Preface

This booklet contains selections from the Cornell Engineering Quarterly concerning the history of the Arecibo Observatory. A companion collection has been assembled from the Cornell Alumni News.

The PDF containing these articles (in chronological order) includes bookmarks, and with the Acrobat Reader, the file opens with the bookmarks displayed.

These materials were written for a broad audience and, hopefully, provide additional context for the collection of oral histories about the Arecibo Observatory.

The original articles may be viewed and downloaded from the eCommons collection, Engineering Quarterly, at https://ecommons.cornell.edu/handle/1813/2211

An Oral History of the Arecibo Observatory is at https://ecommons.cornell.edu/handle/1813/33201

These include extended interviews with persons who were intimately involved with the creation and use of the Arecibo Observatory. The on-camera participants include:

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This video collection also includes a short history of the Arecibo Observatory and the Memorial honoring the late Bill Gordon.

The assistance of Dianne Ferriss and Hal Craft are gratefully acknowledged.

Enjoy!

JRC  March 2016
Selections from

ENGINEERING: Cornell Quarterly
Concerning the History of the
Arecibo Observatory


PROBING OUR ATMOSPHERE AND BEYOND, Engineering: Cornell Quarterly, v13n2 (1978), entire issue:


“Communication with Other Intelligences,” by Frank D. Drake, pp 24-35.

“Faculty Publications,” pp 36-40.


AN EYE AND EAR TO SPACE:
The Man Who Developed Arecibo

By K. Toby Clarey

In this era of emphasis on automation, it is refreshing to meet such a man as Dr. William E. ("Bill") Gordon and remember that it is still the engineer, the man, who is responsible for making possible most of our modern scientific and technological marvels. One of these marvels is Cornell’s Arecibo Ionospheric Observatory, the world’s largest radar-radio telescope, at Arecibo, in Puerto Rico. Dr. Gordon, the Walter R. Read Professor of Engineering at Cornell, was largely responsible for this engineering achievement. He has now been named Dean of Engineering and Science at Rice University in Houston. Dr. Gordon will continue a Cornell association through three Ph.D. candidates at Rice whose research will be undertaken at Arecibo.

William Edwin Gordon’s biographical sketch reads like a synopsis for the legendary American success story, and the man himself bears out the image, perfectly “cast” for the part. Tall, lean, gracious, and very human, this Professor of Electrical Engineering speaks warmly of his early experience as a ninth grade teacher. He recalls his students “on the edges of their seats, spellbound at the simplest of experiments.” His mother had been a teacher, and this, together with the depression years, pointed him toward nearby Montclair (N.J.) State Teachers’ College, where he received his B.A. degree in 1939. Until 1942, when he earned his M.A. at Montclair, he taught mathematics, science, and physical education in New Jersey, at Montclair and Oradell High Schools.

World War II, however, changed Bill Gordon’s future considerably. He enlisted in the Air Force in 1942 as a cadet in meteorology. During this period also he was an instructor in meteorology at New York University; research meteorologist at the Army-Air Force Weather Service, and meteorologist for the Office of Scientific Research and Development. In 1946 he was awarded the M.S. in Meteorology at New York University. It was while he was in the service that the effect of weather on radar first drew his interest: “We were seeing things that we weren’t supposed to see on our radar screens . . . why was radar too short or too long?” He worked with a weather station operated by the Massachusetts Institute of Technology in Orlando, Fla., and then with a civilian group at The University of Texas studying radar and meteorological parameters. It was at Texas that he received his discharge from the Air Force with the rank of Captain. At Texas, also, Dr. Gordon met Professor Charles R. Burrows, former Chairman of Cornell’s School of Electrical Engineering. “Charlie Burrows got me more deeply involved with the riddles of weather in radar, and through him I became interested in Cornell,” he explains. Dr. Gordon became a research associate at Cornell in 1948, received his Ph.D. in 1953 and the same year was promoted to Associate Professor; he was appointed Professor in July of 1959.

In addition to heading the team of Cornell engineers who designed Arecibo, Dr. Gordon has an impressive list of affiliations. He was supervisor of Cornell’s troposphere project, and of the radio astronomy and solar noise projects. He has been Chairman of the Joint Commission on Radio Meteorology.
Dr. William E. Gordon, the developer of the Arecibo Ionospheric Observatory, stands on the catwalk that connects the ‘big dish’ feed arm support with the ground.

and was Chairman of the United States National Commission of the International Scientific Radio Union. He has been widely published, and has presented papers at the Joint Commission of Radio Meteorology in Brussels, at the Radar-Weather Conference in Montreal, and at the Radio-Wave Propagation Symposium in San Diego.

Dr. Gordon was a National Academy of Science-Research Council delegate to the General Assembly of the International Scientific Radio Union at Sydney in 1952, at The Hague in August 1954, and at Boulder in 1957, and he led the United States Delegation to London in 1960. He is a member of Sigma Xi; Phi Kappa Phi; Kappa Delta Pi; Tau Beta Pi; a Fellow of the Institute of Radio Engineers and Professional Group on Antennas and Propagation, and he is a Professional Member of the American Meteorological Society.

“The creation of scientific puzzles: Why does Venus move in a contrary direction? Observation of the rotation of the planets, the comparison of radar maps with optical maps, new pieces of knowledge, getting Arecibo itself built” — these are some of the many satisfactions that Dr. Gordon, not yet fifty years of age, enjoys.

Rice University has its own satellite program: Project Owl, a brainchild of the Rice Department of Space Science. In addition to space science, there are five other science departments and four engineering schools that Dr. Gordon will lead as Dean of Engineering and Science. He intends to teach one course per term and to supervise the research of several graduate students. “At Rice even President Pitzer teaches and directs graduate students,” he comments. Dr. Gordon adds that he was impressed with the quality of the approximately 1,200 engineering and science students during a visit to Rice, at which time he stayed in their quarters and joined them at seminars.

Dr. Gordon says, “Texas has been described as an educationally developing state with a big gap in the middle which needs to be filled, but the state is making great strides in upgrading its program.” He looks forward to fostering research at Rice.

The Gordon family liked living in the tropics during their Arecibo stay, and are delighted to be going again to a warm climate. They have purchased a swimming pool in Houston “surrounded by a house.” Son Larry, married, has finished the fourth year of a five-year course in architecture at Rensselaer Polytechnic Institute. A daughter, Nancy, is a biology major at Jackson College, Tufts University.

Dr. Gordon’s hobby is sailing. In Puerto Rico he had access to a 28-foot sloop in which he voyaged to the Virgin Islands. In Ithaca he made the most of Cayuga Lake, and now expects Galveston Bay to be a second home.

It is a long way professionally from Montclair State Teachers’ College to the Deanship of Engineering and Science at Rice. Dr. Gordon made the journey a fascinating one, by way of Arecibo. The Cornell College of Engineering will follow with pride the future course of one of its gifted men.
Take a basketball and cut off about one-third of it, making a bowl. Then imagine yourself to be the size of the head of a common pin situated at the bottom of the bowl, looking up at its rim. Roughly speaking this is the sort of sensation you would experience if you were looking up toward the rim of Cornell's Arecibo Ionospheric Observatory in Arecibo, Puerto Rico.

The Observatory's major facility is a large spherical reflector with a surface radius of curvature of 870 feet. However, since the reflector is only a portion of a ball, instead of a diameter of 1,740 feet, it is 1,000 feet across at its rim. This facility is both the largest known radio "ear" and "camera lens" in the world; and this big "ear" and "lens" system is oriented to space measurements and sustained observation of the chemical, physical, and dynamical properties that form the atmosphere and the objects it contains.

When functioning as a "camera" (or radar telescope) the instrument transmits a pulsed signal produced by a "feed," and receives between pulses that portion of the signal reflected back by electrons in the ionosphere or from the moon or planets such as Mars or Venus. When operating as an "ear" it listens to radio energy emitted by the sun, the planets, and distant celestial radio sources.

It was Dr. William E. Gordon's interest in atmospheric radio wave research (the scattering of waves by the free electrons in the atmosphere) that led him to conceive of an apparatus which could observe this behavior quantitatively. Basing his calculations on existing transmitter and receiver capabilities, he determined that a parabolic reflector 1,000 feet in diameter would utilize the upper limits of transmitter and receiver technology and make possible the measurement of atmospheric temperature, motion, and composition. The big question was whether such a large surface could be built. Dr. Gordon consulted two Cornell professors of structural engineering, George Winter and William McGuire. They concluded that a structure's weight. Obviously a "wavy" lens would produce a "blurred photograph"; and an "ear" listening for faint noises could tolerate little structural variation. With Dr. Gordon, Professors Winter and McGuire decided that an earth-stabilized reflector, built close to the ground, would best meet the design criteria.

Having concluded that the reflector was structurally possible, Dr. Gordon approached another Cornell Engineering faculty team for assistance. Could a site be located in which such a reflector...
could be built—a natural bowl with a minimum of excavation and filling, and good drainage? The aerial photo studies group, headed by Professor Donald Belcher of the College's School of Civil Engineering, was asked to suggest potential sites near the equator. These sites had to fulfill several requirements: They had to be located where solar system objects pass more nearly overhead (the tropics); they had to be in a climate of moderate temperature changes, to reduce problems of structural expansion and contraction, and be removed from the electrical interferences of metropolitan areas or air routes.

With his knowledge of the surface of the earth, Professor Belcher suggested several possible locations that met these requirements. With the aid of aerial survey maps, the possibilities were weighed and then narrowed to a few locations, and on-site inspection of these few was made by Belcher and Gordon. A 125-acre site in Puerto Rico, 11 miles from Arecibo and the coast, and protected by surrounding hills, was chosen. It had been located originally by an aerial survey analysis of an area whose sinkhole...
topography was caused by the collapse of huge caves formed by the solution of limestone in water.

In 1958 the support of the Advanced Research Projects Agency of the Department of Defense (ARPA) was sought. ARPA was interested in the ionosphere, the medium in which many future scientific and military flights would be made. It was suggested that greater radar flexibility would result if the original fixed antenna design with a ± 2 degree scan was modified to introduce greater steering—or scanning—capability. Because the United States Air Force Cambridge Research Laboratories had nearly a decade's experience with steerable spherical reflectors of up to 10-feet-diameter serving as receiving antennas, their report enabled Gordon to design a more flexible steering system for directing and receiving signals within a 40-degree cone centered overhead. A spherical reflector was substituted for the earlier parabolic surface.

With ARPA support a contract for the construction was signed by Cornell and the USAF Cambridge Research Laboratories in November 1959. Construction began in June 1960, and the Observatory was dedicated November 1, 1963. Dr. Gordon directed construction and served as first Director of the Observatory until September 1965, when he returned to the campus as the Walter R. Read Professor of Engineering.

RECENT ACTIVITIES AT ARECIBO

Since the fall of 1963, part of the observing time has been used to calibrate the various components in the system and to determine operating characteristics, particularly the degree of accuracy of the observations. However, three major concurrent areas of study are presently being undertaken at Arecibo: One has to do with studies of electron density in the ionosphere; another is concerned with the properties and behavior of the moon and inner planets; the third uses the unsurpassed sensitivity of the antennas for radio astronomy.

It was Dr. Gordon's interest in radio-wave interaction with the atmosphere—the scattering of radio waves by the "freed" electrons in the ionosphere—that led him to contemplate what would be the best optimum transmitter and receiver mechanism to study this phenomenon. About 30 miles up from the surface of the earth the thin atmosphere contains electrons that have been freed by solar radiation from their attachment to atoms of molecules of gases. The density of these electrons, and the resulting positive ions that are formed in the process of freeing an electron from its molecule, vary with height and with time.

At some height between 60 and 180 miles the electron density (number of electrons in a unit volume) is sufficient to reflect radio waves at frequencies of up to 10 megacycles. It is this reflective ability that enables us to have long-distance radio communication by reflecting the radio signal back to the ground one or more times as it travels around the earth from transmitter to receiver. Arecibo's powerful radar produces a profile of electron density by recording at different times the total power back-scattered to the antenna.
While the free electrons scatter the radio waves, it is the positive ions that dominate the wave motions. Thermal velocities will be higher when warmer, lighter ions are present; thus temperatures of the charged particles and the ionic species may be deduced by comparing the transmitted frequency with those frequencies contained in the signal scattered back from a unit volume of the upper atmosphere. With this knowledge and data, temperature and ionic (atmospheric composition) profiles, both as a function of height, are being established at Arecibo. Such studies are contributing greatly to our understanding of the dynamics and chemistry of the ionosphere.

The planetary radar studies, the second of the present threefold study mission, have already “unearted” new findings about the planets which suggest that the half-life of present-day astronomy textbooks will grow shorter. For example, it has been found that the planet Mercury rotates with an alternation of day and night rather than permanently sunlit on one half and night on the other half as had been believed on the basis of optical information. The planet Venus, named for a beautiful woman, has been found to rotate about its axis in a contrary direction from that of the other planets of our solar system. Why this is so is furnishing the Observatory with another interesting problem.

Another significant undertaking at Arecibo is the development of our first map of the surface of Venus, which can never be optically observed because of the planet’s dense cloud cover. To develop techniques for this project, radar photos have been made of areas on the moon and then compared with optical photographs. Professor Ray Jurgens, a Ph.D. candidate under Dr. Gordon and now on leave from Clarkson College of Technology, is presently preparing the first surface map of Venus.

The third of the major areas of investigation at Arecibo is the instrument’s use as a radio listening device. To date 3,000 radio sources in the universe have been located of which only about 100 have been identified optically. Among these are the sun, the moon, some planets, the Milky Way and other galaxies, and many nebulae. The design of the

“dish” for radio astronomy combines great collecting area with an ability to resolve fine detail in the sky, both by day and night, and in any weather.

Since the beginning of its operations the Arecibo Ionospheric Observatory has been used by personnel from Pennsylvania State University, the University of Colorado, the University of Florida, Rice University, the University of California at San Diego, and the Air Force Cambridge Research Laboratory. “At any given time,” Dr. Gordon comments, “the working group has an international flavor.” Three Indians, a Frenchman, several Australians, a Swede, and a German are presently doing work at the Observatory. Its facilities are available to qualified engineers and scientists upon approval of a research proposal. Operating funds are provided by contract with the Air Force Office of Scientific Research with support from the Advanced Research Projects Agency, Department of Defense. 28
The story is told of a cowboy who on seeing the Grand Canyon for the first time exclaimed, “Something happened here!” Anyone flying over Arecibo for the first time must surely feel a sensation of awe at the magnitude of this scene. Here something on a grand scale has happened, not because of the forces of nature and of time but because a few years ago a young man had an absorbing interest in weather and a scientific desire to explore some of the mysteries of weather’s effect on forces which are changing the age in which we live. Not only did he have an idea but he also, with the collaborative efforts of other skilled professionals, pursued that idea through to its successful execution. Today man is pushing back the frontiers of space. And because “something happened” at Arecibo as a result of the vision and perseverance of Cornell engineers, the world’s largest radio telescope has come into being to play its part in the mighty space effort.
 Throughout history man has relied on the soils and rocks of the earth’s crust to support a wide variety of structures. He has also used these materials for the construction of roads, dams, canals, harbors, and many buildings. The pressure to extend man’s use of the earth’s surface has been intensified by a rapid increase in population and by the quickened pace of the growth of technology and production. The population increase has created an almost insatiable demand for land for shelter, transportation, production, and recreation.

In many parts of the world, the more desirable land sites with relatively simple foundation problems have all been used, and further developments require that marginal land, such as swamp or landslide areas, be reclaimed. The growing demand for land has emphasized our need for greater knowledge of those materials which occur near the earth’s surface, as well as our need for a more rational approach to land utilization and planning.

Generally, the materials which make up the earth’s crust are in dynamic equilibrium with their environment. Changes in this environment, either natural or man-made, may cause movements in the earth’s surface or in deeper layers of the crust that can have adverse effects on any structures near these movements. For example, changes in the ground water regime following the construction of a dam may trigger large-scale landslides. Pumping water from wells may lead to substantial settlements of the ground surface in surrounding areas.

ACTIVITIES OF THE GEOTECHNICAL ENGINEER

Geotechnical engineering deals with the basic components of sites and structures: soil mechanics, surveying, engineering geology, ground water, construction materials, and the functional demands of the structure on the site. The following areas of interaction among these components must be thoughtfully considered:

- Methods of construction relating to the site.
- The costs of site preparation as affected by various positionings of units.
- Design characteristics related to site foundations, rock quality, and earthquake shock.
- Soil strength as influenced by ground water changes; rocks as affected by weathering and solution; landslides as caused by construction surcharge.
- Tie-in of a site to its adjacent area: its feeder roads, its water supply, its waste disposal.

THE ARECIBO TELESCOPE

The intricacies of modern, complex structural designs and site developments can be illustrated by Cornell’s Arecibo
The 125-acre site for the Ionospheric Observatory met these conditions: (a) location where solar objects pass most directly overhead; (b) economical construction facilitated by natural topographical features; (c) climate where temperature variations, wind velocities are low.

Sinkholes in a flat terrain, characteristic of Karst topography, dominate this area. The solution of limestone in water caused the formation of large caves and later caused the collapse of the cave roofs, thus creating sinkholes. Tropical weathering has left only the nubs of hills upon which the feed support towers were constructed.

The site is well-drained, the area under the reflector base being much above the permanent water table. The porous limestone is easily worked, winds are usually light, and major tropical storms are rare. The maximum temperature variation is only 30 degrees.

1. Topographic layout with circular excavation contours superimposed, showing the conformity of the terrain to the design requirements of the reflector surface.
2. The completed facility. Note the service road leading to the bottom of the bowl.
3. An aerial photo showing the site selected from the twenty-eight considered with its unusual sinkhole topography.
radio-radar telescope. This telescope is the largest known radio "ear" and "camera lens" in the world, with a 1,000 foot span across the rim of the spherical reflector. It is set into an earth "bowl" about 350 feet deep at its center, and is located on a 125-acre site some 11 miles from Arecibo, Puerto Rico, and the coast.

Several requirements were critical to the consideration of the site. First, it had to be located where solar system objects pass more directly overhead (which placed it in the tropics) and where there would be moderate temperature fluctuations so that problems of structural expansion and contraction would be minimal. The site had to be well removed from the electrical interferences of metropolitan areas or airline routes.

Beginning with the problems of the physical site itself, to excavate a site of such magnitude would not only be costly but also impossible to maintain: excavated in soil, it would fill with water or the sides would slide in, or both. Steel framing combined with a more manageable, shallow depression would take on the proportions and costs of a large stadium. Geotechnical staff experience and course materials from our files pointed the way to an optimum solution: look to the natural bowl-shaped depressions found in tropical limestones. With the use of aerial photographs analyzed in Ithaca, the most suitable site was pinpointed in an area of 700 square miles of incredibly rough terrain in the remote highlands of Puerto Rico.

Now the structural project had to be tailored to the site. Before the site was chosen, the telescope had been conceived of as a reflector dish and signal "feed" tower 500 feet above it. With a naturally formed bowl and the surrounding peaks at the chosen site, the signal "feed" could be suspended above the reflector dish using lateral support towers on the adjacent peaks. This concept formed the basis for the final design that stands today, showing the influence of site characteristics in producing a less costly and more electronically efficient radio telescope.

Finally, the geometric shape and positioning of the mesh of the reflector surface of the telescope with respect to the feed mechanism had to be calibrated. This is analogous to testing the grinding of the lens and prisms in an optical telescope. The shape of this mammoth reflector was determined photogrammetrically to a precision of plus or minus one centimeter. This was accomplished from precise measurements of aerial film by methods of analytic aerotriangulation, a technique that was recently developed by the Department of Geotechnical Engineering at Cornell.

ADVANCES IN SURVEYING AND MAPPING

One prerequisite essential for planning and for construction is having accurate maps of both large and small areas. Recent developments in aerotriangulation and electronic distance measuring devices have produced faster and more accurate mapping. While the advent of earth and moon satellites and space vehicles has raised new problems of position fixing and navigation, it has also provided new tools which can be used to give more accurate geodetic
data on the shape of the earth and on the relative distances between widely spaced points on the earth’s surface.

The use of space vehicles for photographing the surface of the moon has provided valuable new information on the surface conditions to be expected when a manned spacecraft lands on the moon. Of all the instruments to be carried aloft in such vehicles, the aerial camera appears to offer more possibilities than any other for yielding valuable information about the physical universe. As mentioned earlier, such information led to the location of the Arecibo telescope. Through aerial photography, knowledge of far greater detail is available concerning surface soils and rock, vegetation, drainage patterns, geological structure, and ground water conditions. With such information, transportation routes, water supply basins, and sources of construction materials (e.g., gravels) can be located and can be developed at a fraction of the cost of alternative methods.

Much has been said about the potential military capabilities of photoreconnaissance satellites, but the nonmilitary uses of satellites bearing aerial cameras and other related remote sensing instruments are only now being considered. Aerial photographs are of great value in locating areas of instability on the earth’s surface, and using them has simplified the identification and location of areas where landslide problems are likely to be encountered. The use of sequential series of photographs that cover a span of time relate environmental changes to their consequences. Our Geotechnical Engineering Department is carrying out research on potential peaceful uses of photography and other remote sensing imagery from orbiting satellites, particularly for making natural resource surveys. Because the quantities of information being sent back to earth will be so staggering, we are devising ways to automate the extraction of data as much as possible. Recent advances in the field of computer graphics make it possible to present up-to-date data in the form of distribution maps. Results of all this research are in turn being integrated into engineering education at both the graduate and the undergraduate level.

Another possible use for continuously orbiting satellites equipped to provide coverage of the entire surface of the earth would be to monitor the food production schedules of the world. Timely warnings of the likelihood of crop failure could be given, particularly in the critical food producing areas, and with such warning arrangements, redistribution of food supplies and extra plantings might be made in time to moderate the consequences of such failures.

FOUNDATION ENGINEERING

The importance of the overall environment has already been emphasized in the earlier illustrations of geotechnical activity, but the successful implementation of plans for new developments also requires a detailed knowledge of the engineering behavior of the soils and rocks involved in construction operations. Many of the new structures which arise as a result of our increased sophistication in technology require extremely close tolerances on the relative settlement between various portions of the structure. While ingenious structural
"The central problem for the future is to educate engineers to appreciate the whole as well as the detailed aspects of using any unique site for structural purposes."

design can alleviate the consequences of excessive differential settlement, there is, nevertheless, a demand for the refinement of methods for estimating the deformations which will take place as a result of changes in the weight bearing on the ground surface.

Such refined methods were used in the planning of Cornell's 10 billion electron volt accelerator which is under construction on the campus beneath Upper Alumni Field. In this instance, a buried facility was needed, one within walking distance of the Newman Laboratory of Nuclear Studies. Additionally, a concrete-lined tunnel 10 feet in diameter, and approximately 2,500 feet in circumference, sited to reduce potential settlement to a 2mm tolerance, was desired. As in many other types of structures, the depth-to-rock factor was critical. Needed was "Sufficient soil cover to avoid rock excavation, rock close enough to provide solid foundations," and, added to this, there was a hope for "no ground water." These are typical of the prepared statements frequently presented to geotechnical engineers. The Cornell Synchrotron is

Opposite: Donald J. Belcher, professor of civil engineering, widely known for his contributions to photogrammetry, examines an air photo strip of a small village.

Left: Arthur J. McNair, professor of civil engineering, a major contributor to surveying techniques now used in space, reviews triangulation methods for surveying celestial bodies.
"Riding to work" through Cornell's nearly completed circular synchrotron. The tunnel, which is a half-mile around, is set more than 40 feet beneath the surface of Upper Alumni Field. Powered by 10 billion electron volts, the Synchrotron's electron beam will be guided into orbit and held there by magnets.

being built at a depth of 40 feet, achieving most of the desired conditions. The ground water could not be dispelled, but at least geotechnical studies showed in advance that ground water was present and was in a serious state of interaction with the silty soils of the site; this made it possible for structural designers to compensate for the ground water situation.

These exacting demands on the foundation engineer call for advances in our ability to define the field stratification of soils and rocks as well as their deformation properties. The problems are complex. Natural materials vary in both the horizontal and vertical directions and the expense of subsurface exploration limits the range of investigations that can be undertaken. Soils and rocks, in addition, have complicated stress-strain relationships, and the engineering solution to practical problems requires the ability to reach appropriate simplifications of both the environmental and the detailed deformation properties of the natural materials involved. While refinements in theoretical procedures are desirable, they will not, of themselves, produce improvements in our ability to predict with accuracy the field behavior of soils and rocks. The central problem for the future is to educate engineers to appreciate the whole as well as the detailed aspects of using any unique site for structural purposes.

OUTLOOK

In the future, how well we make use of the earth's surface for the construction and planning of new facilities will depend upon a clearer appreciation of the overall environmental factors, and the relationships of soils and rocks to planned construction. We need to remind ourselves that underdeveloped countries are facing critical periods in their history. Their future and our's will depend on better water and food supplies, better transportation routes, and the location, planning, and careful use of natural resources. Concern with both the environmental factors and the detailed problems of mechanical behavior of soils and rocks suggests that geotechnical engineering can look forward to substantial and important contributions to society in the years ahead.

David J. Henkel is Chairman of the Department of Geotechnical Engineering. In 1941 he received the degree of Bachelor of Science in Civil Engineering from the University of Natal in Durban, South Africa, and in 1958 he received the Doctor of Philosophy degree from the University of London and the Diploma of the Imperial College of Science and Technology, London. Professor Henkel came to Cornell in 1965 as a professor of civil engineering.

Following his graduation from the University of Natal, Professor Henkel was head of the Soil Mechanics Division of the National Building Research Institute in Pretoria, South Africa. He has also been a lecturer in soil mechanics at the Imperial College, a visiting lecturer at the University of Illinois, and a professor of soil mechanics at the Indian Institute of Technology in New Delhi.

Professor Henkel is the author of many publications dealing with foundations, shear strength of soils and clays, and the stability of natural slopes. He is a member of the Institute of Civil Engineers, London, and the American Society of Civil Engineers. He is also a fellow of the Geologic Society.
An enormously powerful diagnostic tool for probing the upper atmosphere was outlined twelve years ago in a colloquium at the Cornell University School of Electrical Engineering. At this seminar William E. Gordon, who is now vice president and dean of engineering at Rice University and was then on the Cornell faculty, pointed out the possibility of using radar to study the properties of the upper atmosphere. Unlikely as it might seem, he said, it would be possible for radar equipment then available to detect “incoherent scattering” from the ionosphere. The “incoherent scattering” would occur when free electrons acquired energy from transmitted radar impulses, and then reradiated it in random directions. To be sure, Gordon indicated, the required transmitter power would be measured in megawatts and the antenna area in acres, but everything necessary was within the state of the art.

This talk and the subsequent published paper led to the development and use of incoherent scattering measurements, an area in which Cornell held an early “monopoly.” Gordon’s predictions were the impetus for the first experiments which were carried out soon afterward by Kenneth Bowles, who had received his Ph.D. from Cornell a few years before. Bowles used an existing transmitter located in Illinois and a simple but large vertically directed antenna which was constructed within a few weeks by John Ewanicki, Cornell’s expert in tree care and removal, at a fraction of the cost estimated by antenna construction firms. Although the early measurements were crude, they did show that this experimental technique was feasible and promising.

THE MAJOR RADAR OBSERVATORIES

This initial facility has been superseded by several major observatories which devote a substantial amount of time and effort to measurements of incoherent scattering. The two largest are at Jicamarca in Peru and at Arecibo in Puerto Rico. (See pages 14 and 16.) Bowles directed the construction of the Jicamarca Radio Observatory, which is
Right: A schematic representation of the incoherent scatter measurement technique. Powerful radar signals transmitted from the ground excite electrons in the ionosphere which reradiate part of the signal in random directions. A small fraction of the weak scattered signal is received on the ground.

Located near Lima in the foothills of the Andes and almost on the magnetic equator. The antenna is an oversized version of Bowles' earlier one in Illinois and consists of 18,432 small dipole antennas, all fed in phase. The Arecibo Observatory was built under the direction of Gordon and is still operated by Cornell as a national facility, supported by the National Science Foundation. Its antenna, which is built into a natural limestone sinkhole, is a reflector and can therefore operate over a wide range of frequencies and directions. It is accordingly much more versatile—and expensive—than the Jicamarca array, which can operate at only one frequency and point in a limited number of directions. The Jicamarca radar is devoted almost exclusively to ionospheric work, whereas at Arecibo there are also extensive research programs in radar studies of the planets (radar astronomy) and purely passive studies of the radiation from radio stars (radio astronomy).

Other important incoherent scatter observatories are located in Massachusetts, France, and England. Another which was operating in California is being moved to Alaska. The frequencies used for scatter measurements at the various observatories range from 50 to 1,300 megahertz.

Making Measurements in the Upper Atmosphere

If we are to understand and predict the future behavior of our atmosphere, and perhaps even exert some control over it, we must first be able to measure its properties. Furthermore, we must be
able to do this not only at the comparatively low altitudes where everything we think of as weather takes place, but also at the higher altitudes. As Professor Brice has pointed out in his article in this issue of the Quarterly, our immediate atmospheric environment is only a small portion of a much larger system whose components interact in complicated ways. Therefore, we need to determine atmospheric properties over as wide a range of altitudes as possible.

Physical measurements are not particularly difficult to make near the ground, but at altitudes higher than those where balloons and aircraft can operate, the problems become formidable. How can we make measurements at these higher altitudes? Satellites and rockets come immediately to mind, and of course are used extensively these days. Satellites, however, must generally remain above 200 kilometers in order to avoid burning up in the atmosphere. Rockets can be used at all altitudes, but they can deliver only two quick recordings, one during ascent and one during descent, of the regions through which they pass. The “snapshots” provided by rockets can seldom be combined into a “moving picture,” a continuous study of the interrelated changes in atmospheric properties. Moreover, they are very expensive.

The technique of incoherent scatter measurements is not limited in these ways. It has been used to make comprehensive studies of the properties of the atmosphere, particularly of the charged particles in the upper atmosphere, over an altitude range stretching from seventy or eighty kilometers to almost 10,000 kilometers. The radars used are much more advanced and much more expensive than, for example, ordinary airport radars, but they are still quite cheap when compared to the cost of rocket and satellite programs.

In many respects the satellite and radar techniques complement each other. Satellites can give good broad global coverage, but the resolution in time and space is poor. A satellite instrumented to measure local electron density and temperature, for example, can provide only two measurements of each per day in the vicinity of a particular location, and only at the altitude of the satellite. The satellite can, however, give a good idea of how the temperature and density vary with longitude and latitude. Radar measurements, on the other hand, are obviously restricted to the vicinity of the installation, but they can cover a wide range of altitudes simultaneously and can be made continuously in order to study temporal changes. By combining the very detailed local picture of the upper atmosphere which the radars can provide with the much more crude but broad geographic coverage given by the satellites, we are gradually constructing a realistic picture of how the whole upper atmosphere behaves.

INCOHERENT SCATTER: WHAT IT IS, HOW IT IS MEASURED

What do we mean by incoherent scatter? The very simple basic principle of this phenomenon, which is also known as Thomson scatter, was first pointed out by J. J. Thomson, the discoverer of the electron, more than sixty years ago. If a free electron is made to oscillate (by a radar pulse, for example) it will act like a very small antenna and radiate a small amount of energy. The free electrons radiating in response
Above: The radar facility at Jicamarca in Peru is located in the foothills of the Andes, almost on the magnetic equator. Below: The antenna at Jicamarca consists of 18,432 small dipole antennas, all fed in phase.

