. The economic benefits of improved weather forecasting are immense. These include better crop predictions, the ability to route airlines to avoid storms, and more time to evacuate areas threatened by floods.

Most of us think of weather satellites as old hat--they provide nice photographs on the TV weather news. But their potential has hardly been touched. Satellite photographs provide far more data than meteorologists can use at present. Even though meteorologists use some of today's largest and most powerful computers to interpret the information provided by satellites, the amount of data available far exceeds what even the biggest computers can handle. When "fifth generation" super computers become available sometime in the next decade, weather forecasting will become vastly more accurate and detailed.

- Instead of just predicting that rain will fall somewhere in your state, forecasters may soon be able to predict whether rain will fall in your back yard.

- Using new techniques to control the environment, we even may be able to control the amount of rain that falls in your back yard.

Better forecasting techniques will bring great economic benefits. They also might be a major life saver. Tornadoes are an intensely powerful but highly localized phenomena. The combination of weather satellites and more powerful computers should dramatically increase our ability to predict these killer storms and to take actions that save lives and property.

Remote Sensing. Another type of satellite whose potential is still not fully developed is the Landsat, or Earth-imaging satellite, which provides detailed photographs of the Earth's surface taken from orbit.[9] These photographs are less costly and more accurate for mapmaking and urban planning purposes than are aerial photographs. The higher altitude and clearer images often reveal geographic features, such as ancient meteorite craters that are not noticeable in photographs taken closer up.

The real advantage of Landsat, however, is that it can "see" in infrared and other forms of light that are invisible to the naked eye. The economic potential of this is just beginning to be realized.

- Landsat images can tell us when crops are ripe, how great the yields from farms will be, and whether forests and fields are infected by insect pests.

- Geologists can use Landsat pictures to hunt for minerals, oceanographers can track schools of fish, and environmentalists can monitor air and water pollution.

Advances in technology continually are improving the value of Landsat imaging. In addition to scanning the Earth's surface, new orbiting radars are able to look under the surface.[10]

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9. The U.S. Landsat system is currently the only civilian system from which worldwide data are available. The current annual market for Landsat data is about $10 million. See also, Office of Technology Assessment, Remote Sensing and the Private Sector: Issues for Discussion, (Washington, D.C.: OTA, March, 1984).

10. See Chemistry and Industry, April 3, vol. 192, p. 215.

- Radar imagers can penetrate tropical forest canopies to spot new resources.

- They can look through several yards of sand or loose soil to spot ancient river beds and rock formations hidden from ordinary view.

The potential for archeology, agriculture, and mineral exploration is truly great.

Locating and Navigating. Navigation satellites were originally developed by the military. Navy ships, particularly submarines, need to know where they are at all times in case they are called into battle. The same is true of long-range bombers flying for the Air Force. That is why the military launched a series of "Navstar" global positioning satellites, which broadcast their location with high accuracy as they pass over the Earth. Anyone located below with a radio receiver equipped to listen to these broadcasts can fix his own location on the ground.

Navstar satellites also can benefit the commercial shipping and airline industries. In the highly competitive business of international shipping and air travel, this kind of information is valuable. A ship or plane which constantly wanders off course takes more time and more fuel to reach its destination. The use of navigation satellites will soon revolutionize airplane navigation:

- A navigation satellite was used last year to guide a plane travelling from Iowa to Paris.

- Before long these satellites will be used to navigate virtually all long-distance aircraft and, in the process, will substantially improve air traffic safety.

Global positioning satellites also have dramatically lowered the cost of surveying land. Traditionally, surveyors have to go over an area point by point, establishing line-of-sight contact between each point and fixing their locations relative to the others. This is a time consuming activity. But now, global positioning satellites allow surveyors to fix the location of any point, independent of line-of-sight contact with any other reference point. This has proved to be of great value to oil companies prospecting for new finds in remote locations.[11]

The ultimate use for a global positioning satellite system will be when we can prevent people from getting lost or stranded following plane crashes, ship wrecks or other disasters. If the cost is low enough, motorists could have receiving units in their cars, and backpackers might be able to take them along on expeditions. Already, an experimental system has been developed whereby

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11. See <u>Civil Engineering</u>, February, 1982, p. 65.

light aircraft downed in crashes can send a distress beacon that is picked up by a satellite. The satellite then relays the exact location of the aircraft to authorities conducting a search.

