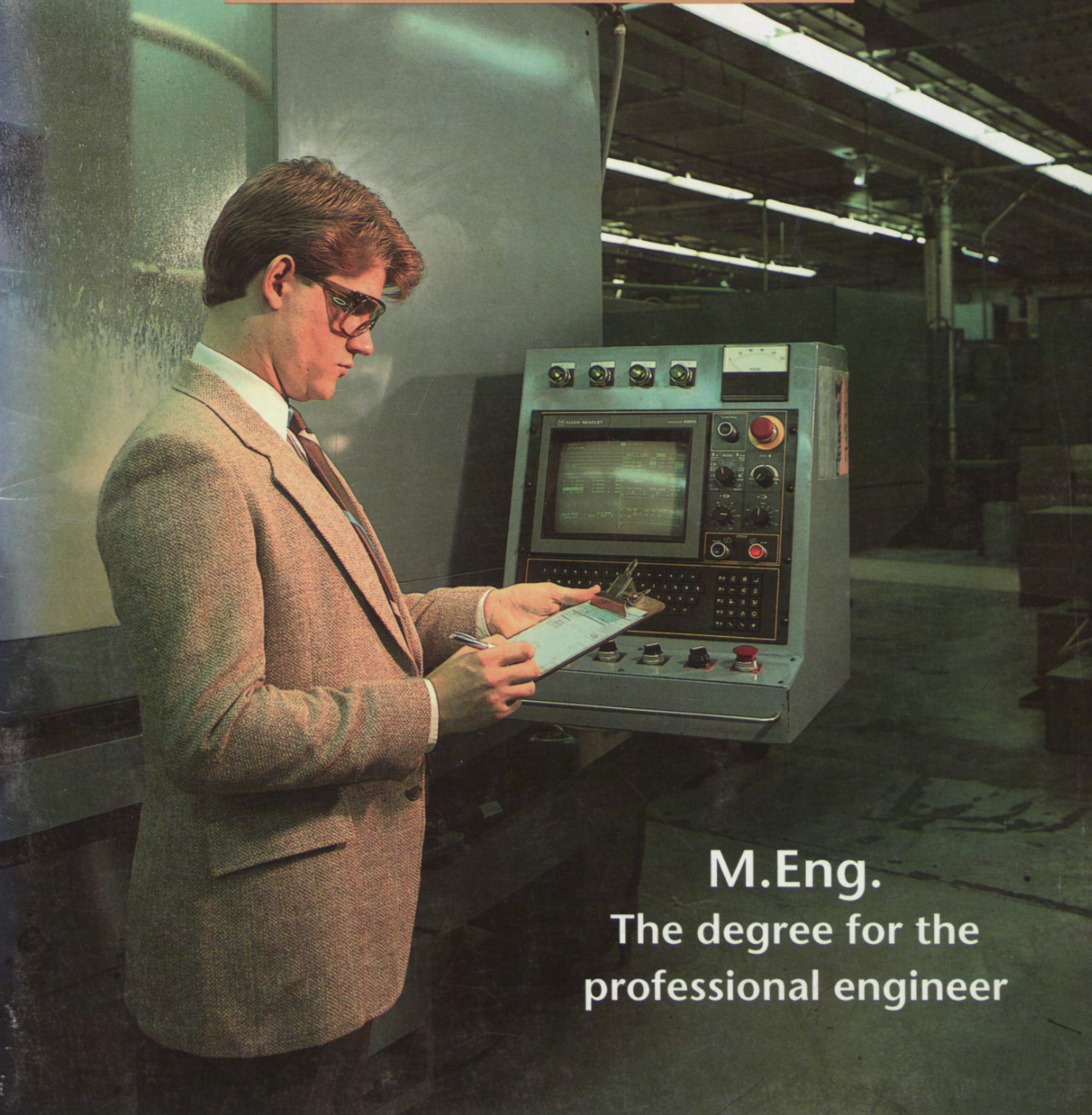
CORNELL ENGINEERING QUARTERLY

Winter 1992 Volume 26 Number 2



M.Eng.

The degree for the professional engineer

CORNELL ENGINEERING QUARTERLY

Winter 1992 Volume 26 Number 2

The cover picture shows Master of Engineering student David Pike at Therm, Inc., in Ithaca, New York.

Cornell Engineering Quarterly (ISSN 0013-7871), Vol. 26, No. 2, Winter 1992.
Published by the College of Engineering, Cornell University, Carpenter Hall, Ithaca, New York 14853-2201.
Subscription rates: $6.00 per year or $9.00 outside the United States.

THE MASTER OF ENGINEERING
A Professional Degree for Today and Tomorrow

by William B. Streett

"A growing body of expert opinion underscores the educational soundness of the Master of Engineering program."

The College of Engineering is currently engaged in a major initiative to expand and strengthen the Master of Engineering degree program. Careful consideration of the evolving relationship between technology and society, as well as the changing role of academic institutions, has made it clear that this is the right course of action. It is educationally sound; it addresses an important national need; and it makes good financial sense.

Factors Leading to the Establishment of the Professional Master's Degree

An engineer, like a lawyer or a doctor, needs a considerable body of highly technical, specialized knowledge. But lawyers and doctors gain their special knowledge in law school and medical school, after earning a four-year bachelor's degree, while engineers are expected to learn everything they need to know during a four-year, undergraduate program. Learning the necessary technical material takes up so much of this time that there is little room left for the variety of courses that would provide a liberal education. This leaves many engineers with an outlook on life that lacks the breadth generally expected of college-educated people and with a less-than-adequate appreciation for the social context of their engineering practice.

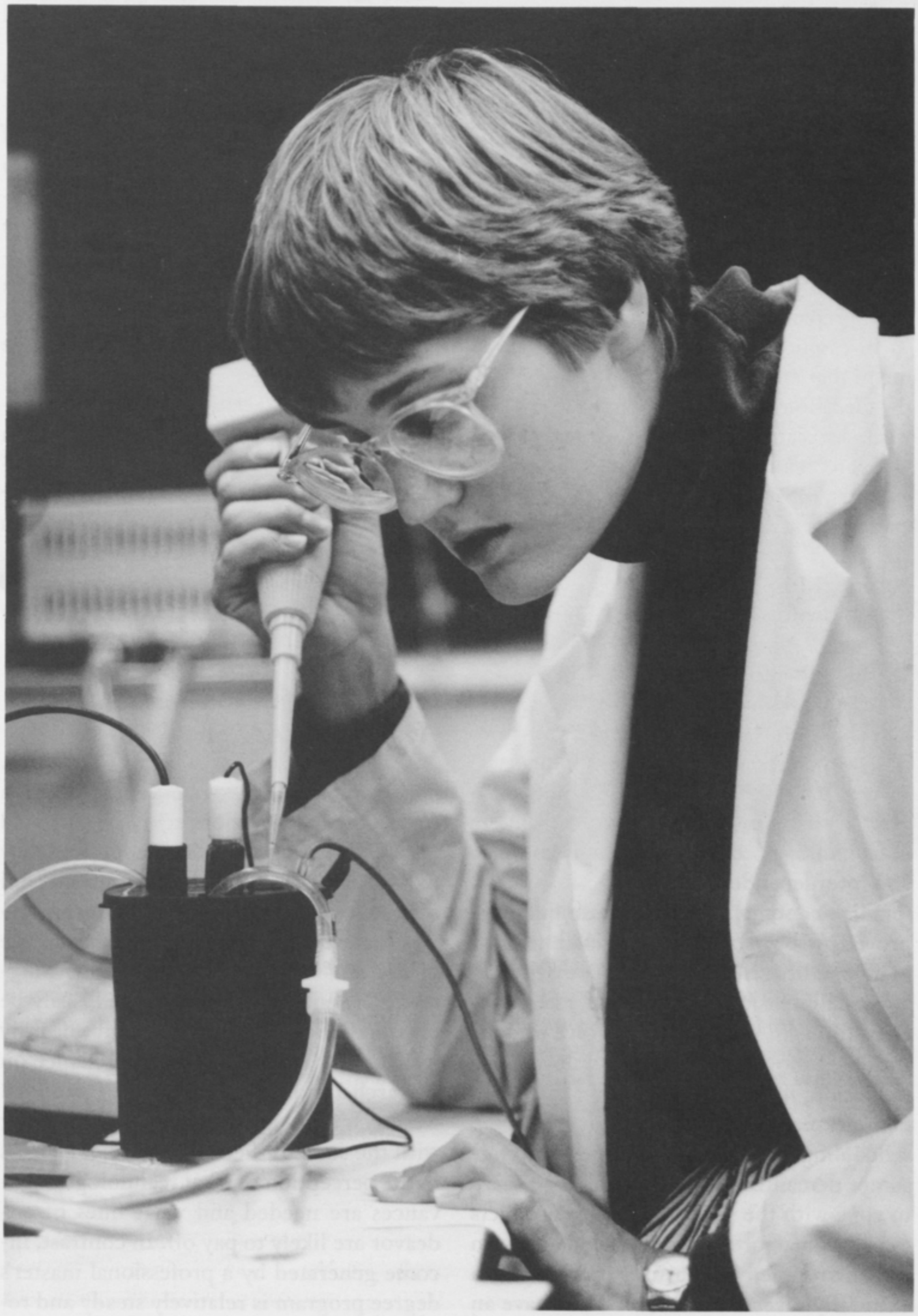
From 1946 to 1964, Cornell attempted to deal with this problem by offering a five-year undergraduate program in engineering. While this unpacked the crowded curriculum, allowing time to educate students for life as well as for a career, the five-year requirement was a disadvantage for Cornell in competing with other institutions. As long as some schools were offering four-year degrees, many students preferred to choose a program that would allow them to enter the job market in 80 percent of the time and at 80 percent of the cost.

The Master of Engineering program was born of an effort to retain the advantages of a five-year degree without making students commit themselves to a program lasting five years. A four-year undergraduate program provides basic technical training as well as a modest exposure to the humanities and social sciences, while a one-year graduate program provides an opportunity for engineers to get the highly specialized training required for professional practice in the modern world.

The Educational Value of the Professional Master's Degree

A growing body of expert opinion underscores the educational soundness of the Master of Engineering program. Virtually every major study of engineering education carried out over the past decade has recommended the expansion of professional degree programs for engineers.

- A committee appointed by the National Research Council recommended that engineering education emphasize a broad curriculum with a strong grounding in fundamentals and science, include greater exposure to nontechnical subjects such as the humanities and social sciences, and postpone extensive disciplinary specialization until the graduate level.
- A task force of the American Society for Engineering Education reported that "at the graduate level, advanced degree programs focused on engineering practice should be vigorously developed by engineering faculties to complement research-oriented degree programs. The majority of baccalaureate students who wish to pursue careers in engineering practice should be encouraged to complete such programs on a full-time basis."
- The M.I.T. Commission on Productivity recommended the development of a



Master of Engineering student Janet Jasinski calibrates a probe that measures the net flux of ammonium and nitrate ions near the surface of barley roots. Jasinski, who studied for the M.Eng. degree while on sabbatical leave from her teaching position at Tompkins Cortland Community College, worked with Professors Larry P. Walker and Daniel J. Aneshansley in the Department of Agricultural and Biological Engineering. Her design project involved development of the ion-selective electrode used in the probe and a computer-controlled method for calibrating it.

program that would offer, as an alternative to the existing four-year curriculum, a broader undergraduate program followed by a professional degree program; the undergraduate program would include courses in subjects such as science, history, economics, management, foreign languages, and cultural diversity.

• The Workshop on Engineering Education in the Twenty-first Century, convened by the National Academy of Engineering, recommended the development of a diverse pattern of longer degree programs (lasting five or six years) that would lead to a master's degree that incorporates elements of management, liberal arts, interdisciplinary work, and international studies, as well as extensive scientific and technical preparation.

In essence, all of these studies recommend that engineering education evolve in the direction taken in the other professions, with a broad undergraduate degree that provides an opportunity for the study of diverse subjects, followed by intense technical specialization at the professional master's level.

National Implications of the Professional Master's Degree

The combination of a more comprehensive undergraduate curriculum and a professional master's program brings greater depth and breadth to engineering education. These changes are necessary as industry is increasingly subjected to influences of a nontechnological nature, while the frontiers of technology become increasingly complex and interdependent.

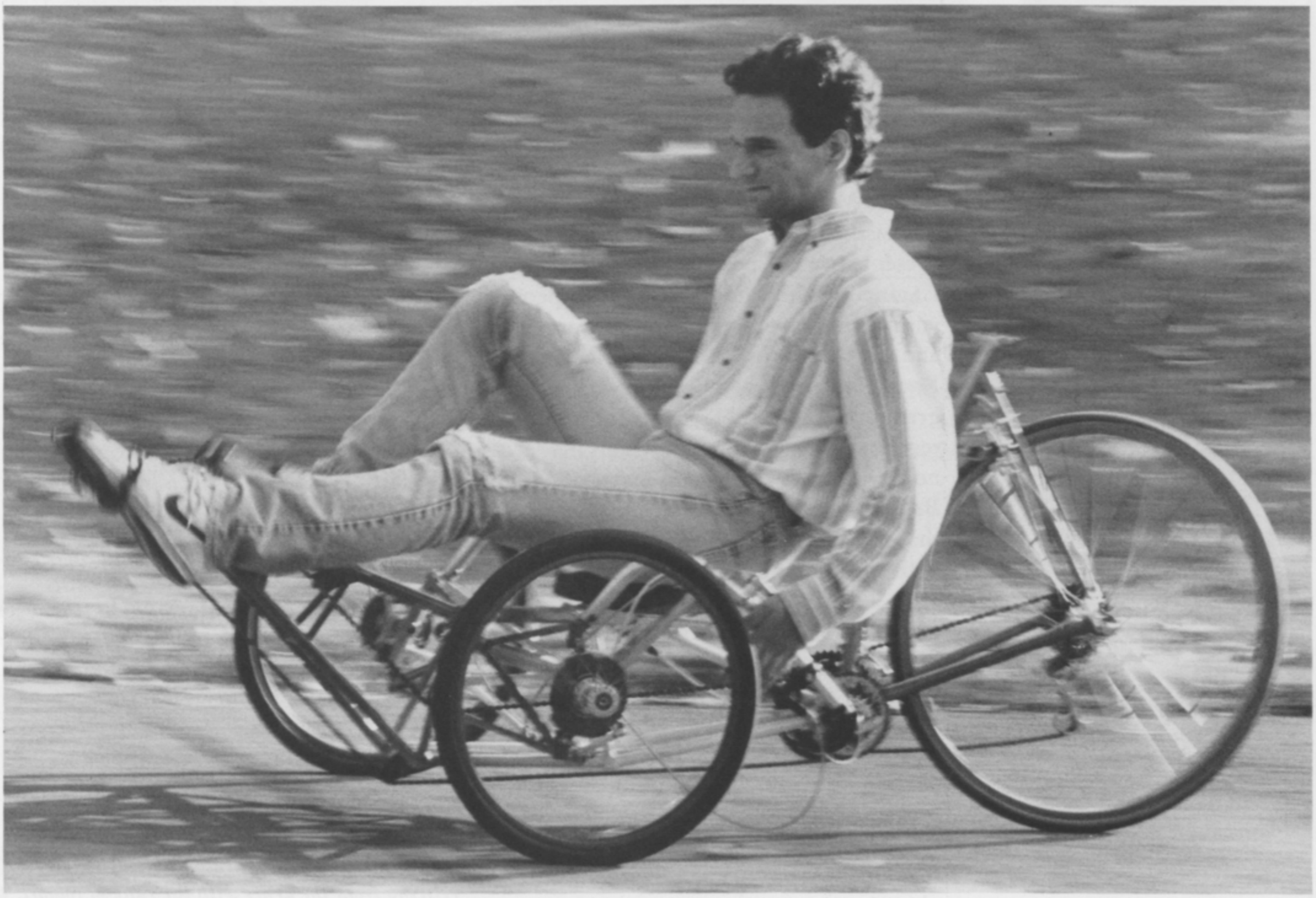
It is clear that productivity cannot be improved by speeding up production lines, and many factors relevant to productivity have a social dimension. For example, many success stories in recent years involve organizational innovations such as employee participation in decision making. Efficient manufacturing options such as just-in-time scheduling require an assessment of consumer demand. It is increasingly necessary to cope with the public desire for products to be manufactured in ways that do not harm the environment. Industries that employ a culturally diverse work force must have an understanding of relevant cultural patterns, as must multinational corporations with facilities in countries around the world. All of these factors militate against narrowly trained engineers who can only cope with problems of a strictly technological nature, and in favor of more broadly trained engineers who have a perspective on how technological advances fit into a broader social context.