The upper atmosphere, particularly the region called the ionosphere, is partially ionized by ultraviolet radiation and x rays from the sun and so contains a significant number of free electrons. This ionized region reflects radio waves below a certain frequency level, and thereby makes long-range radio communication possible. The radar studies with which we are concerned are made at much higher frequencies, however, and all but a very minute fraction of the energy passes through the ionosphere and is lost into space. The small amount which does not escape is due to the induced incoherent radiation from the individual electrons. Part of this radiation impinges on the receiving antenna (usually the same as the transmitting antenna) and is collected. Although this received signal is very weak, it can yield a great deal of information.

The power reradiated by each electron can be expressed in terms of the cross sectional area of a perfectly con-
The technique of incoherent scatter measurements . . . has been used to make comprehensive studies of the properties of the atmosphere . . . over an altitude range stretching from 70 or 80 kilometers to almost 10,000 kilometers.

ducting sphere which would scatter (reflect) the same signal to the receiver. This is called the radar scattering cross section of the electron. For a single electron this area is approximately $10^{-28}$ square meters—a very small mirror.

THE MEASUREMENT OF BACK SCATTERING: A HOPELESS EXPERIMENT?

To get an appreciation of the difficulty of measuring the small amount of back scattering, let's put in a few more typical numbers. Suppose we have a radar that transmits a pulse 67 microseconds long from an antenna with a beamwidth of 1°, and we want to consider the scattering from an altitude of 300 kilometers. The induced radiation would come from all the electrons present in a volume measuring about 5 x 5 x 10 kilometers. A typical electron density during the daytime at this altitude is about $10^{12}$ electrons per cubic meter, and so the total scattering cross section due to all the electrons in the volume is roughly $10^{-28} \times 10^{12} \times 250 \times 10^9 = 2.5 \times 10^{-5}$ square meters, which is equivalent to a square with a side only 5 millimeters long. This is a very small target at a range of 300 kilometers! Only about one part in $10^{12}$ of the transmitted power would be scattered, and of that only about one part in $10^8$ would be received from an altitude of 300 kilometers by an antenna having an effective area of $10^4$ square meters, which is a very large antenna indeed. Even with an antenna as enormous as this, and even with a very powerful transmitter, we could expect to get back only an extremely weak signal. If we were to transmit, say, $10^6$ watts, we could expect to pick up only about $10^{-12} \times 10^{-8} \times 10^8 = 10^{-14}$ watts. Moreover, this is the signal expected from an altitude of 300 kilometers, which is the region of highest electron density in the ionosphere; from other altitudes we would get even less. To make matters worse, the electrons are all moving with randomly directed velocities of the order of 100 kilometers per second or more, and the associated Doppler shifts introduce a frequency spread into the returned signal.

At first glance the experiment looks hopeless, and it is small wonder that no one gave it serious consideration until Gordon's perceptive assessment in 1958, and Bowles' subsequent measurements.

THEORIES OF THE SCATTERING PHENOMENON

These first measurements by Bowles were quite crude, but they showed clearly that the simple scatter theory proposed by Gordon was only partially correct. Although the total scattered power was roughly what was expected, the observed bandwidth of the scattered signal was much narrower than that predicted on the basis of completely free electrons. In fact, if Gordon's prediction had been completely correct, Bowles probably wouldn't have been able to detect the scattering, since the signal-to-noise ratio of the returned signal is inversely proportional to the bandwidth. Experimenters must have faith in the theoreticians, but not too much!

It was quickly realized that the ions present in the ionosphere play an important role in the scattering process, even though it is of course the electrons
Top: A cable car transports staff members to the feed support structure suspended over the reflector “dish” of the Arecibo Observatory. The transmitter has a power of 2.5 million watts. Right: The bowl-shaped reflector at Arecibo is built into a natural limestone sinkhole. At the rim the reflector—the largest in the world—measures 1,000 feet in diameter. The facility, built at a cost of over $9 million, has been in operation since 1963. Below: In order to distribute his weight and not alter the curvature of the half-inch-square wire mesh reflector, a repairman uses a pair of water skis to traverse the surface.
Below: A catwalk leads to the triangular support platform suspended more than 400 feet above the center of the reflector at the Arecibo Observatory. The unit is supported by cables extending from three towers.

that actually do the scattering. Because of Coulomb forces, the ions influence the electron motions and therefore the Doppler shifts. The simplest way to take into account these effects is to treat the ionosphere as a plasma with random variations in electron and ion density, and calculate the scattering due to fluctuations. This turns out to be more than a trivial calculation, but the general theory was soon developed in a variety of ways by a number of people working independently. It is now possible to predict the total scattered power and the frequency spectrum of the scattered signal for almost any conceivable set of parameters pertaining to the ionospheric plasma. In many respects the observed signal resembles scattering which would be produced by fictitious particles having the mass and velocity of the ions, and one half the scattering cross section of the electrons.

THE EXPERIMENTAL WORK

There were many experimental difficulties with the early measurements. It was found to be one thing to detect the effect, and quite another to measure the scattering accurately. The very weak signals often must be averaged over a fairly long time in order to eliminate or reduce the effects of random noise, and the results are subject to a host of subtle systematic errors which were not at first fully appreciated. With the steady improvement in equipment and the use of sophisticated electronic data processing techniques, however, these problems have been pretty well overcome.

The present technique is to couple the radar to an on-line computer which often controls the transmitter as well as processing the data. The receiver output is first converted into digital form, and then either sent directly to the computer or else given a preliminary processing by special purpose, high speed digital equipment. The disadvantage of having the computer alone handle all the processing is that sometimes it isn’t fast enough to keep up with the flow of data. Special purpose devices which can perform many operations in parallel are much faster, even though less flexible.

To get the most out of incoherent scattering measurements, it is necessary
“(The ionosphere) serves as an ideal ‘outdoor laboratory’ for certain experiments in plasma physics. The simplifying assumptions upon which plasma theory is based really are, in most cases, valid in the ionosphere.”

to coordinate the efforts of experts in many fields. These include specialists in transmitter, antenna, and receiver technology, digital data processing, digital equipment technology, computer programming, theoretical plasma physics, and the physics of the upper atmosphere.

Almost all of the physically important parameters of the upper atmosphere have a direct or indirect influence on the scattered signal at some range of altitude. The power and the frequency spectrum of the scattered signal are affected to varying degrees by the following parameters of the ionospheric plasma: electron density, electron temperature, ion temperature (which may differ from the electron temperature), ionic composition (major constituents), ion-neutral particle collision frequency, ion-ion collision frequency, photoelectron velocity distribution, mean plasma drift velocity in the direction of the radar beam, and drift velocity of the electrons relative to the ions (current strength) in the direction of the radar beam.

Generally only a few of these parameters are important at a particular altitude, which is just as well; otherwise, the job of unraveling the data would be truly formidable. Actually, the complexity of the theory and the data is a two-edged sword. It is often quite difficult to analyze the data from regions where several of the physical parameters are important. On the other hand, when the analysis is properly done, it yields a vast amount of useful information about the scattering medium.

PHOTOCHEMICAL AND DYNAMIC PROCESSES IN THE IONOSPHERE

The basic goal of ionospheric research is to gain a complete understanding of the important photochemical and dynamic processes governing the behavior of the ionized and neutral constituents of this upper part of the atmospheric “ocean” in which we live.

Photochemistry is concerned with the production and loss of charged particles and the associated energy transfers and optical emissions. The charged particles are produced when neutral atmospheric particles are ionized by solar ultraviolet and x-ray radiation—radiation which would be lethal if it reached the earth’s surface. Production of the charged particles is controlled by the intensity of the incident solar flux and the spectrum of the radiation, by the composition of the neutral atmosphere, and by the ionization cross sections of the various constituents. Charged particles are lost when they recombine and give up their energy of ionization as heat, a process that is controlled by the density of neutral particles present in the region and by various temperature-dependent rate factors.

Important dynamic processes include diffusion, electromagnetic drifts of the charged particles caused by the combined effects of the electric and magnetic fields in the upper atmosphere, local and global neutral atmospheric winds and gravity waves (which are somewhat like ocean waves but can have very large amplitudes in the upper atmosphere), tides, and thermal expansion and contraction. There is also interaction between the protonosphere, which is the region above 1,000 to
2,000 kilometers where the positive ions are mainly protons, and the lower ionosphere which contains oxygen and other heavier ions. The protonosphere acts in some respects like a huge reservoir of both charged particles and thermal energy. Energetic photoelectrons can escape from the lower ionosphere and travel along the earth's magnetic field lines to heat the protonosphere and perhaps even the lower ionosphere at the magnetically conjugate point in the opposite hemisphere. The energy supplied to the protonosphere can raise its temperature several thousand degrees above that of the lower ionosphere. The excess energy slowly returns to the lower altitudes by conduction. Similarly, some actual plasma flows out into the protonosphere during the day, only to return during the night.

All of these processes are influenced by solar activity. The solar wind, consisting of streams of energetic particles emitted by the sun, impinges on the earth's outermost "magnetic shield" and affects the earth's magnetic and electric field systems. Variations in the solar
Below and opposite: Modelled after the 1,000-foot Arecibo reflector and tilted so as to cover the same region of the sky, is an 85-foot solid-surface radio telescope antenna under construction at the Cornell experimental station in Danby, New York, about fifteen miles from the campus. This experimental antenna is being used to develop techniques for producing reflectors of high spherical accuracy which can be used for measurements at high frequencies. Work is being done on the preparation of the very smooth surfacing that is required. Another aspect of the Danby project will be to develop models for feeds for spherical reflectors such as the one at Arecibo. The Danby antenna will also be used in conjunction with the big one at Arecibo for long-baseline interferometry measurements in which the two telescopes will have an effective resolving power equivalent to that of a single reflector with a diameter of 1,800 miles, the distance between Danby and Arecibo.

wind caused, for example, by solar flares are accompanied by changes in the physical processes in the atmosphere and by visible phenomena such as auroral displays. It is a complicated physical system, but our understanding of it has improved greatly in the last decade or so with the advent of satellite and radar probing techniques.

COMPARISON WITH SATELLITE OBSERVATIONS

The radar measurements give direct information about only the charged particles, but since these serve as tracers in the neutral gas, additional information can be deduced. From the electron temperature, ion temperature, and electron density, for example, one can determine the temperature of the neutral gas in the upper atmosphere to an accuracy of about 5 percent or better.

Such measurements can be compared with somewhat cruder estimates of the temperature obtained from studies of satellite drag. Satellite measurements indicated that the diurnal maximum in the temperature at altitudes above a few hundred kilometers occurs at about 2 P.M., but this conclusion is difficult to reconcile with reasonable theoretical models. The more accurate scatter measurements, on the other hand, show that the maximum is in fact at about 4 to 5 P.M., in much better agreement with theory. Scatter measurements of electron temperature have also shown consistent disagreement with satellite measurements using Langmuir probes. It is now reasonably well established that it is the satellite measurements which are wrong; their values are consistently high, sometimes by as much as 70 percent. In most other respects comparisons between satellite and scatter data have shown good agreement.

THE IONOSPHERE AS AN OUTDOOR LAB

One further aspect of the ionosphere deserves mention. It serves as an ideal "outdoor laboratory" for certain experiments in plasma physics. Although progress toward controlled thermonuclear fusion reactions in a plasma for the generation of cheap commercial
power is dependent primarily on studies of high temperature plasmas in the laboratory, the much cooler plasma of the ionosphere has a number of advantages for certain basic experiments. The simplifying assumptions upon which much plasma theory is based really are, in most cases, valid in the ionosphere, which generally can be considered to be uniform, infinite, stationary in time, and in other respects "well behaved" over the time and distance scales required by theory.

It is probably not overstating the case to say that ionospheric scatter experiments have provided the best quantitative test to date of the basic linearized plasma kinetic theory. No observation has been made which is in any way inconsistent with the theory, and all but a few theoretical predictions have been verified, in some cases to accuracies of the order of one percent.

Scatter measurements similar to those made in the ionosphere, but at microwave and laser frequencies, are now being utilized as a diagnostic tool in laboratory experiments as well.

CONTROLLED MODIFICATION OF THE IONOSPHERE

The main disadvantage of the ionosphere from the point of view of the plasma experimenter is that there is no way to control or alter the medium. One usually has to settle for what nature provides. In recent years, however, a number of experiments involving controlled modification of the ionosphere have been carried out.

In one such experiment a cloud of barium is released at a high altitude from a rocket. The barium is very easily ionized by sunlight, and if enough is released the mean electron density can be raised temporarily by more than an order of magnitude throughout a volume of hundreds of cubic kilometers. The subsequent behavior of the cloud under the influence of diffusion, winds, electric and magnetic fields, etc., can be studied both optically and with radar. These experiments are of course quite expensive to carry out.

A much cheaper and potentially more scientifically productive controlled experiment involves heating the ionosphere with a powerful radio transmitter on the ground. Such experiments have provided useful information about the lower ionosphere (100 kilometers and below) for a number of years, but only recently has it become possible to heat regions above 200 kilometers. The first successful experiments at these altitudes were carried out during the past year at Boulder, Colorado and at Arecibo. If the power is transmitted at a resonant frequency of the ionospheric plasma, a relatively large fraction can be converted into electron thermal energy within a relatively limited vol-
ume. With a mean transmitted power of 100 kilowatts or more, the electron temperature can be raised several hundred degrees Kelvin from the ambient temperature which is of the order of 1,000° K. At Arecibo we can study in detail the effects of this heating by operating the incoherent scatter radar at the same time, and we hope to learn a great deal about thermal and plasma transport processes in the ionosphere with this new tool.

Measurements using very powerful, sophisticated radars are now helping us to unravel many of the mysteries surrounding the behavior of our upper atmosphere. The observations represent both a technological and a scientific challenge. The most advanced radar and data processing technology must be employed in carrying out the experiments. On the other hand, a thorough knowledge of atmospheric physics is required in order to design the right experiments and to properly interpret the results and fit them into the broader global picture. The radar measurements thus serve both as a source of intellectual challenge appropriate to a university graduate research program, and as a source of vital information which is improving our understanding of the total environment in which we live.

Donald T. Farley, professor of electrical engineering at Cornell University, has worked in the field of incoherent scattering since the early days of its development as a means of studying the upper atmosphere. He served as a physicist and then as director of the Jicamarca Radar Observatory near Lima, Peru, from 1961 to 1967, the year of his appointment to the Cornell faculty. During that period the observatory was operated by the United States Environmental Science Services Administration.

While at the Jicamarca observatory, which is located near the geomagnetic equator, Professor Farley studied the incoherent scattering of radio waves at that latitude. For this work he received the Gold Medal of Merit from the United States Department of Commerce in 1967.

Professor Farley earned his bachelor's degree in 1956 and his Doctor of Philosophy degree in 1959, both in engineering physics and both from Cornell. He was a NATO postdoctoral fellow in ionospheric physics at Cambridge University in England for a year, and then spent a year as a visiting professor at Chalmers University in Sweden, where he conducted research on the heating of the ionosphere with intense radio waves. His affiliation with the Jicamarca facility followed.

Professor Farley is the author or co-author of more than thirty professional articles, mostly on the subject of incoherent scattering and plasmas. He received distinguished authorship awards in 1963 and 1964 from the United States Department of Commerce. From 1963 through 1969 he served as associate editor of Reviews of Geophysics. At Cornell he is currently the graduate field representative for Electrical Engineering.

He is a member of the American Geophysical Union, the American Association for the Advancement of Science, the International Scientific Radio Union, and the honorary societies Sigma Xi, Tau Beta Pi, and Phi Kappa Phi.
A common occurrence in engineering classrooms these days is an exchange like this one in an electrical engineering recitation session. The instructor writes on the blackboard a fairly complex expression, the current-voltage relationship for a semiconductor diode

\[ i = I_s \left( e^{\frac{qV}{kT}} - 1 \right) , \]

supplies values for the fixed parameters and the voltage \( v \), and then, almost before he can open his mouth again, is given a value for the current \( i \) by one of the students in the class. Not only does the answer come quickly—it is supplied to eight decimal digits!

What has happened, of course, is that engineering students, along with the rest of the country, have armed themselves with pocket calculators. These miniature instruments have revolutionized the calculator business and rendered the slide rule obsolete; moreover, they are inexpensive enough to pay for themselves quickly when used to shop for bargains at the supermarket. While not the principal subject of this article, the new pocket calculator provides a very public demonstration that computing hardware has become small and cheap. This fact has led also to a revolution in the way laboratory research experiments are performed: They have become “computerized.”

LAB DEVICES AS WELL AS NUMBER CRUNCHERS

To the public, the term computer connotes huge, expensive machines which keep track of income tax returns, make airline reservations, and cause form letters to be mailed. It is true that the major share of computing equipment is engaged in this sort of business data processing. If one singles out the scientific world, however, the picture changes. The large computer installation exists here also; its presence is required by the enormously complex and lengthy calculations needed in many branches of science and engineering. These tasks, known as “number crunching” to the scientific community, totally occupy the time of several of the largest computers in the world. But there is another, quite different, use of computer machinery in science and engineering. This application, which has recently experienced explosive growth, consists of making computer operations an integral part of a laboratory experiment.

What characterizes a computer that is being used as a laboratory device? How is a laboratory computer similar to and how is it different from business data processors and number crunchers? The following characteristics can usually be identified:

1. The primary source of a laboratory computer's input comes not from data generated by human agency, but
Small computers are an essential part of the equipment for space missions. Pictured is the main control panel in the interior of the Apollo Lunar Module. The data keyboard in the lower center of the photograph is used by astronauts to enter data into the onboard computer. (Photo courtesy of the Grumman Aerospace Corporation.)

from electromechanical sensors placed in the environment of the experiment. The computer obtains these data directly through a data acquisition system.

2. Often there will be two sorts of output from a laboratory computer. One is prepared for human observation and is used for monitoring the experiment and sometimes to deliver the results obtained. The other is converted into signals which other components of the system may use to control the experiment itself.

3. The architecture of a laboratory computer is not very different from that of other computers; most machines used as laboratory devices are also employed as general-purpose computers. Machines suitable for laboratory use usually have features that make it easy to connect data acquisition equipment.

4. Unless the computer is serving several different experiments, it will be a fairly inconspicuous component of the experimental equipment. The computer will tend to remain attached to the rest of the instruments and will service only one user at a time.

Perhaps one of the most well known uses of laboratory computers was in the Apollo moon program experiment. Several computers were sent up on board both the Command Module and the Lunar Module. Almost everyone became aware of the difficulties experienced and the success obtained with these crucial components.

AN INSTALLATION USING A LABORATORY COMPUTER
Let us consider a computer which is an integral part of the hardware used to perform a certain experiment (see Figure 1). This computer could be one of the small machines known as minicomputers, whose presence in laboratory equipment is growing so rapidly; if so, it probably is mounted in a rack with other equipment relating to the experiment. A large experiment might have its computer in a room by itself.

Data obtained during the course of the experiment usually consist of the output of several sensors, which deliver a voltage that at all times is proportional to the quantity being
measured. The computer, however, requires its data to be in the form of binary numbers, and so an electrical component to convert a voltage level to a binary number must be included in the instrumentation. This analog-to-digital converter (ADC) is a vital component in most data-acquisition systems. ADC's with an accuracy of one part in 4,000 and able to perform up to 50,000 conversions in one second are cheap and commonplace, and conversion rates of up to ten megahertz and accuracies of one part in 100,000 are possible (though not yet in the same unit).

Experimental data do not always appear in analog form, however. Pulses denoting the occurrence of a particular event are often obtained from an experiment. These pulses do not require conversion, but are used directly to interrupt the computer or to increment an event counter.

If the computer is being called on to direct the experiment, a control system is required. Control equipment will generally require an analog voltage proportional to the amount of control desired. This voltage is provided by a digital-to-analog converter, whose function is thus the inverse of the ADC. Pulse outputs to start and stop the experiment, for example, can be delivered directly from the input-output interface, as shown in Figure 1.

The computer obtains its instructions from a stored program in its main memory. Under operator control from the console, new programs can be loaded from mass memory (for example, a disk) in larger machines or from the console itself, and executed. Under program control, data are acquired, processed, possibly preserved on magnetic tape, and displayed graphically on a display device.

The programs executed by the computer may be prepared in basic machine language on the computer itself, or, if the computer is large enough, in a higher-level language such as FORTRAN. A recent development for small machines is the use of a larger general-purpose brother machine to compile a FORTRAN program into the machine language of its smaller sibling.
APPLICATIONS IN THE COLLEGE OF ENGINEERING

Four facilities available to people in the College of Engineering demonstrate how laboratory computers are used. Three of these facilities are research laboratories or centers with very different objectives and experimental material and with computing equipment that differs in size and speed. The computer installations of all three, however, have the attributes for laboratory use that are described above. The fourth installation is designed primarily to inform undergraduate engineering students about laboratory minicomputers and to give them first-hand experience in operating one as an integral part of simple laboratory experiments.

THE COMPUTER FOR THE ARECIBO RADIO TELESCOPE

The first laboratory computer that was used extensively by College of Engineering personnel is easily the largest. It is also nowhere near Ithaca, being located next to the control room for the radio telescope at the National Astronomy and Ionosphere Center near Arecibo, Puerto Rico. The computer in use now at the Arecibo observatory is a Control Data 3300, installed in 1969.

In ionospheric experiments, the primary input quantity to the computer is a time function representing the power of radar pulses returned from the ionosphere; it is this signal which is converted to digital form by an analog-to-digital converter. The results usually desired involve the computation of correlation functions of the radar return pulse. These computations were originally carried out by the computer under program control, but because correlations require so many multiplications, the computer was unable to perform the calculations in real time—that is, to keep up with data as they arrive. Recently, therefore, the system was improved by the addition of a hardware correlator, a special-purpose computer with a wired-in program for carrying out the required multiplications and additions. Some immediate analysis is done directly by the Arecibo computer, but much of the data is recorded on magnetic tape, forwarded to

Left: The 525-ton antenna feed assembly of the radar and radio telescope observatory at Arecibo, Puerto Rico, is visible from the control room of the Cornell-operated facility. Computer processing of data in real time is an important experimental feature.

Right: A minicomputer is part of the experimental equipment used by Thomas Hall, a postdoctoral associate of Professor David N. Seidman, in a study of point defects in metals by means of atom-probe field ion microscopy. The computer makes possible the fast identification of single atoms evaporated in rapid sequence from a metal surface.
we may soon expect to see computers in equipment everywhere.

The many universities that use the Arecibo facilities, and processed further on the users' computers. The incoming data are used also for monitoring purposes while an experiment is in progress. The computer may exert control over an experiment to the extent that the radar transmitter's pulse code and separation are under program control.

The computer at Arecibo is large enough to permit operation in a multi-user mode, serving the on-line laboratory function and also carrying out general-purpose work.

THE MINICOMPUTER FOR RESEARCH IN MATERIALS

Two research groups in the Department of Materials Science and Engineering have been using a recently acquired Data General Nova 1220 minicomputer in their work. One group is performing experiments on an atom-probe field ion microscope; some of this work has been described in this magazine (see the Autumn 1972 issue, Vol. 7 No. 3, pp. 21-29). Under computer control, a pulse evaporates an atom of unknown species from a sharply pointed probe and starts a timer. The atom passes through a time-of-flight tube, which sends pulses to the computer when it enters and leaves. The computer then calculates the charge-to-mass ratio of the atom and compares it with a stored library. After many repetitions of this process, a histogram showing the various species present may be plotted. This kind of study requires the rapid performance of a great number of experiments, an accomplishment that was impossible until the appearance of computers to handle the analysis and control.

A study of quenched-in vacancies in tungsten, also mentioned in the earlier Quarterly article, makes extensive use of the high-speed analog-to-digital conversion facilities of this laboratory computer system. A fine tungsten wire is heated up to a temperature close to the melting point and then rapidly quenched. The voltage appearing across the specimen under application of a constant current is converted and processed to yield a curve for temperature as a function of time that has an accuracy of ± 1°K.
A TOOL FOR CORNELL'S ELECTRICAL ENGINEERS

An ongoing research project at the School of Electrical Engineering is concerned with the characterization of noise associated with line-of-sight and tropospheric microwave communication links. Two properties of interest are the frequency spectrum and the probability density function of the amplitude of this noise. The experimental work consists of making standard analog tape recordings of the noise as observed on microwave links in actual operation. The tapes are sent to Cornell for processing by Computer Signal Processors equipment whose central component is a Varian 620/L minicomputer. To obtain the noise spectrum over a 0.1-second interval, the tape is played back into an ADC which receives and digitizes 1,000 samples of the noise at a rate of 10 kilohertz. These samples are then processed into a spectrum in less than a second by a stored program coded to carry out the so-called Fast Fourier Transform (FFT) algorithm, and the spectrum is displayed on a built-in oscilloscope or copied onto a plotter. Also, a histogram representing the probability density function of the noise may be accumulated and displayed in real time: One may see the histogram developing as the tape is played back into the system.

The School has found that this equipment is excellent also as an aid in communicating the elementary concepts of signal processing to undergraduates. Simple periodic waveforms generated with standard equipment can be processed and spectra of their functions displayed almost immediately, giving a convincing classroom demonstration of the relationship of the Fourier series to the actual problem of signal processing.

TEACHING ABOUT LABORATORY COMPUTERS

The electrical engineering faculty realized some time ago that an introduction to the operation and potential uses of laboratory computers is a necessary part of the experience of most electrical engineering students. Last year, with funds from the National Science Foundation Undergraduate Laboratory Equipment Program, matched by the College of Engineering, we were able to purchase a Digital Equipment Corporation PDP 11/40 minicomputer, together with all the peripheral devices represented in Figure 1. We are now designing experiments for use, beginning this spring, in a required junior-year laboratory course. The experiments are planned to meet as many as possible of the following criteria:

1. The experiment itself must be simple. A suitably modified experiment already performed without a computer is a possibility.

2. The experiment should employ a maximum amount of computer equipment without becoming too complex. Especially valuable is an experiment that is controlled by the computer.

3. The results should lend themselves to graphical display.

4. One small part of the computer program should be written by the student in a higher-level language such as BASIC or FORTRAN. Creating, editing, compiling, and running a program from an on-line terminal is an important part of the educational process.
**THE REVOLUTION IN SIZE AND COST**

What has caused the enormous increase in the use of computers, especially minicomputers, as laboratory devices? The answer appears to be their flexibility and low cost. Special-purpose control equipment is inflexible—a slight change in requirements may render the device obsolete—and it is expensive, since only a few pieces are built. A computer, by contrast, is controlled by a stored program which can be changed at will to meet changing needs, and, most importantly, a minicomputer can be purchased at comparatively low cost. The price of minicomputers has decreased drastically over the last four years and is still going down. It is now technologically possible to fabricate an enormous amount of computer logic in a very small space at a unit price that is extremely low if many units are sold.

The new generation of pocket calculators proves the point. These calculators are not based on a discovery of simpler ways to do arithmetic operations. They are extremely complex, but complex circuits no longer require...
Right: Professor Pottle and junior student Ronald Linton, seated, inspect the minicomputer recently acquired by the School of Electrical Engineering for teaching purposes. Now being designed are experiments for a junior-year laboratory course.

much room. At the minicomputer level, the next stage above the calculators, a similar drastic change has taken place. A recent advertisement offers a complete central processing unit with memory and with more computing power than the computers of the mid-1950s for less than $1,000. At this price, we may soon expect to see computers in equipment everywhere. Already appearing are computers on automobiles, controlling everything from fuel mixture and ignition to modulated braking and speed control.

Further uses for the computer in research and instruction cannot be far behind. The revolution in computer size and cost presages a new mode of operation in the laboratory.

Christopher Pottle, associate professor of electrical engineering, has a special interest in the use of computers as research tools. At the present time, his research is centered on the development of minicomputers as laboratory instruments.

He is known also for his work on the application of the digital computer to system and signal theory, especially for the development of a large-scale network analysis program, called CORNAP, that is used in universities and industries around the world. He began work on this program at the Bell Telephone Laboratories during the summer of 1965.

Pottle came to Cornell in 1962 from the University of Illinois, Urbana, where he was a graduate student and subsequently a member of the electrical engineering faculty. He took his undergraduate education at Yale University, earning the baccalaureate degree in electrical engineering in 1953, and then worked for a year with the Sperry Gyroscope Company and served for several years in the U.S. Army before beginning graduate study. His advanced degrees are the M.S. (1958) and the Ph.D. (1962), both in electrical engineering.

He has undertaken concentrated research in the area of computer applications during several leaves from Cornell. In 1966-67 he received a Fulbright grant for lecturing and research at the Universität Erlangen-Nürnberg in Germany, and worked on the use of computer techniques in the design of linear circuits and systems. During a sabbatic leave in 1970-71, he worked with the mathematical science group of the IBM Watson Research Laboratories in the development of computer-aided network design techniques, especially the use of computer graphics.

He is a member of the Institute of Electrical and Electronics Engineers, the Association for Computing Machinery, and several honorary professional societies.
1876 . . . The Centennial Exhibition in Philadelphia.

One piece of hardware at that grand exhibition that featured the achievements of American invention and technology was a dynamo. It was the first of its kind ever built in the United States—and it had been done at Cornell. In a physical sense, it represented the beginnings of electrical engineering at the University.

The Cornell machine had been copied from the French Grammé dynamo, but several design modifications worked out in the Sibley Hall shops had made it unique. It was historic also because it made possible the first outdoor lighting system in America: after its return from the Philadelphia exhibition, the dynamo was installed in the basement of Morrill Hall (the nation’s first electrical laboratory for educational purposes) and used to provide electricity for two carbon-arc lights on the campus. In tandem with a four-horsepower petroleum engine, the dynamo also supplied electricity to the Physical Lecture Room in adjacent McGraw Hall. The construction of this dynamo helped to focus academic attention on the development of a new technology; electrical engineering programs at both Cornell and the Massachusetts Institute of Technology produced their first graduates less than a decade later, in 1885.

Interest in matters electrical had begun much earlier, of course. Ben Franklin’s primitive experiments with electricity and Michael Faraday’s and Joseph Henry’s efforts to develop the principles of modern electrical science had attracted the interest of America’s early tinkerers and inventors.

One of these was Samuel F. B. Morse, who dabbled in electrical experiments while pursuing his career as an artist (he was known as one of the great portrait painters of the pre-Civil War era). While he was an art professor at New York University in the mid-1830s, Morse was able to find some time to work on “the instantaneous transmission of intelligence by means of electricity.” Judge Stephen Vail, who owned the Speedwell Iron Works in nearby Morristown, New Jersey, was the first person persuaded to invest money in Morse’s telegraph. He also provided machine shop facilities, and his son Alfred made the instruments. Later, in 1843, President John Tyler signed a bill to provide $30,000 for a demonstration project. That famous demonstration—the first
Right: This polar-mounted equipment was used in the 1950s in early radiophysics and space research at Cornell. The people in the photograph have been identified as S. Michel Colbert (on the platform), who is now a staff member of Cornell’s Center for Radiophysics and Space Research, and Ralph Bolgiano, now professor of electrical engineering and then a graduate student.

Below: The world’s largest radar-radio telescope was conceived and designed by Cornell engineers and built under their supervision at Arecibo, Puerto Rico, in the early 1960s. The dish-shaped reflector is 1,000 feet in diameter. (A discussion of this facility is included in the accompanying article by G. Conrad Dalman.)
federal government into contract research sponsorship at universities. In engineering fields, the government’s aims were to sustain the flow of technological activities that had been so critical to the success of the Allies in World War II and to aid in the education and development of engineers who could work in the new technologies.

These three factors—the G.I. Bill and the returning veterans, the visibility of electronics technologies, and federal support of research—brought new life to electrical engineering at Cornell and elsewhere.

