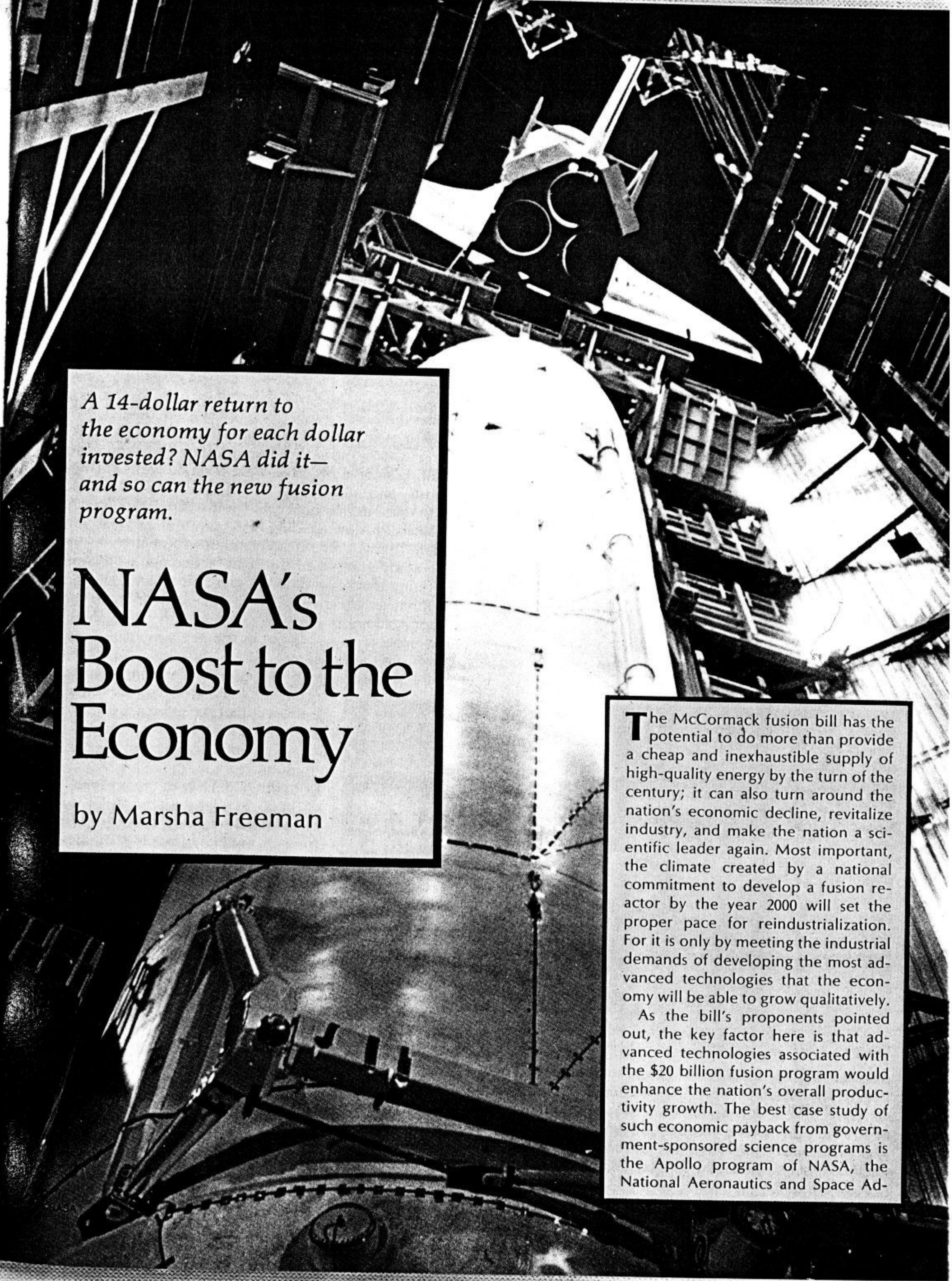


A 14-dollar return to the economy for each dollar invested? NASA did it—and so can the new fusion program.