But engineers are also expected to have a detailed knowledge of increasingly sophisticated technologies. At the beginning of this century, there was only a moderate gap between a mechanical engineer and a mechanic—it was even possible for a bicycle mechanic to make the transition to aeronautical engineer. This is a far cry from the fund of knowledge needed to design rockets, computer components, or composite materials.

Industry's appreciation of the superior capabilities of candidates for employment with graduate training is apparent in starting salaries, which are $6,000 to $10,000 higher for those with master of engineering degrees than for those with bachelor's degrees alone. Those who can speak German or Japanese, or who have lived abroad, are especially in demand.

The Financial Implications of an Expanded M.Eng. Program

For the College of Engineering, the M.Eng. program is financially sound. It is on a much firmer footing than the research-oriented M.S./Ph.D. program, which is supported by federal grants, industrial contributions, and the general-purpose revenues of the university. A good research program is the pride of any technical institution, and the long-range benefits of research cannot easily be measured in dollars and cents. But a healthy institution cannot place undue reliance on research funding as a source of support. Research funding is precarious, fluctuating with the state of the economy and changes in the perception of what technological advances are needed and what lines of endeavor are likely to pay off. In contrast, income generated by a professional master's degree program is relatively steady and re-



Master of Engineering student Edward DeBiase demonstrates the Mark II Practical Human-Powered Commuter Vehicle, which was designed and built by a group of engineering students under the guidance of Professor Samuel E. Landsberger. Developed as a practical, safe, and healthy alternative to the automobile for short trips, the vehicle placed ninth in the International Human-Powered Vehicle Competition, held in Milwaukee last August. The three-wheeler features an innovative "lean-to-steer" mechanism and an optional bubble fairing for protection against inclement weather. A Mark III vehicle, which will include an electric motor to assist with large loads on steep hills, is currently in development.

liable, representing, as it does, direct payment for value rendered.

The M.Eng. program not only pays for itself but also generates income that can be used for other purposes, including defraying the cost of research. An increase of one hundred M.Eng. students per year would provide the College of Engineering with close to $1.5 million in increased revenue. This could be accomplished with a modest increment in the commitment of individual faculty members to the M.Eng. program.

A Series of Perspectives on the M.Eng. Program

This issue of *Cornell Engineering Quarterly* presents five perspectives on the Master of Engineering program, written by people with an intimate knowledge of the program and how it works. S. Leigh Phoenix and Petru Petrina show how the M.Eng. program makes it possible for students to master the details of a complex, emerging technology such as composite materials. John Belina provides an inside view of a school that has a long and successful involvement with the program. Albert R. George presents a contrasting picture, showing a new program, oriented to a genuine need, that is off to a strong start. Clifford Wagoner looks at the M.Eng. internship program from the perspective of industry, describing its advantages for prospective employers. And finally, Edmund T. Cranch looks at professional master's degrees in broad perspective, outlining the qualities that enable them to meet their educational objectives.

Interspersed among these essays are portraits of students involved in typical M.Eng. design projects. These projects are the heart of the program, contrasting with the reseach expected of M.S./Ph.D. students. They form the nexus between academic experience and the real world of the professional engineer, and they provide the last word in an engineering education that is both broad and focused, general and specific, theoretical and practical.

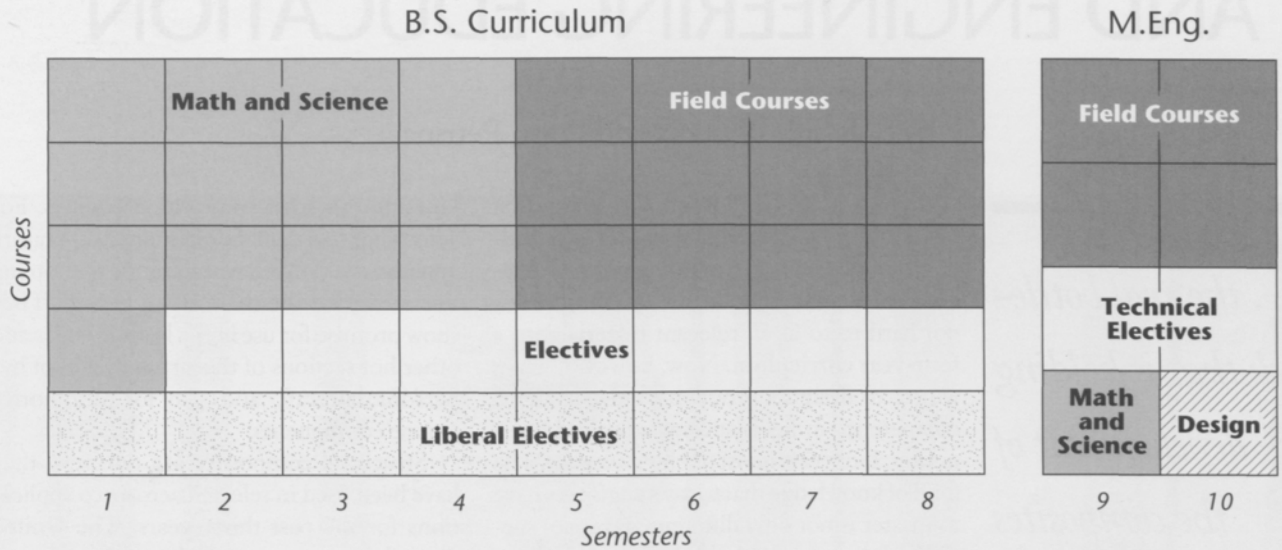
Dean William B. Streett came to Cornell in 1978 after a distinguished career at the United States Military Academy.

Streett received the B.S. degree at West Point and was commissioned into the U.S. Army in 1955. During his military service, he earned M.S. and Ph.D. degrees in mechanical engineering at the University of Michigan. After teaching astronomy and astronautics at West Point from 1963 to 1965, he spent a year at the University of Oxford as a NATO postdoctoral research fellow in chemistry. He returned to West Point as associate professor of chemistry, and in 1969 he became assistant dean for academic research and founding director of the Science Research Laboratory.

Streett's research activities focused on the molecular properties of dense fluids. After retiring from the army with the rank of colonel, he continued this work as a senior research associate at Cornell's School of Chemical Engineering. In 1981 he was made a full professor and associate dean for research and graduate studies at the College of Engineering. In 1984 he became acting dean, and in 1985 he was appointed the Joseph Silbert Dean of Engineering.

Streett has been a Guggenheim fellow and an invited lecturer at six Gordon Research Conferences. He is a member of Tau Beta Pi, Sigma Xi, the American Institute of Chemical Engineers, the American Chemical Society, and the Royal Society of Chemistry.

The M.Eng. Degree Program



A typical curriculum for the integrated B.S. and M.Eng. programs includes eight undergraduate semesters and two graduate semesters. In this diagram, each block represents one course. Many undergraduate courses are valued at three academic credits, but graduate courses, which are required for the M.Eng., are usually valued at four. Field courses are in the discipline that is the major subject.

Degree Choices and Current Enrollment

Aerospace Engineering	3
Agricultural and Biological Engineering	3
Chemical Engineering	8
Civil Engineering	62
Computer Science	28
Electrical Engineering	118
Engineering Mechanics	5
Engineering Physics	20
Geological Sciences	1
Materials Science and Engineering	5
Mechanical Engineering	23
Nuclear Science and Engineering	2
Operations Research and Industrial Engineering	45

Special Options

M.Eng./M.B.A. A joint offering of the College of Engineering and the Johnson Graduate School of Management that enables students to earn both degrees in five semesters.

Program in Engineering Management. A special curriculum that prepares students to assume managerial responsibility for projects and complex technical systems.

Manufacturing Option. A special focus on manufacturing, including economic, social, and technical considerations, that is available in several fields.

(*Dean's Certificates,* awarded in conjunction with M.Eng. degrees, attest to curricular concentration in particular areas such as management and manufacturing.)

Advanced Engineering Degrees Granted in 1991

M.Eng.	194
M.S.	123
Ph.D.	137

ADVANCED COMPOSITES AND ENGINEERING EDUCATION

by S. Leigh Phoenix and Petru Petrina

". . . the real bottleneck that is holding back development of the composites industry is the lack of a sufficiently knowledgeable engineering work force."

When Cornell University first offered a course of study leading to the Bachelor of Mechanical Engineering degree, in 1871, it was not hard to to fit all relevant material into a four-year curriculum. Now, however, when we try to design a program to give students competence in fields such as advanced composites, four years is just not long enough. The fund of knowledge that today's engineers have to master is not only different and more specialized than that of their nineteenth-century counterparts—it is also more extensive. That is why the Department of Theoretical and Applied Mechanics has recently instituted a Master of Engineering Program in Advanced Composites and Structures.

Tailor-Made Materials for High-Tech Applications

Composites are hybrid materials consisting of reinforcing fibers or particles embedded in a matrix. Together, these two phases yield a material with more useful properties than either of the constituent materials. A composite that has a number of potential uses in civil engineering is fiber-reinforced concrete. Newer, more esoteric composites that have been developed in recent years are polymer-matrix composites (PMCs), ceramic-matrix composites (CMCs), and metal-matrix composites (MMCs). PMCs already have many applications, while the technologies for CMCs and MMCs are still emerging.

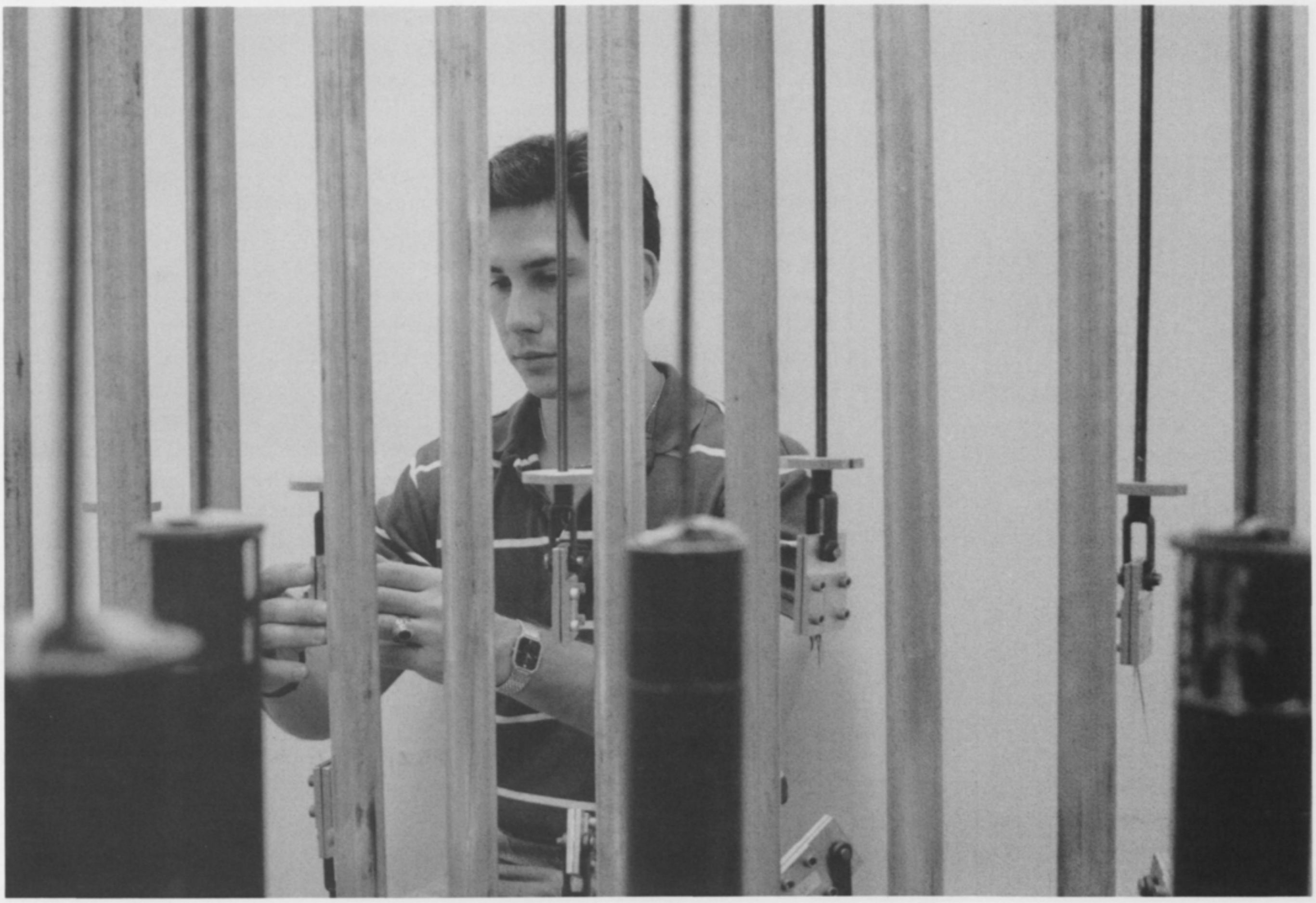
PMCs are lighter, stronger, and stiffer than traditional metal alloys, which makes them ideal for many aerodynamic and automotive applications where weight and strength are critical to performance and efficiency. They also have great potential for civil-engineering applications such as bridges and support structures. CMCs can withstand extremely high temperatures and may be used in advanced propulsion systems such as aircraft turbines and internal combustion engines. For somewhat less demanding high-temperature applications, MMCs with ceramic reinforcing fibers may be the material of choice. They show promise for use in the leading edges and other hot sections of the airframe skin of hypersonic aircraft, and also for automotive engine components.

Structural composites are not new; they have been used in selected aerospace applications for the past thirty years. The United States has a strong research and manufacturing base, which developed to serve NASA and the Department of Defense. But American suppliers have paid relatively little attention to the potential of the commercial market. In contrast, Japanese and European firms have positioned themselves for rapid development involving commercial applications. Dramatic expansion in the use of structural composites can be expected as the industry becomes increasingly international. Recently, worldwide growth of the advanced composites industry has been approaching a rate of 15 to 20 percent per year.

Composites will soon be used in products manufactured for virtually every sector of the economy. Annual sales of advanced composites (not including fiberglass) are expected to top $20 billion by the year 2000. A lowering of manufacturing costs and a better understanding of reliability factors will lead to even more rapid growth. But the real bottleneck that is holding back development of the composites industry is the lack of a sufficiently knowledgeable engineering work force.

The Need for More Specialized Engineers

Growing recognition of the importance of composite materials in fields such as mechanical engineering, aerospace engineering, civil engineering, and biomedical engineering has generated pressure to reformulate the under-



Master of Engineering student William F. Davidson checks the alignment of an epoxy-impregnated graphite strand with the aid of a creep-rupture tester in the composites laboratory at the Department of Theoretical and Applied Mechanics. Davidson's design project involved the wing structure of a sailplane. Over the past two years, some thirty-five seniors and M.Eng. students, guided by Professor David A. Caughey, have contributed to the design of an unpowered aircraft. Davidson had to figure out how to make the wings both strong and light. Working with Leigh Phoenix and Petru Petrina, he developed a structural material consisting of half-inch-thick balsa wood with six layers of a graphite-epoxy composite on either side.

"New courses on composites are needed to produce better prepared professional engineers. . . ."

graduate curriculum in schools around the country. New courses on composites are needed to produce better prepared professional engineers, and adjustments are necessary in order to fit them in. Some undergraduate programs, especially those associated with major research centers, have responded with new elective courses at the senior level or changed the scope of undergraduate courses in mechanics, materials, and design. Unfortunately, the ground that has to be covered to train a knowledgeable professional engineer is far too great to be traversed in an already-crammed, four-year curriculum.

Comprehensive education in the technology of composite materials has occurred largely at the doctoral level, where students have taken specialized courses to complement standard disciplinary courses and have also written a research-oriented dissertation. Professional engineers, on the other hand, have had to make do with the short courses typically offered through university extension services. These courses usually involve twenty to thirty hours of intense exposure to theory, software, and sometimes, laboratory experience. But they often lack rigor, have minimal homework, and allow insufficient time for students to assimilate the material covered in lectures.