FROM THE IONOSPHERE TO SOLID-STATE DEVICES

During the twelve years that Charles R. Burrows directed the Cornell School of Electrical Engineering, twenty new faculty members were added (eleven of these are still active). Burrows had a great interest in radiophysics, especially wave propagation, and this was reflected in the interests of the professors he appointed, as well as in the contract research undertaken by groups in the School. Henry Booker, William Gordon, Charles Seeger, Ralph Bolgiano, Benjamin Nichols, Donald Farley, Neil Brice—all these contributed to research programs which developed in solar and radio noise and ionospheric propagation and scattering. Cornell became one of the world’s centers for radiophysics and space research.

One of the internationally recognized achievements in this area was the conception, design, and construction of the world’s largest radar-radio telescope in Arecibo, Puerto Rico. Gordon, a graduate student of Burrows and Booker, was mainly responsible for the conception of this immense “eye-and-ear,” and had overseen the installation of the dish and the subsequent establishment of an international research program at the Arecibo observatory before leaving in 1966 to become dean of engineering and science at Rice University. He had drawn extensively on Cornell faculty resources not only in electrical engineering, but also other areas, especially civil engineering.

Another important construction project during Burrows’ term as director was the long overdue building of a new home for the School of Electrical Engineering. Phillips Hall, a gift of the Ellis L. Phillips
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William E. Gordon, now dean of the School of Natural Sciences at Rice University, was a professor of electrical engineering at Cornell when he conceived and supervised the construction of the world's largest radio–radar telescope at Arecibo, Puerto Rico, and served as first director of the observatory there. His current research includes radar study of high-altitude motion.

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Donald T. Farley, Cornell professor of electrical engineering, considers how clues to the mysteries of nuclear fusion, as well as of the aurora, may be provided by ionospheric radar experiments combined with computer simulation.

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Michael C. Kelley, a leader in the relatively new study of the electric field around the earth, discusses the use of rockets, satellites, balloons, radar, and ground-based sensors for electric-field measurements. He is an associate professor of electrical engineering at Cornell.

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Frank D. Drake, pioneer in the search for extraterrestrial intelligence, discusses the technique of radio communication and assesses the chances for success in contacting other civilizations in space. A Cornell engineering graduate, he is the Goldwin Smith Professor of Astronomy at the University and director of the National Astronomy and Ionosphere Center, which Cornell operates for NSF.

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Planets and Their Satellites, a companion issue to the current one on Probing Our Atmosphere and Beyond, will appear in December, 1978. Included will be articles on volcanism in the planets, moons in our solar system, the moons of Mars, and electrical conductivity of Earth's moon.

Engineering: Cornell Quarterly, Vol. 13, No. 2, October 1978. Published four times a year, in April, July, October, and December, by the College of Engineering, Carpenter Hall, Campus Road, Ithaca, New York 14853. Second-class postage paid at Ithaca, New York. Subscription rate: $5.00 per year.

Opposite: Auroral bands over Alaska. Outside cover (clockwise): part of the Arecibo Message of 1974; the feed support platform of the radar–radio telescope at Arecibo; a coronal aurora; a rocket for atmospheric measurements.
Between 1960 and 1965 I had the good fortune to live on the beautiful island of Puerto Rico in a home that faced the Atlantic Ocean. Aside from enjoying the pleasures of swimming nearly daily in the surf, I became fascinated by the many moods of the sea. The surf changed from ocean waves that were barely perceptible to waves that crashed mightily against the rocks and sand of the shoreline, and in between displayed the more usual condition of waves beating regularly on the beach. In response to the regular surf, the sands shifted to form semicircular lagoons when the beach was protected by a coral reef with a small opening, and in response to the more violent surf, the shoreline shifted, the beaches eroded, and homes and roads too close to the waterline were swept away.

While the local wind had an effect on the state of the sea, the most violent surf was produced not by local disturbances, but by storms thousands of miles away in the North Atlantic. Those storms would establish swells or waves that travelled that great distance, retaining enough energy to rearrange the coastline and destroy property. Such damaging seas were observed on days that were sunny and clear, with relatively little wind. That the sea could be so violent when the atmosphere was nearly tranquil created a striking and memorable contrast.

Less striking but easily observable was the effect of the ocean tides, which shifted the waterline in regular oscillations between high-water and low-water marks. The local phenomenon was again the response of the ocean to a remote disturbance, in this case the gravitational pull of the sun and the moon on the earth.

On a more local basis, the winds could drive the surface water and any material floating in it up the beach or down the beach, depending on the wind direction. With sufficient speed, the wind could pick up spray from breaking waves and even sand from the beach, carry them great distances, and deposit them, to the detriment of the vegetation and to the annoyance of the bathers, on the tropical vegetation fringing the beach.

Anyone who has lived near the beach for any time will have observed these effects and can readily place them in the three categories described above: remote effects associated with major storms, remote effects (tidal) associated with the sun and moon, and local effects associated with variations of the wind.

In much the same way, the atmosphere can be thought of as an ocean washing over us, and the same three categories of effects can be observed. The effects are somewhat more difficult to discern, for the atmosphere is not directly visible, as is the ocean, and there is no vantage point comparable to the beach. Nevertheless, the effects are present in the atmosphere and they can be observed.

The most common observation of waves in the atmosphere is in cloud formations; it is not difficult to discern horizontal cloud patterns with wavelengths extending from a fraction of a mile to hundreds of miles and wave periods of minutes to days. Most of the wave effects in the atmosphere are not visible to the eye, however, and to observe them one requires special in-
Atmospheric motions detectable by radar measurements are analogous in some ways to waves in the ocean surf and in cloud formations such as the roll clouds pictured here. "Storms" produced by charged particles in the solar wind cause the auroras visible at high latitudes.

The aurora pictured below is an Air Force satellite image; the geographical location is indicated by the outline of the eastern half of the United States, shown by city lights.
This aerial view shows the world’s largest radio—radar telescope, located near Arrecibo, Puerto Rico. This instrument is used for a variety of research projects in astronomical and ionospheric physics, including the study of motions in the upper atmosphere. The Arecibo Observatory is part of the National Astronomy and Ionosphere Center, which is operated by Cornell University under contract with the National Science Foundation.

The bowl-shaped perforated-aluminum reflector, 305 meters in diameter, is situated in a natural depression. The 600-ton triangular feed support structure is suspended, 150 meters above the reflector surface, from three high towers. Also visible in the photograph are buildings housing the control rooms, offices, and service facilities, and a helicopter landing pad. (See also the photographs on page 28 and the inside back cover.)
The powerful radio–radar telescope at the National Astronomy and Ionosphere Center near Arecibo, Puerto Rico, is such a special instrument, and for many years has produced data on atmospheric waves. The Arecibo radar is able to obtain echoes from the atmosphere over a wide range of heights, and by making these observations over an interval of time, one can deduce motions in the atmosphere that have characteristics similar to the motions of the sea. So let us concentrate on the wave motions in the atmosphere as observed at the Arecibo observatory and at the few other radio observatories throughout the world that have similar capabilities.

THE DYNAMICS OF LARGE ATMOSPHERIC WAVES

In the category of the remote major storm producing large waves that travel great distances, we have a striking phenomenon. Energetic particles from outside the earth’s atmosphere bombard the upper atmosphere at high latitudes and locally produce a visible aurora. In effect, the splash made by the bombarding particles produces waves, and these waves ripple through the upper atmosphere from the northern latitudes towards the equator. The waves may be observed, as they pass overhead, on instruments such as the one at Arecibo. The waves are both strong and long; that is, they have large amplitudes and long periods. They churn up the atmosphere in passing through it, and the effects are visible to the proper instruments during the passage and for hours later. These waves, unlike large waves on the surface of the sea, do not result in the destruction of property, but they produce effects in the atmosphere that are only beginning to be known.

NEW RADAR STUDIES OF SUN–WEATHER RELATIONS

An unparalleled opportunity to study atmospheric dynamics between the ground and an altitude of several hundred kilometers is available for the 1980’s. Through a coordinated research program involving a chain of ground-based radar stations, new attacks can be mounted on the practical problems of sun–weather relations and the movement of pollutants into and through the stratosphere.

The challenge is to understand the dynamic coupling of the layers of the atmosphere—troposphere, middle atmosphere, ionosphere, and magnetosphere. The dramatic short-term response of the upper layers to the solar energy input is in contrast to the more modest response of the lower layers. The source, the sun, contributes energy through ultraviolet, visible, and infrared radiation, and through energetic particles and fields in the solar wind. Each form of solar energy is deposited characteristically at particular altitudes or geographic regions of the atmosphere, and transported vertically and horizontally by atmospheric motions on a global scale. A chain of radar stations, each with good height resolution, is ideally suited to measure these motions and their changes.

For the upper atmosphere, the largest source of variability is the energy input into the auroral zone at ionospheric altitudes. This input can be monitored by a suitably located incoherent scatter radar and the energy that is transferred to lower latitudes and altitudes by winds and waves can be

“These waves . . . produce effects in the atmosphere that are only beginning to be known.”
... new attacks can be mounted on the practical problems of sun-weather relations and the movement of pollutants into and through the stratosphere.''

observed by a chain of suitably located incoherent scatter radars. Three existing observatories, all supported by the United States, provide the basis of such a chain: they are at Millstone Hill in Massachusetts, Arecibo in Puerto Rico, and Jicamarca in Peru. The establishment of an additional station and some impending upgrading of the three existing stations will provide the necessary facilities for investigating the relationship between solar energy distribution and weather on the earth.

In addition, an east–west chain of radars (in Alaska, in Urbana, Illinois, and a new station) capable of measuring winds in the mesosphere, stratosphere, and troposphere, supplemented by a transportable set of smaller radars with capabilities in the stratosphere and troposphere, will allow a careful study of the interaction of atmospheric layers across the tropopause and extending well upward and downward from it. The investigation will include measurements in unprecedented detail in space and time of the motions associated with the jetstream. In view of the concern over the effects of man-made substances in destroying ozone in the stratosphere, this study of atmospheric dynamics has obvious practical benefits.

This work being planned for the 1980's will complement thrusts by NASA with satellite systems and measurements by the European Incoherent Scatter Facility in Scandanavia.

STUDIES OF ATMOSPHERIC TIDES AND WINDS

Other atmospheric motions, analogous to the effects of tides and winds on surface waters, will also be studied with the use of radio–radar telescopes.

The pull of the sun and the moon on the earth's atmosphere produces regular changes in the atmosphere which correspond to the regular changes in the height of the sea surface associated with tides. Like the atmospheric waves produced by major distant storms, these atmospheric tides are most easily observed at relatively high heights, of the order of one hundred kilometers. The Jicamarca instrument is superb in making measurements from about fifteen kilometers to heights of many thousands of kilometers, and other radars will be upgraded to function similarly.

Local effects, comparable to the action of wind on the surface of the sea, are also observable in the upper atmosphere. At relatively high heights, the solar wind is capable of producing cloudy patches in the atmosphere similar to the patches that might be observed in what usually is referred to as ground fog. In the case of the upper atmosphere, however, the clouds consist of high-energy electrons precipitated from the plasma of the solar wind. These electrons are capable of enhancing or upsetting radio transmissions, including those broadcast on television bands.

I am looking forward to working with students and with some of the scientists at Arecibo and other observatories to study the winds in the atmospheric region from about fifteen kilometers to one hundred kilometers above the earth's surface. We are interested in learning more about atmospheric tides and also about turbulence, which may have an important role in the transport and distribution of pollutants throughout the atmosphere.

We expect to find that the fascination engendered by observing the ocean
waves and their response to various
disturbances will be transferred to our
studies of the waves in the atmosphere.
Being washed by the ocean waves is an
exhilarating experience; we expect to
be stimulated equally by observing the
atmosphere wash over us.

William E. Gordon, now professor of
electrical engineering and space science
and dean of the School of Natural Sciences
at Rice University, was a Cornell profes-
sor when he conceived and supervised the
construction of the world's largest radio-
radar telescope near Arecibo, Puerto
Rico. He served as the first director of the
Arecibo observatory from 1960 to 1965.

Gordon, who held the Walter R. Read
chair in engineering here, first came to
Cornell in 1948 as a research associate
of Professor Charles R. Burrows in elec-
trical engineering, received his Ph.D. in
1953, and remained as a member of the
faculty until 1966. His present ties with
Cornell include membership on the Uni-
versity Board of Trustees and on the
Advisory Board for the Arecibo facility,
which Cornell now operates for the
National Science Foundation (NSF).

Gordon has been interested in the use
of radar to study atmospheric phenomena,
including weather conditions, since his
World War II service as a research me-
teorologist in the Air Force. Throughout
his career, he has been active not only
in research in the general field of radio
science and engineering, but also as an
industrial consultant and as a member of
national and international committees,
commissions, and conferences. He served
as chairman of the United States delega-
tion to the International Scientific Radio
Union (URSI) assembly, for example, and
as a member of of the advisory panel on
radio telescopes for NSF. Currently he is
a member of the research advisory com-
mittee of NSF, vice chairman of the board
of trustees of the University Corporation
for Atmospheric Research, and vice presi-
dent of URSI.

His honors include election to the
National Academy of Sciences and the
National Academy of Engineering, the
1966 Van der Pol Award for distinguished
research in radio science, and the 50th
Anniversary Medal of the American
Meteorological Society, granted in 1970.
He is a fellow of the Institute of Electrical
& Electronics Engineers and a member of
a number of professional organizations,
including the American Geophysical Union
and the American Meteorological Society.
He is a member also of several honorary
societies in science and engineering.

Gordon received B.A. and M.A. degrees
from Montclair (New Jersey) State
Teachers' College and served as a second-
ary school teacher before World War II.
While in the Air Force he earned the
M.S. degree in meteorology at New York
University and subsequently worked with
an Air Force Group in Florida and with
a University of Texas group studying
meteorological effects on radar. He is
registered as a professional engineer in
Texas.
It is quite easy to describe mathematically and understand the behavior of small ripples on a pond or small-amplitude sound waves in the atmosphere. These represent linear problems, in which the propagation velocity of the waves and the rates of attenuation are independent of the wave amplitude. Nonlinear problems are another matter. A familiar example is the breaking of ocean waves on a beach. When the height of a wave becomes comparable to the ocean depth, the wave velocity starts to vary according to height; the top of the wave travels faster than the bottom, the wave steepens and eventually breaks, and a chaotic spectrum of new waves is generated.

Such nonlinear wave phenomena are often very difficult to cope with theoretically, but they are important in practice and therefore much effort is being made to try to understand them. Nonlinear processes frequently control transport rates of matter and energy that are of critical importance in geophysical and laboratory phenomena. Examples include the turbulent flow of fluids in a pipe, the earth's large- and small-scale weather systems, solar flares, current flow in the ionized portion of the upper atmosphere, and laboratory experiments involving confined high-energy plasmas and controlled nuclear fusion reactors.

The energy levels, plasma densities, scale sizes, time constants, and current strengths encountered in the last two areas are very different from those characteristic of the other examples, yet all the problems have some interesting similarities and it may be that ionospheric research, besides helping us to understand and predict the behavior of our environment, will contribute to our understanding of the fundamental plasma processes that occur also in high-energy plasmas. In both cases, a magnetic field strongly inhibits the motion of electrons and ions, and so the important processes are essentially two-dimensional. In some respects, the ionosphere provides a more convenient "laboratory" for the study of plasma processes than do the high-energy machines. Although it is difficult to do controlled experiments on such "outdoor" plasmas—we usually have to make do with the ambient conditions that nature provides—there are no walls to worry about and there is plenty of time for observations. In a fusion plasma experiment, the ambient conditions may change in a time of the order of milliseconds or microseconds, whereas in the ionosphere the plasma turbulence remains in a statistically steady state for minutes or even hours.

RADAR USED TO STUDY THE EQUATORIAL ELECTROJET

Of particular interest to those of us concerned with ionospheric plasma physics is a region near the magnetic equator at an altitude in the range of 100 to 110 kilometers. A current called the equatorial electrojet, relatively strong by ionospheric standards, flows in this region. Electric field strengths of the order of ten millivolts per meter produce current densities of the order of $10^{-5}$ amperes per square meter and a total current in the equatorial belt of the order of $5 \times 10^4$ amperes. These currents correspond to mean electron velocities, relative to the ions, of several hundred meters per second, a velocity
level sufficient to cause the region to be unstable: an assortment of plasma waves will grow spontaneously when the electron velocity exceeds a few tens of meters per second, and still more are generated when the velocity exceeds the acoustic velocity, which is roughly 350 meters per second. These plasma density waves are somewhat like sound waves in the neutral atmosphere, but since they consist of ionized particles, they can and do affect radio-wave propagation through the medium. These effects have been observed for decades, and have been studied fairly intensively since the International Geophysical Year in 1957–58. Even more intense currents flow at about the same altitude in the auroral zone during magnetically disturbed conditions, and similar plasma instabilities are observed there. The auroral case is more complicated and difficult to study, however, because the currents often undergo rapid changes of position, direction, and intensity.

Most of the progress to date in understanding the equatorial instabilities has been stimulated by radar observations made at the Jicamarca Radio Observatory, which is located in a dry valley in the foothills of the Andes, about twenty miles from Lima, Peru. Cornell people have been associated with this observatory since its beginnings in 1960: it was designed by a Cornell graduate, Kenneth Bowles; in the first several years of its existence all the resident scientists, including myself, were Cornell graduates; and Cornell faculty members, research associates, and graduate students continue to visit there periodically to carry out research.

The Jicamarca Radio Observatory, located almost on the magnetic equator in the Andean foothills of Peru, is the chief radar facility used in studies of plasma instabilities in the equatorial ionosphere—studies that are important for an understanding of interferences in radio communication, as well as of basic ionospheric physics. The antenna of the Jicamarca radar comprises 18,432 dipoles, all fed in phase, and covers an area 300 meters square. In addition to the large Jicamarca radar, Professor Farley's group uses smaller radars at the observatory, and has begun auroral studies with equipment set up near Cornell.
The main antenna at the Jicamarca observatory is an enormous array of 18,432 dipoles covering a square area about 300 meters on a side (an area slightly larger, even, than Cornell’s famous spherical dish antenna in Arecibo, Puerto Rico). Some radar studies of the electrojet instabilities are done with this large antenna and the large 50-megahertz transmitter (with a peak power of several megawatts) that goes with it, but this radar was designed for other experiments that require much more sensitivity; the plasma waves in the electrojet can be detected easily with much smaller antennas and transmitters. A variety of smaller radars, some of which can be easily steered—as the large radar cannot—are also used in the Jicamarca observations.

Although most of our efforts have been devoted to studying the equatorial instabilities from the observatory in Peru, we also have begun a modest program of auroral radar studies near the Cornell campus in Ithaca, New York. Visual sightings of the aurora, or “northern lights,” are infrequent in Ithaca, but quite often echoes can be obtained from disturbances several hundred kilometers to the north of us. Cornell is also involved in a program of rocket probing of both auroral and equatorial plasma phenomena. This program is under the direction of Michael C. Kelley, who discusses part of it in another article in this issue.

RADAR MEASUREMENTS OF PLASMA TURBULENCE

How do we study the plasma turbulence with radar? The basic idea is quite simple. The ionized particles slightly alter the refractive index of the medium at the radar frequencies used. Small density variations associated with the turbulence cause even smaller irregular variations in the refractive index, but these are more than large enough to scatter or partially reflect back to the receiver a tiny, but easily detectable, fraction of the transmitted radar pulse. Furthermore, since the density irregularities or scattering centers are moving, the frequency of the received signal generally will be slightly different from that of the transmitted pulse. By studying the spectrum of these Doppler shifts, we can investigate the velocity distribution in the medium. From another point of view, we can represent the plasma density fluctuations as a summation of acoustic-like waves with a variety of wavelengths and velocities and traveling in different directions. The radar is sensitive only to the waves whose length is half the radar wavelength and which are propagating either exactly toward or exactly away from the radar.

The technique is illustrated in Figure 1. The signal received from the limited...
Electrons

Doppler shift

scattering region is sampled, digitized, and analyzed by a computer to produce spectra of the sort shown. When the mean electron velocity in the electrojet is sufficiently large, very strong echoes with a sharply peaked spectrum (type 1 in the figure) are obtained; when the velocity is smaller, the echoes are weaker and the spectrum is broader with smaller Doppler shifts (type 2). From observations at different radar elevation angles, we find that the mean Doppler shift of the type 2 echoes corresponds closely to the component of mean electron velocity parallel to the radar beam, whereas the type 1 spectral peak is practically independent of the elevation angle and corresponds closely to the acoustic velocity in the electrojet region. The first of these results is more or less what one would expect on the basis of well established linear theory of plasma instabilities; the narrow peaked type 1 spectra are not so easily explained, however. In fact, it is not altogether clear why there are two distinct types of spectra; only very tentative ideas have been advanced.

Figure 1. A schematic diagram illustrating how radar is used in studies of plasma turbulence in the equatorial electrojet. Small density variations caused by the turbulence result in a weak scattering of the transmitted radar pulse, and signals reflected back to the receiver are analyzed by computer to produce frequency spectra of the two types shown. Type 2 has been simulated on a computer and is reasonably well understood. The nonlinear processes controlling the type 1 spectra remain to be explained.

These observations present a nice challenge to the theorists. The ambient conditions under which the two types of spectra are observed are well known, as are the basic equations governing the physics. The observations are clear-cut and uncomplicated by extraneous experimental effects. The two spectral shapes are obviously quite different, but why? A comprehensive theory that would explain both should have application to other more complicated or less well specified problems.

COMPUTER SIMULATION FOR NONLINEAR PROBLEMS

One route toward unraveling problems that involve nonlinear effects is to try to simulate the natural phenomena on a computer. For example, suppose we specify the initial positions and velocities of a large number of electrons and ions. We can then easily write the equations for the interactions among all the particles. From these we can find the new positions and velocities a small increment of time later, and by repeating this process enough times, we can follow the development of instabilities
and turbulence. The difficulty, of course, is that it may require an awful lot of particles to make a realistic model, and if each particle has three spatial and three velocity coordinates to keep track of and solve for, the amount of computation involved is overwhelming, even for the largest and fastest computers. In practice, it is generally easier to consider the plasma density, the electrostatic potential, and the mean electron and ion velocities at equally spaced grid points to be the variables.

Still, to cover a reasonable range of scale sizes, one usually needs a grid of at least 64 or 128 points for each spatial dimension—a requirement that again shows why three-dimensional problems are avoided. Fortunately, because of the magnetic field in the ionosphere, our problem can be approximated reasonably well by a two-dimensional simulation, as can many other plasma problems in which the magnetic field plays an important role.

The simulation calculations are not trivial, however, and much effort has been devoted to developing efficient computer programs. In particular, one must be aware of the fact that the necessarily discrete nature of the calculation introduces purely numerical instabilities that have nothing to do with the physics of the problem. The calculation must be designed so that these are not important; the growth rate of the physical instabilities must be significantly faster. This can always be done by increasing the number of grid points and making the spacing smaller, but of course that increases the cost. Usually the numerical and physical problems are understood well enough to permit a reasonable compromise.

SIMULATION AS AN AID IN UNDERSTANDING PLASMAS

Simulating the plasma phenomena is of course not the same as understanding them; the simulation is only a step, though an important one, in that direction. Still, if the simulation is realistic enough, it allows us to see in detail what is really happening in the plasma and, in addition, permits us to vary the plasma parameters at will and so conduct controlled "experiments." Actual physical radar and rocket measurements can only give us a few hints as to what is taking place in the ionosphere—a very fuzzy picture at best—and we must try to deduce the rest. Simulation, on the other hand, permits perfect diagnostics: we can ask the computer any question we want to about the state of the simulated plasma. In particular, we can ask what the Doppler spectrum of radar echoes at a particular wavelength would be. If the answer obtained from the simulation agrees with the actual observations from the ionosphere, we have some reason to believe that the simulation is reasonably good, in spite of simplifying approximations that may have been made, and that answers to other questions we may ask are likely to be correct also.

Work of this sort was done recently in the Laboratory of Plasma Studies at Cornell by Professor Ravindra N. Sudan and his associates Richard L. Ferch, who was a postdoctoral fellow at the time, and Michael J. Keskinen, then a graduate student. Figure 2 shows some of their simulation results, which were calculated with use of a grid of
Figure 2. Contour plots of ionospheric plasma density fluctuations, obtained by a computer simulation. Contour lines represent equal increments of density between the maximum (plus signs) and the minimum (minus signs). (a) illustrates the assumed initial plasma distribution; (b) corresponds to a later time when density fluctuations have begun to distort the contours; and (c) shows a state of turbulence. A radar spectrum generated by this simulation was compared with experimental measurements (see Figure 3).

128 by 128 points. The initial plasma density contours are shown in (a); in (b) the effect of the instability is beginning to distort the contours; and in (c) turbulence has developed and the contours have become very chaotic. In Figure 3 we see a simulated radar spectrum based on computer work of this kind, in comparison with an actual spectrum of type 2 echoes measured under reasonably similar conditions. The agreement is good enough to convince us that the essential features, at least, of the processes associated with these echoes are well described by the simulation. Furthermore, many other features of the simulation can be explained by a turbulence theory, developed by Sudan and Keskinen, that was inspired by these simulations. We feel we have a pretty good understanding of what is going on.

The same cannot be said for the type 1 spectra, however. We are still groping for a convincing theory and have not yet successfully simulated the echoes. The simulation is more difficult in the case of type 1 spectra because (1) the range of important wavelengths is

Figure 3. Simulated radar spectra compared with experimental (type 2) measurements. The purpose of the experimental work, conducted by Professor Farley and his associates, is to study plasma instabilities in the ionosphere. The close agreement between the numerical simulation (executed by Professor Sudan and his associates) and the measured spectra indicates that the numerical model satisfactorily describes the actual physics and can be used with some assurance to study the effects of parameter changes.
greater, so that a larger number of grid points should be used if at all possible, and (2) the equations are more complicated, and therefore more time-consuming and expensive to solve, because of terms that can be neglected in the type 2 calculation but not in the type 1, in which the driving forces of the instability are greater. On the other hand, since computers become bigger and faster and—unlike most things—cheaper every year, time is on our side.

The simulations are especially important in the type 1 case because we badly need some clues to identify the key nonlinear process that causes the change in character of the instability and of the echo-producing irregularities. The general shape of the type 2 spectra can be understood, at least qualitatively, by making reasonable extrapolations of simple linear plasma instability theory, and the recent simulations have shown that such educated guesses are essentially correct. In the nonlinear type 1 case, though, our guesses are still really guesses.

When we do succeed in sorting out the important physics in this problem, the results should help us understand the more complex phenomena in the auroral zone, and it would be surprising if the theoretical results and techniques could not be applied in some way to important problems in experiments with high-energy laboratory plasmas. Clues to the mysteries of nuclear fusion, as well as the mysteries of the aurora, may well be provided by Earth's outdoor laboratory in the ionosphere.

Donald T. Farley, professor of electrical engineering and a specialist in ionospheric physics and radio propagation, was educated at Cornell and has been a member of the faculty here since 1967. He received his baccalaureate degree in engineering physics in 1956 and his Ph.D. in 1959.

Before joining the faculty here, Farley served for six years as physicist and then as director at the Jicamarca Radar Observatory near Lima, Peru. For his work at Jicamarca on the incoherent scattering of radio waves he received the Gold Medal of Merit from the United States Department of Commerce in 1967. He has continued to conduct and supervise research at Jicamarca as well as at the National Astronomy and Ionosphere Center at Arecibo, Puerto Rico. His current research is supported by grants from the National Science Foundation and the National Aeronautics and Space Administration.

Prior to his years at Jicamarca, Farley served as a NATO postdoctoral fellow in ionospheric physics at Cambridge University in England, and as visiting professor at Chalmers University in Sweden.

He has published numerous articles in the fields of incoherent scattering and plasma physics, and received awards for distinguished authorship from the Department of Commerce in 1963 and 1964. He is a member of the International Scientific Radio Union and has served on the executive committee and several commissions of that group. He is a member also of the American Geophysical Union, the American Association for the Advancement of Science, and several honorary professional societies.
The fact that the earth has a magnetic field has been known for centuries. The compass has been used for millennia and magnetic lines have guided the flight of migratory birds for millions of years. Awareness that the earth has an electric field is, by comparison, very recent.

Congruently, the magnetic field has been studied more extensively. In the past twenty years, satellite research has produced detailed mapping of the magnetic field throughout the near-space regions of the planet, while a comparable investigation of the electric field is still in its early stages. A comprehensive program of research is now underway, however, and in fact constitutes a major area of study in the School of Electrical Engineering at Cornell.

The current work here involves measurements by rocket, balloon, satellite, radar, and surface sensors, and the use of this information to identify the multiple sources of the earth's electric field. Ultimately we hope to develop a unified model for the electrical properties of the atmosphere and the near-space regions beyond. These studies have some potential practical applications, in view of the role of electric fields in producing plasma irregularities that perturb radio communication systems. Our primary interest, though, is in understanding the geophysical implications of electric fields.

The electrical structure of Earth's environment

The conventional wisdom is that the earth becomes charged during thunderstorm activity and discharges through the weakly conducting atmosphere. Evidence for this is shown in Figure 1, which compares measurements of the electric field over oceans during fair weather with information on thunderstorm activity over land areas. In both graphs, the data are plotted as a function of Universal Time. These graphs show that during afternoon hours, when thunderstorm activity in various parts of the world reaches its peak, there is also a rise in electric field strength over fair-weather portions of the earth. During discharge—that is, in fair weather—the electric field is directed downward. This fair-weather field, which has a typical magnitude of about 100 volts
Figure 1. The electric field near Earth's surface during fair weather and thunderstorms.

The upper graph shows long-term averages of the fair-weather field over the oceans as a function of Universal Time. The line in color shows data collected over all the oceans. The line in black shows observations taken over the Arctic Ocean during the northern winter.

The lower graph shows the diurnal variation of thunderstorm activity over land areas. A place is regarded as having been in a thunder area at a specified time if thunder was audible during the interval from sixty minutes before to sixty minutes after that time. The data represent long-term averages of observations.

These graphs show that thunderstorm activity is greatest during the afternoon hours, and that this activity is accompanied by a rise in electric field strength over portions of the earth experiencing unperturbed weather conditions. This evidence supports the idea that the earth receives an electric charge during thunderstorms and discharges through the weakly conducting atmosphere.

The data were published in 1929 by F. J. W. Whipple in the Quarterly Journal of the Royal Meteorological Society, vol. 55, pp. 1-17.

The field has two primary sources, one terrestrial and one extraterrestrial. At low and middle latitudes, interaction between the earth's magnetic field and the neutral wind creates electric fields in much the same way that an electric dynamo generates a voltage. At a maximum, this "dynamo" action produces about 20,000 volts and 10,000 amperes, so that the power level is approximately the same as that of a weather system. Roughly speaking, the dawn terminator is charged positively and the dusk terminator negatively.

At latitudes above about 60°, the high-altitude electrical structure is...
Figure 2. Sketch illustrating why the extraterrestrial electric field extends virtually unattenuated through the atmospheric regions measured in rocket and balloon experiments. Because atmospheric density and therefore resistance decreases exponentially with altitude, $R_1$ is much smaller than $R_2$.

Figure 3. Simplified diagram showing the interaction that appears to occur between the magnetic field of the earth and the solar wind, which carries a magnetic field with it. As indicated in Figure 3. The hot ionized gases in these regions can flow most easily in the direction parallel to the magnetic field, and this, in effect, forces the potential to be uniform along the length of the field line. As indicated in the figure, the resulting pattern of field dominated by the interaction between the solar wind and the earth's magnetic field. As the solar wind flows outward from the sun, it carries a magnetic field with it. There is strong evidence that near the earth, these field lines link up with the terrestrial magnetic field, as indicated in Figure 3. The hot ionized gases in these regions can flow most easily in the direction parallel to the magnetic field, and this, in effect, forces the potential to be uniform along the length of the field line. As indicated in the figure, the resulting pattern of field.

