matters of medical science and in providing food supplies and organization of environments in strange circumstances.

Even before the close of this present century, the use of laser-like technologies developed as a byproduct of research and development for beam weapons means a revolution in productivity to the effect of increasing the per capita output of operatives by between two and three times present levels. The great benefits which NASA's R&D contributed to the civilian economy in the past are small relative to the benefits of a similar program attacking the indicated frontiers of science and technology.

In addition to the need for an anti-missile defense and the benefits of space exploration for life on Earth, the side effect of conducting such research and development is a leap upward in the conditions of the life of the average individual on the surface of this planet.

There is also a profound moral benefit to space exploration. Once we begin to define mankind in terms of mankind's prospects for colonization of the Moon and Mars, for example, and realize that it is within our reach to project growing forests on Mars, for example, we think of ourselves and our neighbors in a new way. We think of mankind as an instrument within God's creation, mankind destined to go anywhere in the universe useful work is required of mankind. We lift our noses from squabbling in the mud of this planet, and gain a moral sense of mankind as developing on this planet to fulfill some higher, if yet unknown duty in the universe around this planet.

Perhaps, such tasks will cause humanity to grow up at last.

The time has come, between strategic crises and growing misery on this planet, for the United States to launch a new great effort modeled appropriately on the work of the Ecole Polytechnique under Carnot and Monge. For the work we have indicated, we have presently far too few scientists and engineers, and too little education of our youth. We are a ruined relic of our former national self, and can arise from the misery, ruin, and demoralization of our present condition only by mobilizing ourselves as a people as we did once before during the 1939-43 period of economic mobilization. What we require for this great undertaking now we lack except in the tiniest part; we must create what we lack as we go along, using the crash programs of space exploration and beam-weapon defense as a great school, such that those caught up in that work produce "brigades" of new scientists and engineers as well as operatives with new kinds of skills, and cause the lessons learned from this "crash program" effort to spill over copiously into the life of our national generally.

Let us, therefore, look back to the more glorious days of NASA's past, and view what was accomplished then as a first step—a halted first step—which we must resume today. Let us resume the dedication of NASA from that period, and add to that dedication the broader duties of fundamental research and education needed to replicate the genius of the Ecole Polytechnique.

NASA at 25 years: on the frontiers of space

by Marsha Freeman

October 1 marks the first quarter-century of space exploration by the United States, carried out under the leadership of the National Aeronautics and Space Administration. These twenty-five years represent the fulfillment of mankind's oldest dream—to place his intelligence, his scientific instruments, out above the Earth into the cosmos, and then to go there himself.

Over this quarter-century, NASA has sent probes that will visit all of the solar system's planets, save one; it has sent instruments into space to examine the sun, stars, and galaxies through windows of wavelengths that man could not see, were he to go himself; it has proven that the human species can sustain space flight and accomplish important and useful work in space, and that mankind can bring his human intelligence, in vitro, to a celestial body beside the Earth.

Scientists have learned things about the giant planets of this solar system that challenge the most tenaciously-held beliefs of astronomy and physics. The Voyager missions showed us, for example, that the rings of Saturn cannot be explained by Newtonian physics. No linear calculation of interactions among billions of ring particles can explain the rings' stable yet highly complex geometry and self-developing character. Jupiter's atmosphere, similarly, disobeys the laws that we use to try to explain the weather on Earth, challenging basic assumptions of hydrodynamics.

Over the past twenty-five years explorers have gone out into space and landed on Earth's nearest neighbor, laying the basis in science, technology, and engineering to reshape this dead world into a new home for man. Tentative views from Mars have shown us that there is at least one other nearby body which could be terraformed for intelligent life.

To carry out these programs, NASA became the nation's largest science and technology agency, whose only goal is the increase of human knowledge and technology for the benefit of all mankind. Through budgetary ups and downs, the agency has maintained a core of scientific and engineering expertise, and dreams for the future.

The accomplishments of this first twenty-five years of space exploration are a reflection of the boldest dreams of men. The future will not depend on budget cycles, specific programmatic initiatives, or the particular personalities involved in the space program. It will depend upon the will of man to do what is necessary to fulfill the dreams that make him bigger than himself, and a lawful part of a solar system and universe that challenge his imagination and science.

NASA's challenge to established science

From the beginning of the NASA space effort, a major emphasis was to send probes out to other heavenly bodies. By 1964, just five years after the world's first satellite had been orbited, probes had sent back information about all of the inner planets—Mercury, Venus, and Mars—and the Moon.