The Department of Theoretical and Applied Mechanics at Cornell has initiated a Master of Engineering program to better prepare engineers who want to work with modern composites. The goal of the program is to give students the background they will need to perform as professional engineers in this rapidly expanding field. Now in its second year, the program focuses on the mechanical behavior of advanced composite materials and structures. It is designed for students who have already completed four-year programs in fields such as mechanical, aerospace, structural, materials, or biomedical engineering.

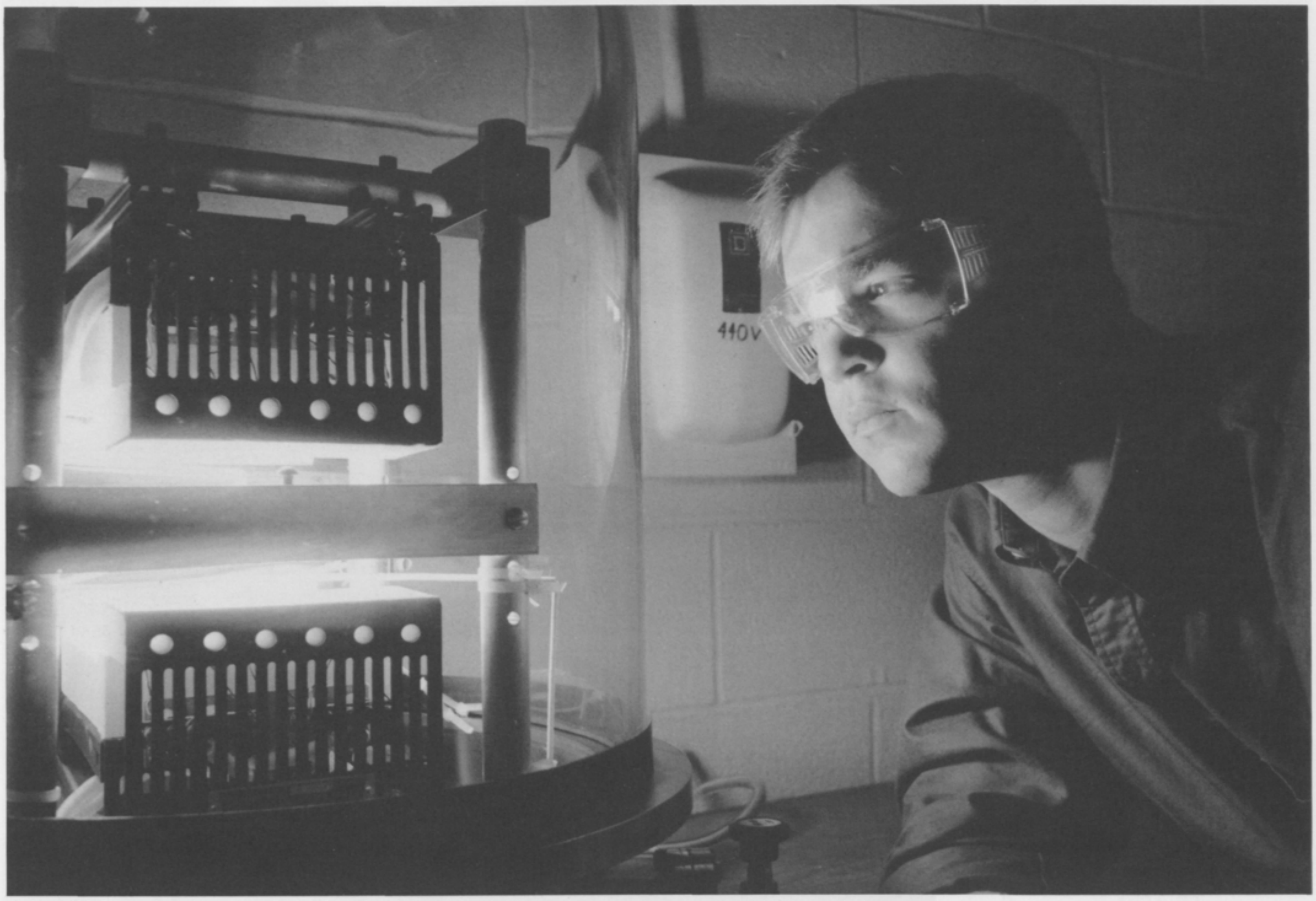
The Anatomy of the Program

As in other Master of Engineering programs, course and project requirements can be met in two semesters. Of the thirty required credits, up to ten may be earned with an individual design project involving composites. Since a number of ongoing research programs in the department are related to composite materials and are supported by excellent experimental and computational facilities, the design project can draw on these resources.

At the heart of the program are two new courses, Introduction to Composite Materials, and Advanced Composite Materials and Structures. The introductory course surveys the different kinds of fibers used for reinforcement and the mechanical properties of various matrix materials. It also introduces the analysis of failure mechanisms and the elasticity of oriented materials. Micromechanical theories of stiffening and strengthening are explored, and manufacturing methods and assembly techniques are discussed. The advanced course is more involved with composites as structural materials. It explores theories dealing with the strength of composites reinforced with continuous and discontinuous fibers, the micromechanics of stiffness and strength, interface mechanics, modes of failure, and statistical models for strength and fatigue. The mechanics of structural components are made relevant to fabrication techniques such as bolt systems and adhesive bonding.

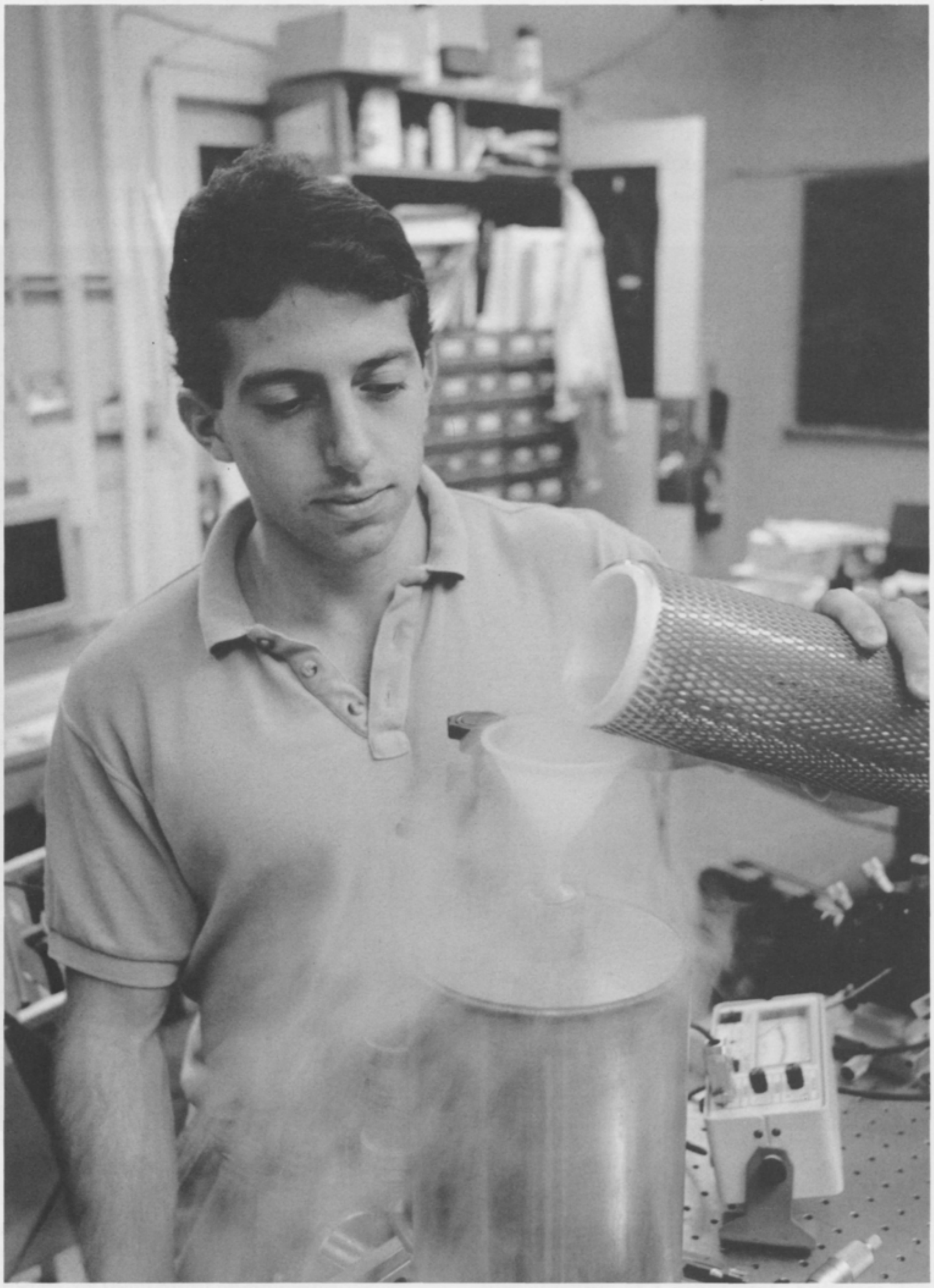
These courses, which are purposely broad in scope, are complemented by a set of one-credit minicourses that make it possible for students to concentrate on particular areas. They are scheduled in three sequential sessions per semester, so that students can earn up to six credits over the course of two semesters. Much of the material is at the cutting edge of research, and it is taught by faculty members who are opening up the field. Currently, minicourses are offered on Analysis of Composite Structures, Biological Composites, Design Principles for Composite Structures, Mechanical Testing of Composite Constituents, Reliability Models for Composites, Fracture Testing of Composites, Software for Composite Design, Nondestructive Testing of Composites, Novel Composite Structures, Effective Properties of Composites, Boundary-Element Methods for Composites, and Interface Failure and Fracture Processes in Composites.

In addition, students can choose among a variety of elective courses offered by the Department of Theoretical and Applied Me-



Master of Engineering student Jeffrey Maggard uses an infrared vacuum furnace to construct fine-pitch solder joints between the metal traces on silicon chips and ceramic packages. "Flip-chip" packaging, in which the active side of chips faces the carriers on which they are mounted, enhances performance but complicates assembly. Connections must be made by positioning tiny bits of solder between chips and carriers, then heating them to melt the solder. Maggard's M.Eng. project, carried out under the supervision of Professor Che-Yu Li in the Department of Materials Science and Engineering, involves the construction and testing of flip-chip solder joints only fifty microns in diameter. It is part of a long-term research program on the reliability of electronic components that is sponsored by the Electronic Packaging Alliance.

Master of Engineering student Tony Puliafico adds liquid nitrogen to a Dewar flask containing a salt crystal that has been prepared to act as a gain medium in a color-center laser. For crystals to lase, they must be treated in a "heat pipe," where they are exposed to sodium vapor at low pressure and high temperature. This induces a microscopic defect—a missing chlorine ion in the crystalline lattice, whose place is taken by a free electron. Puliafico's work, which was conducted in Professor Clifford Pollock's laboratory in the School of Electrical Engineering, involved varying the temperature and pressure in the heat pipe to find out what conditions would produce the most efficient crystals most consistently. In the course of his experiments, Puliafico improved the heat-pipe technology by developing a better holder for the crystals.



chanics as well as other schools and departments. They can learn about the properties of solid polymers, plastic flow, and fracture in the Department of Materials Science and Engineering, mechanical and aerospace structures and biomechanical systems in the Sibley School of Mechanical and Aerospace Engineering, and engineering fracture mechanics and finite-element analysis in the School of Civil and Environmental Engineering.

Enthusiastic Response to the Composites Program

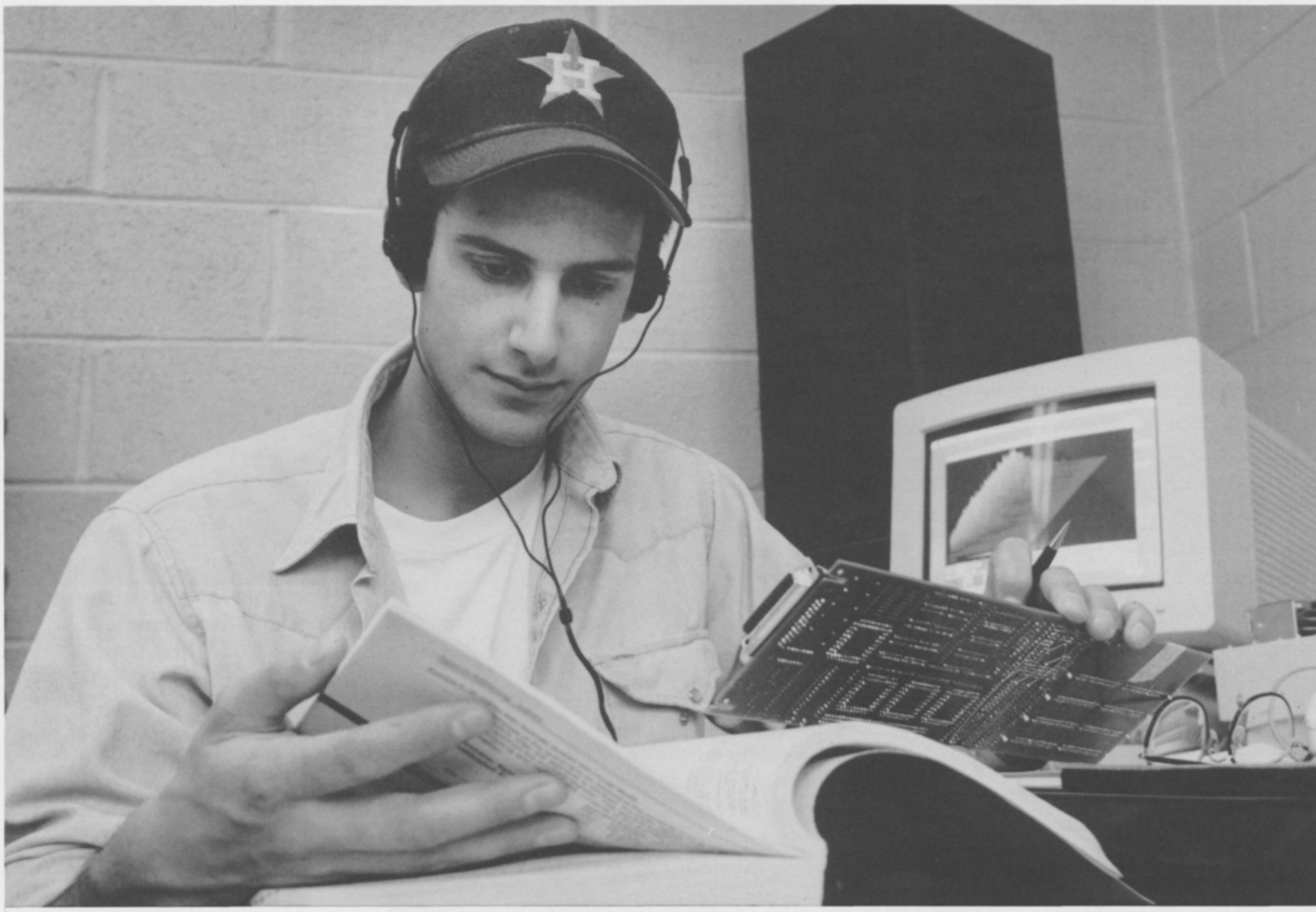
The design project, which is central to the Master of Engineering program, gives students a chance to become involved with the practical details of composites and composite structures. In the first two years of the program, students have been invited to work on topics such as creep-rupture of composites used in cables for bridges and concrete reinforcement, fiber-reinforced epoxy coatings for reinforcing steel in concrete decks, development of acoustic measuring techniques for determining the position of breaks in single fibers, design and fabrication of an all-composite oar, nondestructive ultrasonic measurement of ply layups in laminates, ultrasonic measurements for characterizing elastic properties in composites and detecting defects, and detection and characterization of an impact source on a composite plate.

In addition, some enterprising students have suggested their own topics. Three have worked with mechanical engineering undergraduates in projects to build a lightweight glider and a race car for the annual Mini-Baja competition sponsored by the Society of Automotive Engineers. Both the glider and the race-car body are being made of composites, and the M.Eng. students have overseen the fabrication and testing of prototype parts.

With about five students registered in each of its first two years, the Master of Engineering Program in Advanced Composites and Structures is off to a good start. But the Department of Theoretical and Applied Mechanics expects to see the program grow, within a short time, to about fifteen per year. As designer materials become more common, there will be an increasing demand for people who can design them.