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lines allows the electric field of the solar wind to penetrate deep into the atmosphere. The result is a current of about 50,000 amperes at a potential difference of about 100,000 volts, yielding power an order of magnitude greater than that produced either by weather systems or by the "dynamo" effect of the neutral wind cutting across the earth's magnetic field lines.

THE EARTH'S FIELD AND THE AURORA

The potential induced by the solar wind is instrumental in creating one of the most spectacular of all geophysical phenomena, the aurora. A sequence of satellite photographs taken over North America (see Figure 4) shows the vast extent of a major auroral disturbance; visible below the aurora is the familiar outline of the United States, patterned by lights of the major cities. (Ithaca, New York, home of Cornell University, can be identified as the dark spot southwest of Syracuse.) The correlation of auroral displays with solar flares is illustrated by the photograph at the top of the figure, taken a few days earlier during a storm on the surface of the sun.

It is known that the auroral light is emitted by atmospheric atoms and molecules excited by electrons with

Figure 4. The relation of the aurora to solar flares. Photographs in the composite were taken from Air Force (DMSP) satellites over North America. The scale of the auroral display is shown dramatically by comparison with city lights of the United States. The solar surface was photographed on April 14, 1974, and the satellite photos were taken four days later. (Courtesy of the United States Department of Commerce).
ROCKETS CARRYING CORNELL EXPERIMENTS

Experiments accomplished or planned in this series of launches include some designed by Cornell Professor Michael C. Kelley and his research group as part of their study of the earth's electric field.

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Year/Launch Site</th>
<th>Project and Subject</th>
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<tr>
<td>Aries</td>
<td>1976 Kiruna, Sweden</td>
<td>Project Porcupine II: auroral physics</td>
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<tr>
<td>Nike-Tomahawk</td>
<td>1976 Kiruna, Sweden</td>
<td>Project TRIGGER: auroral wave injection</td>
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<tr>
<td>Nike-Tomahawk (2)</td>
<td>1977 Andernes, Norway</td>
<td>PreSiple: test round</td>
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<tr>
<td>Nike-Apache</td>
<td>1978 Fairbanks, Alaska</td>
<td>BaTMAn I, II: magnetosphere-atmosphere coupling</td>
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<tr>
<td>Aries (2)</td>
<td>1978 Wallops Island, Virginia</td>
<td>BaTMAn III/JASPIC: source of low-latitude ionization</td>
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<tr>
<td>Taurus Orion</td>
<td>1979 Ontario, Canada</td>
<td>Eclipse: electrodynamics of an eclipse</td>
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<tr>
<td>Nike-Black Brant</td>
<td>1979 Kiruna, Sweden</td>
<td>BaGEOS: injection of tracers into magnetosphere</td>
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<td>Castor (2)</td>
<td>1979 Chilca, Peru</td>
<td>BaTMAn IV, V: artificial spread F, neutral winds</td>
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<tr>
<td>Ariane</td>
<td>1979 French Guiana</td>
<td>Firewheel: magnetic bubble, artificial comet study</td>
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<tr>
<td>Nike-Tomahawk (3)</td>
<td>1980 Siple, Antarctica</td>
<td>Siple Rockets: measurements of man-made whistler waves</td>
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Potentials of many thousands of volts. Data from a recent experiment, in which detectors supplied by the University of California at Berkeley were carried on the Air Force S3-3 satellite, showed conclusively that the electrons get this energy by passing through a localized electric field, about 6,000 kilometers above the auroral zone, that points away from the earth and is oriented parallel to the magnetic field. It is apparent that the source of this energy is the high concentration of charged particles emitted by the sun during solar flares. The S3-3 satellite is still in orbit, the study of the acceleration region is continuing, and we are beginning to understand how the energy finds its way into the atmosphere. Cornell electrical engineering personnel are actively involved in the S3-3 analysis.

CORNELL'S ROCKET-BORNE FIELD EXPERIMENTS

Rocket-borne electric-field measurements also play an important role in the Cornell program in atmospheric research. In the five-year period 1976–1980, our group will have performed some sixteen rocket experiments from launch sites all over the world (see the table). For example, a Taurus Orion that will be launched into a total solar eclipse on February 26, 1979, will carry an experimental package designed and fabricated by Paul Kintner and Robert Green of our group at Cornell. The extent of our program is such that at times nearly everyone in the group, including our secretary, Monica Parsons, is in the field helping with observations.

Two different techniques are used in the rocket work. The most straightforward method is to deploy spherical electrodes on long booms and measure the voltage between them with a high-impedance voltmeter. (The S3-3 satellite detector also used this technique, with electrodes extended from the vehicle at the ends of coaxial cables three millimeters in diameter and twenty meters long; the cables were held rigid by the centrifugal force field of the spinning spacecraft.) This technique also allows measurement of fluctuating electric fields due to electrostatic and electromagnetic waves.

Another rocket technique is to use chemical tracers to measure the electric field and also neutral atmospheric winds. We are performing a series of
Experiments in the field and in the laboratory are the basis of Professor Kelley's research on the earth's electric field.

1. Auroral studies in Alaska were the Cornell Ph.D. thesis work of Paul Kintner (at left), who is now a research associate in Professor Kelley's group. Kintner and a technician, John Humenansky, are shown with a payload launched on a Nike-Tomahawk from Poker Flat, Alaska, in 1974.

2. Calibrating the instrument to be used in a launch from Sweden are (left to right) engineer Robert Green, Dave Wong, and Paul Kintner. Wong, a sophomore last year, did summer work on the project.

3. A Cornell University payload was carried by this Nike-Apache rocket launched from Wallops Island, Virgina, in June of this year. This experiment was part of a joint American-Soviet project to compare techniques for studying the intensity of charged particles coming down into the lower ionosphere.

4. A senior project for Dave Noice was building a microprocessor for atmospheric electric-field measurements. In the background of the photograph is Jim Grady, now an M.Eng. (Electrical) student, who helped with the project work. These two students installed the microprocessor this past summer at a scientific post on Mauna Kea, a mountain in Hawaii.
such measurements in conjunction with the Danish Meteorological Institute of Copenhagen. (A member of this institute, Ib Steen Mikkelsen, is now at Cornell for a six-month period of consultation.) Already this year, three experiments have been executed.

For these measurements, a mixture of barium metal and copper oxide is ignited to yield vaporized barium, which is easily ionized by sunlight. If it is dark on the ground—at twilight, say—the barium ions resonantly scatter sunlight and can be traced photographically. The electric field can be deduced from the subsequent motion. Similarly, the neutral wind is studied from photographs of a visible cloud of released strontium. On the same rocket, we can also deploy a trail of trimethyl aluminum (TMA), which burns in oxygen and then can be photographed to yield measurements of the neutral wind as a function of altitude. Examples of photographs from these experiments are shown in Figures 5 and 6.

Our experiments in Alaska have given graphic evidence that the electric field can be deduced from the subsequent motion. Similarly, the neutral wind is studied from photographs of a visible cloud of released strontium. On the same rocket, we can also deploy a trail of trimethyl aluminum (TMA), which burns in oxygen and then can be photographed to yield measurements of the neutral wind as a function of altitude. Examples of photographs from these experiments are shown in Figures 5 and 6.

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It is interesting to note that although the aurora was just becoming visible near the northern boundary of the photograph, the electric field was already quite strong. At midnight on this night, a spectacular auroral display occurred in the Alaskan sector.
Figure 6. A trail of trimethyl aluminum (TMA), part of the photographic record of one of the Cornell rocket experiments. This photograph was taken on June 11, 1978, over Georgetown, Delaware, by Monica Parsons and Miguel Larsen of Professor Kelley's group. The trail extended from 90 to 150 kilometers in altitude, and the elapsed time was about twelve seconds. The structure, with a characteristic hook-like shape, is the result of complex wind patterns in the upper atmosphere.

Figure 7. Results of a statistical study of the possible effect of solar "weather" on terrestrial weather. The object was to discover whether the accuracy of a forecasting model is affected by changes in the solar wind.

The limited fine-mesh model was used to predict the vorticity area index, which is a measure of low-pressure areas. When the accuracy of the model in predicting low-pressure areas over Canada and the United States was examined in terms of the interplanetary magnetic field direction, it was found that the accuracy of the model was degraded when the field changed direction. The interpretation is that the interplanetary field interacts with the earth's magnetic field, allowing direct entry of energy into the atmosphere.

This study was carried out at Cornell by Miguel Larsen as part of his M.S. thesis work in atmospheric sciences. Larsen is now investigating possible physical mechanisms as part of his Ph.D. research.
field induced by the solar wind can act like a motor to put the neutral atmosphere into motion (a mechanism that is the inverse of the “dynamo” operating at low latitudes). The study of coupling effects such as this may help us understand how the solar wind affects surface terrestrial weather, a process for which there is persistent and persuasive statistical evidence. An example of the kind of work that has been done is shown in Figure 7. In this study, the accuracy of a model used to predict low-pressure areas in the atmosphere was found to be degraded subsequent to changes in the direction of the interplanetary magnetic field associated with the solar wind.

These various techniques have enabled our group at Cornell to develop a broad experimental approach. In fact, ours is very likely the only group in the world actively using all the available measurement techniques. With the combined use of ground-based radar and field sensors, airborne rockets and balloons, and orbiting satellites, we are probing the entire range of the earth’s electric field, from the surface of the planet to regions beyond the ionosphere.

THE OVERALL EXPERIMENTAL PROGRAM AT CORNELL

The rocket and satellite experiments I have discussed are only part of our total program of research on Earth’s electric field. Incoherent scatter radars (see the article in this issue by Donald T. Farley) can also be used to measure electric fields, and we are using radar facilities in Alaska, Peru, Puerto Rico, and Massachusetts to study a variety of electric-field effects. In addition, we deployed a fair-weather electric-field sensor in Hawaii this summer, in conjunction with Stanford University.

Michael C. Kelley, associate professor of electrical engineering at Cornell, specializes in studies of the winds, waves, and electric fields in the upper atmosphere. He has served as project manager or participant in experiments on rockets launched at sites around the world, and has also designed and supervised electric-field experiments in balloons and satellites. Currently he heads research projects funded by the National Aeronautics and Space Administration, the Office of Naval Research, and the National Science Foundation. He has published widely and is an active participant in national and international conferences and research projects.

Kelley joined the Cornell faculty in 1975 after serving for four years as a research physicist in space physics at the University of California at Berkeley, where he earned the Ph.D. degree in physics in 1970. In 1974 he received an Alexander von Humboldt fellowship for research at the Max Planck Institute in Germany.

He received his undergraduate education at Kent State University, which awarded him the B.S. degree in mathematics in 1964. His honors at Kent State included the Borden Award for the outstanding freshman man and the Manchester Award for the outstanding senior man. He held an athletic scholarship in basketball.

In addition to his teaching and research activities, Kelley serves or has served as a consultant to the Air Force Geophysics Laboratory, the Space Science Laboratory at Utah State University, the Aerospace Corporation, and Lockheed Missiles and Space, Inc. He is a member of the American Geophysical Union.
COMMUNICATION
WITH OTHER INTELLIGENCIES

by Frank D. Drake

Of all the future forms of communication we might hypothesize or foresee, the one that has created the most excitement and interest, the one that is most tantalizing, is communication with extraterrestrial intelligent life. Until very recently, however, such contacts seemed out of the question. No reasonable evidence of intelligence was detectable with any instruments. It has fallen to our generation to reverse that situation, to develop in many places in the world the technology that could, today, detect manifestations of intelligent life—manifestations no greater than what we ourselves display in the universe—over the vast distances separating civilizations in space.

Indeed, there are civilizations in space. From what we know of the universe, of its $10^{20}$ stars, of the nature of the sun and of life on Earth, there can be no doubt that there are intelligent civilizations somewhere out there. But that is not to say that it is easy to find them. We do not know their numbers or what they are like. The search for them will be very difficult, costly, and time-consuming, but we have made a beginning and have developed some feasible techniques and plans.

INFORMATION FROM ASTRONOMY AND BIOLOGY

There are some important facts about the universe that guide us in designing systems for interstellar communication.

From astronomy we have learned that our universe is an evolving one, in which stars are continuously formed from the rotating gas and dust clouds of galaxies. We know that the forming stars have an enormous amount of spin that must be divested if they are not to fly apart as they collapse from gravity, and we know that this spin is divested by transferring it into the orbital motion of second objects: more than half the stars we have observed are formed as double stars and the rest have created secondary bodies that we call planets. The indications, from both theory and observation, are that space is very rich with planets that are being formed at nearly a continuous rate.

We have also learned that nebulas, like the famous one in Orion, are "factories" not only for stars, but for organic molecules produced in interstellar space. The detection of these interstellar molecules, in much greater numbers and of many more types than we ever imagined, is one of the exciting discoveries made possible by radio astronomy. Among these molecules are carbon monoxide, formaldehyde, methane, and ammonia, compounds that laboratory research has shown are the prime progenitors for life as we know it on Earth. In fact, experiments have indicated that life inevitably will be formed on planets that are suitable for it, since almost nothing could prevent a primitive atmosphere from making the molecules of life. The chemistry that occurred on our planet to create...
The famous nebula in Orion is known to be a place where new stars are being formed and organic molecules, the precursors of life, are being synthesized in interstellar space. An understanding of how stars and planets are formed and how life arises and evolves is the basis of expectations that other civilizations exist in our galaxy and beyond.

Life is not unique but is, in fact, a general phenomenon.

Of course, whether the molecules formed in interstellar space do eventually play a role in the development of life on planets is something of which we are not certain, because such molecules would be destroyed in the heat and turbulence that we believe accompanies the early phases of planetary evolution. Yet there may be "deep freezes" in space—comets that store these molecules and eventually deliver them to new planets. Clouds of stellar gas are also enriched with heavy elements, such as uranium, lead, and gold, derived from supernova explosions; some of these elements are part of the material of life and are found not only in our Earth but even in ourselves, in the same abundance they have in supernova remnants.

Biological studies have indicated, further, that the evolution of preferred forms of life is inevitable because of the finite surface area and therefore limited resources of planets. The eventual consequence is the development of ever-increasing intelligence; the fossil
record of the earth, for example, shows that in the evolution of life forms, only one thing has always improved, always increased, and that is brain size. The indication is that intelligence arises everywhere given sufficient time—time that may be measured in billions of years.

INTELLIGENT BEINGS AND THEIR DETECTION

We estimate from our current knowledge of astronomy and biochemistry that a new system of intelligent beings is being created in our galaxy about once every year. We believe that each of these civilizations eventually develops a technology for the same reason that evolution occurs—the limited resources of planets—and that when technology reaches the level it now has on our Earth, the civilization begins to manifest itself to the universe primarily in the form of wasted energy, such as lights at night and radio transmissions. This means that approximately once a year, somewhere in the Milky Way, a new civilization “lights up.” Radio waves from other planets are coming through at this very moment and we could detect them with our existing equipment if we knew in which direction to point our telescopes and on which frequency to tune them.

We believe that these civilizations do not remain “lit up” forever. As time goes on, they leave the scene for various reasons. Perhaps they destroy themselves through nuclear catastrophes. More likely, they become invisible through increased technical sophistication, for eventually a civilization would learn to preserve energy, leaving perhaps only a vestige of special signals intended for reception by other intelligences. Our own civilization, a very luminous one, may soon disappear, not because we have vanished, but because we have become intelligent enough not to waste energy. To those out there who are looking for Earth, this will be an unfortunate development.

The picture emerges of galaxies like twinkling Christmas trees, with civilizations lighting up, remaining lit for a while, and then going out. The net result is a collection of shining civilizations whose number is constant but whose membership changes with time. Since the rate of production in our galaxy appears to be about one a year, that membership turns out to be numerically equal to the length of time during which civilizations radiate. This presents a difficulty, for the longevity of civilizations is a factor we do not know and cannot know until we have actually detected some. If we guess ten thousand years—a really unjustified extrapolation of human experience—our estimate is that one star in ten million has a civilization. In our search for it, we must reach out one thousand light-years and be prepared to test ten million stars.

RADIO WAVES FOR COMMUNICATION IN SPACE

This leads us to consider what methods might be best for interstellar communication and what kind of messages might be most successful.

Our initial realization is that we cannot be anthropomorphic and use our own technology as a guide to what is preferred in the galaxy. We are a primitive civilization; who knows what levels or forms of technology are in existence elsewhere? It could well be that more than one form of technology is used for interstellar communication. All we can hope to do is to establish which is most probable.

In discussing technologies, we must be inhibited only by the laws of physics. That doesn’t help very much, of course; it leaves, essentially, all bets open. But there is something that can help us in our search, and that is cost—expense by any civilization’s criteria, not just those of Earth. Fortunately, the universe has provided a means of interstellar communication that is fast, efficient, and small in its consumption of energy: electromagnetic radiation. It seems certain that interstellar contact will occur through electromagnetic radiation and that we should not expect, except in very rare circumstances, the actual transportation of objects through interstellar space.

But what kind of radiation? Are there preferred frequencies? It turns out that certain frequencies are much more economical for transmission than others. One basic reason lies in the quantum nature of electromagnetic radiation: quantum energy is proportional to frequency, so that a light photon, for example, has about a mil-
lion times as much energy as a radio photon, and since the same amount of information can be carried by a photon regardless of its frequency, the cost of a radio photon for communication is about one-millionth the cost of a light photon. The use of the very lowest radio frequencies seems indicated, but this is limited by the fact that the galaxy itself emits noise which jams our radio telescopes at the lowest frequencies and requires us to send more than one photon if we are to communicate reliably.

We can construct a graph (see Figure 1) that combines the information on quantum effect and galactic radio noise and shows dramatically the best frequency range for the transmission of communication signals. The well-defined minimum reveals a region, shown as a "window" in the figure, that is referred to by radio astronomers as the "Waterhole." It includes two frequencies associated with atomic hydrogen and the OH radical of the water molecule that are thereby connected with life of the sort we know, and that seem obvious choices for communication frequencies. Figure 1 is not an artifact of our civilization; in countless others, I believe, exactly the same graph has been shown, in some cases many billions of years ago. We can hope to meet other creatures at the "Waterhole," most probably at frequencies associated with water. Indeed, it is at these frequencies that the first searches are being conducted.

**EQUIPMENT TO DETECT INTERSTELLAR SIGNALS**

We do, indeed, have superb equipment for the detection of interstellar signals in this range of frequencies. For example:

![Figure 1. The "Waterhole," probable meeting place for civilizations in space.](image)

The abscissa of this graph is the frequency of electromagnetic radiation and the ordinate is noise temperature, a measure of electromagnetic noise energy that can be taken as an indication of the cost of transmitting a bit of information. One of the curves on this graph shows the noise level of the universe as a result of the original "big bang" (the cosmic background); another shows background galactic radio noise. The third curve indicates the noise due to the quantum nature of light. These three curves define a frequency "window" which is the most feasible region for interstellar communication. Since both scales are logarithmic, it is apparent that cost increases rapidly as one goes even a short distance from the frequency minimum.

Normal television channels fall toward the left of the frequency range on the graph, and the usual radar frequencies are near the middle. The very high frequencies are not yet used commercially. Light frequencies are far off the right side of the figure. It is obvious to Earth scientists, and presumably also to those of other civilizations, that radio frequencies are the best ones for interstellar communication.

Also indicated in the figure are frequencies associated with atomic hydrogen and the OH radical, the two most fundamental frequencies of the water molecule. Because it appears likely that other intelligent beings with life based on water will recognize the fortuitous appearance of these two frequencies in the "window," they are considered prime frequencies in the search for extraterrestrial intelligent life.
The world's largest radio-radar telescope at Arecibo, Puerto Rico, is the one used by Professor Drake and his associates in their search for extraterrestrial intelligence (SETI). Shown is the 600-ton movable triangular feed support structure, which is suspended more than 150 meters above the surface of a bowl-shaped reflector 305 meters in diameter (see also the photograph on page 4). This powerful telescope can be used as a radio receiver and transmitter or as a radar instrument to study distant targets. The Arecibo Observatory is part of the National Astronomy and Ionosphere Center, which is operated by Cornell University under contract with the National Science Foundation.

ample, there is a 65-meter radio telescope near Parks, Australia, that has a fully steerable, parabolic antenna, the largest of its kind in the southern hemisphere. The largest steerable antenna in the world is the 100-meter telescope operated by the Max Planck Institute near Bonn in Germany. Another very large antenna is at the special astronomical observatory of the Soviet Union; it has a 600-meter-diameter ring of reflecting plates, all individually steerable, to direct the beam, and a smaller collecting area for reception, and it is being used for extensive searches for extraterrestrial communications. At the present time, these telescopes can detect signals such as those typical of the earth to a distance of a few thousand light-years.

**SIGNALS FROM ARECIBO AT 100,000 LIGHT-YEARS**

But the largest telescope in the world, and the one most useful for interstellar communication, is the one Cornell operates at the Arecibo Observatory in Puerto Rico. The diameter of this telescope is 305 meters, its total energy-collecting area is about twenty acres—more than the combined collecting area of all the other telescopes in the world—and it can transmit powerful beams of radiation to various parts of the sky. One million watts of input electric power yield one-half million watts of radio energy, which is focused by the bowl of the reflector to give an effective power in the beam of about $20 \times 10^{12}$ watts. That is equal to about twenty times the total electric power production of the entire earth. This is
Figure 2. A record taken at the Arecibo Observatory as part of the search for extraterrestrial intelligent life. This record, covering a thousand frequency bands, was taken in December, 1975, with the telescope pointed toward Alpha Ophiuchi, a star about fifty-four light-years from Earth. A peak on one of the channels is the signal sought in searches of this kind.

by far the most powerful signal leaving our planet; it could be detected by a similar telescope, if such exists, anywhere in the Milky Way. What this means is that manifestations of Earth are now detectable to civilizations like ours or vice versa, even to distances of 100,000 light-years.

These radio–radar telescopes have been used in many searches for extraterrestrial intelligence. At Arecibo we are looking at both nearby stars and nearby galaxies, and we use as many as 65,000 frequencies simultaneously, since there is still uncertainty about which frequency is correct. The sample record shown in Figure 2 was taken with the telescope pointed in the direction of Alpha Ophiuchi, a star about fifty-four light years from us. We could detect the presence of a signal if there were a detectable peak in one of these channels and if the radiated power were as much as one-tenth of what comes out of Arecibo. The Arecibo telescope is, therefore, sensitive to civilizations not just at our own level of technology, but ones that are far fainter.

“. . . approximately once a year, somewhere in the Milky Way, a new civilization ‘lights up.’ ”
The search for extraterrestrial intelligence is only a small part of the work carried out at the Arecibo Observatory. The radar map of Venus shown here was obtained recently at Arecibo in preliminary studies of the planet. It provides the first detailed glimpse of the Venusian surface, which is invisible to optical instruments because of the dense cloud cover. Among the features that can be seen are a large dark basin surrounded by bright rims (top center) and a large bright area (upper right), which is possibly igneous rock that has flowed out from the basin. Similar radar observations of Mars were used to study proposed landing sites for the Viking spacecraft.

The observations of Venus were carried out by Don Campbell and Rolf Dyce, scientists at the National Astronomy and Ionosphere Center at Arecibo, and Gordon Pettengill of the Massachusetts Institute of Technology.

INGENUITY IN SENDING AND RECEIVING SIGNALS

The search for intelligent signals as high peaks of radiation is not as simple as it may seem, however. For example, the presence of excess power in one channel could indicate natural radiation from hydrogen. We must test that possibility.

It helps to recognize that certain frequencies are special. For example, there is the frequency at which a signal would arrive if the transmitting civilization were correcting for the Doppler effect caused by motion of its own star. Or, if the signal were intended for us, if those sending it knew of us, the frequency might be adjusted so that it would arrive at exactly the frequency of the hydrogen atom for our system. When we suspect the latter case, we are tantalized, of course. Is that peak a signal for us? We don't know. What we have to do is make additional observations to see if the peak goes away when we point the telescope elsewhere. An experience of this kind occurred recently when we had the telescope directed toward a galaxy; the record showed a nice high peak, but when we pointed the telescope in a slightly different direction, that peak remained. We had located a broad hydrogen cloud rather than a civilization.

Another way in which a transmitting civilization could draw attention would be to send not just one signal on one frequency, but two or three signals. One strong channel could be explained statistically by noise, but a second peak nearby would be very improbable, and three equally spaced signals would be even more so. When we see sets of peaks like that, as we do, and point our telescope away and still see them, and therefore must recognize that they are not intelligent signals, we discover painfully that the searching of records is not just a simple searching for a high channel. There are many complexities, including clever ways of coding or transmitting radiation and of making the existence of intelligent signals apparent, and we must apply logic and imagination in our search.

PROBLEMS OF LINGUISTICS FOR SPACE COMMUNICATION

It is not enough simply to detect the existence of a signal; we must be able to derive information from it. We have worried, over the years, that there is a linguistics problem. Even here on Earth
we have had such problems. In the case of Egyptian hieroglyphics, we had messages in a language of our own people and could not interpret them, not until the Rosetta stone was discovered. We have had tremendous difficulty dealing with the dolphin languages. It could well be that we will encounter similar difficulties with life in space; we may, in fact, be able to communicate only with a subset of intelligent beings, those with brains that operate like ours. Nevertheless, the question of linguistics has been addressed and solutions have been found, at least here on Earth. The preferred universal solution, I think, will not be determined until we have actually received some messages, but at least we can demonstrate that it is possible to communicate without prior contact.

The simplest way to communicate would be to just put books or pictures or other informative objects on a rocket or spacecraft. In fact, we have done that. We have sent out two rockets (for entirely different purposes of exploration) on trajectories that will carry them out of the solar system, and on each we have placed a plaque bearing a message (see Figure 3) designed for decryption by other civilizations. Subsequently, we sent two Voyager spacecraft to investigate the outer planets and then move out of the solar system, and each of these carried a record of life on Earth as part of the payload. Actually, there is very little chance that these objects will be received by other civilizations. The rockets, for example, will take about 80,000 years to travel the distance of the nearest star and they are probably never to be received by other civilizations. The time (to an accuracy of a few years) and the place of launch could be established by a receiving civilization even after millions of years. Time and distance scales are provided by the diagram (at top left) of the hydrogen atom in its two lowest states: the basic units are the time interval of the transition from one form to the other, and the wavelength of the accompanying radiation. The part of the drawing that shows a group of radiating lines represents a map of the galaxy, placing Earth with respect to the position of fourteen pulsating radio sources in the sky; the period of each pulsar is given in binary code. The time at which the map was made can be calculated by analysis of the pulsar periods, since these change very gradually. To establish the exact planet of origin, the design includes a diagram of the solar system, with the distances of the planets from the sun given in binary code. The creatures of Earth are depicted in a drawing that includes a sketch of the spacecraft to give scale.

The plaque was designed by Professor Drake together with Professor Carl Sagan and his wife, Linda S. Sagan.
Figure 4. The message transmitted by the Arecibo telescope in 1974 and now traveling through space. The figure shows the pictorial interpretation of the message, which was transmitted in a binary format. The notations along the side show how the message is to be decrypted.

In this pictorial form, the message reads from top to bottom and from right to left. The elements of the message convey a number code; the chemical composition of the basic constituents of life on Earth; the chemical makeup, structure, and size of the basic molecule of life on Earth (DNA); the general form and size of humans and their number on the planet; a representation of our solar system, with sun and planets of different sizes, emphasizing the one from which the message was sent; and a diagram of the transmitting telescope, with an indication of its size.
not even headed that way. A much more likely prospect is the detection of our radio signals, which are going out at the speed of light and are powerful enough to be detected by other civilizations.

How might we code messages with radio signals? Several ways have been devised. The most effective approach, at least from our point of view, is to transmit a picture as a sequence of two types of characters—dots and dashes, pulses and spaces, two tones, whatever. Decoding the message would require first figuring out the format to yield the picture, and then interpreting that image.

One message of this sort has, in fact, been sent (see Figure 4). It was transmitted by the Arecibo telescope in November, 1974, in the direction of globular cluster Messier 13, a group of 300,000 stars, and will arrive there in about 25,000 years. It is now four light-years out in space. Every thirty years or so it goes by a star, illuminating it with this message from Earth. When the message was sent, the effective power in the beam was about ten times the total electric power production of the earth; during the three minutes of transmission time, the earth, in the direction of the beam at the frequency of the transmitter, was about ten million times brighter than our sun. For three minutes we became the brightest star in the galaxy.

Thus we see that interstellar communication is possible. We have demonstrated that there are workable linguistic systems, and though we have a very long way to go, we have started the search for messages from other civilizations.

THE SCOPE OF OUR SEARCH FOR INTELLIGENCE

We have already searched a million combinations of stars and frequencies. How many must be searched before we have a reasonable chance of success? What factors must we consider? In addition to all the directions in space, all the frequency bands in the Waterhole, and all the possible bandwidths and polarizations, there is a further consideration. When Arecibo radiates to the sky, it illuminates one ten-millionth of the universe. This means that any particular star gets our strongest signal only one ten-millionth of the time, and that we might illuminate a given intelligent civilization only three or four hours a year. The same probabilities apply to other civilizations, which is to say that one must search not only in frequency and direction, but also in time, because maybe the signal is there at some times and not others.

When all these factors are combined, the number of possibilities is of the order of $10^{25}$. We estimate that about $10^9$ of these possibilities are actually occupied with detectable signals, so that we must make about $10^{20}$ tests of various combinations. So far, we have made $10^5$ such tests, which means that our chances of having succeeded by now are one in $10^{14}$. That's how far we have come in about ten years of work. At that rate, searching all combinations would take us about $10^{13}$ years, which is a thousand times the age of the universe. This is not a very good rate of progress.

Systems are required that will cover many more directions, many more frequencies, and many more possibilities faster. Right now, systems are being developed that will analyze a million different radio frequencies simultaneously, and we can soon expect to see these actually applied on radio telescopes. In addition, systems are being planned on paper that will be able to cover all the necessary number of possibilities in reasonable time spans, of the order of decades. Such systems will be very costly, of course, because of the size of the telescopes required and the necessary electronics.

One such design, known as Project Cyclops (see Figure 5), is being planned not only to detect strong signals such as those of Arecibo, but to eavesdrop on the signals other civilizations use for their own purposes, such as television. In fact, we want to receive those signals because we don't want to have to spend two thousand years to ask a question and wait for the answer. Cyclops is designed to eavesdrop on television such as ours if this comes from stars within a few hundred light-years of the earth.
WHAT WE MIGHT FIND AND ITS IMPLICATIONS

The potentialities of this whole project of seeking to communicate with extraterrestrial intelligence are, perhaps, even more grand than our first naive thoughts would lead us to believe. One might expect to acquire information on technology, science, social systems, and so forth. But I want to speculate about another possibility.

There is in our future, either through extraterrestrial contact or through our own efforts, something that will profoundly affect Earth. It is immortality, biological immortality in the sense that the individual with his assembly of memories can be preserved indefinitely. Either by learning how to reverse or eliminate the process of aging or, in a more complicated way, by transferring the memory of a brain to a new physical body, we will be able to achieve the equivalent of immortality. What has this to do with interstellar communication? In a paranoid civilization (as one with immortal individuals would surely be, since death would occur only as a result of accident or attack), the obvious safeguard would be to keep quiet, to be very careful not to radiate any radio waves into space. In fact, however, that is not a fail-safe technique because others, using their own resources, might still find the immortals. The only real defense would be to make everybody else immortal too.

