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U.S. Department of Energy
Assistant Secretary for
Congressional, Intergovernmental
and Public Affairs
Office of Public Liaison
Washington, D.C. 20585
202/586-4292

BIOGRAPHY

JAMES D. WATKINS
ADMIRAL, U.S. NAVY (RETIRED)
SECRETARY DESIGNATE

James David Watkins was born in California on March 7, 1927, and claims the city of Pasadena as his home. A 1949 graduate of the U.S. Naval Academy, he served on destroyers, cruisers and submarines, as well as in various shore assignments, including three in personnel management. Admiral Watkins' tours as a flag officer include Commander of the Sixth Fleet; Vice Chief of Naval Operations; and Commander-in-Chief of the Pacific Fleet. Admiral Watkins was selected by President Reagan to become the 22nd Chief of Naval Operations on June 30, 1982. He retired from that post June 30, 1986, and entered civilian life.

Admiral Watkins received his master's degree in mechanical engineering in 1958, and is a graduate of the reactor engineering course at the Oak Ridge National Laboratory. He was selected by Admiral Hyman G. Rickover to enter the Navy's nuclear-powered submarine program in 1959, and subsequently completed his qualification as an Engineering Officer of the Watch at the Navy's land-based reactor plant near Schenectady, New York. Thereafter, he had many years of experience in nuclear propulsion, including all aspects of bringing a new reactor plant on line as commissioning Executive Officer of a nuclear-powered submarine; Commanding Officer of a nuclear-powered submarine; and Executive Officer of the world's first nuclear-powered cruiser, the USS Long Beach.

In addition to assignments at sea aboard nuclear-powered vessels, Admiral Watkins served ashore in a variety of assignments associated directly with the selection, education and training of personnel as well as the maintenance and operations of naval nuclear propulsion plants.

The first of these was as assistant to Admiral Rickover for these same matters for three and one-half years at his headquarters in Washington, D.C., in the early 1960's. The second was as Director, Nuclear Power Distribution Branch of the Office of the Chief of Naval Personnel. In this capacity, Admiral Watkins was responsible to both the Navy and the then Atomic Energy Commission for proper execution of the stringent Navy personnel standards for maintenance of their qualifications. Later, as Chief of Naval Personnel and Vice Chief of Naval Operations, Admiral Watkins continued his leadership role as principal advisor to the Chief of Naval Operations and Secretary of the Navy on safe and efficient operations of the Navy's nuclearpowered fleet.

Finally, just prior to his assuming duties as Chief of Naval Operations, Admiral Watkins developed and effected implementation of the leadership transitional strategy from Admiral Rickover to his successor. This included documentation of all proven policies and

procedures employed so successfully over the years and conversion of them into Presidential Executive Order, and later into law. Extensive coordination with selected House, Senate and Department of Energy leaders was required.

While Chief of Naval Operations, Admiral Watkins spoke out about various national issues including the growth of international terrorism, technology transfer, and the evolution of nuclear deterrence from an offensive to a defensive strategy. For his leadership efforts in these and other areas, Admiral Watkins was awarded an honorary Doctor of Humane Letters from Marymount College in Arlington, Virginia, in August 1982; an honorary Doctor of Science degree in June 1983 from Dowling College, Long Island, New York; an honorary Doctor of Laws degree from Catholic University, Washington, D.C., in May 1985; and, in recognition of his technical expertise and for fostering technological growth while Chief of Naval Operations, Admiral Watkins received the Award for Creative Technology from Polytechnic Institute of New York in May 1985.

Admiral Watkins' military decorations include several Distinguished Service and Legion of Merit medals, the Bronze Star with combat "V" and other medals, and campaign and service ribbons. He has been decorated by many foreign nations, including Brazil, Korea, Italy, France, Spain, Japan, Pakistan and Sweden. He also was inducted as a Knight of Malta, an international order of leading Catholic laymen dedicated to humanitarian service, in June 1983.

Since retiring from naval service, Admiral Watkins has remained actively involved in issues regarding America's youth, working for the establishment of a national program for personal excellence. He has served as a member of the Carnegie Council on Adolescent Development, the Math/Science Advisory Council of the National Executive Service Corps, the Board of Directors of the National Center for Health Education, the Board of Visitors of the New York Medical College, and as consultant to both the Exxon Education Foundation and the Education Commission of the States.

Admiral Watkins' energy-related board service has included membership on the Board of Directors or Advisors of several firms: the Philadelphia Electric Company; a biopharmaceutical company, VESTAR, Inc.; SYNTEK Engineering & Computer Systems, Inc.; and the Ford Aerospace Corporation. He has also served as a Trustee on the Committee for Economic Development.

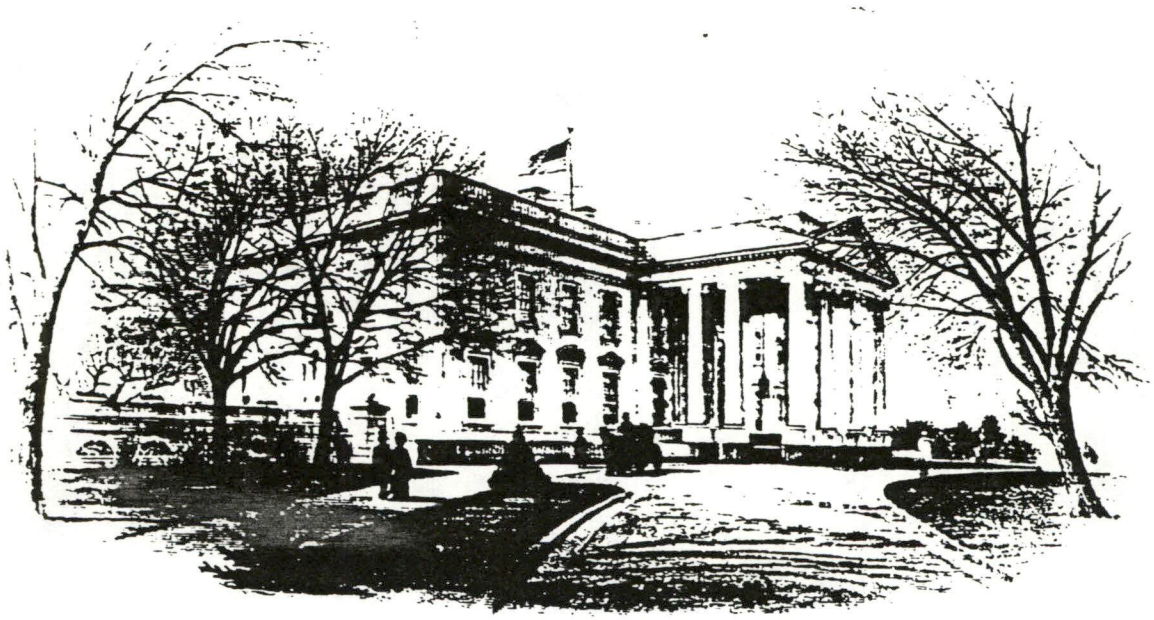
In October 1987, Admiral Watkins was appointed Chairman of the Presidential Commission on the Human Immunodeficiency Virus (AIDS) Epidemic, and submitted the Commission's final report to the President on June 24, 1988. For his work on this commission, he was awarded an honorary Doctor of Humane Letters from the New York Medical College in June 1988.

Admiral Watkins married Sheila Jo McKinney of San Diego, California, in 1950. They have six children: Katherine Watkins Coopersmith, Laura Jo Watkins Kauffman, Susan, Charles, James Jr., and Edward. Admiral and Mrs. Watkins have eight grandchildren.

February 1989

THE WHITE HOUSE

WASHINGTON



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NEWS from National Academy of Engineering

The National Academy of Engineering is a private organization established in 1964. It shares in the responsibility given the National Academy of Sciences under a congressional charter granted in 1863 to advise the federal government on questions of science and technology. This collaboration is implemented primarily through the National Research Council. The National Academy of Engineering also recognizes distinguished engineers, sponsors engineering programs aimed at meeting national needs, and encourages education and research.

2101 Constitution Avenue, NW, Washington, DC 20418

Date: September 28, 1988
Contact: Gail Porter, (202) 334-2138

MAJOR NEW INTERNATIONAL PRIZE ANNOUNCED BY ENGINEERING ACADEMY

EMBARGOED FOR RELEASE at 11 a.m. EDT Wednesday, September 28

WASHINGTON -- The establishment of a major new international award for achievement in engineering and technology, consisting of a gold medal and $350,000 in prize money, was announced here today by Robert M. White, president of the National Academy of Engineering (NAE).

Endowed by the Charles Stark Draper Laboratory of Cambridge, Mass., the prize recognizes engineering and technology achievements "contributing to the advancement of human welfare and freedom." According to White, the recipient of the first Charles Stark Draper Prize will be announced in October 1989. The award will subsequently be given biennially.

The award recipient will be selected by a committee appointed by the NAE and chaired by Robert C. Seamans Jr., senior lecturer, department of aeronautics and astronautics, Massachusetts Institute of Technology. Seamans is also former U.S. Secretary of the Air Force, and former president of the NAE.

"This award is designed to focus worldwide attention on the critical role that engineering and technology play in improving the quality of everyday life. Our society tends to reward the discoverer of basic scientific principles but overlook the engineer who puts that principle into practice in products and services that yield societal and economic benefits," said White at a news conference.

(OVER)

"We hope that in years to come the Charles Stark Draper Prize will be just as well-known and respected an award in engineering as the Nobel Prizes are today for chemistry, physics, and medicine."

White also praised the Charles Stark Laboratory for endowing the award. "It is fitting that this award has been established in honor of 'Doc' Draper," he said. "Draper's life's work epitomized the kind of far-reaching innovation the new award will recognize."

Charles Stark Draper developed the theory and invented and developed the the technology of inertial guidance systems now universally used in aircraft, submarines, missiles, and space vehicles. For example, the space shuttle Discovery carries a computerized inertial guidance system that will automatically guide it to the correct orbit above the Earth's surface after launch, and will direct the craft safely back to Edwards Air Force Base when the mission is completed. Inertial guidance systems use gyroscopes and accelerometers to determine a craft's position in space without any outside reference points such as stars, landmarks, or radio contacts.

Dr. Joseph V. Charyk, chairman of the board of Draper Laboratory said, "I can only surmise, but believe Doc would take great pride in knowing an international prize, recognizing engineering and technological achievements that contribute to the advancement of human welfare and freedom, has been established in his name. It is most fitting that he be so honored, and I'm sure that the people of Draper Laboratory share a sense of pride in the creation of the Charles Stark Draper Prize."

(MORE)

Nominations of candidates for the prize will be solicited from "members and foreign associates of the NAE, National Academy of Sciences, Institute of Medicine; members and foreign associates of academies of engineering worldwide; members of recognized U.S. and international engineering societies; and other individuals deemed eligible by the NAE."

Nomination materials describing the prize state that it may be given to any living individual or group of individuals from any country for either a specific engineering/technology achievement or for a body of work extending over a period of years. Work within all engineering disciplines will be eligible.

A listing of the Draper Prize committee is attached.

# # #

EDITOR'S NOTE: A photographic print of the Draper Prize logo as shown on the front cover of the press kit folder is available from the Office of News and Public Information.

gp: A,C,G,S

CHARLES STARK DRAPER PRIZE COMMITTEE

Robert C. Seamans, Jr. (Chairman)
Senior Lecturer
Department of Aeronautics
and Astronautics
Massachusetts Institute of Technology

Lew Allen, Jr.
Director
Jet Propulsion Laboratory
California Institute of Technology

Erich Bloch
Director
National Science Foundation

Harvey Brooks
Professor of Technology
and Public Policy, Emeritus
John F. Kennedy School of Government
Harvard University

Solomon J. Buchsbaum
Executive Vice President
Customer Systems
AT&T Bell Laboratories

Robert A. Charpie
Chairman
Cabot Corporation

Thomas E. Everhart
President
California Institute of Technology

John W. Fisher
Professor of Civil Engineering
and Director, ATLSS Engineering
Research Center
Fritz Engineering Laboratory
Lehigh University

Allen E. Puckett
Chairman Emeritus
Hughes Aircraft Company

Simon Ramo
Director Emeritus
TRW Inc.

Daniel I. C. Wang
Professor of Biochemical Engineering
Massachusetts Institute of Technology

Alvin M. Weinberg
Distinguished Fellow
Institute for Energy Analysis
Oak Ridge Associated Universities

Sheila E. Widnall
Abby Rockefeller Mauze Professor
of Aeronautics and Astronautics
Massachusetts Institute of Technology

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OPENING STATEMENT

Robert M. White, President,

National Academy of Engineering

News Conference

Establishment of the Charles Stark Draper Prize

September 28, 1988

Good morning. I am pleased to announce this morning the establishment of a major new award to recognize outstanding achievement in engineering and technology development. The Charles Stark Draper Prize will be given on alternate years and will include a gold medal and $350,000 in prize money, making it the largest award in monetary terms of its kind exclusively for engineering and technology achievement. The first award recipient will be announced in October 1989, at the National Academy of Engineering's 25th anniversary annual meeting.

The award is made possible by a generous endowment from the Charles Stark Draper Laboratory in Cambridge, Mass. It is fitting that this award has been established in honor of 'Doc' Draper. Draper's life's work epitomized the kind of far-reaching innovation the new award will recognize. As a professor of aeronautical engineering at the Massachusetts Institute of Technology, director of the university's Instrumentation Laboratory, and later as head of his own independent laboratory bearing his name, Draper pioneered

advanced technology for navigational guidance of aircraft, submarines, missiles, and space vehicles. Derivatives of Draper's "inertial guidance systems" are used in all modern sea, air, and space vehicles to determine a craft's position in space without any outside reference points such as stars, landmarks, or radio contacts. Draper was also responsible for development of the guidance system that safely took the Apollo astronauts to the moon and back.

The National Academy of Engineering has established the Charles Stark Draper Prize as part of a larger program to increase public awareness of the importance of engineering and technology. This award is designed to focus worldwide attention on the critical role that engineering and technology play in improving the quality of everyday life. Our society tends to reward the discoverer of basic scientific principles, but overlook the engineer who puts that principle into practice in products and services that yield societal and economic benefits. We hope that in years to come the Charles Stark Draper Prize will be just as well-known and respected an award in engineering as the Nobel Prizes are today for chemistry, physics, and medicine.

We have asked our selection committee of NAE members to search the world over for the individual or group of individuals from any nation who has made the greatest engineering or technology achievements "contributing to the advancement of human welfare and freedom." The committee will be chaired by Robert C. Seamans, currently a senior lecturer with the department of aeronautics and astronautics at the Massachusetts Institute of Technology and

formerly U.S. Secretary of the Air Force, deputy administrator of NASA, president of the NAE, and last but not least a student of 'Doc' Draper's.

Their task will be a difficult one, but, I suspect, quite rewarding, for in the process of selecting an award recipient they will undoubtedly trace the course of the greatest technological advances of modern times.

At this point my colleagues and I will be happy to answer any questions you may have.

Charles Stark Draper Prize

CHARLES STARK DRAPER PRIZE COMMITTEE

ROBERT C. SEAMANS, JR. (Chairman), Senior Lecturer, Department of Aeronautics and Astronautics, Massachusetts Institute of Technology

LEW ALLEN, JR. Director, Jet Propulsion Laboratory, California Institute of Technology

ERICH BLOCH Director, National Science Foundation

HARVEY BROOKS Professor of Technology and Public Policy, Emeritus, John F. Kennedy School of Government, Harvard University

SOLOMON J. BUCHSBAUM Executive Vice President, Customer Systems, AT&T Bell Laboratories

ROBERT A. CHARPIE Chairman, Cabot Corporation

THOMAS E. EVERHART President, California Institute of Technology

JOHN W. FISHER Professor of Civil Engineering and Director, ATLSS Engineering Research Center, Fritz Engineering Laboratory, Lehigh University

ALLEN E. PUCKETT Chairman Emeritus, Hughes Aircraft Company

SIMON RAMO Director Emeritus, TRW Inc.

DANIEL I. C. WANG Professor of Biochemical Engineering, Massachusetts Institute of Technology

ALVIN M. WEINBERG Distinguished Fellow, Institute for Energy Analysis, Oak Ridge Associated Universities

SHEILA E. WIDNALL Abby Rockefeller Mauze Professor of Aeronautics and Astronautics, Massachusetts Institute of Technology

ORGANIZATIONS SOLICITED FOR NOMINATIONS

American Institute of Aeronautics and Astronautics
American Institute of Chemical Engineers
American Institute of Mining, Metallurgical and Petroleum Engineers
American Society of Civil Engineers
American Society of Mechanical Engineers
Argentinean National Academy of Engineering
Australian Academy of Technological Sciences and Engineering
Belgium Royal Academy of Sciences
Berlin Academy of Sciences
Canadian Academy of Engineering
Danish Academy of Technical Sciences
Finnish Academies of Technology
French Academy of Sciences
Hungarian Academy of Sciences
Indian Academy of Engineering
Institute of Electrical and Electronics Engineers
Israel Institute of Technology
Japanese Academy of Engineering
Mexican Academy of Engineering
Netherlands Forum of Engineers
Norwegian Academy of Technical Sciences
People's Republic of China Academy of Sciences
Polish Federation of Engineering
Royal Swedish Academy of Engineering Sciences
Soviet Academy of Sciences
Spanish Center for Technological Industrial Development
Swiss Academy of Technical Sciences
United Kingdom Fellowship of Engineering
U.S. National Academy of Engineering
U.S. National Academy of Sciences
U.S. Institute of Medicine

NATIONAL ACADEMY OF ENGINEERING

2101 Constitution Avenue, N.W., Washington, D.C. 20418 USA

EXCERPTS OF REMARKS FOR
VICE PRESIDENT GEORGE BUSH
OHIO ASSOCIATION OF BROADCASTERS
COLUMBUS, OHIO
TUESDAY, OCTOBER 25, 1988

We have grown accustomed in the political arena to speaking in the language of economics. We talk of Gross National Product, the consumer price index and the leading economic indicators. The economists sift and tally their numbers and present us with the facts of our economic existence.

But I want to talk today about another kind of economic fact, one that is often overlooked by those numbers, but one that is, in many ways, more fundamental.

Imagine a computer the size of a room, shrunk down to a size that will fit comfortably on your lap. Imagine today's super-computer shrunk down so that it fits on a single silicon chip -- this is the kind of dramatic improvment the experts now predict. This is the computer revolution -- the positive explosion of productivity at the heart of our economy.

It is accelerating the process of discovery, of innovation and change and has helped give America, in these last eight years, one of the most remarkable periods of creativity our economy has ever known.

But the fundamental point I want to make today is this -- these dramatic breakthroughs don't only effect silicon valley or other high-tech centers, its effects are spreading throughout our economy.

It is a mistake to segregate in one's mind "high tech" from the rest of our industrial base. In fact, one of the most profound effects of this technological revolution is the revitalization of our traditional industries -- not replacement, but revitalization -- making our products more competitive in global markets. Technology is America's economic fountain of youth.

We are in a new era of American industry, where the "service sector" melds with the industrial sector to create modern manufacturing. Americans are taking America's high-tech advantage and putting it to work reshaping our factories to be more competitive in the new information age. Some of the most dramatic examples are right here in Ohio.

-more-

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DRAFT

PRELIMINARY
1/31/90

National Academy of Engineering
18-Month Program Plan
January 1990–June 1991

Technology and the Environment Program

It is already clear that humankind's damage to the environment has become a critical issue for all of us. The coming years will see a burgeoning of activities aimed at arresting and reversing environmental degradation at the local, regional, national, and international levels. The decisions that will be made and the actions that will be taken by governments, industries, and individuals are likely to involve significant economic impact and sweeping changes of our life-styles. A long-standing "paradox of technology" is that it can be both a source of environmental damage and our best hope for repairing such damage today and avoiding it in the future.

Following two years of examination of linked technological, environmental, and economic issues, the Academy has made a new three-year program, "Technology and the Environment," its top priority, reflecting the Academy's conviction that this issue is of the utmost importance to society. The program focuses on three themes that underlie the solutions to any of the widespread environmental problems we now face: technological innovation, institutional and economic implications, and international incentives and cooperation. The steering committee list appears as an item at the end of this preliminary program plan.

The program recently received a grant of $450,000 from the Andrew W. Mellon Foundation, and the staff is actively seeking additional private foundation funding. On January 8, 1990, the new NAE Technology and the Environment (T&E) Steering Committee, chaired by NAE President Robert M. White, met for the first time to plan an integrated program that would draw on the particular strengths of the Academy and could contribute substantially to public and private environmental strategic planning and policymaking. From among a wide variety of potential first activities, the committee selected five that could reasonably be initiated with the resources in hand during the first 12 to 18 months of the program.

1. A Technological Perspective on Urban Waste: A Systems Approach. The T&E Steering Committee advocated a systems approach to environmental issues in general. Urban waste was chosen as a case study to which such a systems approach could be applied. The waste explosion in all its manifestations is a universal problem. In the United States the evidence for declining environmental quality correlates with trends in production of solid waste (1/2 ton/capita/year in 1960 to an estimated 1 ton/capita/year in 1990). The purpose of the proposed project is to examine urban waste systems in a way that links production activities with the dispersive material flows to the environment from consumption activities. The NAE project would focus on the following questions:

- What consumption activities contribute most to waste, and which activities and products mobilize and release the most toxic substances?
- Are there alternative product and process technologies that can reduce both the volume and the toxicity of waste?
- What are the flows of materials through the production and consumption systems in urbanized areas, and how can we better monitor or predict them?
- How can the industrial metabolism (products and processes) and financial analysis be harmonized to provide appropriate economic incentives associated with materials flows and linked to environmental goals?
- What kind of evidence would it take to compare production, product, and disposal technologies and to analyze their environmental impact, paying special attention to the systems effects (unintended and often unanticipated impacts) of technological environmental solutions?
- What is the potential of materials accounting as a way of measuring environmental progress?

Assessing the urban waste problem in a broad social, economic, and technological context, it is hoped, may lead to an appreciation of the complexity and possible strategies for ameliorating the problem.

2. A Technology Assessment Study of Alternative Automotive Fuels. Despite two decades of effort on the part of the federal government and the automobile industry to reduce emissions from automobiles, air pollution in American cites has grown steadily worse. About half of the U.S. population lives in areas that do not meet federal clean air standards. Local problems in developed areas include carbon monoxide, oxides of nitrogen, various hydrocarbons, and ozone. There is also growing awareness of the global effects of automotive emissions. Transportation fuels yield about one-third of the air pollutants responsible for the greenhouse effect.

Several alternative automotive fuels have been studied as possible substitutes for gasoline (as it is now formulated), so that a large body of knowledge now exists on each of the major proposed alternative fuels. Notwithstanding the extent of our knowledge, there has been little progress toward implementing alternative fuel technology beyond small demonstration projects. The topic remains both controversial and wrapped in uncertainty.

The consensus of the T&E Steering Committee was that the strength of the NAE as a credible, impartial institution could be bought to bear to give policymakers an appropriately comprehensive perspective on the issue as well as a solid technical basis for deliberations. The proposed study would be a systematic assessment and comparison of leading alternative automotive fuel technology. The goals are (1) to compare the advantages and disadvantages of leading alternative fuels with respect to a common set of criteria—including various key emissions, related environmental effects, energy efficiency, infrastructure requirements, economic costs, and regulatory considerations—and (2) to recommend a strategy for research, development, and implementation, taking into account the total system needed to make use of alternative fuels.

3. Global Warming Policy Prescriptions and the World Energy System. Just as technological decisions lead to environmental effects (frequently unanticipated), upcoming environmental policy decisions will lead to possibly vast technological, social, and economic impacts. What effects would different strategies for environmental amelioration have on other national concerns such as industrial productivity, efficiency in the use of energy and materials, and international competitiveness, and on international trade and relations? As

seen in the example of the Montreal Protocol on Substances That Deplete the Ozone Layers, international agreements are being proposed and ratified ahead of the development of the technologies and institutions which the success of such agreements depends.

Limiting emissions of carbon dioxide is the principal strategy now advocated to ameliorate global warming. Various individual investigations have studied the implications of this strategy for the nation's energy system. It is time for a technically qualified and interdisciplinary body to address the issue. With this in mind, the NAE will undertake a project to resolve some the confusion about the likely impacts of policies to reduce global warming on the world energy system in relation to the time phasing of the implementation of policies. The project will emphasize interdisciplinary examination of the topic in a broad system context, bringing together economists, energy technology experts, and social scientists as well as environmental science and policy experts. The goal is to provide decisionmakers an accurate picture of current understanding of the far-reaching and subtle linkages between their strategic planning on global warming and the changes that would be induced in different nations' energy extraction, production, distribution, and consumption sectors.

4. The Economics, Politics, and Environmental Challenges in Technology Transfer to the Third World. Perhaps the most striking new aspect of environmental issues is the widespread recognition of their international nature. Global environmental awareness grows apace with the already significant globalization of production, markets, technology, and finance. The management of these concurrent changes poses complex and serious economic, social, and political problems for many nations. The NAE, working with the national academies of engineering of other nations through the international Council of Academies of Engineering and Technological Sciences, will investigate promising policy options. Through involvement of industrial and academic leadership of many countries, the NAE will seek to facilitate progress on environmental issues with global implications.

The NAE will conduct an international project to examine what industrialized nations can do through aid, technology transfer, or trade negotiation to shift the technological aspects of the economic development paths of third world countries to development paths that are less environmentally damaging than those followed by the world's current industrialized nations. The approach could be to examine the question broadly or to pick a particular technological question. In this regard, the United Nations Environment Program has offered to sponsor an activity aimed at encouraging and facilitating transfer of chlorofluorocarbon-substitution technology to developing nations. An NAE workshop on this topic could be an international forum for industry and government representatives to develop ideas for exploiting appropriate and practical technology transfer opportunities and other means of advancing the global elimination of environmentally harmful chlorofluorocarbons.

5. Economic Incentives for Environmentally Compatible Innovation. A primary challenge for the next decades in the United States is to integrate environmental considerations into industrial design and production planning in a manner compatible with economic and regulatory imperatives. Recently, the challenge to innovation for environmental quality has been increased by the legitimate concerns of nations about maintaining or improving their international competitive positions. How does engineering for environmentally sound production and consumption affect the economics and competitiveness of an industry? What is the ability of a system of market forces and institutions to provide incentives internationally and to promote practices that lead to environmentally desirable outcomes?

As a first phase in its approach to these issues, the NAE will initiate a study of barriers and incentives to environmentally sound innovation with a particular focus on commercializing more environmentally compatible technologies. The purpose of this activity

will be to develop an agenda for industrial leaders and government policymakers to provide economic incentives for adoption of process and product technologies that are more environmentally benign?

Prospering in a Global Economy

Over the last two or three decades, advances in communications and transportation technologies have changed the nature of the global economy. The degree of interdependence allowed by inexpensive and effective transportation and communications is unprecedented. U.S. businesses now have more than $1.2 trillion in assets abroad, and about one-third of earnings by U.S. multinationals comes from overseas operations. A recent complement to the expansion of U.S. direct investment abroad has been a virtual flood of foreign investment into the United States since the mid-1970s. Today more than 3 million Americans work for foreign multinational corporations with affiliates in the United States; in 1988 direct foreign investment in the U.S. totaled $328 billion, $2 billion more than American direct investment abroad.

The ability to produce advanced goods in many nations, the trend toward globally operated engineering and production, and the homogenization of many previously national product markets have changed the nature of economic activity among industrialized nations. This change has occurred in such a way that volumes of capital, goods, services, components, people, data, and technological know-how flow across national boundaries as part of everyday commerce. Just as technological advance is allowing increased international economic interdependence, so international economic activity is driving changes in the character of the global technological enterprise. In particular, economic interdependence among industrialized nations has brought the technological activities of corporations and governments into closer relationship than ever before, and sometimes into conflict.

The rapid transfer of technology across national boundaries has aided this trend, as have the research and scholarly exchanges among U.S. universities and foreign companies and institutions. Indeed, major U.S. research universities have become a model of truly international institutions—they are international educators, information exchange nodes, and global research facilities. With campuses abroad, student exchange programs, and philanthropic and research funding from both U.S.- and foreign-based multinationals, U.S. universities play an important and growing role in the international flow of technological know-how.

The emerging international integration of industries and research and educational institutions poses new questions and issues for all nations. Although international technology questions are somewhat familiar in Europe and in isolated trading nations such as Japan, this is a new global reality for the United States. The U.S. policy structure is not experienced in dealing with the issues raised by these new relationships among national governments, universities, and multinational companies, especially as they affect the U.S. engineering enterprise. To address these issues, the NAE has launched a major new three-year program, "The Interdependence of Nations: Technology and Economics in Global Relations," aimed at understanding how the United States might prosper in this new global economy. The program recently received a three-year $600,000 grant from the Alfred P. Sloan Foundation—to be matched by NAEF or other funds—for a minimum program size of $1.2 million over three years; the Academy is actively seeking additional funding for the program.

The initial project opportunities presented by this program were discussed by the International Affairs Advisory Committee, the Technology and Society Advisory Committee,

the Academic Advisory Board, members of the NAE committee on working on the precursor project to this program "Engineering as an International Enterprise," and with the on-site officers of the Academy. The three projects described below represent the projects proposed to be initiated or completed in the first 12 to 14 months of the program's operation.

6. **Technology Policy Options in a Global Economy.** The NAE will convene a committee to consider the history, current practice, and future prospects for national policies to encourage economic development through both direct and indirect government support of technological advance. This study would be carried out by a committee of the National Academy of Engineering, augmented when necessary by experts from other fields. The study addresses a topic about which volumes have been written—some by previous NAE committees—but the changing nature of the global economy raises new issues and calls for new approaches.

Although the interests of companies (serving shareholders) and nations (serving citizens) have never been perfectly coincident, there were, in the post World War II period in the United States, few obvious breaks between the interests of U.S.-based multinationals and U.S. citizens. They continue to share closely linked futures, but the increasingly transnational nature of effectively competing U.S.-based multinational companies raises new questions. As the technological capacity of a firm or industry becomes increasingly transnational, it follows that the dependence of that particular firm or industry on any single national engineering enterprise may diminish. With the gradual dissolution of the long-standing special bond between the U.S. engineering enterprise and U.S. companies, decisionmakers are recasting their views of the link between corporate and national interests in, and responsibilities for, U.S. technological enterprise. Conversely the increasing role of foreign-based multinational corporations in the U.S. economy, while generally representing a positive contribution, also raises new questions for the U.S. technological enterprise.

Corporations will do what they need to do to prosper, but can U.S. citizens (and their agent, the U.S. government) continue to rely on large U.S. (and foreign) multinational companies as the source of technological advance that will drive national as well as corporate economic growth? Has the burden of developing a sufficient technological infrastructure—a burden that used to be more evenly shared by firms and the public sector—shifted subtly to governments (local, state, and federal)?

This is not an exclusively American dilemma. Corporate and national interests are significantly changing in the economies of Western Europe, and even the intimate partnership between Japanese government and industry i,s beginning to experience the strains of globalization. Because globalization has intensified competition among nations for increasingly mobile corporate resources, an important aspect of the challenge for technology policy for the next millennium may be to make the United States an attractive place for global corporations to do engineering and technology-intensive industrial activities. Although it is unclear how the distribution of engineering activities will develop or be affected by the actions of different governments, America's trading partners appear to be better prepared to cope with these developments and to compete more effectively for the increasingly mobile technological, managerial, and financial resources of transnational firms.

These are obviously sensitive political questions, and the study itself is not intended to imply that corporate and national interests are now significantly at odds or mutually exclusive. The question that should be asked, however, is whether this diversity of interests requires new mechanisms to ensure that national concerns are recognized while multinational economic enterprises prosper.

7. The Role of Universities in Economic Development. Universities face a unique challenge in the emerging global economy. Unlike companies that are established to advance shareholder interests, or democratic governments established to represent citizens, universities are established to serve both an ideal—the pursuit and dissemination of knowledge—and an array of self-interested constituencies. U.S. land-grant colleges had explicit charters for economic development, but during the post World War II period, U.S. universities have become global intellectual utilities driving development and education not just in the United States but worldwide. It is an approach wholly consistent both with post-war U.S. government approaches to other nations and with the ideal of knowledge as the common heritage of mankind.

As U.S. economic dominance has faded, however, the pressure has steadily increased for universities, especially scientific and technical research universities, to contribute to local, regional, national, and international economic development. At a regional level, every state wants a "Silicon Valley," a "Route 128," or a Research Triangle Park supported in part by local university-based technical talent. At a national level, government agencies increasingly expect research grants to contribute to national competitiveness, and there are congressional concerns about foreign firms' increasingly active use of U.S. university research as a means of gaining free access to emerging technologies. In the next 10 years, U.S. universities are likely to face increasingly searching examinations of purpose as more and more members of their immediate constituencies ask who pays for, and who benefits from, university research and education.

A major study on this topic is proposed as part of the total program but is not yet funded. The topic was extensively discussed by the Academic Advisory Board of the NAE during its January meeting, and, because of the timeliness of this topic, the NAE Program Office will carry out an exploratory symposium in 1990 on the role of university research and education in national economic development. The symposium and subsequent publication will include industrial, academic, and federal and state government perspectives on the topic with a special focus on ways and means for U.S. universities to chart a course and continue to make an important economic contribution through the next 20 years of global economic change.

8. Linking Technology Policy, Industrial Policy, and Trade Policy: A Comparative Study of the Policies of Industrialized Nations. Governments encourage, aid, monitor, oversee, regulate, and control the workings of private industry in the international economy through trade policy, industrial policy, and technology policy in various ways and to differing degrees. One foreign view of the U.S. government position toward industry notes that, "America is the only nation among the advanced industrial countries that does not have a Department of Industry which is responsible for industrial policy. Instead, the Department of Commerce and USTR [U.S. Trade Representative] preside and their only real concern is trade related matters and they criticize others for the failure of American industry" (from *The Japan That Can Say "No"*—portion attributed to Akio Morita of Sony Corporation).

No transnational company is free of the limitations of its history, the legitimate laws and regulations of countries in which it operates, and, in a grander sense, its place in the development of the world economy. The U.S. economy, like the economies of other industrialized nations is a product of both private decisions and government preferences, regulations, and controls. In contrast to their Asian or most European competitors, U.S. firms appear to be driven more by short-term profit maximization than by considerations of market share or longer-term, know-how- based proprietary advantages. The reasons for these apparent national variations in corporate behavior—and the performance of companies in world markets attributed to these variations—are part management practice and accounting procedures, part financial market regulations and shareholder preferences, and

part government tax and fiscal policy, all combined with a host of other legal cultural, institutional, and political influences. These influences, in combination with a nation's trade policy—ad hoc or planned—and both implicit and explicit technology policy, significantly influence competitive outcomes in world marketplaces.

The historical approach of U.S. policy is one that (a) largely downplays attention to the structural composition of U.S. industry, (b) asserts that any (or most) government technology targeting for commercial purposes is doomed to fail because of incompetence and politics, and (c) holds that the only reason the United States deviates from the pure principles of free international trade is because we are forced to by other nations less enlightened than ourselves. It has become increasingly clear that this traditional U.S. stance and the approach it engenders are virtually unique among the world's industrialized countries. Unlike Japan, France, the Federal Republic of Germany, or Sweden, the United States elects to eschew a coordinated national economic development effort centered on technology development and diffusion, trade managed actively to promote the comparative strengths of U.S.-based production, and government-sponsored mechanisms for developing an industrial structure that can yield high value-added jobs for its citizens.

Right or wrong, the United States has taken a different path than its major trading partners, and the NAE proposes to explore this difference in approaches with a special focus on the degree to which U.S. technology policy (implicit and explicit) differs from the technology policies of other countries in its linkages to national development and trade strategies. The primary activity will be a small symposium involving experts—many from outside the United States—to explain and explore how such linkages are made, both informally and formally, in other industrialized nations. Although no comprehensive attempt will be made to assess the effectiveness of such efforts, a successful symposium and subsequent publication could serve as a benchmark for those interested in understanding "how the Japanese organize to penetrate new high-technology markets" or "what limits the ability of small U.S. high-tech companies to find other than British financing for their expansion."

The Continuing Technology Agenda Program (major projects in FY 1991 budget)

9. Time Horizons and Technology Investments. An activity is under way to gather evidence and sort out claims about the investment and planning time horizons of U.S. businesses. The project has a special focus on the interaction of managerial decision making and the overall financial and economic environment—cost of capital, financial markets, mergers and acquisitions, changing company capital structures, and increasing debt levels. Of particular concern are the allegations that the time horizons of U.S. businesses are shortening relative to those of foreign-based competitors and that these shortened horizons are creating a reluctance to invest in activities with slow payoff profiles, which are necessary for firms to build advantage on the basis of advanced technology.

The project will focus on three questions. Do U.S. firms have inappropriately short investment and decision-making horizons? If so, what are the primary contributing factors and consequences? What, if any, private and public-sector actions can be taken to alleviate the problem?The project will first examine methods to measure time horizons and their variations in different industries and countries. The second portion of the research will be to examine financial markets and managerial practices to determine the causes and consequences of the differences in time horizons among firms.