S. Leigh Phoenix (right) is a professor in the Department of Theoretical and Applied Mechanics. He received his Ph.D. from Cornell in 1972, worked for two years as a senior research associate at Fabric Research Laboratories in Dedham, Massachusetts, and then returned to join the faculty. He is associated with the Materials Science Center and the Mathematical Sciences Institute. He spent a sabbatical year at the Lawrence Livermore National Laboratory doing research on the failure of composites (1981–82), and a second leave at the University of Surrey, England (fall 1988). Phoenix is a member of the American Society of Mechanical Engineers, the American Physical Society, and the Fiber Society, from which he received the 1983 Award for Distinguished Achievement in Basic or Applied Fiber Science.

Petru Petrina first came to Cornell from his native Romania in 1971–72 as a Fulbright fellow and a visiting scientist in the Department of Theoretical and Applied Mechanics. He received his doctorate in 1976 and spent three years with Sargent and Lundy Engineers in Chicago, working as a senior structural engineering specialist in the area of nuclear power plants. He then returned to Romania and served on the faculty of the Polytechnic Institute of Cluj, where he was an associate professor of construction mechanics. He was appointed senior research associate in the Department of Theoretical and Applied Mechanics in 1987.



David Bonomi, a Master of Engineering student in the School of Electrical Engineering, examines a digital-audio signal-processing card that is suitable for installation in a Macintosh II computer. Bonomi and a team of ten other M.Eng. students and seniors are developing an advanced digital-audio workstation in the Laboratory of Communications, Data Storage, and Signal Processing, under the direction of Professor Chris Heegard. The students are responsible for all aspects of the workstation's software and hardware design. The cards are fabricated off campus according to their specifications.

TRIED AND TRUE

The M.Eng. in Electrical Engineering

by John Belina

The School of Electrical Engineering has enthusiastically supported the Master of Engineering program ever since it first started, back in 1965. At that time, the school strongly endorsed the idea of phasing out the five-year bachelor's degree curriculum in favor of a streamlined four-year program. Equally strongly, it endorsed an optional fifth year of focused study and graduate specialization to serve as a capstone on the education of engineers about to join the work force. During the first twenty years of the program, nearly 40 percent of the Master of Engineering degrees conferred by the College of Engineering were granted to students in electrical engineering.

Three years ago, the school's commitment to the M. Eng. program was reexamined by the electrical engineering faculty. A central issue was whether the curriculum should be seen as a fifth year of undergraduate study or a true graduate program. The overwhelming consensus was that it is a true graduate program, but far from optional. The faculty actively encourages every undergraduate who wishes to pursue a career in engineering design to plan for graduate training.

The M.Eng. curriculum has been updated, but many traditional features of the program, such as a design project with a final report in place of a master's thesis, have been retained. The faculty decided that the one-year professional master's degree program had withstood the test of time, and all it needed was a good tune-up.

Flexibility:
The Key to Success

The success of the M.Eng. program in electrical engineering is due, in large part, to the fact that we are not committed to a rigid view of what all electrical engineers need to know. We take students from wherever we find them and help them get where they want to go.

Students who apply to the program already have a bachelor's degree in electrical engineering. But what does this mean? There is no general agreement from one engineering school to another on the proper content of an undergraduate curriculum, and students are advised by many educators to avoid excessive specialization. So students arrive to begin the M.Eng. program with varying degrees of preparation and levels of expertise.

All students are expected to achieve a state-of-the-art knowledge in at least one or two areas of specialization. But students are free to choose the areas they want to focus on, and they are at liberty to choose elective courses from a wide range of offerings in engineering, the sciences, or analytically oriented disciplines such as management methods and information systems. Through careful and individualized curricular planning, we can accommodate students from a wide variety of backgrounds who seek advanced training in a multiplicity of different subjects.

Over sixty courses available to M.Eng. students cover such diverse areas as computer engineering, quantum devices, neural networks, communication systems, and signal processing. The promise that students will not be closed out of electrical engineering courses, regardless of how many sign up, is central to the operation of the M.Eng. program. With about 120 M.Eng. students and another 150 M.S./Ph.D. students, the demand for particular courses can be quite heavy. But guaranteed access to courses is important in a one-year program, since students cannot wait for a course to be taught in a subsequent semester. So we are committed to opening another laboratory or recitation section for any course, whenever demand dictates.

"Through careful and individualized curricular planning, we can accommodate students with a wide variety of backgrounds who seek advanced training in a multiplicity of different subjects."

Master of Engineering student Kevin Shaw examines a micromachine with the aid of a scanning electron microscope. The emerging technology for fabricating micromachines makes possible sensors, actuators, motors, and various other instruments on a microscopic scale. The micromachine seen on the display screen is about the diameter of a human hair. Shaw's work with micromachines, conducted under the direction of Professor Noel MacDonald of the School of Electrical Engineering, makes use of the resources of the National Nanofabrication Facility.

M.Eng Design Projects Offer Many Possibilities

The centerpiece of the M.Eng. program is the design project, and the wide-ranging interests of both faculty and students combine to produce a variety of exciting and meaningful efforts. In a recent survey, students indicated that the design requirement is one of the most rewarding and significant features of the M.Eng. program.

The school's faculty members, who represent more than a dozen specialized areas, are continually engaged in research. Their work involves everything from developing tiny motors and tweezers, just a few microns in size, to investigating the electrical properties of the earth's ionosphere. Each semester the school publishes a list of faculty-sponsored design projects that are a part of these ongoing research efforts. More than one-third of the M.Eng. students choose to work on these projects.

Others, however, have their own ideas for design projects. Every effort is made to encourage students with original ideas, and in a faculty of forty-five, even the most unusual projects can generally find a sponsor. Last year, for example, two eager students wanted to explore the principles of speech compression by building a totally digital phone-answering machine. In addition to learning how to digitize and compress human speech, these students had to become familiar with the operation of a telephone network. Several other students developed a substantial part of a high-speed optical Ethernet hub for computer networking. Other students, who made use of the resources at the National Nanofabrication Facility, studied resist systems used for nanometer electron-beam lithography.

In the past three years, a few group projects have been tried. One, headed by Professor Chris Heegard and called DARE (for Digital Audio Research Environment), provides design experience in the development of digital audio systems. A second example is an advanced signal-processing project conducted by a group under Bernard Hutchins, a lecturer in electrical engineering. Yet a third example is the Cornell Electric Vehicle Project, which Professor Robert Thomas and I supervise. This project involves forty-five students, from both electrical and mechanical engineering, at both the undergraduate and M.Eng. levels.

Faculty members enjoy working with M.Eng. students on projects of common interest. They appreciate the contributions that these students can make to on-going research activities and recognize that independent projects may bring unexpected benefits. Some projects afford an opportunity to explore areas of avocational interest, while others may lead to new avenues of research. Indeed, faculty members value M.Eng. project work so highly that they engage in a friendly competition for each new crop of students.

"The centerpiece of the M.Eng. program is the design project. . . ."

Options for Financing an M.Eng. Degree

Increasingly, corporate recruiters are seeking out M.Eng. graduates for prime employment opportunities in engineering design and offering them starting salaries that are \$6,000 to \$8,000 higher than those offered to graduates with only a bachelor's degree. This improvement in earning potential is a strong motive for would-be engineers to spend a fifth year in academia before launching out into the marketplace. But first, they have to pay for the M.Eng. program.

Financial aid for M.Eng. students is a concern of the College of Engineering, and fund raising for the program is a top priority for the college as it participates in the university's current capital campaign. Until these efforts yield tangible results, the main options for financing an M.Eng. degree are a teaching assistantship or corporate support.

Graduate teaching assistantships provide a chance for many M.Eng. students to defray the cost of a graduate professional degree. M.Eng. teaching assistants are in a good position to be effective—typically close enough to undergraduates in age to be accepted as peers, yet motivated, knowledgeable, and willing to serve as mentors for those confronting the material for the first time. The response of students in the

> "the support of industry plays a crucial role in the success of the Master of Engineering program. . . ."

John Belina is a lecturer and assistant director at the School of Electrical Engineering, where he earned the B.S. and M.Eng. degrees in 1974 and 1975. He received the 1975–76 Outstanding Service Award from the student chapter of the Institute of Electrical and Electronics Engineers, and the 1981–82 NRC Award for Outstanding Achievement in Electrical Engineering. A talent for working with people led him into administration, and he has served the College of Engineering as director of advising and counseling, and as assistant dean for admissions and records.

Belina has twice been named most influential educator by Cornell students selected as Presidential Scholars, and in 1990 he was awarded a Dean's Prize of $1,500 for his efforts in advising undergraduates and working with student organizations. He is a member of the honorary societies Phi Kappa Phi and Sigma Xi as well as the New York Academy of Sciences.

classes they work with is generally excellent. Some M.Eng. students also help develop new courses. Daniel Lee, an M.Eng. student who graduated a year ago, was responsible for introducing digital sampling oscilloscopes into the junior-year laboratory.

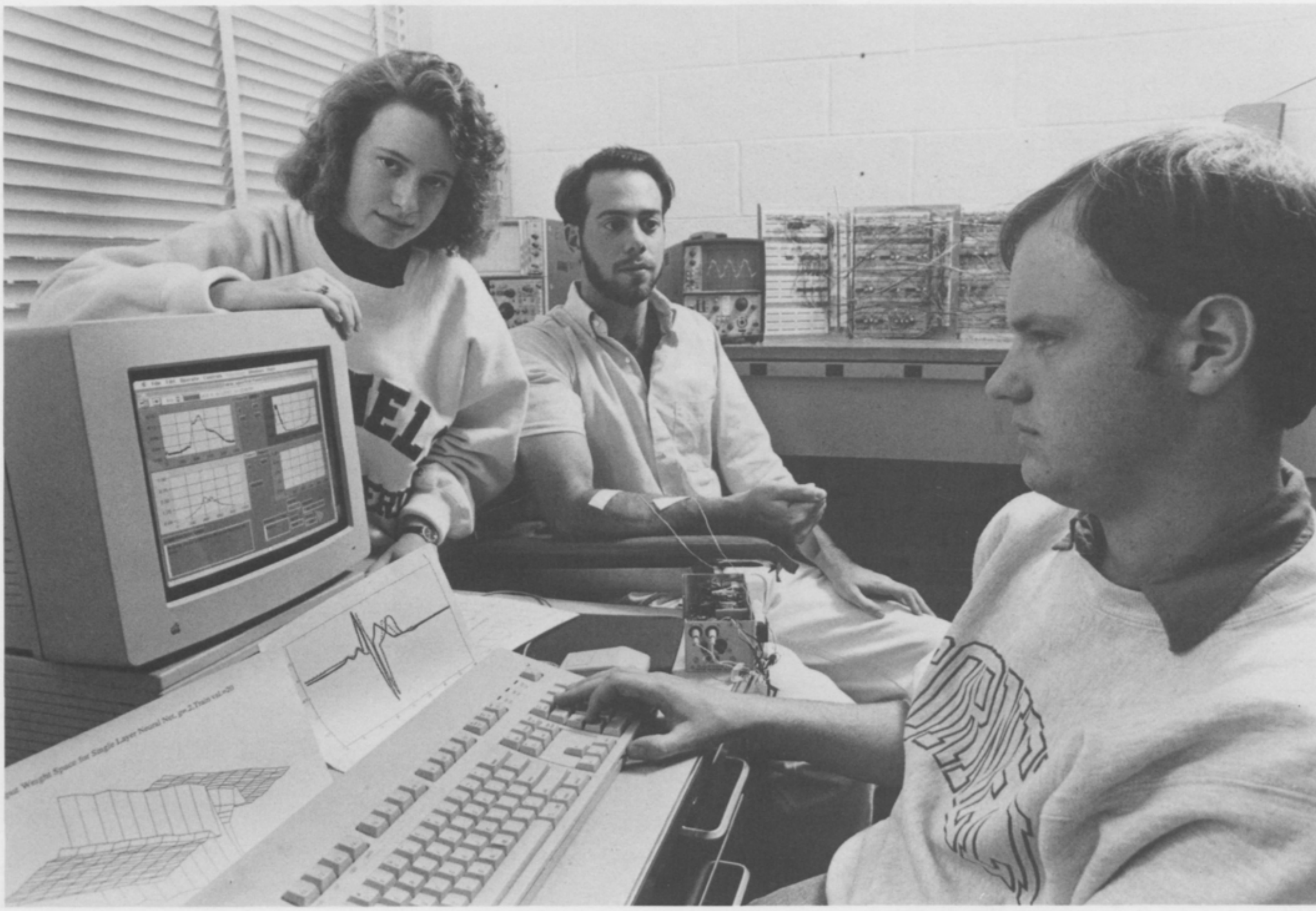
Corporate sponsorship as a way of financing an M.Eng. degree has been growing steadily in importance. More and more companies are sending select employees back to school for professional master's degrees as a way of enhancing their long-term career potential. Over 25 percent of the students in the most recent entering class are receiving at least a partial subsidy from a corporate sponsor.

Support from the Marketplace: The Corporate Tie

In other respects, also, the support of industry plays a crucial role in the success of the Master of Engineering program in electrical engineering. Not only do corporations sponsor some M.Eng. students—they also provide employment for most of them after they graduate. And many companies provide direct support to the school, donating equipment that helps keep laboratories and computing resources up-to-date. In return, the school's industrial partners get to have their fingers on the pulse of academic research and have access to some of the best young talent on the market.

Current forecasts predict that the practice of engineering in the 1990s and beyond will be distinctly different from what it has been since the Second World War. We believe that advanced training is the key to leadership in this new technical environment. With continued enthusiasm and support from students, faculty, and industry, Cornell will remain in the front rank of schools that train masters of the engineering profession.

Christopher Bett (left), James Murphy, and Herbert Darrow (right) peer under the hood of a new Sahara van that will be adapted to run on electric power instead of gasoline. Plans call for a separate motor on each wheel in order to reclaim the efficiency lost by channeling one motor's output through a differential. The electric car project, which is expected to continue for several years, is coordinated by Professor Robert J. Thomas and John Belina. Currently, forty-five Master of Engineering and undergraduate students, from both electrical and mechanical engineering, are working on the project. The van was donated by General Motors Corporation.



The application of electrical engineering to biological problems is illustrated by the design projects of Master of Engineering students Suzanne Bliven, Scott McCormack, and Mark Riccio. Bliven (left) is developing an artificial neural network with pattern recognition capabilities that can be used to interpret electrocardiograms (ECGs). The network will "learn" to distinguish between patterns produced by a normal heart and several different cardiac abnormalities. McCormack (right) has developed a data-acquisition system that provides electronic information to Bliven's neural network. Riccio (seen here in the role of "patient") is developing a portable device that will keep track of a person's circadian rhythm.

The three students have all chosen different paths to the M.Eng. degree. Bliven, an assistant director of Engineering Admissions, is in Cornell's Employee Degree Program. McCormack spent two years in part-time study while employed by a local computer retailer. And Riccio exercised the early admission option, beginning work toward the M.Eng. degree while still an undergraduate.

THE MANUFACTURING OPTION

For a Well-Rounded Manufacturing Engineer

by Albert R. George

Sweeping changes are occurring in the ways that manufactured goods are designed, produced, commercialized, and serviced. Product design is being improved while development time and production costs are being reduced. Changes are often radical, and they are sometimes implemented on a massive scale. The overall effect is a merging of design, manufacturing, and marketing into a seamless whole.

The driving force behind these changes is fierce international competition. Affluent consumers have always appreciated quality and diversity in manufactured products, and the gradual decline of national boundaries as barriers to trade has made it increasingly possible for them to pick and choose. Manufacturers who want to succeed in this free-for-all must do things faster, cheaper, and better.

It has become clear that in order to compete successfully, companies must think of their product realization process as a unified whole rather than a sequence of loosely integrated elements. In order to meet national and international competition, they must consider consumer desires, engineering design, quality, life cycle, cost, design of manufacturing process, distribution, and marketing all at the same time. This new approach has been called simultaneous engineering, concurrent engineering, quality-function deployment, value-added analysis, total quality management, and continuous improvement. The basic idea is that success depends on a broad perspective, and today's engineers must know about a great deal more than just the nuts and bolts.