Here's the speculation. I have already pointed out that the number of civilizations in space can be estimated as the product of the rate of their production and their longevity. Therefore, since the longevity of immortals is infinite, the immortal civilizations in space will far outnumber the mortal ones. Moreover, the immortals must want to contact civilizations, such as ours, that are on the verge of a potentially dangerous technological level. What this suggests is that the dominant radio messages in the universe, the ones that we will detect first, are the songs of the immortals.

What would be the effect on Earth if we were to receive such a signal next year? We would be faced with a momentous decision: we could either
completely alter our civilization by embracing eternal life for those who now exist, or we could choose to adhere to our present way, embracing death and remaining mortal. Interstellar contact may very well make a far more profound impact than any communication we have ever had.

Nevertheless, the question arises as to whether the effort is worthwhile—and specifically, whether it is worth the financial cost. Actually, financial support is growing for the search for extraterrestrial intelligence (known as SETI). For the last few years, NASA has been providing a few hundred thousand dollars annually for the design of systems such as Cyclops. In the coming year, there is a possibility that about two million dollars will be allocated, primarily to build a huge multi-channel radio receiving system. And there is a long-term plan for the construction of a complete Cyclops system, at the cost of five to ten billion dollars, probably in the 1990’s. In the Soviet Union there is even more support.

The value of these studies is, of course, a matter of opinion. My belief is that they are worth every penny that will be spent. The cost of Cyclops is a very large sum, but still less than the cost of landing men on the moon, and only about half of one percent of what the world spends on armaments. It is a small price for giving us, in our lifetime, a real chance to detect intelligent life in space.

Frank D. Drake, a Cornell engineering graduate, is the Goldwin Smith Professor of Astronomy at the University and director of the National Astronomy and Ionosphere Center, which Cornell operates for the National Science Foundation (NSF). This center includes the Arecibo Observatory, an important facility for the search for extraterrestrial intelligence (SETI) that Drake discusses in this article.

Drake is a leading authority on methods for the detection of extraterrestrial intelligent signals. He pioneered in this effort with Project OZMA, beginning in 1960, and at about the same time, he began developing a communication system based on binary coded messages that can be transmitted by radio and translated into "pictures" after decryption. He has also devised an equation, known as the Drake Equation, that provides an estimate of the number of communicative extraterrestrial civilizations we might find in our galaxy. In other astronomical research, he shared in the discovery of the radiation belts of Jupiter and played an important role in the observational studies that led to the early understanding of pulsars.

Drake received the Bachelor of Engineering Physics degree, with honors, from Cornell in 1952, and took his graduate work in astronomy at Harvard University, earning the M.S. in 1952 and the Ph.D. in 1956. During his graduate years, he also served as an electronics officer in the Navy. At Harvard he was associated with the Agassiz Station Radio Astronomy Project, and subsequently he headed the Telescope Operations and Scientific Services division at the National Radio Astronomy Observatory at Green Bank, West Virginia, where Project OZMA was carried out. Later he joined the Jet Propulsion Laboratory at the California Institute of Technology, and then came to Cornell in 1964. During his years here, he has served at various times as director of the Arecibo Observatory, as chairman of the Astronomy Department, and as associate director of the Center for Radiophysics and Space Research.

He has been active in workshops and committees sponsored by the National Aeronautics and Space Administration (NASA), NSF, the National Research Council, and the National Academy of Sciences. He is a member of numerous professional societies and organizations, including the prestigious National Academy of Sciences, and serves on the editorial boards of several journals and reference books. He is a member of the board of directors of two nonprofit astronomy corporations and serves on the advisory committee for the Very Large Array (VLA) of the National Radio Astronomy Observatory.
The following publications and conference papers by faculty and staff members and graduate students of the Cornell College of Engineering were published or presented during the period March through May 1978. Earlier publications inadvertently omitted from previous listings are included here in parentheses. The names of Cornell personnel are in italics.

### AGRICULTURAL ENGINEERING


### APPLIED AND ENGINEERING PHYSICS


GEOLOGICAL SCIENCES


Kaufman, S., and Smithson, S. 1978. Interpretation of Seismic Crustal Reflection Data. Paper read at Spring Meeting of American Geophysical Union, 7-12 May 1978, in Miami, Florida. (Abstract in *E@S Transactions, American Geophysical Union* 59:389.)


Travers, W. B. 1978. Oil spill potential and the prediction of abnormally high pressures on the Atlantic outer continental shelf. *New York Sea Grant Institute program*, pp. 29-47.


## MATERIALS SCIENCE AND ENGINEERING


One of the first of many honors received by Cornell professors of electrical engineering was a silver medal awarded to three men who were responsible for building the first American dynamo. The recipients were Professors George S. Moler and William A. Anthony of the electrical engineering faculty and E. L. Nichols, director of the physics department. The medal was in recognition of the historic value of the machine, which had been shown at the Centennial Exhibition in Philadelphia in 1876, at the World’s Fair in Chicago in 1893, and at the Universal Exposition in St. Louis in 1904.

What became of the medal, the machine, and their story? A bronze rep-
One Tuesday afternoon in the fall of 1958, the speaker at the regular student-faculty E.E. colloquium was Professor William C. Gordon, who announced that he was going to talk about a brand-new idea. "Suppose you had a 1,000-foot-diameter spherical antenna connected to a powerful radar," he said, "with the antenna feed directed so as to send a signal to the planet Jupiter. At about noon you could turn on the radar transmitter long enough to send out some pulses, and then turn it off and go out for lunch. When you returned, you could turn on the radar receiver and be in time to catch the reflected pulse from Jupiter." This was how the E.E. faculty and students first heard about the idea for the famous Arecibo radar astronomy observatory.

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For many years, a high point of the spring term was the annual Engineers' Day, when the various schools and departments in the College would compete in preparing elaborate exhibits for the entertainment and edification of visiting "artsies" and high-school students. E.E. often won first prize, possibly because it was easy for electrical engineers to set up a demonstration in which visitors could participate. A favorite stunt was to rig a d.c. generator with a crank and an accompanying dial calibrated as a "strength indicator." When a young man ap-

The annual faculty-student banquet of the E.E. Delta Club was always an outstanding spring event. One year the after-dinner speaker was Professor William H. Erickson, who was then in charge of a "service" course he had titled "Electrical Engineering for Non-Electrical Engineers." Bill's keen interest in the "sport of kings" was well known, so it came as no surprise that his topic was "Horse Racing for Non-Horses." After entertaining the assembly with a long stream of race-track gags, he finally reached into his coat pocket, pulled out a scroll, asked for a volunteer helper from the audience, and with the comment that he was "about to reveal for the first time the secret of my success at the race track," proceeded to unroll about four feet of paper covered with complex-looking mathematical symbols. A demonstration of the reputed skill of the engineer in putting theory to practical use, it brought down the house.

One Tuesday afternoon in the fall of 1958, the speaker at the regular student-faculty E.E. colloquium was Professor William C. Gordon, who announced that he was going to talk about a brand-new idea. "Suppose you had a 1,000-foot-diameter spherical antenna connected to a powerful radar," he said, "with the antenna feed directed so as to send a signal to the planet Jupiter. At about noon you could turn on the radar transmitter long enough to send out some pulses, and then turn it off and go out for lunch. When you returned, you could turn on the radar receiver and be in time to catch the reflected pulse from Jupiter." This was how the E.E. faculty and students first heard about the idea for the famous Arecibo radar astronomy observatory.
Fifty years ago Cornell's College of Engineering was a very different place. It was a lot smaller, with about 850 students and eighty-one faculty members. The administration consisted of the dean and the directors of the three schools—in civil, mechanical, and electrical engineering. The College was still in a twenty-five-year period of falling enrollments and decline in reputation. Most different of all was the attitude toward research: the College was overwhelmingly a teaching institution, with emphasis on training young men for careers in the rough-and-ready world of professional engineering practice. (Young women in those days became nurses and teachers and secretaries—and housewives—but not engineers.)

Today there are about 240 faculty members in twelve schools and departments and some 2,400 undergraduates—almost one-fourth of them women—plus close to 1,000 graduate students. Administration has grown. Cornell once again has a prestigious engineering college, with both undergraduate and graduate applications increasing every year in numbers and quality. And research is big business; it is the principal activity of many of the faculty members, and an important activity of nearly all of them.

The change in the perceived mission of the College of Engineering from teaching to an integrated teaching-and-research function makes a fascinating story.

DEAN KIMBALL'S TEACHING FACULTY: 1934–35

In 1935 professors were concerned with preparing students for professional careers. True, they built on a foundation of mathematics and physics, and at Cornell this preparation was generally very good; but the “engineering” part of the curriculum was devoted to practical matters—the design, construction, and maintenance of structures, highways, and machinery, and the operation and administration of factories and electric-power systems. (Chemical engineering and agricultural engineering were both offered in 1935, but not in the College of Engineering.) The material taught was largely empirical. To most practical engineers, the attitude toward scientists was admiration from a distance, or disdain, or something in between; certainly many on the engineering faculty felt that science had little relevance to their interests (“Real engineers don't do research”). Although professors did write books and articles, these were mainly on topics of applied engineering; and actually, a faculty member could have a successful university career without publishing anything. He didn't have to worry about tenure—the tenure system didn't begin at Cornell until some time after 1938.

He didn't need an advanced degree, either. Doctorates were especially rare in engineering faculties. At Cornell, of the eighty-one active professors, assistant professors, and instructors (there were no associate professors), only six had doctorates. Over half the faculty had only an “Engineer” degree—C.E., E.E., or M.E. Twenty-two had master's degrees, but all but three of them were “Master of Engineering” professional degrees rather than research degrees. Five had baccalaureate degrees and two professors and two instructors had no college degree at all.

In July 1959, when Hollister’s long period of leadership ended, Dale R. Corson, chairman of the physics department, was appointed dean of engineering. This was a break with tradition; it would have been unthinkable, before World War II, to choose a physicist to head the engineering college. But the space program wasn’t the only successful example of applied physics: transistors were beginning to revolutionize computing equipment and electronics generally, and nuclear power was showing great promise. Over half the engineering faculty members now had doctor’s degrees (see Figure 1a) and interest in research was growing fast. Things were ripe for change.

Very quickly the new dean promoted the expansion of the Center for Radio-physics and Space Research. Interest in that field by College faculty members led to the conception, planning, and building (in 1963) of the 1,000-foot radar-radio facility at Arecibo, Puerto Rico. Corson also proposed to the Advanced Research Projects Administration (ARPA) the establishment of the Materials Science Center, a multi-million-dollar interdisciplinary facility. It was funded and began operation in 1963.

Seizing still another opportunity, Corson in 1960 made a proposal to the Ford Foundation outlining needs of the College of Engineering and requesting several million dollars to meet them. His proposal reflected a greatly increased emphasis on research by engineering professors and graduate students. The new research was to be fundamental rather than empirical, and
For twenty-five years Engineering: Cornell Quarterly has covered developments in research, in the various engineering disciplines, in the profession, and in the academic and extracurricular programs of the Cornell University College of Engineering. Over the years, most of the authors have been members of the faculty.

For this silver anniversary issue, we have called on the faculty once again, for reflections on the past quarter century as they have observed and experienced it academically and professionally. We contacted former deans and those professors, some now emeritus, who have been on the Cornell scene for as long as the Quarterly has, and invited them to contribute a commentary.

The charge was not very specific, and perhaps dauntingly comprehensive: we suggested short articles about “changes that have taken place in their fields, or in the profession, or in education, and perhaps a view of the future which might include comment on ramifications such as effects on national and world economies or on people’s lives.” It is hardly surprising that the result is a heterogeneous collection of essays: reminiscences, personal observations, historical accounts of departments or research ventures, assessments of scientific and technological developments, discussions of specific aspects of the Cornell engineering program, speculations about the future. Some of the authors managed to stay within the recommended length and others found it necessary to have more space. All in all, it is an interesting collection from a remarkable group of Cornell professors.

The essays are arranged alphabetically by author.
Arthur L. Bloom
Geological Sciences

When the Department of Geological Sciences was administratively transferred to the College of Engineering as a bi-collegiate undergraduate department in 1970, I was the only permanent faculty member who carried over from the preceding long tradition of geology in the College of Arts and Sciences. That tradition dated back to the founding of Cornell University in 1868.

The subsequent development of the department to its present leading status, with an almost completely new and enlarged faculty and research staff, is certainly the dominant feature of the last two decades of my life at Cornell. The pace-setting Consortium for Continental Reflection Profiling (COCORP) Project to study the continental lithosphere has influenced every aspect of that area of geology, and in addition it has trained a cadre of graduate students who are now leaders in academic and industrial research.

My own involvement has been with the Andes Project, conducted by a group of congenial and like-minded researchers who almost accidentally found converging interests in Andean studies beginning in the early 1980s. Our independent and joint research efforts, covering a wide range of geologic topics and diverse collaboration with South American colleagues, has progressed through a series of projects funded by NSF, NASA, and other agencies, culminating in our selection for one of twenty-eight NASA EOS (Earth Orbiting System) interdisciplinary projects. Bryan Isacks is the principal investigator of the Cornell EOS group.

Bloom has spent leaves as a visiting lecturer at Yale; as a senior Fulbright scholar at James Cook University of North Queensland and at the Australian National University; and as a research fellow at Kobe University, Japan. He has lectured in Korea and China and collaborated in research projects with scientists in those countries. In recent years, most of his research has been in collaboration with Argentine scientists.

Bloom is a fellow of the American Association for the Advancement of Science and the Geological Society of America. He is an editor of several professional journals.

We are now . . . doing geology on a scale hardly possible before the advent of computer-driven image processing and information handling.

The Department of Geological Sciences moved into its new building, Snee Hall, in 1984. The atrium with its display cases provides an architectural center for the four-story building.

Arthur L. Bloom, a professor of geological sciences, joined the Cornell faculty in 1960 after completing doctoral studies at Yale University and teaching there for a year.

Before starting graduate school, Bloom earned a bachelor’s degree at Miami University and a master’s at Victoria University in New Zealand, and served in the amphibious forces of the Pacific Fleet.
In the aftermath of World War II, throughout the 1950s, the meteorological community learned to make extensive use of radar in the detection and analysis of weather systems, especially in the study of severe storms. By the mid-1960s, radars—usually large, land-based systems with relatively coarse resolution—were regularly being used to collect substantial amounts of meteorological data. These data were, in turn, fed into weather-prediction systems on national and international scales.

In the two and one-half decades since then, significant improvements in sensitivity, resolution, and on-line information-processing capability, as well as the advent of highly miniaturized equipment (all of which can be traced, directly or indirectly, to developments in solid-state electronics), have extended greatly the role that radar now plays in the field of meteorology. The wide use of Doppler radar for windfield analysis and clear-air-turbulence studies is a case in point.

It is now possible to detect and measure air motions—both their speed and their direction—even in the absence of precipitation or other airborne tracers. Instances of intense wind shear or turbulence, which may pose great danger to aircraft and their passengers, can be observed and suitable warnings issued. The structure of the windfield in severe storms (frontal systems, hurricanes, and tornadoes) can be mapped and analyzed remotely, in great detail—a capability of paramount significance to the atmospheric scientist attempting to gain a better understanding of these often catastrophic natural phenomena.

We shall, of course, never be able to do much more than talk about the weather. Now, however, our conversation can at least address with some precision the degree of vorticity present in that “howler” to which we were subjected last night.

“...and clear-air-turbulence studies is a case in point. It is now possible to detect and measure air motions—both their speed and their direction—even in the absence of precipitation or other airborne tracers.”
By 1966 nuclear engineering had become a well established field at many universities. At Cornell it had grown from one course taught in 1952 by Trevor R. Cuykendall to eleven courses and a faculty of six in Engineering Physics; fourteen M.S. and eighteen Ph.D. degrees had been awarded. In 1961 it had moved into its own building (named in 1968 for J. Carleton Ward, Jr.) housing a TRIGA reactor, a zero-power reactor, and a gamma irradiation cell.

The intervening twenty-five years did not witness the rosy future for nuclear power foreseen in 1966. Although many nuclear plants were successful projects, it was the few failures that caught public attention. Although the atmospheric-test-ban treaty reduced the public's radiation exposure, people still associate nuclear power with weapons. Nuclear radiation is viewed by the media and the public as little understood and fearsome. The drumbeat of opposition increased with Three Mile Island and Chernobyl. Official reassurances are distrusted, in part because of the government's denials until recentely that its own weapons program, conducted in urgency and secrecy, exposed many people and left a legacy of ill-stored wastes. Along with other universities, Cornell has not been immune to public reaction. Enrollments have decreased and professors in key areas who retired or moved have not been replaced.

Nonetheless, nuclear energy has a place in 1991 and beyond. Controlled thermonuclear fusion is on the verge of realization. Non-power reactors are necessary for beneficial uses in medicine and biology and for

Right: The TRIGA reactor, a source of neutron and gamma rays, has been in use since 1961.
Many observers expect nuclear power to return as an important component of an overall energy program for the United States and the world.

Clark

analytical uses in fields from archeology to textiles. Furthermore, many power reactors have been built on schedule within budget and have run safely. Nuclear power can be efficient and safe, with environmental advantages over the use of fossil fuels. Techniques for safely segregating wastes from the biosphere are available. It is therefore conceivable that public suspicion can be allayed, with time, through education. Many observers expect nuclear power to return as an important component of an overall energy program for the United States and the world.

In anticipation of this resurgence, Cornell is continuing its graduate programs and introductory undergraduate courses, teaching nuclear science and engineering, and conducting research in power reactor design, plasma physics and controlled fusion, underlying atomic and nuclear sciences, and non-power applications of nuclear energy.

David D. Clark is a professor of nuclear science and engineering and of applied and engineering physics and the director of the J. Carlton Ward, Jr. Laboratory of Nuclear Engineering. He also heads the academic Program in Nuclear Science and Engineering. He is a specialist in nuclear physics, activation and prompt gamma analysis, and radiation measurement.

Clark came to Cornell in 1955 after earning B.S. and Ph.D. degrees at the University of California at Berkeley and serving as a research associate in physics at Brookhaven National Laboratory for two years.

He was a Euratom fellow at Ispra, Italy, in 1962, a Guggenheim fellow at the Niels Bohr Institute in Copenhagen in 1968–69, a visiting professor at the Technical University in Munich in 1976, a visiting scientist at Brookhaven in 1982 and during numerous summers, and a guest scientist at the Center for Analytical Chemistry of the National Institute of Standards and Technology in 1990.

Bart Conta
Mechanical and Aerospace Engineering

When the Quarterly was born, the country was engaged in a hot war in Southeast Asia and a cold war with the U.S.S.R. Engineers in industry, government, and the universities were largely concerned with the fascinating and challenging problems of sophisticated technology presented by the military and space industries and agencies. Although a few voices were raised to point out the industrial and social problems that were suffering from neglect in this hubristic era, the warnings fell mostly on deaf ears.

Now it is much more generally recognized that the country is in deep trouble. A crippling national debt continues to grow, a trade deficit seems to be permanent, and we have lost much of our conventional industrial base to countries in Europe and Asia. We are faced with overwhelming problems of air, water, and land pollution; acid rain and ozone depletion; decay of the infrastructure of our cities and transportation systems; storage of hazardous chemical and nuclear waste; crime; drugs; and poverty. Compared with other industrialized nations, we rank quite low in education, health care, infant mortality, equitable distribution of both income and wealth, and even in GNP per capita.

The present era is a crucial one. To even begin to solve these mundane but vital industrial, economic, and social problems will
require drastic changes. In national politics it will require a near-revolutionary change. One cannot expect leadership to come from a free-enterprise industrial structure with its emphasis on the bottom line. Perhaps our universities offer the best hope of charting the way to solve these long-neglected problems.

Bart Conta became an emeritus professor in 1984, but has taught some courses since that time. His special interests include the history of science and technology and their social impacts, and intermediate technologies.

He studied mechanical engineering at the University of Rochester, earned a master's degree at Cornell, and joined the faculty in 1937. Except for a year at the Texaco Corporation and four years on the Syracuse University faculty, he spent his career at Cornell. He is registered as a professional engineer in New York and has served as an industrial consultant.

During leaves, Conta was a Ford Foundation visiting professor in Colombia, a National Science Foundation fellow at the University of California at Berkeley, and a researcher on the history of technology at the British Museum and the Science Museum in London.

Dale R. Corson
Dean, 1959–1963

On July 1, 1959 I became dean of the College of Engineering, following a remarkable twenty-two-year period of building and rebuilding under the leadership of Dean S. C. Hollister. “Holly” moved Engineering from the north end of the campus to the south end. He created the five-year undergraduate program. He established the Graduate School of Aeronautical Engineering and the Department of Engineering Physics. He recruited some outstanding faculty members. These were remarkable achievements.

In 1959 Cornell had a high-quality, predominantly undergraduate engineering school. I believed that we had to change the emphasis to add quality graduate education. I saw our society and our economy moving rapidly to ever higher and more complex technology and we had to educate people who could understand, work with, and develop that technology. Not only were we moving toward more complex (what we now call “high tech”) machines and processes, we were creating a whole new set of problems for ourselves—pollution, toxic waste, and radiation hazards. I even gave talks about global warming and the “greenhouse effect”. I did not believe that engineers educated only at the undergraduate level could cope with these problems.

The primary mission of the university is education. We teach undergraduates to understand our common heritage of learning left by those who have gone before. We teach young people to think clearly and to reason logically. We give them the perspectives and the fundamental tools to sustain them in their mature lives.

At the graduate level we teach students to solve difficult, novel problems. We do that by apprenticing them to teachers who are themselves solving difficult, novel problems and who, in the process, are creating the new insights and understanding on which we will build our technical future. These teachers constitute the research faculty.

I remained as dean only four years, but those years came at a good time. We could command support if we had good ideas. We set about restructuring the college in a number of ways. I say “we” advisedly. Everything that happened in those years was a cooperative effort with the faculty. We established the Division of Basic Studies so that students could explore engineering for a couple of years before deciding on a specialized major field—a plan that is basically still in effect—with a consequent retention rate that was much higher than it had been. We were able to obtain a multimillion-dollar grant from the Ford Foundation to help us on the road to the graduate and research program we sought.

The Ford grant, plus matching gifts from industry and alumni, along with a commitment from the university central administration, enabled us to appoint a dozen new

“Cornell moved rapidly to the front in graduate study and research in many areas.”
Three Cornell engineering deans were photographed at the 1971 convocation marking the first century of engineering at Cornell. Dale R. Corson is at left; his predecessor, the late S. C. Hollister, is at center; and Andrew Schultz, Jr., his successor, is at right. Schultz was dean at the time.

and distinguished faculty members in the fields where we saw the greatest need. Cornell moved rapidly to the front in graduate study and research in many areas. The college and its program have been well documented in *Engineering: Cornell Quarterly*, a great journal established by my successor, Dean Andrew Schultz, Jr.

The college now has ninety more faculty members than it had thirty years ago, and the additions are people at the front of their disciplines. We now have many graduate study and research fields that are among the best in the country. Our faculty members are winning major national awards. We get our share of the best students. The future is bright.

I salute those who are making it all happen.

Cornell physics department in 1946, he participated in the design and construction of a cyclotron at Berkeley, was a staff member of the Massachusetts Institute of Technology Radiation Laboratory (1941-43), served as a technical adviser on radar to the Air Force during World War II, and worked at the Los Alamos Scientific Laboratory, where he had primary responsibility for organizing Sandia Laboratory.

Corson has served on numerous national and New York State committees, panels, and commissions concerned with such topics as higher education, international technical cooperation and assistance, industrial research and development, satellite power systems, and scientific communication and national security.

He has been a consultant to the Ford Foundation and a director of several corporations. Among his publications are two books on electromagnetism.

He is a fellow of the American Academy of Arts and Sciences and the American Physical Society and a member of the National Academy of Engineering. His honors include six honorary doctoral degrees.

Dale R. Corson is president, emeritus, of Cornell University. He became Cornell's eighth president in 1969, after six years as provost. Before that, he spent four years as dean of the College of Engineering. In 1977-78 and 1978-79 he served as chancellor of the university.

Corson was educated at the College of Emporia in Kansas, the University of Kansas, and (for his doctorate in physics) the University of California at Berkeley. Before joining the
Edmund T. Cranch  
Dean, 1972–1978

Engineering education in the United States and the educational challenge facing the profession are at an evolutionary turning point. A new interpretation of the curriculum and degree structure is imperative.

The achievements in engineering education since World War II have been impressive. They include a strengthening of the scientific and mathematical content of the curriculum; increases in the course work in the humanities, social sciences, and other subjects; the introduction of new disciplines and subdisciplines associated with new or advanced technologies; incorporation of the computer as an essential and integral tool in teaching engineering analysis and design; and the building of a system of Ph.D. education and sponsored research.

One result, however, has been severe curricular compression at the undergraduate level—a kind of gridlock exists within the framework of the usual four-year program. Yet academic, industrial, and business constituencies cite the need for still more curricular depth and breadth. Among the changes that are called for are improved development of communication skills; more design, manufacturing, and processing content and hands-on experience; enhanced content in the humanities, social sciences, and languages to make engineers better able to function in an international context; courses to develop management skills; and greater depth of specialization. Obviously, the challenge requires much more than a quick fix.

An underlying cause of the need for educational change is the fundamental changes that are taking place in the engineering workplace. Increasingly, engineering problems are approached through synthesis of existing knowledge and through simulation. The engineering handbooks of the past have become computer programs, and the “bread board” prototypes have become simulation models. A design iteration that once took six months may now take six days or even six hours. And the geographical proximity once required for technology transfer has been eliminated.

An accompanying change is the expanding range and complexity of careers in engineering. Many new opportunities arise from the role and interaction of technology in addressing urgent societal and economic problems—medical, environmental, and economic on a global scale—as well as technical. Interdisciplinary or multidisciplinary collaboration is increasingly needed.

Currently, engineering education, from the baccalaureate to the doctoral level, is ill-structured to respond to the new dimensions of professionalism. Obsolescence, an issue that haunts engineering, continues to be a major problem; considering its importance, it is surprising that engineering education has given essentially no attention to this topic.

After studying the growing problems confronting engineering education, I have reached the conclusion that properly structured master’s degree programs can respond to the imperatives of the saturated undergraduate curriculum and can extend the productive period of practicing engineers.

Cornell pioneered in establishing its Master of Engineering program in 1966. Indeed, this may be its most significant contribution to engineering education in the last fifty years. Subsequent advances in technology and developments in engineering education have placed Cornell’s M.Eng. program in a position of leadership for the next turning point in engineering education.

Key features in programs that can meet the needs of the profession now and in the foreseeable future are:

- **Articulation between the bachelor’s and master’s degree programs.** Cornell has been a leader in developing ways of doing this; they include the possibility of early admission to master’s degree courses, and flexibility in arranging individual curricula. There is opportunity for additional creative approaches. Currently, a national study along these lines is being conducted by the Council of Graduate Schools.

- **Development of increased technical proficiency.** A well planned master’s degree program can accomplish this along with the development of a broad-based and critical approach to advances in a particular field or an area—such as manufacturing, an option in Cornell’s M.Eng. program—that does not easily fit within traditional departmental
boundaries. The development of such programs is one of the main recommendations of the 1988 ASEE report "A National Action Agenda for Engineering Education".

- **Interdisciplinary opportunities.** To be effective, engineers must be well grounded not only in their specialty, but in associated disciplines. To meet this need, flexible, joint master's degree programs can be structured; Cornell's joint M.Eng.-M.B.A. program is an example.

- **Interaction with practicing professionals.** The required design project and the opportunity for industrial internship that are part of Cornell's M.Eng. program provide this dimension. Telecommunications technology also has immense potential to enhance the interaction between the educational institution and industry.

If engineering education is to move beyond its present constraints and strengthen the educational base of the profession consistent with the demands of technological change, its structure must include a coherent program extending through the master's degree level. Cornell's Master of Engineering program provides such a base and its graduates are educated for positions of professional leadership.

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**G. Conrad Dalman**  
Electrical Engineering

At this time, as the *Quarterly* completes twenty-five years of publication, I would like to take a twenty-five-year "back to the future" look at the School of Electrical Engineering.

Of the many changes that have occurred in my own field of microwave electronics, one of the most significant is the rapid evolution from high-vacuum, discrete devices toward complete microwave and millimeter-wave systems on a chip. Today, for example, complete satellite communications receivers have already been integrated on a single chip. In the near future, with the further development of millimeter-wave technology, receiver dishes can be expected to shrink from the huge size now in use to as small as a foot in diameter. These developments are largely due to the many recent advances in solid-state technology and computer-aided testing and design.

Students graduating in this area are finding more interesting, stimulating, and challenging careers than the graduates of twenty-five years ago did. Many are finding, however, that they must aggressively seek out job opportunities rather than select from as many as three or four or more, as some of the earlier graduates were able to do.

Over the past twenty-five years, the size of the electrical engineering faculty has increased about 10 percent, and the ratio between the number of theses supervised and the number of faculty members has remained about the same. The faculty has continued to be very active in acquiring research grants and contracts to support graduate students and to help build up the research facilities.

Although proposal writing continues to be an effective way for faculty members to
“...research problems are more interesting and challenging, laboratory facilities are vastly superior, computing facilities are abundant, and—most importantly—the quality of electrical engineering students continues to be excellent.”

clearly define new programs of research, funding has become more difficult to obtain because of an erosion in research dollars for individual investigators. Twenty-five years ago, the probability that proposals would be accepted was very good, both because there was less competition and because money was relatively plentiful—the country was just entering what has come to be considered the “golden age” of research funding. Currently there is a concerted effort, led by NSF and other agencies, to restore university research to the important place it held in the 1960s.

Despite concern about funding for research, electrical engineering at Cornell is in far better condition today than it was twenty-five years ago: research problems are more interesting and challenging, laboratory facilities are vastly superior, computing facilities are abundant, and—most importantly—

the quality of electrical engineering students continues to be excellent. We are optimistic that with perseverance and diligence, today’s problems can be resolved.

G. Conrad Dalman, an emeritus professor of electrical engineering, joined the faculty in 1956. He had earned the B.E.E. from the City College of New York, and the M.E.E. and D.E.E. from the Polytechnic Institute of Brooklyn, and had had fourteen years of industrial experience at RCA, Bell Laboratories, and Sperry Gyroscope.

At Cornell he served as acting director and as director of the School of Electrical Engineering. He is a recipient of the school’s Excellence in Teaching Award.

Dalman spent sabbatical leaves at Chiao Tung University, Hsinchu, Taiwan, where he served as International Telecommunications Union/United Nations Manager of the China Project (1962–63), and at TRW (1980–81). He has served as a microwave consultant to six major industrial firms. He has been awarded four U.S. patents and one is pending.

He is a fellow of the Institute of Electrical and Electronics Engineers and the American Association for the Advancement of Science.

P. C. Tobias de Boer
Mechanical and Aerospace Engineering

When the first issue of Engineering: Cornell Quarterly appeared, I had been at Cornell’s Graduate School of Aerospace Engineering for just two years.

I had visited Cornell for the first time in 1958, when I was working and studying at the University of Maryland. Ed Resler* had been on the faculty there, and I had taken over some of his experiments. Ed had recently moved to Cornell, and there was a need to discuss some recent results. I recall that my wife and I stayed at Willard Straight Hall. We found the guest rooms there pleasant and comfortable, although they generally were considered out-of-date because they did not have private bathrooms; but having arrived from Europe only one year before, we did not consider this unusual. Ed was in the Aero School, which at that time was housed in a “temporary” building near Beebe Lake. It was an old wooden building, filled with fascinating experiments and people. I still have a number of photographs of the campus taken during that visit. Student dress was quite formal: jackets for the men, dresses for the women. Books were carried without briefcase or backpack—an impressively large stack of books could be arranged so that it could be carried under one arm.