10. Foundations of Manufacturing Systems. The 1987 NAE-sponsored conference "Design and Analysis of Integrated Manufacturing Systems: Status, Issues, and Opportunities" pointed to a growing need to explore whether a manufacturing system discipline can be created. A committee has been formed to identify likely elements of such a discipline and will seek to interest experts, both educators and practitioners, in developing position papers on this topic. The results of this project will be a report describing and discussing the major intellectual elements of manufacturing system design, analysis, and operation. If it does prove possible to create such a discipline, or elements of it, both the practitioner and the educator should benefit—the practitioner by the development of generic tools that would assist in analyzing, designing, and controlling systems, and the educator because the teaching of generic tools and the representation of a systematic body of knowledge would be of great value to the student. Elements of a discipline might include agreement on definition of terms and the "basic laws" of manufacturing systems; a taxonomy of manufacturing, including reference languages, data structure, and a classification of functions; primitive descriptors for timing, control, scheduling, etc.; metrics for common descriptors, such as flexibility, adaptability, and economies of scale; and the design of processes. In addition, the discipline could explore basic theories for product design, process design, and system optimization.

11. NRC Support (Projects executed outside the NAE Program Office but supported wholly or in part by NAE funds)

Manufacturing Forum. It has been recognized that in the United States there is no means for policymakers to communicate on such key issues as technology development and utilization, incentives and disincentives for investment, strategic national plans as they relate to U.S. manufacturing industries, current and future trends in the labor force, and long-term educational needs and opportunities for the manufacturing sector. In March 1988 the Academies held a workshop under the chairmanship of Morris Tanenbaum (NAE) of AT&T to explore means by which policymakers from government, industry, and universities can meet to discuss these issues that influence the competitiveness of manufacturing industries. As a result, a Manufacturing Forum is being formed under the chairmanship of Dr. Ruben Mettler, former chairman and CEO of TRW, Inc. The Forum, a joint project of the National Academy of Engineering and the National Academy of Sciences, is supported by the National Science Foundation and the Office of Science and Technology Policy. The Forum will operate for at least two years.

New Directions in Catalysis Science and Technology. Catalysts are the engines of U.S. industries that manufacture chemicals, refine petroleum, produce polymers and fibers, and use precisely controlled chemical reactions for environmental control of pollutants. Although the United States has led the development of catalysis science and technology since the late 1940s, in recent years this leadership has come under an increasingly aggressive challenge from researchers in Western Europe and Japan. The NAE, in its continuing examination of competitiveness of U.S. industries and in support of its Technology and Environment program, is providing the NRC's Board on Chemical Sciences and Technology with partial support for its project "New Directions in Catalysis Science and Technology." A committee of the Board will prepare a substantive examination of catalysis research frontiers to focus attention on new directions in the field and serve as a brief guide to promising research opportunities for an audience of researchers in formative stages of their careers, scientists and engineers in related research areas, and research managers in industry and government. A high-visibility short report is planned for publication within one year of the project's full funding.

Committee on Women in Science and Engineering. It is widely agreed that, to a greater extent than for men, women with the potential to be excellent scientists and engineers have not been recruited and educated for this purpose. This, along with a new concern about the possibility of serious skill shortages in the future, led the National Research Council to organize a Planning Group to Assess Initiatives for Increasing the Participation of Women in Scientific and Engineering Careers. In 1988 this group recommended the establishment of a Committee on Women in Science and Engineering with the goal of increasing representation of women in scientific and engineering careers. The NAE will provide the NRC's Office of Scientific and Engineering Personnel (OSEP) with partial support for this committee's three-year effort contingent on OSEP obtaining an additional commitment of funds from other sources. The committee is composed of individuals representing the diversity among the scientific and engineering disciplines and includes educators, employers of scientists and engineers, and researchers of the status of women in science and engineering. The committee will act as a resource, information clearinghouse, and catalytic agent to encourage better understanding of the issues and to promote unified, structured interventions, research, and data-sharing. It is expected that these activities will result in the publication of information based on the committee's data-collection activities, workshop and symposia proceedings, and analytical studies. This information would be disseminated to sponsors and members of the scientific community, decisionmakers, and program managers in government, industry, and academe; researchers; employers; and others interested in the issues.

Other NRC Projects for Potential NAE Funding (capstone money or total funding only).

- Engineering and the Law (CETS project initiated with a workshop held at the behest of the NAE; submitted for approval by NRC Governing Board Executive Committee on November 15, 1989)
- Bioprocess, Engineering: Research Priorities and Policy Options (Commission on Life Sciences project; approval by NRC Governing Board Executive Committee on July 11, 1989)
- Competitive Status of Electrical Apparatus Equipment Industry (CETS project initiated at the behest of several NAE members; approved by NRC Governing Board Executive Committee on April 7, 1989)
- International Intellectual Property Protection (OIA project, exploratory funding provided by NAE; full study project approved by NRC Governing Board Executive Committee on September 14, 1988)

12. Engineering as a Social Enterprise (1990 Annual meeting technical session). The 1990 Annual Meeting Technical Session symposium concluding the 25th anniversary year of the Academy explores the ways in which technology and society form inseparable elements in a complex sociotechnical system. Each influences and constrains the other in both obvious and subtle ways. In the short term, technology often appears to be in the driver's seat—engineers and nonengineers alike tend unthinkingly to see technology as the main determinant of social change. For the longer term, the influence of society on technology is, in fact, at least equally crucial. In the end, social judgment, as much as technical performance, determines what counts as successful engineering. If this is true engineers, as well as nonengineers, need to gain a better understanding of engineering as a sociotechnical enterprise. Symposium participants should come away with an increased appreciation of how society influences technological choice and how the engineering community can be more aware of the society it serves.

The Continuing Technology Agenda Program (projects to be completed in FY 1990)

1. **Engineering as an International Enterprise.** The project focuses on international technological interdependence and its implications for sustaining national technological competence. The 18-month project culminated in a symposium at the Beckman Center on 4-5 December 1989; a report will be published in early 1990. The study addresses three basic types of questions.The first of these relates to scope, rate of change, and composition of global sourcing of engineering activities. The second set of questions focuses on causes of global sourcing, how they differ from one industry to the next, and how they have changed over time. Finally, there are questions that address implications of global sourcing for U.S. engineering capabilities as well as for U.S. economic growth. This work involves documenting and analyzing trends toward global sourcing of engineering talent, with the goal of providing U.S. policymakers and the U.S. engineering community with insight into possible alternative futures for the U.S. engineering enterprise and strategies for achieving them.

2. **Profiting from Innovation: Commercialization of New Technologies.** Commercial application of technological advance is fraught with challenges and problems, both inside a company working to bring a new product to market and in the interactions the company has with its suppliers, product users, and competitors. With the intent of enhancing the commercialization process, the NAE will examine these challenges in order to assist U.S. companies establish market positions and achieve an adequate return on investment. The activity will conclude with a report offered for comment and discussion among the U.S. business leaders, with the ultimate aim of dissemination to business leaders, decisionmakers, the business press, and students of technology management. More specifically, this study addresses the following questions, among others: (1) Why are many inventive contributions not brought to commercial success by the inventor, or within the inventor's own company, and sometimes not within the inventor's own country? (2) How can the needs, values, and preferences of the ultimate users of new products be perceived and incorporated in the process of product development? (3) Once the need for a product has been identified, how are the decisions made about the technology that will be included in the product that is considered to meet the need? (4) How can product adaptation to meet the requirement of different categories of buyers with varied performance and price criteria be planned and managed?

3. **Human Resources and Adoption of Workplace Technologies.** One of the major strategies used by manufacturing and service firms to increase productivity and improve quality has been the implementation of new workplace technologies. Frequently, however, the results have been less than satisfactory, and as a result, managers, policymakers, and scholars are now paying increasing attention to the organizational and human factors that facilitate or constrain the adoption and implementation of new technologies. Organizations faced with new technological frontiers must balance factors such as hiring decisions, training, and incentives in an attempt to establish a basis for operation in a changed, more competitive environment.

This interdisciplinary project is being conducted jointly with the Commission on Behavioral and Social Sciences and Education (CBASSE) of the National Research Council. Reports will be published based on a symposiumentitled "Designing for Technological Change: People in the Process," held 13-14 March 1989 at the Beckman Center. The

symposium and related activities have explored three specific technology areas—automated manufacturing technologies, office automation, and medical technologies. The objective of the activity is to provide insights on how social science findings can be converted into prescriptive guidelines for technologists and managers. Another outcome may be the development of an agenda of issues requiring further research.

4. Fostering Flexibility in the Engineering Work Force. Early in 1989, the Education Advisory Board of the NAE identified the adaptability of the engineering work force—i.e., the ability to transfer a given set of engineering skills among engineering fields and activities, between engineering and nonengineering fields and activities, and among sectors of the economy—as an issue with important implications for the United States' ability to exercise technological leadership and to compete effectively in international markets. The NAE asked the National Research Council's Office of Scientific and Engineering Personnel to conduct a study of what is known, and what needs to be known, about adaptability among the engineering work force in the United States, as a prerequisite to understanding what policy mechanisms may be needed, and what action might be taken to enhance the adaptability of the U.S. engineering work force. OSEP convened a steering committee of engineers and scientists from industry, academe, and the professional engineering societies and conducted a workshop on 29 September 1989 to explore the issue. The committee's principal conclusions will appear in the final report (currently in press) to the NAE.

5. Engineering, Engineers, and Engineering Education in 21st Century. Early in 1989, the Directorate for Science and Engineering Education (DSEE) of the National Science Foundation (NSF) requested the NAE to provide guidance to the NSF on the evolving character of engineering work, its effect on the characteristics of engineers who do the work, and its effect on engineering education.

In response to the request, the NAE convened a workshop (supported by a grant from the NSF) on 19-20 December 1989 to elicit the ideas of 18 experts from a variety of fields--engineering, industry, education, government, etc.--on what engineering and engineers might be like as they evolve in the next century. Bold new insights were sought, without presumptive assessments of the ideas and without an expectation of consensus. The resulting collection of views will be submitted to the NSF in the form of a letter report, to be used to obtain reactions and stimulate discussions in the wider professional community.

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NEWS From the National Academy of Engineering

The National Academy of Engineering is a private organization established in 1964. It shares in the responsibility given the National Academy of Sciences under a congressional charter granted in 1863 to advise the federal government on questions of science and technology. This collaboration is implemented primarily through the National Research Council. The National Academy of Engineering also recognizes distinguished engineers, sponsors engineering programs aimed at meeting national needs, and encourages education and research.

2101 Constitution Avenue, NW, Washington, DC 20418

Date: Oct. 3, 1989
Contact: Stephen Kay, (202) 835-8843
or Gail Porter (202) 334-2138

CREATORS OF INTEGRATED CIRCUIT RECEIVE WORLD'S TOP ENGINEERING AWARD

FOR IMMEDIATE RELEASE

WASHINGTON -- The National Academy of Engineering (NAE) has awarded the first international Charles Stark Draper Prize to Jack S. Kilby and Robert N. Noyce. Each will receive a gold medal and the two will share the $350,000 cash award -- the largest prize in the world given exclusively for engineering achievement. The two will receive their award at a ceremony in Washington, D.C., in February.

Kilby and Noyce are recognized by the scientific and engineering community as independent co-inventors of the monolithic (meaning formed from a single crystal) integrated circuit, better known as the semiconductor microchip. The NAE is honoring them as well for their separate work in bringing the integrated circuit into successful commercial production and application in commercial products.

Kilby is an independent consultant in Dallas and chief technical officer for the Houston Area Research Center. He is also a former assistant vice president for Texas Instruments. Noyce is the current president and chief

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executive officer of Sematech in Austin, Texas, as well as co-founder of Fairchild Semiconductor and the Intel Corp.

"Very few things have changed the world as dramatically as the integrated circuit," said Robert M. White, president of the National Academy of Engineering. "The development of the integrated circuit was the single most important event that helped usher in the Information Age. Like the invention of the telephone, the light bulb, or the automobile, the creation and widespread practical application of the integrated circuit has fundamentally changed our lives -- transforming computation, communications, manufacturing, and transportation and giving birth to a host of entirely new industries and services. The Academy is honored to present Jack Kilby and Bob Noyce with the first Charles Stark Draper Prize."

The Draper Prize was established by the NAE in 1988 and is endowed by the Charles Stark Draper Laboratory Inc. of Cambridge, Mass. Charles Draper -- "Doc" to his friends and associates -- was the father of modern inertial navigation systems. He conceived the basic idea of combining gyroscopes with an accelerometer to provide precise course corrections for long-distance navigation. He then converted this idea into practical systems now universally used in aircraft, space vehicles, strategic missiles, and submarines. Draper also developed the sophisticated navigational system that landed the Apollo astronauts on the moon and returned them safely to earth.

The Draper Prize, to be awarded every two years, honors individuals who have contributed significantly to the advancement of engineering and whose achievements have produced important benefits to the "well-being and freedom of all humanity." This year's recipients were chosen by a 13-member committee

of prominent engineers from industry, government, and academe. Robert C. Seamans Jr., senior lecturer at the Massachusetts Institute of Technology, chaired the committee. A complete list of members is attached.

"We believe," said White, "that the Draper Prize will focus world attention on the important contributions of engineers in the same way that the Nobel Prize now focuses attention on the accomplishments of scientists."

Despite his many previous awards, Noyce said that receiving the Draper Prize is particularly special for him because "it is given by a prestigious body in the name of a man for whom I had a great deal of respect."

Thirty years after the integrated circuit was developed by Kilby and Noyce, the ubiquitous integrated circuit is an essential component in items ranging from consumer goods to manufacturing equipment to medical imaging devices (such as the CAT scan) to automated bank tellers. Hand-held calculators, digital watches, automatic cameras, videocassette recorders, compact discs, and facsimile machines are among the multitude of everyday products that depend on integrated circuits.

The invention of the integrated circuit in the late 1950s represented an enormous improvement in capability for storing and manipulating information in a very small space. Prior to the advent of the integrated circuit, electronic products such as computers were made with miniaturized, discrete components such as transistors, resistors, and capacitors. Depending on the electronic function being performed, the manufacture of these products required that thousands of electrical components be individually interconnected with wire and solder.

Integrated circuits, by contrast, are constructed on a solid piece of

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silicon crystal. Through techniques that incorporate photographic processes and principles similar to those used in silk screening or lithography, hundreds of thousands of electronic components may be constructed and interconnected simultaneously in a space the size of a newborn's fingernail. The variety of electronic functions previously achieved through individual components is accomplished instead by creating a kind of bumpy silicon "sandwich," in which different layers and regions of the material have different electrical properties.

The small size, low cost, high reliability, and vastly increased speed of integrated circuits allowed engineers to create an array of new products. Production of personal computers, for example, would be impossible with the old technology. Since Kilby's and Noyce's pioneering work, the information-processing capacity of a single integrated circuit "chip" has doubled about every three years -- a rate of improvement in performance that is unprecedented for any other type of technology.

"When I started in electronics," commented Kilby, "all equipment was built with vacuum tubes. The transistor had not yet been invented. I don't think anyone would have thought at that time in terms of the revolution that's come about."

Kilby and Noyce were also responsible for the commercial success and expansion of the integrated circuit within the electronics industry. Jack Kilby led the development of the first computer that used integrated circuits and that of a family of integrated circuits for the improved Minuteman missile, the first military system to use integrated circuits. He also co-invented the hand-held, solid-state calculator and invented the semiconductor

gate array. His efforts helped to establish Texas Instruments as one of the world's largest manufacturers of integrated circuits.

Noyce co-founded Fairchild Semiconductor in 1957, which provided integrated circuits to the National Aeronautics and Space Administration for the on-board computer of the Gemini space capsule, one of the company's first sales of the new technology. In 1968, he co-founded Intel Corp., the first company to produce high-density memory components and microprocessors. These developments led to the present far-reaching applications and accessibility of the personal computer.

Both Kilby and Noyce have received additional honors for their inventions. They were named as joint recipients of the Franklin Institute's Ballantine Medal in 1967 and the Cledo Brunetti Award of the Institute of Electrical and Electronics Engineers in 1978. Kilby received the National Medal of Science in 1969, and in 1982 was inducted into the National Inventors Hall of Fame of the U.S. Patent and Trademark Office. A year later, Noyce was also inducted into the Patent Office's Hall of Fame. Noyce also received the National Medal of Science in 1979 and the National Medal of Technology in 1987. Both are members of the National Academy of Engineering.

Kilby became an independent consultant in 1970 following a 12-year career at Texas Instruments. He currently lives in Dallas, Texas.

In 1988 Noyce was named president and chief executive officer of Sematech in Austin, Texas, where he currently resides. He served Intel as president from 1968 to 1975, as chairman of the board from 1975 to 1979, and as vice chairman from 1979 to the present.

The NAE is a nonprofit organization comprising approximately 1,500

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members representing all engineering disciplines. Founded in 1964, it advises the federal government on issues in engineering and technology, sponsors engineering programs aimed at meeting national needs, and promotes the public understanding of the important role engineering and technology play in everyday life.

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Massachusetts Institute of Technology

JACK S. KILBY

BIOGRAPHY

Jack S. Kilby, co-inventor of the integrated circuit, was born in Jefferson City, Mo., in 1923. He is currently an independent consultant in Dallas and chief technical officer for the Houston Area Research Center.

Kilby graduated from the University of Illinois in 1947 with a bachelor's degree in electrical engineering, and in 1950 received a master of science degree in electrical engineering from the University of Wisconsin.

After designing small electronic parts for Centralab in Milwaukee, Wis., Kilby joined Texas Instruments Incorporated in 1958, where he set out to devise a solid-state instrument that could make electronics simpler, faster, and more reliable. His work culminated in the successful operation of the integrated circuit.

Kilby retired from Texas Instruments in 1970. Since then, he has served as a consultant on integrated circuits and semiconductors for a variety of firms. In 1982 he was elected chairman of the Department of Defense Advisory Group on Electron Devices (AGED). Affiliated with AGED since 1966, Kilby has given counsel to several U.S. defense organizations.

In addition to his nearly 60 U.S. patents, Kilby has received numerous awards, including the Ballantine Medal from the Franklin Institute and the Cledo Brunetti Award of the Institute of Electrical and Electronics Engineers (IEEE), both of which he shared with Robert Noyce. He received the National Medal of Science in 1969, and in 1982 was inducted into the U.S. Patent Office's National Inventors Hall of Fame. Other honors include the IEEE's Sarnoff Medal; the Zworykin Medal from the National Academy of Engineering; the Medal of Honor from the IEEE, and the Holley Medal of the American Society of Mechanical Engineers. Further recognition of his accomplishments in engineering, technology, and the sciences include the Alumni Honor Award from the University of Illinois's College of Engineering, the Alumni Achievement Award from the same institution, and membership in the National Academy of Engineering.

ROBERT N. NOYCE

BIOGRAPHY

Robert N. Noyce, co-inventor of the integrated circuit, was born in Burlington, Iowa, in 1927. President and chief executive officer of Sematech in Austin, Texas, since 1988, he is also vice chairman of Intel Corporation, a firm he co-founded.

Noyce graduated from Grinnell College in 1949 with a bachelor's degree in physics and mathematics and a membership in Phi Beta Kappa. He earned his doctorate in physical electronics at the Massachusetts Institute of Technology in 1953.

Following college, Dr. Noyce engaged in research at Philco Corporation and Shockley Semiconductor Laboratory. He co-founded Fairchild Semiconductor Corporation in 1957. In 1968, Noyce co-founded Intel with long-time associate Gordon E. Moore with the objective of making large-scale integration a practical reality. Today the company is the nation's third-largest semiconductor producer.

Noyce was a founding member and the first president of the Semiconductor Industry Association. He also was a member of the President's Committee on Industrial Competitiveness and the Defense Science Board.

Noyce holds 16 patents for semiconductor devices, methods, and structures. He and Jack Kilby have jointly received the Ballantine Medal of the Franklin Institute and the Cledo Brunetti Award of the Institute of Electrical and Electronics Engineers (IEEE). He and Gordon Moore have received the Harry Goode Award for leadership in computer science from the American Federation of Information Processing Societies, Inc. Dr. Noyce was awarded the National Medal of Science in 1979 and and the National Medal of Technology in 1987. He has also received the Medal of Honor from the IEEE and the Faraday Award from the Institute of Electrical Engineers (Great Britain). He is a member of the National Academy of Engineering, the National Academy of Sciences, the American Academy of Arts and Sciences, and is an IEEE Fellow. Dr. Noyce has been inducted into both the U.S. Patent and Trademark Office's and *Fortune* magazine's National Inventors Hall of Fame. He also is a member of Grinnell College's Board of Trustees.

NATIONAL ACADEMY OF ENGINEERING

2101 Constitution Avenue, N.W.
Washington, D.C. 20418

THE NATIONAL ACADEMY OF ENGINEERING

History and Objectives

"The genie will not go back in the bottle, the rush of technology will not slow down, and we cannot stop the world and get off to take a breather. Our challenge is to learn not only to live in a global marketplace, but thrive in it so America can maintain its leadership position."

Walter B. Wriston
Retired Chairman, Citicorp/Citibank

The United States has long stood in the front ranks of technology. Over the past twenty-five years, however, the staggering expansion and acceleration in the creation of new technologies around the globe has made it increasingly difficult for nations -- including our own -- to adapt. Governments require ever greater technical expertise in order to make enlightened policy decisions in an age of technology.

The National Academy of Engineering of the United States (NAE), a private, nonprofit institution, has dedicated itself to the wise use of technology in this country and around the world. In the United States, the Academy serves as an adviser to the federal government, helping to apply the nation's best engineering talent to the field of public policy. Domestically and abroad, the NAE provides a focal point for engineering excellence by recognizing outstanding engineering achievement and encouraging the study and practice of the engineering disciplines.

The NAE: Its Organization and Purposes

The NAE was established in 1964 under the congressional charter of the National Academy of Sciences, which was granted in 1863 during the Lincoln administration. It is an autonomous Academy in its management and membership. Purposes of the NAE are to:

- Promote public education and discussion of technology, trade, engineering, innovation, education, and the impact that technology has on our society;
- Advise the federal government, when called upon, on matters of national importance pertaining to engineering and technology;
- Assist the changing technological and engineering needs of America, and encourage engineering activities that are in the national interest;

- Recognize outstanding contributions to the nation by leading engineers ; and
- Promote public awareness of the role of engineering and technology.

Selected NAE Activities

The NAE conducts and oversees a large number of programs whose common goal is to maintain and enhance the technological health of the country.

The NAE believes that the economic well-being of the United States is indissolubly linked to the advancement of technology. Recently, in response to the deep concern over the deterioration of the competitive position of many sectors of U.S. industry, the NAE prepared reports on the role of technology in economic growth, the state of engineering education in the United States, ways to improve manufacturing productivity, and the competitive status of various industries. These examinations have led the NAE to recommend new courses of action for government, industry, and academia in order to strengthen the technology base of the nation in an age of global competition. The Academy also has focused on national space and environmental policies, as well as on engineering research priorities.

The NAE's many programs, along with those carried out within the National Research Council (described below), require the efforts of more than 400 NAE members every year, who give their time voluntarily and without compensation.

National Research Council

Most NAE activities are implemented by the National Research Council, which also serves the National Academy of Sciences. With more than 900 study committees, the Research Council conducts studies of national importance involving science and technology, whenever called upon by Congress or agencies of the federal government. More than 9,500 men and women serve on a volunteer basis on Research Council committees.

Membership

Many of the nation's engineering and technology leaders in industry, government, and universities are members of the NAE. Members are elected to the Academy on the basis of pioneering achievements in the development of new technologies, for important contributions in engineering practice and theory, and for demonstrated leadership in the technology community. All engineering disciplines are represented by the NAE membership, which totals approximately 1,500 persons, including more than 100 foreign associates. More than half of the NAE's members are from industry and around 40 percent are from academia. Each year, the Academy elects about 70 new members.

Governing Council

NAE members elect six officers and twelve additional members to the NAE Council; this body governs and directs the activities of the Academy. Officers for 1989-90 are:

Robert M. White, **President**
President
National Academy of Engineering

John F. Welch Jr., **Chairman**
Chairman and Chief Executive Officer
General Electric Co.

Ralph Landau, **Vice President**
Consulting Professor of Economics
Stanford University

Edward R. Kane, **Treasurer**
Former President
E. I. du Pont de Nemours and Co.

Alexander H. Flax, **Home Secretary**
President Emeritus
Institute for Defense Analyses

Gerald P. Dinneen, **Foreign Secretary**
Vice President, Science and Technology
(Retired)
Honeywell Inc.

NEW YORK TIMES

NEW YORK, MONDAY, JULY 27, 1987

Charles S. Draper, Engineer; Guided Astronauts to Moon

By JOHN NOBLE WILFORD

Charles Stark Draper, a pioneer in advanced guidance technology for aircraft and missiles and developer of the navigation system that steered Americans to the moon and back, died Saturday at Mount Auburn Hospital in Cambridge, Mass. He was 85 years old.

Described by his peers as one of the foremost engineers of our time, Dr. Draper was a longtime professor of aeronautics and astronautics at the Massachusetts Institute of Technology. He founded M.I.T.'s Instrumentation Laboratory to develop his inventions applying gyroscopic principles for World War II gunsights and for the guidance systems that made possible intercontinental ballistic missiles.

Howard W. Johnson, a former chairman of the M.I.T. Corporation, said, "His research created a whole new industry in intertial instruments and systems for airplanes, ships, submarines, missiles, satellites and space vehicles."

'In the Category of Genius'

Inertial guidance is based on the familiar principle that keeps a child's gyroscopic top from falling: a rapidly spinning wheel will resist forces working to twist it from the plane in which it is revolving. For his guidance systems Dr. Draper used three spinning gyros, each responsive to only one direction of motion — up and down, right and left and rolling. These gyros formed a basis for a self-contained system that remembers an object's course of flight and can measure changes in that course.

The system devised by Dr. Draper for the moonbound Apollo spacecraft included telescopes, a sextant and a computerized inertial guidance device that told the astronauts where they were in space, where they were headed and how fast. Such data were used to direct all the spacecraft's propulsion systems.

James Killian Jr., a former M.I.T. president, described Dr. Draper as a "great teacher as well as an engineer whose technological achievements clearly placed him in the category of genius."

Doc Draper, as he was usually called, became a legend on the M.I.T. campus almost from the day he arrived there as a student in 1922. A stocky man with a fighter's broken nose and a scrappy temperament to match, he was the kind of student who took professors on terrifying airplane rides to prove some point of aerodynamics. As a professor himself, he was a compulsive and creative tinkerer.

He was born Oct. 2, 1901, in the small town of Windsor, Mo. After two years at the University of Missouri, he transferred to Stanford University and earned a bachelor's degree in psychology in 1922, intending to become a physician. But on a trip East he visited the M.I.T. campus in Cambridge, became fascinated with work in aeronautical engineering and decided to enroll. He learned to fly an open-cockpit biplane, earned another bachelor's degree and then a doctorate in physics in 1938.

The following year, Dr. Draper became a full professor at M.I.T. and founded the Instrumentation Laboratory. The group's first major achievement was the Mark 14 gyroscopic gunsight for the Navy, which made it possible for antiaircraft guns to take deadly accurate aim on attacking aircraft even while a ship was rolling and tossing.

Out of this research came the guidance systems for jet fighter planes and the Polaris, Poseidon and Trident submarines and missiles as well as key components for the Atlas and Titan rockets. Dr. Draper's laboratory was chosen in 1961 to develop the Apollo guidance and navigation system.

As Dr. Draper recalled in an interview several months before the first moon landing in 1969, James E. Webb, the space agency administrator, told him: " 'Stark, this is going to be a hell of a job. Can it be done?' I said yes. We used to give lunar navigation problems as thesis work for our students, and I knew it could be done. 'It'll be ready before you need it,' I told Webb — and, I might add, it is."

A few months after the moon landing, Dr. Draper was forced to step down as director of the Instrumentation Laboratory. He was caught in the middle of widespread protests against military work being done on university campuses. He insisted that any organization has an obligation to society to provide "services which fall within its special competence," adding: "That includes defense work. If defense is neglected, all is lost."

In 1973, the laboratory became independent of M.I.T. and was renamed the Charles Stark Draper Laboratory.

Dr. Draper was awarded the National Medal of Science in 1965. He was an honorary fellow of the American Institute of Aeronautics and Astronautics. He was also inducted into the National Inventors Hall of Fame and the International Space Hall of Fame.

Survivors include his wife, the former Ivy Hurd Willard; three sons, James and Michael of Newton, Mass., and John of Hampton Falls, N.H.; a daughter, Martha Draper Ditmeyer of Fairway, Kan., and six grandchildren.

Funeral services will be private.

Office of Public & Employee Communication
The Charles Stark Draper Laboratory, Inc.
555 Technology Square, Cambridge, Massachusetts 02139 Telephone (617) 258-2605

DR. CHARLES STARK DRAPER (1901 - 1987)

Founder and Senior Scientist
The Charles Stark Draper Laboratory

The "father of inertial navigation," Dr. Charles Stark Draper evolved the theory, invented and developed the technology, and led the effort that brought inertial navigation to operational usage in aircraft, submarines, missiles, and space vehicles.

Inertial guidance systems use gyroscopes (rotating devices that react to changes in direction) and accelerometers (instruments that detect changes in velocity over time) to keep a steady course. The information obtained from the gyroscopes and the accelerometers is fed into a computer, which calculates the degree of drift from the intended course and recommends appropriate corrections. Completely automatic inertial navigational systems can sense tiny deviations from the intended course and quickly correct them, resulting in very precise navigation anywhere in the world. Before Draper developed his inertial guidance systems, navigators depended upon more laborious methods, such as celestial navigation and radio navigation.

Founder of Draper Laboratory in Cambridge, Mass., and Institute Professor Emeritus at Massachusetts Institute of Technology, "Doc" Draper advanced from the position of assistant professor in the department of aeronautics and astronautics at MIT in 1935 to the post of Institute Professor in 1966. During his tenure at MIT, he also held posts as associate professor and department head.

Dr. Draper stood among the pioneer members of the first group of aircraft engineers. Such monumental efforts as the Apollo landing on the moon and the guidance systems for all strategic missiles in the U.S. inventory, both land- and sea-based, bear the stamp of his genius. Nationally, Dr. Draper's work has created a multibillion-dollar industry.

First sponsored by the Sperry Gyroscope Co., Dr. Draper's engineering work led to the development of the Mark 14 gunsight during World War II. He continued work with gun pointing and firing control developments until the late 1950's, which earned him the title "Mr. Gyro" because of the persistence and effectiveness with which he applied the gyroscope to guidance and control instruments and to gun, bomb, and rocket pointing and firing control instruments and systems.

His later research resulted in the development of a complete inertial navigation system for manned and unmanned vehicles, which perform successfully in unfavorable weather and do not rely on information from external sources.

DR. CHARLES STARK DRAPER -- 2

In 1942 the *USS South Dakota* , using Dr. Draper's gunsights shot down 32 Japanese kamikazes, an unprecedented anti-aircraft score. Under Dr. Draper's supervision, the MIT FEBE system in 1949 was the first to employ inertial properties of gyroscopic instruments for purposes of aircraft navigation. The Space Inertial Reference Equipment -- SPIRE -- followed in 1953. As the first fully inertial system, SPIRE is considered a milestone in the development of the inertial art. SPIRE Jr., an improved version of the system, was ready for flight in 1957.

Dr. Draper's work on inertial navigation systems for marine vessels proved successful in the 1954 sea tests of MAST (Marine Stable Element). This led to the SINS (Submarine Inertial Navigation System) later that year.

The Air Force applied Dr. Draper's work on inertial guidance for intercontinental ballistic missiles to the THOR guidance system. Since 1957, Draper Laboratory has developed the guidance systems for the family of Fleet Ballistic Missiles for the U.S. Navy: Polaris, Poseidon, Trident I, and is currently working on the Trident II system.

Dr. Draper's work on the guidance and navigation system for NASA's historic Apollo moon landing was the largest single program at Draper Laboratory until the Trident II program.

Born in Windsor, Mo., on Oct. 2, 1901, Dr. Draper began his college work in arts and sciences at the University of Missouri in 1917. In 1919 he entered Stanford University, Calif., and graduated in 1922 with a B.A. in psychology. He entered MIT the same year, earning a B.S. in electrochemical engineering in 1926, S.M. in 1928 without specification of department, and Sc.D. in physics in 1938.

Dr. Draper extended the curriculum of courses in the fields of instrument engineering and fire control while he was head of the department of aeronautics and astronautics at MIT. He wrote extensively in the fields of instrumentation and control, and served as consulting engineer to many aeronautical companies and instrument manufacturers. He held a number of patents for measuring and control equipment.

Dr. Draper's small team of students and technicians at MIT expanded to become the Instrumentation Laboratory (a part of MIT). The laboratory later divested from MIT in 1973, and formed a separate, nonprofit research and development laboratory -- The Charles Stark Draper Laboratory, Inc.

Dr. Draper was a member of several government science advisory groups and served as chairman of the National Inventors Council. He was a past president of the International Academy of Astronautics; an Honorary Fellow of the American Institute of the Aeronautical Sciences and the British Institution of Mechanical Engineers; and an honorary lifetime member of the Instrument Society of America. He held an honorary fellowship with the British Interplanetary Society and the Royal Astronautical Society, and was an honorary member of the German Society for Guidance and Navigation and the British Institute of Navigation.

He was also a fellow of the American Physical Society, the American Academy of Arts and Sciences, the American Society of Mechanical Engineers, the American Association for the Advancement of Science, the Institute of Electrical and Electronics Engineers, the American

Astronautical Society; and a member of the National Academy of Engineering, the National Academy of Sciences, the American Institute of Consulting Engineers, the Society of Automotive Engineers, the American Ordnance Association, the American Society for Engineering Education, the Massachusetts Society of Professional Engineers, the New York Academy of Sciences, and the French National Academy. He was a past president of the MIT Soaring Society, and a member of Sigma XI, Tau Beta Pi, and Sigma Alpha Epsilon.

Among his more than 70 honors and awards, five have come from foreign countries, including the U.S.S.R. and Czechoslovakia. He was inducted in the National Inventors Hall of Fame and into the International Space Hall of Fame.

He received the prestigious Langley Medal of the Smithsonian Institution, the NASA Public Service Award, the Dr. Robert H. Goddard Trophy of the National Space Club, and the National Medal of Science from President Lyndon Johnson.

Dr. Draper was named the New England Inventor of the Year in 1981. In 1978, MIT established the Charles Stark Draper Professorship of Aeronautics and Astronautics in his honor. Dr. Draper received the "Engineering for Gold Award" from the National Society of Professional Engineers in 1984. The society cited his work in inertial guidance systems as one of the 10 outstanding engineering achievements of the past 50 years.

Among the honorary degrees he received are doctoral degrees from Eidgenossische Technische Hochschule, Zurich, Switzerland, in 1966; the University of Portland, Portland, Oregon, in 1970; the University of Missouri, Rolla, in 1975; and Boston University in 1984.

Many of Dr. Draper's former students are leaders in government, industry, the military, and academia.

Dr. Draper was married to Ivy Hurd Willard, with whom he had three sons, one daughter, and six grandchildren. His children are James Draper and Michael Draper of Newton, Mass.; John Draper of North Andover, Mass.; and Martha Draper Ditmeyer of Fairway, Kansas.

OPENING STATEMENT -- DRAPER PRIZE NEWS CONFERENCE

Robert M. White, President
National Academy of Engineering

October 3, 1989

Good morning. It is a pleasure to be here today to announce the recipients of the first international Charles Stark Draper Prize. Following extensive deliberations conducted over the past year, the National Academy of Engineering's Charles Stark Draper Prize Committee has selected Jack S. Kilby and Robert N. Noyce as the first recipients of the Draper Prize, the largest prize in the world given exclusively for engineering achievement.

We are fortunate to have Jack Kilby with us here today, as well as Robert Seamans Jr., chairman of the Draper Prize Committee, and Joseph Charyk, head of the Draper Laboratory Inc. of Cambridge, Mass., which endowed the prize. Robert Noyce had hoped to attend but was unable to because of prior commitments.

Kilby and Noyce are being honored here today for their separate co-invention of the single-crystal integrated circuit, better known as the semiconductor microchip. The award is also based on their skill in bringing the integrated circuit to successful production and application in commercial products.

Very few things have changed the world as dramatically as the integrated circuit has. Its development was the single most important event that helped usher in the Information Age. Like the invention of the telephone, the light bulb, or the automobile, the creation and widespread practical application of the integrated circuit has fundamentally changed our lives -- transforming computation, communications, manufacturing, and transportation, and giving birth to a host of entirely new industries and services.

In just a moment, Dr. Seamans will describe the Draper Prize Committee's selection process, followed by some remarks by Mr. Kilby. But first, I'd like to tell you something about Charles Stark Draper, for whom this prize is named.

Draper is often referred to as the "father of inertial navigation," and is best known for creating and developing the navigation guidance system that landed the Apollo astronauts on the moon. Similar versions of this system today continue to provide aircraft, submarines, missiles, and space vehicles with pinpoint navigational accuracy. Draper's work in this important area strengthened our nation's space and defense programs and evolved into an industry that generates billions of dollars in sales each year.