NASA's Boost to the Economy

by Marsha Freeman

The McCormack fusion bill has the potential to do more than provide a cheap and inexhaustible supply of high-quality energy by the turn of the century; it can also turn around the nation's economic decline, revitalize industry, and make the nation a scientific leader again. Most important, the climate created by a national commitment to develop a fusion reactor by the year 2000 will set the proper pace for reindustrialization. For it is only by meeting the industrial demands of developing the most advanced technologies that the economy will be able to grow qualitatively.

As the bill's proponents pointed out, the key factor here is that advanced technologies associated with the $20 billion fusion program would enhance the nation's overall productivity growth. The best case study of such economic payback from government-sponsored science programs is the Apollo program of NASA, the National Aeronautics and Space Administration. A study conducted in 1976 by Chase Econometrics, a consulting firm associated with Chase Bank, estimated that for every dollar spent in the program, 14 dollars were returned to the economy in new jobs, factories, technologies, and other economic benefits. However, even this astounding rate of return is probably an underestimate, because the study did not take into account the full, qualitative effects on productivity of the advanced technologies that NASA developed. And despite the fact that the funding for the NASA program has gone downhill since the late 1960s, the enormous range of technologies developed to make manned space travel possible are continuing to have new applications throughout the economy.

Most of today's NASA critics probably have no idea of the tremendous advances made possible here on earth by space technology. The takeoff of the U.S. electronics and computer industries, two leading sectors of the U.S. economy today, for example, was sparked by the Apollo program, as was the development of a long list of advanced products such as remote sensors for monitoring infants in intensive-care units, artificial limbs, and all-weather tires.

But perhaps the single most important economic effect of the Apollo program was the upgrading of science training at all levels of the U.S. education system and the development of a new generation of American scientists. To take one area where this influence has been vital: many of the scientists working in the fusion program on the problems of advanced plasma physics, in materials development, and in other frontier areas got their education as a result of NASA-funded or NASA-inspired science programs. This process of educating future scientific discoverers and the long-term effects of the introduction of new technologies have an incalculable effect on society. As Dr. Lloyd Berkner, former chairman of the Space Science Board of the National Academy of Sciences and one of the leading scientists in the U.S. space program, put it:

> Each new technology derived from science has a permanence that continues to benefit society indefinitely in the future. Thus capital represented by discovery outlives all other forms. Consequently, the investment in basic research should be written off over an indefinitely long time against the permanent gains acquired by society.

The Payback from NASA

When the funding for NASA research and development began to stagnate and then decline in constant dollars starting in 1965, the U.S. economy lost its major source for the infusion of new ideas, new technologies, and new scientists and engineers. The dropoff in productivity growth that became noticeable in the early 1970s was the price paid for downgrading NASA and the nation's commitment to scientific research and development.

The study completed by Chase Econometrics in April 1976 found that federal dollars spent on NASA R&D were four times as effective as other R&D spending and that the applications of technological breakthroughs in the NASA program were visible in the economy within two years of their achievement.