One of the outstanding problems in aerospace engineering during the 1960s was the “reentry problem”. Reentering spacecraft create a bow shock in front of them, causing a very large increase in temperature. The resulting problem has two aspects: how to avoid serious damage to the vehicle, and how to overcome the temporary loss of radio

*See the commentary by Edwin L. Resler, Jr., beginning on page 31.
contact that is caused by high levels of ionization in the gas behind the bow shock. Faculty and students in the Aero School worked on both of these aspects.

A principal idea for limiting damage due to high heat was to use magnetic fields to keep the hot, ionized gases away from the reentering vehicle. This gave rise to a new discipline, *magneto-fluid dynamics* (MFD), in which Bill Sears, Ed Resler, and their students were pioneers. One of the interesting experiments consisted of shooting a bullet through a plasma in the presence of a magnetic field in order to record the wave system around the bullet. MFD was never applied to the reentry problem, however. A much simpler solution was found: the use of ablating heat shields, in which the heat of ablation keeps the spacecraft cool. (Another solution, applicable to manned spacecraft, is to make the reentry gradual and thereby limit the rate at which heat is generated. This allows the use of ceramic tiles, which can withstand the high temperatures without disintegrating.)

Problems related to the temporary loss of radio contact between ground and spacecraft were studied with shock-tube techniques that had been developed at the Aero School. . . .

“Problems related to the temporary loss of radio contact between ground and spacecraft were studied with shock-tube techniques that had been developed at the Aero School. . . .”

ing, which results in an *N-wave* for pressure recorded on the ground as a function of time. There were lengthy discussions about whether the *N*-wave could be avoided through airplane design, but eventually it was accepted as unavoidable for practical aircraft; part of the “solution” is to require supersonic planes such as the Concorde to fly subsonically over land.

Over the past twenty-five years, many physical changes have taken place on campus—for instance, the Engineering and Theory Center Building now stands where there used to be a lawn in front of Grumman Hall—and so have a few ways of doing things. We used to have Saturday morning classes, which at the Aero School were pleasantly combined with Saturday-morning coffee arranged by the school’s secretary, Toni Anthony. Toni’s title has changed over the years—she is now the administrative associate in the Sibley School of Mechanical and Aerospace Engineering—but she still takes care of many matters, and in fact, still provides coffee to students and faculty on many Saturday mornings.

P. C. Tobias de Boer, a professor in the Sibley School of Mechanical and Aerospace Engineering, is a specialist in high-temperature gasdynamics, fluid dynamics, and transonic flow.

Before he came to Cornell in 1964 as a member of the aerospace engineering faculty, he had earned the degree of Ingenieur at the Technological University in Delft, The Netherlands, and the Ph.D. at the University of Maryland, and had spent seven years at the Institute for Fluid Dynamics and Applied Mathematics at the University of Maryland.

He has been a visiting professor at the von Kármán Institute for Fluid Dynamics in Belgium (1968), the Cornell Aeronautical Laboratory (1969), and the Technological University in Delft (1985–86). During the 1960s, he spent several summers at the Aerospace Corporation, and he has spent sabbatical leaves at the Ford Motor Company and the Gas Turbine Division of General Electric.

He is the North American associate editor of Applied Scientific Research.

P. C. Tobias de Boer
Since I have spent my entire career in environmental engineering, my contribution to this issue of the Quarterly is an assessment of developments in the area of public health and the environment that have occurred over the past twenty-five years.

No realistic understanding of the changes that have taken place is possible without knowledge of some significant events that shaped those years.

In the last quarter of the nineteenth century, Pasteur’s germ theory led to a new understanding of how to protect against epidemic disease. This information was examined in the United States by the Hygienic Institute of the United States Public Health Service (USPHS) and the Lawrence Experiment Station in Massachusetts, where health-related research on water and waste water was initiated. By 1914 the USPHS had promulgated the first drinking-water standards, and by 1915 thirty states had established sanitary (environmental) engineering units (although half of these consisted of only one person).

Although more than one hundred water-pollution-control bills had been introduced into Congress since 1900, no legislation was enacted until 1948, when the first federal Water Pollution Control Act was passed. This act established new policies for federal financial aid and provided for enforcement, and although implementation of these policies was weak, they broke a half-century-long log jam that had pitted American industry and many state and local governments against further federal responsibility.

That same year there was an air-pollution disaster in Donora, Pennsylvania, in which twenty persons died and six thousand were made ill. The public concern that was triggered by this tragedy resulted in 1955 in legislation that laid the foundation for the current national air-pollution-control program. By the mid-1960s Congress recognized that the people were willing to proceed toward a stronger environmental-management program. Amended and strengthened water- and air-pollution acts emerged as part of President Johnson’s Great Society program, and good, but not final, achievements were made in the 1970s and 1980s.

It is against this background that the advances of the past twenty-five years took place. Conservation education stimulated by the Office of Education and non-governmental agencies also contributed, and writings such as Rachel Carson’s Silent Spring played a role. There developed a growing concern for nature and beauty, animal life and genetic diversity, Amazon forests, and an ecosystem approach to the management of our planet.

In addition, two technological developments contributed to public attitudes toward environmental issues. These were the use of animal experimentation by the federal Food and Drug Administration and the development of instrumentation to measure the presence of substances in parts per billion or less. A result was that people became aware that certain chemicals, many in common use, can produce cancers, and this was the major impetus for an immense public concern about environmental public-health issues. Subsequently, societies everywhere, led importantly by the United Nations, have developed a new consciousness of environmental issues.

In thinking about what may transpire in the next twenty-five years, I find that society is in the middle of a learning curve. An understanding of the new threats to human and all other life is perceived. Resources necessary to seek solutions to both national and planetary problems are becoming increasingly available. Answers are awaited to the critical problem of how to balance the vital needs of environmental management with the potential uses of scientific discovery, with technical advances, and with the industrial and economic development that is needed to maintain and improve living conditions.

The 1992 United Nations Conference on Environment and Sustained Development should help set the stage for this next quarter century, when answers to questions of priorities, degrees of risk, costs, and the balance between development and the environment will be increasingly sought. Universities such as Cornell will be crucially involved in confronting these issues, and face real challenges in the years to come.

Leonard B. Dworsky, an emeritus Cornell professor of civil and environmental engineering since 1985, spent twenty-eight years as an environmental engineer in local, state, military, and federal organizations before joining the university faculty in 1964.

This experience included eighteen years with the United States Public Health Service, during
which he participated in the formulation and administration of the national environmental programs initiated between 1948 and 1965.

More recently he has been concerned with problems of water-resources management at the nation's boundaries. He sat on the Science Advisory Board of the International Joint Commission (United States and Canada) and was an adviser on water resources to President Lyndon Johnson. He was a principal organizer of a United States-Mexico-Canada conference on boundary issues that was held in April in Florida under the sponsorship of the International Transboundary Resources Center of the University of New Mexico School of Law. Dworsky is a senior associate of that center.

Dworsky graduated from the University of Michigan in 1936 and received a M.A. degree from American University in 1955.

At Cornell he directed the Water Resources and Marine Sciences Center from 1964 through 1974. He has served on the national water and energy-policy committees of the American Society of Civil Engineers and is a diplomate of the American Academy of Environmental Engineers.

Dworsky

Peter Gergely
Structural Engineering

Some important facets of academic life in engineering at Cornell have not changed much in the past quarter century, but others have fundamentally altered the way we do our teaching, research, and professional activities. The quality of students has remained very high, and for me that has been one of the most satisfying aspects of working at Cornell. Most other things have changed to various degrees since I came here in 1963.

Cornell has become much bigger in every sense. The administration has grown and controls more of our operations, both as perceived and in reality. There are more rules, more offices, and more red tape. There is much more diversity all around, especially in the student population, which had been rather homogeneous until the end of the 1960s. Now we have many more female, minority, and foreign students.

The Master of Engineering program, which resulted from the demise of the five-year curriculum, has become very successful and solid. We in structural engineering are especially pleased with our interaction with eminent practicing engineers who help our M.Eng. (Civil) class.

Undoubtedly, the introduction of computers has had the greatest impact on our teaching and research. Pioneering developments in the use of computer graphics in powerful analysis programs has immeasurably improved our teaching in structural engineering. Instead of assigning one trivial problem as homework, we can ask students to analyze numerous complex structures and study the results. Furthermore, we can display the analytical procedures in ways that were impossible on paper or on the blackboard.

“Pioneering developments in the use of computer graphics in powerful analysis programs has immeasurably improved our teaching in structural engineering.”

The volume of research has increased exponentially. The obvious benefits are funding for graduate students, broadening of the horizons of students and faculty, financing of lab equipment, and increase in stature for the college. However, there are negative aspects as well, which have become apparent only in recent years. The tremendous amount of work associated with sponsored research (proposal writing, reporting, conferences, other meetings, budgeting) has strained the faculty and others. Successful research also leads to other commitments, including consulting. As a result, we are much busier and more hurried than we were a quarter century ago. I used to attend classes in the arts college and get to know several faculty members there—that was a long time ago. Is it possible to compromise and reduce the exciting research and associated activities? I doubt it, because one has learned to go after funding incessantly and has not learned to say no to opportunities.

Much of our recent research has been concerned with earthquake engineering. In addition to its national importance and technical challenges, this field of research is especially exciting for most of us in structural engineering because of the cooperative
An intensive between-terms design session in which industrial consultants work with the students has long been a feature of the M.Eng. (Civil) program. In 1976, for example, Richard Christie of Hardesty and Hanover helped students work on a bridge design; the actual Hardesty and Hanover design was used in a bridge constructed in New England.

nature of projects undertaken through the National Center for Earthquake Engineering Research. Cornell is one of several universities in the New York State region that are participants in the center, which was established in 1986.

The variety of research, both within structural engineering and across the college, makes this place an inspiring and stimulating environment, and we continually try to infuse this excitement into the classroom. These efforts keep our faculty active and vigorous, as many visitors have observed. The college’s current renewed emphasis on teaching is welcome and will require masterful balancing of the opportunities and responsibilities.

Peter Gergely is a professor in the structural engineering group of the School of Civil and Environmental Engineering. He has served as director of the school and is currently manager of the Cornell program of the National Center for Earthquake Engineering Research and one of the center’s principal investigators.

He began his university education in Budapest and completed a bachelor’s degree in engineering at McGill University in Montreal. He did his graduate work at the University of Illinois and joined the Cornell faculty after receiving his Ph.D. in 1963.

He has spent sabbatical leaves with the Pittsburgh–Des Moines Steel Company (1969), at the Hungarian Academy of Sciences and the University of Toronto (1976), and at the Lawrence Livermore National Laboratory and the University of California at Berkeley (1983).

Gergely is a fellow of the American Society of Civil Engineers (ASCE) and the American Concrete Institute (ACI) and has served on the board of directors of the ACI. He has received four national awards, including the ACI’s 1982 Distinguished Service Award.
S
ome twenty-five years ago, in 1965 to
be exact, the Cornell Department of Com-
puter Science was formed. It was one of the
very first computer science departments—
the academic field was in its infancy. The
initial mission of the department was to
produce Ph.D.s—the researchers and the
educators of the many students who were
expected to become interested in computer
science.

With a faculty of five, the department
occupied the north side of the fourth floor
of Upson Hall. The south side still con-
isted of large rooms filled with drafting
tables, where freshman engineers learned a
skill that computer science was soon to
help obviate. There was no women’s bath-
room on the fourth floor, for few women
studied engineering in the 1950s, when
Upson Hall was built for mechanical engi-
neering. The elevator in Upson had a sign
on it: “For Faculty Only”.

In contrast to our small beginning, the
department now has twenty-five faculty
members and produces some fifteen Ph.D.s,
thirty Masters, and seventy Bachelors per
year; a total of 150 Ph.D.s in computer
science have been granted by Cornell. An
undergraduate degree in computer science
was not available at Cornell until 1978.

The field of computer science as a whole
has also mushroomed. Currently, the
nation’s approximately 135 institutions that
grant doctorates in computer science pro-
duce more than 700 Ph.D.s per year, which
is getting close to the number of Ph.D.s in
mathematics, and probably about 850 de-
partments produce graduates with master’s
or bachelor’s degrees.

The discipline of computer science was
in its infancy in 1965. Research in areas
such as the theory of formal languages,
automata theory, and programming lan-
guage semantics had indeed begun, but
most of the key broad ideas—for example,
NP-completeness, structural complexity,
structured programming, parallel program-
ing, axiomatic semantics, denotational
semantics, type theory, and relational data-
bases—had not yet been invented. The hot
topics of interest were compiler writing,
operating systems, algorithm design, for-
mal languages, automata theory, and the
new field of computational complexity.
Artificial intelligence was pursued at only
a few places, most notably M.I.T., Stanford,
and Carnegie-Mellon.

If research was in its infancy in 1965,
what did computer scientists teach? At
Cornell, there were a few undergraduate
courses in programming, machine archi-
tecture, assembly language programming,
and the like, but the emphasis was on gradu-
ate courses and research. Compiler writ-
ing, for example, was taught in a graduate
course. Most of the material now taught in
the senior-level course on compiler writing
had not yet been developed. There were
few usable textbooks twenty-five years ago.
In fact, Cornell’s computer science depart-
ment played a large role in upgrading edu-
cation by producing textbooks that set the
national tone in areas such as the theory of
automata and formal languages, algorithms,
compiler writing, programming, and informa-
tion organization and retrieval.

The major high-level languages in use
were FORTRAN, PL/I, Algol 60, LISP,
"Historically, one talks of two revolutions that totally changed the world: the agricultural revolution and the industrial revolution. We are now in the midst of a third important revolution: the information revolution."

and COBOL. FORTRAN was taught to engineers initially, and was replaced by PL/C (Cornell’s scaled-down version of PL/I), in the early 1970s. Among today’s popular programming languages that did not exist at the time are Pascal, C, Ada, Prolog, and Scheme. The UNIX operating system was nonexistent.

For at least its first ten years, the department relied on Cornell’s main computer, an IBM 360, for all its computing. To run a program, one brought the deck of punch cards, or IBM cards, as they were called, that contained the program to be run to the basement of Upson Hall, where key-punches, lineprinters, and links to the mainframe were located. The deck of IBM cards was placed in a card reader; the job would be run and the results printed anywhere from ten minutes to a day later. One mistake on an IBM card—a missing semicolon, for example—could mean waiting a few hours or a day to run the program again.

Today, few students know what an IBM card is—or realize that the side of Olin library reminds us oldsters of one. They also don’t realize how instant their computer gratification has become, compared to the old days. Computer science was really in its infancy then, with limited computers and frustrating interfaces to them, and with only the beginnings of the theory of the field, few programming languages, and little software. The best thing going for us was that we did not know that everything was so backward—we could not read the future.

So what did we computer scientists and engineers do at the time? Well, we spent twenty-five years developing, designing, and building the better computers, theory, programming languages, and software that are in use today. The advances have been breathtaking. From a time in which computers were used only by the chosen few, it has taken only twenty-five years to reach the point that computers and computing are ubiquitous and affect the lives of every one of us—to reach the point that there is a respectable, interesting, and deep theory behind the field.

Today is the era of the individual workstation and the desktop computer, which have more horsepower than the single mainframe computer the Cornell community shared twenty-five years ago. We have instant execution, e-mail, instant access to larger computers, windowing systems, editing systems, spread sheets, graphics, laser printers, and on and on: all driven by the research, development, and education that took place in the past twenty-five years.

Computing—by that term I mean computer science and engineering—has joined mathematics as an enabling discipline for almost all other scientific and engineering fields. And simulation by computer has joined theory and experiment as a third paradigm for doing research; today one cannot do, say, physics or mechanical engineering without using computing.

Computer science has developed a new concept, a new idea. While mathematics has concentrated on frameworks for explaining “what is”, computing has given us frameworks for explaining “how to” and the machinery—the computer—for carrying out that “how to”. The notion of an algorithm, and how we understand it, has become so important that perhaps all educated people should be familiar with it.

Historically, one talks of two revolutions that totally changed the world: the agricultural revolution and the industrial revolution. We are now in the midst of a third important revolution: the information revolution. This information revolution relies heavily on the processing and transmittal of information using computers and, therefore, rests on the intellectual disciplines that focus on the representation, manipulation, storage, and use of information and on the development of computers: computer science and engineering.

This information revolution promises to have just as much effect (both good and bad) on our culture and way of living as did the earlier two revolutions. It has already brought about marvelous products and services and has made the world a smaller place. All means of communications (for example, telephone, FAX, and e-mail), and all means of travel (for example, the shuttle, airplane, and car) rely heavily on comput-
ing these days. At the same time, the information revolution has made the world a more complex and fragile place, and it has led to a more frenzied pace of living. We should be aware of both the good and the bad effects of "progress".

It is hard to predict the future changes that will be caused by the intellectual development of computer science and engineering and the transmittal of the results into products and services. But we do expect the next twenty-five years to be as momentous and exciting as the past twenty-five have been.

David Gries, a professor of computer science at Cornell, is a specialist in programming methodology, programming languages, and compiler construction, and is author or coauthor of three books on these subjects. Currently he is working on a new programming language and a new undergraduate text on programming and discrete mathematics.

Gries was educated at Queens College (B.S. 1960, the University of Illinois (M.S. 1963), and the Munich Institute of Technology (Dr.rer.nat. 1966). Before joining the Cornell faculty in 1969, he was a mathematician-programmer in Kahlgrén, Virginia, and taught at Stanford University. He has spent sabbatical leaves at the Munich Technical University, as a Guggenheim fellow at Oxford University, and at the University of Texas in Austin.

In 1986 he received the Education Award of the American Federation of Information Processing Societies (AFIPS). In 1990 he received the annual award for contributions to computer science education from the Association for Computing Machinery. Also last year he was elected a fellow of the American Association for the Advancement of Science.

Paul L. Hartman
Applied and Engineering Physics

A quarter of a century is time enough for the world to become almost unrecognizable. This is true of science and technology no less than of society and geopolitics.

In the School of Applied and Engineering Physics, the undergraduate curriculum, which stresses the physics needed in engineering, along with mathematics, has not changed greatly. Engineers do not yet need to know quark and high-energy physics, although quantum mechanics has entered their world. But the technology part of our curriculum—applied physics—has indeed broadened widely.

This has occurred in perhaps no field more than in optics, which is still pretty much wave optics but at a level of sophistication well beyond that of 1966. Today it plays a large role in much of engineering—in communications (where copper wire is rapidly being replaced by optical fibers), engineering holography, data (and music) storage, and mensuration. And research in nonlinear optics is finding numerous applications.

Leaning on quantum ideas, we have tunneling phenomena in superconducting junctions, leading to extremely sensitive magnetic field detection; we have the tunneling microscope, providing surface topography on an atomic scale; and, while not yet fully understood, we have high-temperature superconductors with computer and machinery applications not yet dreamed of.

Chaos has entered our vocabulary through phenomena such as turbulence and dynamic instabilities, but while there are some pretty and fascinating experiments, chaos is still largely in the domain of mathematics.

By 1966 the transistor and the laser were
“...roughly twenty-five years ago, almost overnight, [the use of integrated circuitry] in computers and calculators made antiques of the engineer's slide rule and gear-driven calculator.”

from the use of x-rays that are now generated as a byproduct in the operation of high-energy electron synchrotrons and storage rings. The Cornell High Energy Synchrotron Source (CHESS) is one of the best machines of this kind in the world.

Problems of energy supply have become increasingly pressing over the last quarter century. Plasma researchers have made progress in the development of hydrogen fusion machines for power production, although reaching that goal is still ahead of us. The use of fission reactors for power production, so promising at the beginning of this period, is today in abeyance and decline, but it cannot remain so; safer designs are in the works and a resurgence will come. Fossil fuels have their disadvantages, global warming among them. Not that nuclear fuel is all that benign: the problem of waste-product disposal is still with us, as it was in 1966.

Would we today recognize technology as it will be in the year 2016? Can we anticipate what the world will be like? Probably not, but we can say that whatever changes take place, engineering as applied physics will have had a hand in shaping that world.

Paul L. Hartman, an emeritus professor of physics and of applied and engineering physics, first arrived at Cornell in 1934 after graduating from the University of Nevada with a degree in electrical engineering. After earning a Ph.D. in physics in 1938, he was an instructor for a year, worked for seven years at Bell Telephone Laboratories, and then returned to Cornell in 1946 as a member of the physics faculty.

At Cornell he helped establish the engineering physics program and when a new department in that area was formed, he became a member of it as well as of the physics faculty. He participated in the development of the experimental facilities at the Cornell High Energy Synchrotron Source (CHESS) and the program of the Laboratory of Atomic and Solid State Physics. Since his retirement in 1983, he has continued to be active in these areas and in writing histories of physics and of applied and engineering physics at Cornell.

He has served as a consultant to the Hughes Aircraft Company and the Los Alamos Scientific Laboratory, and spent leaves and summers at those facilities. He has been an editor of the Review of Scientific Instruments.
When reflecting on the changes that have taken place in mechanics in the twenty-five years since the founding of this magazine, I am tempted to say: nothing. Yet on further reflection, it sometimes seems that everything has changed.

Mechanics still plays a major role as interpreter to the traditional engineering disciplines of the newest developments in the "purer" studies of, for example, physics and mathematics. We continue to focus our energies and intellects on the general rather than the specific character of the mechanical behavior of materials, mechanisms, and structures. Our undergraduate and graduate students, as in the past, help us build experiments that provide answers to basic questions; they contribute, through their facility with classical methods of applied mathematics, as well as modern computers and software, to our understanding of the details of the thermal/chemical/electrical/mechanical behavior of models of materials and structures.

Many of the subjects of study have changed in twenty-five years, however. Such contemporary topics as advanced composite materials, chaos, materials for electronic packages, nonlinear dynamical systems and "strange attractors", and applications of the theory of neural networks to nondestructive testing are frequently discussed over coffee in the lounge and during the traditional Friday faculty lunch in Collegetown. We now talk less of beams and plates and Timoshenko, and spend more time exploring the subtleties of Poincaré's theories. . . .

"We now talk less of beams and plates and Timoshenko, and spend more time exploring the subtleties of Poincaré's theories. . . ."

"red clay" of real engineering, is as exciting intellectually as it always has been. The challenges of developing a clear and accurate "engineering description" of the fundamentals of the behavior of the world around us are unabated.

Richard H. Lance has been a member of the Department of Theoretical and Applied Mechanics since 1962.

He has served as acting chairman of the department twice, and he was the college's associate dean for external affairs (1974–1980) and associate dean for undergraduate programs (1981–1986).

Lance earned a bachelor's degree in mechanical engineering at the University of Illinois at Urbana-Champaign, an M.S. at the Illinois Institute of Technology, and a Ph.D., granted in 1962, at Brown University. Between periods of study, he worked as an engineer at the Minneapolis Honeywell Company and at the Ingersoll Milling Machine Company, and served in the armed forces.

While on sabbatical leaves, Lance has been a visiting professor at the University of Edinburgh, and a senior scientist at Hughes Aircraft Company. He has been a consultant to the IBM Corporation.
The Great Northeast Blackout of November 9, 1965, and its aftermath precipitated an unprecedented examination of the nation's electric-energy supply facilities. Consumers lost their faith that electric power would always be available at the flick of a switch. The energy crisis of the early 1970s and the lack of new generating capacity as a result of unanticipated difficulties with planned nuclear power stations were additional factors that moved the electric-utility industry to correct deficiencies in its system operations.

An effective and relatively quick solution to the problem of potential reductions in power-system reliability was to construct very-high-voltage (345 to 765 kV) transmission lines to serve as solid ties between major power systems. During the twenty-five years that have passed since the Blackout, this interconnected-network mode of operation has become the mainstay of bulk electric-power transmission in the United States.

System engineers soon found that the resultant stiff grid was not only useful in helping to prevent large-scale outages during emergencies, it also could allow bulk power to be "wheeled"—that is, transferred from point to point within a system and from one system to another—to meet demand requirements. When coupled with modern computerized control facilities, the expanded grid has been able to offset the lack of new generation by taking advantage of regional differences in demand. Consequently, the interconnected networks could become an "interstate transmission highway" where, in principle, all connected loads could be supplied by the network, which, in turn, would draw power from discrete input points. This potential capability is of particular interest to so-called "co-generation" facilities, where excess capacity from local non-utility generators is available for sale either to the utility or to specific customers. Thus far, operational problems and regulatory disputes have limited the general adoption of this open-market concept.

Since technological and economic factors limit the feasible lengths of ac transmission lines to between one hundred fifty and three hundred miles, long-distance high-voltage direct-current (HVDC) lines have become accepted as useful alternatives. HVDC lines can be a thousand or more miles long, and can act as stabilizers for ac systems. They also permit power transfer between the western and eastern networks that, because of the Rocky Mountain barrier, cannot otherwise be interconnected. Additional modifications to transmission capability will result eventually from current research on underground superconducting and gas-insulated...
Simpson Linke, a professor of electrical engineering, emeritus, came to Cornell as a graduate student in 1946, after earning a bachelor's degree at the University of Tennessee, working with the electric utilities board in Knoxville, and serving in the Army Signal Corps during World War II. He received the M.E.E. degree in 1949 and joined the faculty at that time.

At Cornell he supervised the Power Network Calculator Facility until 1960, and later served as assistant director of the Laboratory of Plasma Studies. He collaborated in the establishment of a program in power systems engineering at the School of Electrical Engineering in 1983. He retired in 1986.

During the 1970s, Linke chaired the International Symposium on the Hydrogen Economy, held at Cornell, and a joint Cornell–Los Alamos Scientific Laboratory Seminar on Superconducting Magnetic Energy Storage. He edited a series of proceedings of symposia held in connection with the 1985 centennial celebration of electrical engineering at Cornell.

Daniel P. Loucks
Civil and Environmental Engineering

More than twenty-five years ago, I came to Cornell as a graduate student on the advice of the current dean of the university faculty (Walter R. Lynn, a professor of civil and environmental engineering), who persuaded me to work in a new—at least to civil engineering—subject area called systems analysis and its application to environmental and water resources management. I was told that systems analysis involved mathematical models and computers, and was a way to integrate economics into engineering management and decision-making. It was an approach to simulating and finding optimal solutions to problems involving the design and operation of large complex multivariate systems (whatever they were). All I had to do was to learn some mathematics, economics, computer programming, and environmental and water resources engineering. Twenty-five years ago I thought I could.

So what has happened over these past twenty-five years? With the help of our colleagues and students, those of us in this field have managed to learn enough to be able to introduce systems analysis to every undergraduate who studies civil engineering at Cornell. At most major universities throughout the world, systems analysis has become a subject area studied by everyone interested in environmental and water resources management.

But we have learned that there is much more than economics and technology that influences engineering management decisions. We have learned that it is impossible to identify optimal solutions to real problems involving real people with differing interests, values, or goals. Nevertheless, management agencies are increasingly asking for information related to decisions they must make and the impacts that may result from those decisions. They want to know what will happen if they do A or B and who will care. Those questions are getting more comprehensive, are involving more disciplines, and hence are becoming much harder to answer. This is what drives our continuing research.

In the past twenty-five years we have seen enormous improvements in the mathematical and computational resources that we can apply to our work. We have come a long way from the days of punching out our computer programs on cards or paper tape.
But the complexity of our problems seems to have increased accordingly, and it will take more than supercomputers and sophisticated algorithms to solve many of them.

For example, while we have generally mastered the management or control of oxygen and oxygen-demanding wastes in rivers or lakes, we know little about how to manage the amounts of water, nutrients, and toxic substances entering wetlands and their impacts on deer and wading birds. (This is currently an issue in a major lawsuit in southern Florida.) Understanding and modeling the interactions between the ground and surface waters and all the substances in those waters in the detailed time and space scales required is difficult enough. Add to that the even more difficult task of modeling and predicting the complex ecology of those interdependent subsystems. This is only one example of the challenges our current graduates are being asked to meet.

Today in many countries water management is a major component of the national economy. For example, among other events taking place in the Middle East, construction projects costing billions of dollars are underway to pump, transport, and use the “fossil” water found in very deep aquifers. The water to be obtained will be somewhat like oil, in that it will be very expensive and once it is gone, cannot be replenished. The conflict between Israel and Jordan over the West Bank is not just about who is to occupy the land; it is also over who is to control the underlying aquifers, currently a major source of Israel’s fresh water. And, of course, we observe (as I write this) the critical drought situation in southern California, where some residents of Santa Barbara have been photographed painting their dead grass green. (Water management issues can really be serious!)

If our young engineers are going to play a leadership role in helping to build a better society, it seems to me they will need a broader education than they now receive in a four-year program. Some twenty-five years ago, Cornell had to drop its five-year undergraduate engineering degree program. Today I believe Cornell should be joining other major engineering universities to work toward establishing engineering throughout the country as a graduate program.

Engineering, like business, law, and medicine, should be a profession requiring postgraduate education. This would allow our undergraduates more time to explore the liberal arts as well as the physical, biological, social, and engineering sciences. It would allow graduate students more time to learn the multidisciplinary art as well as the science of engineering, and to consider what we as engineers can do to improve our society and our natural environment. I believe our engineering graduates will increasingly need this additional liberal as well as professional training and knowledge if they are to be among those who lead us in defining the direction of our future development and in implementing that development over the next twenty-five years.

Daniel P. Loucks, a Cornell Ph.D. and professor of civil and environmental engineering, joined the faculty here in 1965 after completing his doctoral studies. He earned his B.S. degree at Pennsylvania State University and an M.S. degree at Yale University.

A specialist in environmental systems engineering, including water resource planning and environmental control, Loucks has worked with the World Bank, the International Institute for Hydraulic and Environmental Engineering, and the International Institute for Applied Systems Analysis, and he has been a consultant to a number of government and international organizations concerned with resource development and management. He is currently advising the International Institute for Applied Systems Analysis, the United Nations, and the North Atlantic Treaty Organization on several projects in Africa and Europe.

At Cornell he has served as associate dean for research and graduate education at the College of Engineering, and as chairman of the environmental engineering department (now integrated into the School of Civil and Environmental Engineering).

Loucks is a recipient of the Walter L. Huber and the Julian Hinds awards of the American Society of Civil Engineers. He is a member of the National Academy of Engineering.
Reflections from twenty-five years ago:

- Industrial Engineering and Operations Research (IE&OR) had recently (in 1963) broken off from Mechanical Engineering to form a separate department, and already a new Department of Computer Science was in the making, growing out of IE&OR. Don Iglehart was soon to depart for Stanford, which was to become our arch rival in operations research.

- In 1967 IE&OR became a school, with Byron Saunders, who had chaired the department, as director. Bob Bechhofer headed the newly formed Department of Operations Research and nurtured its growth to preeminence. (In 1975 the school was reorganized under its present designation of OR&IE.)

- The school’s undergraduate program attracted large numbers of students—I recall teaching a class of one hundred seniors in 1967. The M.Eng. program was much stronger than it is now, with ample support for students. There was federal support for U.S. students at the Ph.D. level, and we were able to attract the very best; some of these are now leaders in our field.

- The Burroughs 220 and the CDC 1604 were our computing engines for the entire campus; they were something like a fast PC in horsepower.

- Dick Conway, Bob Walker (of the mathematics faculty) and I embarked upon CUPL, the predecessor of PL/C and current instructional computing languages.

Today’s OR&IE undergraduates work on projects in the new microcomputing laboratory.

- Dick Conway (then of the computer science faculty and now of Cornell’s Johnson Graduate School of Management) and I were finishing the work on our book, The Theory of Scheduling, which is a classic; it is out of print, yet still relevant.