We are grateful to the Charles Stark Draper Laboratory Inc. for providing the endowment necessary to establish this prize in "Doc" Draper's name. It is fitting that the prize should be

named after Draper because he epitomizes the kind of engineering excellence -- especially the successful commercial application of new technologies -- that we want to highlight with this prize. The Draper Prize, with its accompanying $350,000 cash award and gold medal, will be given every two years to an individual or individuals who have made outstanding contributions to the advancement of human welfare and freedom through their engineering achievements.

We believe that the Draper Prize will focus world attention on the important contributions of engineers to society in the same way that the Nobel Prize now focuses attention on the accomplishments of scientists.

At this point, Dr. Seamans will describe the committee's selection process and tell you why we believe that Jack Kilby and Robert Noyce aptly meet the Draper Prize criteria described above. Currently a senior lecturer at the Massachusetts Institute of Technology, Dr. Seamans is uniquely qualified to chair the Draper Prize Committee as a former Secretary of the Air Force, former president of the National Academy of Engineering, and as one of "Doc" Draper's former students. Thank you.

OPENING STATEMENT -- DRAPER PRIZE NEWS CONFERENCE

Robert C. Seamans, chairman, Charles Stark Draper Prize Committee, National Academy of Engineering, and senior lecturer, Massachusetts Institute of Technology

October 3, 1989

Thank you, Bob. During my 48-year career in numerous government, industry, and academic posts, I have held many difficult jobs, but serving as chairman of the Draper Prize Committee has to rank among the most challenging. Choosing just one engineering achievement that has had the greatest impact in advancing human well-being and freedom is a very tall order.

We are literally surrounded by the products of engineering from the moment we wake up to an automatically prepared cup of coffee, put on our no-iron, wash and wear clothing, make a telephone call from our cars while driving to work, and sit down at a personal computer to write a letter, balance the books, read the mail, or draw a picture.

Our 13-member committee of prominent engineering leaders from industry, academia, and government began the job of selecting the Draper Prize recipients in November of 1988. We invited more than six thousand individuals, institutions, and professional societies from around the world to submit nominations. We also welcomed any unsolicited nominations.

After several long and detailed discussions about the many

high quality submissions we received, we unanimously settled on Jack Kilby and Robert Noyce for a number of what we believe to be persuasive reasons.

First, their separate co-invention of the monolithic integrated circuit has been credited by many as the initial step of the microelectronics revolution and the advent of the Information Age. This one invention has affected virtually all industries from banking, to transportation, to communications, while at the same time having a profound effect on everyday living through such consumer products as the pocket calculator, digital watches, automatic cameras, videocassette recorders, and compact discs.

Second, the men who created this invention were instrumental in designing cost-effective manufacturing processes to produce actual commercial products. Kilby's work with colleagues at Texas Instruments led to development of the first computer made with integrated circuits and later to production of the first hand-held calculator. As co-founder of Fairchild Semiconductor, Noyce helped produce the computerized navigation system used for the Apollo missions. Later as co-founder of Intel Corp., his company produced the first high-density memory components and microprocessors, the critical element that made production of personal computers practical.

Finally, our committee was convinced that no other invention in modern times has had as pervasive an effect in meeting the true spirit of the Draper Prize by advancing human welfare and freedom.

It has often been said that just as the first Industrial Revolution, based on motors and improved machinery, freed humans from back-breaking labor, the second industrial revolution, based on the semiconductor microchip, has freed us from mind-numbing intellectual chores.

For these reasons, the National Academy of Engineering is very pleased to honor Jack Kilby and Robert Noyce as the first recipients of the international Charles Stark Draper Prize. We are planning a special event in February during National Engineers Week, when they will formally receive a gold medal and $175,000 each.

It is a fitting reward for two men whose work has done so much to improve all of our lives.

At this point, perhaps Jack Kilby would like to make a few comments and then we will be happy to answer your questions.

Office of Public & Employee Communication
The Charles Stark Draper Laboratory, Inc.
555 Technology Square, Cambridge, Massachusetts 02139 Telephone (617) 258-2605

THE CHARLES STARK DRAPER LABORATORY, INC.

A Brief Overview

The Charles Stark Draper Laboratory, Inc., is a private, nonprofit corporation dedicated to scientific research, development, and education. It is engaged primarily in research and development of guidance, navigation, and control systems (inertial, satellite, and radio-aided); fault-tolerant system design; precision pointing and tracking system design; flexible and automated manufacturing methods; undersea-vehicle systems design; advanced spacecraft, both manned and unmanned; and specialized scientific instrumentation.

Located adjacent to the Massachusetts Institute of Technology (MIT) in Cambridge, Mass., the Draper Laboratory was originally established as the Instrumentation Laboratory of MIT in 1938. It was renamed in 1973 to honor Charles Stark Draper, the technological pioneer whom, in the words of James Killian, Jr., a former MIT president, was, "...a great teacher as well as an engineer whose technological achievements placed him in the category of genius." Presently, the Draper facility contains more than 100 laboratories.

In its early years, the laboratory pioneered the development of gyroscopically based gun pointing and firing systems for shipboard and fighter-aircraft use. These systems are driven by three spinning gyros, each of which responds to only one direction -- up and down, right and left, and rolling. This enabled the development of a system that remembers an object's course in flight and can measure changes in that course.

Over the past 50 years, the Draper Laboratory has:

- continually improved the performance levels of new inertial components and systems;
- been a leader in the development of highly reliable digital computers and their applications to fly-by-wire vehicle controls for vehicles ranging from spacecraft to hydrofoils; and
- developed fault-tolerant computing systems for a number of diverse applications.

Constantly searching for the brightest minds in engineering, the Draper Laboratory actively recruits engineers from academic fields such as aeronautical, electrical, and mechanical engineering; computer sciences; and physics. With more than 2,000 employees, the Draper Laboratory is a major source of seasoned personnel for government agencies and private industry. Its employees are trained to plan, manage, technically direct, design, fabricate, and test complete avionics and advanced digital control systems.

CHARLES STARK DRAPER LABORATORY - 2

The Draper Laboratory provides services to the U.S. Air Force, the National Aeronautics and Space Administration (NASA), and the U.S. Navy as an engineering design agent. Beginning as early as 1957, the laboratory designed the U.S. Fleet's ballistic missile guidance system for the Polaris and continues in the same manner for the Navy's new Trident series missiles.

Current projects at the Draper Laboratory include:

- Guidance, Navigation, and Control: continuing design and development of guidance, navigation, and control systems for spacecraft, missiles, and ships. This work supports programs of the U.S. Navy and NASA;
- Fault Tolerant Computing: developing fault-tolerant computing to ensure reliability among on-board navigational systems for NASA;
- Strategic Defense Initiative: designing the inertial and interceptor guidance systems for ballistic missile defense;
- Applications of Artificial Intelligence: progressing toward higher levels of automation and artificial intelligence for computer and guidance systems. Use of this technology can be applied to a variety of systems;
- Industrial Automation: contributing to improvement of the nation's industrial sector to keep it competitive by improving industrial productivity and robotics. One area of concentration lies within the textile/clothing industry by designing automated robotics systems to assemble clothing.

THE WHITE HOUSE

WASHINGTON

MEMORANDUM

TO: Sig Rogich

FROM: **JOSEPH W. HAGIN**

SUBJECT: **APPROVED PRESIDENTIAL ACTIVITY**

EVENT: Present the Draper Engineering Award

DATE: February 20, 1990 ---- Tuesday

TIME: 8:30 p.m.

DURATION: 30 minutes

LOCATION: The State Department, 8th Floor

ATTIRE: Black Tie

REMARKS REQUIRED: Yes

MEDIA COVERAGE: TBD

FIRST LADY PARTICIPATION: No

ADDITIONAL INFORMATION: POTUS will arrive after dinner as program begins

CONTACT: Phil Peter (General Electric) 637-4455

TELEPHONE: **OFFICE** _____ **HOME** _____

NOTE: **PROJECT OFFICER, SEE ATTACHED CHECKLIST**

Ed Rogers	**Marlin Fitzwater**	**David Bates**
James Cicconi	**David Demarest**	**David Valdez**
Fred McClure	**Jean Lamb**	**USSS - PPD**
Susan Porter Rose	**Sig Rogich**	**Gary Walters**
Patty Presock	**John Keller**	**WHCA Audio/Visual**
Chriss Winston	**Tim McBride**	**WHCA Operations**
Laurie Firestone	**J. Bonnie Newman**	**C. Boyden Gray**
William Kristol	**Paul Bateman**	**John Herrick**
Jackie Kennedy		

1/6/90 Draper

Phil Peter (Gen. Electric) 637-4455
(Kathleen)

Chris Schroeder 647-8745

Judith Bostock x3840

Natl Academy of Engineering
Dr. Bob White
334-3200

Charles Stark
(3) ~~Charlotte~~ Draper
MIT
then lab. in Chmbr.
father of inertial navigation
called upon for guidance system → for the moon

non-profit research lab.
guidance system for Trident submarine
pre eminent
contributing to human welfare & freedom

Nobel never had award for engin.
never received much attention as other sciences

$350,000 + gold medal
largest award for engineering

bring home the importance of engineering

prestigious selection comm.

2 people

requirements for award

patents for microcircuit

→ reduction to practice – turn an idea into something practical

washing machine
telephone
T.V.
~~tv~~

announcement made in Oct.
This is presentation

Chrmn of G.E. will introduce POTUS
POTUS hang awards

Steve Bechtel visited POTUS this wk

Transformed society

Highlight of Engineer's Week

Internatl. prize

- one did it @ TI
- founders of Intel

pgs 55 & 60

Garrix

~~Kilby~~ Levindowski; N. E. A.
334-1657

~~Garrix~~

Jack Kilby TI
Robert Noyce - founders of Intel

harnessing tech.
(is essential to
protecting the environmental degradation
(preventing)
greater strength

300 people - fam., members, & spouses

Draper led the world by (inventing) the guidance system that brought us to the moon

~~Appropriate that the 4~~ honorees have led the world

that ~~created~~ (deterred) war by advancing deterrent systems

Press kit

Competitiveness - last few yrs.

Launching environmental program
how technology can protect the environment
18 months

inspire kids to get involved in engineering

Doug Watford

~~Phil Peter~~

Natl. Engineer's Week started 1951

Discover E

engineers going to schools teaching a class

~~Stephen Bechtel~~ - ~~former~~ Hon. Chairman of Natl. Eng. Week

500 engineers teaching in h.s.

Natl ~~Assoc~~ Society of Prof. Engineers

[The highlight of Natl. Engineers Week]

Satellite communication

- Bob White

Chairman of Draper Lab.

My endowed ⇒ - Joe Choryk

- Bob Seamans - chrmn of selection process

Jack

Ed

In the space of one transistor took, you can fit 1 million

Refridgerator ⇒ pen calculator

GE - Paul Ostergard 203 373-2250

Draper Prize Presentation Dinner
Department of State
February 20, 1990

6:30 p.m. **Reception** - Jefferson and Adams rooms

7:30 p.m. **Dinner** - Benjamin Franklin Room

Welcome and Opening Remarks

8:30 p.m. **Robert M. White**, President, National Academy of Engineering

- o Goes to podium
- o Welcomes guests
- o Recognizes host - Ivan Selin, Under Secretary of Management, Department of State
- o Presents overview of prize including that recipients each receive $175,000
- o Introduces **Joe Charyk**
- o Returns to table

8:34 p.m. **Joseph V. Charyk**, Chairman, Charles Stark Draper Laboratory, Inc.; Retired Chairman and Chief Executive Officer, Communications Satellite Corporation

- o Goes to podium
- o Presents brief remarks about why Draper Laboratory endowed the prize and Charles Stark Draper
- o Introduces **Bob Seamans**
- o Returns to table

8:37 p.m. Dr. **Robert C. Seamans, Jr.**, Chairman, Draper Prize Committee; Senior Lecturer, Massachusetts Institute of Technology

- o Goes to podium
- o Discusses selection process
- o Introduces **Jack Welch**
- o Returns to table

Presentation

8:40 p.m. **John F. Welch, Jr.**, Chairman, National Academy of Engineering; Chairman and Chief Executive Officer, GE

- o Goes to podium
- o Brief remarks about Kilby and Noyce and that Academy is pleased to recognize them with the first Charles Stark Draper Prize
- o Introduces **President Bush** to present awards
- o Stays at podium with Bush

8:44 p.m.

- o **President Bush** goes to podium - speaks for five minutes
- o Calls **Kilby** and **Noyce** to podium
- o **Welch** hands Kilby's medal to **President Bush**
- o **President Bush** congratulates and puts medal on **Kilby**
- o **Welch** hands Noyce's medal to **President Bush**
- o **President Bush** congratulates and puts medal on **Noyce**
- o **Welch** acknowledges that **Kilby** and **Noyce** will each make brief remarks, **Kilby** going first
- o **President Bush, Welch,** and **Noyce** return to their seats

[If **Bush** leaves at this point, appropriate thanks and recognition should be given before **Welch** acknowledges **Kilby** for his remarks.)

Acceptance Remarks

8:48 p.m.

- o **Kilby** presents brief remarks
- o Returns to table

8:58 p.m.

- o **Noyce** returns to podium
- o Presents brief remarks
- o Returns to table

Conclusion

9:08 p.m.

- o **White** goes to podium
- o Gives appropriate congratulations and thanks and closes program.

9:10 p.m.

- o Program ends.



OFFICE OF PRESIDENTIAL ADVANCE

IN-TOWN EVENT CONTACT SHEET

Name	Office	Phone Number
Presidential Advance		456-7565
Gladys Battle Presidential Advance Office Fax Number	Press Office (State Dept) Protocol	647-2492 456-2820 647-2299
Ray Bruce		
Lucy Mulkerrin	Pres. Advance	456-7565
Bill Davis	STATE - MGR 8TH FLOOR	647-3242
Lee Henderson	General Services	647-2275
Kelvin Arrington	Technical Services (Audio)	647-1630
Cynthia Bienvenue	National Academy of Engr	334-2345
Berit Ellenes	Design Cuisine Catering	979-9402
Kaz Nielsen	Design Cuisine Catering	979-9400
BARBARA HUFF	NAT'L ACADEMY of ENGINEERING	334-3200
Carrie Levandoski	NAE	334-1657
Marilyn Yarnell	Dept of State, Protocol, Visitor Unit	647-1432
Stephanie Blessing	W.H. Speechwriting	456-7750
DOUGLAS WOLFORD	NAT'L ACADEMY of ENGINEERING	334-1657
Susan Turner-Lewis	Nat'l Acad. of Engineering	334-2138
Gail Porter	Nat'l Acad of Engineering	334-2138
Steven Ross	W.H. Press Advance	633-2415
JOHN GIBBONS	WH LEAD ADV.	0-377-5001 H-256-1457
Mike Fox	USSS - Lead	395-4011
BRUCE CAUGHMAN	WH MILITARY OFFICE	456-2150
DAVID PISTILLI	WH COMMUNICATIONS	395-4012/2000
Daniel Pistole	PPD	395-4011
Steve Scott	USSS/WHD	634-8700
DOUG CALLEN	USSS - LIA	535-5838
Chris Holland	DS/PRD	6631363
Lizz Wood	DS/PRD	663-1885
PAUL MCLAIN	DS/UPB	647-0249

E300
.6
.W5
v.35
WH

Wilson, Woodrow, Pres. U.S., 1856-1924

THE PAPERS OF WOODROW WILSON

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Most heartily do I congratulate you and remain, as ever,
Faithfully & affectionately yours, R. H. Dabney.

ALS (WP, DLC).

An Address to the Daughters of the American Revolution[1]

[Oct. 11, 1915]

Madam President and ladies and gentlemen: Again it is my very great privilege to welcome you to the City of Washington and to the hospitalities of the capital. May I admit a point of ignorance? I was surprised to learn that this association is so young, and that an association so young should devote itself wholly to memory I cannot believe. For, to me, the duties to which you are consecrated are more than the duties and the pride of memory.

There is a very great thrill to be had from the memories of the American Revolution, but the American Revolution was a beginning, not a consummation, and the duty laid upon us by that beginning is the duty of bringing the things then begun to a noble triumph of completion. For it seems to me that the peculiarity of patriotism in America is that it is not a mere sentiment. It is an active principle of conduct. It is something that was born into the world, not to please it, but to regenerate it. It is something that was born into the world to replace systems that had preceded it and to bring men out upon a new plane of privilege. The glory of the men whose memories you honor and perpetuate is that they saw this vision, and it was a vision of the future. It was a vision of great days to come, when a little handful of three million people upon the borders of a single sea should have become a great multitude of free men and women spreading across a great continent, dominating the shores of two oceans, and sending West, as well as East, the influences of individual freedom. These things were consciously in their minds as they framed the great government which was born out of the American Revolution. And every time we gather to perpetuate their memories, it is incumbent upon us that we should be worthy of recalling them, and that we should endeavor by every means in our power to emulate their example.

The American Revolution was the birth of a nation. It was

[1] At Memorial Continental Hall, on the occasion of the twenty-fifth anniversary convocation of the Daughters of the American Revolution. Daisy Allen (Mrs. William Cumming) Story, president-general, presided at the meeting.

To SB

Date _____ Time 1:35

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THE WHITE HOUSE
WASHINGTON

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10/25/88

SCIENCE, TECHNOLOGY AND INNOVATION

FACT SHEET

Today, America stands as the freest, the fairest, the most productive nation on the face of the earth. That's how George Bush wants America to enter the 21st Century -- on the leading edge. To maintain our technological edge, we must make a national commitment to the best education and the strongest competitive spirit in the world. Technology is the key to the future, but people are the key to technology.

As we move into the 1990s and the 21st century, George Bush believes that America's economic success and national security depend to an ever greater extent on our scientific and technological progress. Technology is America's economic fountain of youth.

Technology has created productivity growth in both the service sector and the industrial sector. Flexible manufacturing systems and numerically controlled machining depend on sophisticated computer software and skilled people. Never before has such a symbiotic relationship existed between the service sector and the industrial sector to produce technological breakthroughs in manufacturing.

Scientific and technological advancement has always been at the very heart of our nation's pioneer spirit, pushing the boundaries of our knowledge, creating economic opportunity and increasing our standard of living. It is the spirit that drove Henry Ford, that soared with the Wright brothers, and it is the spirit that enabled Americans to walk on the moon.

A hero of the 19th century, Thomas Edison, inventor, technician and entreprenuer, embodied the pioneer spirit. The pioneer spirit pushed George Washington Carver, scientist and educator, to make advances of world renown in agricultural research. The pioneer spirit carried Sally Ride, physicist, astronaut and explorer, into space in the 20th century. The 21st century will demand even more of America's pioneer spirit. We must be prepared to step up to the challenge.

THE REAGAN-BUSH RECORD

Growth in research and development. The percentage of our gross national product dedicated to research and development is now at its highest level since the late 1960s. Since 1981, the Reagan-Bush Administration has increased funding for basic research

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by over 50 percent, after adjusting for inflation. Industry and government will spend $132 billion on research and development (R&D) in 1988, an increase of 131 percent since 1980.

Establishment of new research centers. The Reagan-Bush Administration has started creating university-based, interdisciplinary research centers in engineering, science, and technology. These centers bring the federal government, industry and university labs together to promote the long-term competitiveness of the American economy. Advances have been made in manufacturing and biotechnology; others will follow.

THE BUSH PHILOSOPHY

The following principles would guide science and technology policy in a Bush Administration:

- Federal government investment in R&D should focus on basic research. The private sector has the best incentives for deciding which technologies will have the most potential in the marketplace.

- The federal government should ensure that the rules of the game are fair in the global market. It is up to the federal government to ensure that American intellectual property is protected in world markets and that American companies have as much access to foreign research projects as foreign companies have to American research projects.

- There are many active players in R&D in the United States -- federal government, state governments, national laboratories, university laboratories, and business. The federal government should not attempt any kind of central planning of American research activity. However, the federal government should promote greater cooperation among these different groups.

CHALLENGES OF THE FUTURE

George Bush believes science and technology forms the foundation of economic power -- the power to create value.

George Bush believes that the combination of dedicated, skilled people and technological advancement can improve our standard of living and our competitive position in the global marketplace.

George Bush will focus on four priorities critical to America's technological advancement and economic growth:

- o Strengthening Federal Science and Technology Policy
- o Improving Math and Science Education
- o Encouraging Private Sector Investment
- o Promoting Commercialization of Technological Breakthroughs

THE BUSH PLAN -- THE ROAD TO INNOVATION AND WORLD LEADERSHIP

Strengthening Federal Science and Technology Policy

o George Bush will upgrade the President's Science Advisor to Assistant to the President for Science and Technology and reinvigorate the Office of Science and Technology Policy (OSTP). George Bush will also seek advice on science and technological matters from the private sector. George Bush will create a President's Council of Science and Technology Advisors, composed of leading scientists, engineers and distinguished executives from the private sector.

The Assistant to the President for Science and Technology will report directly to the President and be an active member of interagency policy groups such as the Economic Policy Council and will also be involved with the national security planning process. The Assistant to the President for Science and Technology will head the Office of Science and Technology Policy and be responsible for developing, and coordinating a federal science and technology strategy. George Bush believes an integrated approach is needed to better manage the federal science and technology process. George Bush will seek the active involvement of a diverse group of American scientists and engineers in this process.

George Bush believes we need an overview of the entire federal R&D picture. He also believes a stronger OSTP is needed, one that can coordinate the President's federal science and technology policy among agencies. OSTP should be able to perform analyses and help prepare budgets on an across-the-board basis.

o George Bush proposes to double the National Science Foundation's budget over the next five years. George Bush supports both large and small science projects. He will consider a key priority of the National Science Foundation's increased funding the retooling of science and engineering labs at colleges and universities.

o George Bush supports making all federal R&D authorizations for 5 years and all federal R&D appropriations for 2 years to provide greater certainty to laboratories. Currently, the federal government typically provides R&D authorizations for only 1-3 years and appropriates funds for only 1 year. However, R&D projects have long time horizons -- 5, 10, or even 15 years long. Universities, businesses, and government labs need more assurance of federal R&D funding in future years to plan projects better.

Improving Math and Science Education

We must redouble our efforts in science and technology by focusing on developing the core of people needed to continue pushing the nation forward.

Too many elementary schools graduate children who have not learned basic skills, especially in math and science. Today's and tomorrow's production workers need the right mathematics and science background to operate computers and sophisticated machinery. By 1995 the United States will need an estimated 300,000 additional secondary-school math and science teachers. Fifty years ago a production worker could get by having only arithmetic. But the operator of a sophisticated robot needs to know algebra and basic physics.

In our colleges and universities we need improvement and expansion in science and engineering. We need better trained college graduates to satisfy our economy's expanding needs for engineers, physicists, chemists, and computer professionals. Foreign students represent about 40 percent of enrollments in U.S. graduate schools of engineering.

George Bush knows that better science education is needed for our young people in order to prepare them for jobs which are increasingly technical. Science education is an integral part of George Bush's education policy:

o George Bush believes study of the sciences should be part of every child's basic education; he believes all students -- whether in academic or vocational-technical programs -- should graduate with an understanding of scientific principles and their application.

o George Bush supports increased funding for magnet schools, recognizing that many of them emphasize science education.

o George Bush believes that support for science education must continue to be a key priority for the National Science Foundation.

o George Bush knows that in many states, teachers who are trained in the sciences and in mathematics are hard to find. He supports efforts of states to enhance math and science education by developing alternative certification programs which can bring distinguished professionals with strong backgrounds in the sciences to the classroom.

o George Bush will convene a White House Conference on Education placing special emphasis on math and science education. George Bush and the governors from the 50 states will discuss and define the goals of our Math and Science curricula.

Encouraging Private Sector Investment

We must ensure the economy provides a climate which encourages businesses to take economic risks and invest in new, bold technologies. George Bush understands how important a strong economy is to technological advancement. During the late 1970's, industry did not find it profitable to invest in new technology. High interest rates and high inflation squelched investment and modernization. The Reagan-Bush Administration cut interest rates in half and slashed inflation by two-thirds. George Bush will work hard to keep interest rates low and to ensure incentives are in place for the private sector to fund a high level of advanced research.

o George Bush will make the R&D tax credit permanent. Instead of just extending the 20 percent R&D tax credit for short periods of time as Congress has done over the past several years, George Bush supports making the tax credit permanent to provide a stable economic environment for American business.

o George Bush supports cutting the capital gains tax rate from 28 percent to 15 percent on all assets held more than one year. We have seen countless examples like Silicon Valley in California and Route 128 around Boston of what cutting the capital gains tax rate can do to stimulate entrepreneurship. Many of our most important technological developments have taken place in small, start-up firms. There is no more powerful incentive for individuals to start up a business than a low capital gains tax rate.

Promoting Commercialization of Technological Breakthroughs

George Bush will enhance the ability of American business to commercialize new ideas and new technologies. The commercialization of technology requires consistent economic incentives, regulatory reform and a coordinated approach to federal science and technology policy making.

o George Bush supports and encourages Partnerships for Progress -- partnerships between business, universities, and government to advance base-building technologies and the rapid transfer of new knowledge from laboratory to marketplace.

o George Bush is committed to working vigorously in international negotiations, especially the new round of multilateral trade negotiations, to ensure that American intellectual property rights are protected.

THE WHITE HOUSE

WASHINGTON

January 23, 1990

Dear Mr. Welch:

On behalf of the President, I wish to acknowledge and thank you for your letter inviting him to present the first Draper Award in commemoration of Engineers Week this February.

The President is pleased to accept. This has been entered on his schedule for February 20, and nearer the date, Mr. John G. Keller, Jr., Deputy Assistant to the President and Director of Advance, will contact you about the President's attendance.

The President's acceptance of this invitation should not be announced to anyone until official notification is given by the White House Press Office, and any public announcement of this event must be coordinated with Mr. Jay Allison who may be reached at 202/456-2100.

You should be aware that certain physical facility requirements exist for any Presidential appearance. The costs associated with these requirements are generally the responsibility of the host and are summarized on the attached list.

If you wish to alter the current plans for this event in any way, such as changing any part of the format, the location, or the participants, please direct your request for the proposed change to the Office of Presidential Appointments and Scheduling.

With best wishes,

Sincerely,

JOSEPH W. HAGIN II
Deputy Assistant to the President
for Appointments and Scheduling

Mr. John F. Welch
Chairman of the Board
General Electric Company
3135 Easton Turnpike
Fairfield, Connecticut 06431

JWH/lhw
CC Mary Rawlins
CC & incoming to Helen Donaldson

DWP 4

John F. Welch
Chairman of the Board

General Electric Company
3135 Easton Turnpike, Fairfield, CT 06431

November 21, 1989

The President
The White House
Washington, D.C. 20500

Dear Mr. President:

I need your help.

Engineers Week is February 19 - 23, 1990, and as Chairman of the National Academy of Engineering, I would like to invite you to make it a memorable and important one by presenting the first Draper Award for "outstanding achievement in engineering and technology that contributes to the advancement of human welfare and freedom." We would hope that you could present it on either the evening of February 20 or 22, after a black-tie dinner at the State Department.

We believe the Draper Award will become the "Nobel Prize for Engineering," with a cash award of $350,000 to the annual honoree. We feel this event will reemphasize the importance of engineering to national competitiveness and way of life, and your presentation of it would impart a significance that would make it an enduring symbol of excellence and achievement in engineering in the years to come.

Every engineer in the country will be honored -- I know I will be -- if you could set aside this event for us.

I hope you can do it.

Sincerely,

Jack

PHILLIPS S. PETER
VICE PRESIDENT

Nov. 22, 1989

Dear Tony,

As discussed, here is the invitation from Jack Welch, GE's Chairman, to the President for him to present the Draper Award (the engineering/technology equivalent to the Nobel Prize — same $350,000 cash award) on the evening of February 20 or 22, 1990 at the State Department during Engineering Week.

Thanks for your help on this.

Sincerely,
Phil

GENERAL ELECTRIC COMPANY
1331 PENNSYLVANIA AVE., N.W.
WASHINGTON, D.C. 20004
(202) 637-4455

PHILLIPS S. PETER
VICE PRESIDENT

Nov. 22, 1989

Dear Ed,

As discussed, here is the invitation from Jack Welch, GE's Chairman, to the President for him to present the Draper Award (the engineering/technology equivalent to the Nobel Prize + same $350,000 cash award) on the evening of February 20 or 22, 1990 at the State Department during Engineering Week.

Thanks for your help on this.

Sincerely,
Phil

P.S. Tony Benedi is aboard on this.

GENERAL ELECTRIC COMPANY
1331 PENNSYLVANIA AVE., N.W.
WASHINGTON, D.C. 20004
(202) 637-4455

The indispensable engineers

What engineers do is so infinite and various that the discipline beggars description. They take science and use it to solve the problems and challenges of life, from the eraser on your pencil to the exploration of Mars. Lately there's been a lot of discussion about the "knowledge-based" society to come, but engineers have always lived in a knowledge-based society. They've shaped our high-tech world—and starting February 18th, the whole country will honor them through National Engineers Week.

Mobil's interest in the celebration is obvious: we make our living through high technology. Engineers—probing oceans, jungles, and mountains; in their research labs; at their computers—help us find and produce the raw materials and natural resources that Mobil customers require. Engineers help us move these resources to where they're needed, design ways to refine and manufacture them, market the fuels and products that result. We couldn't get along without them—and neither could you.

So many simple needs—thread, a paper clip, a spoon, a shoelace, good water from the tap, a clean sheet of paper—depend on engineers. Their name itself means they are the contrivers, and at its root, that they embody talent. They make things. They fix things. They dream things—like light bulbs, moon rockets, and horizontal oil wells—that never were. And we are all better off because they make those dreams come true.

Not everyone wants to be an engineer, at play (as Isaac Newton put it) upon the shores of the great ocean of truth. Business, the arts, and many other occupations and professions offer satisfying careers to millions. But engineers are in demand. By the turn of the century—just one more decade—the United States will be short 150,000 engineers.

For our part, we've launched a number of programs to attract the best students—in engineering and other disciplines we require—for careers at Mobil. At certain key universities, a team of Mobil employees from different operating units visits regularly to meet students and teachers, share ideas, and set up internships that provide potential recruits with hands-on technical experience. We also provide scores of grants designed to keep U.S. engineering expertise among the world's best and to fund research that expands U.S. technological capabilities.

Engineers are the world's worst at tooting their own horn. Most are so busy getting the job done—turning out quality products, protecting the environment, safeguarding public health—that they have little time to crow. But this reticence has harmed their need to attract tomorrow's crop of engineers: The young people who must design and manage the 21st Century. There are rewarding careers and immense challenges awaiting any youth who prepares for the engineering profession.

The global economy is upon us. Those countries—and companies—that prepare for its highly competitive enterprise and technological sophistication will flourish. Since engineers will be in the front lines of that struggle, we hope everyone will join their coming celebration of science, invention, and creativity.

They'll probably be as quiet as usual during National Engineers Week—but let's make sure they all hear three rousing cheers from the rest of us.

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Marconi

VOLUME 18

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BROWN BROTHERS

Guglielmo Marconi at one of the radio transmitting and receiving stations that inaugurated the era of radio.

MARCONI, mär-kō'nē, **Guglielmo** (1874–1937), Italian inventor, who received half of the 1909 Nobel Prize for physics for his work in developing wireless telegraphy. This award surprised many physicists, since previous awards had been for such laboratory studies as revealing X rays, radium and radioactivity, and the electron. What had Marconi done? Measured by the extent to which he had shattered firmly established "laws of nature," Marconi was well qualified for the prize. Mainly in the years 1900–1903, he had shown that the electromagnetic waves predicted by James Clerk Maxwell and demonstrated by Heinrich Hertz could carry messages at frequencies of a few hundred kilohertz 2,000 miles (3,200 km) and more around the earth's curvature, many times farther than any known theory would allow. It was a major geophysical discovery not fully explained until the 1920's.

Marconi's background for the accomplishment was unusual. His 38-year-old widower father, Giuseppe, a businessman of Bologna, Italy, had eloped in 1864 with 17-year-old Annie Jameson, a music student from a well-to-do family in Ireland. Their children were Alfonso, born a year later, and Guglielmo, born in Bologna on April 25, 1874. About 1855, Giuseppe's father had sold the Marconi ancestral estates and bought the Villa Grifone, a manor house with several hundred acres at Pontecchio near Bologna. This was Marconi's home until the age of 22, and here he performed his first crucial experiments in wireless telegraphy using radio waves generated by electric sparks.

Frequent childhood visits with his mother to relatives in Britain made Marconi fluently bilingual at an early age. Formal schooling started with a tutor at home, and ended about 1894 after seven years at the Leghorn Lyceum, a sort of technical institute. He failed entrance examinations to both the University of Bologna and the Naval Academy at Leghorn. Marconi's later testimony that at age 20 he was "fairly well acquainted" with prior work on radio waves by Maxwell, Kelvin, Hertz, Édouard Branly, Oliver Lodge, Augusto Righi "and many others" cannot easily be attributed to the resources at Leghorn. His oldest daughter Degna's 1962 biography of her father says that Righi, a professor at the University of Bologna and a neighbor of the Villa Grifone, allowed the eager young Marconi to audit classes and do laboratory exercises at the university, and offered advice when requested.

Whatever the preliminaries, Marconi seems to have first hit on the idea of communication by radio waves in mid-1894, after reading a memorial review of Hertz' work written by Righi. In the Villa Grifone's long attic he assembled a Hertz-Righi spark transmitter and a Branly-Lodge coherer receiver, and by early 1895 he could ring a bell a few yards away. For greater distance the experiments were moved outdoors. Major improvements resulted when horizontal wires a few feet long were extended from each side of the transmitter spark circuit and terminated in suspended metal plates, and a similar structure was attached to the receiver circuit. When in late 1895 these wires were changed to a vertical position, and the lower plates laid flat on moist earth, Marconi's radio operated a Morse "inker" at the remote end of the estate, more than a mile away and over a small hill. This antenna-ground structure was a major invention.

Marconi's parents now agreed that it was time to explore commercial prospects. Following rejections in Italy, an Irish relative and grain-milling engineer, Henry Jameson Davis, invited Marconi to come to London. Marconi arrived there with equipment in February 1896. By July a patent was applied for and granted, and a successful demonstration was made to Post Office engineers over a distance of almost a mile. When the Wireless Telegraph and Signal Company was formed a year later, the distance achieved was close to 10 miles (16 km).

For the next three years Marconi, with company money, engaged mainly in building several experimental wireless stations, extending the maximum distance of transmission and making demonstrations whose publicity might bring business. A major obstacle to commercial success was the total government monopoly in Britain and many European countries of all facilities for commercial message-handling within or between the countries. Communications exempted from the monopoly included ship-to-ship and ship-to-shore service and a few transoceanic routes. Thus the company's first small income-producing contracts were with Lloyd's of London, the British Army and Navy, and three shipping companies.

By mid-1900, Marconi had persuaded his directors that transatlantic service was of prime financial importance. The company's first superpower station, with a transmitter designed by consultant John A. Fleming of the University of London, was ready at Poldhu in Cornwall a year later, followed shortly by a similar station at South Wellfleet on Cape Cod, Mass. When both flimsy antenna structures collapsed in autumn storms, Marconi had a simpler one built at Poldhu and then hurried to Newfoundland with receivers and kite antennas to establish the historic priority of transatlantic wireless by receiving the famous letter S on Dec. 12, 1901.

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There will always be those who doubt that Marconi received the legendary S, given the difficult conditions and the claimed frequency of about 800 kilohertz. However, on his next east-west Atlantic crossing a few weeks later, Marconi carried equipment that received confirmed Morse-inker messages to 1,550 miles (2,500 km), and the letter S in headphones to 2,100 miles (3,380 km), from Poldhu. It was noted at the time, but not fully appreciated, that this occurred only at night, and that nothing was received beyond 700 miles (1,130 km) in the daytime.

While always pursuing other projects, Marconi focused his primary attention after 1902 on the achievement of commercially reliable two-way transatlantic wireless telegraph service. He was finally successful in 1908, with stations in Clifden, Ireland, and Glace Bay, Nova Scotia.

This attainment of his original dream marks the summit of Marconi's role as innovator and driving force behind the company, now called Marconi's Wireless Telegraph Company, although he remained a world-famous figure and irreplaceable company representative. In 1910 the company acquired an aggressive general manager, Godfrey Isaacs, who waged such relentless legal warfare against infringers of Marconi's strong patents that by 1912 the biggest U.S. companies were forced out of business. In 1915, when Italy entered World War II on the side of the Allies, Marconi began a long period as a distinguished international diplomatic representative of his native land. His interest in technical experimentation reappeared for a few weeks in 1916 when he carried out pioneer communication tests with "very short waves" at frequencies of 100 to 300 megahertz, using highly directional antennas. The work was far ahead of its time. A decade later his assistant on this project, company engineer C. S. Franklin, along with H. J. Round and others, built for the British Post Office a worldwide system of high-power short-wave stations using vacuum tubes at about 10 megahertz.