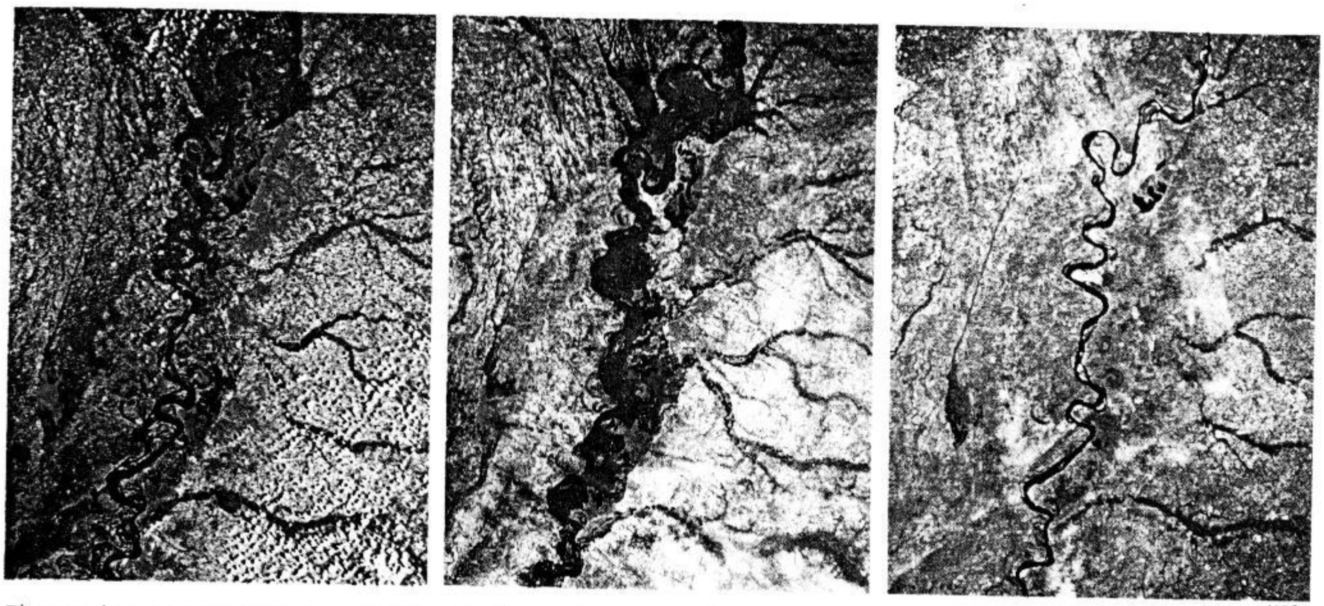
More impressive than any quantitative estimate of the economic impact of NASA spending is the fact that the space program has accounted for every important advance in industry, agriculture, and transportation in the United States from the mid-1960s to the present.

The U.S. edge in electronics and telecommunications stems directly from the miniaturization techniques and reliability standards instituted by NASA. In 1964, NASA established a reliability program and standards for microelectronic products for use in its own programs, which were subsequently adopted by the Defense Department and the industry as a whole. The production of components in accordance with NASA standards reduced the percentage of spoiled parts and increased production yields in the industry by about 20 percent. Today U.S. exports of microelectronic components continue to account for more than two-thirds of the world market.

The takeoff in a related field, the computer industry, was made possible

NASA

Frontispiece: The space shuttle Orbiter Enterprise is lowered into the 36-story test facility at Marshall Space Flight Center. Above: This sophisticated dispatch computer system operated by the Philadelphia Electric Company monitors and controls electric power throughout the company's network. Called SAMAC, System Automatic Monitor and Control, it incorporates technology developed for the Apollo program by Rockwell International and a separate spinoff by Philco-Ford.



NASA

The Landsat satellite program, a NASA spinoff, has the potential to revolutionize agricultural planning. Shown here are composite photographs of the Mississippi River flood in spring 1973, taken by Landsat I. Healthy crops, trees, and other green plants are bright red; suburban areas, light pink; barren lands, light gray; cities and industrial areas, green or dark gray; clear water, black. At left is the flooding near its maximum; the center image shows the extent of flood damage to the lowlands, where most of the farmland is water-logged; the final picture shows the remarkable recovery in the region by late summer.

by the cheapening of semiconductor components and solid-state technologies that resulted from NASA-funded research. There are now 1 million computers in the United States, operating in every aspect of business, industry, and agriculture.

The computer hardware and software developed for space systems have also had specific applications in manufacturing and industrial research. The multiplexer circuit developed for the Marshall Space Center for use in the Saturn rocket was installed in most U.S. textile weaving mills between 1968 and 1971, yielding productivity increases of an estimated 2 to 3 percent.

NASTRAN, a computer software package developed for analyzing the behavior of elastic structures under a wide range of conditions, was released for public use in November 1970. The system, which was developed at the Goddard Center between 1965 and 1970 at a cost of $3 million—an investment no individual firm could afford—is now being used in aircraft and auto production, bridge construction, and power-plant modeling studies.

In the course of producing spaceships that would take men and equipment through millions of miles of hostile environment, NASA researchers had to develop extraordinarily precise, nondestructive techniques for testing reliability and performance standards. An ultrasonic testing technique developed by NASA for $2 million has now turned into an industry with annual sales of $50 million. The testing equipment is being used for quality control in the production of steel, rails, aircraft, nuclear reactors, and automobiles. An infrared scanner and TV display screen developed for the Marshall Center are now being produced commercially by the NASA contractor, who founded a new company called Dynarad, Inc. The highly sophisticated equipment is being used for research in a large number of industries: steel, aluminum, petrochemicals, rubber, nuclear fuels, aircraft, and electrical power; it is also being used in the diagnosis of breast cancer.