- The Burroughs 220 and the CDC 1604 were our computing engines for the entire campus; they were something like a fast PC in horsepower.

- Dick Conway, Bob Walker (of the mathematics faculty) and I embarked upon CUPL, the predecessor of PL/C and current instructional computing languages.

William L. Maxwell, the Andrew Schultz, Jr. Professor of Industrial Engineering, is currently associate director for graduate education in the School of Operations Research and Industrial Engineering.

He was educated at Cornell, earning the B.M.E. degree in 1957 and the Ph.D. in 1961, and has been on the faculty since 1960. He has been a recipient of the Excellence in Teaching Award at the College of Engineering.

During leaves, Maxwell has been a consultant in residence at the RAND Corporation, General Motors Manufacturing Development, and SI Handling Systems, and he is currently a consultant to several companies. He has held visiting professorships at the University of Michigan, the Wharton School of the University of Pennsylvania, and Stanford University.
Gerald E. Rehkugler  
Agricultural and Biological Engineering

In August 1966, when I returned to Cornell with a fresh Ph.D. after a two-year hiatus at Iowa State University, a new era in teaching had begun. I had previously taught several courses in agricultural engineering, and in some even taught the use of the slide rule. But in 1966 I had access to the computational power of the mainframe computers, albeit accessed via punch card and batch processing. (It was only a few years ago that I threw away the last of those punch cards from my earlier teaching modules.) And now on my desk and on many students' desks we have the computing power that was available only in the mainframes a decade or two ago.

Instrumentation for teaching in the 1960s and early 1970s remained quite primitive. It was always a test of ingenuity to set up a laboratory and obtain useful data within the two and one-half hours allotted. Stability of the signal output of most of our devices was nonexistent. The standard procedure for obtaining each data point was: balance, calibrate, read, and then repeat the process again and again.

An example of the evolution of teaching a lab course is illustrated by an exercise in traction testing that I taught with an agricultural tractor. In the 1960s and 1970s, when we wanted to measure traction versus wheel slip, we used a stopwatch, a hydraulic dynamometer, and a steel measuring tape. Each student had a task and everything was recorded on 10-column data sheets, which we shared by hand-copying at the end of the tests. It took most of the afternoon to get enough data for a few curves; obtaining answers to “What if?” questions was impossible in the time available. Today that same test is conducted with slip sensors, ultrasonic or radar speed measurement, an electronic dynamometer, and a digital data-acquisition system. Output of the results can be obtained in minutes and each student can access an electronic file of the results. “What if?” questions can be explored and answered in minutes rather than hours. We believe that these advances in technology have increased the effectiveness of teaching and learning, as well as research.

All of this has caused me to reflect on the influence of technological and scientific advances on both my teaching and student learning. With the proper use of technology, I now have the capability to condense, present, and interpret information with

“[Today] output of the results can be obtained in minutes [and] ‘What if?’ questions can be explored and answered in minutes rather than hours.”
greater ease. However, the sorting process is much more difficult because of the immense glut of information. We have the tools to do things right, but unfortunately, we have a more difficult time being leaders in education by doing the right things. For instance, now we teachers can expect laser-sharp graphs and reports from our students, but neither we nor they may have concentrated on the understanding and the insights that are at the core of education.

In spite of all our technological advances, I believe that the fundamental process of teaching remains the same as when I started in the 1950s: (1) Establish your instructional objectives. (2) Assemble strategies and delivery systems to achieve those objectives. (3) Measure and monitor the progress toward meeting those objectives. (4) Readjust, improve, and modify on the basis of feedback and further insight. The delivery systems have changed, but the process remains.

The other essential factor in the educational process is the student-teacher relationship. Regardless of the times, the technology, or the system, the student and teacher must be mutually motivated and sharing in the learning process. This rapport is a timeless characteristic of education and when you have it, there is lasting satisfaction.

Thus I conclude that although I have had the satisfaction of participating in the technological development of fruit and vegetable harvesting equipment that has eliminated back-breaking labor for thousands of people, the most pleasure comes from the encounter with the former student who says, “Yes, I had you in Course xxx. That was a great course and I really found it useful.”

Edwin L. Resler, Jr.
Mechanical and Aerospace Engineering

“Aeronautical to Aerospace and Beyond,” my subject here, calls for more than the page or so suggested for these Reflections, and the account needs to begin earlier than the target date of 1966. I have been granted a little more leeway in my remarks. My story begins in the fall of 1946, when the Graduate School of Aeronautical Engineering was founded at Cornell. Its first director was William Sears, previously of Northrop Aircraft, where he was chief aerodynamicist. He brought with him John Wild; the two of them had participated in the design and building of the Black Widow fighter and the Flying Wing. They were joined by Arthur Kantrowitz from the NACA (forerunner of NASA) Langley Field Laboratories; Y. H. Kuo, a Cal Tech graduate; and Carlo Riparbelli. Already here was Fred Ocvirk of “short bearing fame”. The team was completed by Alice (Toni) Anthony, now administrative associate of the Sibley School of Mechanical and Aerospace Engineering, who was the earliest arrival, after Sears, and still looks after the school’s graduates.

The first class to enter that school was made up primarily of World War II veterans who had either flown or maintained aircraft. Most of the chatter among those classmates was about their wartime experiences. The change from soldier to student was accomplished with great difficulty, but outstanding faculty members within and outside the school were on hand. For instance, Sears arranged that Richard Feynman, who was then at Cornell, would teach the students the mathematics they needed. Those early students formed a flying club and somehow managed to acquire a small airplane, and since there were a number of instructors in
1. Toni Anthony and founder William Sears were photographed at one of the early annual picnics of the Graduate School of Aeronautical Engineering, established in 1946. Toni Anthony is currently the administrative associate in the Sibley School of Mechanical and Aerospace Engineering.

2. Most of the members of the initial faculty appear in this photograph (loaned by Toni Anthony). From left to right are David Sears, Y. H. Kuo, John Wild, William Sears, Arthur Kantrowitz, and Carlo Riparbelli. Fred Ocvirk was also a member of the first faculty.

3. William Sears and John Wild helped design the YB-36 Flying Wing—precursor of today’s Stealth aircraft—before they came to Cornell. (The picture of the Flying Wing, 3a, is from a glass transparency loaned by Resler. The photograph of the F-117 Stealth, 3b, was provided by Aviation Week and Space Technology.)

4. Sears returns to Cornell each year for the distinguished lectureship series that has been established in his honor. In this 1985 photograph he is greeting old friends (including Thomas Gold, at center). Sears piloted his own plane on the trip from his home in Arizona.
"Students in the school very quickly achieved Mach number flows greater than their age, but it took a number of years before they achieved Mach number flows greater than their weight."

the class, a majority of those at the school who were not already pilots learned to fly. This included members of the faculty.

The oldest member of the school in those days was not a faculty member, but a student—he had been a wing commander in the Canadian R.A.F. The youngest, called "Junior", was fresh out of the Navy, where he was the assistant engineering officer at the Miami Opa Locka Naval Air Station: the author of this piece.

The aircraft in those days were all propeller-driven. The students usually arrived at Cornell via the Lehigh Valley Railroad, but if they came by air it was via a twin-engined Beechcraft on Robinson Airlines. (Robinson Airlines later became Mohawk, then Allegheny, and is now U.S. Air.) The school had acquired a Link trainer for the DC-3, as well as one of the first jet fighters, "Smokey Stover", and also a partially completed P-49. The Link trainer was popular at parties. It was finally given to Mohawk so they could train their pilots to fly the DC-3s they had acquired.

The students were enrolled in a two-year master's degree program. Their theses were on automatic controls, boundary-layer control, combustion, shock tube studies, and wave engines. The first graduating class went out and participated in the design of the DC-8 and the Boeing 707, the first jets used in commercial service.

In the ensuing years the interests of the school became more wide-ranging. John Wild participated in the design of the Air Force's Arnold Engineering Test Center (he subcontracted much of the work to the students so they could earn extra funds); he became the Center's first Chief Engineer and so became the first faculty member to leave the Cornell school.

The shock tube technology developed by Kantrowitz and his students was used to help solve the reentry problem for ballistic missiles. (Missile ranges in the early 1950s were around 150 miles, not the 6,000 miles of those in the silos today.) Kantrowitz left Cornell to found the AVCO Everett Research Laboratories; the majority of the employees were Cornellians. The lab designed, and AVCO built, and still does, reentry nose cones for the long-range missiles. Other Cornell graduates of the school were engaged in similar studies at the General Electric Space Laboratory in Valley Forge, Pennsylvania, and the Cornell Aeronautical Laboratory in Buffalo, New York, which was then owned and operated by Cornell (it later became Calspan, Inc.). In those days "High Mach Number" was the buzzword. Students in the school very quickly achieved Mach number flows greater than their age, but it took a number of years before they achieved Mach number flows greater than their weight. When Kantrowitz left Cornell in 1956, I returned, this time from the Institute for Fluid Dynamics and Applied Mathematics at the University of Maryland.

It was an exciting time at Cornell. Bill Gordon and Henry Booker were designing the huge radio-radar telescope that was subsequently built near Arecibo, Puerto Rico, in the early 1960s. It was thought that the ionosphere surrounding the earth might emit waves or "jiggle" if an enemy long-range missile were to pierce it, and Sears and I were involved in the project to estimate such an effect. It turned out that the "jiggle" was not detectable, and the telescope was then free for radio astronomers to use to study quasars and other far-off heavenly bodies, and also to map out the contours of the moon in preparation for moon landings. At about this time, Tommy Gold, an old friend of the school, joined Cornell officially; later he founded the university's space center.

The field of magnetohydrodynamics became popular and was pursued by many graduates of the school. Various magnetohydrodynamic generators and pumps were designed and built with varying degrees of success. This work at Cornell led to the establishment in 1967 of the Laboratory of Plasma Studies, a cooperative venture of the university and the Naval Research Laboratory. The first director was Peter Auer of the aerospace engineering faculty. New projects at the lab resulted in new personnel in astronomy, electrical engineering, and engineering physics, as well as in the Graduate School of Aerospace Engineering, as it was then called in accord with the growing interest in aerospace technology.

The shock tube techniques that were developed to study the reentry problem were adopted, refined, and improved by members of the chemistry department, chiefly Simon Bauer. (The cooperation extends to this date, although Bauer officially retired a number of
The huge radio-radar telescope near Arecibo, Puerto Rico, was designed at Cornell and built in the early 1960s, and has been upgraded since then. It is now operated by Cornell under an agreement with the National Science Foundation.

years ago.) Work done at Cornell aided the development of the high-powered laser, the “death ray” of early “star wars” developments. The patent for the gasdynamic CO\(_2\) high-powered laser is held by four persons, three of them veterans of the Aero School.

One of the first artificial heart pumps was built in the shop of the Aero School. It was designed by Kantrowitz and used in animals by his brother, who was on the staff of a New York hospital. Much was learned from the early experiments, and the work continued at the AVCO research laboratory in cooperation with Massachusetts General Hospital in Boston. Heart pumps and artificial hearts, now routinely used, and also other medical devices, are being designed and manufactured by graduates of the Aero School.

The faculty of the school participated in the formation and growth of the Department of Engineering Physics (now the School of Applied and Engineering Physics). And in 1963 Sears founded and became involved in the Center for Applied Mathematics at Cornell; while remaining on the Aero School faculty, he turned the directorship over to me. Later Sears joined the faculty of the University of Arizona.

At about that time, research at the school included work on the design of the United States supersonic transport, especially the sonic-boom aspects of the program. While on sabbatical, I worked on exotic propulsion schemes for submarines (such as portrayed in *The Hunt for Red October*) and began the early development of ferro-fluids, which are now produced by Ferrofluidics Corporation and play a role in audio equipment, computers, farm machinery, vacuum seals, etc.

Some members of the faculty became interested in the flow of fluids in the interior of the earth and one—Donald Turcotte—joined the Department of Geological Sciences and later served as its director. (A standing joke in that department, he has said, is that he is the only member who never studied geology.)

Nicholas Rott participated in propulsion studies sponsored by Ramo-Wooldridge; the schemes involved plasma propulsion, magnetohydrodynamic propulsion, and the use of liquid hydrogen. Also participating in this project was the present mayor of Ithaca, Emeritus Professor Ben Nichols. Rott left Cornell and ultimately became director of the Institut für Aerodynamik in Zürich. Another member of this group, Richard Seebass, followed Sears to Arizona; he is now dean of engineering at the University of Colorado.

In 1972, at a time when the novelty of space was wearing off, the Aero School and the Sibley School of Mechanical Engineering were merged to form the Sibley School of Mechanical and Aerospace Engineering. I became the first director, Al George became the second, and the incumbent, Frank Moon, is the third. Moon works in aerospace structures and the new field of chaos; Tob de Boer, the present associate director, is working on plasma ignition of jet engines for restart at high altitudes.

Another Sibley School professor who was a member of the Aero School faculty is Shan-Fu Shen, a member of both the Academy of Sciences of China and the National Academy of Engineering of the United States. Shen did extensive work in the field of the aerodynamics of rarefied gases and has continued to develop the theory of boundary-layer separation, a phenomenon to be avoided by any worthy aircraft. He participated also in the Cornell Injection Molding Program at the Sibley School, applying his expertise in
viscous flow to the flow of molten plastic on its way to being formed into useful products.

I have mentioned only some of the projects worked on over the years by a few of the faculty members who were associated with the old Aero School. Another story worth telling would be that of the school’s graduates, who have become leaders in their field throughout the world. An early graduate, Frank Moore, went to the Cornell Aeronautical Laboratory and became the director of the Aerosciences Division there before returning to Cornell as a faculty member in 1965 (he is now the Joseph C. Ford Professor of Mechanical Engineering). Another graduate, Lewis Crabtree, served as president of the Royal Aeronautical Society; and Gerald Marsters is now the director of the National Aeronautical Establishment of the National Research Council of Canada. Other graduates are active in China, Japan, Germany, France, England, Canada, Australia—whenever the boundaries of space projects have been extended.

What is on the horizon? With the rapid growth of computer technology, aircraft and spacecraft can be designed more quickly and effectively, requiring much less testing. The aircraft being designed today will fly faster and higher and more safely. The spacecraft will explore further in our solar system, but to do so will require better propulsion units, maybe utilizing plasma dynamic systems and magnetohydrodynamics.

Flying higher and faster has opened new environmental problems—namely, the effect of engine exhaust on the ozone layer and the noise generated by the larger engines around airports. Work in the Sibley School that was directed toward the control of automobile exhaust emissions can be built on to help solve problems of emissions from future jet aircraft.

Since 1947, materials used in engines have improved immensely, as have the methods of using them in jet engines. Present engines utilize single-crystal, aerodynamically cooled blades, but because these blades are not good enough for the engines now being designed, replacing material blades with waves, which neither melt nor break but accomplish the same task, is again being considered. It’s back to the wave engine! This time, however, we have thirty years’ experience in appropriate aerodynamic theories and the aid of supercomputers.

Since the founding of the Aero School, many of humanity’s dreams have been realized. Men have walked on the moon and returned safely, probes have explored the reaches of our solar system and beyond, and jet airports resemble the bus stations of yesteryear. Present projects are concerned with realizing the dreams for the year 2000 and beyond. The fulfillment of these dreams will no doubt be accomplished with the help of people trained by alumni of the old Aero School.

Edwin L. Resler, Jr., came to Cornell in 1947 after graduating from Notre Dame University, and received his Ph.D. in aeronautical engineering in 1951. He taught at Cornell for a year, and after four years at the Institute for Fluid Dynamics and Applied Mathematics of the University of Maryland, he returned to Cornell in 1956. Currently he is the Joseph Newton Pew, Jr. Professor of Engineering.

Resler worked on the early design of wave engines and in the areas of shock-tube research, magnetohydrodynamics, and ferrohydrodynamics. A number of patents resulted from studies pertaining to the control of combustion and the elimination of pollution in automobile engines. He is currently working on jet-propulsion systems for aircraft and space vehicles.

He has spent leaves at the AVCO Corporation, Pratt and Whitney’s Advanced Engine Design Group, and NASA’s Lewis Research Center. He has been a consultant to many industries.

He is a fellow of the American Institute of Aeronautics and Astronautics. He has served as an editor of various professional journals, as chairman of NASA’s Advisory Committee for Fluid Mechanics, and as chairman of the Magnetohydrodynamics Committee of the American Rocket Society.
One memorable word of advice was whispered to Dustin Hoffman in the 1967 movie The Graduate. That word was plastics. The advice would have been well worth taking, for the use of plastics, the fastest growing sector of the polymer industry, has indeed boomed in the last quarter century. United States sales went from 10.5 billion pounds in 1965 to 58 billion pounds in 1990.

Of the other polymer-based industrial sectors, synthetic fibers also grew. Whereas in 1965 more cotton was used than all synthetic fibers put together, in 1990 mill usage of polyester alone exceeded that of cotton. Uses for coatings, adhesives, and rubber have grown at a slower pace, but even with these, the advances in polymer technology are readily apparent to consumers. Today's radial tires last twice as long as the old bias-ply tires, super glues and silicone adhesives are commonplace, and latex-based coatings have taken over many outdoor paint markets and almost all the indoor paint markets.

These innovations have been primarily the result of work by chemists and chemical engineers who are the technological backbone of the American chemical industry supplying consumer needs. Except for the development of some exotic composites and certain fibers, very few of the advances in polymers have been driven by military applications.

To keep pace with industrial advances, the number of course offerings in chemical engineering at Cornell has grown. In 1966 a polymer program—including undergraduate and graduate courses that Charles C. Winding had established in the 1940s—was already in place, but over the past twenty-five years there has been considerable growth in both supported research and specialty courses in the areas of polymer physical science (Professor Claude Cohen) and polymers for electronic applications (Professor James R. Engstrom and I). In addition, the importance of synthetic polymers has been recognized by people in other fields of science and engineering at Cornell.

With the dramatic growth of plastics in bottles and other forms of disposable packaging, a fresh challenge is apparent in the new industry of recycling, still in its infancy. It would be foolhardy to abandon the safety, economy, and convenience of modern packaging, most obvious in foods and medicines. But reduction of the small yet highly visible fraction of polymers in municipal waste is a realistic goal, and chemical engineers, with their knowledge of the chemistry and physics of polymeric materials, are leading the effort to find ways of achieving it.

Ferdinand Rodriguez, professor of chemical engineering, earned his doctorate at Cornell in 1958 and became a member of the faculty that fall. He had already earned B.S. and M.S. degrees at Case Institute of Technology and worked for four years at the Ferro Corporation. He is a registered professional engineer in Ohio.

He has spent leaves in industry—with Union Carbide, Imperial Chemical Industries, and Eastman Kodak—and (in 1985) at Queen Mary College, University of London.

At Cornell Rodriguez is associated with the National Nanofabrication Facility through his work on advanced lithography.

He is a fellow of the American Institute of Chemical Engineers.
It was in 1955—eleven years before the advent of Engineering: Cornell Quarterly—that I arrived at the Cornell College of Engineering. What was it like at the college then? The faculty was dedicated to teaching undergraduates; there was little research underway. Usually the parents of the undergraduates paid for most of the students' education. The students understood the source when you quoted from Hamlet, cited Seneca or Marcus Aurelius, or referred to classical Greek art or the Renaissance. The administration was capable of providing free parking. At Cornell freedom of speech was practiced and strongly defended and we were free of social engineering.

What is the college like in 1991? We now have a major research effort; there are currently 801 graduate students in M.S./Ph.D. programs in engineering, and 247 in the professional Master of Engineering program. We have new departments, including Materials Science and Engineering, which was established in 1965; in MS&E we now have an undergraduate program (rated first in the nation in the Gourman report) with twenty-five or thirty seniors graduating each year. Our students are bright, but I find they are less knowledgeable in mathematics and liberal arts than students used to be. Parking is inadequate and expensive. The "politically correct" syndrome is prospering at Cornell and is the most serious threat to free speech since the time I arrived on campus.

There are now major facilities that make Cornell a mecca for research in materials science. These include the Materials Science Center, the Cornell High Energy Synchrotron Source (a national resource), the National Nanofabrication Facility, and the Cornell Theory Center (which includes a national supercomputer facility). These, and the research performed, are primarily supported by the federal government, but close to 20 percent of our research support now comes from industry, much of it via the Cornell Ceramics Program, the SRC Program on Microscience and Technology (Cornell is a SRC "center of excellence"), and the Industry-Cornell Alliance for Electronic Packaging.

In our department we have expertise in ceramics, metals, polymers, and semiconductors, and on materials for structures large and small: composites for airplanes, for example, or carefully made materials for computer chips. We have achieved static pressures greater than those at the center of the earth, carried out x-ray diffraction on samples as small as 10^{-11} cubic centimeter, and studied polymer interdiffusion with use of Rutherford backscattering. Our research is internationally respected.

Of our more than one hundred Ph.D. students, about 25 to 30 percent are foreign—the best and brightest from their native lands. Since many of these foreign students remain in the United States, this constitutes a giant brain drain—a lend-lease in reverse. If better United States applicants were available, we'd take them. Our criterion is: excellence. A great department, a great college, a great university, and a great country owe their eminence to a relentless drive for excellence.
Andrew Schultz, Jr.
Operations Research and Industrial Engineering; Dean, 1963–72

Twenty-five years ago, when Engineering: Cornell Quarterly was started, our immediate objectives at the college seemed obvious and accepted. The goal was to put the Cornell University College of Engineering in a position to play an important role in modern engineering education and in the research and technology essential to it. This required development of new standards for faculty recruitment and tenure decisions, as well as for graduate-student admissions. It also required a curricular structure that made it feasible for the faculties of the various schools and departments to respond to societal needs as well as to scientific and technological developments, and thereby to provide opportunities attractive to excellent undergraduates, wisely selected. Publications, procedures, faculty seminars, committee activities, and administrative structural changes all played a role in these endeavors, which were largely successful.

One change, instituted shortly before the Quarterly began publication, was a change from the five-year undergraduate curriculum that had been in place since 1946—a curriculum that led to a bachelor’s degree in one of the engineering schools—to a four-year Bachelor of Science program followed by an optional one-year professional Master of Engineering program in a particular field. The idea behind the five-year curriculum was that this length of time was needed to provide students with both an adequate foundation in science and technology and sufficient opportunity to explore social and environmental issues. For many reasons, the five-year curriculum had become less attractive, however, and so the program was restructured: There are two decision points—one after two years of basic study, when the student chooses an undergraduate field in which to concentrate, and another after four years, when the B.S. degree is awarded and the student has the opportunity to select a professional field in which to pursue a year of graduate study concentrated on advanced technology and design and culminating in an M.Eng. degree. This program is educationally sound, offering an opportunity for the student to experience the design process in a realistic environment, and although it has required some time to become widely understood and recognized, it appears to be well accepted now.

What changes in engineering education are needed today? There is no question that the country and therefore the profession face serious challenges in modern economic competition. The problems are complex and intractable, with political as well as technological aspects. The United States is preeminent in scientific and technological advancement, but once the developments are in process or completed, they seem to be adopted much more rapidly in other industrial economies. In the United States the linkages between academia and industry are somehow more limited than they should be, and the nation pays the price for this, not only in the loss of markets, but also in diminished ability to sustain superior technological and scientific development in related areas.

In my time, I was quite familiar with two developments that illustrate this difficulty. In each case, a generation was to pass before the ideas were adopted by a significant number of industries.

One is the concept of statistical quality control. This was originally developed within Bell Laboratories and was fully exposed in the late 1920s and early 1930s in various publications, including a book by W. A. Shewhart. By 1946, accelerated without doubt by federal intervention in World War II, a significant number of large industrial firms had become familiar with the technology and were applying it. Unfortunately, many discarded it after the war was over.

The second concept is that of work simplification, which was introduced by a Cornellian, the late Allan Mogensen. Again, there was a gap of almost a generation before the idea was adopted and implemented, even though Mogensen developed an educational program to hasten the process. By the 1950s, though, techniques of work simplification were used by a number of large corporate organizations.

These two concepts are the foundation of the Quality Circles so successful in Japan, and they have led to many other changes in management and personnel relations there.

With our ability at Cornell to carry out research and technological development in so many areas, a major challenge is to maximize the importance and the economic im-

“In the United States the linkages between academia and industry are somehow more limited than they should be, and the nation pays the price for this. . . .”
pact of the activities selected. Engineers and scientists in general enjoy the challenge of new problems and the process of solving them; however, selection of the important ones demands knowledge of the problems of industry as well as those of the specific field. Such knowledge is desirable for the classroom as well as for the research laboratory, and a major problem facing both colleges and industries is how to knit the kinds of relationships that produce the essential knowledge on both sides. Integrating their aims and implementing them effectively are important for both industry and education, and ultimately for the well-being of society.

In this space it is not possible to elaborate much on the breadth and depth of the industrial-productivity problem that faces the nation. But this problem does present a most serious challenge to us all, and extends beyond the limits of engineering education. Required for its solution are major changes in public policies, relationships between workers and management, and industrial organizational structure as well as financial and accounting systems and measures. These issues must be resolved before the country's abilities in research and technology can be fully realized.

Andrew Schultz, Jr., the Spencer T. Olin Professor of Engineering, emeritus, began his Cornell career as an undergraduate in administrative engineering (class of 1936), earned a doctorate in 1941, joined the faculty after World War II, headed the Department of Industrial Engineering and Administration for twelve years, and served as dean of the College of Engineering from 1963 to 1972 and as acting dean in 1978. Now living in Ithaca, New York, and Ponte Vedra Beach, Florida, he continues to be active in educational and professional affairs.

Schultz helped develop the new field of operations research on the basis of his wartime experience as an officer in the Office of the Chief of Ordnance, as well as a sabbatical leave spent at the Army's Operations Research Office. At Cornell he established the department that is now constituted as the School of Operations Research and Industrial Engineering. As dean he initiated and supported many educational and extracurricular innovations (including the establishment of Engineering: Cornell Quarterly).

He has been active also at the national level, particularly as a board member of the Engineers Council for Professional Development; as a member of the Commission on Education for the National Academy of Engineering; and as vice president and director of research for the Logistics Management Institute in Washington, and subsequently, for twelve years, as chairman of the Board of Trustees of that organization. In addition, he has been active as an industrial and educational consultant.

Schultz is a fellow of the American Institute of Industrial Engineers and the American Association for the Advancement of Science.

Norman R. Scott
Agricultural and Biological Engineering

Agriculture during the twentieth century has provided a bounty of low-cost, nutritious, and healthful foods for not only the United States, but the world. From the early part of the century, when the focus was on agricultural production, to the present, with its focus on the quality of foods and maintaining the environment, agricultural engineers have played a key role in the workings of a highly efficient food-producing machine.

The era of mechanization led to tremendous improvements in production efficiency during the 1940s and 1950s and into the 1960s. Following and overlapping this era of mechanization, agriculture experienced immense gains through "chemotechnology"—the development of inorganic fertilizers, herbicides, pesticides, and fungicides. Beginning in the late 1950s, but gaining momentum in the early 1980s, agriculture entered the era of biology. The promise of biotechnology to dramatically transform plant and animal agriculture is perceived as almost limitless.

Clearly, agricultural engineers were at the very heart of the era of mechanization, in the development of power units and equipment to create a mechanized agriculture that became the envy of the world. In fact, the tremendous success due to mechanization through advances in engineering research and design has led to a perception that agricultural engineers are "tractor engineers" or "tractor drivers!" Then, and today, agricultural engineers are frequently asked what it is they do. The question provides the agricultural engineer an opportunity to explain his or her role as an engineer applying scientific
"The promise of biotechnology to dramatically transform plant and animal agriculture is perceived as almost limitless."

expertise to any and all elements of the production of food, from the seed to the consumer.

Prior to the 1970s, education in agricultural engineering consisted of a broad engineering background with a main focus on physical processes in food production. The curriculum was heavily entrenched in mathematics, physics, and an array of engineering sciences, including thermodynamics, fluid mechanics, materials, and electrical systems; it provided a relatively small number of courses in the biological sciences. Research and design was concerned primarily with physical systems for farm machinery, farm structures, irrigation, drainage, farm electrification, and systems for processing and handling materials.

Today there is a changing focus, as reflected in the recent renaming of the department as Agricultural and Biological Engineering. Where the emphasis used to be on machines for harvesting fruits and vegetables, now it is on the biological properties of these products, and the interaction with mechanical systems. Where the early emphasis was on farm structures, the focus is now on the biological interactions of animals and products housed within those structures. Today’s agricultural and biological engineer takes the biological-systems approach to bio-processing, food engineering, livestock engineering, plant and cell mechanics, preservation and handling of agricultural products, biological waste treatment, alternative energy systems for production and conservation, and environmental protection and management.

John Naisbitt assessed the outlook for agriculture in his book Megatrends. “Things aren’t going to get better,” he wrote. “They are going to get different.” Engineering for agriculture in the 1990s and the next century is going to be different because its main concern will be with biological systems for applications in farming, food processing, forestry, and the environment. Agricultural and biological engineers will make a difference.

Norman R. Scott spends more time these days in Day Hall than in the barn, since he is Cornell’s vice president for research and advanced studies as well as professor of agricultural and biological engineering.

Scott was graduated from Washington State University in 1958 and joined the Cornell faculty after completing his doctorate here in 1962. He served as chairman of his department from 1978 to 1984, and then as director of the Agricultural Experiment Station and director for research at the College of Agriculture and Life Sciences until 1989. He has spent leaves at Case Western Reserve University with the biomedical engineering faculty, and at the National Institute for Research in Dairying in England.

He is a fellow of the American Society of Agricultural Engineers and has received four awards for research publications from that organization. In 1990 he was elected to the National Academy of Engineering.
It is always a good thing to begin at the beginning. So where was the Sibley School of Mechanical and Aerospace Engineering at the birth of the Quarterly in 1966?

That was about the time the College of Engineering returned to a four-year undergraduate program after the twenty years of the “noble experiment”—the five-year program. For Sibley, this was symptomatic of a change in emphasis from the undergraduate program to graduate study and research.

The importance of research activity had been recognized for some time, but its growth was leisurely. Some figures tell the story: in 1966, only about 50 percent of the Sibley faculty had the doctoral degree; today there are none without it. In 1966, there were thirty-five or forty mechanical engineering graduate students; today there are just under one hundred. It is this growth that shapes my perspective of major change over the years of the Quarterly.

This viewpoint is consistent with the results of an event in 1973 that was of great consequence for two divisions of the college: the amalgamation of the Graduate School of Aerospace Engineering and the Sibley School to form the Sibley School of Mechanical and Aerospace Engineering. The Sibley School faculty increased from sixteen people in mechanical engineering to a total of twenty-three, with the seven new members providing a lively group of researchers in high-tech engineering.

So now in 1991, M&AE has a research standing second to none. But, after twenty-five years, have we thrown the baby out with the bath water? Countrywide, there are screams of anguish regarding the state of education in practically every level and discipline, from day school to college (except for graduate research).

This may suggest a prospect for the future, but I am quite unable to prophesy, except to predict that overall the future will be an electronic one. Or am I behind, and we are already in the quarkic age?

Nevertheless, I still relish a verse of long ago, whose provenance I have forgotten, but whose words I remember:

A decent docent doesn’t doze,
He teaches standing on his toes,
His student dassn’t doze but does,
And that’s all teaching ever wuz.

Dennis G. Shepherd, the John Edson Sweet Professor of Engineering, emeritus, has been a member of Cornell’s mechanical engineering faculty since 1948.