A Professional Degree Program with Emphasis on Manufacturing

The Manufacturing Option in the Master of Engineering Program is Cornell's response to a growing need for engineers educated to deal with the wide-ranging changes now occurring in industry. It is an opportunity for M.Eng. students who are interested in manufacturing to acquire breadth through the study of relevant subjects outside their core disciplines. It provides, in effect, a second major, in manufacturing, to complement the technical major. It introduces students to subjects such as finance, operations management, personnel management, and manufacturing processes. It offers students the technical competence expected of Master of Engineering graduates, while placing technical considerations in a broader manufacturing context.

The Manufacturing Option achieves this synthesis by preempting the elective courses in the usual Master of Engineering curriculum. All M.Eng. students take four technical courses in their area of specialization, and choose four more courses in accordance with their interests and in consultation with their adviser. In the Manufacturing Option, students take four technical courses and four cross-disciplinary manufacturing courses. In addition, they attend a weekly manufacturing seminar and participate in a cross-disciplinary manufacturing design project.

One of the four core courses of the Manufacturing Option is a manufacturing-process survey course. Students may choose between two options: Survey of Mechanical Manufacturing Processes or Principles of Electronic Packaging. Each course assumes only a general engineering background, without specialized knowledge, and students can select the course that best fits their needs. Thus, practicing mechanical engineers without undergraduate training in mechanical manufacturing processes might take this opportunity to catch up, while engineers with the requisite undergraduate background could take this opportunity to broaden their horizons and learn about electronic packaging. The survey of mechanical manufacturing processes, which is offered by the Sibley School of Mechanical and Aerospace Engineering, reviews the prop-

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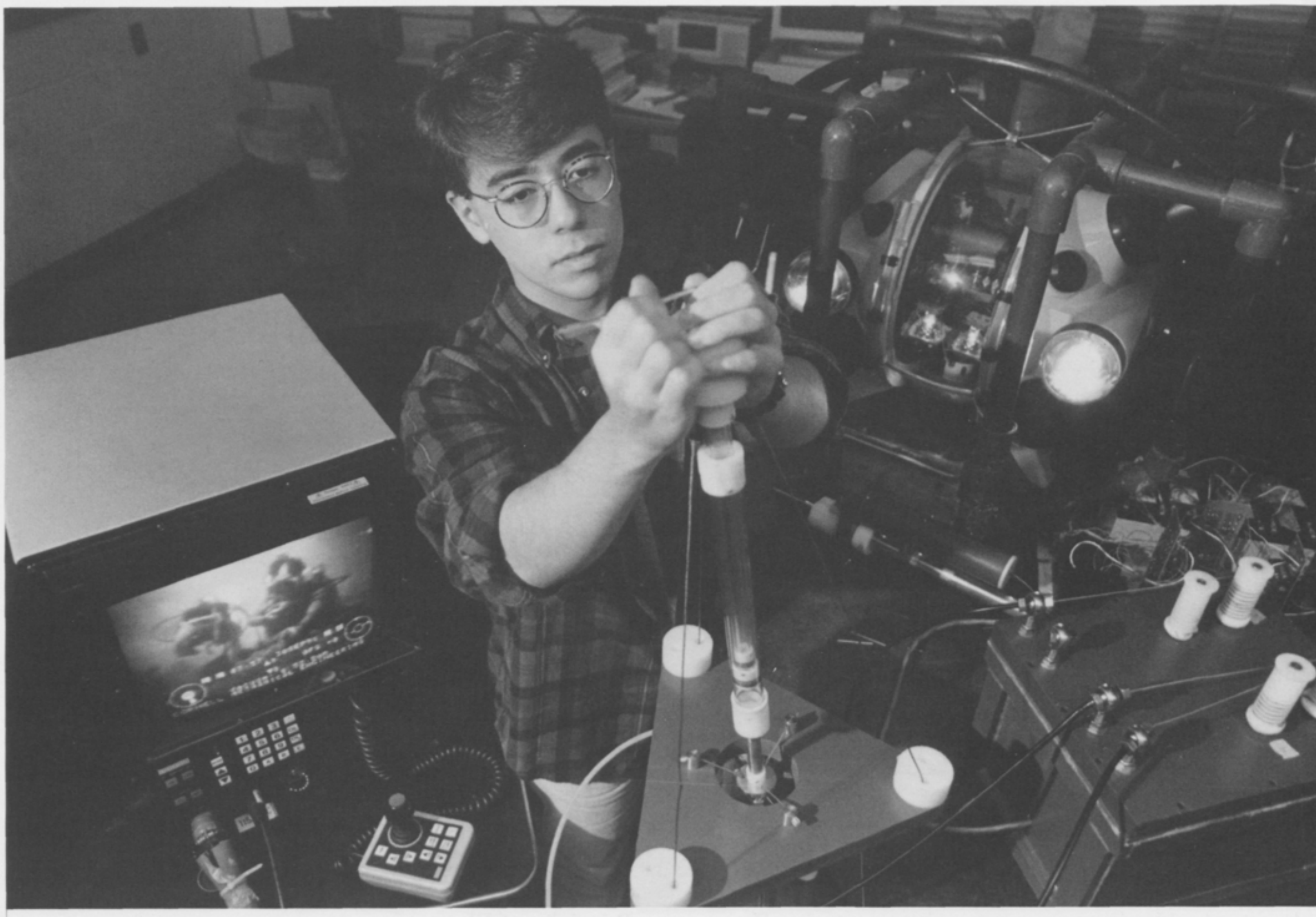


Master of Engineering student William Brandt adjusts the telescopic backbone of a novel parallel-link cable-controlled manipulator arm designed for use on a small underwater robot. The arm is moved by cables that act in concert, much as human neck muscles work together to position the head—but tension in the cables must be maintained while the arm extends and contracts. Brandt, a student in mechanical engineering who works with Professor Samuel Landsberger, developed various telescopic spines for maintaining cable tension. The robot, shown in the background, is used for environmental sampling; it may also be capable of removing zebra mussels that clog underwater pipes. The arm may have applications in surgery, shipbuilding, and work in outer space as well as under water.

erties of materials; provides an overview of major processes such as machining, casting, forging, and welding; discusses assembly technologies; investigates relative process economics; and looks at design in terms of ease of manufacture and assembly. The introduction to electronic packaging, which is offered by the Department of Materials Science and Engineering, covers packaging technology from chip to board, including the materials (metals, ceramics, and polymers), the design, the processes, and the principles involved.

A second core course is Manufacturing Systems and Logistics. Offered by the School of Operations Research and Industrial Engineering, this course focuses on the analysis and design of effective manufacturing and distribution systems, and studies the interactions between discrete processing, transport, and storage modules. It includes analytical techniques, such as stochastic models and mathematical programming, as well as the uses of computer simulation.

A third core course is Economics of Manufacturing, offered by the Johnson Graduate School of Management. This covers fundamental techniques for the economic evaluation of manufacturing alternatives, such as full life-cycle costs, net present value, and risk analysis. It also covers cost accounting as a basis for assessing performance and allocating resources to products and projects, introduces activity-based costing, and evaluates the cost implications of maintaining quality.

The fourth course in the manufacturing core is Organizational Implications of World Class Manufacturing. This course, which is offered by the New York State School of Industrial and Labor Relations, may be unique to Cornell among professional Master of Engineering programs. It focuses on the relationships between individuals with regard to job attitudes and communication; group dynamics and politics; leadership, authority, and bureaucracy; and organizational structures, cultures, and strategies. Case studies involve the introduction of just-in-time warehousing, manufacturing cells and teams, total quality management, concurrent engineering, and ties between manufacturers and suppliers.

Students also participate in group design projects centered on major manufactured products. They consider both the product and the system for its manufacture. They take into account the market for the product as well as its design, economics, financing, quality, life-cycle costs, distribution, and marketing. Since real manufacturing problems rarely fall into a single disciplinary area, all of the groups include students from at least three majors—such as mechanical, electrical, and industrial engineering. Thus, the students gain experience in solving problems as members of a cooperative, cross-disciplinary group.

The projects continue throughout the year, but make special use of the January intercession, when no regular classes are scheduled. The groups are supervised by faculty members and interact with representatives from industry who have volunteered to participate. This year's projects involve three local companies (Therm, Kolar Machine, and Emerson Power Transmission), two out-of-town companies (IBM and General Foods), and two on-campus initiatives aimed at the design of innovative semiconductor-related products and manufacturing equipment.

The final piece of the curriculum is the Manufacturing Seminar, which brings in a speaker from industry each week to explain how things are done in the "real world." This provides a salutary leavening for course-based learning, and keeps everyone—students and professors alike—in touch with current trends.

On graduating, students receive degrees that designate their technical fields, such as M.Eng.(Electrical) or M.Eng.(Mechanical), and certification attesting to their specialization in the Manufacturing Option.

The Best Response to the Needs of the Manufacturing Industry

The Manufacturing Option was conceived and organized by the Cornell Manufacturing Engineering and Productivity Program (COMEPP), with support from its external Policy Advisory Board, which includes representatives from various kinds of industry. It is coordinated by COMEPP, which works cooperatively with the participating fields and the Master of Engineering program.

COMEPP was founded in 1982 to provide a focus for research and education in manufacturing, design, and production manage-

"This course [Organizational Implications of World Class Manufacturing] may be unique to Cornell among professional Master of Engineering programs."

"The best way to bring about these sweeping changes is with the help of engineers who have been educated to take the broadest possible view of the manufacturing process."

ment. It is a cross-disciplinary program that interacts with many other entities, both inside and outside of Cornell, to foster manufacturing research, education, and industrial collaboration.

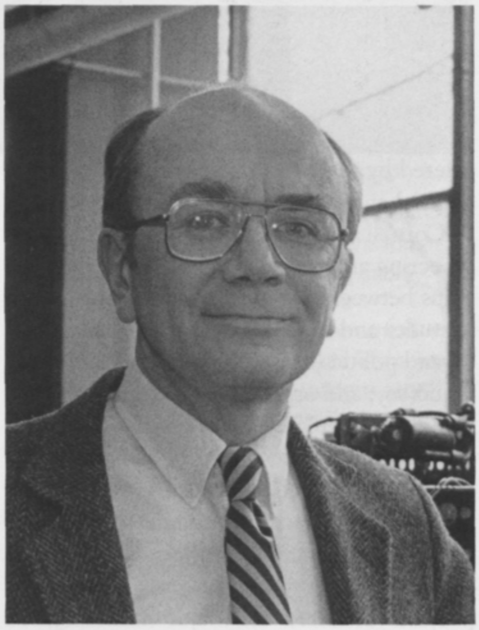
Under the dynamic leadership of John Muckstadt, COMEPP's first director, several major corporations agreed to help sponsor the initiative, and industrial support rapidly grew to $600,000 per year. Enthusiasm ran high, and there was an optimistic belief that techniques of systems analysis and research being developed at the university could make a major difference in the productivity and competitiveness of participating companies in the short term. It soon became clear, however, that there were no "silver bullets" that could magically solve all of a company's problems.

In October 1990, a special two-day meeting was held to reexamine COMEPP's mission. It was attended by COMEPP's director, Herbert B. Voelcker, Deans William B. Streett of the College of Engineering and Alan G. Merten of the Johnson Graduate School of Management, members of COMEPP's Policy Advisory Board, other special guests from industry, and faculty members representing many schools and departments. The consensus was that successful manufacturing in the evolving context of the international marketplace depends on numerous technical and cultural changes, as well as changes in product planning, product realization, and manufacturing. The best way to bring about these sweeping changes is with the help of engineers who have been educated to take the broadest possible view of the manufacturing process.

Accordingly, COMEPP designed the new Manufacturing Option, which initially became available through Master of Engineering programs in Civil and Environmental Engineering, Electrical Engineering, Mechanical Engineering, and Operations Research and Industrial Engineering. It is expected that yet other M.Eng. programs will offer the Manufacturing Option in the near future

The new program was not publicized until May 1991. By that time of year, most people who wanted to be graduate students in the fall had already committed themselves to the programs of their choice, so no one expected more than ten or fifteen applicants. Surprisingly, however, thirty-five signed up—nineteen who had already been students at Cornell, thirteen from other colleges, and three who were already working in industry. This response suggests that there is a real market for the kind of broad engineering training that the option was created to provide. If the initiative fulfills its early promise, the manufacturing industry will increasingly look to Cornell's Master of Engineering Program and its Manufacturing Option for the kind of savvy engineers who can make things happen in today's increasingly international and highly competitive economy.

Albert R. George is a professor in the Sibley School of Mechanical and Aerospace Engineering and director of the Cornell Manufacturing Engineering and Productivity Program (COMEPP). He received his Ph.D. in 1964 from Princeton University and joined the Cornell faculty in 1965. His research interests concern the aerodynamics of both aircraft and ground vehicles, especially the aeroacoustic mechanisms that result in noise. During sabbatical leaves, he has been a visiting senior fellow at the University of Southampton, England (1971–72); a section head at BMW, in Munich, Germany (1987–88); and a senior research associate at NASA's Ames Research Center in California (1988). He served as director of the Sibley School from 1977 through 1987.



M.Eng. students in the Manufacturing Option discuss the operation of a computer-controlled dual-wheel grinder with Don White (second from left), an employee of Therm, Inc. The Manufacturing Option encourages cross-disciplinary projects that involve local manufacturers. During the current academic year, ten students are working with Therm, Inc., an Ithaca firm that makes turbine blades and vanes for aerospace, marine, and industrial applications. The student projects seek to improve creep-feed grinding, machine setup, and work-in-process inventory. Students pictured are (from left) Jawad Shaikh (mechanical engineering), and Marius Ghercioiu and Eric Hannay (operations research and industrial engineering).

Tom Soh, a student in mechanical engineering, works on a hopping robot in Professor Jeff Koechling's laboratory. The robot, which will run forward and backward by hopping up and down, was developed in order to study the control of freely falling bodies that intermittently contact a passive environment. In running, the robot must reposition itself during each hop to modulate its interaction with the ground. A better understanding of running, and the transition between walking and running, could lead to a legged vehicle capable of walking slowly over rough terrain and running quickly over smooth surfaces. Soh, who is a senior, has been accepted into the Master of Engineering program and may continue working on the hopping robot for his design project.

THE M.ENG. INTERNSHIP

A Win/Win Option

by J. L. Clifford Wagoner '62

From a corporate perspective, Cornell's Master of Engineering program provides a near-optimum combination of undergraduate and graduate curricula designed to produce literate, articulate, and technically competent professionals. By not putting pressure on the undergraduate curriculum to increase its technical concentration, the Cornell program offers students the opportunity to achieve the broad-based education necessary to meet the diverse demands facing engineers. This approach seems especially appropriate in the complex culture of today's global community.

Cornell's long-standing commitment to the liberal enrichment of an engineering education is exemplified by its pioneering five-year undergraduate program in the 1940s and '50s. The five-year program was later replaced by the more flexible option of a four-year Bachelor of Science undergraduate degree that could be followed by a one-year Master of Engineering program for a professional degree.

Other undergraduate programs in engineering have often concentrated too strongly on applied technical subjects; for example, their curriculum may include three sequential courses in a single applied area. In contrast, Cornell undergraduate engineering has been characterized over the years by graduates who are well-grounded in liberal arts as well as science and mathematics.

During the thirteen years I worked at Schlumberger Well Services, the company had a close association with many Cornell faculty members. Similar relationships were established with M.I.T., University of Illinois, Berkeley, and Stanford. All of these institutions have outstanding faculties, but we found that Cornell's Master of Engineering program produces graduates of greater breadth without sacrificing technical competence.

The company with which I was affiliated has been involved with the recruiting of graduate students for all of its history. Most university work-study programs feature three-month employment periods. Almost all the company's technical leaders feel that appointments this short serve mostly to benefit the students. The work period does not allow time for students to become knowledgeable enough about the company and the project to make a real contribution. The only benefit to the corporation is in identifying outstanding students for possible future employment.

The Cornell Master of Engineering internship, announced in 1985, includes twelve months of continuous employment. This innovation appeared to have significant advantages for the corporation, and management enthusiastically joined the program. The first year the company interviewed many outstanding seniors, and selected seven of them for internships. Over the subsequent years, a total of seventeen students have interned at the Houston office, and the program continues.