Over the first decades of the space age, we learned that Mars did not have any observable life, which contradicted the hopes and expectations of most scientists. We learned that Venus could not be inhabited, as its 900 degree atmosphere would melt lead. The Moon, it was confirmed, was a cratered, lifeless world.

But the most startling discoveries occurred when two sets of spacecraft, Pioneer and Voyager, encountered our two largest planets—Jupiter and Saturn. Every 175 years, the outer planets are in aligned orbits, which astronmers knew would occur for the first time during the space age at the end of the 1970s.

With these orbits aligned, space planners knew it might be possible to send a spacecraft on a trajectory to Jupiter, and then use the gravitational pull of the giant planet as a gravity assist to propel the spacecraft to an encounter with Saturn, and perhaps other planets.

The original Grand Tour of the solar system was reduced to the two Voyager missions due to budgetary cutbacks, but it is likely that every outer planet but Pluto will be visited by Voyager II on its journey, due to the durability of the spacecraft and the ingenuity of NASA planners.

When Voyager was still 68 million miles from Saturn, the images it was sending back were better than any from Earth-based observation. Its closest encounter in August 1981 was 77,000 miles from the cloudtops.

When Pioneer 11 reached the ringed planet two years earlier in 1979, surprises were already turning up. Pioneer discovered that Saturn, like the Earth, Mars, and Jupiter, does have a magnetic field, and, though there were anomolies in the relationship of its magnetic field to the axis of the planet, the real challenge was the rings. What Galileo described as "cup handles" in 1610 were turning out to be considerably more complicated than previously thought.

Earth-based observation indicated there might be up to a half-dozen rings. Pioneer 11 showed that an estimate of 10-50 rings was more likely. The mysterous F ring was seen for the first time.

The better our observing instruments became, the more rings we discovered. Voyager I placed the number of rings at at least 1,000 and the second Voyager, with better resolution and from a different angle, showed 100,000 rings! Scientists now expect that the number of rings observed will increase with the fineness of resolution of the instruments we send to Saturn. The major puzzle is why there are so many rings, how they formed, and why they are still there.

Because there were a couple of years separating the Pioneer and two Voyager encounters, we were able to observe the dynamic features of the rings. On first glance, the F ring was braided or twisted, made up of more than one strand. This braiding disappeared on later encounters.

Rings were shown to shift position, to coalesce and to form structures, or "spokes" inside them. Not only was the system stable, it was constantly changing!

As scientists tried to make sense out of this data, a spokesman at the Jet Propulsion Laboratory in California maintained a positive attitude stating, "If we knew what we were going to find there, there would have been no reason to go there." Dr. Andrew Stofan from NASA headquarters remarked, "We learned more about Saturn in one week than in all of recorded history." But no one could explain the rings.

After the Voyager I observations, scientists posited that there might be small moons that would "shepherd" the rings, and keep them in tow. Voyager II found no such moonlets. Scientists from the Fusion Energy Foundation stated at the time that a simple extension of Newton's equations, which attempted to explain such phenomena on the basis of the gravitational relationship between all of the individual particles, could not explain the rings' formation and continued existence.

The problem was similar to the breakdown of Newtonian physics in explaining the relationship between more than two bodies of any size in the universe, the so-called "three-body problem." New physical concepts, based on the dynamic relationships of collections of particles, such as the rings, would have to be developed to unravel the Saturn mystery.

The giant of the solar system, Jupiter, posed as many challenges as its ringed neighbor. Radiating 1.8 times more heat than it receives from the sun, this gas giant still baffles astronomers.

In 1979 Voyager I showed that Jupiter has a rapidly changing atmosphere, which looks like it is made up of swirling liquids, though it is actually gaseous. The great red spot had changed shape, position, and color since Pioneer had observed it four years earlier.

Huge cyclones were seen traveling across the face of the planet at up to 200 miles per hour. A permanent jet stream of frozen ammonia swirled at 350 miles per hour above Jupiter's clouds. The puzzle to hydrodynamicists studying Jupiter's weather was that, at the high velocities at which the phenomena were traveling and at the level of viscocity or resistance associated with the materials of the atmopshere, the atmosphere was expected to be randomly turbulent. But instead it was found to be highly ordered and stable over significant periods of time.