MANUFACTURING IN SPACE

An orbiting spacecraft provides a unique environment for the manufacturing of products that might be impossible to make on Earth. Above the Earth's atmosphere there exists an unlimited vacuum. While small vacuum chambers can be built on Earth, the vacuum available for the asking in outer space is of a purity and volume that cannot be duplicated on Earth. The other condition that cannot be established on the Earth's surface is weightlessness. A space ship in orbit is in a condition of free fall. Although the force of gravity is present, it is exactly offset by the motion of the craft as it orbits the Earth. Anything or anyone inside the space ship feels no weight at all. This weightlessness can be achieved momentarily on Earth, by jumping down an elevator shaft, for example. But as a practical matter, weightlessness can be sustained only in space.

The pull of gravity is so pervasive on Earth that it is hard to visualize all the consequences of its absence. Yet the absence of gravity would have both simple and profound affects on almost every aspect of our daily lives.

You can't smoke a cigarette in space. On Earth, a burning match or a cigarette stays lit precisely because of the pull of gravity. The gases released by these burning objects are lighter than air. In the presence of gravity, the gases rise and allow a continuous flow of oxygen to sustain the fire. In space, however, a burning match or cigarette will snuff itself out because the hot gases do not rise and carry themselves away from the flame.

This phenomenon is useful beyond enforcing a no-smoking policy in a spacecraft. It will allow the production of wholly new materials which cannot be produced on Earth. For example, mercury iodide is used to detect gamma rays and X-rays, yet its structure is so delicate that growing sufficiently large crystals is almost impossible on Earth. The crystals are crushed under their own weight. In outer space, they can be grown to any desired size.

Space laboratories also are ideal places to produce tiny latex spheres for use in calibrating microscopes and other areas of medical research. Scientists are able to make 10 micron (one four-thousandth of an inch) spheres in space. On Earth, because of the distorting effect of gravity, perfect spheres larger than three microns cannot be made.

In space, you can make a perfect oil and vinegar salad dressing. Things mix well in space that do not mix well on Earth. On Earth, if you shake up a bottle of Italian salad dressing the oil and vinegar will soon separate, the lighter oil on top, the heavier vinegar on the bottom. The basic effect of gravity is to separate out the components of a mixture according to their density. The denser parts, with more mass per volume, get pulled down by gravity, while the lighter parts, with less mass per volume, rise to the top of the mixture. In an orbiting spacecraft, however, once a bottle of salad dressing is shaken it stays thoroughly mixed, with no tendency to separate.

One problem with the perfect oil and vinegar salad dressing is that it can never be brought back to Earth without separating. Fortunately, there are other products mixed in space which can be brought back for use on Earth. These include about 500 combinations of materials, including new and exotic metal alloys that have never before been formed. The prospects look good for the space-based production of super-light high strength materials for use in homes, cars and airplanes.

When metals of different densities are melted together on Earth, they tend to separate again as the new alloy solidifies. In addition, if two components have different chemical characteristics, they also may have problems of miscibility, or the tendency to mix. If two immiscible metals are combined, the resulting alloy is weak because the crystals from each have failed to join in a sufficiently tight grip.

Both of these problems can be overcome by processing the alloys in space. Metallurgists are planning to experiment with new alloys formed on board the space shuttle. Manganese-bismuth, mercury-cadmium-telluride, and lead-tin-telluride are some of the combinations under consideration. One experiment with considerable commercial importance will be attempts to produce metal alloys with a special crystalline structure that could become magnets many times stronger than any produced on Earth.

In space, it can take more than an hour to boil a pan of water. When you heat a pan of water on the stove in your home, tiny bubbles form on the base of the pan where the heat is applied, and then rise to the top. The behavior of these bubbles reflects the way heat is spread throughout the pan. Hotter water on the bottom rises to the top, where it cools off and then sinks to the bottom again. These currents of water are called convection currents, and they occur in all heating processes that take place under the pull of gravity.

In space, however, the bubbles that form on the bottom of the heated pan don't rise; they stay there. In the absence of gravity there are no convection currents. This phenomenon may have a profound impact on the electronics industry.

The integrated circuits at the heart of all electronic devices, from digital watches to massive computers, are built on tiny "chips" of silicon. The silicon wafers from which the chips are cut are grown as crystals from a vat of hot, molten silicon. To give the chips the desired electronic properties, trace amounts of impurities called dopants are often added to the liquid silicon. However, it is virtually impossible to get these dopants to be deposited uniformly throughout the silicon crystal because of convection currents in the melted silicon. The electronic properties are not the same from one chip to another, and many of them have to be rejected.

Growing crystals of silicon in the weightlessness of space eliminates convection. As a result, chips requiring highly uniform properties, including those for detecting infrared and nuclear radiation, are candidates for space-based production. Already, a number of experiments aboard the Skylab and space shuttle have been conducted along these lines.