By 1921, Marconi was wealthy enough to buy a 220-foot (67-meter) oceangoing steam yacht, named by him the *Elettra,* which the British government had seized in wartime from its Austrian owner. Using it as both a globe-roaming laboratory and a home, Marconi spent much of the rest of his life aboard. In 1932 it was the base for his last important experimental discovery, that microwaves at frequencies of 500 megahertz and higher bent farther below the horizon than textbooks said they should. This work anticipated the "scatter propagation" communication technique used 20 years later in polar regions.

Living in the heyday of the giant ocean liners, Marconi greatly enjoyed traveling with socially elite passengers in first-class luxury. He is said to have made more than 100 Atlantic crossings, usually at company expense. Several shipboard engagements were made and broken before his first marriage in 1905 to a charming, aristocratic Irish girl, Beatrice O'Brien. Romances with international socialites recurred at intervals. The marriage was terminated by Vatican annulment in 1927, when he married Cristina Bezzi-Scali, a beautiful titled Italian less than half his age.

For many reasons, including company transformations and health problems, the center of Marconi's life after 1927 gradually reverted to Italy. He died in Rome on July 20, 1937.

ROBERT A. CHIPMAN, *University of Toledo*



AP/WIDE WORLD

Ferdinand and Imeldo Marcos as they were about to become president and first lady of the Philippines in 1965.

MARCOS, mär'kōs, **Ferdinand E(dralin)** (1917–), Philippine political leader. He was the country's first president to succeed himself, its first prime minister, and its first chief executive to be exiled.

Marcos was born in Sarrat, Ilocos Norte (Luzon), on Sept. 11, 1917. Throughout his political career he capitalized on his claim that he had led a guerrilla unit against the Japanese during World War II, an assertion that U.S. Army documents made public in 1986 denied. Marcos was Liberal minority leader in the lower house of Congress from 1949 to 1959 and a senator from 1959 to 1965. After becoming Senate president in 1963 he switched to the Nationalist party, and in the 1965 election for president of the Philippines he defeated Diosdado Macapagal.

During his first term as president, Marcos built roads, bridges, airports, and schools, and oversaw a tenfold increase in rice productivity. He was reelected in 1969, but campaign waste and mounting inflation led to violent demonstrations. In 1971 grenades were exploded at a public rally of the opposition senatorial candidates, all of whom were wounded. Marcos took advantage of this incident to suspend habeas corpus and to intern thousands of dissidents. Meanwhile, in order to circumvent the constitutional limit of eight consecutive years for a president's term of office, Marcos had called a constitutional convention to create a parliamentary form of government. As prime minister under this system, he could rule indefinitely.

By 1971, Muslim unrest was increasing in the south, and open revolt had broken out in the north led by the New People's Army, a Maoist group. Disorder spread to central Luzon in mid-1972 following disastrous floods. In September 1972, Marcos proclaimed martial law. As temporary president and (from 1973) concurrent prime minister under the new but suspended constitution, he ruled by decree. He muzzled the press, nationalized major industries, and seized properties of his opponents—whose leader, Sen. Benigno Aquino, was convicted of subversion by a military tribunal and imprisoned until 1980. International groups protested Marcos' violation of human rights, charging his government with torture and murder.

In 1978, his emergency rule endorsed by questionable referenda, Marcos permitted the

Henry Ford

VOLUME 11

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FORD, Henry (1863–1947), American automobile manufacturer, who revolutionized the early industry with his low-priced Model T, produced by assembly-line methods. He popularized the automobile as a means of transportation for the average American and created a major company.

Early Life. Ford was born in Springwells township (now part of Dearborn), Mich., on July 30, 1863. He attended rural schools and early displayed mechanical and inventive skills. In 1879 he moved to Detroit, where he obtained a job as a machinist's apprentice. During the next few years he worked for several different companies, repaired watches and clocks as a sideline, and improved his knowledge of machinist and engineering skills by reading and practice.

After his apprenticeship, Ford set up and repaired Westinghouse steam engines in southern Michigan for about a year. He married Clara J. Bryant on April 11, 1888. They moved to Detroit in 1891 and two years later Ford was made chief engineer of the Edison Illuminating Company. On Nov. 6, 1893, the Fords' only child, Edsel Bryant, was born.

Car Builder and Racer. Fascinated by the promise of the internal combustion engine and its application to a self-propelled vehicle, Ford constructed a 1-cylinder gasoline motor in 1893. He went on to build his first car, a light carriage powered by a 2-cylinder engine, which was completed in June 1896. He resigned from the Edison company in 1899 to organize the Detroit Automobile Company.

The new company was forced into bankruptcy in less than two years, and Ford decided to make a reputation for his cars as racers. This decision brought him into conflict with the backers of the reorganized Detroit Automobile Company, now known as the Henry Ford Company. Unable to develop a racer on company time, he left the firm (which then dropped his name) in March 1902. Ford's racers brought him the publicity he sought. He defeated Alexander Winton in a memorable race at Grosse Pointe, Mich., in October 1901, and Barney Oldfield, driving a Ford racer, added to the builder's reputation. Ford drove his "999" to a world's record of 39.4 seconds for a mile over the ice on Lake St. Clair in January 1904.

Ford Motor Company Organized. Meanwhile, Ford, with the financial backing of a Detroit coal dealer, Alexander Y. Malcolmson, and a small group of investors, had organized the Ford Motor Company on June 16, 1903. Its principal assets were Ford's talent and that of his assistant, C. H. Wills, backed by the business acumen of James Couzens, Malcolmson's office manager and later U. S. senator from Michigan. Ford owned 25.5% of the stock of the new company, which was capitalized at $150,000, of which only $28,000 was paid in cash. The first car produced by the new company was sold within a month, and from then on orders and production rose rapidly.

In 1905, Malcolmson and Ford were at odds over the type of car on which the company should concentrate. Malcolmson favored an expensive car that the market appeared to demand, but Ford argued for a simple, inexpensive model. As a result of their disagreement, Malcolmson was put under pressure to sell his interest in the company. When he finally did so, Ford became the majority stockholder and president in 1906.

Success of the Model T. Free to follow his own ideas, Ford found overwhelming success. From the low-priced Model N, he moved to the Model T, which appeared late in 1908. The black, sturdy vehicle had a 4-cylinder, 20-horsepower motor; ignition was provided by a magneto built into the engine; a planetary transmission eliminated the gear shift and danger of stripping the gears; "splash" lubrication was used; and vanadium steel, easy to machine but of high tensile strength, was employed in many of the car's parts. Although his associates contributed significantly to the novel features of the vehicle, Ford was responsible for the overall concept and many of the basic ideas embodied in the construction of the Model T.

The car, which sold for $825 as a roadster and $850 as a touring car, clearly met the needs and means of the American public. In the first year more than 10,000 Model T's were sold. In 1914 the number reached 250,000, and Ford held just under 50% of the nation's automobile market. By the time its production ceased in 1927, 15 million T's had changed American motoring.

Ford's concentration on the Model T permitted him to utilize standardized parts and assembly-line production. The volume of production made it possible to reduce the price of the car steadily without detriment to profits. A major advertising campaign kept the Model T in the public's eye, and nationwide distribution was handled through a carefully devised network of branch agencies and dealerships. "Road men," working out of branch agencies, ensured that dealers, who numbered some 7,000 by 1913, provided adequate repair service and presented a favorable image.

Patent Victory and $5 Daily Wage. Ford was always of an independent frame of mind, and he refused to join the automobile manufacturers who accepted the validity of a patent obtained by George B. Selden on a basic gasoline engine and paid royalties to the holders of the patent. A court fight resulted, and in 1911 Ford's position that he had not infringed the patent was upheld.

His reputation was further enhanced in 1914 when the company announced a $5 daily minimum wage for employees who met certain basic requirements. This step was hailed as an innovation in employee compensation and made employment at the Ford plant a prize.

Changes and Troubles. Ford's position in the company was so strong that he could dictate policy when he was so inclined. After 1914 he became increasingly disposed to exercise this power. His decision to integrate operations from raw material to finished vehicle threatened the Dodge brothers, parts suppliers who held a 10% interest in the Ford firm. A controversy erupted, but Ford acquired the Dodges' stock, and by 1919 he and his immediate family held complete control of the Ford Motor Company.

Despite setbacks, especially in the post-World War I Depression, Ford continued to integrate production processes under one roof at the huge new Rouge plant in Dearborn. However, he lost or dismissed many of the key individuals who had helped to build the company's early success.

Ford's son, Edsel (1893–1943), became president of the company in 1919 and displayed considerable executive talent. The automobile market was changing and the purchasing public wanted more than a sturdy, compact, black car such as the Model T. The car buyer was willing to buy on the installment plan, but Henry Ford had little sympathy for sales on credit. Edsel was

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Santa Claus

"Dear Editor: I am 8 years old.
"Some of my little friends say there is no Santa Claus.
"Papa says 'If you see it in *The Sun* it's so.'
"Please tell me the truth; is there a Santa Claus?

"Virginia O'Hanlon.
"115 West Ninety-fifth Street."

Virginia, your little friends are wrong. They have been affected by the skepticism of a skeptical age. They do not believe except they see. They think that nothing can be which is not comprehensible by their little minds. All minds, Virginia, whether they be men's or children's are little. In this great universe of ours man is a mere insect, an ant, in his intellect, as compared with the boundless world about him, as measured by the intelligence capable of grasping the whole of truth and knowledge.

Yes, Virginia, there is a Santa Claus. He exists as certainly as love and generosity and devotion exist, and you know that they abound and give to your life its highest beauty and joy. Alas! how dreary would be the world if there were no Santa Claus. It would be as dreary as if there were no Virginias. There would be no childlike faith then, no poetry, no romance to make tolerable this existence. We should have no enjoyment, except in sense and sight. The eternal light with which childhood fills the world would be extinguished.

Not believe in Santa Claus! You might as well not believe in fairies! You might get your papa to hire men to watch in all the chimneys on Christmas Eve to catch Santa Claus, but even if they did not see Santa Claus coming down, what would that prove? Nobody sees Santa Claus, but that is no sign that there is no Santa Claus. The most real things in the world are those that neither children nor men can see. Did you ever see fairies dancing on the lawn? Of course not, but that's no proof that they are not there. Nobody can conceive or imagine all the wonders there are unseen and unseeable in the world.

You may tear apart the baby's rattle and see what makes the noise inside, but there is a veil covering the unseen world which not the strongest man, nor even the united strength of all the strongest men that ever lived, could tear apart. Only faith, fancy, poetry, love, romance, can push aside that curtain and view and picture the supernal beauty and glory beyond. Is it all real? Ah, Virginia, in all this world there is nothing else real and abiding.

No Santa Claus! Thank God! he lives, and he lives forever. A thousand years from now, Virginia, nay, ten times ten thousand years from now, he will continue to make glad the heart of childhood.

FRANCIS P. CHURCH, "Is There a Santa Claus," editorial, *The Sun*, New York City, September 21, 1897, p. 6.

After Church's death on April 11, 1906, *The Sun* broke its policy of editorial anonymity to announce that he had written this editorial.

Science

1661 It is not enough that you should understand about applied science in order that your work may increase man's blessings. Concern for the man himself and his fate must always form the chief interest of all technical endeavors; concern for the great unsolved problems of the organization of labor and the distribution of goods in order that the creations of our mind shall be a blessing and not a curse to mankind. Never forget this in the midst of your diagrams and equations.

ALBERT EINSTEIN, speech at the California Institute of Technology, Pasadena, California, February 16, 1931, as reported in *The New York Times*, February 17, 1931, p. 6.

1662 Science without religion is lame, religion without science is blind.

ALBERT EINSTEIN, paper prepared for initial meeting of the Conference on Science, Philosophy and Religion in Their Relation to the Democratic Way of Life, New York City, September 9–11, 1940.—Einstein, *Out of My Later Years*, chapter 8, part 1, p. 26 (1950, rev. and reprinted 1970).

1663 Modern civilization depends on science . . . James Smithson was well aware that knowledge should not be viewed as existing in isolated parts, but as a whole, each portion of which throws light on all the other, and that the tendency of all is to improve the human mind, and give it new sources of power and enjoyment . . . narrow minds think nothing of importance but their own favorite pursuit, but liberal views exclude no branch of science or literature, for they all contribute to sweeten, to adorn, and to embellish life . . . science is the pursuit above all which impresses us with the capacity of man for intellectual and moral progress and awakens the human intellect to aspiration for a higher condition of humanity.

JOSEPH HENRY, first secretary of the Smithsonian Institution. Inscription on the National Museum of American History, Washington, D.C.

1664 What is a scientist? . . . We give the name scientist to the type of man who has felt experiment to be a means guiding him to search out the deep truth of life, to lift a veil from its fascinating secrets, and who, in this pursuit, has felt arising within him a love for the mysteries of nature, so passionate as to annihilate the thought of himself.

MARIA MONTESSORI, *The Montessori Method*, trans. Anne E. George, p. 8 (1964).

1665 A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it.

MAX PLANCK, *Scientific Autobiography and Other Papers*, trans. Frank Gaynor, pp. 33–34 (1950).

1666 I have seen the sea lashed into fury and tossed into spray, and its grandeur moves the soul of the dullest man; but I remember that it is not the billows, but the calm level of the sea from which all heights and depths are measured.

Representative JAMES A. GARFIELD, speech nominating John Sherman for president.—*Proceedings of the Republican National Convention*, Chicago, Illinois, June 2–8, 1880, p. 184 (1881).

Garfield himself was ultimately nominated at this convention.

1667 As they say on my own Cape Cod, a rising tide lifts all the boats. And a partnership, by definition, serves both partners, without domination or unfair advantage. Together we have been partners in adversity—let us also be partners in prosperity.

President JOHN F. KENNEDY, address in the Assembly Hall at the Paulskirche, Frankfurt, West Germany, June 25, 1963.—*Public Papers of the Presidents of the United States: John F. Kennedy, 1963*, p. 519.

Kennedy used the "rising tide" image a number of times.

BUDGET OF THE UNITED STATES GOVERNMENT



FISCAL YEAR 1991

III.C. ENHANCING RESEARCH AND DEVELOPMENT

RESEARCH AND DEVELOPMENT: AN INVESTMENT IN THE FUTURE

Research and development (R&D) yields new knowledge, products and processes that, over the long term, result in economic growth and improved quality of life for all Americans. Investment in research and development is a top priority for an Administration that believes in investing in the future. It is the key to enhancing American competitiveness, improving our quality of life, and laying the groundwork for building a better tomorrow.

The budget proposes to allocate about $71 billion in budget authority for research and development, including R&D facilities, in 1991. This is an increase of $4.5 billion, or 7 percent over 1990 enacted levels. Civilian R&D will increase by 12 percent while defense-related R&D will increase by 4 percent. Within this total, $12 billion will be allocated for basic research, an increase of $1 billion or about 8 percent over 1990.

The 1991 budget contains a number of new and expanded programs and initiatives that will contribute greatly to the Nation's R&D enterprise. Examples include:

- ***Doubling of the National Science Foundation budget.***—An increase of over 14 percent which will continue progress toward doubling the NSF budget by 1993.
- ***Global Change.***—An increase of 57 percent for the U.S. Global Change Research Program (USGCRP), to a total of over $1 billion. This program places the United States in a world leadership role in climate change research. A major portion of this increase will be used to initiate the Earth Observing System, a series of instruments on space platforms to be developed by the U.S., Europe and Japan over several decades.
- ***Agricultural Research Initiative.***—The budget proposes the first step of a new program in agricultural research, designed to enhance production efficiency, food safety and environmental quality.
- ***Human Immunodeficiency Virus/Acquired Immune Deficiency Syndrome.***—An overall increase of 18 percent in all aspects of the Federal response to HIV/AIDS: research, prevention, treatment, and income support.
- ***Moon-Mars Exploration.***—A major new effort of $1.3 billion to develop the enabling technologies and begin the robotic science missions needed to carry out the President's goal of manned exploration of space beyond Earth orbit. This effort is the first step toward a manned lunar base and a manned mission to Mars.
- ***Space Station Freedom.***—A 36 percent increase for the development of Space Station Freedom to a total of $2.6 billion. This increase will provide for the critical transition from design to the initial fabrication of long-lead hardware elements.
- ***Superconducting Super Collider (SSC).***—An increase of $100 million (or 46 percent) for the SSC to a total of $318 million. This will support continued work to complete the design of the prototype magnets, and transition from prototype to production. The funding level maintains the 10-year design and construction schedule.

ENHANCING RESEARCH AND DEVELOPMENT

(Dollar amounts in millions)

	Budget Authority				Outlays			
	1990 Enacted	1991 Proposed	Dollar change	Percent change	1990 Enacted	1991 Proposed	Dollar change	Percent change
Major initiatives: [1]								
Doubling the NSF budget	2,084	2,383	+299	+14	1,959	2,213	+254	+13
Global Change	659	1,034	+375	+57	595	853	+258	+43
Agricultural Research Initiative	43	100	+57	+133	36	46	+10	+28
HIV/AIDS	2,932	3,463	+531	+18	2,454	3,203	+749	+31
Moon/Mars Exploration	859	1,267	+408	+47	767	1,037	+270	+35
Space Station Freedom	1,928	2,627	+699	+36	1,434	2,198	+764	+53
Magnetic Levitation Transportation	2	10	+8	+400	2	7	+5	+306
Superconducting Super Collider	218	318	+100	+46	188	293	+105	+56
Advanced Technology: Robotics	150	192	+42	+28	126	166	+41	+32
Science and Engineering Education	839	1,061	+222	+26	723	871	+148	+20
Government-wide totals:								
Conduct of R&D:								
Basic Research	11,398	12,366	+968	+8	10,961	11,886	+925	+8
Civilian	10,459	11,372	+913	+9	10,016	10,911	+895	+9
Defense [2]	939	994	+55	+6	945	975	+30	+3
Applied Research and Development	52,313	55,773	+3,461	+7	51,124	53,745	+2,622	+5
Civilian	13,375	15,346	+1,971	+15	12,321	14,449	+2,129	+17
Defense [2]	38,938	40,427	+1,490	+4	38,803	39,296	+493	+1
Subtotal, Conduct of R&D	63,711	68,140	+4,429	+7	62,085	65,632	+3,547	+6
R&D Facilities	3,023	3,059	+36	+1	2,590	2,738	+149	+6
Total [3]	66,734	71,199	+4,465	+7	64,674	68,370	+3,695	+6

[1] Major initiatives include funds for research and development which also are included in the Government-wide totals for R&D as well as funds from other non-R&D programs.
[2] Includes military-related programs of the Departments of Defense and Energy.
[3] Components may not add to totals because of rounding.

- ***R&D for Advanced Technology.***—An increase of 28 percent for robotics R&D, and continued support for R&D on high-performance computing, semiconductors, superconductivity and advanced imaging.
- ***Science and Engineering Education.***—The Administration is committed to improving the quality of science and engineering education. The budget will propose over $1 billion for science and engineering education activities in five agencies.
- ***Magnetic Levitation Transportation.***—An increase of nearly 400 percent in funding to $10 million to explore the possibility of stepped-up U.S. efforts in this emerging technology.
- ***Intellectual Property.***—The Administration will aggressively pursue improved international protection of intellectual property. The current negotiations in the Uruguay Round of the General Agreements on Tariffs and Trade are an important forum for this activity.
- ***R&E Tax Credit.***—The Administration will propose to make the Research and Experimentation Tax Credit permanent.
- ***Encouraging R&D by Transnational Companies.***—The Administration will propose to make permanent the rules for allocation by transnational companies of R&D

search) will be funded at $3.4 billion in 1991. The Department of Energy R&D activities include the research, development and testing of all nuclear weapons. The Department also conducts R&D on nuclear-powered directed energy weapons for the Strategic Defense Initiative, Naval reactor systems, and technology to verify arms control treaties.

STRENGTHENING SCIENCE AND TECHNOLOGY EDUCATION

At a time when the number of American students pursuing advanced science and engineering education is declining, the scientific and engineering (S&E) workforce is becoming more critical to the strength of the overall economy. This is a disturbing trend.

Many jobs created in the future will require people who are well-versed in mathematics and science and who have greater facility with higher order reasoning skills than most high-school and college graduates now have. Between 1976 and 1986, S&E employment grew at an average annual rate of over 6 percent, four times as fast as annual growth in the total U.S. workforce and twice the yearly rate of increase in total professional employment.

The "pipeline" of young people that feeds the S&E workforce may not be adequate in either numbers or quality to provide the workers that will be needed during the next decade and beyond. Between 1980 and 2000, the number of 18–24 year olds will decline by 19 percent while the overall population will increase by 18 percent. Even if the historic average holds, and 5 percent of 18–24 year olds obtain S&E degrees, the resulting shortfall in the S&E workforce could reach into the hundreds of thousands. Moreover, many students with an expressed interest in science and engineering careers leave the pipeline before getting a degree in science and engineering. This is particularly true for underrepresented minorities. Currently Black and Hispanic children constitute 25 percent of our school children; by the year 2000 this percentage will rise to 47 percent. Yet it is these groups that are now the most underrepresented in the S&E workforce: in 1988, only 231 Black and Hispanic Americans earned doctorates in science or engineering fields (excluding psychology or the social sciences). Together, Black and Hispanic Americans constitute 20 percent of the Nation's population but only 4 percent of employed scientists and engineers.

ONLY A SMALL PROPORTION OF STUDENTS RECEIVE SCIENCE AND ENGINEERING (S&E) DEGREES

	S&E Students who are underrepresented minorities	Total S&E student population
Total sophomores in 1977	856,000	4,000,000
High school sophomores with S&E interest	86,000	730,000
High school seniors with S&E interest	65,000	590,000
College freshmen, S&E preference	40,000	340,000
College juniors, S&E major	14,000	214,000
S&E B.S. degrees	13,000	206,000
S&E graduate students	2,500	60,000
S&E M.S. degrees	2,000	46,000
S&E Ph.D. degrees	Under 400	10,000

Note: Science and engineering participation reported here excludes psychology and the social sciences.

This situation is compounded by an even more serious factor. The performance of U.S. precollege students in math and science is far below that of students in other major industrialized nations. The quality of education, particularly science, mathematics, and engineering education, must be improved if America is to be competitive in the future.

The Administration is moving aggressively on a number of fronts to address the shortcomings in the Nation's science and technology education enterprise. The 1991 budget provides the concrete manifestation of the Administration's commitment in this area. It should be noted, however, that the responsibility for both the quality and the quantity of the Nation's S&E workforce belongs to every sector, not just, and not primarily, to the Federal Government.

INVESTING IN SCIENCE, MATHEMATICS, AND ENGINEERING EDUCATION

(Dollar amounts in millions)

Department or Agency	Budget Authority			
	1990 Enacted	1991 Proposed	Dollar change	Percent change
National Science Foundation	357	463	+106	+30
Education	136	230	+94	+69
National Aeronautics and Space Administration	42	51	+8	+21
Energy	17	25	+8	+47
National Institutes of Health	287	292	+5	+2
Total	839	1,061	+222	+26

The 1991 budget proposes a total of $1 billion in direct spending in four agencies for science, mathematics, and engineering education, an increase of 26 percent above 1990. The direct spending programs include a variety of measures to support teacher training, curriculum development, and direct assistance to students. In addition, there is a much greater amount of funding for fellowships and other forms of support that is provided indirectly through research grants.

The 1991 budget provides $463 million to the *National Science Foundation* for a range of activities designed to improve education and develop human resources for science and engineering. This is an increase of $106 million or 30 percent over 1990. NSF directly supports high-leverage science, math, and engineering education programs aimed at improving the quality of teaching, the quality of students and the numbers of students entering and staying in the S&E pipeline. Examples include: workshops for teachers, development of innovative educational materials, research experiences for high-school and college students in working research laboratories, and support for innovative programs at many of the Nation's science museums. In addition, NSF supports many programs aimed specifically at recruiting and retaining underrepresented groups.

The *Department of Education* maintains strong relationships with State educational entities and has the ability to reach thousands of students and teachers through its large formula grant programs. The 1991 budget proposes $230 million, an increase of $94 million or 69 percent over 1990, for the Dwight D. Eisenhower Mathematics and Science program, which will be provided to States to develop and im-

Student aid.—The other large program area for Federal funding is postsecondary education financial aid. The 1991 budget continues to support over $18 billion in aid to almost 6 million students with budget authority of $9.5 billion. This aid, in the form of grants and subsidized loans and jobs, helps make it financially possible for qualified students to obtain a postsecondary education, regardless of family income.

In recent years, some schools have taken advantage of the availability of Federal student aid to enroll students who are not truly qualified for postsecondary education or for whom they will not be providing a good education. Many of these students are not equipped for the job market when they leave school and often drop out of school very early while the school keeps the Federal aid. Some of these dropouts have taken out large loans which they cannot repay, and thus default. The Education Department is taking aggressive regulatory and administrative actions to stop these schools from taking advantage of Federal aid and of disadvantaged students. Additional legislative proposals will further strengthen the Secretary's enforcement powers to prevent program abuses.

Much of the Federal student aid now supports vocational training, in addition to the traditional support for students attending two and four year colleges. The Administration is considering means to rationalize support for vocational training under the student aid programs, the Job Training Partnership Act, and the Vocational Education Act.

The Educational Excellence Act

Shortly after taking office, President Bush proposed eight education initiatives. In addition to providing renewed Presidential commitment to improved education, his goal was to reinvigorate the education reform movement by selectively adding Federal money in selected areas.

The President transmitted his bill, "The Educational Excellence Act", on April 5, 1989. This bill would give incentives to schools to improve educational achievement, expand the use of magnet schools, reward excellent teachers and students, promote the hiring of persons with proven subject matter knowledge and management abilities to be teachers and principals, increase the endowment funds of the nation's Historically Black Colleges and Universities, and provide special funding for the school districts with the worst drug abuse problems.

Congress did not complete action on the bill. Appropriations were provided for 1990 for the two largest programs, Merit Schools and Magnet Schools of Excellence, contingent upon passage of the authorizing legislation.

The budget assumes that Congress will pass the Educational Excellence Act on a timely basis. For 1991, the budget includes $401 million in budget authority for these programs.

Other Education Initiatives

Support for programs for the disadvantaged absorbs the bulk of Federal education spending. Other Federal program activities are less costly, but perhaps in the long run more important for educational improvement. The budget for research and statistics and the Even Start program have already been discussed. Other key policies in the 1991 budget include:

Summit follow-up.—$20 million is requested for activities related to implementing the Summit Agreements. Uses may include activities to help States implement proposed legislation providing flexibility and enhanced accountability, and additional funding for development of measures of progress toward national educational goals.

Dropout demonstrations.—$45 million is requested for a program of dropout prevention demonstrations. These projects will be carefully designed to build on the learning from $22 million in dropout demonstrations now coming to an end. Coupled with evaluation of the prior demonstrations, and $5 million in new dropout research, these projects will help States learn how to prevent young people from dropping out of school and how to help them return to school if they do drop out.

School principals.—Principals and other administrators play essential leadership roles in school reform. A new $25 million program is included in the budget that will improve the abilities of school principals and other administrators. Under this program, talented persons

preparing to become principals will receive some short-term training and then spend a year with a proven successful principal to learn from this "mentor" how best to address the complex problems of school administration.

Mathematics and science education.—$230 million is proposed for the Dwight D. Eisenhower Mathematics and Science Education programs, a 70 percent increase over what Congress provided in 1990. These programs provide funds to States to improve the knowledge and teaching abilities of mathematics and science teachers. In addition, programs for science, mathematics and engineering education in the National Science Foundation are proposed to be increased by $100 million, to $460 million, a 28 percent increase over 1990. Other Federal agencies, such as the National Aeronautics and Space Administration and the Energy Department, also have education initiatives. The Domestic Policy Council Working Group on Education is providing coordination across agencies.

Literacy.—$239 million is proposed for the Adult Education programs of the Department of Education, an increase of more than 25 percent over what Congress provided in 1990. In 1991, $200 million would be distributed to States to help finance remedial education and thus to improve the literacy levels of adults. The Education Department will also create a new Adult Literacy Clearinghouse to help States, volunteer groups and the private sector share knowledge of what works in literacy programs. Funding is also proposed to be doubled from $3 million to $6 million in 1991 for the VISTA (Volunteer in Service to America) Literacy Corps of the ACTION agency, which supports volunteer efforts to overcome the problems of illiteracy. The Domestic Policy Council Working Group on Education is coordinating literacy initiatives across many agencies of government, and is developing plans for close cooperation with volunteer and private sector literacy action efforts.

Historically black colleges and universities.—$95 million is provided to support the operations of historically black colleges and universities and graduate institutions. Most importantly, an additional $15 million is provided for matching endowment grants for these institutions, triple the amount provided in 1990. Encouraging the building of endowments is the government's most effective contribution to the future financial independence of these institutions.

SUMMARY OF THE EDUCATION BUDGET AND POLICIES FOR 1991

The 1991 budget for the Education Department asks Congress to provide $1.2 billion more in 1991 than it did in 1990 for discretionary programs. This is a 6 percent increase. The projected decline in interest rates, to which guaranteed student loan subsidies are tied, produces anticipated savings of nearly $700 million which help finance the discretionary program increases. The combination of discretionary increases and loan subsidy savings results in a total Federal Education Department budget of $24.6 billion, an increase of $500 million over total 1990 budget authority. This is the largest education budget ever proposed.

The Presidential and State commitments to educational improvement supported by this budget represent a new beginning for national education policy. There can now be some cautious optimism for improvements in education in the 1990s and far into the next century.

IMPROVING JOB TRAINING OPPORTUNITIES

Learning does not end with graduation from high school or college. It is a constant life-long process. If giving every child the opportunity for a basic education is essential in a democratic society, so is providing access to additional training beyond the classroom. Although most job training is provided by employers for their employees, the government also provides second chance job training for those with poor skills who have not succeeded in the traditional education establishment or work environment.



BUILDING A BETTER AMERICA

"We live in a peaceful, prosperous time, but we can make it better... A new breeze is blowing, and a nation refreshed by freedom stands ready to push on. There is new ground to be broken, and new action to be taken."

-- President Bush
Inaugural Address
January 20, 1989

December 11, 1989

restructuring of the education system; and measuring performance. A commitment was made to develop national goals and initiatives to increase flexibility and accountability by early 1990.

- On April 5, the President submitted to Congress a comprehensive set of education initiatives, **The Educational Excellence Act of 1989.** The Act proposes:

  -- **The Presidential Merit Schools program** -- to reward schools that are making substantial progress in raising students' educational achievement, creating a safe and drug-free school environment, and reducing the drop-out rate.

  -- **A new Magnet Schools of Excellence program** -- to support the establishment, expansion or enhancement of magnet schools, focusing on disciplines important to the Nation's economic competitiveness such as math and science, increasing parental choice and improving quality education.

  -- **The Alternative Certification of Teachers and Principals program** -- to assist States interested in broadening the pool of talent from which to recruit teachers and principals.

  -- **President's Awards for Excellence in Education** -- to recognize public and private school teachers in every state who meet the highest standards of excellence.

  -- **Drug-free Schools Urban Emergency Grants** -- to provide special assistance to selected urban school districts that are disproportionately affected by drug trafficking and abuse.

  -- **A National Science Scholars program** -- to provide college scholarships to high school seniors who have excelled in the sciences and mathematics.

  -- **Additional Funding Authorization for Endowment Matching Grants at Historically Black Colleges and Universities (HBCUs)** -- to strengthen HBCUs by building endowments, an especially effective way to create financial strength and long-term security.

- On April 24, the President issued a new **Executive Order on Historically Black Colleges and Universities.** Highlights of the order include:

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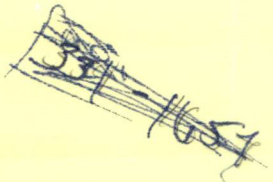
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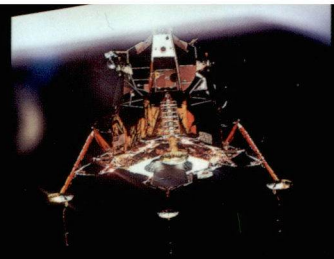
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THE ADVANCEMENT OF

HUMAN WELFARE

Outstanding Achievements 1964–1989

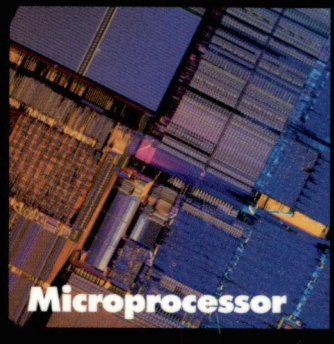


Moon Landing





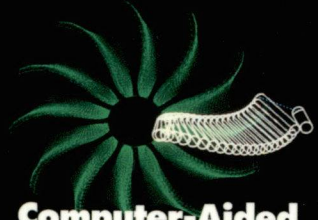
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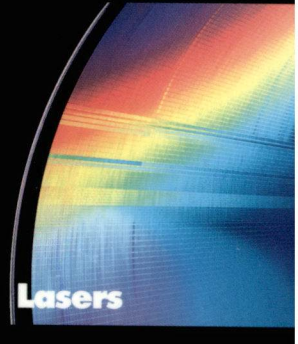
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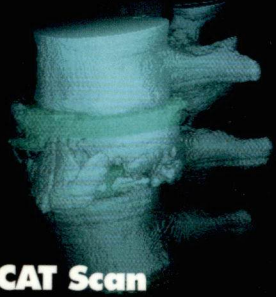
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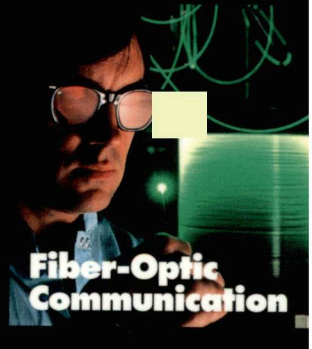
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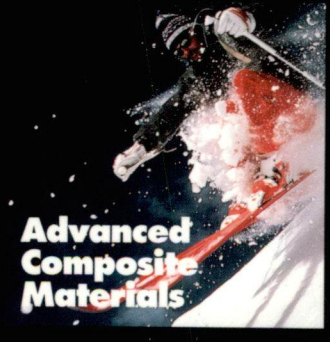
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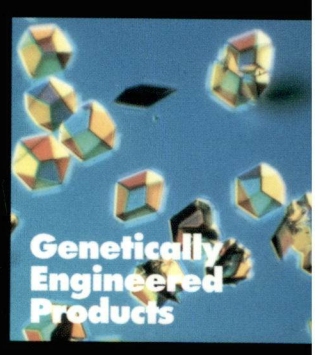
CAT Scan



Fiber-Optic Communication



Advanced Composite Materials



Genetically Engineered Products

NAE 25

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10 ENGINEERING AND THE ADVANCEMENT OF HUMAN WELFARE

Outstanding Achievements 1964–1989

Selected by the National Academy of Engineering
on the occasion of its 25th anniversary
December 5, 1989

NAE25

Carrie Levandoski
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Introduction

The years 1964 to 1989, the first 25 years of the National Academy of Engineering, have witnessed more advancement in technology and, consequently, greater change in the lives of people than any previous 25-year period in recorded history. As part of its anniversary celebration, the Academy has selected what it considers to be the 10 outstanding engineering achievements that have reached the public since the Academy's founding on December 5, 1964. Each represents a major advance or breakthrough in engineering and a significant contribution to human welfare.

This brochure presents each of the 10 achievements in a separate story, where we share with you some of the engineering challenge, insight, and excitement that attended the achievements. In doing so, we hope also to convey a better understanding of what engineering does and how it has contributed to human welfare over the past quarter century by improving our lives, extending our possibilities, and expanding our horizons.

Members of the Academy and representatives of several professional engineering societies submitted suggestions of outstanding engineering achievements. More than 340 suggestions were reviewed by the NAE Advisory Committee on the 25th Anniversary Celebration. The Council of the Academy approved the top 10.

No such list can encompass all the technological advances important to society; many other engineering accomplishments nearly made our list. The Indus Basin Scheme and its Tarbela Dam, for instance, bring flood relief and stable water supply to millions in Pakistan. The entirely new cities of Jubail and Yanbu—ports at either end of the crude-oil pipeline across Saudi Arabia—gave modern living conveniences to tens of thousands of people in the desert. The Alaska pipeline, deepwater oil platforms, and drilling technologies help supply much of our energy need. Auto emission control systems, including the catalytic converter, and processes for vitrifying hazardous waste—sealing them in glass for long-term storage—provide additional protection for our environment. Artificial hearts, cardiac pacemakers, and orthopedic implants give new life to thousands of people.

The top 10 achievements are presented here in nearly chronological order. In some cases we have grouped related achievements. For instance, lasers stimulated the development of fiber-optic communication, so we placed them together. And we chose to lead the list with the moon landing, which is truly one of the outstanding engineering achievements of all time.

The most striking aspect of these 10 diverse achievements is how closely they are tied together. The microprocessor, which has probably had the widest impact of all, has contributed to the development of today's application satellites, the CAT scan, computer-aided design and manufacturing, as well as genetically engineered products. Modern jumbo jets benefit from microprocessors, computer-aided design and manufacturing, lasers, fiber-optic communication, advanced composite materials, and application satellites. In turn, many of these achievements are closely tied to earlier, sometimes seemingly unrelated advances in the basic sciences, including mathematics.