Advantages of the Internship to the Company

With the twelve-month internship, both the company and the student "win." The company wins by gaining the same contribution normally expected from a first-year M.S. graduate at an equivalent cost, but with some important advantages. Because the employees are students in absentia, the company pays Cornell directly, without the additional expense of paying for fringe benefits. The total cost of an internship, including two semesters on campus and one year at the work site, is about $45,000. Since an M.S. graduate would normally receive a salary of at least $35,000 per year plus 40 percent benefits, the net cost to the company is about the same. But the advantages of taking on an M.Eng. intern over hiring an M.S. graduate include opportunities for: (1) a complete evaluation of the

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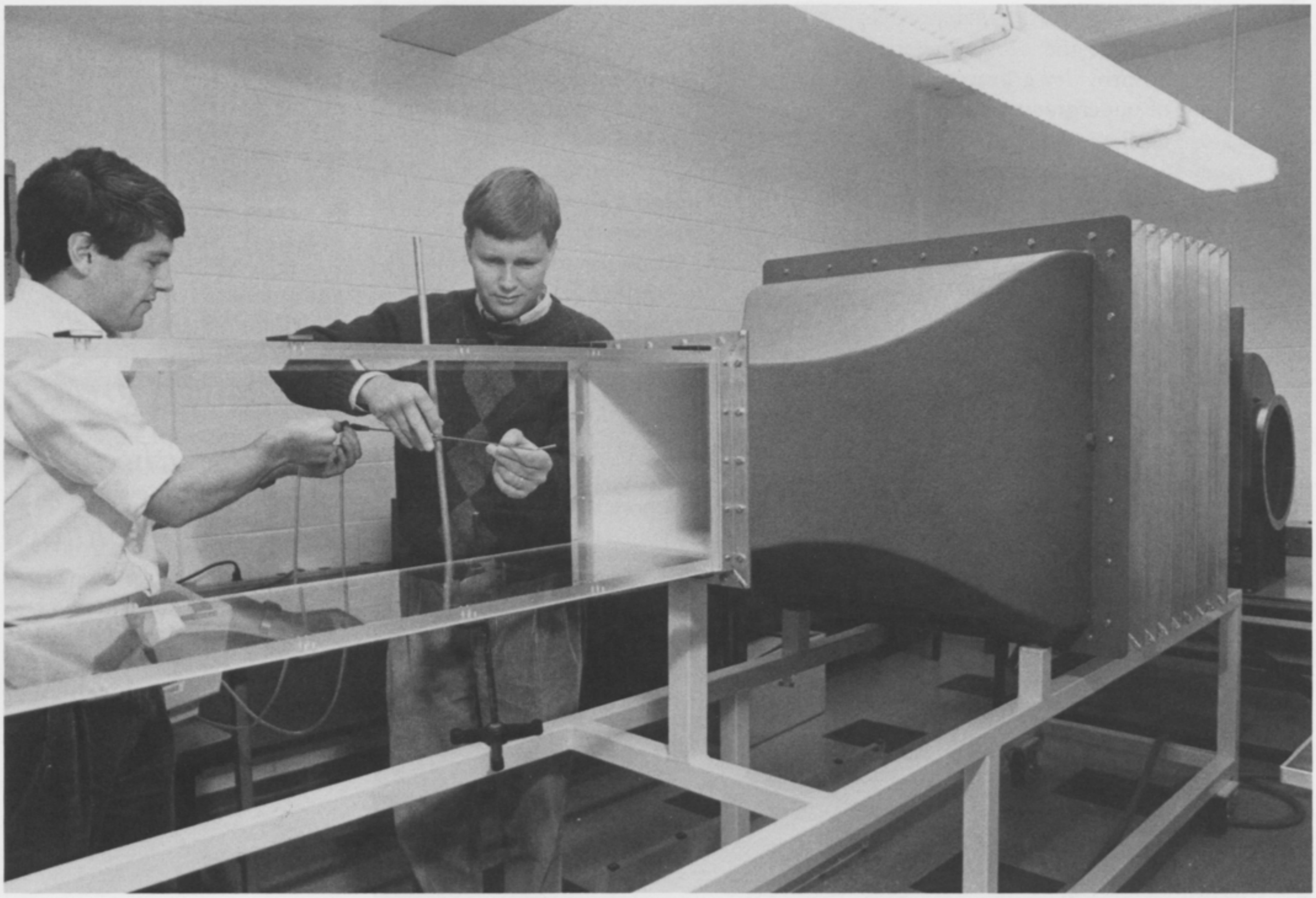

Research student Greg Miller (left) and Professor Charles Williamson set up the second of two new wind tunnels, which are used to study laminar-turbulent transition in the wakes of bodies. In addition to these facilities, which are available to both M.Eng. and Ph.D. students in aerospace engineering, a novel computer-controlled *x-y* towing tank used for visualizing the wakes of bodies in unsteady motion has recently been installed in Williamson's Water Facilities Laboratory.

student prior to employment, and (2) the enhancement of the corporate relationship with Cornell. A more subtle but sometimes important advantage is that students are not included in the total head count of full-time employees, which is often used to manage budgets in engineering departments.

Advantages of the Internship to Engineering Students

Students win by having their living expenses, tuition, and fees paid, and by having an opportunity to evaluate their field and the employer in depth. Student employees get hands-on experience with real engineering projects. In our case, several interns were assigned to projects relating to physical instrumentation for use in the oil fields: a listener/talker integrated circuit for digital communications for all instruments, bore-hole compensation software for a dual-induction tool, field analysis and redesign of antennas on an electromagnetic propagation tool, identification of a peak in a gamma ray spectroscopy tool as an iodine contribution, mapping of fields from a neutron generator in a thermal decay tool, and analog-to-digital integrated-circuit converters.

As a result of their internships, all seventeen students desired permanent employment with the company. Unfortunately the oil industry was severely depressed at that time, and it was not possible to offer positions to all of them. Even under these circumstances, the value of the program both to them and to us was very high.

Structuring a Successful Internship Program

There are many ways to structure a successful internship. The approach we used is outlined here as an example.

The first and key step is to find a line manager in one of the technical departments who is a Cornell engineering or science graduate. This person must believe that the company's mission is fundamentally dependent on the excellence of its employees and that Cornell graduates are among the very best potential employees. An enthusiastic and effective leader is critical to the success of the program.

Once a program leader is identified, that person gains informal approval of the program from company peers. Then it is necessary to seek approval from the manager of the technical center to hire interns. Persuasive advantages of the program include employee selection, full twelve-month productivity, cost effectiveness, and enhanced university relations.

Once approval is obtained, our approach calls for the following agenda:

Visit Cornell. During this visit, company representatives meet with key faculty members and administrators of the Master of Engineering program. The purpose of the initial meeting is to introduce the company, its technical interests, and its intention to offer an internship. Subsequent meetings are useful in identifying outstanding members of the senior class for interviews.

In arranging campus visits, company managers take advantage of university assistance to plan open houses and receptions in the engineering departments. University personnel, including student organizations, are very helpful. For example, Associate Dean K. Bingham Cady organized a reception for the company in the main atrium of Snee Hall with one hundred guests. The company makes routine campus visits and offers internships each year to increase mutual contacts and to maintain its reputation among the students.

Schedule interviews and select candidates. Our company conducts interviews early in the year before seniors choose between the M.Eng. program and a job. Internships often make the difference in a student's ability to pursue a professional degree.

We bring successful first-round candidates to the company for uniform interviews, all conducted on the same day. Interviewers evaluate these candidates at the end of that day while the discussions are fresh in their minds.

After successful candidates have been chosen, company employees meet to design a job or jobs to propose to each candidate. Offers are made immediately.

Provide mentors. When students accept the offer, we match each intern with a company "mentor." This mentor, responsible for the intern throughout the entire twenty-one-month period, contacts the student immediately to discuss the proposed job and to sug-

"Student employees get hands-on experience with real engineering projects."

A team of Master of Engineering students specializing in engineering management is developing software for the General Motors Powertrain Division to use in planning its manufacturing capacity. The students recently toured the Tonawanda Engine Plant near Buffalo, New York to learn more about the operation of plants where their software will be used. Shown here are students (from left) Donna Swenson, John Yeh, Hiroyuki Matsumura, Adina Kessler, Masaki Takai, Charles Huang, and Benson Yeh watching GM's Mary Dool (far right) inspect the installation of crankshaft bearings in V-6 engines.

gest relevant course work. All of the above activity is completed by March or April, before registration for the fall term.

Toward the end of the fall semester, the mentor contacts the intern for pre-orientation. Once the intern arrives at the work site, the mentor explains initial training procedures and launches the project.

Offer ongoing review and support. The program leader, mentors, and interns meet once a month at lunch. Also invited are the manager of the technical center, the human resources manager, and the college programs coordinator. At these luncheons, interns make presentations on their projects. There is also a roundtable discussion on other projects and on matters of concern and interest to the interns. Interns also make formal reports to both their employers and their Cornell advisers at the end of each project and at the end of the twelve-month work period.

Evaluate performance and offer permanent positions as appropriate. A detailed evaluation of the intern is made by the mentor and knowledgeable company managers. If the evaluation is positive, and business conditions permit, a job offer is made as soon as possible. Both the company and the student realize maximum benefits if the intern continues in the same project area after graduation. At that time, the student will have been away from the job for only one semester.

Working Together to Achieve Excellence

It is of vital importance to the United States for industries, universities, and students to work together to achieve excellence in science and engineering. The Master of Engineering internship option, linking academia and industry, offers a real opportunity to do so. Practitioners fulfill an adjunct professor's role in the educational process and faculty members discover new insights for practice-oriented research, while students fine-tune their technical specializations with on-the-job experience. In the corporate view, Cornell's internship option is the capstone of an outstanding curriculum that is unparalleled in preparing engineering students to meet the challenges ahead.

J. L. Clifford Wagoner, director of contract business at Kewaunee Scientific Corporation in Statesville, North Carolina, received the Bachelor of Electrical Engineering degree from Cornell in 1962. The five-year engineering curriculum then in effect was much like a combined B.S./M.Eng. program, and graduates have subsequently received Certificates of Advanced Engineering Study in recognition of this fact. Wagoner also holds an M.S. in engineering management from Northeastern University.

Following his graduation from Cornell, Wagoner spent three years as a project engineer in the Air Force. He then joined BIW Cable Systems in Boston, Massachusetts, and rose to the position of vice-president of manufacturing.

His career with Schlumberger began in 1977 at the company's Vector Cable Division. He transferred to Schlumberger Well Services in 1982 where he became the manager of the Engineering Technology Department. He has worked with Kewaunee Scientific since February 1991.

Wagoner is a registered professional engineer in the state of Texas and a senior member of the Institute of Electrical and Electronics Engineers. He holds a patent for optical-fiber cable construction and is listed in Who's Who in Finance and Industry.

"In the corporate view, Cornell's internship option is the capstone of an outstanding curriculum. . . ."

Jim Upright, a Master of Engineering student in the Department of Geological Sciences, is using gravity and seismic techniques to search for buried gorges in the Ithaca area. Gorges like those that now cut through the Cornell campus were present in other places before the last ice age, but they were filled with the debris that was bulldozed south by the glaciers. The location of these buried gorges is of interest because they may affect drainage patterns in agricultural fields. Upright sends seismic waves into the ground by striking a metal plate (near his left foot) with a sledge hammer. The returning waves, which are picked up by the seismic recorder, can be analyzed to reveal the boundaries of a buried gorge.

THE ENGINEERING MASTER'S DEGREE

Achieving Educational Objectives

by Edmund T. Cranch

Over the past twenty-five years, education leading to the master's degree has undergone a remarkable transformation. More than 300,000 master's degrees are granted every year, constituting one-fourth of all the higher degrees awarded in the United States. This surge of growth has come about because, to an increasing extent, the master's degree is recognized as the best port of entry and the best route to advancement in professional practice. These are among the findings of a recent national study of master's education carried out under the auspices of the Council of Graduate Schools.

Much of the attention given to graduate study in engineering has focused on doctoral research, with the master's degree viewed as merely a steppingstone on the path to the Ph.D. Between 1957 and 1970 the annual crop of engineering doctorates grew from 600 to 3,600—a compound annual growth rate of 15 percent—and in the academic year 1989–90 the number reached 5,424. This emphasis on research is largely patterned after the physical sciences, where the traditional goal has been scholarly research leading to the Ph.D. degree.

But a career in engineering is different from a career in the sciences, and a master's degree in engineering should be more than a vestigial appendage to the Ph.D. Nearly 85 percent of the master's degrees granted today are in professional fields, with 70 percent in education, business, health sciences, public affairs—and engineering. The time has come to strengthen the master's degree as an educational base for the engineering profession.

A program designed to achieve this goal must meet three objectives:

- It must increase technical competence;
- It must involve students in the process of professionalization through practice-related experience; and
- It must prepare engineers for lifelong learning in support of careers with evolving objectives.

Technological Change and Technical Competence

Dominant features of today's society are its technological character and the accelerating pace of technological change. As the industrial revolution pushes wider and deeper into almost all realms of human activity, it is bringing about a marked change in the work force, with a growing number of functions requiring a substantial level of skill and sophistication. To an increasing extent, engineering problems are approached by a synthesis of existing knowledge and computer simulation. Engineers and applied scientists have made great advances in the characterization of materials and processes, in more powerful and sensitive instrumentation, in new conceptual and analytical techniques, and especially in new methods of processing, utilizing, and evaluating information. The power of the computer to simulate and manage these highly complex processes and systems gives engineering its great practical impact.

These changes mean increased educational requirements in all fields of engineering. The list of "unmet needs" includes not only greater depth of specialization, but also

- increased design, manufacturing, and processing content;
- greater involvement in hands-on laboratory and project work to stimulate creativity and inventiveness;
- development of managerial skills, with attention to economics and finance, leadership and human resources, and training in team participation; and the unending call for
- enhanced content in the humanities, social sciences, and languages to enable engineers to function in a global context.

The volume of material that must be taught is so great that it simply cannot be accommodated within the traditional four-year undergraduate curriculum. Additional education at the master's level is essential.

". . . the master's degree is recognized as the best port of entry and the best route to advancement in professional practice."

Professor Wolfgang Sachse (left) and Richard A. Baker, a Master of Engineering student in the Department of Theoretical and Applied Mechanics, adjust a loading frame used to test composite specimens that contain just one reinforcing fiber. As a load is applied, the fiber becomes fragmented along its length. This process can be monitored by the acoustic signals that are emitted, and the strength of the bond between the fiber and the matrix can be measured. For his M.Eng. project, Baker designed and built a PC-based system that makes such measurements.

Practical Preparation for Professional Practice

A second objective of graduate study for engineering practice is the incorporation of programs that expose students to the practical realities of the work they will do after graduation. An academic program that presents material from only a theoretical point of view does not fully prepare students for the professional world. A master's program needs to expedite the transition from student to practicing engineer, making professionalization a gradual process rather than an abrupt change of course. In all the fields investigated in the Council of Graduate Schools' study, the incorporation of experience that aids in professional development appears as an important factor motivating students to earn master's degrees.

A recent report published by the American Society for Engineering Education also stressed the place of preparation for professional practice in engineering master's programs. The report, "A National Action Agenda for Engineering Education," urges the establishment of advanced degree programs focused on engineering practice in a variety of technological specialties. According to the report, "The majority of baccalaureate students who wish to pursue careers in engineering practice should be encouraged to complete such programs on a full-time basis as the appropriate route to a working depth of knowledge and skill."

Preparation for a Career with Evolving Goals

As engineering graduates progress in their careers, they need to stay abreast of advances in technology. Professional obsolescence occurs when the time constants of technological change are substantially less than the time constants of a professional career and the associated process of education. As the baby-boom generation grows older, the proportion of technically trained people in the work force who are over the age of forty is increasing. Since the technical and economic progress of society is in large part dependent on the productivity this group, we must learn more about the relationships among aging, obsolescence, workplace performance, and education.

While continuing education attempts to keep engineers abreast of technical developments, little research has sought to determine how the fundamental educational parameters of normal academic degree programs affect the length of professional productivity. One of the most revealing studies, carried out at Harvard Business School, was done over twenty years ago.* Data were obtained on the performance of 2,500 technically trained people of different ages, including both formal evaluation ratings by managers and the engineers' own assessment of how their performance changed as they got older.

A significant finding of this study was that people who completed graduate degrees were rated appreciably higher than those without graduate degrees. But the performance ratings of engineers with master's degrees held up *ten to fifteen years longer* than those of engineers with bachelor's degrees only. This finding suggests that engineering education should give much more attention to the master's degree and how it can contribute to extending the productive careers of engineering practitioners.

It is important to recognize that professional goals change during the course of an engineer's career. As engineers get older, many assume management responsibilities or enter a more multidisciplinary environment. And technological change often occurs at the interface between disciplines, so that interdisciplinary or multidisciplinary collaboration is the key to avoiding professional obsolescence.