Hundreds of materials have been transferred from the space program to industry, including high-temperature resistive alloys and ceramics and radiation-shielding materials for space and nuclear radiation protection. Or to take an example familiar to all automobile owners: The development of a type of rubber that does not become brittle at low temperatures led to the production of all-weather tires.

The technology spinoffs of the Apollo program have begun to transform a number of key sectors of the economy:

Transportation. The techniques developed for guiding and monitoring traveling spacecraft have, of course, been applied to aircraft of all types. They have also begun to be applied to the nation's outmoded and inefficient railroad system with extremely promising results. The most significant increase in productivity in the U.S. rail system in the past 20 years came from the installation of a computerized train dispatching and control system by the Southern Pacific Railroad. The system was originally developed by TRW as the Apollo Guidance System for the Johnson Space Flight Center in the early 1960s and was subsequently adapted for ground transport.

Agriculture. In agriculture, the introduction of remote sensing by satellites has given farmers an invaluable tool for determining the extent of crop damage, the spread of pests, ice accumulation in winter, spring water run-off, and soil condition. Landsat, for example, is revolutionizing agricultural planning.

Weather. Accurate weather forecasting and advances in meteorology, other spinoffs of the Apollo program, have alerted farmers to advancing hurricanes, tornadoes, and destructive rains. Global spot-checking of the growth of crops through meteorological equipment will one day enable farmers to coordinate planting on a worldwide basis.

Medicine. The applications of space-age technologies to medicine have been among the most extensive. NASA imaging technology, designed to develop pictures taken from satellites and spaceships from a distance of thousands of miles, is now used in developing medical X-rays. Artificial limbs were created by applying the remote handling technology developed by NASA and by the Atomic Energy Commission (AEC) for use in nuclear plants. Mass spectrometers preset to collect and analyze the atmosphere, a pilot's breath, the space environment, and the soil of Mars have been modified to measure eight critical components of a hospital patient's breath and emit a signal when any of them fall below critical levels. These spectrometers are being used in 200 intensive-care units worldwide.

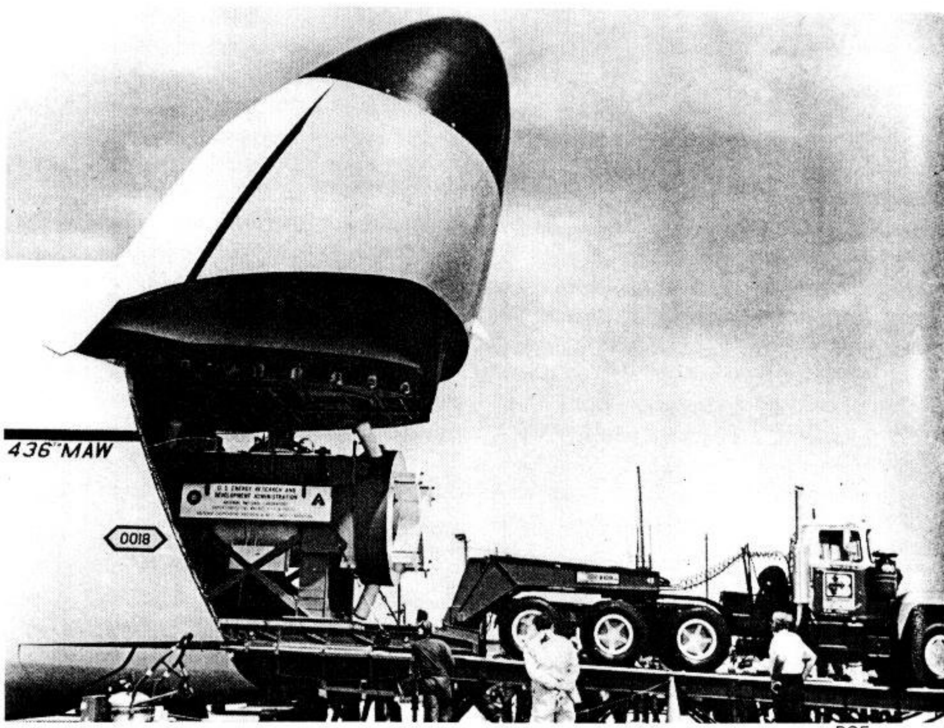
In 1968, NASA's Office of Technology Utilization collected reports on the new technologies that NASA had developed with its contractors in order to computerize and index them for further use. Five hundred thousand were cataloged at that time, and new technologies were coming in at the rate of 6,000 per month.