It is also striking how widely and deeply these engineering advances have affected our daily lives. Weather satellites, which have been routinely used only since 1966, generate the satellite pictures seen on almost every television weather report. The microprocessor, invented in 1971, operates toys, televisions, videocassette recorders,

microwave ovens, and burglar alarms in probably the majority of U.S. homes. Advanced composites, which first appeared in commercial products in 1973, are now used by most people who golf, ski, or play tennis. And every telephone call of any distance is undoubtedly carried on beams of laser light flashed through fiber-optic cable, a service that has been commercially available only since 1977.

Because some engineering achievements are often viewed as sources of environmental degradation, it is important to note the beneficial effects many of these 10 have had on the environment. For example, the famous pictures of the earth taken by Apollo astronauts on their moon flights vividly show us how delicate and small our planet is compared with the forbidding immensity of space. Photos from Landsat and other earth-observation satellites for the first time have given us a good look at our fragile global environment, pinpointing areas needing help. And microprocessors, by improving the efficiency of everything from cars to power plants, help conserve scarce natural resources and greatly reduce the amount of pollutants released into the environment.

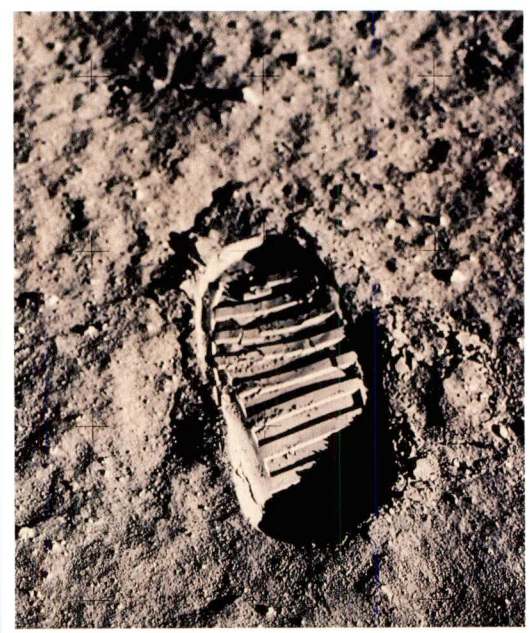
The next 25 years will witness even more advances in technology, bringing ever-greater changes to our way of life. It is therefore important, if we are to ensure the wise use of technology, that all of us—engineers and nonengineers alike—understand the nature of engineering and how it can be used to benefit us individually and as a society.

Finally, it is obvious that many more fascinating challenges for engineers lie in the future. We've built CAT scans and other wonderful machines that peer into the unopened human body, but can we develop devices and techniques that perform a total chemical analysis of the body without breaking the skin? We've used microprocessors to make soda machines talk, but can we use them to make computers really think before they speak? And yes, we have been to the moon, but what about going to Mars? The engineering achievements of the future are limited only by the laws of nature and our own imagination.



ROBERT M. WHITE
President

1 Moon Landing



Right: The first steps of an earthling on another celestial body are recorded in moon dust.

Six hundred million people—nearly one-fifth of the world's population—watched on television in July 1969 as an earthling first set foot onto another celestial body. With that step, human consciousness leaped a quarter million miles into space, expanding mankind's vision to a degree unequalled since Columbus's voyage to the New World. "The astronauts didn't just go to the moon," said one observer. "All our minds went to the moon."

Looking back from the moon, people saw white wispy clouds and blue sparkling water covering a planet framed by immense darkness. Earth appeared as a highly integrated unit, not just a collection of isolated oceans and continents. And it was strikingly obvious how small, fragile, and beautiful our planet really is, a precious oasis in the vastness of space.

The Apollo program sent nine spacecraft to the moon from 1968 to 1972, landing a dozen astronauts at six different sites. The rocks and scientific information they brought back revealed that the moon was formed at the same time and of the same elements as earth but that it lacks water, atmosphere, and life. The astronauts also left instruments to gather data on ground tremors and other phenomena. A laser reflector left by *Apollo 11* astronauts is still being used to measure the earth-to-moon distance and study the movement of continents.

The feat of landing men on the moon and returning them safely home ranks the Apollo project with the Egyptian pyramids, the Panama Canal, and the Manhattan Project as outstanding engineering achievements of all time. It stands alone for the advances in size and sophistication it made over prior technology. Apollo required a

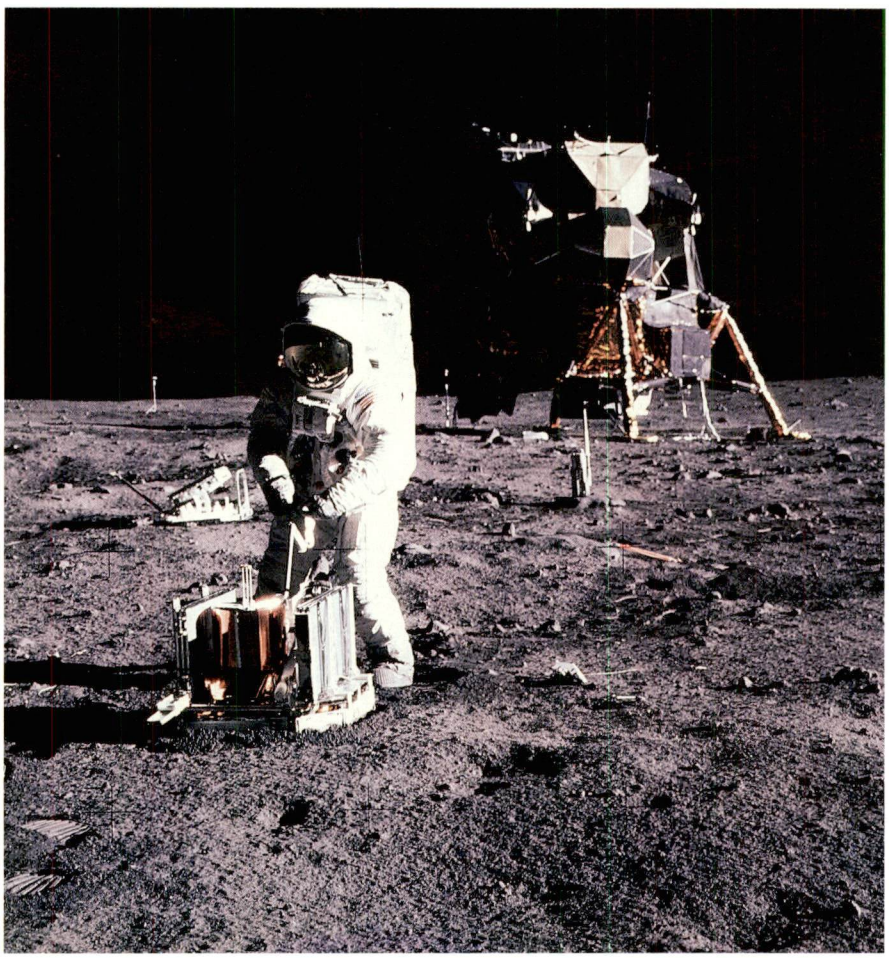


rocket 15 times more powerful, a navigation system far more reliable, a unique lunar landing craft, and improved space suits capable of withstanding a very hostile environment. In addition, the program demanded a novel, comprehensive management system to ensure that thousands of government and industrial organizations worked together well enough so that millions of parts would arrive where they should on schedule and would fit and function properly.

The Saturn/Apollo system was composed of an Apollo spacecraft, a lunar lander,

***Apollo 17* is readied for a nighttime launch toward the moon, peeking out from the clouds beyond. The spacecraft carried the first scientist to the moon and was the only one launched at night in the Apollo series.**

and a three-stage Saturn V rocket, which launched them toward the moon. Once in lunar orbit, the spacecraft released the two-stage lander, which carried two of the three astronauts to the surface. The lander's ascent stage later returned them to the spacecraft and was abandoned. Just before they reentered the atmosphere, the astronauts jettisoned the large service unit that supplied power, water, and oxygen and returned to earth in the small command capsule of the spacecraft.



An *Apollo 11* astronaut unpacks a scientific experiment to measure ground tremors on the moon. The small laser reflector, on the ground behind the astronaut, is still being used for laser measurements of the distance between the earth and moon.

Buildings shook and the ground trembled when a Saturn V rocket roared skyward with the first trio of astronauts heading for lunar orbit in December 1968. The rocket developed roughly enough thrust to hurl a small house into earth orbit. Thirty-six stories tall and weighing as much as a good-sized Navy destroyer, the Saturn/Apollo vehicle used the biggest, most powerful rocket ever built.

The first stage of the three-stage Saturn V dwarfed the largest rockets of its day. An Atlas ballistic missile, for instance, produced 360,000 pounds of thrust. The first-stage engines of the Saturn V, however, each produced 1.5 million pounds, and there were five. Together they burned 3 tons of kerosene and liquid oxygen per second. Building reliability into such monstrous engines was a monumental challenge. Yet, all 12 Saturn V rockets launched in the Apollo series succeeded.

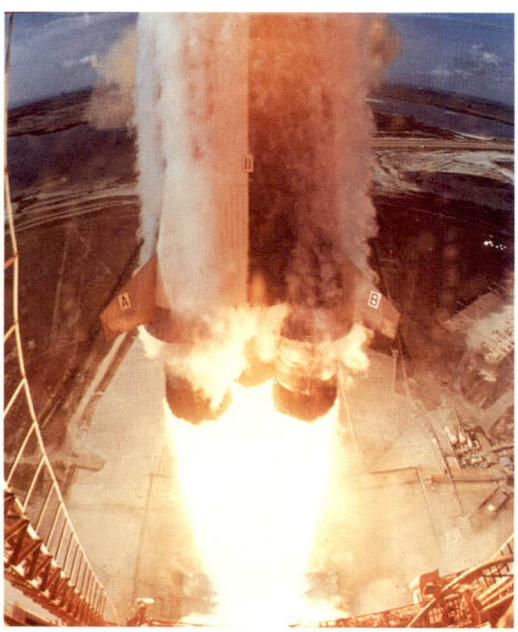
To fuel the second and third stages, engineers chose liquid hydrogen, which gave 40 percent more thrust per pound of fuel burned than kerosene. The second stage was a cluster of five engines, while the third had just one. But unlike those in lower stages, the third-stage engine had to be restartable in order to push the spacecraft toward the moon after coasting an hour and a half in earth orbit.

Building a rocket of such size and design required many new and advanced engineering techniques. The field of fracture mechanics, for example, advanced greatly in answering questions raised during construction of the second-stage fuel tank, which was 65 feet long, 33 feet in diameter, and held liquid hydrogen at -423 degrees F. The aluminum tank was pieced together with literally miles of welds, which could contain a few tiny cracks. But how big could the cracks be before they began to weaken the tank? By analyzing aluminum with similar cracks, engineers calculated the amount of pressure the metal could stand before cracks of various sizes begin to grow and thus become dangerous. To ensure its safety, they tested each second-stage tank by loading it with liquid hydrogen at a pressure 5 percent higher than the maximum required for flight. If cracks did not grow at that pressure, they would not grow at the lower pressure during flight.

The Apollo flights would have been impossible without inertial navigation, which was developed in the 1950s and was just being installed in the early 1960s on aircraft, submarines, and ballistic missiles. Radio navigation from earth was impractical during the final minutes of a landing approach to the moon. The time radio signals take to travel that distance is too long for the immediate reactions needed to land a craft safely. Radio navigation was also useless for flights behind the moon because it requires line-of-sight transmission from earth.





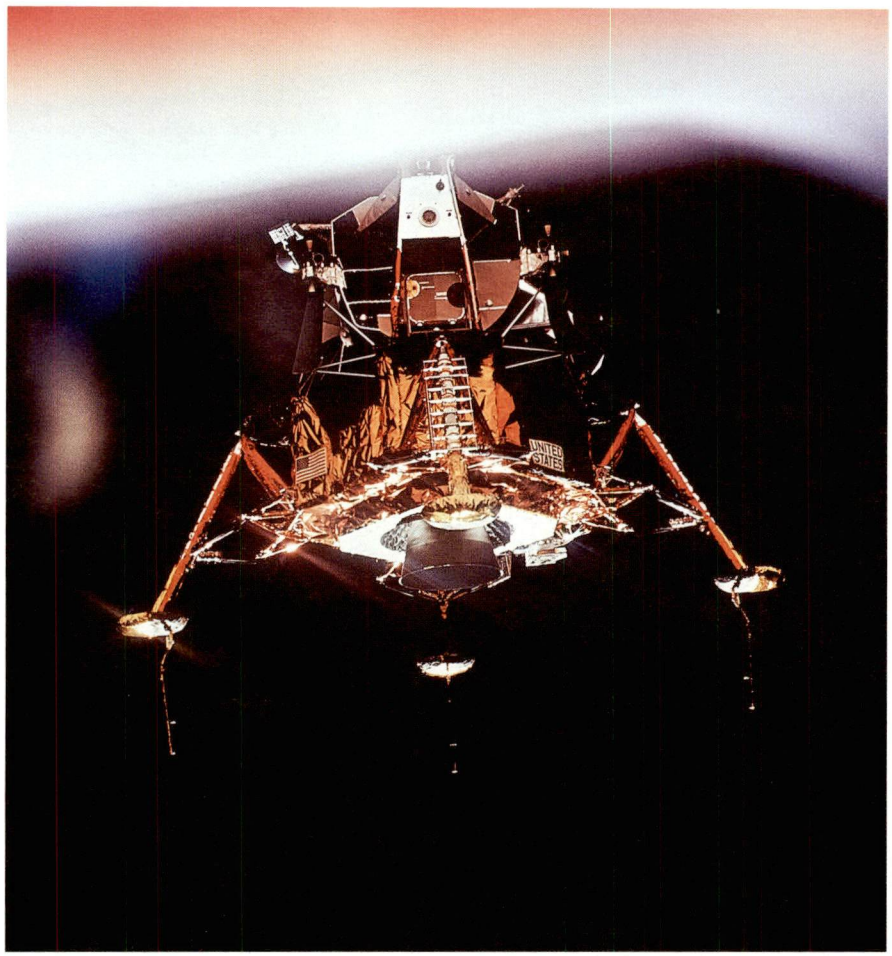


Apollo's navigation—the rocket, spacecraft, and lunar lander each had a separate system—included gyroscopes and accelerometers, which sensed change in direction and speed. They were combined in single subsystems, called inertial measurement units, or IMUs, which measured movement along, as well as off, the desired course due to rocket thrust or atmospheric resistance. When leaving or approaching the earth or moon, IMUs were critical for making quick guidance decisions. Gravitational influences of the earth and moon were calculated before flight and added to onboard guidance computers. This information and the IMU data permitted control systems to keep the craft almost exactly on course. During the flight, astronauts used a sextant in calculating midcourse corrections. In practice, however, ground radar stations usually performed this time-consuming task and radioed up commands to correct deviations.

The two-stage lander that ferried astronauts to the lunar surface was the first manned vehicle designed to fly solely in space. Its structure could be extremely lightweight, since the moon's gravity is only one-sixth that of earth. And aerodynamics did not need to be considered, since there is no air on the moon. The lander was essentially built inside out. Its thin aluminum pressurized cabin was inside, wiring and tubing surrounded that, and a patchwork of black or golden insulating materials covered the outside. These materials absorbed or reflected light, depending on whether that part of the lander needed protection from cold or heat. Its four spiderlike legs with wide foot pads could keep the lander upright, whether it touched down on a slope, in deep dust, or under any of 500 other combinations of terrain and landing conditions anticipated by the engineers.

One of the most critical parts of the lander was the small ascent engine. Once the astronauts landed, they were completely dependent on this engine to return them to the mother ship. There was no backup. The basic portion of the flight engine had been briefly test-fired on earth. Its fuel system, however, had not previously been exposed to the highly corrosive propellants for fear of weakening its seals and corroding its valves. So engineers ground-tested ascent-engine prototypes for every failure they could

The five first-stage engines of the mighty Saturn V rocket lift *Apollo 11* off the launch pad and start the spacecraft toward the moon. Astronauts are in the conical command capsule atop the rocket. Just below the capsule is the cylindrical service unit. Below that, the lunar lander is packed in another cylinder just above the rocket's third stage.



The lunar lander, seen from the *Apollo 11* spacecraft, heads for a landing on the moon. The descent stage, with outstretched legs and protruding rocket nozzle, will remain on the moon when the upper ascent stage brings the two astronauts back to the mother ship.

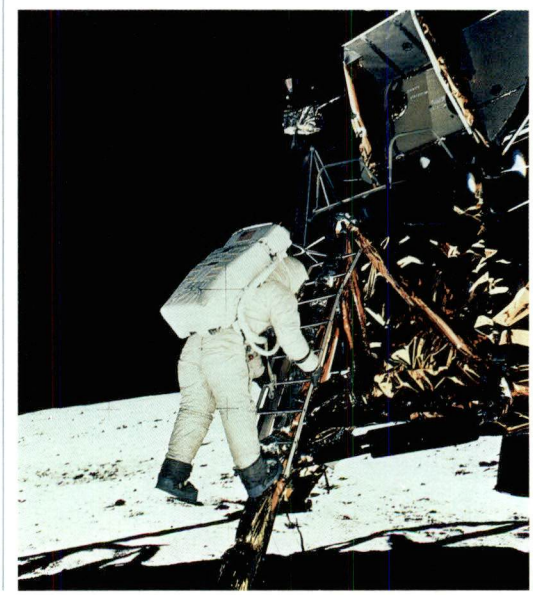
Right: Dressed in a three-piece space suit, an *Apollo 11* astronaut climbs down a leg of the lunar lander and hops onto the hard, dusty surface of the moon. His life-support back pack carried enough oxygen for a 4-hour tour outside the lander.

imagine that might happen in flight. None did.

Astronauts who walked on the moon wore a three-piece space suit and backpack of life-support equipment for up to four hours outside the lander. The ensemble weighed 190 pounds on earth but only a sixth of that on the moon. The first piece was a cooling undergarment of knitted nylon-spandex with a network of plastic tubes filled with water circulating from the backpack. The next piece was the basic suit, a rubber-coated nylon bladder sandwiched between a cloth lining and a nylon cover to shape the suit. The third piece was a protective outer garment of 17 layers, including 6 layers of Beta cloth. This is a fireproof fabric of fiberglass threads coated with Teflon to prevent itching. The outfit was completed by a helmet, boots, gloves, and the backpack, which also carried a radio and antenna.

The Apollo program was probably the most complex and ambitious engineering project ever attempted. A moon flight required more than 450 persons in the launch control center and nearly 7,000 others on 9 ships, in 54 aircraft, and at stations around the world. At its peak, 400,000 people were working on Apollo at three major space centers and 20,000 contractor sites. The people who managed Apollo pioneered techniques that remain the model for operating a massive, well-run engineering program. In 1961 NASA estimated that the project would cost $20 billion and would put a man on the moon before 1970. The space agency actually spent $25.4 billion for all the Apollo flights. And two *Apollo 11* astronauts stepped onto the moon on July 20, 1969.

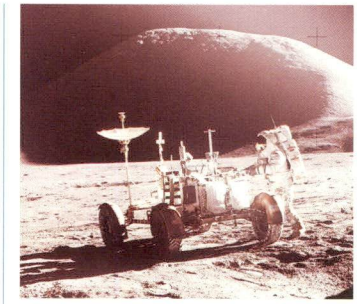
On the planning and control side of the program, the Apollo managers created a monitoring system that gave them enough information to ensure that the millions of pieces for the project were coming together at the right time and place, in the right engineering configuration, and for the right price. To do this, they identified a few hundred critical milestones—such as "rocket first stage complete" or "stage shipped to Cape Kennedy"—for each program area. Once a month, contractors reported their progress to the three NASA centers, who reported to the Apollo managers. The managers, in turn, identified projects that were falling behind—most of them did—and devised solutions to bring them back on schedule. For instance, when a tragic fire killed three astronauts during a ground test of their spacecraft, managers swiftly reviewed the safety of nearly the entire Saturn/Apollo system, redesigned the spacecraft and space suit, and brought the program back on schedule in little more than a year.



On the technical side, the great challenge was to create a management system that would ensure the precise interface among millions of pieces—the Saturn V alone had 6 million—manufactured by thousands of contractors. Careful records were kept of specifications for all the parts and the interfaces between them. This documentation was especially valuable when, for instance, during the unmanned second Apollo flight, the first-stage engines began to flicker, a piece of an aluminum panel fell off, and two second-stage engines quit early. By comparing flight instrument data with the documentation, engineers were able to find the problems, simulate them on the ground, and correct them with enough confidence to go ahead with the next flight—the first with astronauts aboard.

astronauts traveled over the lunar surface in a motorized rover to gather rocks and conduct scientific experiments. *Apollo 17*, the last of the program, carried the first scientist—a geologist—to the moon in December 1972.

Since the inception of the Apollo program, nearly all the known planets in our solar system and many of their moons have been visited by unmanned spacecraft. Between them, the United States and the Soviet Union have sent automated probes to Earth's two neighbors, Mars and Venus, as well as to Mercury, the planet nearest the sun. U.S. probes have journeyed to all the other planets except Pluto. The most celebrated unmanned spacecraft, *Voyager 2*, left Earth in 1977, rendezvoused with Jupiter in 1979 and then with Saturn, Uranus, and finally Neptune in 1989. Yet, it was man's



***Apollo 15* astronauts explore the moon in a lunar rover, which was packed aboard the lander and unfolded on the lunar surface. It carried the astronauts 17.5 miles during three exploratory tours and helped them collect 170 pounds of moon rocks for the return to earth.**



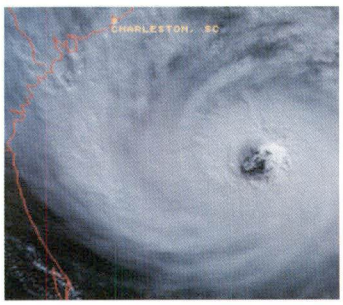
The first two moon flights—*Apollo 8* and *10*—put astronauts into lunar orbit; *Apollo 11* and *12* put them on the moon. An exploding oxygen tank in the service unit crippled *Apollo 13*, whose astronauts took temporary shelter in the lunar lander during the emergency return to earth. *Apollo 14* went smoothly. During the next three missions,

landing on the moon that truly captured the world's imagination, an engineering achievement that has extended the human domain far beyond the boundaries of earth.

The earth, like a sparkling jewel against black velvet, rises above a barren lunar landscape to greet the *Apollo 11* astronauts 240,000 miles out in space.

2 Application Satellites

In November 1982, a U.S. weather satellite spotted a hurricane developing southwest of Hawaii and watched it start moving north. Suddenly the storm turned east and raked across the islands less than 24 hours later, leaving nearly a quarter billion dollars of damage in its wake. But only one life was lost. Hurricane warnings, based largely on satellite pictures, had alerted most people in time to take shelter.



The 125-mile-per-hour winds of Hurricane Hugo begin to lash the coast of the southeastern United States under the constant gaze of a U.S. weather satellite. Satellite images warned residents of Charleston (upper left) of the approaching Hugo, still 210 miles away in this picture, giving them several days to prepare for the storm and evacuate the city.

Twenty-five years ago, there were no operational satellites for weather forecasting or for any other routine application. Today, however, satellite systems girdle the earth watching for storms, relaying communications, mapping uncharted terrain, and helping ships and airplanes navigate anywhere on the globe.

Satellites started to become routine in April 1965, when the first nonexperimental commercial satellite flew into space and parked in orbit over the Atlantic. *Early Bird* carried circuits for 240 telephone calls or television service between Europe and North America. Today, several generations of satellites later, *Early Bird*'s descendants handle up to 120,000 calls at once or share the capacity with TV broadcasts, computer data, and electronic mail. They are part of a worldwide communications network launched by the International Telecommunications Satellite Organization, or Intelsat, which now has more than 100 member nations.

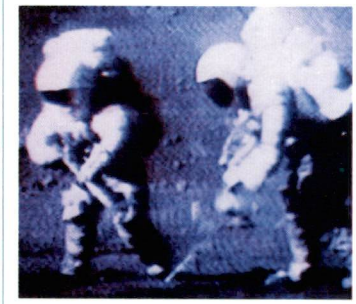
Communications satellites have dramatically altered the nature of our global community. Twenty-five years ago, reliable communications existed only between countries in the developed world. But communications satellites and the development of small, portable television cameras have linked people together around the globe. In 1969, for example, communications satellites brought TV coverage of the first manned lunar landing—live from space—to nearly a fifth of the world's population. Today they bring instant coverage of news and events to every corner of the earth.

Scores of civilian and military communications satellites sit in a ring around the earth 22,300 miles above the equator. At that altitude they complete one revolution every 24 hours and therefore remain stationary relative to the surface of the earth below. Satellites in this geostationary orbit provide high sky platforms for relaying signals to and from ground stations, vehicles, boats, and planes scattered over the surface below.

The idea for a system of radio-relay satellites in geostationary orbit maintained by astronauts was described by science fiction writer and futurist Arthur C. Clarke



An astronaut retrieves a communications satellite, *Westar VI*, that failed to go into high geostationary orbit after being launched into low earth orbit. The space shuttle brought the satellite back to earth, where it was refurbished. Pending U.S. government approval, the satellite will be launched aboard a Chinese rocket and will provide a communications link for East Asia.



Communications satellites relayed live television coverage of moon missions to millions of people around the world. Here, *Apollo 15* astronauts collect rock samples.

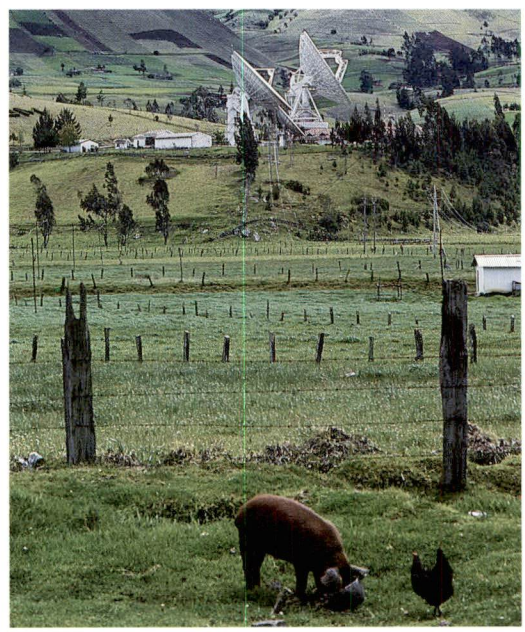
in 1945. Astronaut custodians, however, were impractical and, when *Early Bird* went up in the 1960s, shown to be unnecessary. Transistors and other solid-state components of the satellite's innards were far more reliable than the vacuum tubes of 1945-vintage radios and small enough to fit into a tiny satellite. *Early Bird* lasted more than three years without maintenance, and today's communications satellites frequently last until their fuel runs out, about a decade.

A country divided by mountains, jungles, water, or distance is now often united by a domestic satellite communications system. In 1965 the Soviet Union established the Molniya system using satellites in oblong orbits looping over the northern latitudes. These satellites were not geostationary. However, one always rose above the country just as another set. Now more than 40 countries have established their own satellite communications systems, often by constructing ground stations and renting circuits on commercial satellites.

Before the era of routine satellite use, weather observations were available for less than 20 percent of the globe. Much of the unobserved region covered the vast oceans of the Southern Hemisphere and the tropics, where a storm could churn into a hurricane with no one knowing until it sank a ship or washed away a town. But since 1966, when the first fully operational weather satellite

system was launched, no major tropical storm has gone undetected anywhere in the world.

Two U.S. weather satellites circling from pole to pole scan the earth from low orbit twice a day. Soviet satellites also routinely survey global weather from polar orbit. High-flying satellites in geostationary orbit monitor wide reaches of the planet and generate the weather pictures seen on television. The United States launched the first such operational satellite, GOES (Geostationary Operational Environmental Satellite), in 1974 and now maintains one above the western Atlantic and another over the eastern Pacific. A European satellite hovers over Africa, an Indian satellite over the Indian Ocean, and a Japanese satellite over the western Pacific. These five provide



Two dish antennas near Bogota, Colombia, aim at a communications satellite in geostationary orbit above the equator.

continuous coverage of weather throughout the equatorial and midlatitude regions of the earth.

Radiometers carried by weather satellites measure reflected solar energy and infrared energy radiating from the earth and atmosphere. Computers then turn the data into images of clouds and weather patterns. Radiometers also measure radiation at precise wavelength intervals, generating information that allows scientists to determine atmospheric temperature, water vapor, and ozone levels. Today's radiometers are sensitive enough to sound the atmosphere from geostationary satellites more than 22,000 miles up in space.

Weather satellites frequently carry equipment to relay data collected by thousands of remote automatic ground stations from instruments such as rain or river-flow gauges. And, since 1982, increasing numbers of U.S. weather satellites, as well as Soviet navigation satellites, have also been carrying search-and-rescue radio equipment, some of it supplied by Canada and France. The devices pick up distress calls from ships and planes in trouble, leading to the rescue so far of more than 1,200 persons.

Images generated by weather satellites have been used to study snow cover, geologic faults, and other large ground features. But the need for more detailed information gathered in a systematic, repetitive way led to the development of specialized terrain-observation satellites. These orbiters create high-quality images that can be used to help study worldwide crop production, search for minerals and petroleum, monitor environmental problems such as desert creep and deforestation, and measure snowmelt to predict water resources and control flooding. In 1972 the United States launched the first in a series of Landsat satellites, which scrutinize the entire earth from near-polar orbit, observing each spot at the same local time every 18 days.

All Landsats have carried multispectral sensors that measure solar energy and infrared radiation at four or more wavelengths. Every type of terrain reflects and absorbs sunlight and emits infrared radiation in ways that reveal its identity and condition. Objects often show up better at one wavelength than another, which gives this technique an advantage over conventional photography. The data are transmitted back to one of several ground stations, processed into images, and made available to the public. France and the Soviet Union have launched similar satellites and make their images available commercially. The French SPOT system produces particularly high quality images.

Infrared satellite images do not show as much detail as visible images, but they yield thermal information that the others cannot provide. Water, for example, that collects in faults usually holds more heat than surrounding rock. Infrared sensors detect this heat differential, revealing an otherwise hidden geologic formation. Infrared imaging is also useful for monitoring pollution, observing volcanic activity, and leading

fishing boats to warm waters where fish might be gathered.

More recently, experimental terrain-observation satellites have been carrying microwave radar, which penetrates all types of weather, day or night. Microwave radar can, to a certain extent, penetrate leaves and is used to map jungle terrain. It can also penetrate dry sand and has been used to trace buried watercourses in the desert. Radar return signals also tell much about the land that is useful for mineral and petroleum exploration.

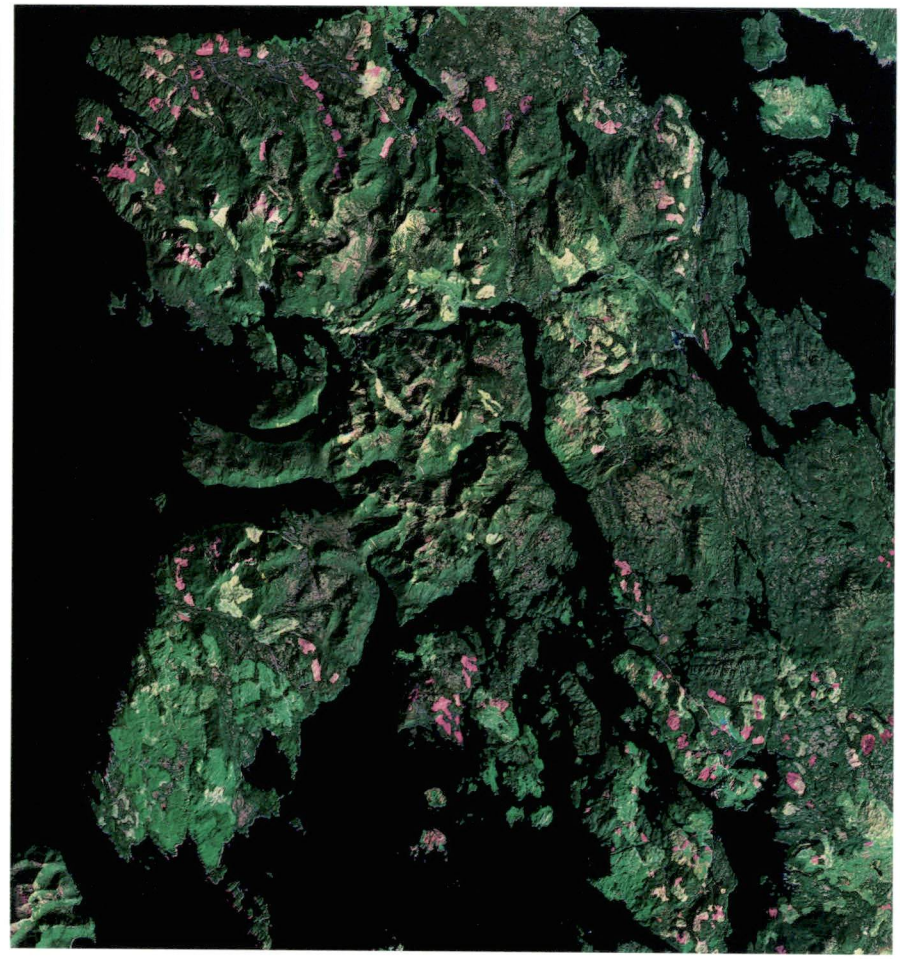
The military forces of the United States, the Soviet Union, and other countries use their own terrain-observation satellites to keep track of foreign troop movements, electronic communications, military installations, and rocket launchings. The satellites are hardier than their civilian counterparts, as well as more sophisticated, capable, and flexible. These "eyes in the sky" have greatly reduced the possibility for surprise attack and have thus helped maintain peace among world powers for the past quarter century.

In the future, satellites may be used to monitor the health of the entire earth biosphere. A major step in that direction will be taken as part of the International Space Year in 1992. A "Mission to Planet Earth" is being organized using earth-observation satellites and other means to study such problem areas as polar ozone holes, deforestation, ocean productivity, landcover change, and global warming caused by the "greenhouse effect."

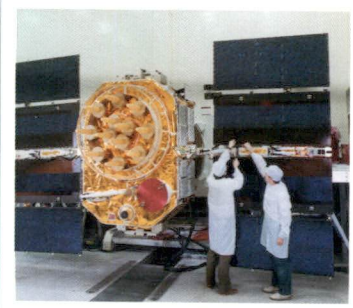
The precision of their orbits makes satellites ideal instruments for navigation. They have all but replaced the sextant since about 1968, when the Navy completed a system of navigation satellites, called Transit, for ballistic missiles fired from submarines. Transit employs satellites in near-polar orbits that are spaced to provide global coverage. Using data encoded on satellite signals, a computer-aided receiver on a ship or plane can determine its location to within less than a quarter mile.

Several satellites have already been launched for a new navigation system—the Global Positioning System (GPS), or Navstar—that will have 18 satellites plus 3 spares when completed. Using GPS, receivers in ships, planes, ground vehicles, and portable packs will be able to determine their locations to within 10 meters. The heart of the system is an atomic clock in each satellite that loses or gains just one second every 33,000 years. A plane, for example, receives signals from four satellites, each signal telling the time it was emitted and the position of the satellite. The plane's computerized receiver calculates how far each signal has traveled, then uses this data to pinpoint its position in space.

In 1988 a satellite was launched to track long-haul trucks in the United States. A freight company using the system immediately found one of its trucks 300 miles off course. More advanced systems used by some military aircraft show pilots a map of the local area. Cars may someday be equipped to receive satellite signals that provide drivers with a street map of the city being traveled. Indeed, satellites may become our standard means of navigation, whether on land, in the air, or at sea.



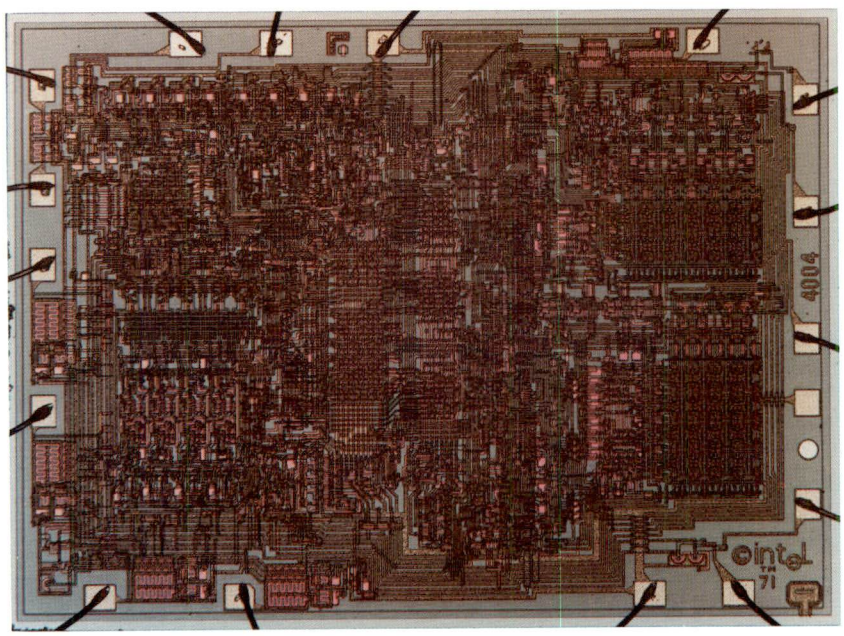
Satellite image reveals extensive clear cutting in Tongass National Forest on the northern tip of Prince of Wales Island, Alaska. Recently cleared areas appear pink, cleared areas that have started to recover are light green, and undisturbed forests are dark green.