From a curricular perspective, multidisciplinary work requires a knowledge base and maturity that is almost impossible to create at the bachelor's level. But master's degree programs provide an opportunity to incorporate this dimension in the curriculum, in the form of major-minor combinations such as engineering and management, engineering and waste disposal, engineering and biotechnology, engineering and materials, and many other possibilities. One way to further strengthen such combinations is through a well-planned articulation between bachelor's and master's degree programs. Flexibility is crucial, and several approaches to multidisciplinary career objectives have been developed.

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* Dalton, G. W., and P. H. Thompson. 1971. Accelerating obsolescence of older engineers. *Harvard Business Review*, September-October, 1971, pp. 57–67.

"The time will come ... when Cornell awards at least as many engineering master's degrees as bachelor's degrees."

Attributes of Effective Master's Programs

The study recently conducted under the auspices of the Council of Graduate Schools analyzed master's degree programs in eleven fields, including electrical engineering. In all fields, from the performing arts to nursing, effective programs were characterized by eight attributes.

• Explicit administrative support for the master's program helps overcome years of neglect during which the B.S. and Ph.D. were more favored degrees.

• A good balance of theory and practice holds in check the academic bias in favor of pure theory.

• Students are given an opportunity to see how professionals work, through an internship, apprenticeship, or similar immersion experience.

• A project, thesis, or other tangible product provides an opportunity for students to experience practice-related competence.

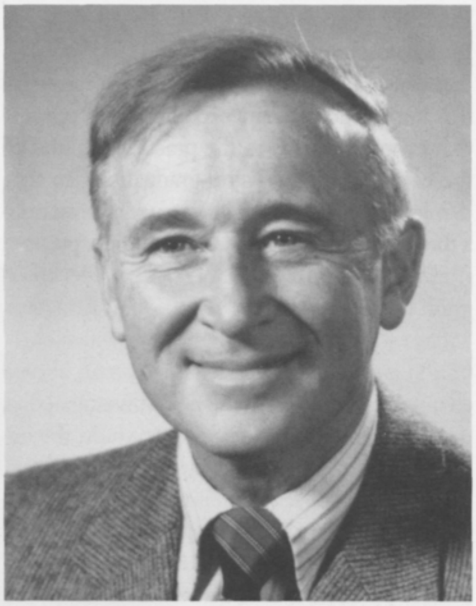
• Exposure to practicing professionals or faculty members who possess current know-how boosts motivation.

• The programs benefit from energetic departmental leadership and active support of tenured professors.

• The learning environment allows students to interact with one another intellectually and present their work before peers.

• Applicants have the talent, time, and motivation to participate in a vigorous, professional degree program.

In Cornell's long and pioneering experience with the engineering master's degree, all of these attributes have been incorporated into the program. Cornell is fortunate to possess the learning environment, program structure, faculty, and student resources to play a national role in the further development of professional master's education. In so doing, Cornell will meet the future needs of its students and give them the educational preparation for professional leadership. The time will come, I am sure, when Cornell awards at least as many engineering master's degrees as bachelor's degrees.



Edmund T. Cranch was a student (B.M.E. 1945, Ph.D. 1951), a faculty member in theoretical and applied mechanics (1951–78), a departmental chair (1956–68), an associate dean (1967–72), and dean (1972–78) at the College of Engineering. In 1978 he became president of the Worcester Polytechnic Institute, and between 1985 and 1987 he was president of the Wang Institute of Graduate Studies. He is now Granite State Distinguished Professor at the University of New Hampshire.

In addition to his academic duties, Cranch has been active as a consultant to industry and as a member of various industrial and educational organizations. He is a fellow of the American Society of Mechanical Engineers and a past president of the American Society for Engineering Education.

In recent years Cranch has become increasingly concerned with educational policy. He was a member of the American Society for Engineering Education's Task Force on a National Action Agenda for Engineering Education, and he served as chair of the National Research Council's Panel on Engineering Undergraduate Education. He was a member of the National Advisory Board for the study mentioned in this article, which was directed by Clifton F. Conrad of the University of Wisconson. A book-length report of this study will be published shortly by The Johns Hopkins University Press.

Master of Engineering students in structural engineering, geotechnical engineering, and engineering management participate in a group project involving the planning and design of a large building. Practicing engineers who serve as consultants provide basic information on a building that is currently under development, and the students work out their own structural design, including cost estimates and construction plans. Here, Professor Gregory Deierlein examines a model showing the students' solution to an actual project designed by Skidmore, Owings & Merrill. Pictured with Deierlein are Douglas Kirkpatrick (left), Rebecca Frein, and Peter Gant (right).

Gladys McConkey Retires

Gladys McConkey, who is responsible for making the *Quarterly* one of the finest magazines of its kind, retired on August 31, 1991. She began working on the *Quarterly* in 1970, when it was still in its infancy, and she organized, edited, and designed each issue with motherly devotion. Once the magazine attained a certain degree of maturity, after twenty-one years of careful guidance, she stepped away and gave it a chance to go forward on its own.

She began her journalistic career as Gladys Voorhees, with the editorship of her high school newspaper in Cleveland, Ohio. After graduating, she attended Western Reserve University, where she majored in chemistry and became editor of the college newspaper. Her predecessor as editor was James McConkey, whom she married shortly before he went off to Europe as a soldier in the Second World War. While awaiting his return, she began graduate study in chemistry and worked in the research laboratory of Standard Oil Company of Ohio.

After the war, the couple went to the University of Iowa, where James McConkey embarked on a doctoral program in English. Gladys McConkey had a research assistantship in biochemistry and worked in the university hospital's pathological chemistry laboratory. She earned a master's degree, but progress toward a doctorate was interrupted when the family, which now included a son, moved to Morehead State College in the hills of eastern Kentucky.

At Morehead, Gladys McConkey taught a class in journalism, acted as adviser to the student newspaper, and ran a one-woman public-relations office for the college. She also helped her husband publish two anthologies of Kentucky writing, which were produced with such limited resources that the pages had to be collated by hand around the dining-room table.

In 1956 James McConkey was offered a position in the English department at Cornell, and the family (now with two sons) moved to Ithaca. Gladys McConkey began her Cornell employment with six years as a part-time research assistant in the chemistry department, in the laboratory of Nobel Laureate Peter J. W. Debye. (The third McConkey son was born during those years.) Subsequently, she spent six years with biochemistry professor George P. Hess, mostly working on research publications.

During her years with Debye, McConkey and colleague Alfred Prock spent extra hours working on a book, *Topics in Chemical Physics,* based on a series of lectures Debye had given at Harvard University. Since he had not done the actual writing, Debye insisted that Prock and McConkey be listed as the book's authors. It was published by Elsevier and later translated into Japanese. Despite the great volume of writing and editing that Gladys McConkey has done over the course of her career, this is the only book that bears her name.

In August 1970, she was hired by Donald Berth as associate editor of the fledgling *Engineering: Cornell Quarterly,* which he had founded four years earlier. By the winter of 1972, Berth had moved on and McConkey replaced him as editor. Throughout her tenure, she produced the *Quarterly* almost single-handedly. In addition, she compiled *Cornell Annotation,* a bimonthly newsletter of research abstracts, from October 1970 until the series ended in March 1986. From that time onward, she produced the college newspaper, *Cornell Engineering News.* She also designed and edited brochures, announcements, books, newsletters, fliers, and posters. Over the years, as the work load increased, addi-

Gladys McConkey with Donald Berth in 1971, shortly after she began working on the *Quarterly.*

tional staff was gradually added in the publications office, but McConkey continued to craft each issue of the *Quarterly* herself.

In each of her previous jobs, McConkey says, she learned something that was helpful in her work on the *Quarterly*. From her newspaper experience she learned how to write a good lead—an opening paragraph that will get the reader's attention. In her various laboratory jobs, she learned about the day-to-day realities of research, and the importance of understanding things in their context. (One of her first assignments at Standard Oil, for example, involved analyzing the deposits that build up on pistons—although when she started out she had little idea what pistons do.) From Debye she acquired the conviction that there is always some way to make difficult material understandable. She remembers Debye discouraging excessive reliance on mathematical formulas and telling students, "If you can't say it in words, you don't really understand it." From Hess she learned the trick of writing an article backwards—first the conclusion, then the data, then the methods, then the introduction, and finally the abstract.

As an editor, McConkey imposed uncompromisingly high standards on the *Quarterly*. She insisted on correct grammar and punctuation, and was no less concerned about substantive accuracy. But her most important contribution was more profound. She had a vision of what the

Gladys McConkey at a reception marking her retirement, which was held at the A. D. White House on August 29, 1991. She is talking to Professor Emeritus Paul Hartman, one of more than a hundred faculty and staff members who honored her with their presence.

Quarterly should be, and made it what it is. She developed a view of the readership as consisting of "technically trained nonspecialists," and she tried to pitch the articles so that a chemical engineer could understand a story about celestial mechanics, or a civil engineer could understand recent advances in microcircuitry. She also developed a sense of what to feature in the magazine. Each issue focuses on a particular subject, involving either research or educational programs, and she worried, when she first became editor, that she would not be able to come up with appropriate topics. But that never became a problem.

Spontaneously tactful and diplomatic, McConkey earned the respect and confidence of faculty authors throughout the College of Engineering. While professors are often enthusiastic about their research, they seldom know how to convey their excitement. McConkey was able to draw them out, looking for the significance of the most abstruse research, and placing it in context. She knew how to identify what authors really want to communicate, and helped them get their point across. She tried to keep the flavor of an author's individual style, and she made doubly sure that her editing was acceptable before an article was published.

During McConkey's tenure as editor, the *Quarterly* won many awards. It won Graphic Arts Awards from the Printing Industries of America in 1972 and 1974, and numerous citations, special merit awards, and exceptional achievement awards from the Council for Advancement and Support of Education. Among these are awards for Magazine Publishing Program of the Year (1976), Top Ten Magazine Awards (1973, 1981), a Special Issue Award (1982), and a Best Articles of the Year Award (1983).

Over the years, Gladys McConkey gave the *Quarterly* its character and made its reputation. Under her guidance, it became a record of engineering research and education. She gave the world a portrait of Cornell's College of Engineering, but she placed it firmly in the broader context of twentieth-century technology. She established a model of excellence in technical writing for others to follow, and she built up a fund of good will among the faculty that will continue to pay dividends in the future.
—DP

On December 12, 1991, the Board of Trustees approved the election of five faculty members to endowed chairs in the College of Engineering.

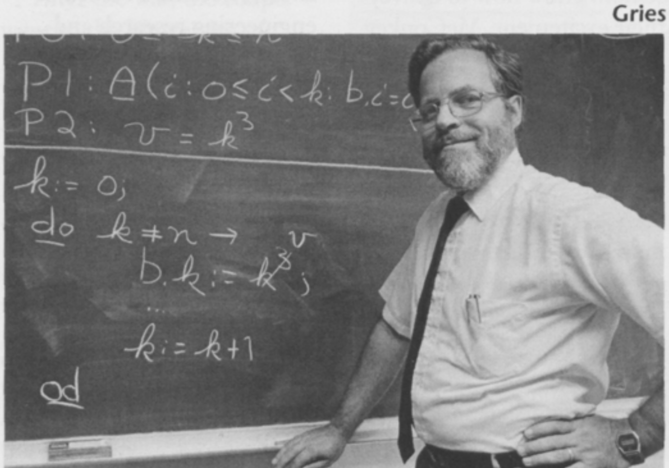
■ ***David Gries,*** in the Department of Computer Science, was elected the first William L. Lewis Professor of Engineering. Gries is known internationally for his work on programming methodology and compiler construction. His current research deals with several aspects of programming, including extending current methodologies to larger programs and specifying concurrency problems in distributed programs.

Gries holds a bachelor's degree from Queens College, a master's degree from the University of Illinois, and a doctorate from the Munich Institute of Technology. Before joining the Cornell faculty in 1969, he spent three years as an assistant professor of computer science at Stanford University. He was a visiting professor at the Munich Technical University in 1975–76, and he spent his 1983–84 sabbatical leave as a Guggenheim fellow at the University of Oxford. In 1986 he received the prestigious AFIPS Education Award from the American Federation of Information Processing Societies.

William L. Lewis, ME '22, had a long and successful career with IBM and was a tireless supporter of Cornell University and the College of Engineering. The professorship that bears his name was endowed through a trust established in his will, which also supports a number of Master of Engineering fellowships.

■ ***David A. Hammer,*** a member of the Program in Nuclear Science and Engineering, was elected the first J. Carlton Ward Professor of Nuclear Energy Engineering. Hammer's research focuses on the physics, technology, and application of extremely high-power, short-pulse ion beams and plasma-radiation sources. As director of Cornell's Laboratory of Plasma Studies, he administers the world's largest university-based program in intense charged-particle beams.

Gries



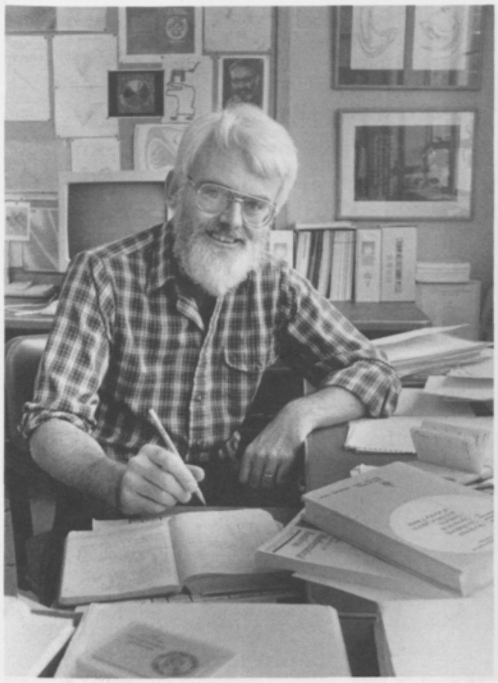
Hammer

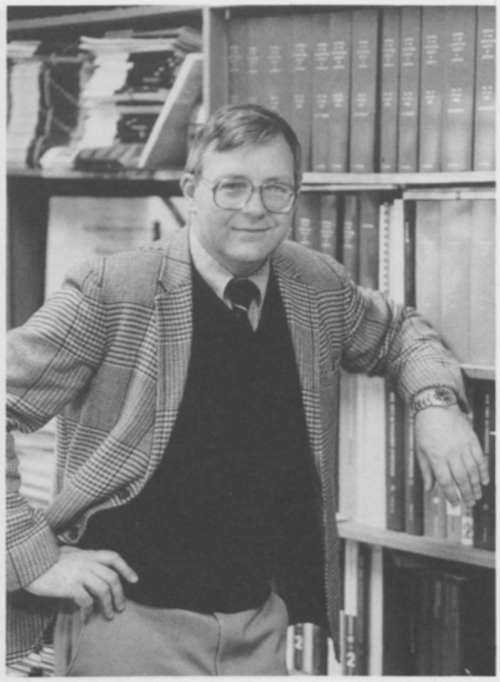
Hammer holds a bachelor's degree from the California Institute of Technology and a Ph.D. from Cornell University. After receiving his doctorate, he worked for seven years as a research physicist at the United States Naval Research Laboratory. He also taught at the University of Maryland and at the University of California at Los Angeles before joining the Cornell faculty in 1977. During the 1983–84 academic year, and again in spring 1991, he was a visiting senior fellow at Imperial College, London, under the sponsorship of the National Science Foundation.

The Ward professorship was endowed through a trust established by J. Carlton Ward, ME '14, a strong proponent of nuclear energy. During a long career, Ward held a number of important industrial posts. He was president of the Fairchild Engine and Aircraft Company during World War II, and he was instrumental in the transfer to Cornell of the Buffalo Aeronautical Laboratories. He was a long-time member of the Engineering College Advisory Council, and served as its chair in the 1960s.

■ ***Philip J. Holmes,*** in the Department of Theoretical and Applied Mechanics, was elected the first Charles N. Mellowes Professor of Engineering. Holmes, who is also a member of the Department of Mathematics, is an expert in complicated dynamical behaviors; his research is aimed at improving basic understanding of deterministic nonlinear dynamical processes. In 1980 he spent six months as a visiting scholar at the University of California at Berkeley, and in 1988–89 he was a Sherman Fairchild Distinguished Scholar at the California Institute of Technology. He has served as director of Cornell's Center for Applied Mathematics.