The puzzle of Jupiter's weather system challenges the very basis of weather science here on Earth. Considering the success forecasters have had with the weather on Earth, there is no doubt that solving the discrepancies in current hydrodynamic theory by examining the weather of Jupiter could benefit this science for immediate applications.

Nearer-Earth space has also proven to be a valuable vantage point from which to look at our Earth. An impressive array of remote sensing technologies, communications satellites, and military spacecraft have been used to develop resoures on Earth.

Developing the Earth

The first satellite launched by NASA, on January 31, 1958, discovered something very important about the environment of our Earth. We are surrounded by a series of radiation belts, made up of particles that have come to us through interplanetary space from the sun. These "Van Allen belts," named after their discoverer, capture these high energy particles and protect the Earth, making life possible.

Later in the same year, Vanguard I made measurements of the Earth to determine its exact shape, and in early 1959 Vanguard 2 sent back the first satellite photograph of our planet. Today's Landsat satellites observe the Earth in wavelengths that can inventory world agricultural production and predict floods.

Over the past twenty-five years, NASA has launched satellites to observe the weather, oceans, lands, and atmosphere of the Earth. One of the most important applications for this wealth of technological capability and data is to facilitate the large-scale development of whole sections of our underdeveloped home planet, even as we are moving on to create other worlds.

Surveys and maps of inaccessible parts of the world have become possible using Landsat capabilities. Before any new infrastructure is designed, especially for transportation or large-scale water projects, satellite data should be consulted. Satellite data has helped update maps for road construction projects in Upper Volta, for example. Satellite images taken at different times of the year were able to provide planners with a water inventory of the region targeted for construction, and indicated small man-made water reservoirs that had been built but did not appear on maps, so a more accurate plan could be made for new roads.

Areas of the world which are uninhabited but potentially rich in minerals and raw materials will be developed over the next decades as a result of space exploration. In November 1981 the Space Shuttle carried into orbit a multispectral infrared radiometer, designed to observe the Earth in the nonvisible near- and far-infrared wavelengths. The instrument flew over the Baja California region of Mexico during its test in space, a desert region that has never been prospected for natural resources. Scientists examining the data observed the presence of certain molecules which indicated a past activity of certain hydrothermal processes.

Geologists knew that regions in the United States with a similar composition had been found to contain deposits of gold, silver, copper, lead, and zinc. A team of scientists, both American and Mexican, was sent to the site via helicopter and verified the Shuttle findings.

A global resource inventory using techniques of this kind could open up presently unknown reserves for economic exploitation. Industrial activity will spread to now-barren regions of the world.

Every year the world loses billions of dollars and millions of tons of food through disease, drought, and spoilage. Landsat data, through the Agristars and other programs, has demonstrated that crop disease can be identified early enough to stop its spread and initiate treatments.

Water inventories, including snow cover in mountains in winter and the water levels in reservoirs and other bodies, can alert farmers to pending flood or drought. Crops can be monitored for moisture during growth seasons, indicating where problem regions may develop.

Accurate weather forecasting is key for agricultural production and satellite data has proven indispensable for this activity. Satellite-assisted rainfall monitoring has been successfully used in irrigation design in Indonesia, water management in the Arabian peninsula, and desert locust monitoring and control in north-west Africa.

Satellite communications is the most promising solution to the great problem of mass education in the developing nations. During the 1970s, India conducted the Satellite Instructional Television Experiment, or SITE. The part of the NASA ATS-6 satellite designated for the SITE experiment carried educational television programs to nearly 2,500 rural villages scattered over the entire country. Programs were transmitted to the NASA satellite from Delhi and Ahmedabad and were received on small television receivers in the villages. The average audience for the community receiving sets was about one hundred. Most of the participants were illiterate and had never before been exposed to radio or newspapers.

Interviews and surveys conducted during and after the experiment indicated that children exposed to the educational programming showed gains in language skills and an increased interest in learning. Importantly, 50,000 rural teachers were also exposed to curriculum material for teaching science and mathematics.

Farmers learned about new methods in agriculture and basic health practices from programs which were beamed into these villages. On the basis of the SITE success, India decided to include two high-powered television transmitting devices on the INSAT communications and weather satellites in operation now. The second in this series of multi-purpose satellites was launched on the last flight of the Space Shuttle.

Communications using satellites will, in general, be the nearest-term solution to creating unified industrial nations in the developing sector. The island nation of Indonesia has launched satellites for communications since 1976 to link together the hundreds of islands that are inhabited. Since August 1976 telephone and television links have been in service, and newer satellites have extended coverage also to the Phillipines, Thailand, and Malaysia.