In space, you can boil a pan of water without the pan. One limitation of gravity that is so obvious we barely stop to consider it is that any liquids must be placed in containers. In weightlessness containers aren't necessary. Liquids stay where they are, and, to a certain degree, hold together. As a result, containerless processing, impossible on Earth, is feasible in space.

This turns out to be very important in the glass industry. The clarity of glass, its translucence, depends on its being made of just the right materials with no impurities. Any foreign matter, including impurities present in a container, interferes with the passage of light and degrades the quality of the glass.

Making glass in the weightlessness of space eliminates problems of contamination. The raw materials can be held at a point in midair with high frequency sound waves, and melted from a distance by a radiant heater. Scientists are so optimistic about this technique that they foresee glass being made without any impurities at all. This could result in the development of new standards of purity for optical glass for use in telescopic lenses, microscopes, and other scientific equipment. Another great commercial potential is the development of improved fiber optic cables to replace copper telephone wires.

In space, if you don't like the cream and sugar in your coffee, you can remove them. Just as things mix in space which do not mix well on Earth, so things separate in space that do not separate well on Earth. In the absence of gravity, scientists can achieve separations of materials that might be impossible on Earth.

The separation is achieved by placing a liquid solution of materials in an electromagnetic field. If one substance consists of lighter molecules, and another substance of heavier molecules, then the electrical force pulls them apart, the lighter molecules moving ahead more quickly while the heavier molecules lag behind.[12] In principle this technique can be used to separate the sugar and cream from a cup of coffee.

On Earth, this process works very slowly and inefficiently because of gravity. In weightlessness, on the other hand, the process works far better. Compounds whose molecular weights differ by only a fraction can be drawn apart with amazing accuracy. In a continuous flow system now under development, a liquid solution of molecules can be processed over and over again without problems of sedimentation and convection currents.

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12. The process is called electrophoresis. For an explanation of how it works, see Analytical Chemistry, vol. 55, no. 12, October, 1983, p. 1187.

SAVING LIVES AND CURING DISEASES

One of the most important consequences of this new separation technique is that space-based laboratories will be able to produce pharmaceuticals that save lives and cure diseases.

Producing life-saving drugs. Many of today's diseases are due to a lack of some substance which is produced naturally in the human body. These substances include certain kinds of cells, enzymes, hormones and proteins. Frequently, the cure for these diseases is to extract the substance from the tissue of a healthy human and introduce it into the body of the person who is ill. Cells produced in the pancreas, for example, provide a potential cure for diabetes. Urokinase, a clot-dissolving enzyme found in kidney cells, is useful in treating hemophilia. Erythopoietin, a hormone found in kidney cells, is useful in treating anemia. Perhaps the most well-known substance is interferon, an experimental drug to treat cancer. In order to obtain these substances on Earth, they must be extracted from enormous amounts of biological material.

Enter the space-based laboratory. In space, large quantities of drugs with unequaled purity can be produced using only a fraction of the material required on Earth.[13]

- On Earth, about 14,000 lbs. of starting material is required in order to extract one pound of biological material for use in pharmaceuticals.
- In space, 500 times more material can be extracted from the same quantity of starting material with up to five times more purity.
- There are from 40 to 50 medical products which are candidates for space-based production. (Some of the most promising are listed in the accompanying table.)

Locating Hospitals in Space. Persons with medical problems or physical handicaps might find a prolonged stay in space-based hospitals or convalescent homes very beneficial. The chronically bedridden on Earth must deal with the pain of bedsores. Burn victims also have the problem of constant contact with their bedding. In weightlessness, these problems would not exist. In addition, people who suffer arthritis could move more freely and heart patients would be under less stress. Perhaps the most enthusiastic residents of space would be paraplegics. In weightlessness, legs are of little use, and those whose legs cannot function would be at no disadvantage.

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13. See Aviation Week & Space Technology, May 31, 1982, pp. 51-57.

EXAMPLES OF BIOLOGICAL SUBSTANCES TO BE PRODUCED IN SPACE

Biological Substance	Potential Effects on Health	Number of People Who Could Benefit Each Year
Beta Cells	Cure for diabetes.	3.2 million
Interferon	Creates immunity from viral infections. Possible treatment for cancer.	20 million
Epidermal growth products	Promotes skin growth. Important in treating burn patients and in healing wounds.	1.1 million
Growth hormone products	Stimulates juvenile bone growth and heals ulcers.	850,000
Antitrypsin Products	Limits the progress of emphysema and helps cancer chemotherapy.	500,000
Antihemophilic Products	Treats hemophilia.	500,000
Collagen	Used to replace or repair damaged human organs (e.g., can be used to produce artificial corneas or to replace blood vessels).	20 million

Source: Aviation Week and Space Technology, May 31, 1982, pp 51-57 and NCPA estimates.