Technicians prepare a Navstar navigation satellite for launch. The 12 spike antennas will form the satellite's signal into a cone covering the entire hemisphere below.

3 Microprocessor

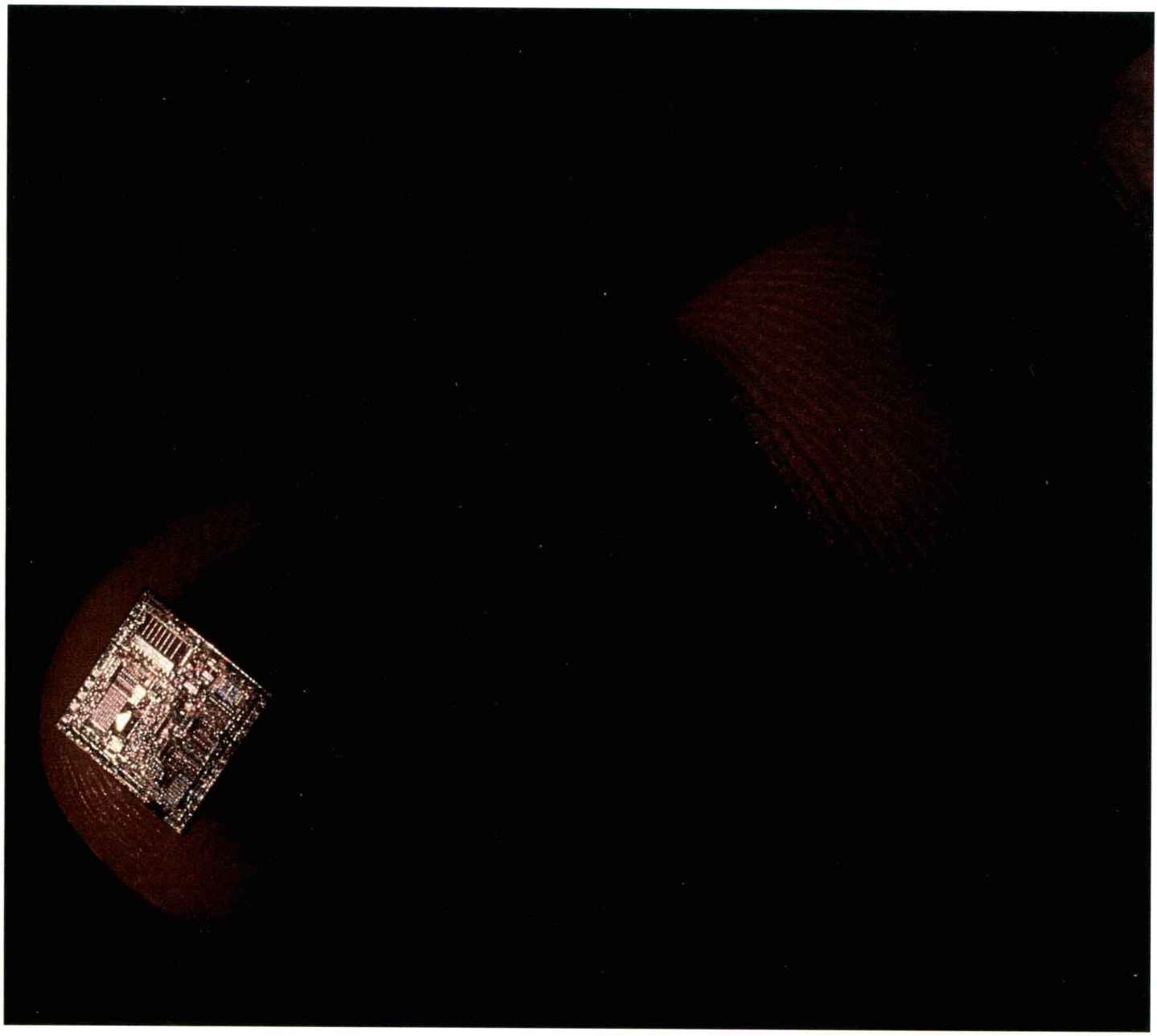
The microprocessor—a tiny "computer on a chip" no bigger than your fingernail—has quickly and quietly infiltrated our lives since it was introduced in 1971. At home, microprocessors are the brains in electronic devices that control microwave ovens and change television channels from across the room. At work, they help design complex buildings and control huge manufacturing machines. In between, they coordinate traffic lights and improve fuel efficiency in cars. And everywhere there is a personal computer, there is a microprocessor churning away inside.



A web of electronic circuitry spreads across the face of the 4004, the first microprocessor. The chip contains 2,300 transistors yet measures only 1/16 inch by 1/4 inch, about the size of a child's fingernail.

A microprocessor works something like a juke box's record player, which plays the tune on a record retrieved from its collection. A microprocessor, however, plays the set of instructions retrieved from a memory chip, performing simple functions—such as addition or subtraction—programmed into the instructions. Microprocessor and memory chips alike rely on microscopic integrated circuits to perform their tasks.

Before microprocessors, integrated circuit chips were generally not programmable. They could do only a single function for which they were designed, like a record player playing one tune engraved on its turntable. The first microprocessor, in fact, was developed by an American engineer who was given the task of designing 12 single-function chips for a Japanese calculator. Instead, the engineer designed one general-purpose chip that performed all 12 functions according to instructions stored in a memory chip. Because each instruction contained only four bits—the electronic 1's



and 0's of digital code—the microprocessor was classified a 4-bit chip.

Microprocessors of the first generation were too feeble to power anything resembling a personal computer. But they were—and still are—powerful enough to drive pocket calculators and control machines performing simple tasks. They have become, like the motor, a tool for every use. Millions are sold each year to operate home burglar alarms, remote television controllers, programmers for videocassette recorders, and dozens of toys. The "4-bitter" was the hottest selling microprocessor every year until 1988, when 8-bit chips took the lead.

Microprocessor chips in a variety of sizes provide the delicate control that improves the efficiency of power plants, cars, and heating and cooling systems in buildings, which translates into lower operating costs and less pollution. They are also widely used in the cockpits of advanced commercial airliners to control navigation and other avionics systems, thereby improving the efficiency of aircraft and crew.

Second-generation microprocessors—the mighty 8-bit chips that appeared in 1974—had enough calculating power to operate low-performance computers. These "microcomputers" were built around microprocessors and remained curiosities, the electronic playthings of hobbyists, until

Microprocessors are the tiny "brains" inside microcomputers and hundreds of other electronic devices.



Microprocessors make modern airliners easier to fly by displaying flight instrument data on video screens, as in the cockpit of this advanced 747. These data display screens and other design improvements helped reduce the number of cockpit lights, switches, and gauges to fewer than 400 in this aircraft compared with nearly 1,000 in earlier models.

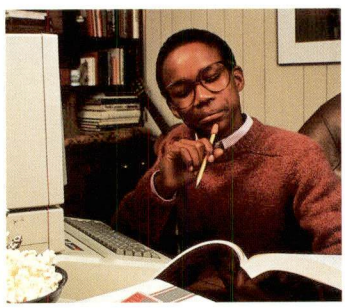
the introduction of third-generation chips in 1975. These delivered much better performance than their forerunners and brought down microprocessor prices to as low as $25 from nearly $200. Within two years, they spawned commercial lines of home microcomputers that were soon being used for nonhome tasks.

It was, however, the fourth generation—mostly the powerful 16-bit microprocessors—that convinced the traditional computer industry that microcomputers based on these chips were powerful enough for more than home video games. And in 1981 the mainframe-computer industry began marketing microcomputers for such computational tasks as graphics, desktop publishing, managing large data bases, and computer-aided design in business and industry.

Microcomputers would have been useless without software, the programs of simple commands that tell computers how to perform complex tasks. Each computer has coded operating instructions already wired into it, but they are awkward for people to use. So the codes have been translated into languages, such as BASIC, FORTRAN, and COBOL, based on easy-to-use words and symbols. The languages further simplify programming by using single symbols for some simple functions that are generated by a series of instructions. For example, "*" might trigger the series of instructions for the function "multiply". The languages, in turn, are used to program larger sets of instructions, or programs, that perform complex tasks such as word processing. For instance, word processing software might be programmed so that typing C-O-P-Y initiates the thousands of instructions for duplicating a page of text on the computer screen.

Software was not readily available for the earliest microcomputers. Hobbyists labored to compose their own operating systems—programs telling a computer how to run itself—and application programs for tasks such as word processing or playing Space Invaders. However, a cottage industry of programmers began to sprout in the mid-1970s and was soon turning out commercial programs for a multitude of applications, including word processing, video games, inventory control, and personal finance management.

The combination of ready-made software and low-cost microcomputers produced the true personal computer, a machine so affordable and easy to use that it was available to almost everyone. The impact has been enormous. PCs have done for computing power what the printing press did for knowledge—gave it to the masses. Connected by telephone lines, PC users tap into networks of computers as well as into data banks for stock quotations, medical information, and legal cases. In the future they may be able to draw on data bases of library books, newspapers, and magazines from all over the world.

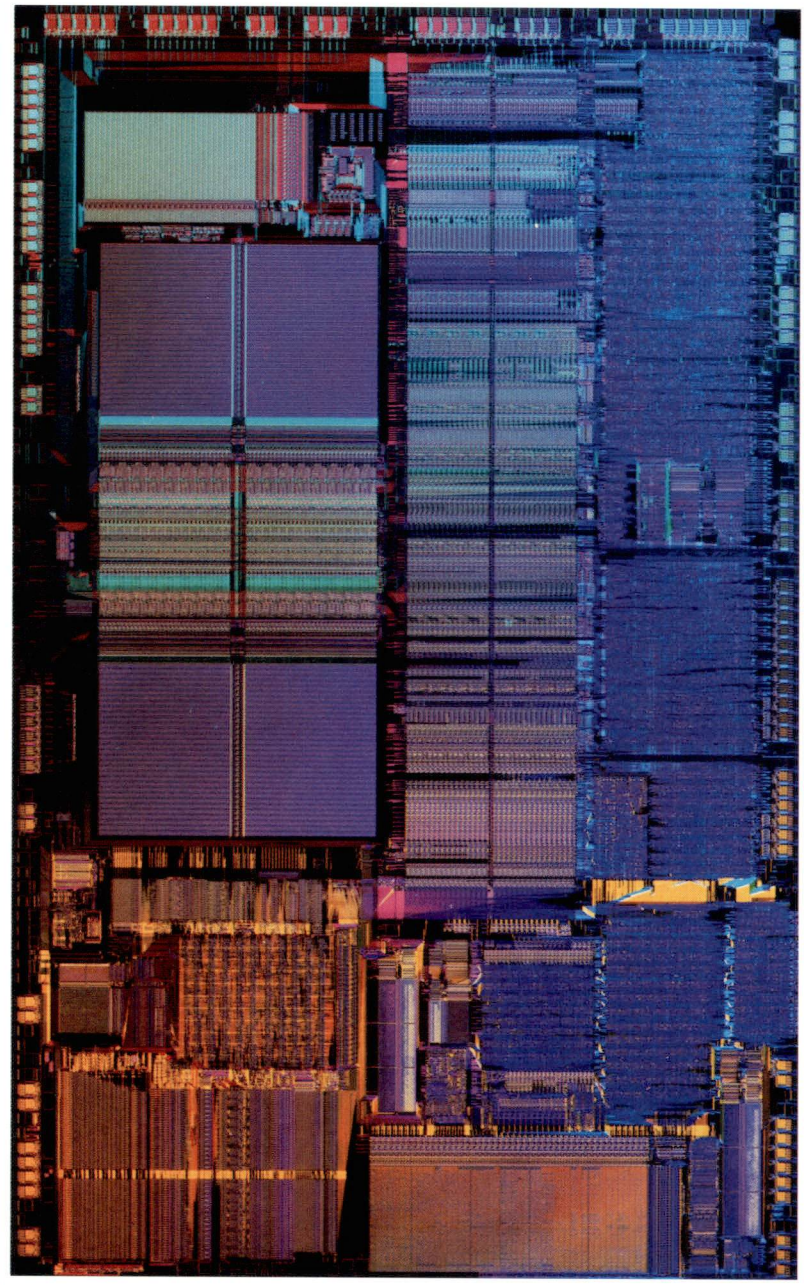


Small, inexpensive personal computers built around microprocessors bring computer power into millions of homes around the world. Ready-to-use programs have made it easy for children as well as adults to use these computers for video games, word processing, and dozens of other applications.

Today's microprocessors greatly outperform their 4-bit ancestors. One 32-bit chip, for example, is a thousand times faster. Another carries 500 times more transistors, packing 1 million of them onto a chip no bigger than a postage stamp. Others—made by a process called CMOS, for complementary metal-oxide semiconductor—use less energy and produce less heat than conventional chips. They are used in satellites, portable computers, and other devices where energy consumption is critical. The speed of some microprocessor chips has been improved by a design known as RISC, or reduced instruction set computer, which uses a small number of simple instructions. Complex instructions, which occur infrequently, are handled in software. Larger memory chips have also been developed to hold the complex programs that exploit the power of the new microprocessors.

In the future, multipurpose microprocessor chips will probably grow to 64 bits, some containing as many as 10 million transistors. Application-specific processors will be designed for just a few specific tasks. Such chips are faster and more efficient at a single job than a chip designed to do everything. The key to making application-specific processors will be advanced computer-aided design (CAD) systems—themselves based on microprocessor chips—that design such specialized chips quickly and inexpensively.

The new microprocessors and the systems they run will have the power to generate better graphics and higher-quality three-dimensional images for CAD systems. Microcomputers, for example, will certainly be more adept at human talents, such as understanding spoken words, speaking, or even learning and reasoning—artificial intelligence. And they will be able to process incredible amounts of data at lightning speeds. Work is under way on a new generation of supercomputers, which would link hundreds, even thousands, of microprocessors in parallel arrays. Each chip would work on a different part of a massive problem, such as a global weather forecast, solving the entire problem in a fraction of the time needed if each part were solved one after the other. The challenge of parallel-array systems is to develop mathematical formulas and operating systems to coordinate the work of all the microprocessors.

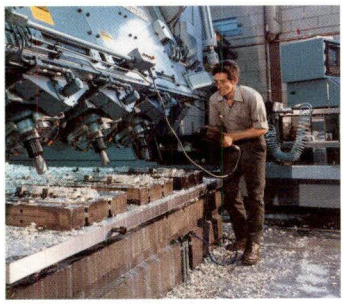


An even greater challenge lies in figuring out how to take best advantage of the wonderfully powerful computers based on these new microprocessors. That is the task of the programmers, whose work is limited only by their ability to think creatively.

The i486 microprocessor squeezes 1.18 million transistors—500 times more than the first microprocessor—onto a chip about the size of an adult's thumbnail.

4 Computer-Aided Design and Manufacturing

Hidden behind factory walls throughout the world, another industrial revolution is unfolding around the computer. It is changing industry as profoundly as power machinery did in the eighteenth century and mass production, typified by the assembly line, did early this century.



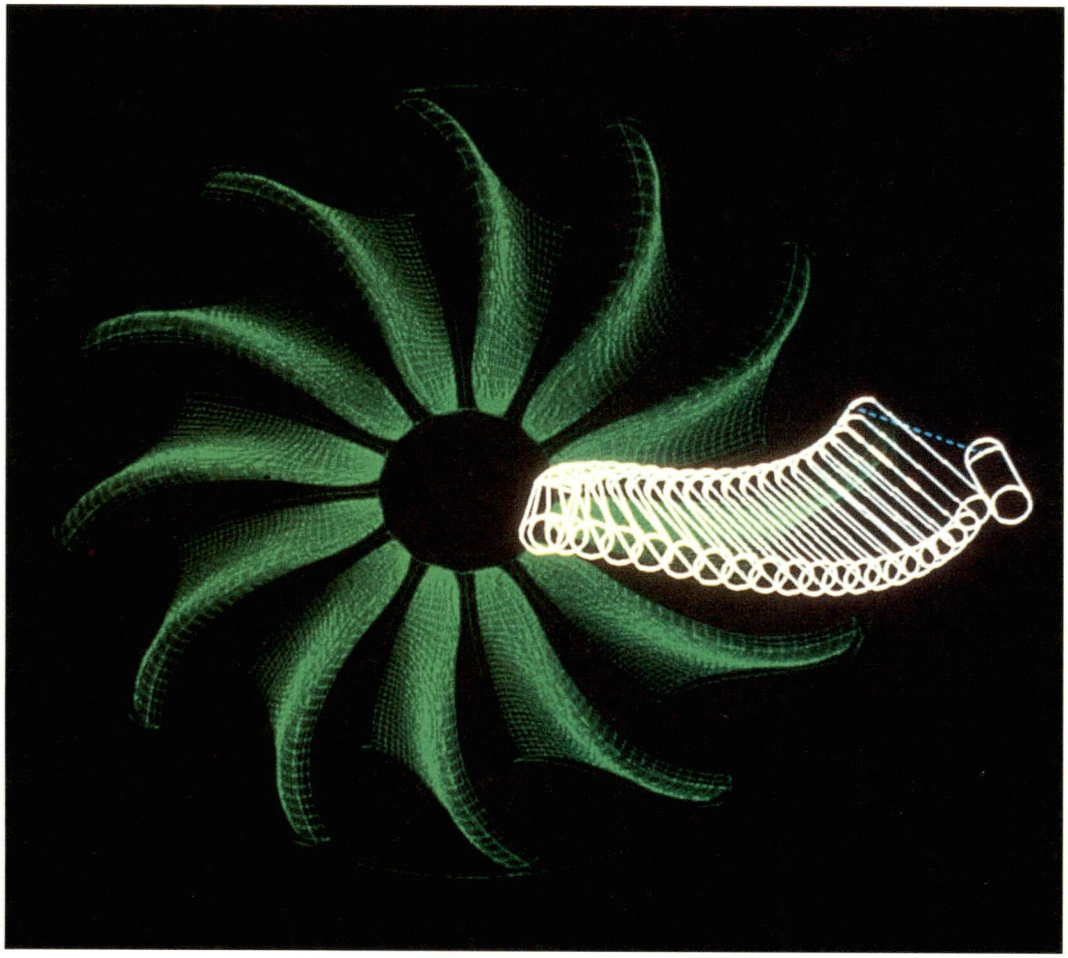
A worker sets up a computer-controlled profiling machine that cuts complex parts out of aluminum, steel, and titanium. The program of instructions for making a part is usually generated on a separate CAM system, then transferred to the machine's computer, which can store programs for dozens of parts.

Computer-aided design and computer-aided manufacturing—CAD and CAM—have already increased speed and efficiency for many manufacturers. They are improving the quality of products while decreasing the time to take them from idea to market. And they are giving manufacturers the flexibility to respond to an ever-changing market.

Essentially, CAD covers the use of computers on the design side of a product while CAM refers to their use on the manufacturing side. On the design side, engineers use computer graphics to design the new part or product. Other engineers use analytical programs to determine whether the part, as it is designed, will hold up under the stress of actual use. Drafters use computerized devices to add detail to the design and produce the final drawings. On the manufacturing side, computers help engineers write instructions for the automatic tools that will create the part. Small computers on the machines themselves allow the machines to be quickly changed from producing one part to making another. Small computers have also spread to other areas of the factory, controlling manufacturing processes, operating robots that move pieces from one machine to another, and guiding automatic carts that move materials, parts, and finished products around the plant.

Modern CAD and CAM systems began appearing on the market around 1970, following the marriage of CAD and CAM computer programs to minicomputers in the $100,000 range. Previously they were limited to a few large manufacturers of aircraft, autos, and textiles who wrote their own CAD and CAM programs and ran them on mainframe computers that often cost a million dollars or more.

The roots of CAD and CAM reach back to two Air Force programs in 1949. CAD hardware—the machines—began with efforts to build an air defense system by linking radar to computers, whose data were displayed on video screens. At the same time, the forerunner of CAM software—programs to run the hardware—began with the creation of punched tapes to operate numerically controlled (NC) machines. These machines cut, drill, and perform other tasks according to instructions fed into their control units on a punched paper tape. Tapes for the first generation of commercial NC machines were laboriously punched by hand. After the creation of a computer



The screen of a CAD/CAM system illustrates the complex tool path that a milling machine must follow to create the curving surface of an impeller blade for a jet engine.

programming language called APT, for Automatically Programmed Tools, tapes were generated on mainframe computers.

Modern CAM really began in 1969 with the appearance on the market of a less complex language, called Compact II, for programming NC machines. Before then, companies produced their NC tapes by hand, made them with APT on a mainframe computer, or sent the work to be done on a time-sharing basis on an out-of-house mainframe. Compact II was initially a time-sharing service. But later the program was sold to run on a minicomputer, further reducing the cost of the service. With such a CAM system, an engineer could quickly write a program to produce a part, press a button, and the computer would punch out the correct instructions on an NC tape. The tape was taken to the NC machine to make the part.

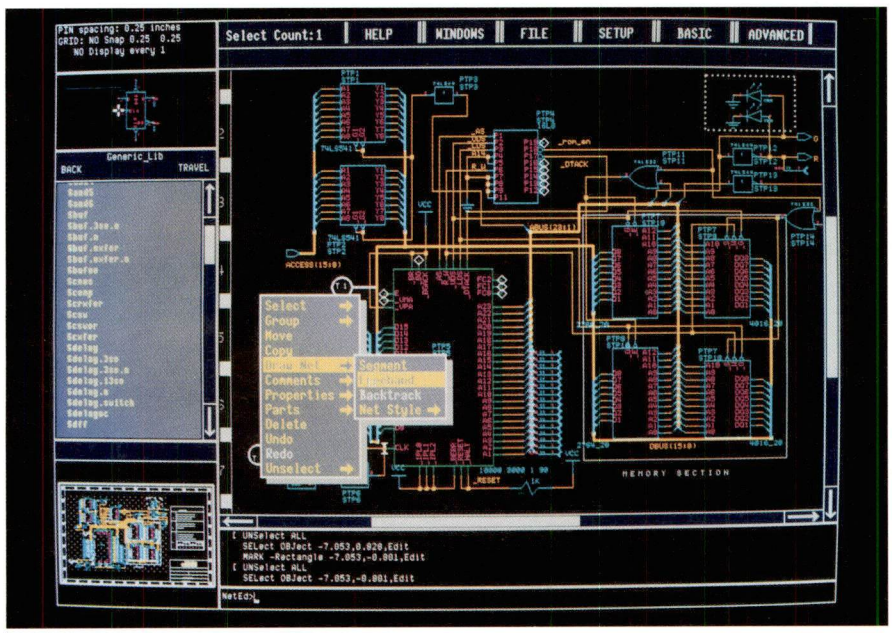
Today, even easier languages have been introduced for programming NC machines. In some systems, the tapes have been eliminated by hooking the programming computer directly to the machine tool. And many NC machines have small computers that store several programs for producing different parts.

Computer-aided design has sparked its own revolution within the broader movement toward factory computerization. Like the telescope and the microscope, CAD systems have opened up new worlds of understanding to the engineers who design, analyze, and test today's sophisticated products. CAD is applied to nearly every large or complex engineering project undertaken today, from designing modern jumbo jets to planning energy-efficient buildings. It was, for example, extensively used in designing *Stars & Stripes*, the racing yacht that won the America's Cup competition held in Australia in 1987. And CAD is absolutely essential for designing the tiny circuits in microprocessors and other integrated-circuit chips that run most electronic devices.

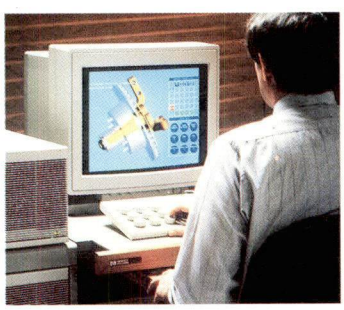
The second wave of the CAD revolution rose in 1981 with the introduction of single-user CAD workstations. Workstation computers are powered by microprocessors and generally have more computing power

and graphics capability than personal computers, which are also based on microprocessors. However, a workstation costs about one-tenth as much as a minicomputer. Today, the price of some workstations is under $10,000, and their power equals that of most minis.

Modern CAD did not spring full grown into existence. It began as a drawing aid for drafters and developed along two parallel paths. One led through electronic design, and the other through mechanical design.



A microprocessor is designed with the aid of an electronic CAD system. Using this program, an engineer can quickly design an electronic circuit by placing and connecting symbols of components on the screen. The computer automatically adds the details to the final design.



An engineer uses a workstation and a mechanical CAD program to design a new wheel hub assembly.

In the electronics industry, the great problem facing engineers in the late 1960s was the design of increasingly smaller and more complex integrated circuits on tiny silicon chips. NC machines had been developed for cutting the stencil-like masks used in etching circuit patterns onto chips. But instructions for the machines were still calculated and punched into the tapes by hand. In 1970 one of the first commercial electronic CAD systems, called Design Assistant, appeared on the market. It consisted of a minicomputer, screen, sketch pad, and keyboard plus software. The engineer drew the circuit on the pad, watching the design appear on the screen. After correcting mistakes, the engineer pressed a button, and instructions for cutting the design were punched into an NC tape. This early CAD system sold for about $150,000. But just two years later, improved versions were selling for half that price.

In the mid-1970s, new electronic CAD programs for "design rule check" came to the market. They not only copied the circuit pattern but also told the engineer whether the patterns were too close together or violated any other design rules. In the early 1980s, even more intelligent programs were developed. Called "performance models," they could tell a design engineer what would happen when electric signals flowed through the circuit and point out flaws in the design. Today, no self-respecting engineer would design a circuit without performance modeling.

One of the first modern CAD systems for mechanical design arrived in 1971 on the heels of electronic CAD. It was really a drafting aid that consisted of a drawing table, computer, screen, and plotting arm that digitized its movements: that is, translated them into digital electronic signals. By moving the plotter to different points on the table and telling the computer what to draw between them, a draftsman could copy a design into the computer while watching it materialize on the screen. After correcting the design, the draftsman pressed a button, and the plotting arm automatically redrew the design on a clean piece of paper. Called Interact I, this mechanical CAD system ran on a minicomputer with four terminals and cost around $375,000.

The early mechanical CAD systems could draw points, lines, circles, arcs, and symbols in two dimensions but with no mathematical idea of what they were doing. By 1973 more intelligent programs were developed that could not only create three-dimensional figures on the computer screen but understood the geometry and mathematics associated with them. These were wire-frame models like the 3-D figures engineers traditionally drew.

More important than creating 3-D design models, though, was the intelligence of such a CAD program. Using a mathematical model of the design in its data base, it could answer questions from the engineer: How long is that line? What is the area of this plane? Where is the center of gravity? And if, for example, the engineer tried to put a 2-inch piece in a space 1.75 inches wide, the CAD program would reply that the piece was 0.25 inch too long. It was smart enough to calculate and draw a new line through a model if the engineer so requested. It could also calculate a section, in effect slicing the model in two so the engineer could see how

parts fit together inside the design. And it could turn the model to be viewed from different angles. This was not just a drafting device but a true CAD system that helped an engineer design a part.

The newer mechanical CAD programs were also intelligent enough to perform simple analyses on the design, to see how it would hold up under the stress of actual use. They could also prepare a design for more complex analysis by dividing the model into the hundreds or thousands of geometrical shapes that formed it. The data were then sent to analytical engineers who tested the design on powerful mainframe computers. This preparation, which the CAD program did in seconds, would have taken engineers hundreds of hours to do by hand.

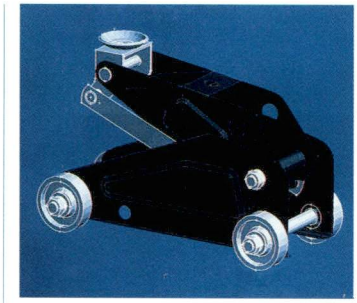
In the late 1970s, computer models of solid objects came onto the market. These were even better for analysis than 3-D wire-frame models. Nevertheless, since there are so many variables in designing a mechanical part, mechanical CAD systems today are only beginning to reach the level of performance modeling that electronic CAD systems achieved nearly a decade ago. However, programs are being developed that allow engineers to analyze mechanical systems for a large number of variables. For example, engineers soon could be able to model the performance of a mechanical system as complex as a commercial power plant.

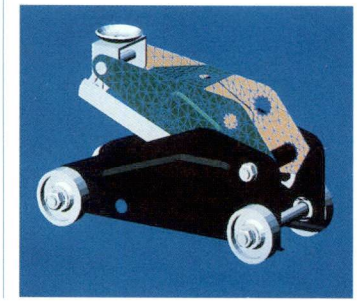
CAD programs of the late 1970s also began linking to CAM systems on the manufacturing side of factories, eliminating the need for many paper design drawings and reducing the time manufacturing engineers need to write instruction programs for the NC machines that make the parts. Previously, engineers had to study the paper drawings in order to calculate tool movements. These CAD systems, however, could simulate the movement of a cutting tool around the design model in order to determine the necessary tool movements. These were not only determined more quickly using CAD models, they were also more accurate.

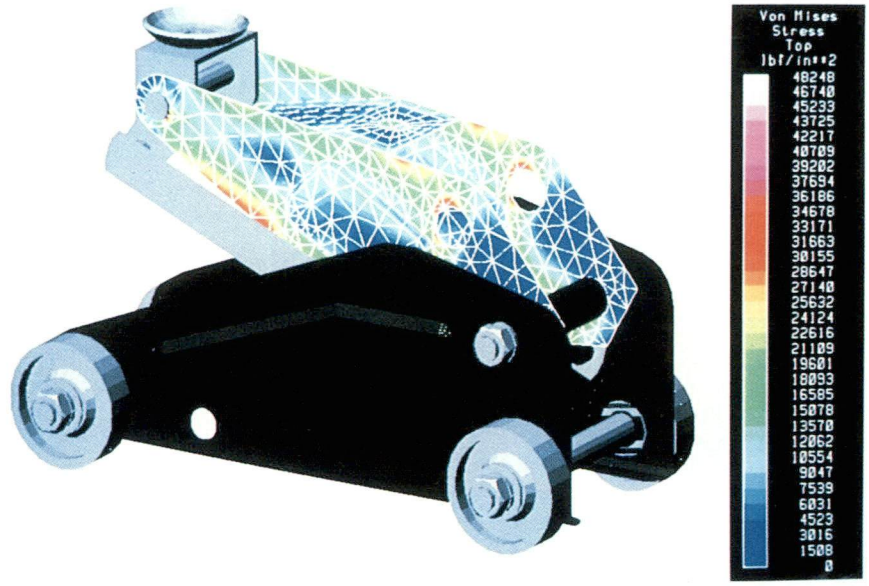
In the future, engineers will seek ways to use CAD and CAM more effectively. Today CAD programs are linked to CAM systems in only a small number of factories. On the design side of factories, separate CAD systems often exist independently in design, drafting, and engineering departments. Drawings are still often carried from one office to another, where it may take 50 to 100 hours to enter the data into another computer system. On the manufacturing side, computers are only slowly being applied to tasks that they could perform faster and more effectively. In addition, many factories could greatly increase their productivity by joining isolated computerized systems into integrated networks. Such computer-integrated manufacturing, or CIM, has begun in a few factories, and some of the results have been spectacular. For example, the highly integrated use of computerized systems at one company that manufactures motor-starter components helps it produce and ship the parts in less than 24 hours, a job that used to take about 15 days.

Another challenge in computerizing the manufacturing process lies in integrating computers throughout the company, not just at an individual factory. Such a CIM network might include finance, market forecasting, material ordering, customer service, and stocking, as well as CAD and CAM. Current debate swirls around how to integrate the computers—whether to design one big network or to integrate computers only where and when it becomes necessary. Too much integration could flood and slow the network with needless data.

Computers have found an indispensable role to play in manufacturing through CAD, CAM, and other automated systems. No one really disagrees. How big a role they will play, and when, are the real questions for the future.

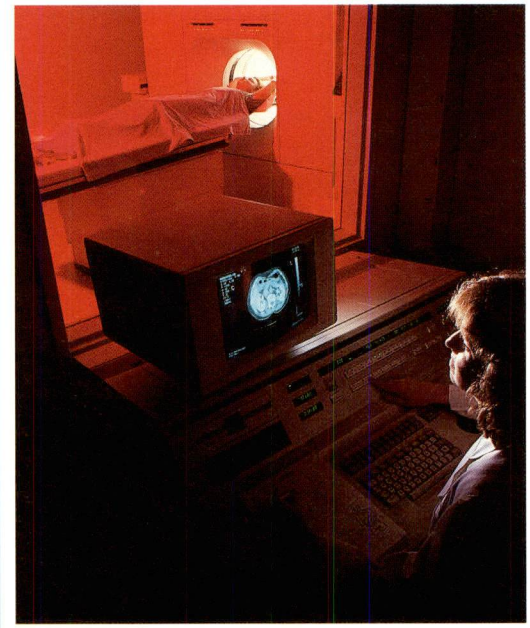






An engineer uses a mechanical CAD program to analyze stress on the lifting arm in the design of an automobile jack assembly. The program creates a solid model of the device, top. It uses a mesh to divide the lifting arm into small "finite elements" that are analyzed for stress individually, center. The program then uses color coding to indicate varying levels of stress throughout the component, telling the engineer where to strengthen the design, bottom.

5 CAT Scan

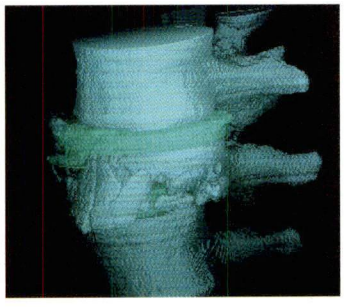


Right: A patient lies quietly as a CAT scan's x-ray tube shoots from hundreds of points around her head. Sensors opposite the tube record the strength of beams passing through the patient. With this data, the CAT scan computer generates an image showing the structure in that cross section of her head.

Ever since 1895, when German physicist Konrad Roentgen took the first roentgenogram, x-ray pictures have been clouded by shadows of bones, teeth, and tissue piled together on one piece of film. But the marriage of modern computers to this old technology has given birth to a machine that produces clear, detailed images of things inside the body.

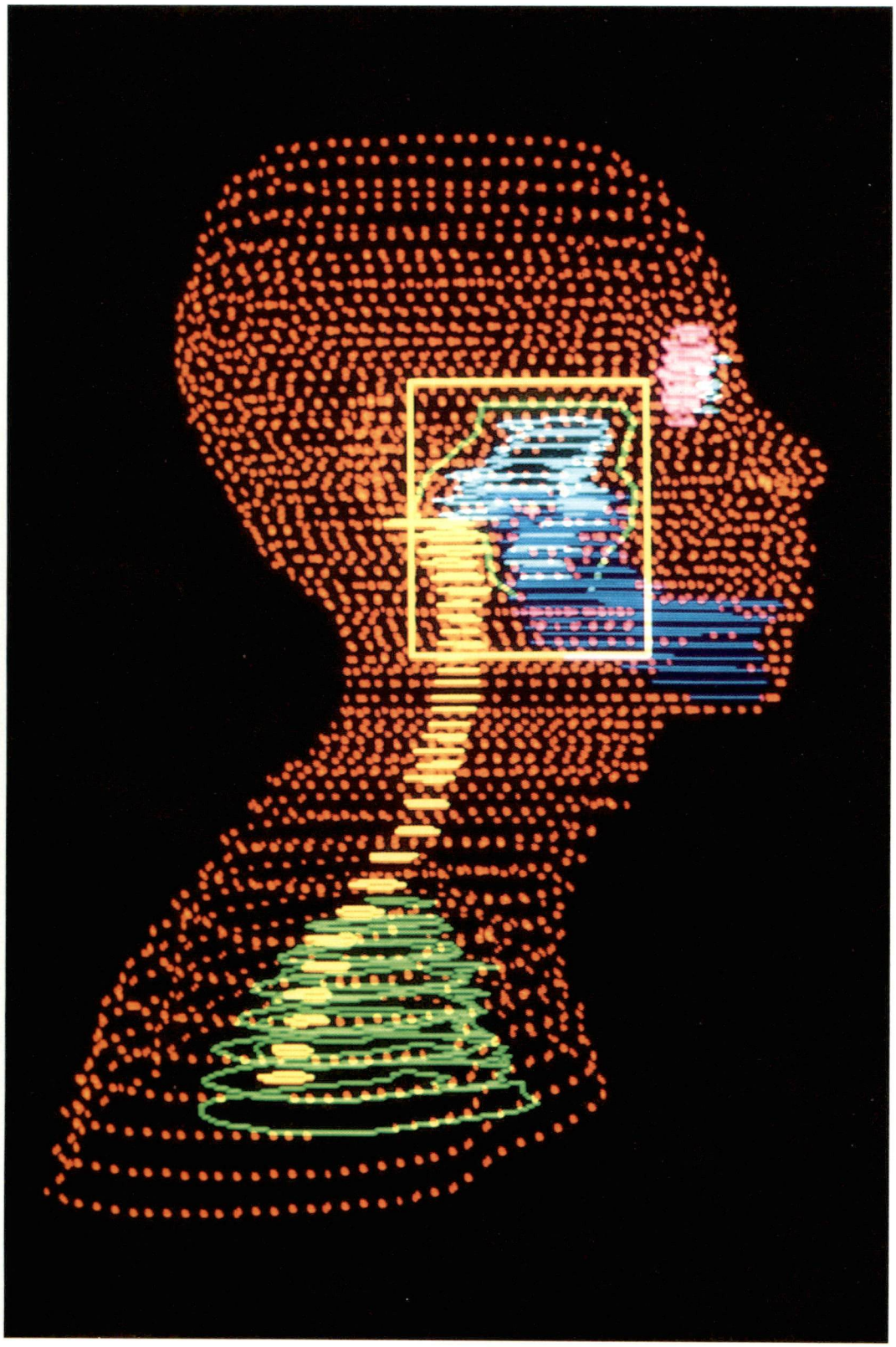
The machine is called a CAT scan, for computerized axial tomography scanner. The wedding of computers to other diagnostic techniques has subsequently led to ultrasound imaging, magnetic resonance imaging (MRI), and other new procedures that peer inside the body without resorting to surgery. Indeed, many doctors believe that more progress has been made in medical diagnostics since the CAT scan was introduced than in all previous medical history.