Holmes received his undergraduate education at the University of Oxford and earned the Ph.D. at Southampton where he held a research assistantship, and later a fellowship, at the Institute of Sound and Vibration Research. He joined the Cornell faculty in 1977.


Holmes


Sachse

The Mellowes professorship was created in 1991 through a gift from the Mellowes family of Milwaukee, Wisconsin, on the occasion of the 80th birthday of Charles N. Mellowes. Three generations of the Mellowes family graduated from the Cornell College of Engineering. Charles '33 and his father Alfred '06 founded the Charter Manufacturing Company, a speciality steel concern, in the 1930s. Charles's son John '61 is currently president and chief executive officer.

■ *Wolfgang Sachse*, in the Department of Theoretical and Applied Mechanics, was elected the first Meinig Family Professor of Engineering. Sachse's research focuses on developing quantitative ultrasonic and acoustic-emission techniques applicable to nondestructive testing and materials characterization. He is an author of more than 140 publications and holds two U.S. patents. An associate technical editor of *Materials Evaluation*, he serves on the advisory board of *Ultrasonics* and has organized several international conferences. In 1989 he won the Dean's Prize for Innovation in Teaching in recognition of his introductory course, Sensors and Actuators.

Sachse holds a bachelor's degree from Pennsylvania State University, and received his master's degree and doctorate from The Johns Hopkins University. Before joining the Cornell faculty in 1970, he was a Humboldt fellow at the Institut für allgemeine Metallkunde und Metallphysik in Aachen, Germany.

The Meinig Family professorship was established in 1991 through a gift from Peter C. Meinig, ME '61, and his wife Nancy Schlegel Meinig, Human Ecology '62, of Tulsa, Oklahoma. The gift was made on behalf of all the members of the Meinig family who have attended Cornell. These include, in addition to Peter and Nancy, their daughters Anne and Kathryn, and Peter's father, Carl H. Meinig, AB '31, EE '33. Peter Meinig is chairman of ElectroCom Automation, Inc., which markets equipment for information processing and materials handling.

■ *Michael Shuler*, in the School of Chemical Engineering, was elected the Samuel B. Eckert Professor of Chemical Engineering. Through his research, Shuler seeks to gain a better understanding of how cells function and to develop strategies for the design and operation of biologically based reactors. His laboratory was the first to apply engineering principles to the production of chemicals from plant-cell culture, and his group developed a new class of mathematical models to describe cell growth. In 1989, Shuler was elected to the National Academy of Engineering, and in 1991 he received the Professional Progress Award from the American Institute of Chemical Engineers.

Shuler, who holds a bachelor's degree from the University of Notre Dame and a Ph.D. from the University of Minnesota, joined the Cornell faculty in 1974. He is a member of the graduate fields in food science and microbiology, as well as chemical engineering, and he has been active in the development of

Shuler

the Biotechnology Institute and Biotechnology Center.

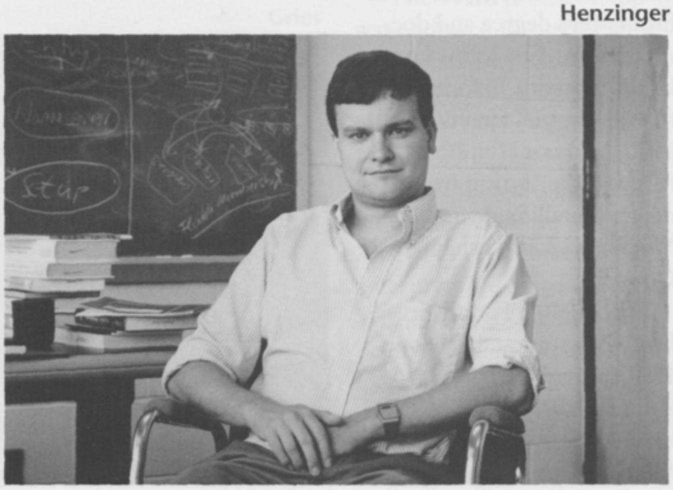
Samuel B. Eckert, ME '08, spent most of his career with Sun Oil Company, where he became vice-president and director of the Sun Shipbuilding and Drydock Company. Prior to his death in 1973, he established a trust that made possible the three Eckert professorships in engineering. The other Samuel B. Eckert Professors are Edward J. Kramer, in the Department of Materials Science and Engineering, and Sidney Leibovich, in the Sibley School of Mechanical and Aerospace Engineering.

■ Assistant Professor ***Thomas A. Henzinger*** joined the Department of Computer Science in January. Henzinger, whose research interests include the logical foundations of computer science and their ramifications for language and system design, is a diplomate of Kepler University in Linz, Austria, where he graduated with honors, and holds an M.S. degree from the University of Delaware and a Ph.D. from Stanford University. He was a Fulbright Fellow (1985–86) and an IBM Graduate Fellow (1988–91). Henzinger received the 1989 George E. Forsythe Memorial Award for Excellence in Student Teaching at Stanford. He has been a visiting scientist at the Department of Applied Mathematics at the Weizmann Institute of Science in Rehovot, Israel, and a postdoctoral visitor at Fourier University in Grenoble, France.

Jelinski

■ Professor ***Lynn W. Jelinski***, joined the engineering faculty as director of the Biotechnology Program in the fall of 1991. Her research centers on the application of nuclear magnetic resonance and magnetic-resonance imaging techniques to problems in biophysical and biomedical engineering. Jelinski came from AT&T Bell Laboratories, which she joined in 1980, after holding postdoctoral and staff fellow positions at the National Institutes of Health. While at AT&T, she headed the departments of biophysics and polymer science and performed fundamental research in both areas. She is a Fellow of the American Physical Society, a member of the advisory board of Chemical Abstracts Service, and a member of the Molecular and Cellular Biophysics Study Section of the National Institutes of Health. She is past chair of the Experimental NMR Conference, of the advisory board of the High Field NMR Facility at M.I.T., and of the National Academy of Sciences Colloquium on Industrial Ecology. She holds a B.S. degree from Duke University and a Ph.D. from the University of Hawaii.

Henzinger



■ The Board of Governors of the American Society of Mechanical Engineers has elected Professor ***Donald L. Bartel***, of the Sibley School of Mechanical and Aerospace Engineering, to the grade of fellow. Bartel, who holds a joint appointment as a professor in Cornell's College of Engineering and as a senior scientist in the Department of Biomechanics of the Hospital for Special Surgery in New York, was cited for his accomplishments in education and research.

■ The Council of the American Physical Society has elected Professor ***Stephen B. Pope***, also of the Sibley School of Mechanical and Aerospace Engineering, to fellowship in the society. Pope was honored for "contributions of archival value to probability-density-function methods in turbulence modeling, to understanding of the geometry and distortion of surfaces in turbulent flows, and to extraction of Lagrangian statistics from direct numerical simulations."

Current research activities at the Cornell University College of Engineering are represented by the following publications and conference papers that appeared or were presented during the four-month period June through September 1991. (Earlier entries omitted from previous Quarterly *listings are included here with the year of publication in parentheses.) The names of Cornell personnel are in italics.*

AGRICULTURAL AND BIOLOGICAL ENGINEERING

Bartsch, J. A. 1991. Controlled atmosphere storage systems for fruits and vegetables. Paper read at International Workshop on Role of Food Engineering Research in the Development of Indonesian Food Industry, 2–6 September 1991, in Jakarta, Indonesia.

Campbell, J. K. 1991. Sorghum syrup production in New York State. Paper read at International Summer Meeting, American Society of Agricultural Engineers, 23–26 June 1991, in Albuquerque, NM.

Delwiche, S. R., R. E. Pitt, and K. H. Norris. 1991. Examination of starch-water and cellulose-water interactions with near infrared (NIR) diffuse reflectance spectroscopy. *Starch* 43:85–92.

Derksen, R. C., and *D. Wasson.* 1991. Calibration and application accuracy of orchard sprayers. Paper read at International Summer Meeting, American Society of Agricultural Engineers, 23–26 June 1991, in Albuquerque, NM.

Derksen, R. C., Z. Sagi and *J. Sanderson.* 1991. Greenhouse liquid applicator performance evaluations. Paper read at International Summer Meeting, American Society of Agricultural Engineers, 23–26 June 1991, in Albuquerque, NM.

Gao, Q., and *R. E. Pitt.* 1991. Mechanics of parenchyma tissue based on cell orientation and microstructure. *Transactions of the ASAE* 34:232–38.

Jewell, W. J., D. E. Fennel, Y. M. Nelson, S. E. Underhill, T. E. White, and *M. S. Wilson.* 1991. *Methanotrophs and methanogens for pollution control: PCE, TCE removal from groundwater and macro nutrient removals from wastewater.* Report no. GRI-91/0011. Chicago, IL: Gas Research Institute.

Marsh, L. S., and *L. D. Albright.* 1991. Economically optimum day temperature for greenhouse hydroponic lettuce. I. A computer model. II. Results and simulations. *Transactions of the ASAE* 34(2):550–62.

Muck, R. E., *R. E. Pitt,* and *R. Y. Leibensperger.* 1991. A model of aerobic fungal growth in silage. I. Microbial characteristics. *Grass and Forage Science* 46:283–99.

Parlange, J.-Y., R. Haverkamp, and C. Fuentes. 1991. Discussion of the first stage of drainage from ponded soils with encapsulated air. *Soil Science* 151:323–24.

Pitt, R. E., R. E. Muck, and *N. B. Pickering.* 1991. A model of aerobic fungal growth in silage. II. Aerobic stability. *Grass and Forage Science* 46:301–12.

Rehkugler, G. E. 1991. A view of biological and agricultural engineering. Paper read at Annual Conference, American Society for Engineering Education, 16–19 June 1991, in New Orleans, LA.

Richards, B. K., R. J. Cummings, W. J. Jewell, and F. G. Herndon. 1991. High solids anaerobic methane fermentation of sorghum and cellulose. *Biomass and Bioenergy* 1(1): 47–53.

Sagi, Z., and *R. Derksen.* 1991. Detecting spray droplets on leaves with machine vision. Paper read at International Summer Meeting, American Society of Agricultural Engineers, 23–26 June 1991, in Albuquerque, NM.

Sagi, Z., and J. Throop. 1991. Evaluation of computational algorithms for measurements by cluster segmentation. Paper read at International Summer Meeting, American Society of Agricultural Engineers, 23–26 June 1991, in Albuquerque, NM.

Sander, G. C., I. F. Cunning, W. L. Hogarth, and *J.-Y. Parlange.* 1991. Exact solution for nonlinear, nonhysteretic redistribution in vertical soil of finite depth. *Water Resources Research* 27:1529–36.

Seginer, I., G. Shina, *L. D. Albright,* and *L. S. Marsh.* 1991. Optimal temperature setpoints for greenhouse lettuce. *Journal of Agricultural Engineering Research* 49:209–26.

Selker, J. S., J.-Y. Parlange, and *T. S. Steenhuis.* 1991. Comments on laboratory tests of a theory of fingering during infiltration into layered soils. *Soil Science Society of America Journal* 55:896.

APPLIED AND ENGINEERING PHYSICS

Cool, T. A., and *P. M. Goodwin.* 1991. Observation of an electronic state of C_2H near 9 eV by resonance ionization spectroscopy. *Journal of Chemical Physics* 94(11):6978–88.

Kwong, Y. K., K. Lin, P. J. Hakonen, *M. Isaacson,* and *J. M. Parpia.* 1991. Interfacial resistive anomaly at a normal-superconducting boundary. *Physical Review B* 44(1):462–65.

Fernandez, A., H. D. Hallen, T. Huang, R. A. Buhrman, and *J. Silcox.* 1991. Elastic scattering in ballistic-electron-emission-microscopy studies of the epitaxial $NiSi_2$/Si(111) interface. *Physical Review B* 44:3428–31.

Silcox, J. 1991. The Materials Science Center: Cornell's premier interdisciplinary laboratory. *Cornell Engineering Quarterly* 26(1):2–5.

Williams, B. A., and *T. A. Cool.* 1991. Two-photon spectroscopy of Rydberg states of jet-cooled C_2H_4 and C_2D_4. *Journal of Chemical Physics* 94(10):6358–66.

Xu, P., P. Miller, and *J. Silcox.* 1991. The nucleation and epitaxial growth of Au and Ag on thin silicon studied with a scanning transmission electron microscope. In *Evolution of thin-film and surface microstructure,* ed. C. V. Thompson, J. Y. Tsao, and D. J. Srolovitz, pp. 19–24. Materials Research Society Symposium Proceedings, vol. 202. Pittsburgh, PA: MRS.

CHEMICAL ENGINEERING

Aizpiri, A. G., A. Rey, J. Dávila, *R. G. Rubio, J. A. Zollweg,* and *W. B. Streett.* 1991. An experimental and theoretical study of the equation of state of CHF_3 in the near critical region. *Journal of Physical Chemistry* 95:3351-57.

Aul, R. W., and *W. L. Olbricht.* 1991. Coalescence of freely suspended liquid drops in flow through a small pore. *Journal of Colloid and Interface Science* 145:478-92.

Balbuena, P., and *K. E. Gubbins.* 1991. Classification of adsorption behavior: Simple fluids in pores of cylindrical and slit-shaped geometry. Paper read at 11th Symposium on Thermophysical Properties, 23-27 June 1991, in Boulder, CO.

Carpenter, J. K., E. C. Agger, and *P. H. Steen.* 1991. Fluid mechanics and heat-transfer of planar-flow melt-spinning. In *Proceedings, 5th International Conference on Modeling of Casting and Welding Processes,* ed., M. Rappaz, M. Özgü, and K. Mahiu, pp. 621-27. Warrendale, PA: The Metallurgical Society.

De Miguel, E., L. F. Rull, M. K. Chalam, and *K. E. Gubbins.* 1991. Location of the isotropic-nematic transition in the Gay-Berne model. *Molecular Physics* 72:593-605.

Duncan, T. M., T. W. Root, and A. M. Thayer. 1991. Studies of dynamics at catalytic surfaces by selective excitation of nuclear magnetic resonances. Paper read at 4th Chemical Congress of North America, 26-30 August 1991, in New York, NY.

Guedes, H. J. R., J. A. Zollweg, and *W. B. Streett.* 1991. Enthalpy of mixing of liquid (carbon dioxide + ethane) at the temperature 230.8 K and of liquid (carbon dioxide + *n*-butane) at 221.4 K and 241.4 K. *Journal of Chemical Thermodynamics* 23:239-45.

Hall, E. J., H. J. R. Guedes, and *J. A. Zollweg.* 1991. *Thermodynamics of the liquid mixture carbon dioxide + butane below 285 K.* Report no. GRI-91/0088, Chicago, IL: Gas Research Institute.

Lackney, V. K., R. M. Spanswick, T. J. Hirasuna, and *M. L. Shuler.* 1991. Characterization of nitrate and vanadate-sensitive ATPases in the tonoplast of cultured grape cells. Paper read at Annual Meeting, American Society of Plant Physiologists, 28 July–1 August 1991, in Albuquerque, NM.

Mohindra, S., and *P. A. Clark.* 1991. A distributed fault diagnosis methodology using causal digraph models of process behavior. Paper read at 4th International Conference on Process Systems Engineering, 5–9 August 1991, in Montebello, Quebec.

Murgel, G. A., L. W. Lion, C. Acheson, M. L. Shuler, D. Emerson, and *W. C. Ghiorse.* 1991. An experimental apparatus for selection of adherent microorganisms under stringent growth conditions. *Applied Environmental Microbiology* 57(7):1987–96.

Rubio, R. G., J. A. Zollweg, J. M. G. Palanco, *J. C. G. Calado, J. Miller,* and *W. B. Streett.* 1991. Thermodynamic properties of simple molecular fluids: Tetrafluoromethane and trifluoromethane. *Journal of Chemical and Engineering Data* 36:171–84.

Rhykerd, C., Z. Tan, L. A. Pozhar, and *K. E. Gubbins.* 1991. Properties of simple fluids in carbon micropores. *Faraday Transactions* 13:2011–16.

Shah, N. N., J. A. Zollweg, and *W. B. Streett.* 1991. Vapor-liquid equilibrium in the system carbon dioxide + cyclopentane from 275 to 493 K at pressures to 12.2 MPa. *Journal of Chemical and Engineering Data* 36:188–92.

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Published by the College of Engineering, Cornell University

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Printing
Davis Press
Worcester, Massachusetts

Photography Credits
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