In 1961, at the beginning of the Apollo project, no one dreamed that once the project's goal was accomplished—the landing of a man on the moon—the United States would not continue the manned quest of the rest of the solar system. To go farther than the moon, NASA would need propulsion systems that did not rely on chemical propellants, but on advanced nuclear and fusion plasma systems, and NASA began to develop these. In 1963, NASA and the AEC launched the ROVER project to develop an in-flight nuclear reactor and the Nuclear Engine, Rocket Vehicle Application Program (NERVA) to develop a nuclear-powered engine.

The joint programs were canceled in 1972, even though the initial work showed that the difficult problems of nuclear-powered space flight could be overcome, because no plans were being made for continued manned space exploration.

Both programs had important spinoff applications for the ground-based nuclear industry, however. Work done on compact, high-temperature nuclear fuel arrays led to the development of composite fuel elements, which have been used in safety experiments in the liquid metal fast-breeder program. Advanced reactors in the NERVA program incorporated "beaded" fuel particles—highly enriched uranium cores coated with pyrolytic graphite—embedded in a graphite structure. This approach to fuel fabrication has been applied to use in high-temperature gas-cooled nuclear reactors.

When the NERVA program was discontinued, many of the 450 Westinghouse employees who had worked on the program applied the analytical techniques developed to maintain high reliability and safety in space travel to the Clinch River breeder reactor program, for which Westinghouse was the lead manufacturer.



DOE

The spinoffs from the U.S. fusion program are likely to surpass those of NASA. An immediate technology for development is superconducting magnets. Here a U.S. Air Force C-5 Galaxy transports a huge superconducting magnet fabricated by the Argonne National Laboratory in Illinois. The magnet was sent to Moscow for use in a cooperative program in magnetohydrodynamics.

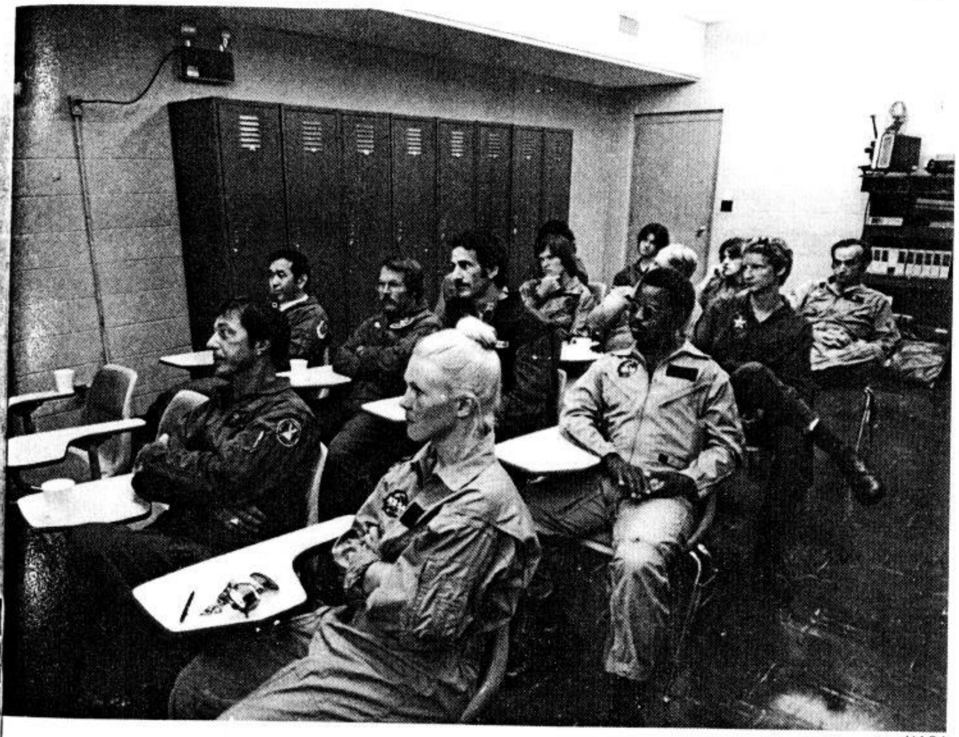
From the beginning of the space program, NASA scientists were involved in the development of plasma-based systems for space propulsion and direct conversion systems for on-board electrical power. Conferences on plasma propulsion sponsored by NASA through the 1960s drew together scientists from fusion, magnetohydrodynamics, and related fields, and played a significant role in the subsequent progress of both the U.S. fusion and MHD programs.