CAT has so far had the widest impact of the new imaging technologies. It has saved untold numbers of lives by quickly finding tumors, infections, bleeding, and blood clots that would have been found too late or missed altogether by regular x-rays or other diagnostic techniques. A normal series of 30 scans is performed in about 20 minutes and usually without injections. CAT scans have reduced the need for some diagnostic techniques that require uncomfortable injections and a stay in the hospital.



A young man's vertebrae, broken in a motorcycle accident, appear almost lifelike in a three-dimensional image created from dozens of CAT scans. CAT scans are particularly good for showing the fine detail of bone structure.

The procedure has also revealed to researchers brain abnormalities in some persons suffering from schizophrenia, alcoholism, manic-depressive illness, and Alzheimer's disease. CAT scans locate brain tumors precisely for radiation treatment and are used to build three-dimensional models for reconstructive surgery. CAT is especially good at finding internal injuries because it easily distinguishes between blood and



A cross on this three-dimensional image generated from a series of CAT scans marks the location of a tumor near the center of the patient's head. Color coding shows sensitive areas, such as the eyes, spinal cord, and lungs, that should be protected from unnecessary radiation when the tumor is treated.

tissue. Some hospitals now have a CAT scanner in the emergency room, and the U.S. Army is developing a rugged, lightweight one that can be transported by truck or helicopter to medical stations in combat zones.

CAT—often shortened to CT, for computed tomography—doesn't make a flat picture on photographic film, like a normal x-ray. Instead, it constructs a television image



An enhanced MRI scan shows a tumor growing in the spinal cord of a 4-year-old girl, who lost her ability to walk. A doctor quickly removed the tumor, and the girl eventually recovered the use of her legs.

based on density measurements of a "slice" of the patient. The process is something like seeing a slice of salami without cutting the meat.

To measure density, the CAT scan's x-ray tube shoots a thin beam edge-to-edge through a slice while circling the patient. Detectors circling opposite the tube measure the strength of the emerging beam—and therefore the density of the slice—from hundreds of points around the patient. With this information, the CAT scan computer calculates the density for each of more than 250,000 tiny bits of tissue in the slice. It then displays these values in a television picture showing density patterns that reveal the fine structure of the slice.

The practical CAT scanner emerged from the confluence of several new technologies. The most important developments were low-cost minicomputers and, later, parallel-array computers that could perform many calculations at the same time. These high-speed computers and the mathematically complex programs to operate them made it possible to run millions of calculations for each slice. In 1979 the Nobel Prize in physiology or medicine was awarded to British research engineer Godfrey Hounsfield for pioneering the CAT scan and to U.S. physicist Allan Cormack for work on the mathematics behind it. The first CAT scanners were

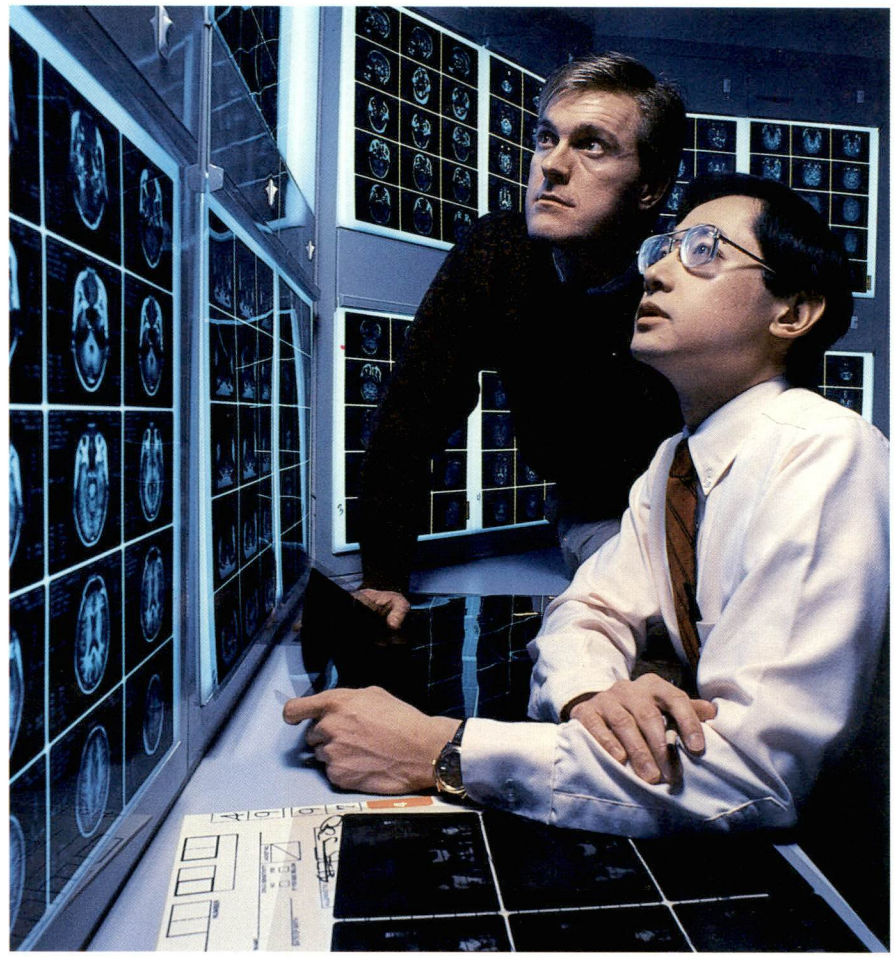
installed in Great Britain in 1971 and in the United States two years later. Today they are used in more than half of U.S. hospitals and in hundreds of clinics.

Very small x-ray detectors and ultrasensitive signal amplifiers have greatly increased the speed of CAT scanning. An early scan took about 4 1/2 minutes. Today it takes less than 2 seconds as a scanner's 1,000 detectors each record 2,000 separate measurements. The machine's sensitivity has improved, too. Now, for example, CAT can detect a liver tumor of almost the same density as normal tissue. The difference would not show up on a regular x-ray. Tomorrow's scanner will produce even more detailed images as scan slices become progressively thinner and scan times decrease even more. The patient will move continuously through the scanner, like a car on an assembly line, completing a 40-slice series in about a minute. And it may soon become routine for a treating doctor to beam the scan image via satellite to a consulting specialist thousands of miles away.

Small, powerful computers have been applied to other diagnostic imaging techniques since the CAT scan. Each uses a different means of probing the patient, but the image is constructed by computer. Low-level radioactive isotopes are injected into the blood during positron emission tomography (PET) and single-photon emission computed tomography (SPECT). With digital subtraction angiography (DSA), a computer subtracts an earlier x-ray image from another one taken after a contrast substance has been injected into the blood, leaving the clear contrast outline of blood vessels on the second image. Ultrasound devices bounce high-frequency sound waves off internal surfaces to indicate their position and motion.

The most promising computer-assisted technique, though, uses magnetic fields and radio waves to coax information from the nuclei of atoms in body chemicals. This nuclear magnetic resonance imaging, or MRI, is particularly good for examining the brain and spinal cord, whose surrounding bone is invisible to it.

CAT culminates the development of Roentgen's technology. And although traditional x-ray pictures still account for 80 percent of medical diagnostic imaging, they may one day be completely replaced by computer-generated video images. The continued development of CAT, ultrasound imaging, and especially MRI should further reduce the need for exploratory surgery or invasive imaging techniques such as those involving injection of contrast agents that may occasionally cause allergic reactions. In fact, in 10 or 15 years, MRI may be able to perform an entire diagnostic chemical analysis of a patient, without breaking the skin.



Doctors discuss features revealed by MRI images. MRI employs radio waves and magnetic fields to produce images in which bones are invisible. It is therefore very useful for looking at soft tissue inside the skull and spinal column.

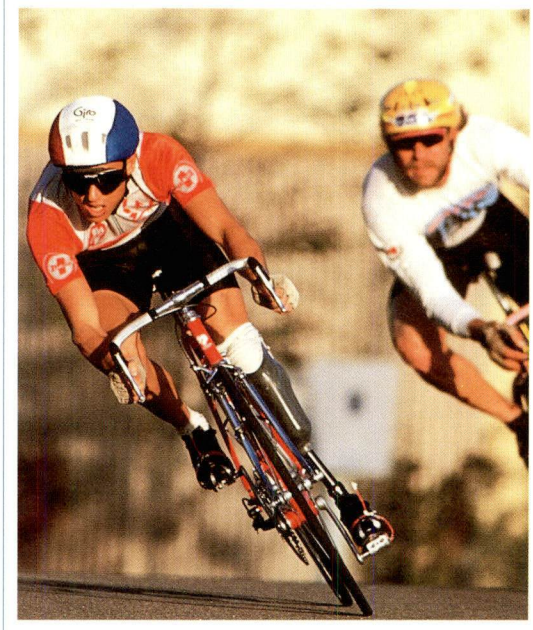
6 Advanced Composite Materials

The unusual design of the Starship business plane—slender wings, vertical wing tips, down-hanging rudder, and winglets on the nose—masks the real revolution behind this aircraft. Its body and wings are made entirely of advanced composite materials far lighter and stronger than the aluminum most aircraft are made of today. As a result, the plane needs less maintenance than conventional aircraft and flies as far on a gallon of fuel as planes much smaller.

Advanced composites like those in the Starship were unheard of 25 years ago. Yet they have already spread throughout the transportation industry and into everyday objects where higher performance provides an advantage. They add lightness and strength to racing boats and cars, golf clubs, and electric guitars.

Composites are simply a matrix of one material reinforced by fibers or particles of another. Humans have been making composites since the ancients discovered that putting straw into mud bricks makes the bricks stronger. Today steel rods are used to reinforce concrete highways, bridges, and buildings. Resin reinforced by glass fibers is probably the most widely used composite today.

Advanced composites, however, are in a class alone. Most were originally developed to provide lighter, stronger, more temperature-resistant materials for military aircraft and spacecraft. Skyrocketing fuel prices in the 1970s made the new materials attractive to civil aviation, where their lower weight has helped cut the cost of operating airliners. The broadening market and more efficient processing techniques have reduced the cost of composites to a level where they can now



Right: A strong, ultralight leg prosthesis of graphite/epoxy composite helps an athlete compete in world-class bicycle races.



Graphite/epoxy and other advanced composite materials are used to construct the entire body and wings of the Starship business plane and account for more than 70 percent of its overall structural weight.

be used in many other products, especially sporting goods.

The matrix of an advanced composite is often an organic material, such as epoxy resin, but can also be metal or ceramic. High-strength fibers, such as graphite or Kevlar, are frequently used as reinforcements. But many combinations of matrix and reinforcement are created for particular uses. Knowledge about their interactions—how fibers or particles function within a matrix—is the key to designing these high-performance materials. And it has ushered in an era of designing new materials to meet new needs.

Advanced composites came directly out of Air Force efforts in the early 1960s to find materials with higher strength-to-weight and stiffness-to-weight ratios than aluminum. The most promising was boron, which is stronger than steel but weighs less than aluminum. The challenge, however, was to put it into a usable form. The best, easiest, most cost-effective method turned out to be making it into a fiber that could be embedded in a matrix of epoxy. Epoxy holds the fibers in place, distributes the load among them, and protects them from the environment. To make an aircraft part, strips of epoxy tape with fibers running through it are laid in a mold in directions that will reinforce



Layers of woven Kevlar fibers strengthen composite downhill snow skis while reducing weight and damping vibration. Advanced composite materials are used in many sporting goods, whose high performance provides a competitive advantage.

sections where strength is critical. High heat and pressure transform the epoxy into a solid, lightweight part. Such composites were introduced to operational aircraft in tail sections of the F-14, which was delivered to the Navy in 1972.

Boron fiber is expensive. So parallel work in England and Japan focused on graphite as a less expensive high-strength fiber. Graphite is a form of carbon, and its fibers are made by transforming organic fibers such as rayon, acrylic, or pitch.

The first high-strength graphite fibers produced in the late 1960s were made by a time-consuming, labor-intensive process and cost around $400 per pound. It began with an acrylic fiber that was wound on steel racks to stretch the fiber and align its long molecules into stronger, parallel orientation. The fiber was heated at low temperature to stabilize the orientation, then cut into strands and slowly baked in a furnace with inert gas—usually nitrogen—to burn away impurities. The remaining graphite fibers were treated with chemicals to help them bond to a resin matrix.

In 1971 a U.S. company started making graphite fibers by a continuous process that took less than eight hours. These fibers cost only $125 per pound, and their price dropped steadily over the next decade. The first production graphite-composite parts went into F-15 aircraft delivered to the Air Force in 1974. And today's Starship business plane is made primarily of graphite/epoxy.

The first commercial graphite-composite products, though, were sporting goods. In 1972 a California company began making golf club shafts of graphite/epoxy, which is stronger and lighter than the steel in conventional shafts. The new shafts appeared in Japanese golf clubs the following year. Graphite composite increased stiffness and reduced shaft weight by about 40 percent, allowing golfers to swing the club faster and drive the ball farther than they could with heavier clubs. Composite tennis rackets appeared next, followed by fishing rods, race-car chassis, and other sports equipment.

Auto manufacturers are investigating graphite composite to replace steel in passenger cars, but its price is still generally too high to make it economical for mass-produced vehicles. However, since 1988 a graphite composite has been used to reinforce aluminum drive shafts on some light trucks.

Another high-strength fiber, Kevlar, is widely used in composites where high tensile strength—resistance to being pulled apart—is important but the stiffness of graphite fibers is unnecessary. Kevlar is a trade name for an aromatic polyamide, or P-aramid, fiber that is derived from petroleum. It is lighter than fiberglass but five times stronger than steel on a pound-for-pound basis. It appeared commercially as a replacement for steel cord in radial tires in 1972. A high-strength form of Kevlar is used in resin-matrix composites for aircraft bodies, sailboat hulls, snow skis, and artificial limbs.

P-aramid fibers were discovered in 1965, but the breakthrough came five years later in learning how best to convert the substance into much stronger fibers. P-aramid would not melt like other plastics nor would it dissolve easily in any normal solvent used in making synthetic fibers. The substance, it turned out, needs an especially strong solvent—100 percent sulfuric acid—to dissolve it. Normal sulfuric acid solvent contains about 3.5 percent water, but this is enough to keep P-aramid from dissolving in it.

In addition, P-aramid molecules would not align themselves in strong, parallel orientation during a normal fiber-producing process. Usually a solution containing a fiber substance is forced through a plate, called a spinneret, with hundreds of tiny holes. The emerging fibers are pulled directly into a bath that leaches out the solvent, then stretched to align the molecules before being wound around a spindle. This did not work with P-aramid. The problem was solved, however, by stretching the fibers—and aligning their molecules—in an air gap just as they emerge from the spinneret. Then they are pulled into a cold-water bath that leaches out sulfuric acid, gels the fibers, and fixes molecular orientation. Finally the fibers are dried and wound onto a spindle.

High-strength fibers and particles are also embedded in metal matrices for use at high temperatures that would melt organic matrices such as epoxy. Metal-matrix composites, however, have a rather slim range of current applications in diesel and jet engines, spacecraft structures, and high-performance sports equipment.

The first commercial use of a metal-matrix composite was in high-performance diesel engines by a Japanese automaker in 1982. The composite, made of aluminum with various reinforcements, forms a reinforcing ring around the crown of the pistons. It resists wear as well as steel but is much lighter. Many automakers are investigating metal-matrix composites for use in pistons and other moving engine parts. Lightweight composite parts would use less energy and would reduce the total weight of the engine.

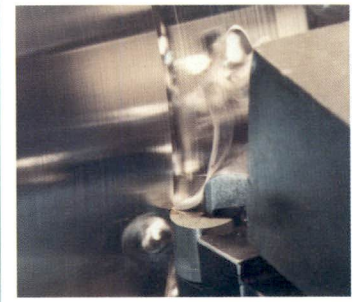
The first actual use of a metal-matrix composite, though, was probably the boron/aluminum structural tubing used in the space shuttle, which first orbited the earth in 1981. Aluminum-oxide/aluminum is now being used in handlebars of lightweight racing bicycles. And although silicon-carbide/aluminum is relatively expensive, it still costs less than half as much as the beryllium it is replacing in an instrument housing for the inertial navigation system of a Navy ballistic missile.

Composites with ceramic matrices are theoretically superior to metal-matrix composites for high-temperature applications. Ceramics—materials that are neither metallic nor organic—also have great strength and light weight, but brittleness often limits their use. Reinforcements, however, can toughen them. Since the mid-1980s, aluminum oxide reinforced with silicon-carbide whiskers has been used in cutting tools. Similar composites are being developed as armor to protect helicopters, armored personnel carriers, tanks, soldiers, and police. These composites are up to five times tougher than unreinforced ceramics, lighter than steel, and less expensive than other advanced materials now used for armor.

Ceramic composites are also being studied for use in car and jet engines, where their light weight and heat resistance would substantially boost fuel economy. They may find wider use in low-temperature applications where their ability to withstand hostile environments gives them an advantage over other materials. For example, ceramic-matrix composites might be used in valves and reactor vessels handling corrosive chemicals or in structures, such as satellites, that must endure the harshness of space.

Carbon is similar to a ceramic, and composites made of graphite fibers embedded in a matrix of graphite are extremely heat resistant. This carbon/carbon composite is used in the nose and leading edges of the space shuttle to protect against the searing heat of atmospheric reentry. And, because of its light weight and durability, it is being used increasingly for wheel brake linings in military and commercial aircraft.

Special composite materials are being developed for the experimental National Aero-Space Plane, which is designed to take off and land on runways, cruise at hypersonic speeds of Mach 6 (six times the speed of sound) or greater in the upper atmosphere, and reach Mach 25 while climbing into orbit. The plane's skin, frame, and engines will need to be extremely light, strong, and heat resistant. The skin, in particular, will have to withstand repeated exposure to extreme heat and cold and must be far thinner than the composite tiles that protect the space shuttle. The plane is scheduled to fly in the late 1990s. But before it does, a new generation of advanced composites will have to be born.



A strong, light ceramic-composite tool cuts a thin chip from a fast-turning bar of tough nickel alloy. The durability of this ceramic composite at high temperatures allows it to withstand the heat produced in high-speed cutting.



The National Aero-Space Plane flies far above the earth in an artist's drawing. New advanced composite materials are being developed for its skin, engines, and other components that will allow the space plane to climb into orbit or cruise in the atmosphere at more than six times the speed of sound.

7 Jumbo Jet

People react much the same when a jumbo jet lumbers up to the boarding gate: eyes widen, jaws slowly drop, and speech fails until the looming giant rolls to a stop just outside the window.

To most passengers, a jumbo jet is huge outside, spacious inside, and a lot more comfortable to fly than lesser planes. To the airline industry, the jumbos, with their huge capacities of 300 to 450 passengers or more, are economy of scale. It is more economical, for example, for an airline to fly 400 passengers in a single jumbo jet than 100 each in four smaller planes. Jumbos also carry passengers much farther without costly refueling stops. Earlier jets with a range of about 4,500 miles, for example, had to refuel in Hawaii during a flight to Tokyo from San Francisco. Some of today's jumbos, flying 6,500 miles or more nonstop, make the same trip uninterrupted from San Francisco, Chicago, or even New York.

Jumbo jets also help relieve air traffic congestion at airports, which can handle only a limited number of takeoffs and landings per hour whether the plane holds 4 or 400 passengers. In the mid-1960s, when the first jumbo jets were designed, air travel was growing at a rate that would double the number of passengers every five years. But the introduction of jumbos in the early 1970s reduced the immediate need to expand many airports or build new ones. In fact, no major U.S. airport has been built since 1974.

The 747, DC-10, and L-1011 jumbo jets joined the commercial air fleet in 1970, 1971, and 1972, respectively, forming a necessary link in a chain of events that introduced long-distance air travel to the masses. Since then the combination of rising fuel prices, lower air fares, and economical long-range jumbos has helped triple the annual revenue passenger miles (one RPM equals one paying passenger carried one mile) logged by the U.S. airline industry. In 1988, 420 billion RPMs were logged, and the figure is projected to surpass 760 billion by the year 2000.

The origin of the jumbo jet lies in the competition for the giant Air Force C-5A cargo plane, which began operational flights in 1969. The challenge of building the jumbos was to fit those design advances plus other state-of-the-art technologies into a huge machine that was not only safer than earlier airplanes but less expensive to operate. The 747, for instance, reduced the per-mile cost of carrying a passenger 20 to 30 percent.

The jumbos also introduced an era of safer aircraft designed with a strong emphasis on several redundant, or backup, systems. The failure of a single system would not cripple the airplane. For instance, designers of the 747 put four main landing-gear legs on the plane instead of the usual two and added a middle spar to the wings. If the front spar were damaged in a collision, the middle and rear ones could hold the wing together for



The introduction of jumbo jets in the early 1970s helped relieve air traffic congestion at airports.

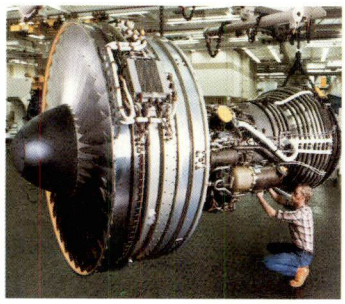


landing. Designers of the L-1011 built in four separate hydraulic systems to operate the critical pitch control system—elevators and stabilizers—which moves the nose up or down. Three are powered by the plane's three engines and the fourth by an auxiliary power unit. The DC-10 was designed with five generators—each of which can keep the plane flying—plus an emergency backup battery system. Three of the generators are powered by the aircraft's three engines, one by an auxiliary power unit, and the other by an extendable windmill.

The jumbo jets owe much of their success to the high-bypass engine, which was introduced to military aviation on the C-5A and to the commercial sector on the 747. They help the big planes fly farther, consume less fuel per passenger mile, and climb into the sky with a murmur compared with the scream of earlier jet aircraft. Advanced metal alloys, new cooling systems, and the high-bypass design help the engines deliver almost twice the thrust per pound of engine weight, while using 20 to 25 percent less fuel per pound of thrust than conventional turbojet engines.

The core of a high-bypass engine operates like a pure turbojet, in which whirling compressor blades pull air into the engine's combustion chamber, where the air and fuel are burned. This creates a hot, rapidly expanding gas that thrusts the engine

The size of jumbo jets sets them apart from earlier airliners, and so does their increased emphasis on safety. The four main landing-gear legs on the 747 instead of the usual two are an example of the multiple backup systems that add a wide margin of safety to jumbo jets.



The high-bypass engine gets its name from the huge fan that thrusts air past the combustion chamber, the section where the technician is working. In the conical back end of the engine, expanding gas from the combustion chamber spins turbines on a shaft that turns the fan.

Right: Nickel-alloy turbine blades cast as single crystals have greater strength and durability and higher temperature capability than blades made of earlier materials. The wavelike patterns, enhanced for this photo by chemical processing, are caused by minute chemical differences between parts of the crystal that solidify earlier in the casting process and those that solidify later.



Large fans on the high-bypass engines of these DC-10s push air out the back of the silver engine cowlings while combustion chambers shoot expanding gas through the gray cones.

forward. The gas also spins a turbine, whose shaft runs back through the hollow engine core to turn the compressor blades.

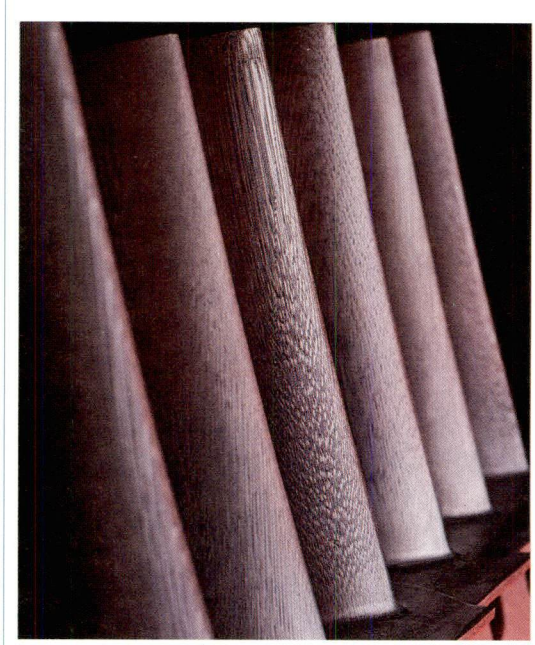
The high-bypass engine, however, takes advantage of the fact that for a given power level, a large volume of slowly moving air will generate more thrust than a small volume of fast moving air. In the high-bypass engine, the turbine also turns a wide fan at the front, which pushes a large mass of air past the combustion chamber. The ratio of air bypassing the combustion chamber to air flowing through it was 5:1 on the first commercial high-bypass engines and 8:1 on military versions. The fat cowling covering the large fan clearly distinguishes the high-bypass engine from the slender, less efficient turbojet.

The new engines are much quieter, too. All the thrust of a turbojet comes from its exhaust, which shoots out at twice the speed of sound with an ear-splitting roar. But a high-bypass engine mixes quieter low-velocity air with the high-velocity exhaust to slow its speed and reduce its noise. The noise level of the first DC-10's, for example, was about half that of earlier four-engine airliners.

High-bypass engines are also more efficient than earlier turbojets in part because they operate at higher combustion temperatures. Turbines in the new engines tolerate burner-exit gas temperatures up to 2,800 degrees F, about 500 degrees greater than the earlier engines. Much of this higher tolerance results from new air cooling systems that allow turbine blades to operate in gas streams at temperatures higher than their material melting point. The blades are cooled by compressed air that is channeled around the combustion chamber and directed onto the whirling disk holding the blades. A pressure differential causes the air to flow into the base of each hollow blade, where a network of passages carries the air throughout the blade to cool it from inside. As air escapes through strategically spaced holes, it flows over the external surface in a protective film that insulates the blade from hot gas. Gas temperatures are 200 or more degrees hotter than the melting point of the blades.

Some of the increased engine performance also came from an advanced process, called directional solidification, for casting the nickel-alloy turbine blades. Whirling blades under high centrifugal force tend to creep, or elongate, at turbine operating temperatures. Creep causes cracking along the boundaries between alloy crystals, which form when the blade is cast. In earlier blades, the crystals solidified in random alignments. Directional solidification, however, forces the alloy to solidify in long crystals that grow from one end of the blade to the other. This eliminates crystal boundaries across the blade and so reduces creep and cracking.

Directional solidification begins by pouring molten alloy into a mold that sits inside a hot furnace. At the bottom of the mold is a water-cooled chill plate, where the alloy starts cooling and crystals begin forming. The mold is slowly lowered out of the furnace, causing the first crystals to continue growing up in parallel columns toward the top of the mold. Turbine blades made this way could operate at temperatures



up to 100 degrees F hotter than conventional blades.

The heat tolerance of turbine blades has since been raised another 100 degrees by making each blade out of just one crystal. With a single crystal and no boundaries, engineers could remove from the alloy several boundary-strengthening ingredients that, essentially, had prevented the blades from tolerating higher heat. The trick was to select a single crystal that would grow both vertically and horizontally to fill the entire mold. The problem was solved by putting a corkscrew bottleneck between the chill plate and the mold. As with directional solidification, several crystals start to grow from the chill plate. But the bottleneck is small enough that only the crystal with the best horizontal



and vertical growth properties can worm through the corkscrew into the mold. The first single-crystal turbine blades went into engines for the midsize 767 jetliner in 1982 and subsequently into new jumbo-jet engines.

Many of the engineering advances developed for jumbo jets have been incorporated in smaller aircraft. High-bypass engines are now found on nearly all new commercial airliners of every size. The jumbos, in turn, are benefiting from new technologies developed for commercial aircraft in general: composite structural materials, automated landing and flight systems, and "all glass" cockpits in which instrument readings are displayed on color television monitors.

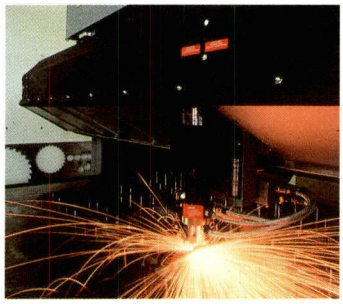
Over the next 10 to 15 years, the current family of jumbos will continue to expand in size, range, and capability. Future jumbos may weigh 1 million pounds, compared with 870,000 pounds today. They will carry over 600 passengers more than 8,000 miles nonstop. Currently, only short-range jumbos carry that many passengers and long-range jumbos carry many fewer. In addition, the three jumbo families will be joined by a fourth, the A330/340, in the early 1990s.

Supersonic transports, such as the Concorde, generate an unacceptable sonic boom that limits their use over populated areas. The next really advanced commercial aircraft therefore may be one that travels at hypersonic speeds at and above Mach 6 (six times the speed of sound). A proposed hypersonic plane, the National Aero-Space Plane, is expected to travel at speeds and altitudes where its sonic boom would create less of a problem. It will probably burn liquid hydrogen in a propulsion system that uses jet engines while in the atmosphere and rockets while in space. It remains to be seen, though, whether hypersonic planes will become economical for long-haul commercial transport. In the meantime, the jumbos and their descendants will undoubtedly remain the workhorses of the airlines into the twenty-first century.

L-1011s, here under construction, have four separate hydraulic systems for added safety. They operate the elevators and stabilizers on the wings, which control the pitch of the jumbo's nose.

8 Lasers

Before lasers were invented, scientists dreamed of harnessing the unique properties of light to study the swift motion of molecules, atoms, and electrons. The military wanted light's awesome power to annihilate enemy tanks, planes, and missiles. Once the practical laser was built, however, the "glamorous blowtorch" began doing jobs no one had dreamed of. Today lasers play music, read price tags, carry phone calls, cut cloth, perform surgery, and test the quality of air. And although the military is still waiting for a light-ray weapon, lasers have become standard research tools for scientists and engineers in laboratories around the world.

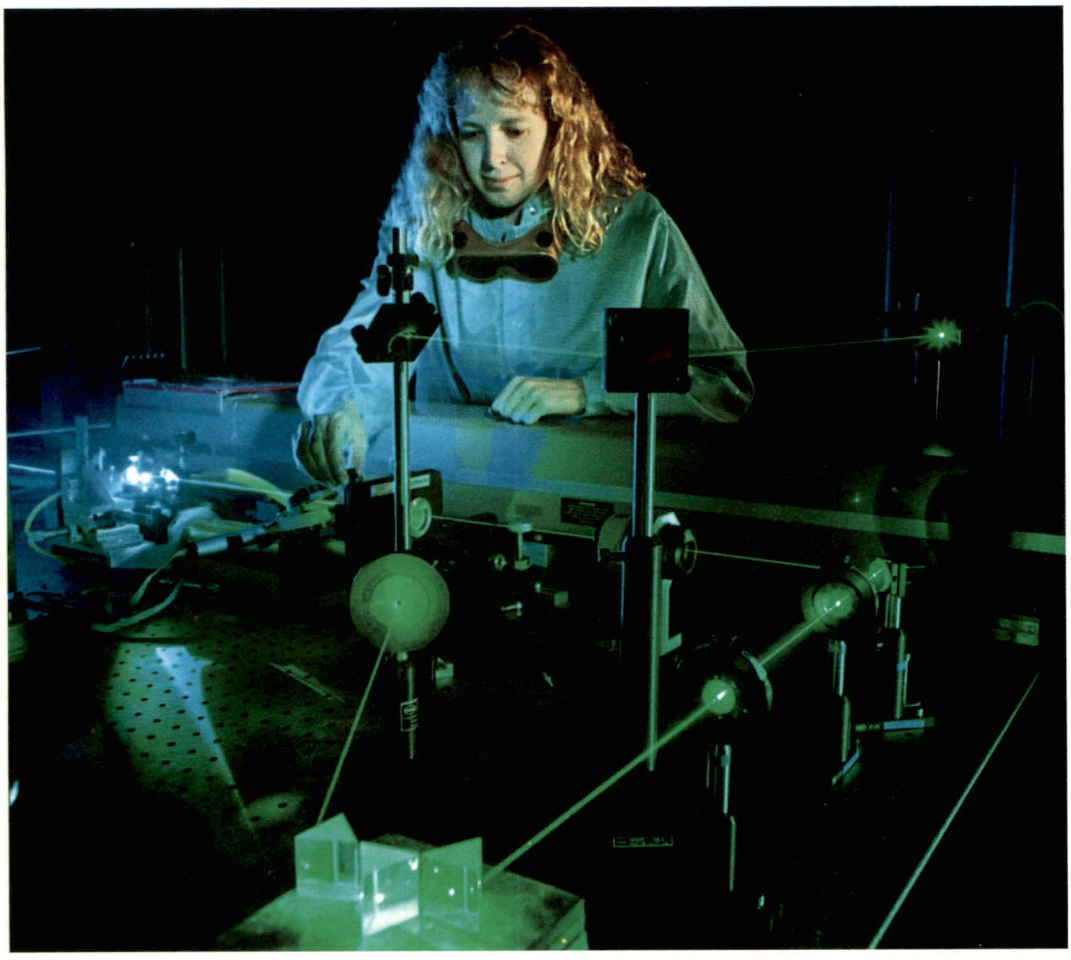


A carbon dioxide (CO_2) laser cuts heavy-duty circular saw blades from 1/4-inch steel sheet. The powerful CO_2 laser, the workhorse of industry, has been applied to a wide assortment of tasks, ranging from tough metal work to delicate surgery.

The word *laser* stands for *l*ight *a*mplification by *s*timulated *e*mission of *r*adiation, and laser light is unlike any other. Light waves from a laser all have the same frequency, creating a beam with one characteristic color. The light is also coherent, its waves traveling in phase—crest next to crest, trough next to trough. Coherency intensifies the waves' combined power, much as football fans intensify their combined sound by chanting in unison. In addition, the waves are almost perfectly parallel and so travel in nearly the same direction. This directionality keeps the waves concentrated in a narrow beam that widens only gradually over great distance. Incoherent light waves from the sun, light bulbs, and other nonlaser sources travel out of phase at different frequencies in a beam that quickly spreads and disappears from sight.

Laser waves are no more powerful than waves of other light. But, because of their unique properties, they are easily focused to a point that can vaporize diamond and steel. Where continuous power of this magnitude is needed, the carbon dioxide laser has been the workhorse since it was introduced commercially in 1967. It drills holes in hard ceramics, cuts through composite materials, and heat-treats metals to harden them. A CO_2 laser beam focuses to a fine point for the delicate work of cutting cloth or drilling holes in rubber baby-bottle nipples. Doctors use the CO_2 laser as a surgical knife; the laser cauterizes blood vessels as it cuts, eliminating much bleeding. Because light from a CO_2 laser is infrared and thus invisible, a red, low-energy helium-neon laser is often used to aim it.

Laser light is useful, too, in other areas of medicine. Its single-frequency nature lets a

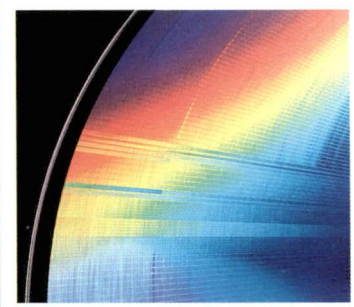


A researcher aims the beam from a YAG (yttrium-aluminum garnet) laser at a sample of gallium arsenide in an experiment to measure impurities in the semiconducting material.