After studying engineering mathematics and engineering physics at the University of Michigan, he spent fourteen years in industrial research and development in Canada and in his native England, where he participated in early work on turbojet engines and gas turbines. A more recent interest has been wind energy. He is the author of books on fluid mechanics, turbomachinery, and propulsion.

At Cornell he served as head of the Department of Thermal Engineering and later as director of the Sibley School of Mechanical Engineering. He twice received the College of Engineering’s annual Excellence in Teaching Award.

Shepherd has held visiting appointments at Imperial College, London, the Technische Hogeschool in Delft, The Netherlands, and the Organization for European Economic Cooperation. He is a fellow of the American Society of Mechanical Engineers and was awarded that society’s Worcester Reed Warner Medal. Other honors he has received include a Guggenheim fellowship.
From the perspective of 1991, the decade of the 1960s takes on the aura of a “golden age”. One result of the U.S. response to the first Sputnik was to identify the development of advanced materials as a priority, and Materials Research Laboratories were established at selected universities across the country to enhance the training of scientists in this field. These centers were provided with the sophisticated equipment and other support needed for carrying out multidisciplinary research of the type conducted in the nation’s premier research laboratories, such as Bell Laboratories. One of these new Materials Research Laboratories was established at Cornell as the Materials Science Center. This was the situation when I arrived at Cornell in 1961 to join the Department of Engineering Physics. Now, thirty years later, I am director of the Materials Science Center, and I am struggling with somewhat the same issues that were prevalent in the decade of the sixties. Once again, concern over materials is high and a renewed federal priority may emerge in the next few years.

My field of research is electron microscopy of materials. Shortly before I arrived at Cambridge University’s Cavendish Laboratory to do Ph.D. thesis work with Peter B. Hirsch, his group had startled the materials world by demonstrating that dislocations in thin metal films could be imaged directly through the use of transmission electron microscopy. This was recognized as immensely important for the study of materials, since such microstructural defects are often critical in determining practical properties of materials. Today electron microscopy is deeply embedded in materials science departments in this country—it is taught even at the undergraduate level—but it is not an active field of research in physics departments, as it is in Britain. Cornell is almost unique in that there is a group in physics (myself and Michael Isaacson in the School of Applied and Engineering Physics) pursuing work that attempts to realize the full potential of this approach.

What else has happened in thirty years? For one thing, the cost of equipment—such as an advanced electron microscope—needed for an advanced materials research center has gone up by a factor of almost forty, from around $40,000 to around $1.5 million. This reflects a growth in complexity, as illustrated in the cartoon on the opposite page, and it represents enormous progress in the field. The level at which we can now ask questions and expect to find a useful answer in studies of the microstructure of materials includes not just atomic arrangements, but also microchemistry and even microelectronic structure.

Other costs, including graduate tuition, have also gone up. Since graduate tuition is paid primarily through fellowships or outside research support, the high cost is not seen by the students themselves, but is a matter of concern to the program directors of the federal agencies and to the faculty members who are directing the graduate research. Even at Cornell, the struggle to provide adequate resources for an active research program is assuming proportions that, at a minimum, carry the potential for significant distortion of the educational process. Maintaining a balance between research and educational activities has become a “hot” issue. Unfortunately, in my view, the debate has taken on a confrontational tone and there seems little effort to resolve the real issues and to reduce the real pressures that are involved.

The past thirty years have also brought changes in the undergraduate program. When I came to Cornell, the notion of an engineering physics undergraduate program was new to me, and appealing; my education had been in physics, but my Ph.D. thesis work was clearly in an applied area. The Cornell program, which provided a physics-based curriculum in an engineering environment, was impressive—strong in mathematics and physics, and equally strong in engineering. The curriculum included course work in electronic circuits, gas-phase dynamics, thermodynamics, statistical mechanics, and solid mechanics, and also in chemistry (including organic chemistry). The program even included a seminar course that provided training in presenting work through written and oral reports and a project. All this was achieved in a five-year curriculum with a solid set of requirements through the fifth year (where a few electives crept in). The program attracted motivated, intellectually strong students who well merited the “intel-
Below: Electron microscopy THEN and NOW, as depicted by Tom Malis and Ron Anderson. This cartoon appeared previously in The Bulletin of the Electron Microscopy Society of America.

THEN

-- Calm, cool
-- Happy, Friendly
-- Goes to Church every week

NOW

-- Harried, nervous
-- Glazed eyes
-- Drinks too much

Over the years, the program has changed from five years to four, and the first two years are now essentially the same for all engineering students, so as to defer the need to choose a major until, usually, the junior year. Students entering engineering physics are not likely to have taken advanced courses in the underclass years, and in addition, we have reduced the upperclass requirements to permit flexibility in electives. (As a conservative old fuddy-duddy, though, it is my view that flexibility in a later career is made possible by using the undergraduate years for achieving a solid basis in the fundamentals rather than for getting an introduction to the latest whiz-bang technology. The latter may get you started, but what happens when the next new technique comes along?) Our students are still very bright and hard-working. We do our best to challenge them and to provide the careful advising they need to navigate the route in the two years we still have left. They seem to succeed, although whether the successes of the students we had in the sixties will be matched is hard to predict.

The education of both undergraduates and graduate students has become much more difficult and challenging, with programs at both educational levels presenting new needs and priorities. A result, not only in my field but all across the engineering disciplines, has been a growing tension between undergraduate and graduate programs in decisions about how those needs and priorities should be met. In my view, simplistic measures for reducing this tension by cutting back on one side or the other are likely to fail, particularly at Cornell, where all our students are taught by the same active, practicing professionals. How effective the faculty
is in both aspects of its responsibility depends on how carefully that responsibility is defined. I believe that the continued high reputation of engineering at Cornell depends on a successful resolution of this issue.

John Silcox is the David E. Burr Professor of Engineering in the School of Applied and Engineering Physics, and currently he is the director of Cornell's Materials Science Center. He has twice served as director of his school.


He is a fellow of the American Physical Society and a member and past president of the Electron Microscopy Society of America. He has served on the Solid State Sciences Committee of the National Academy of Sciences/National Research Council, and currently he is a member of the Materials Advisory Committee for the National Science Foundation. He also serves on advisory committees for the Argonne National Laboratory and Arizona State University.

Silcox

Julian C. Smith
Chemical Engineering and Continuing Education

Continuing education—the provision of courses for off-campus students—was a special concern of mine twenty-five years ago. For seven years, beginning in 1965, I organized a variety of programs, mostly noncredit, for engineers in industry. As a land-grant university, Cornell has an obligation to provide extension education, and these programs were offered as part of that effort. They were designed to combat a perceived rapid obsolescence of practicing engineers. "With technology changing so fast," we predicted, "an engineer with no continuing education will be obsolete five years after graduation."

Some programs succeeded very well. Others didn't. The ambitious Guideposts Program would have brought practicing engineers to Cornell for several weeks each year for up to five years to take a series of noncredit courses. This program failed to attract any participants, however. More successful offerings included:

- Modern Engineering Concepts—a full-time, four-week, noncredit course given each fall at IBM’s facility in Endicott, New York. The purpose was to provide engineers in middle management with an overview of current concepts in a range of technical subjects. Cornell professors gave lectures summarizing developments in their various fields.
- Blackboard by Wire—courses in metallurgy, given in-house for Sylvania (GTE) at the plant in Towanda, Pennsylvania, and simultaneously to students at Cornell. Two such courses were given by Robert Balluffi, and one by George Smith and Che-Yu Li, all of the Department of Materials Science and Engineering. Most of the off-campus students took these courses for academic credit. The professor talked to the students by telephone while writing on an X–Y plotter at Cornell, sending signals over the telephone lines so that his writing was reproduced on a TV screen at the Sylvania plant. (This was considered high technology at the time.)
- Basics of Chemical Engineering for Chemists—a four-week, noncredit course given in Endicott at IBM’s request. Ray Thorpe of the School of Chemical Engineering was the professor.
- A group of six to eight noncredit courses on various subjects, given on campus for between four and twelve days each summer. The most popular (and lucrative) of these courses was Introduction to Finite Elements, taught by Richard Gallagher of the School of Civil and Environmental Engineering.
- Two major federally funded programs: Modern Technology in the Construction Industry, sponsored by the U.S. Department of Commerce; and a program of technology transfer for industries in the Southern Tier of New York State, sponsored jointly by the federal and state Departments of Commerce. The course on construction technology flourished for several years with good industrial participation. It involved a series of lectures on campus each winter, and periodic visits by Cornell faculty members to construction sites. This program was headed by George Blessis of Civil Engineering and later by Brig. Gen. (Ret.) Richard Jewett. The technology-transfer program was funded under the State Technical Services Act of 1965, part of President Lyndon Johnson’s “Great Society” initiative. It was run by Donald Gordon of the college staff. He and I studied the feasibility of giving courses by TV to nearby industries, but concluded it was too expensive.

Later, an off-campus program designed to lead to a Master of Engineering degree
“While Ithaca and Cornell are still ‘centrally isolated’ geographically from major industrial centers, they are no longer isolated electronically.”

was organized (not through my office) by Byron Saunders, a professor in the School of Operations Research and Industrial Engineering, and approved by the Graduate School on an experimental basis. Films were made during regular class sessions of several courses, mostly in engineering mathematics. The classes were held in a specially modified classroom in Phillips Hall and the films were sent to nearby industrial sites for the students to view. The students took the course examinations at their workplace, and their papers were returned to Cornell for grading by the professors. Corning Glass Works provided the bulk of the funding for this venture, as well as most of the students. The initial enrollment was about fifty, but only one or perhaps two of the people ever received a Cornell degree by this means.

All the noncredit programs, except for the summer courses, ended in 1971. The construction and technology-transfer courses lost their funding, and IBM decided that seven years was long enough for their in-house offerings. Overall, the program was only moderately successful, despite a lot of effort. It made no money for the college; in fact, it never quite broke even. The noncredit programs were overwhelmingly more popular than the credit programs; at that time, most practicing engineers in nearby industries evidently did not have the time, the motivation, or sometimes the ability, to meet Cornell’s high academic standards.

In spite of this history, however, there may be a place for continuing education in Cornell’s future. Requests by industry for in-house programs continue to increase. While Ithaca and Cornell are still “centrally isolated” geographically from major industrial centers, they are no longer isolated electronically. Communication methods are now available that would make possible all kinds of off-campus programs at reasonable cost.

The success of any such programs, however, requires the enthusiastic support of Cornell faculty members who see the effort needed as something they want to do. Given faculty support and that of the Graduate School and the College of Engineering administration, continuing education in the twenty-first century could well become a significant part of the educational mission of the college.

Julian C. Smith has spent not just twenty-five years at the Cornell College of Engineering, but more than fifty. He entered as a freshman in 1937, graduated with the B.Chem. degree in 1941 and the Chem.E. in 1942, and joined the chemical engineering faculty in 1946 after four years with E. I. du Pont de Nemours. He became professor, emeritus, in 1986.

During his tenure, Smith served as director of continuing education for the College of Engineering, and as associate director and then director (from 1975 to 1983) of the School of Chemical Engineering.

He is a co-author of Unit Operations in Chemical Engineering, now in its fourth edition, and has published extensively in his specialty fields of mixing, solids handling, and phase equilibria. He also wrote a history of the School of Chemical Engineering, published in 1988. He holds two patents.

Smith is a licensed professional engineer in New York and has served as a consultant to many government agencies and industrial firms, including du Pont and Rockwell International. He has been a visiting professor in Scotland, a UNESCO consultant in Venezuela, and a visitor to Nigeria and Colombia on behalf of the U.S. Department of State. He is a fellow of the American Institute of Chemical Engineers.
had prepared for a career in the heavy electrical industry that the newly independent India had projected for the future in its Five Year Plans. But delays in the execution of such plans forced me to look elsewhere. Through a combination of fortuitous circumstances, I found myself at Cornell in November 1958, working as a research associate for Sam Linke.

This was an especially opportune time because great changes were imminent in the College of Engineering. After World War II, the federal government became almost the sole architect of the research-funding edifice that has powered the universities and national laboratories for the past forty years or so. The impact of this development was about to be felt in the college through the appointment of Dale Corson as the new dean of engineering in 1959. In the same year, Henry Booker took the helm in electrical engineering as its director. Booker had led the theoretical effort behind British radar development during the war. He possessed both the scientific credentials and the personal qualities needed to radically transform the School of Electrical Engineering into a research-oriented institution.

In that period I was tempted by two major scientific currents at Cornell. Bill Gordon of Electrical Engineering had come up with the idea of using a giant radar to probe the ionosphere—a seminal concept that led to the formation of the Center for Radiophysics and Space Research in Phillips Hall and the construction of the Arecibo Radio Telescope in Puerto Rico. Soon Henry Booker, Tommy Gold, Bill Gordon, and Ed Salpeter had set up a world-class enterprise in space science. The other thrust was in Aerospace Engineering under Bill Sears, Ed Resler, and Arthur Kantrowitz. The science of a magnetized conducting fluid (magnetohydrodynamics) was being developed and pioneering work on shock waves in ionized gases was in progress.

Rather than work with these two groups, where my ignorance could easily be unmasked, I chose to study high-temperature collisionless plasma, a regime close to but not covered by the major-league players. By the spring of 1963, I had mustered enough courage to give the first course on the kinetic theory of plasma. I was fortunate to attract a very fine group of graduate students to this class. I have all along suspected that they knew more than I did but were too polite to let on. Don Kerr, now president of EG&G, Mike Roberts of the Department of Energy, and Moshe Lubin, president of Hampshire College, Tommy Gold, Bill Gordon, and Ed Salpeter had set up a world-class enterprise in space science. The other thrust was in Aerospace Engineering under Bill Sears, Ed Resler, and Arthur Kantrowitz. The science of a magnetized conducting fluid (magnetohydrodynamics) was being developed and pioneering work on shock waves in ionized gases was in progress.

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In the development of radar and other science-based technologies during World War II, it had become very evident that the training of engineers on the basis of detailed study of particular devices was woefully inadequate for dealing with new concepts. To correct this situation, a conscious decision was made to increase the effort devoted to fundamental sciences in engineering education. As a consequence, newly hired faculty members were oriented more toward applied sciences than toward conventional engineering. The electrical engineering curriculum underwent a radical change. Hallowed courses in electrical machinery, illumination design, etc. were dumped without much ceremony or regret. The college also trimmed its five-year bachelor's degree program to four years, in line with the competition. This swift wind of change had a somewhat chilling effect on me: I was obsolescent before I had begun my career at Cornell. It is said that the threat of execution clears the mind instantly and wonderfully. I can testify that it worked for me.

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"Both currents—space science and plasma physics—have merged in the present Laboratory of Plasma Studies."

Instruments, were among the members of this class.

The activity in plasma physics flourished and at the urging of Ed Resler it was consolidated by Dean Andy Schultz into the Laboratory of Plasma Studies. Its subsequent growth under Deans Ed Cranch, Tom Everhart, and Bill Streit is chronicled in a special collection of articles from Engineering: Cornell Quarterly that was published in 1987 in connection with the laboratory's twentieth anniversary. Both currents—space science and plasma physics—have merged in the present Laboratory of Plasma Studies.

I have also closely observed and participated in the arrival of the Computer Age at Cornell. My first research task in 1958 was to analyze the electrical performance of a power station under disturbed conditions; this was done on the university's IBM 650 computer, in retrospect only a toy machine compared to its descendants. In the early seventies, Geoffrey Chester, Ed Salpeter, Ken Wilson, and I operated a terminal that gave us access to the remote supercomputers at U.S. national laboratories. In the eighties, I was happy to be associated with Ken Wilson in the big push to establish a NSF-supported supercomputer facility on campus in partnership with IBM. There is no doubt that the Cornell Theory Center has altered the scientific and intellectual landscape of the university.

It appears to me that the pendulum of curricular change initiated in the early sixties has reached the full extent of its swing. There is a certain loss of patience with courses on basic sciences; more discussion of devices and design-oriented curricula are sought. Perhaps this is necessary to restore the balance between analysis and synthesis, but we should also keep in mind lessons of the past.

Another debate that has erupted is one that pits teaching versus research. This is unfortunate because, as all of us know, these two synergistic activities are intertwined. Neither survives for long without the other in a great university.

Ravi Sudan, the IBM Professor of Engineering at Cornell, is a faculty member of both the School of Electrical Engineering and the School of Applied and Engineering Physics. He is a member of the Laboratory of Plasma Studies and was its director from 1975 to 1985. He also helped establish the Cornell Theory Center, a national supercomputer facility, and served as its deputy director from 1985 to 1987.

Sudan studied in India and subsequently in England, where he earned a Ph.D. from Imperial College, University of London, in 1955. After working for several years in England and India, he came to Cornell in 1958.

His research has been in the areas of plasma physics, thermonuclear fusion, high-power electron- and ion-beam physics, and space physics. He has had visiting appointments at laboratories in England and Italy, as well as the United States; these include the U.S. Naval Research Laboratory, where he headed the theoretical plasma physics section. He has chaired several international conferences and has given invited lectures in the U.S.S.R., France, and Germany. He is co-editor of two volumes of the Handbook of Plasma Physics and is on the editorial boards of several journals.

Sudan is a fellow of the American Physical Society and in 1989 was awarded its James Clerk Maxwell Prize. He is a fellow also of the Institute of Electrical and Electronics Engineers and of the American Association for the Advancement of Science.
Optoelectronics is today one of the most active and fertile fields of research, with enormous potential for benefits to society.

Its origin goes back to the invention of the laser in the late 1950s and the semiconductor laser in the early 1960s. At first it was by no means clear that these devices were anything more than interesting sources of coherent radiation, useful primarily for scientific research in the esoteric subject of spectroscopy. A joke sometimes heard in those days was that the laser was a solution looking for a problem. Today the question is whether and how to bring fiber optics to every home. What a difference twenty-five years of research and development have made!

In looking ahead to the next quarter century, I would like to add a word of caution. The period beginning in the early sixties was an exciting and rewarding time for university researchers. Americans were stimulated by the launching of the Soviets' artificial satellite Sputnik, and expanding and raising the standards of research and education in high technology became a national goal. Support for research and graduate education was at its peak, and they flourished. So did the undergraduate educational programs. In the research-university community it was understood that the knowledge and the vitality generated in the graduate research program would enrich the undergraduate program as well. The fact that research universities such as Cornell have attracted highly qualified undergraduate students speaks well for policies that promote a strong research program and recognize its value to students, faculty, the institution, and the nation. This is a particularly important consideration in the present era of global economic competition, when there is urgent need to raise the standards of engineering education in order to produce more and better-trained engineers.

We would be wise not to lose sight of the philosophy upon which past successes in research universities are based.

“A joke sometimes heard in those days was that the laser was a solution looking for a problem. Today the question is whether and how to bring fiber optics to every home.”

C. L. Tang, a specialist in laser physics and technology, is the Spencer T. Olin Professor in the School of Electrical Engineering.

He holds the B.S. degree from the University of Washington at Seattle, the M.S. from the California Institute of Technology, and the Ph.D. from Harvard University. Before coming to Cornell in 1964, he spent a year at the Technical University in Aachen, Germany, and four years as a researcher at the Raytheon Company.

Tang is a member of the National Academy of Engineering and a fellow of the American Physical Society, the American Optical Society, and the Institute of Electrical and Electronics Engineers.
In 1956, when I came to Cornell, there was one computer, an IBM 650, for Electrical Engineering, perhaps for the entire university. This machine used a magnetic drum as its memory and the basic machine code programming was the order of the day. Just recently, an instructional computing facility was opened in Phillips Hall with sixteen Mac IIs, nine HP Vector workstations, and seventeen Apollo workstations, each of which is many, many times more powerful than the IBM 650.

Progress in device technology, machine organization, and software development all contributed to this amazing evolution in computing and communications, and Cornell has developed vibrant research programs in all these areas. In device technology, for example, we have made significant contributions in materials, fabrication, and measurements. Currently, the School of Electrical Engineering, with industrial cooperation, is developing a center for research in optoelectronics and photonics.

In the late 1950s the school offered only one course, Switching Circuits, that was related to computer design, and there was one faculty member with even tangential interest in the subject. We now offer some fifteen courses in the design, architecture, implementation, and applications of computers, and there are nine faculty members involved with computer engineering, and a highly regarded Department of Computer Science besides.

Recently, faculty members from Electrical Engineering and Computer Science launched Project 2000, in which we seek to develop, evaluate, and implement the bold, innovative concepts in computer systems design and applications that are needed as we proceed toward the twenty-first century.

This instructional computing facility was recently opened at the School of Electrical Engineering. Fifty workstations and computers were provided by Hewlett-Packard and Apple.

During two sabbatical leaves, Torng served as a member of the technical staff at Bell Laboratories, and he has been a consultant to government and industrial organizations. He is a fellow of the Institute of Electrical and Electronics Engineers (IEEE) and served as a Distinguished Visiting Lecturer of the IEEE Computer Society from 1983 to 1986.
Robert L. Von Berg
Chemical Engineering

In the period just before 1965 there was considerable activity at Cornell in nuclear energy, and I was heavily involved in it. The Ward Laboratory of Nuclear Engineering was designed and built; it contained a versatile research reactor and perhaps the best facility for using gamma radiation that existed in any university.

At this time I taught courses in nuclear engineering and the applications of chemistry and chemical engineering, and consulted with several national laboratories. I was fortunate to have several students supported by Atomic Energy Commission fellowships, and we used the gamma radiation facility in research on nuclear-fuel processing and radiation chemistry. The development of nuclear power was considered to be important to the future, and there were many graduate students in nuclear science and engineering and in chemical engineering who hoped to work in the field of nuclear engineering.

Looking back, it is amazing to see how quickly all that changed. In large part, the reasons have been political rather than scientific or technological. Now we still have a few students who plan to go into the nuclear-power industry, but the future of that industry is a big question mark.

My teaching and research slowly moved toward chemical process and plant design, but I still have great interest and confidence in nuclear power. I still look forward to the day when nuclear engineering will again be an important field.

Robert L. Von Berg, an emeritus professor of chemical engineering, joined the Cornell faculty in 1946 after completing his doctoral studies at the Massachusetts Institute of Technology and working for several years in the engineering department of E. I. du Pont de Nemours and Company. He holds B.S. and M.S. degrees from West Virginia University.

In recent years his research interests centered on the desalination of salt water by a freezing process and in the use of gamma radiation for controlled chemical conversions such as ammonia synthesis.


Lionel I. Weiss
Operations Research and Industrial Engineering

As with many other fields, a major force for change in operations research and industrial engineering has been the increasing speed, power, and availability of computers.

First, some background. The name industrial engineering goes back much farther than operations research. Both fields are concerned with finding efficient ways of carrying out activities, but industrial engineering tends to look at less complicated activities than operations research does. For example, early in its history, "time and motion study" was an important part of industrial engineering. In such a study, the movements of an operator of a machine might be observed to see whether a change in the physical setup could improve the operation in some way, and data would be collected and subjected to statistical analysis of a fairly unsophisticated kind. Operations research looks at much more complicated activities. It developed during World War II, when teams of scientists and mathematicians were asked to help plan industrial and military operations, and over the years its usefulness has increased along with that of the computer.

Several new mathematical techniques have been applied in operations research. Probably the best known is linear programming, which is an algorithm for minimizing (or maximizing) a linear function of several variables that must satisfy a set of linear equalities and inequalities. A concrete example is the "feed mix" problem, in which several varieties of grain are available, each variety having its own content of various vitamins, minerals, fiber, and moisture, and each costing a different amount per unit weight. The problem is to create a mixture of
"[An important] effect of the availability of powerful computers is the ability to actually solve problems in which there is a very large number of variables."

these grains weighing, say, one ton, and containing at least a certain specified amount of each vitamin and mineral, and no more than specified amounts of fiber and moisture, at minimum possible cost. The familiar techniques of differential calculus cannot be applied to such a problem because of the inequalities imposed.

There are many other situations in which linear programming problems are encountered; two important ones are fuel-mixing problems (in which different varieties of fuel are to be mixed) and transportation problems (in which the least costly routes must be found to deliver goods from a set of origins to a set of destinations). Some linear-programming problems of practical importance have more than a thousand variables and more than a thousand linear restrictions of these variables.

For many years, the algorithm used to solve linear-programming problems was the simplex method developed by G. B. Dantzig. This worked well on many large problems arising in practice; however, it was shown that it was possible to create "worst case" linear programming problems that could not be solved within a reasonable time by the simplex method, even with the most powerful computers then in existence. Thus it created quite a stir when, in 1979, the Russian mathematician Khachian published an algorithm that could do this. The stir was so big, in fact, that it was described in a front-page article in the New York Times. Not many developments in mathematics get this sort of attention. It turned out that in most problems arising in practice, the simplex algorithm performed better than Khachian's, but this did not diminish the interest in worst-case comparisons in linear programming problems and also in problems requiring other kinds of algorithms. An important result of the availability of powerful computers is research into just how powerful a computer would have to be in order to solve any mathematical problem of a specified type. This research is often highly mathematical.

A second important, and more obvious, effect of the availability of powerful computers is the ability to actually solve problems in which there is a very large number of variables. This capability has led to large savings in fuel mixing, telephone-call routing, and other operations involving the use of valuable resources.

Computer simulation is a third important technique that is often used in operations research. Here a mathematical model of a complex system is created, and the computer is set to work to find out how the performance of the system would be affected by various changes in the system. The mathematical model is often quite elaborate, and usually must take random occurrences into account. Some sophisticated statistical techniques have been developed to analyze computer output in simulation studies.

Simulation studies are required when it is not feasible to experiment on an actual system. An example is a study to determine which firefighting facilities in New York City could be closed down without creating dangerous gaps in coverage. This is not the sort of situation in which tinkering with the actual system without prior careful analysis would be desirable. This kind of analysis, for all but the simplest systems, would be impossible without the existence of powerful computers.

Lionel I. Weiss is a professor in Cornell's School of Operations Research and Industrial Engineering. Currently he is serving as associate director for undergraduate education, as well as pursuing research in statistical theory.

Weiss studied at Columbia University for an undergraduate degree in mathematics and economics, and M.A. and Ph.D. degrees in mathematical statistics. After receiving his doctorate in 1953, he taught economics at the University of Virginia and mathematics at the University of Oregon before joining the Cornell faculty in 1957.

He has been a consultant to the General Electric Company and the Exxon Corporation. He is a fellow of the Institute of Mathematical Statistics.

Weiss
While I perceive that students seem to be getting younger each year, there has not been any substantial change, over the thirty years I have been at Cornell, in the attitudes, study habits, and overall goals of our undergraduate students in engineering. We continue to be blessed with exceptionally capable young people with essentially unlimited potential.

We now see, however, a much stronger demand for students with graduate degrees, particularly the professionally-oriented Master of Engineering degree. In fact, many of the leading design firms now hire only at the master’s level. We also see greatly increased opportunities in civil engineering practice for engineers with Ph.D. degrees—a reflection of the fact that many aspects of practice have become much more sophisticated.

Computing permeates our every activity and has drastically changed the way civil engineering is practiced, particularly in my discipline of structural engineering. In the 1950s and early 1960s, we still had “small armies” of people with slide rules and hand calculators doing analysis and design of structures. Thanks to the computer and to well developed analysis and design software, we can now undertake most designs without these tedious hand calculations. The greatly enhanced efficiency of computer-aided design and drafting enables civil engineers to devote much more time to better conceptual and preliminary designs; it also leads to more refined designs of complex structural systems. We have pioneered the development of these methodologies for improving our teaching of structural engineering at Cornell. I think that all of these computer-related changes have been extremely positive.

Another “quiet revolution” that deserves mention is the use of better and higher-strength materials in construction. Concrete design strengths used in practice in the 1990s can be more than four times the typical strengths used thirty years ago. Indeed, all of our construction materials have been improved, and this has led to higher design stresses and smaller structural dimensions and often to less inherent resistance to certain structural actions. Thus, designs must be done more carefully and more thoroughly, with proper attention to durability and to extended service life.

Another point I want to mention is our better appreciation for the environment and the continuing development of technologies to handle serious problems such as hazardous waste. Cornell led the way nationally by changing the name of our school from Civil Engineering to Civil and Environmental Engineering. The challenge for the future is to do even better in how we use, build in, and manage our environment.

Richard N. White, the James A. Friend Family Distinguished Professor of Engineering, has been a Cornell faculty member since 1961. He has served as director of the School of Civil and Environmental Engineering and as associate dean for undergraduate programs at the College of Engineering.

White holds three degrees from the University of Wisconsin; he received his doctorate in 1961. Early in his career, he worked for a firm of consulting engineers in Madison, and served in the U.S. Army Corps of Engineers in Virginia. He has spent sabbatical leaves at the University of California at Berkeley and at Gulf General Atomic.

He is a fellow of the American Concrete Institute and of the American Society of Civil Engineers, and a co-recipient of the ASCE’s Collingwood Prize. He is a registered professional engineer in the State of New York.

White is a co-author of five texts on structural engineering.
George Wolga
Applied and Engineering Physics
and Electrical Engineering

In my view, three significant changes have taken place within the College of Engineering during the three decades I have been teaching here.

The first is a transition from a faculty in great part representing engineering practice, to a faculty promoting engineering science over the broadest spectrum. The two engineering units I have had most experience with are Applied and Engineering Physics and Electrical Engineering. The former was my own school as an undergraduate. With EP, as it was then referred to, establishing engineering science was fundamental; that was the motivation for creating EP in the first place. Within EE, the situation in 1961 was much more in transition. There was a strong group of faculty members active in work on radio waves, and the Arecibo radio-radar telescope was under construction. In the areas of microwaves, control, and systems, faculty members trained in research were starting to build research programs. My own hiring led to the first research with lasers, then an idea looking for significant applications and now almost ubiquitous in research groups throughout the college. Today engineering science is so strong that we are all concerned about ensuring that engineering practice is sufficiently represented in our various curricula.

The second significant change is the growth of centers and interdisciplinary research and teaching. In 1960 the Materials Science Center had been created as a result of the vision of Cornell faculty and the availability of ARPA (now DARPA) funds. This center was the first, and an enduring, example of the interdisciplinary approach to research. Subsequently, many centers were proposed and funded to take advantage of significant research frontiers. The National Astronomy and Ionosphere Center (which operates the Arecibo facility), the National Nanofabrication Facility, the Center for Applied Mathematics, the Cornell Theory Center and its Cornell National Supercomputer Facility, and the Cornell High Energy Synchrotron Source (CHESS) are other examples of the successful melding of faculty expertise in interdisciplinary centers and programs with a common focus.

The third change I wish to mention is the introduction and subsequent proliferation of computers across the college. I remember in the early 1960s when the Hewlett-Packard HP-35 pocket calculator was demonstrated to the EE faculty. At that time slide rules were still in use, some early study of analog computers had begun, and to my best recollection no digital computer was in use in Phillips Hall. Today our students use "calculators" more powerful than some mini-computers of the past. We have the Department of Computer Science and a section of computer engineering within the School of Electrical Engineering, and each engineering undergraduate takes courses in programming and uses computers as an integral part of much coursework. A revolution indeed!

George J. Wolga, a professor in two Cornell engineering schools, lists his specialty fields as lasers, applied spectroscopy, and semiconductor materials and devices.

Wolga earned a bachelor's degree in engineering physics at Cornell in 1953, studied at the Massachusetts Institute of Technology for a Ph.D., awarded in 1957, and taught at M.I.T. before returning to Cornell as a faculty member in electrical engineering in 1961. His joint appointment in applied and engineering physics began in 1964.

That same year he founded the Lansing Research Corporation in Ithaca and currently serves as vice president and consultant to that firm, which specializes in laboratory and electronic equipment. He has been a consultant to a number of other firms and to the Naval Research Laboratory, where he served as head of the Laser Physics Branch in 1969-70.