MHD, a technology for directly converting a hot, ionized gas from fossil fuels, nuclear energy, or fusion to electricity, has used actual rocket engines for testing components of the energy production system. The main laboratory used by the Department of Energy for experimental research on liquid metal MHD systems is NASA's Lewis Research Lab, and all of the work on MHD has benefited greatly from the high-temperature materials developed for space exploration. In addition, NASA's management skills have been applied to the MHD program—NASA's Lewis Lab is managing the next-step Engineering Test Facility for the Department of Energy program.

pact—was the creation of a new generation of scientists. In 1962 NASA set up its Sustaining University program.

The aims of the program were to help finance postgraduate training for young scientists and engineers, to build new research facilities or improve existing ones at colleges and universities, and to distribute funds for space science research.

At the height of the program more than 200 educational institutions were receiving money for space research; 1,500 faculty members and more than 2,000 graduate students in the sciences were engaged in space science and technology research in 1967.



NASA

NASA's major contribution to upgrading U.S. science education was felt from the top levels of advanced education down to the elementary school level, where the principles of rocketry and space science became classroom topics. Here astronaut candidates are shown in a course at Vance Air Force Base in Oklahoma on what to do if ejected from an aircraft.

Grants awarded by NASA for research in colleges rose from $3 million in 1959 to $128 million in 1968. Between 1959 and 1969 NASA distributed more than $700 million to university programs. Of this, about $500 million went for direct work on space science projects, and $200 million went for student grants and the upgrading of teaching facilities.

By 1964, NASA was spending $20 million per year just for predoctoral training programs, and 3,600 students were working on space-related problems in 30 academic disciplines under NASA sponsorship.

NASA was simultaneously working closely with the National Science Teachers Association (NSTA) to improve public and parochial school science curricula. In 1960, the NSTA began publication of a series of 13 paperback science books for children. NASA later gave NSTA a grant of $19,000 to develop a science curriculum for kindergarten through grade six called Investigating Science with Children.

Both NASA and the science teachers felt it would be of immeasurable value to give the nation's brightest science students the opportunity to meet and talk with scientists in the space program. From 1963 to 1971, Youth Science Congresses were held at 10 NASA regional laboratories, where the students presented their own papers, heard critiques of their work from NASA scientists, their peers, and science teachers, and visited the NASA labs.

The AEC was also involved in this educational process, and in 1960 initiated a series of National Youth Conferences on the Atom. Financed by 60 investor-owned utilities, the program drew significant interest. However, the change of the title to National Youth Conference on Science and the Environment in 1972 was symptomatic of the bowing of industry to environmentalist pressure.

NASA and NSTA recently revived their program for directly involving the nation's youth in the activities of the

When both the space program and the nuclear energy effort were going full throttle, joint work by the AEC and NASA attacked scientific problems and engineering challenges in fusion, MHD, superconductivity, and other frontier areas to create the technologies for the future. This type of cooperative research, which waned with the downgrading of the space effort and the escalating attacks on nuclear power, is a crucial prerequisite for relaunching U.S. R&D to bring whole new energy and industrial technologies into being in the 1980s.

Another crucial prerequisite is building the necessary scientific manpower through upgraded educational programs. The most important effect of the space program—the one with the least measurable but most lasting imspace program and are requesting ideas from high school students for experiments to be flown on the NASA Space Shuttle in the mid-1980s. But the momentum behind science education in the United States waned by the late 1960s and has yet to recover.