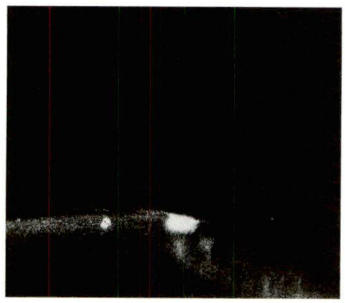
laser zap one kind of tissue while causing little harm to another. This is because some materials absorb more light energy at one particular frequency than at others. The colorless central portion of the eye, for example, absorbs little of the argon laser's green light, which is readily absorbed by blood-containing tissue at the back of the eye. Doctors, therefore, use the low-powered argon laser to spot weld detached retinas and seal the leaking blood vessels that often blind diabetics. Lasers also vaporize brain tumors, perform delicate inner-ear surgery, and remove warts and gynecological cysts. Laser light goes inside the body through fiber-optic endoscopes to burn fatty deposits out of clogged arteries, pulverize kidney stones, stanch bleeding stomach ulcers, and open blocked fallopian tubes.

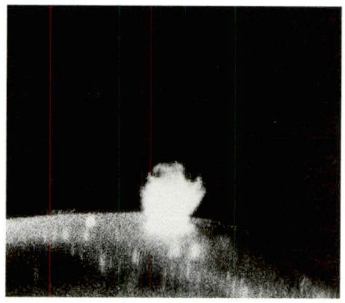
Coherent light is necessary for constructing the three-dimensional pictures called holograms. They are made by shining one part of a laser beam directly onto photographic film while bouncing the other part off an object and then onto the film. Waves from the two beams interfere with each other in complex patterns that are recorded on the film. When the film is developed, these patterns act like a complex system of microscopic mirrors. They reflect back the object's image if the original laser light is shined on the film at the original angle. The patterns are so intricate that they reflect a slightly different image in slightly different directions. This lets you see the object from different angles and gives the image its three-dimensional quality.

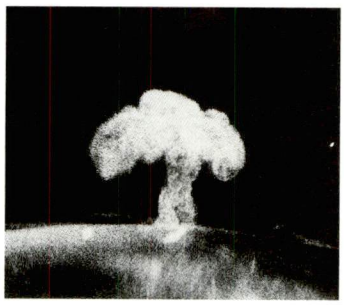
Holograms are difficult to counterfeit and so are used as tamper-proof seals on boxes of videocassettes and auto parts as well as on credit cards and passports. Double-exposure holograms are used widely for quality control in, for example, the aircraft tire industry. Disruptions in the delicate wave pattern on a double exposure of a tire reveal defective bulges only 6 millionths of an inch high. Since 1980 holograms have been used to direct the beam in many laser scanners that read price bar codes at checkout counters. Holograms on a whirling disc bend a red helium-neon laser beam in different directions, allowing it to scan for the bar code up to 1,800 times per second. The light pattern reflecting back to



Rows of microscopic bumps on this video disc carry digital information that is read by a laser and translated by computer into visual images.







A fraction of a second after the flash of an ultraviolet laser beam, a "smoke" plume erupts from the corneal surface of the eye, shoots upward, and turns into a microscopic mushroom cloud during a surgery experiment. Laser beams of other frequencies pass harmlessly through the cornea to perform surgery inside the eye.

sensors from any successful scan will transmit the code.

The directionality of laser light makes it very useful for aligning new buildings, tunnels, and pipes as well as leveling and grading land. And the ability to switch them rapidly on and off lets lasers produce the tiny pulses needed for timing measurements of long distances. Lasers can generate pulses of less than 0.1 billionth of a second—far shorter than those made by mechanical or electrical switches. By timing pulses bounced off reflectors placed on the moon by U.S. astronauts and Soviet unmanned landers, laser instruments measure the earth-to-moon distance with less than 1 centimeter of error.

Scientists use even shorter laser pulses to observe the lightning movement of atoms, molecules, and chemical reactions. The pulses can, in effect, take "snapshots" quickly enough to prevent blurring. One laser system generates a pulse of just 6 quadrillionths of a second, fast enough to take step-by-step shots of a chemical reaction lasting only 100 quadrillionths of a second.

Lasers are also good for measuring very slow movements. Geologists use them to measure the almost imperceptible creep along the San Andreas Fault in California. A two-laser device on one side of the fault shoots red and blue beams at a reflector farther up the fault on the other side. One beam could be used to measure the distance. But by comparing two beams of different frequencies, geologists calculate how much the atmosphere has slowed the beams on a given day. With this information, they compensate for measurements taken under different atmospheric conditions. Shooting at a reflector 5 kilometers away, the instrument can detect a shift in the earth of only 2 millimeters.

The ability to develop lasers with special talents opened the door to their use in communications in the 1970s. The breakthrough came with development of a semiconductor laser that operates at room temperature, is smaller than a grain of sand, and produces a light frequency that travels well through glass optical fiber. This laser made it practical to use fiber-optic cables for long-distance telephone lines that carry thousands of calls at once. The installation of fiber-optic telephone cables since then has expanded long-distance telephone service and reduced its cost.

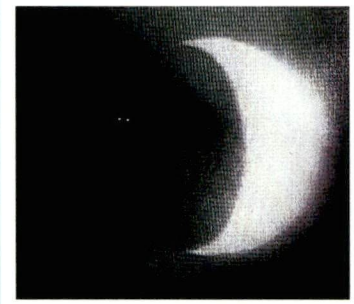
The semiconductor laser quickly became the key to compact disc (CD) recordings, which store large amounts of information and can be played at home. CDs were invented in the Netherlands, and the first audio CDs were introduced in Japan in 1982. Information for a disc is translated into the 1's and 0's of digital code and then stamped onto the upper side of the disc in a series of long pits. To read the information, a pinpoint laser beam scans the bumps on the underside. Flat surfaces between the bumps reflect a strong return beam; bumps scatter the light and weaken the beam. Sensors detect differences between strong and weak beams, interpreting them as digital code. Music, video, and computer data can all be stored in digital form on compact discs.

Other types of laser are especially useful for probing the environment. Government agencies and private organizations around the world use ground-based and airborne lasers to measure air pollution, monitor the weather, and study climate. Laser instruments have been used to study holes in the ozone layers over the North and South poles, particulates and gases over the Amazon rain forests, and dust drifting across the Atlantic from the Sahara.

Laser radar, or *lidar* (*li*ght *d*etection *a*nd *r*anging), detects airborne particles of dust, moisture, and chemicals by measuring the strength of laser light reflected back to the instrument. These fine particulates are invisible to normal radar. Weather scientists use lidar plus knowledge of the Doppler shift to study wind speeds. Light reflected off particles moving with the wind changes frequency, which gets higher if the particles are moving toward the observer and lower if they are moving away. A similar frequency shift causes a train whistle to sound higher while a train approaches and lower as it speeds away.

Another system, called differential absorption lidar, uses laser beams at two frequencies to detect the presence of a gas in the atmosphere and measure whatever is there. The first beam uses lidar to measure the light reflected back by particulates. The second beam, at a wavelength absorbed by a gas such as ozone, scans the same area. Some of its light is absorbed by the gas but some is reflected back by particulates. The amount of gas in the air and its location are revealed by comparing the return echoes of the two beams.





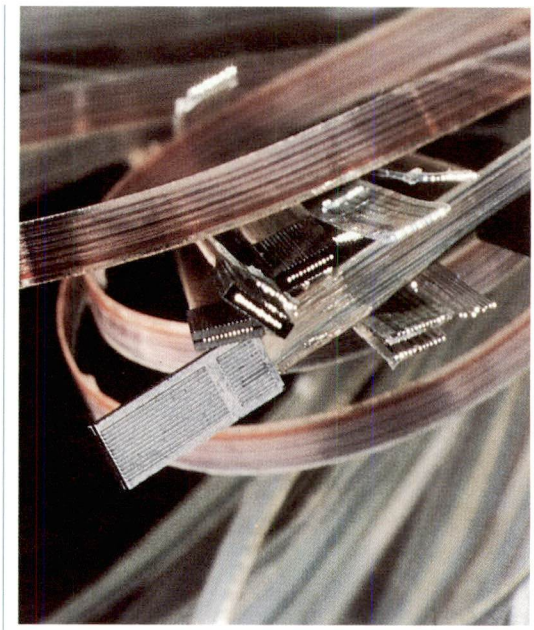
A laser beam shoots moonward from an observatory, left, in a test to learn whether a laser could hit a small target on the moon. Laser beams from this and another observatory appear as two tiny dots of light, above, sparkling on the dark side of the earth in a photo taken from the moon by a television camera on the *Surveyor 7* lunar probe. This test led to the use of lasers for measuring the earth-to-moon distance.

In the future, laser research will aim at reducing the size and cost of lasers while expanding their versatility. Technology is being developed for arrays of tiny semiconductor lasers—which are limited in size—that develop enough power for devices such as printers and facsimile machines. The search for a powerful laser that can be tuned to many frequencies has sparked interest in the free-electron laser. This laser generates light by sending electrons through a periodically alternating magnetic field. Its periodicity or its strength can be altered to change the frequency of the light beam.

At the same time, existing lasers are being applied to many new tasks. Lasers will find use in industries seeking greater speed and efficiency. They fit well into automation schemes because they can be operated by computer and used by robots. And, because light beams are quickly redirected with mirrors and fiber-optic cables, lasers can be assigned new jobs without costly retooling.

The fastest growing field for lasers, though, is undoubtedly medicine. Lasers are being investigated for reshaping the cornea to correct eye problems. They are being tested for activating toxic anticancer drugs that accumulate in tumors but pass through the rest of the body. And lasers are being used experimentally for drilling new blood channels in weakened hearts and for other techniques aimed at reducing heart disease, the leading cause of death in the United States.

9 Fiber-Optic Communication

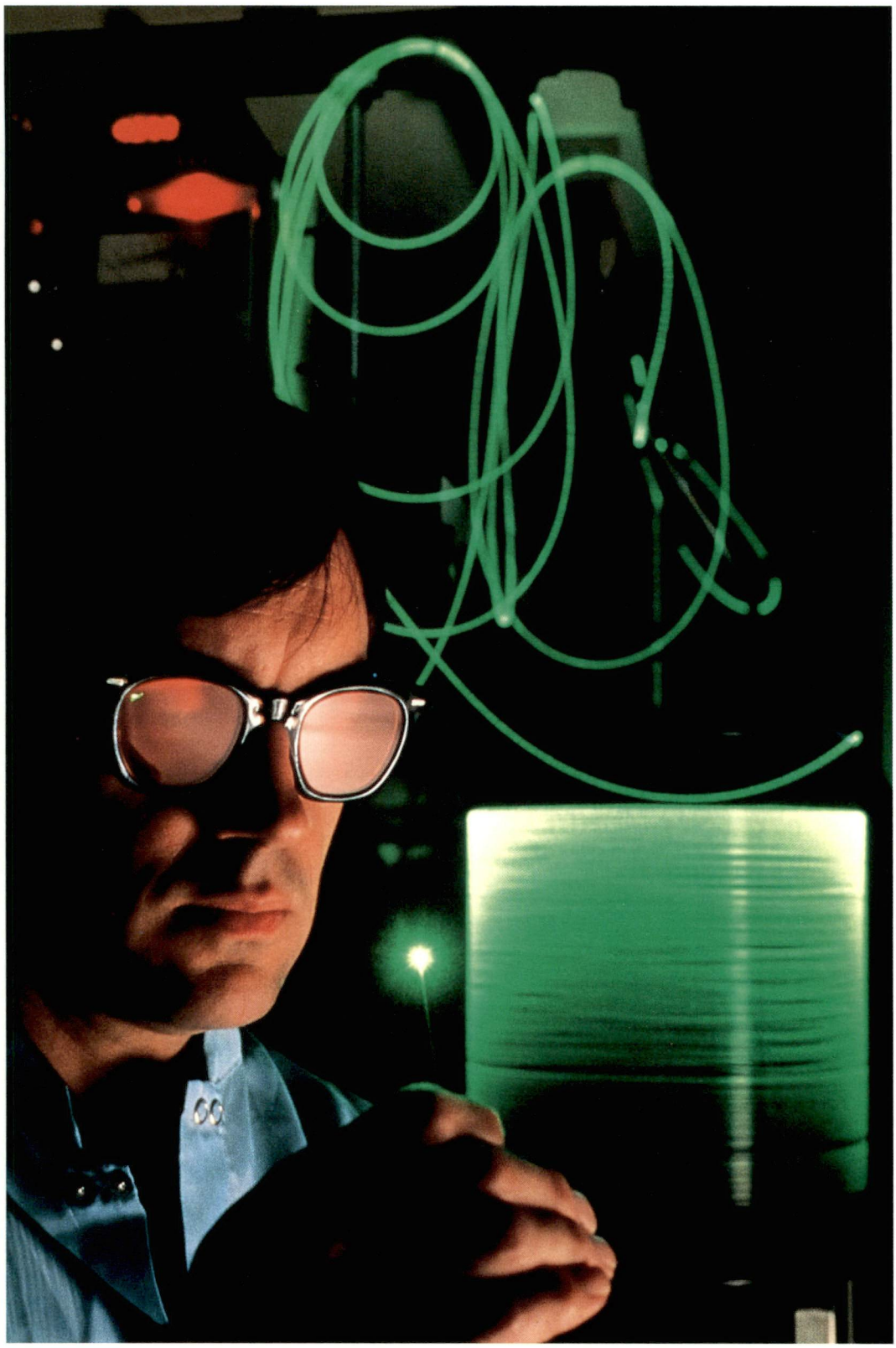


Right: Ultrapure glass fibers encased in protective ribbons are the mainstay of fiber-optic communication systems.

The information revolution of the 1960s created such an avalanche of data that futurists saw it soon overwhelming the telephone lines and radio waves that carry information around the globe. That vision—and the invention of lasers—spurred research into the tremendous potential of light, which can carry thousands of times more information than either electric signals or radio waves. The work led in 1970 to a very transparent glass thread whose appearance quickly opened the door to fiber-optic communication, a technology able to channel the flood of information into the twenty-first century.

Today's optical fiber is thinner than a human hair. Yet it carries so much information that four fibers—two in each direction—in a trans-Atlantic telephone cable are handling up to 40,000 calls at once. The cable, called TAT-8 and laid in 1988, is the first transoceanic fiber-optic cable. TAT-7, the copper cable laid in 1983, carries less than a fourth as many calls and is twice as thick. The huge capacity of optical fibers translates into lower construction cost per telephone circuit. The first trans-Atlantic copper cable, for example, cost more than $1 million per circuit to install in 1956; 32 years later, TAT-8 cost less than $10,000 per circuit.

Waves of light carry more information because they have higher frequencies—measured in wave cycles per second, or hertz—than either radio waves or the electric waves on copper telephone wires. High-frequency waves can be switched on and off faster than low-frequency waves, so they can



The green light of a an argon laser flows through several miles of experimental optical fiber wound around a spool. Similar hair-thin optical fibers are the heart of cables that carry 40,000 or more simultaneous telephone calls on beams of laser light under oceans and across continents.

be divided into more pulses per second. The pulses and gaps between them represent the 1's and 0's of digital information. The infrared laser light used in optical telephone cables has a frequency of about 100 million megahertz, 100 million times higher than a typical AM radio signal and 100 billion times higher than an electric telephone signal.

Fiber-optic communication became practical with the development of fibers that carry light pulses a substantial distance

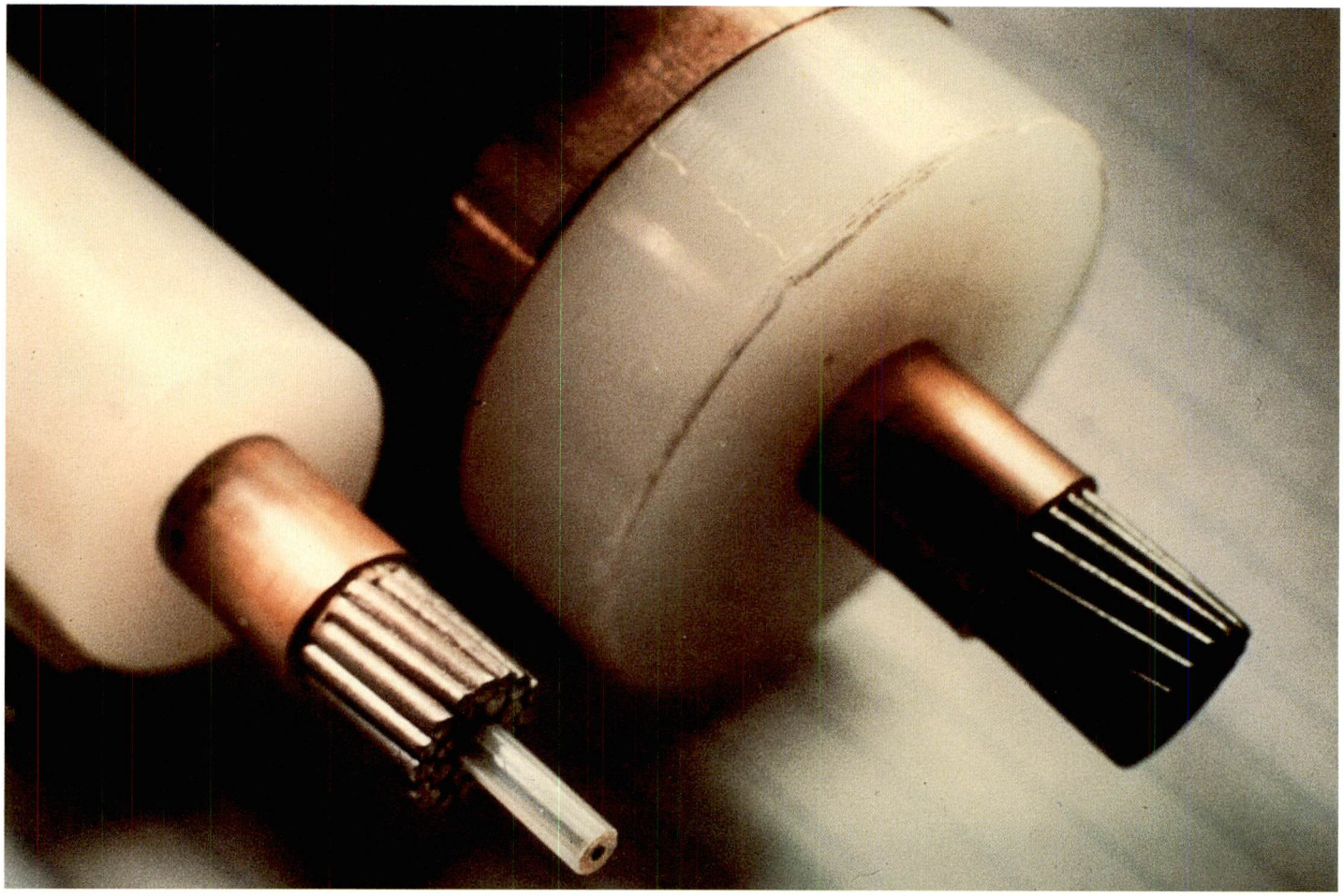
Below: Fiber-optic cables carry many more communication signals than do copper cables of similar size. Fiber cable laid in the trans-Atlantic link is less than half the size of copper cable used in an earlier link but carries more than four times as many telephone calls.

before needing a repeater. Their cores are made of silica glass, one of the most transparent solid substances known. Impurities in early glass fibers weakened pulses so much that light lost 99 percent of its energy after just 20 meters. But a new chemical process, pioneered in the 1970s, now produces cores of such high transparency that fibers in TAT-8 need only 101 repeaters to boost signals across the Atlantic. TAT-7, the copper cable, needs 662.

The debut of a practical fiber coincided with the development of other technologies needed for fiber-optic communication. In 1970 a room-temperature, semiconductor laser was built that could transmit well-defined pulses through long-distance optical fiber. Photodetectors were developed that could handle the torrent of pulses pouring out the other end and convert them into electric signals. For short-distance systems, tiny light-emitting diodes (LEDs) were devised that use less power and are less expensive than lasers. Although their signals deteriorate over long distances, LEDs are efficient for short links between, for example, a compact-disc player and stereo amplifier or computers in a local network.

Optical fibers can handle many times more information if they carry light pulses of several frequencies at the same time. The bandwidth of light (its range of frequencies) is about 10 billion megahertz from infrared to ultraviolet and can be divided into millions of signal channels, each at a slightly different frequency. Radio waves cover a relatively tiny bandwidth, leaving little room for multiple channels. The bandwidth is even smaller for electric channels.

Most optical fibers today carry light of only one frequency, although they are capable of transmitting several more. So far, it has proved economical to use multifrequency systems only in special cases of growing demand where limited numbers of fibers have already been installed. For example, fiber pairs that were carrying 24,000 voice circuits between Chicago and Philadelphia have been upgraded to transmit





The C.S. (Cable Ship) *Long Lines* laid more than 3,600 miles of the TAT-8 fiber-optic cable, from the United States to a point off the coast of Europe. From there, British and French ships laid branch cables to their respective countries. In all, nearly 4,200 miles of cable were laid.

two frequencies, so they now carry 48,000 circuits.

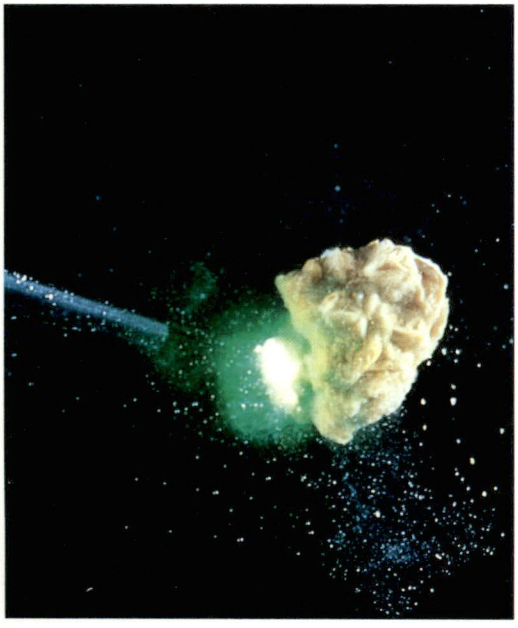
Fiber-optic communication has other advantages over radio and electric channels. Light signals do not produce the external halo of electromagnetic waves that surround electric telephone lines and cause "cross talk" between them. Optical fibers are also relatively secure from unwanted eavesdroppers, who can easily intercept radio waves or tap electric telephone signals without being detected.

Optical fibers have been quietly weaving into communication networks since the first commercial system opened in Chicago in 1977. Since then more than 1.5 million miles of optical fiber have been installed across the United States; copper cables are no longer laid for main lines between U.S. cities. An undersea fiber-optic cable that U.S. and Japanese cable ships laid across the Pacific was activated in 1989. Optical fibers have also been adapted for sensing movement in gyroscopes, linking industrial lasers to cutting and drilling tools, and threading light into the human body for examinations and laser surgery.

A future engineering challenge lies in building a computer that uses light instead of electricity. Theoretically, an optical computer would be 1,000 times faster than the best modern supercomputers. Another challenge closer to home is in stringing fibers to individual users from the optical main lines that now exist. At present, copper wires connect homes to central telephone exchanges, where electric signals are converted into light pulses that are channeled into the main lines. Telephone authorities in the United States, Great Britain, Japan, France, Canada, and West Germany have been running optical fibers to homes on an experimental basis since 1980. Once economic and regulatory obstacles are overcome, the pace of replacing copper wires with optical fibers to individual homes in the United States should pick up. Economical optical switches and converters for such "end-to-end" systems still need to be developed. But early in the twenty-first century, many people could be enjoying hundreds of television shows, movies, newspapers, and books brought into their homes through a single, hair-thin optical fiber.



A technician in Philadelphia checks a device that uses microprocessors to pinpoint a malfunction among signal regenerators along the heavily used fiber-optics line between New York City and Washington, D.C.



Left: Optical fibers can be threaded into the ureter, the tube leading from the bladder to the kidney, to bring in laser light that dislodges kidney stones. The photo here shows a laser chipping a kidney stone into fragments small enough to pass through the ureter naturally.

10 Genetically Engineered Products

The first fruits of genetic engineering—the products made by organisms implanted with a foreign gene—have contributed handsomely to human welfare in the few short years since they appeared.



Technicians inspect the control unit at the bottom of a large-scale evaporator used in the final steps of purifying human insulin produced by genetically engineered bacteria.

• Insulin, needed by millions of diabetics, has been produced commercially by genetically engineered bacteria since 1982. The product is identical to human insulin and so does not cause the allergic reactions sometimes produced by insulin derived from animals. Nor is its supply subject to the ups and downs of the livestock market.

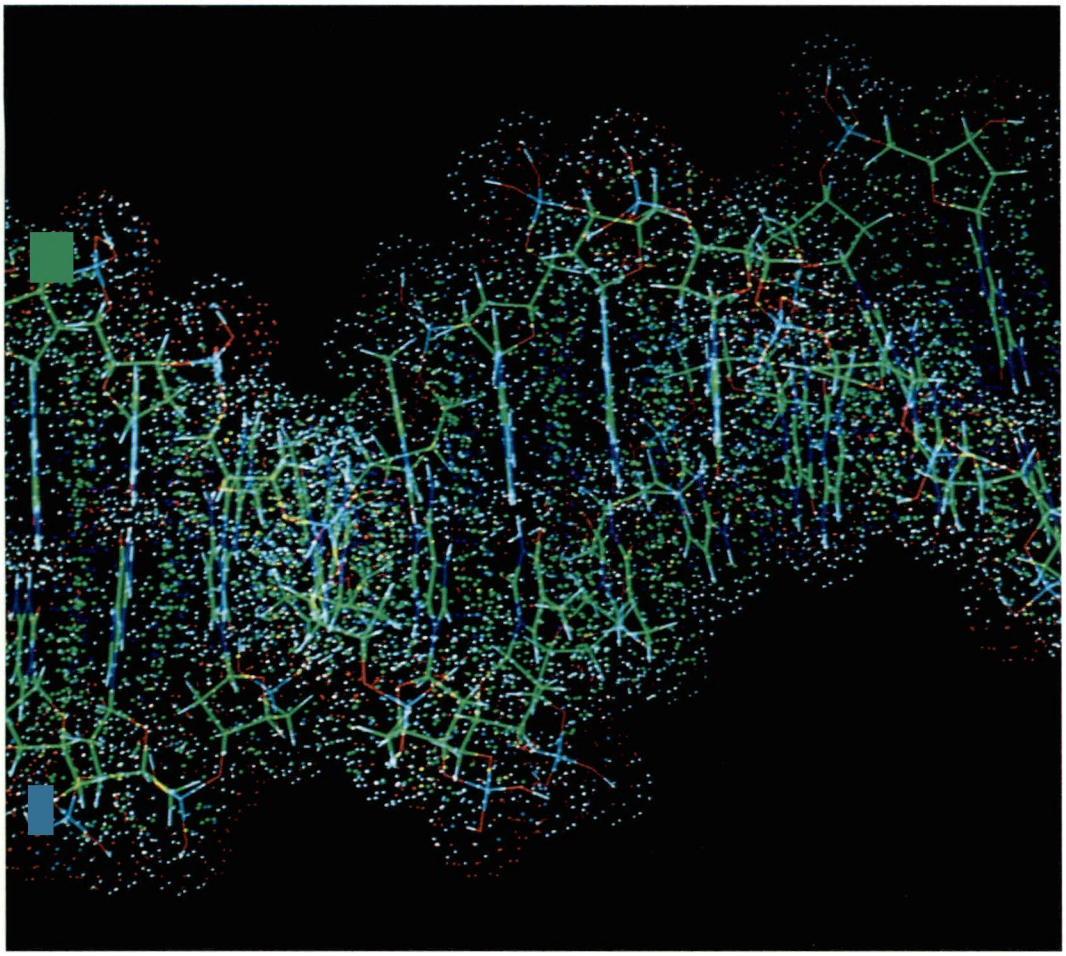
• Human growth hormone (HGH), needed for normal physical development, has been available as a genetically engineered product since 1985. Previously, many of the more than 10,000 U.S. children low in HGH could not get treatment with the natural substance, which is extracted in tiny amounts from the pituitary glands of cadavers at autopsy. And in 1985, distribution of HGH from this source was stopped after evidence suggested it might be contaminated with a virus causing a rare, fatal disease. Today, however, there is plenty of pure biosynthetic HGH.

• Tissue-plasminogen activator, or t-PA, appeared as a genetically engineered product in late 1987. It quickly dissolves blood clots that cause heart attack and prevents their recurrence. It is already standard treatment for heart attack victims at hundreds of U.S. hospitals.

These and other genetically engineered products now available are created through the efforts of biologists and engineers. It is biologists who "engineer" new organisms by splicing a gene from one organism into another. Traditional engineers provide an indispensable bridge from biology lab to the public. They design and build the mechanical systems that allow the new organisms to grow in large quantities and that process the valuable substances the organisms produce. In addition, they develop complex laboratory instruments that simplify and speed the work of genetic engineering.

A genetically engineered product begins with biologists who find a gene that produces a valuable substance such as HGH. Using enzymes that dissolve bonds to neighboring genes, they cut the valuable gene out of the DNA, the genetic material of a cell. Then they insert this gene into another organism—such as the common bacterium *Escherichia coli*—that will multiply itself and the foreign gene along with it.

Once the genetically engineered "bug" has been created, engineers design a system in which its product can be produced and processed in large quantities at a reasonable cost. The production of human insulin, the first commercial product of genetic engineering, is a good example. It was developed in the United States and appeared commercially under the trade name Humulin, first in the



A spiraling chain of DNA, the genetic blueprint of life, shimmers in this computer-generated molecular model. Certain DNA segments make up the genes that produce insulin, human growth hormone, and other important substances.

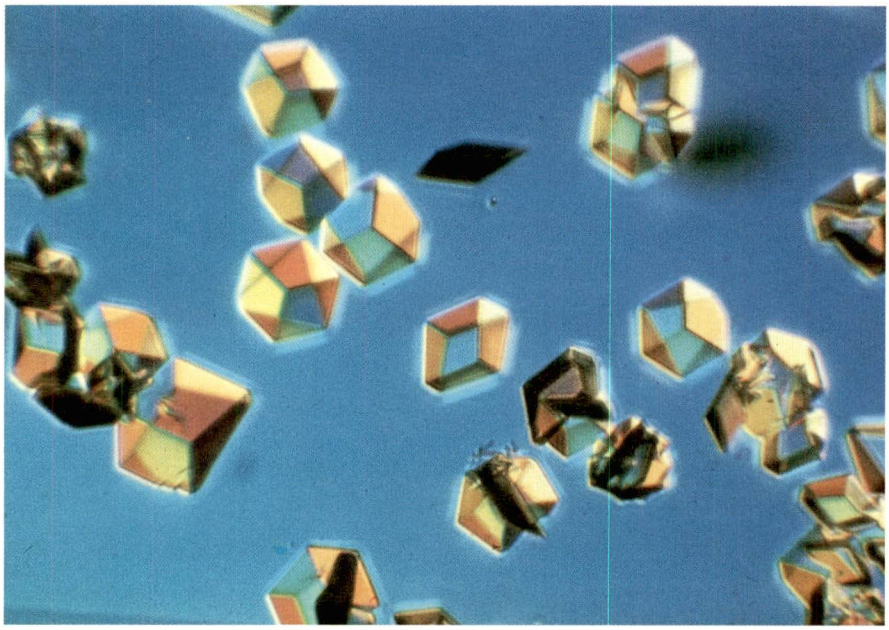
United Kingdom and later in the United States.

The insulin molecule is composed of two parts called A and B chains. The original Humulin process used two versions of *E. coli* to produce the chains. One version contained a gene producing A chains and the other contained the B-chain gene. Each version was grown, or fermented, in a large separate tank. The chains they produced were extracted from the bacteria and purified. Afterward, A and B chains were combined in a third vessel. The complete molecules were then purified and crystallized into a usable form of human insulin.

The Humulin process demanded special engineering to handle the uncertainty surrounding the first large-scale use of genetically engineered microbes. Scientists in the late 1970s did not know whether such bugs might survive in nature and contaminate the environment. So the bacteria were grown in closed stainless steel tanks with the inflow of nutrients and oxygen carefully controlled by computer. Water vapor and carbon dioxide that flowed out were decontaminated. A special double seal was invented to prevent the escape of microbes from around the shaft of the paddle-like agitator that stirred the culture. And the tanks were designed to function under negative pressure—the opposite of conventional tanks—to suck back any bacteria that otherwise might escape. Engineers also developed a new pasteurization system hot enough to kill the bacteria as they were withdrawn from the tanks, but cool enough not to damage the A or B chains.

The big challenge in producing Humulin, however, was in scaling up production from expensive 10-liter batches in the laboratory to less expensive batches of 40,000 liters in the factory. The scaleup was particularly difficult because these bacteria store the A or B chains within themselves, unlike microbes that produce antibiotics and secrete them. Engineers devised a way to extract the chains by pressurizing the cells in a tank and then shooting them out into normal atmosphere, where the pressure change caused the cells to explode like balloons and release their contents. The

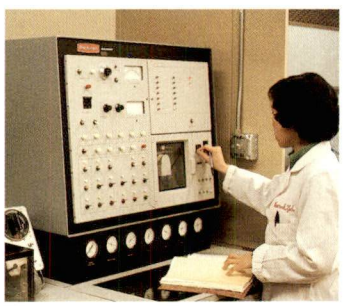
chains were separated from cell debris in several steps ending with high-performance liquid chromatography. This laboratory technique is performed by pouring a mixture through a pencil-sized column of material that sifts out certain molecules. But for large-scale Humulin production, columns 10 feet tall and 12 to 16 inches in diameter had to be designed. Today, Humulin is produced by a similar, but more efficient process involving a new type of genetically engineered bacteria and only one fermentation tank.



The first insulin produced by bacteria implanted with human insulin genes was processed into crystals. The insulin must be separated from the bacteria and purified in relatively large quantities in order to be useful to many diabetics.

Traditional engineers are not directly involved in some other aspects of genetic engineering, such as the genetic alteration of plants and animals or the potential treatment of humans with genetic disorders. They are, however, becoming more involved with processing the products that are produced by genetically altered plants and microorganisms. Biologists are modifying organisms to produce everything from pharmaceuticals to food processing agents to specialty chemicals. In fact, the greatest use of genetic engineering in the future may be in the production of products that are now created by chemical processes, which often involve high temperatures and pressures as well as toxic by-products. Biological synthesis, on the other hand, usually takes place at room temperature under normal pressure and produces biodegradable waste.

In the meantime, people have already begun to investigate the use of genetically altered microbes to clean up toxic waste, degrade pesticides, or to turn organic waste material into useful products. They may one day use genetically altered bacteria to loosen underground oil so it can be pumped to the surface or to leach precious minerals from ore.



Potentially useful genes are often identified by analyzing the proteins they produce. A protein sequencer is used to determine the order of amino acids making up a chainlike protein molecule, thereby uncovering the identity of the gene that made it.

Perhaps the biggest contribution of traditional engineering to this field has been the development of instruments that speed the process of genetic engineering and expand its possibilities. Two devices—the protein sequencer and the DNA synthesizer—have already had tremendous impact on the detective work of genetic engineering. For instance, one biologist working with a DNA synthesizer can do the amount of work in one afternoon that would have taken 25 biologists five years to complete in the early 1970s.

The discovery of a valuable gene often begins with identifying the sequence of amino acids in the protein it produces. There are only 20 different amino acids. But the chainlike protein molecules have hundreds of amino acids linked in specific order. An instrument that can decipher this sequence appeared on the market in 1969. It is essentially a computer-controlled plumbing device that uses solvents to cut one amino acid at a time from the end of a protein molecule. Knowing the amino acid order, biologists can identify the gene that made the protein.

Another device, which entered the market in 1982, can actually build small genes or gene fragments out of DNA—the genetic material found in cells. A DNA synthesizer hooks together subunits, called bases, in the proper order for a particular gene or gene fragment. These synthetic genes and fragments can then be used for several purposes, including genetic engineering. For example, the genes that produce Humulin are really synthetic genes created by a DNA synthesizer.

The dream machine of genetic engineering, though, is a device that can rapidly sequence DNA, much as proteins are sequenced. Human DNA contains more than 3 billion bases, and today's DNA sequencers can analyze only about 9,000 bases per day. The challenge for today's engineers is to develop in the next four or five years machines that are at least 10 times faster than present sequencers.

The amount of genetic information already being generated by DNA sequencers is overwhelming. To check a new sequence against the massive, growing data bank of



known sequences will require faster computer systems. One under development uses a series of 500 or more microprocessors that can each be programmed to recognize one of the four types of DNA base. Essentially, the series is programmed to reflect the order of bases in the new DNA sequence. As known sequences from the data bank flow past the series, each microprocessor "lights up" when its particular base passes by. When all light up together, they signal the location of an identical sequence in the data stream. Using this recognition system, the computer can search the DNA data bank for similar patterns thousands of times faster than existing computers.

Work is under way to determine the entire sequence of human DNA, called the genome, and map the location of all 100,000 or so genes. This data would reveal more about human biology and disease than has been learned in the past 200 years. Scientists and engineers would dearly love to map the entire human genome. With the right tools, they may soon do it. Completing the project would be, some believe, the biological equivalent of putting a man or woman on the moon.

For nine years, a deficiency in human growth hormone (HGH) stunted the growth of this California girl. But in her tenth year, injections of HGH produced by genetically altered bacteria stimulated a 5-inch burst of growth, catching her nearly up to the normal height of a girl her age.

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