BUILDING THE SUPER COMPUTER

The silicon revolution has served us well. As the material from which integrated circuits are made, silicon has supported phenomenal advances in computer technology. Nevertheless, "star wars" defense systems, advances in robotics and many other technological innovations will require super computers that perform billions of computations per second. Designs for these super computers are already on the drawing board, but in order to make them work a replacement for silicon must be found. Many people expect to find that replacement in space.

In the zero-gravity of space, scientists will be able to grow crystals which cannot be grown on earth. Compared to silicon, these space-produced crystals generate less heat, use less electricity and are less susceptible to interference by radiation. They also can perform switching functions many times faster than silicon. The implications of this development are staggering. Some experts believe the overall impact of these crystals on the electronics industry could rival the revolution brought on by the transistor.[14]

The so-called fifth generation super computers currently on the drawing boards in Japan and the United States are expected to understand and mimic natural speech, predict the weather with complete accuracy, run a "star wars" defense in space, and even design more powerful computers.

DRAWING ENERGY FROM SPACE

The energy crisis of the 1970s, with sharp rises in the price of fossil fuel, led many people to search for alternative energy sources. One source we may be tapping in the near future is solar energy. Plans are on the drawing board to place large solar power collectors in orbit and then transmit the power down to Earth in the form of microwaves. These futuristic plans foresee the possibility of tapping an unlimited, non-polluting source of energy.

Solar energy is the power of choice for those who object to the pollution of coal burning generators, the political uncertainty of foreign oil, or the anxiety of living next door to nuclear plants. Solar energy collectors on Earth, though, suffer from one fundamental, unavoidable problem: The sun doesn't shine at night. Since electricity currently cannot be stored efficiently, people who rely on solar energy often must purchase supplemental electricity from local power companies.

The beauty of space is that solar collectors in orbit can operate 24 hours a day. Placing ten-mile-wide solar generating plants in space

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14. See Electronics, January 26, 1984, pp. 89-91; and Mechanical Engineering, June, 1981, pp. 35-38.

will be an unprecedented feat of engineering, but the proponents of solar stations are confident it can be done.

CONTROLLING THE ENVIRONMENT

As we peer further into the future, some rather speculative but plausible commercial uses of space can be seen. One potential venture that would not involve any brand new technology and could be done at a relatively low cost would be placing large mirrors in orbit around Earth.

Space mirrors would have two uses. One would be to illuminate the night sky at selected locations. For example, lighting highways at night might lead to sizeable reductions in traffic accidents and injuries. Space illumination of high-crime urban areas could make the streets safe for law-abiding citizens. Mirrors also could provide lighting when essential work had to be done outdoors at night in remote locations. Lighting the beachhead during the U.S. operation in Grenada, or the Falkland Islands when the British moved in, would have made miliary operations easier.

The other major use of space mirrors would be weather control. While weather satellites help us predict the weather, space mirrors might permit us to do something about it. What drives the weather patterns of the globe is essentially the light of the sun. The sun heats oceans, strong at the equator, weak at the poles. These temperature differences drive the air currents that form the basis of our weather patterns. If space mirrors were sufficiently large, they could focus enough sunlight on the Earth to create artificial disturbances in the weather.[15]

- A moderate-sized mirror could be used to burn off fog at an airport, or to disrupt a severe thunderstorm or tornado.
- A similar mirror could keep orange groves illuminated at night and raise the temperature just enough to prevent frost damage.
- A larger mirror might be able to steer a hurricane or typhoon away from populated areas, saving lives and preventing property damage.
- A truly huge mirror, or a bank of mirrors, might be powerful enough to rearrange climatic patterns, bringing rain to Texas, Arizona or the Sahara Desert.

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15. See Astronautics & Aeronautics, vol. 18, May, 1980, pp. 64-67.

FACILITATING TOURISM

When the first astronauts rocketed into space in the 1960s, NASA was deluged with requests from ordinary people who wanted to go along for the ride--to become space tourists, so to speak. Today, even though it has the capacity to take along paying passengers in the space shuttle, NASA so far has refused to take advantage of this commercial opportunity.

What sort of people would be willing to pay money to go into space? "Fools," might be the reply of the less adventurous. Nonetheless, space travel might be a golden opportunity for entrepreneurs.