It will not be possible to move forward in the development of fusion without turning around the decline in science education during the last decade. Recognizing this, the DOE Office of Fusion Energy has established a program for supporting graduate education. Beginning in the coming fiscal year, the program will support the graduate education of a total of five students.

Under the guidelines of the McCormack fusion bill, the DOE must submit to Congress within one year an assessment of the scientific manpower requirements for meeting the goal of commercial demonstration of fusion energy by the turn of the century. The number of scientists in the United States working on the problems in fusion today is not significantly different from what it was two decades ago. Whatever the specific findings and recommendations of the manpower assessment, it is clear that a new generation of young scientists must be created to realize commercial fusion.

The development of commercial fusion power by the year 2000 will have a similar reordering effect on the entire economy as the NASA Apollo program did before it. The job is tougher, for the nation's basic industries—steel and machine tools, to take two examples—have declined precipitously in the last 20 years. But the promise for the economy is even greater, as the combination of an unlimited energy source and myriad new technologies bring the economy to qualitatively new levels of growth and development. In terms of reindustrialization, fusion will be setting the new frontier.

Even before fusion gives the nation the energy required to revolutionize materials processing and every aspect of energy production, the program will have major spinoff applications throughout the economy. A key example is the area of cryogenic technologies:

Commercial-scale magnetic fusion reactors will use large superconducting magnets. Such magnets, made of materials that are kept at a few degrees above absolute zero and operate with almost no energy losses through electrical resistance, are used today in scientific experiments but not commercially. (The exception to this is that Los Alamos Scientific Laboratory has just begun a project to build such a magnet for commercial long-distance electricity transmission.)

Since there has been no large-scale demand for the equipment, no mass production industry has developed to provide it. The special wire for superconducting magnets is fabricated on a made-to-order basis with the magnets wound by hand. But with commercial fusion power plants on the horizon, a whole series of superconducting industries will be required.

The importance of developing industries that can fabricate superconducting wire and cable, produce the cryogenic equipment to store and transport the liquid helium needed to keep the magnets cold, develop the insulation required for all parts of the technology, and integrate and control such a delicate technology is not merely that it will make the large-scale production of magnets economical. All aspects of power production, transport, conditioning, handling, and distribution will be revolutionized through the commercial availability of superconductivity.

Superconducting power transmission systems, laid in underground cables and cryogenically cooled, can eliminate the up to 10 percent loss of electricity now common in electrical transmission lines. Superconducting electrical components such as generators can eliminate losses and extend the life of such components.

The superconducting magnets themselves are also needed for other advanced energy systems, such as magnetohydrodynamics conversion.

Smaller magnets are already being used in advanced no-wheel train systems in Japan, called magnetically levitated trains. Using the electromagnetic fields generated by strong superconducting magnets, rather than wheels and petroleum-based diesel engines, these trains are running at 300 miles per hour and causing no noise or pollution.

Applications of superconductivity have been under development in industry and government laboratories for years. What is needed is the "push" from a government-sponsored research program, which will pay for an accelerated R&D effort—the way NASA did in the fields of computers and electronics.

A fusion-based revitalization of the nation's research and development program will affect every high-technology field in the economy. It will pose the immediate need to get the sagging U.S. nuclear industry back on its feet to make sure the nation can meet the electrical demands posed by a growing economy. This, in turn, will require modernized, efficient steel and machine-tool industries as well as a transportation grid that can carry the new load. The success of the fusion program will also require that we set new timetables for the commercial deployment of advanced nuclear technologies and MHD.

The way to solve economic problems has always been from the top. The NASA program created more jobs than any succeeding government make-work program. It brought more income to American families than any social welfare program. It created a pool of scientists and engineers unmatched by any other peacetime mobilization.

An Apollo-style fusion program, along with an upgraded and revitalized space effort, can provide the basis for an economic boom in the 1980s—and fusion energy in the 1990s.

Marsha Freeman is the director of industrial research for the Fusion Energy Foundation.

Note

1. For a full discussion of how high technology is essential for real economic growth, see *Fusion*'s special report "The Great Reindustrialization Debate" in the Oct. 1980 issue. The 64-page report is available in reprint from the FEF at $1.25 postpaid. Especially of interest is Uwe Parpart's article "Recovering World Industrial Leadership: The High Technology Path."