The goals of the Indonesian satellite communications program are to provide for growth in capacity for telephone, telegraph, and telex throughout the country, particularly in the outer provinces; to extend television service to all of the provinces; and to introduce educational television on a national basis.

Other geographically dispersed nations, from Canada to China, will find that to enter the twenty-first century they must make use of the most advanced space-based technologies.

Man into the cosmos

One of the most difficult challenges of the first quarter-century of the space age has been the development of capabilities to sustain not only sophisticated instruments in space, but man himself. NASA has followed the philosophy that, although unmanned planetary probes will bring us a wealth of new knowledge that man can not go and gather himself at the present time, the presence of man in space is the key to spreading human culture and civilization beyond the Earth, to carrying on unique experiments in space, and to observing and reporting phenomena our instruments can not yet capture.

As nuclear and fusion technologies develop that take man further away, they will be able to propel our unmanned spaceships even further. There will always be a need for both capabilities in space.

In the press materials issued by NASA three weeks before the historic mission that landed men on the Moon, the statement was made: "If the mission—called Apollo 11—is successful, man will accomplish his long-time dream of walking on another celestial body." After a break-neck speed eight-year program, NASA met the mission objective set by President Kennedy in 1961.

The Apollo mission involved the most difficult space maneuvers, and the most massive space components man has yet ever taken off the Earth. The dozen steps from Earth launch to splashdown were practiced in stages through the Mercury, Gemini, and Apollo manned programs.

After the liftoff of Apollo 11 atop the Saturn V rocket, the third stage of the rocket attached to the Command Module, Service Module, and Lunar Module was put into a 100-mile Earth parking orbit. The Command Module would house astronaut Mike Collins while the rest of the crew was on the lunar surface. It would also be the reentry vehicle for the whole crew.

The Service Module would carry the consumables needed for the trip, and would be jettisoned before reentry. The Lunar Module would separate from the mother ship in lunar orbit, land on the Moon and then fire and link up with the Command Module.

The third stage of the giant Saturn V rocket would be re-ignited when the approval came to embark on a translunar trajectory. After the third stage separated from the spacecraft, one of the most difficult maneuvers would take place, involving the redocking of the Lunar Module at the front of the Command Module.

Approaching the Moon, the spacecraft would be put into first an elliptical and then a circumlunar orbit, about 60 miles above the surface of the Moon. After twenty-one hours of orbiting the Moon, the Lunar Module would descend and orbit alone at 50,000 feet. After descent and touchdown, the Lunar Module was to stay on the Moon for two hours and forty minutes.

While on the Moon, astronauts Neil Armstrong and Buzz Aldrin initiated two experiments to be left on the surface. The first was a passive moonquake experiment, to see if this satellite has the same kind of geological motions that characterize the Earth. The second was a reflector to mirror laser beams from the Earth and back again. The amount of time it took the light to travel back and forth would be used to measure the distance between the two bodies to an accuracy of a few feet.

Over the years following the June 20, 1969 first lunar landing, a dozen astronauts walked on the Moon, collected samples, conducted experiments, and explored with specially designed vehicles.

The Apollo program required that NASA build a vehicle that could place 50 tons of equipment and men on the Moon. The Saturn V rocket contained 41 rocket engines, using solid, liquid hydrogen, and kerosene fuels. It stood taller than the Statue of Liberty and delivered 7.6 million pounds of thrust—the highest-powered rocket that has even been built.

The 33-foot diameter of the rocket required that new, out-of-vacuum electron beam welding technology be designed and developed, before parts of the rocket could be welded together. New materials were created to withstand the heat and cold of the Moon. A revolution in electronics and computer technology was required to monitor the astronauts' heartbeats in space and to take a spaceship a quarter of a million miles, and land it exactly where you aimed it.

Virtually the entire array of new technologies that entered the industrial factory over the decades of the 1960s and 1970s was developed from part of the $20 billion R&D program of Apollo. It has been estimated that for every dollar spent by NASA, more than ten dollars has been generated in overall economic activity.

New industries were created by the special demands of the space program and were then available to upgrade all of U.S. industry for decades.

An entire generation of scientists and engineers was created to meet the goal of going to the Moon. Hundreds of educational institutions benefited from upgraded science curriculum and materials that NASA developed for the classroom. And man fulfilled one of his oldest dreams—to put himself on a new potential Earth.