The advantage of space as a tourist attraction would be its sheer novelty. The unique environmental factor of space--its weightlessness--also might attract tourists. Most of the astronauts who have been in orbit describe weightlessness as a sheer joy to experience. Movement is effortless. Science fiction writers have imagined a number of amusements and games that would be possible in low or zero-gravity. In The Menace From Earth, Robert Heinlein described strapping wings to one's arms and flying. A space entrepreneur along the lines of Walt Disney might well be able to come up with a highly popular resort. And what the Japanese euphemistically call "love hotels" might prove to be popular in the zero-gravity of space.

MINING IN SPACE

Although the moon has approximately the same land area as Africa, we have visited only a few spots on it. One thing we know as a result of these visits is that the same minerals that are found on Earth also are found on the moon. What we do not know is whether there are sufficient quantities to warrant mining. But it's a good bet that in the near future some people will be willing to risk their money to find out.

A number of specialists have speculated that some of the asteroids lying between Mars and Jupiter may be made up of solid, uncorroded iron or nickel. Mineral resources of unimagined value also may await us on other nearby planets. Mars is smaller than Earth, but because it has no oceans its land area is equal to our own planet. Venus is virtually a twin of Earth in all respects. The point is there probably are valuable resources out there worth looking for. The environmental savings to Earth in terms of mining and processing these minerals from afar would be enormous.

COLONIZING SPACE

At the boundary where prediction gives way to sheer speculation are several proposals that, while fascinating, are not yet feasible under today's technology. With the exception of the Apollo moon landing, all manned space expeditions have been trips to spots in empty space. There is quite literally nothing there when we get there. While nothingness has its uses, all of the great explorers of history, from Marco Polo to Columbus to Lewis and Clark, had economic goals. Columbus wanted to get to the Far East, but found a valuable piece of acreage called America on his way. The great explorers quickly became the great real estate agents.

What are the places in space that people might want to go to? The moon, Mercury, Venus, Mars, the major moons of Jupiter and Saturn, and the asteroids are all possibilities. Yet these bodies have drawbacks as places to live and work. They either have no atmosphere, or an unbreathable atmosphere like Venus. They either are too hot or too cold. They have no water and no hope of supporting life as we know it. If they somehow could be converted into habitable environments, the benefits might be incalculable.

Essentially two types of efforts could be undertaken to make these planets habitable, efforts that could be done separately or together. The atmospheres of the planets could be reshaped until they were suitable for terrestrial life, including humans. For Mars, this might involve melting the polar ice caps to create an atmosphere. For Venus, perhaps an artificial strain of micro-organism could be created through genetic engineering that would eat up the thick atmosphere of carbon dioxide and leave a more usable one of oxygen.

REARRANGING SPACE

The second fundamental step would be to move Mars and Venus to more suitable locations in the same orbit as Earth. Venus is closer to the sun than Earth, and is too hot. Mars is farther away, and is too cold. There are two spots in Earth's orbit where other planets could be placed (called Lagrangian stability points after the French mathematician who discovered the places in a gravitational field where three objects can coexist stably). Needless to say, moving planets would require enormous amounts of energy. One possible solution might be to use asteroids to bombard Mars and Venus and shove them into the desired orbital locations. Large hydrogen bombs might be used to set the asteroids in motion. While the technology for doing this does not exist today, no laws of physics rule it out.

CONCLUSION

If we look back in history, we see that many of today's vital technologies had humble, obscure beginnings, often growing out of research with other goals. Conversely, many new products originally touted as important never achieved success. It is instructive to read the predictions made by visionaries 50 or 100 years ago. While making straight-line extrapolations of what they were familiar with, they seemed to be blind to important developments that were then in embryonic stages. Science fiction writers, for example, predicted robots that could do the work of human beings. They described the artificial brains that guided their robots. But no science fiction writer thought of taking that artificial brain out of the robot and putting it on a desk for the purposes of making complex calculations. They failed to predict the computer.

The development of outer space undoubtedly will take a similar course, with unexpected events that will seem inevitable only in hindsight. One safe prediction that can be made is that future economic development of space will, in the long run, be greater than most of us predict.

There probably will be two phases to the development of space. At first there will be a "disappointment phase," when the reality does not match up to expectations. But beyond that, economic growth will accelerate faster than expectations, and we will enter the "excitement phase" where actual economic development is actually better than predicted. It is for this phase that the proper perspective was suggested by Arthur C. Clarke when he wrote, "Earth is the cradle of mankind, but man does not live in his cradle forever."

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